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VCE PHYSICS

Units 1 & 2

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Units 1 & 2

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Edrolo

At Edrolo, we're transforming the way the students learn and teachers teach.

Our mission is simple: to improve education.

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FEATURES OF THIS BOOK

Edrolo's VCE Physics Units 1 & 2 textbook has the following features.

Theory

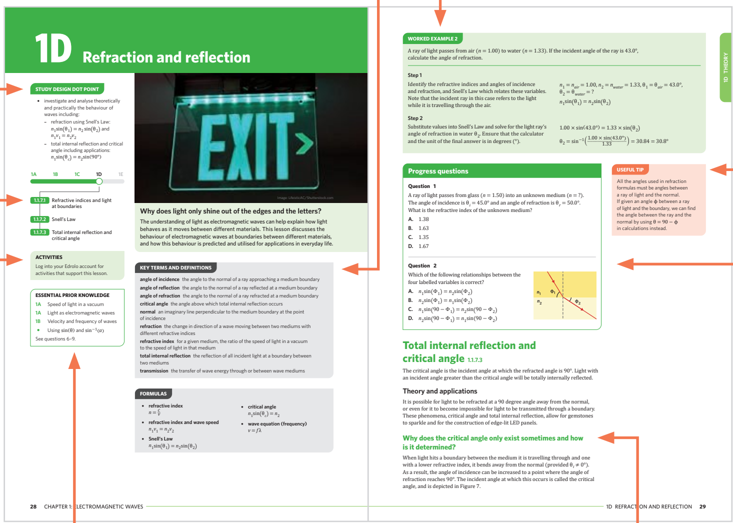
Study design dot points provide explicit links between the content covered in each lesson and the VCAA study design.

Key terms are defined and highlighted to support learning

Worked examples apply content to exam-style questions with strategies, full working and explanations of each step in the process.

Key knowledge units break down the theory into smaller chunks that help navigate the corresponding theory lesson videos on the Edrolo online platform.

Activities are provided on the Edrolo online platform and allow engagement and further understanding of the content.



Explore boxes include misconceptions, useful tips, strategy, and keen to investigate boxes.

Progress questions test if students can remember bite-sized chunks of theory and overcome common misconceptions early in the learning journey. They are stepping stones between the content and exam-style questions.

Essential prior knowledge questions are designed to break down any misconceptions and highlight prerequisite knowledge from previous lessons that is 'essential' to understanding the lesson's content.

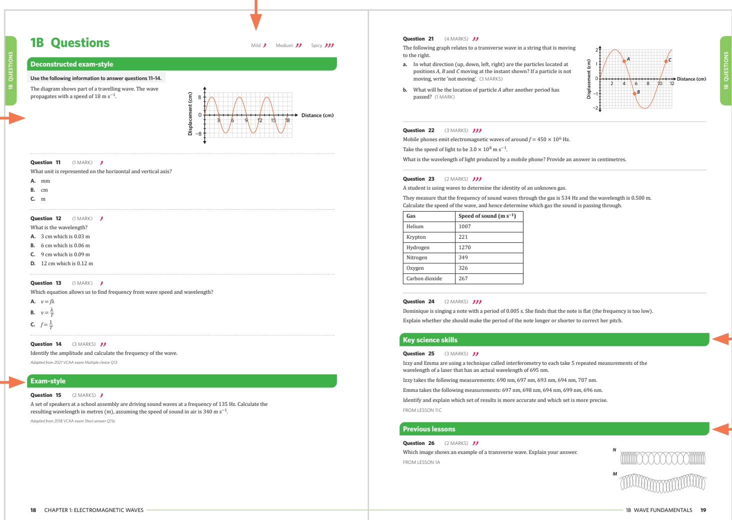
Guiding questions focus and simplify the key knowledge required by the VCAA study design.

Questions

Spiciness rating of questions measures the difficulty and increases within each type of question type.

Deconstructed questions provide prompts for students to piece together the steps needed to answer an exam-style question.

Exam-style questions reflect the style of questions presented in end-of-year exams.



Key science skills questions develop inquiry skills students need for SACs and other assessments.

Questions from previous lessons combine key knowledge from previous lessons to develop a deeper understanding of concepts.

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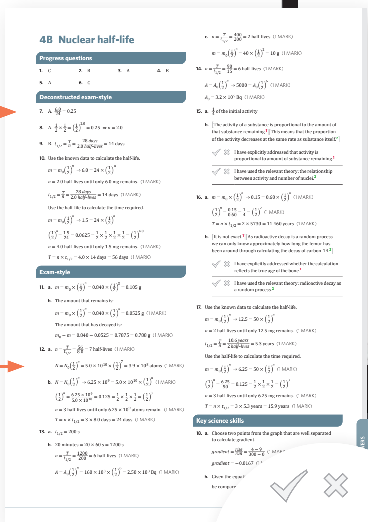
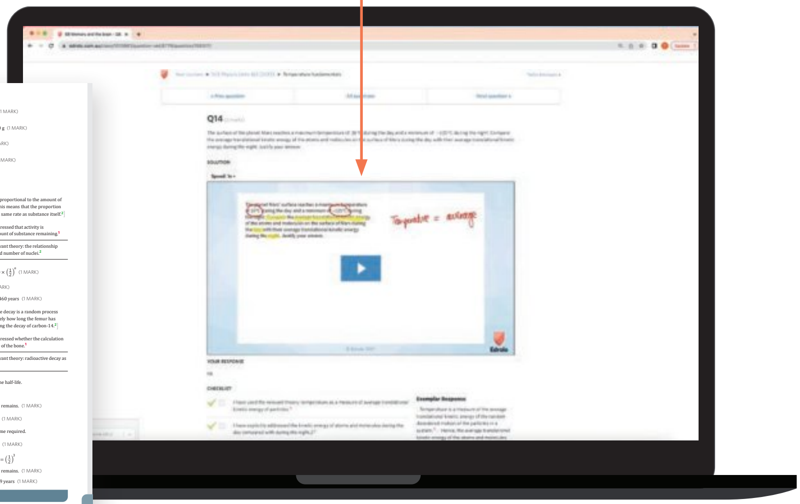
Answers

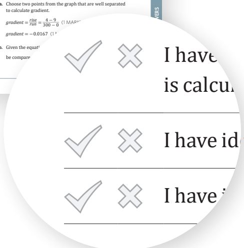
Worded and visual responses include exemplar answers to all questions to show what a full mark response looks like.

Online video solutions provide immediate feedback and extra guidance on how to answer questions.





Calculation responses show full working along with mark allocations to help students form good habits and to provide more detailed guidance for students.

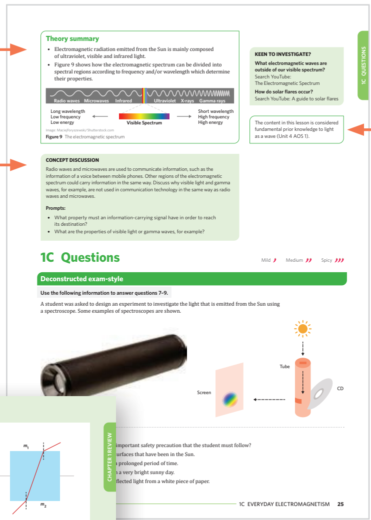


Checklists are provided for all answers (worth more than 1 mark) and they explain the purpose of each part of a full-mark answer to help students develop their scientific communication skills.

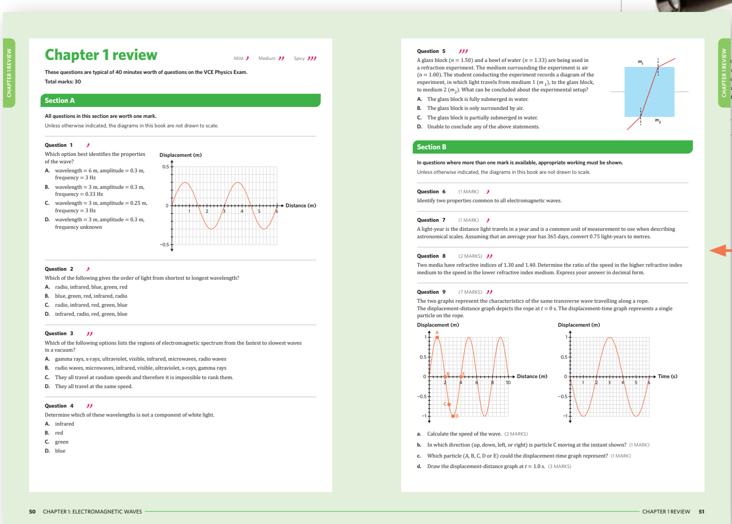
Reviews

Theory summary is an outline of the knowledge from the entire lesson.

Concept discussion questions encourage students to discuss relatable situations where the physics concepts from the theory apply. They are all designed to be accessible to all students while promoting a deeper understanding.



The content in this lesson identifies the parts of the Unit 3 or 4 course the theory presented in the lesson is relevant to.



Chapter reviews consists of end-of-year exam-style questions that cover content from that chapter or area of study. They are structured into three sections: multiple choice, short answer and key science skills questions.

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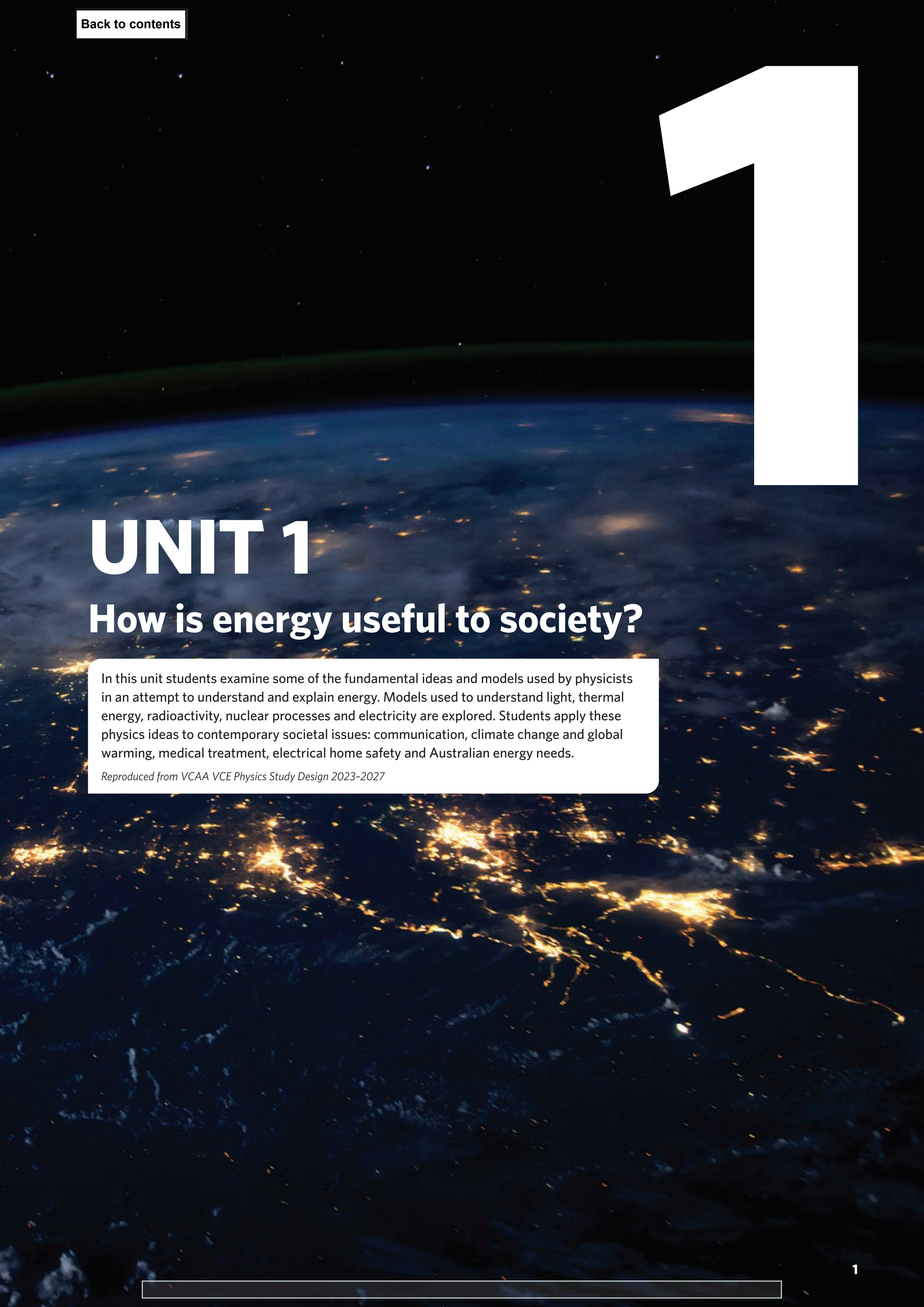

1

UNIT 1

How is energy useful to society?

In this unit students examine some of the fundamental ideas and models used by physicists in an attempt to understand and explain energy. Models used to understand light, thermal energy, radioactivity, nuclear processes and electricity are explored. Students apply these physics ideas to contemporary societal issues: communication, climate change and global warming, medical treatment, electrical home safety and Australian energy needs.

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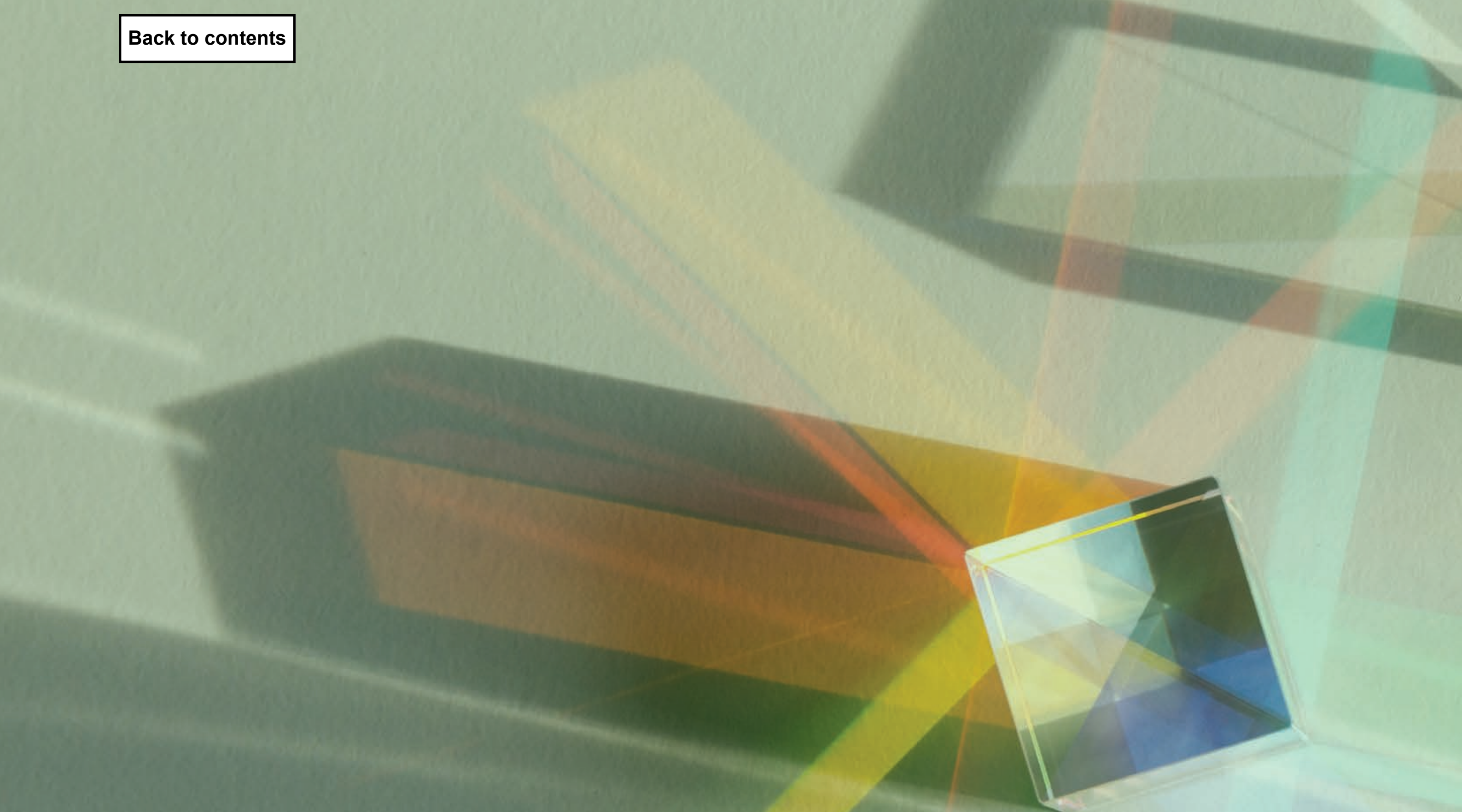

UNIT 1 AOS 1

How are light and heat explained?

In this area of study, students study light using the wave model and thermal energy using a particle model forming an understanding of the fundamental physics ideas of reflection, refraction and dispersion. They use these to understand observations made of the world such as mirages and rainbows. They investigate energy transfers and explore how light and thermal energy relate to one another. They apply light ideas to explain how light is used through optical fibres in communication, and how physics is used to inform global warming and climate change.

Outcome 1

On completion of this unit the student should be able to model, investigate and evaluate the wave-like nature of light, thermal energy and the emission and absorption of light by matter.

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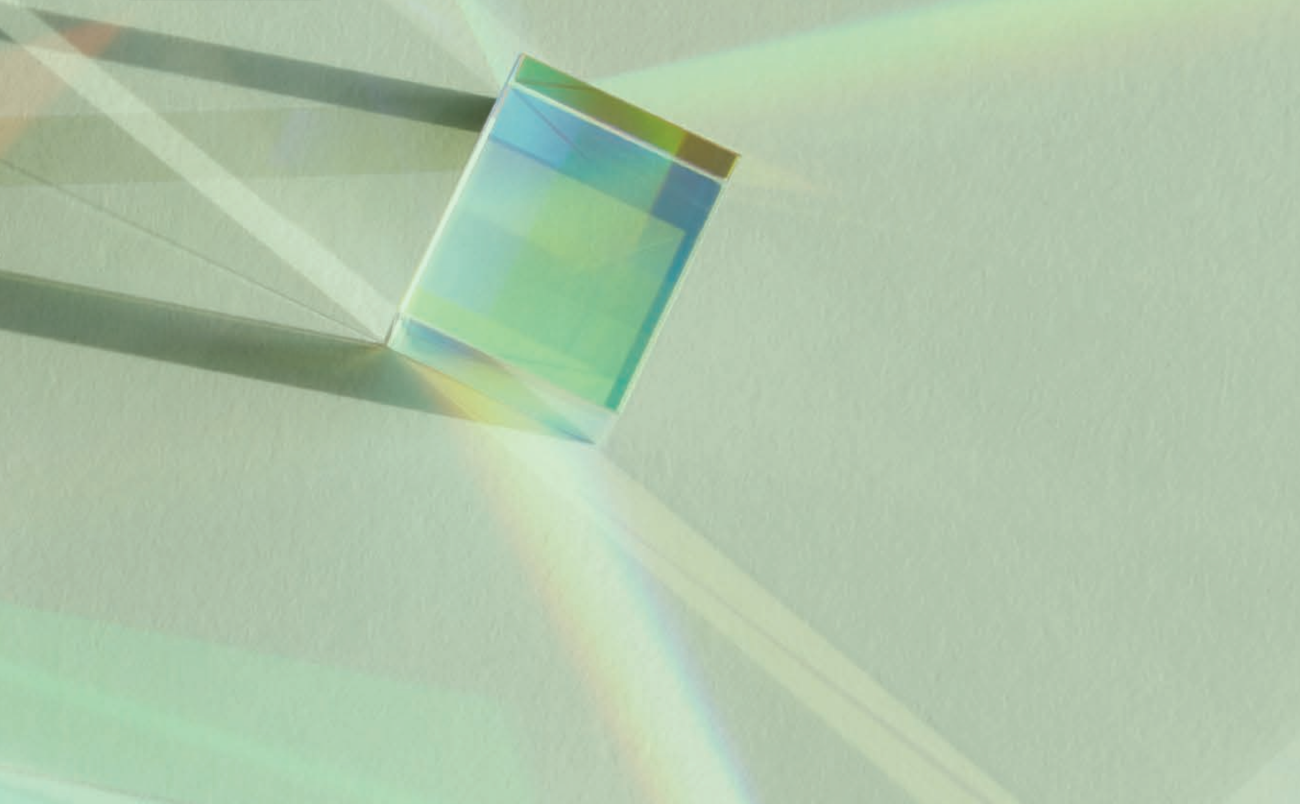

1

CHAPTER 1

Electromagnetic waves

STUDY DESIGN DOT POINTS

- identify all electromagnetic waves as transverse waves travelling at the same speed, *c*, in a vacuum as distinct from mechanical waves that require a medium to propagate
- identify the amplitude, wavelength, period and frequency of waves
- calculate the wavelength, frequency, period and speed of travel of waves using: $\lambda = \frac{v}{f} = vT$
- explain the wavelength of a wave as a result of the velocity (determined by the medium through which it travels) and the frequency (determined by the source)
- describe electromagnetic radiation emitted from the Sun as mainly ultraviolet, visible and infrared
- compare the wavelength and frequencies of different regions of the electromagnetic spectrum, including radio, microwave, infrared, visible, ultraviolet, x-ray and gamma, and compare the different uses each has in society
- investigate and analyse theoretically and practically the behaviour of waves including:
  - refraction using Snell's Law: $n_1\sin(\theta_1) = n_2\sin(\theta_2)$ and $n_1v_1 = n_2v_2$
  - total internal reflection and critical angle including applications: $n_1\sin(\theta_c) = n_2\sin(90°)$
- investigate and explain theoretically and practically colour dispersion in prisms and lenses with reference to refraction of the components of white light as they pass from one medium to another
- explain the formation of optical phenomena: rainbows; mirages
- investigate light transmission through optical fibres for communication

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LESSONS

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1A Introduction to waves

STUDY DESIGN DOT POINT

- identify all electromagnetic waves as transverse waves travelling at the same speed, *c*, in a vacuum as distinct from mechanical waves that require a medium to propagate

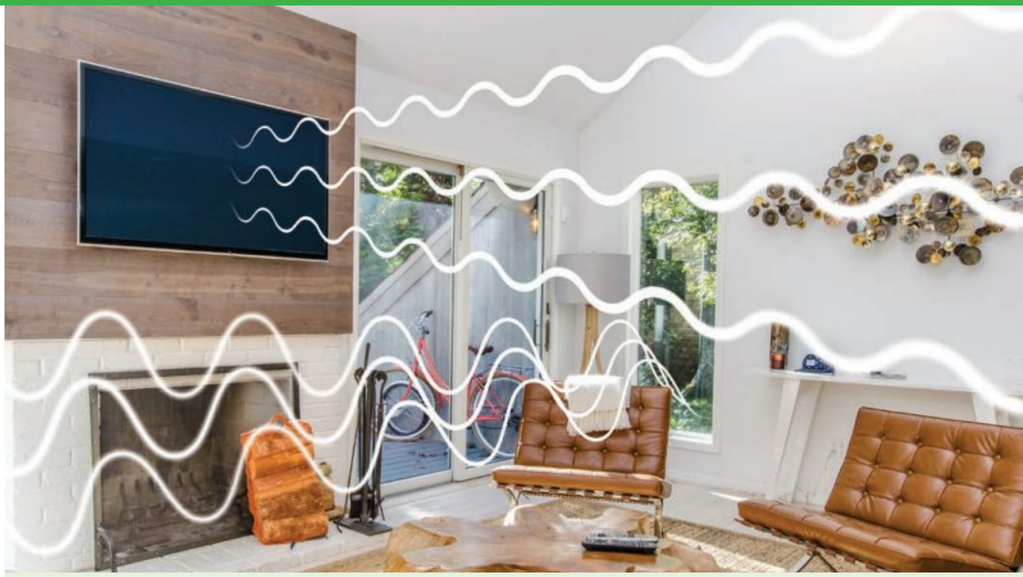
1A 1B 1C 1D 1E

1.1.1.1 Wave definition

1.1.1.2 Mechanical and electromagnetic waves

ACTIVITIES

Log into your Edrolo account for activities that support this lesson.



What type of waves are all around us?

When most people think of waves, they picture water waves moving across the ocean, however, this is just one example of a wave. In reality, waves are all around us. Sound, light, earthquakes, and plucking a guitar string are examples of waves that can be found in everyday life. This lesson defines what a wave is and identifies the difference between mechanical waves and electromagnetic waves.

KEY TERMS AND DEFINITIONS

electromagnetic wave a wave that consists of perpendicular electric and magnetic field oscillations

longitudinal wave a wave in which the oscillations are parallel to the direction of wave travel and energy transmission

mechanical wave a wave which requires a material medium

medium (waves) a physical substance through which a wave propagates

oscillate to move back and forth in a regular motion

propagate the way in which a wave travels

transverse wave a wave in which the oscillations are perpendicular to the direction of wave travel and energy transmission

vacuum a region that does not contain matter

wave the transmission of energy via oscillations from one location to another without the net transfer of matter

Wave definition 1.1.1.1

As waves are a method of energy transfer they are fundamental to many physics phenomena.

Theory and applications

From sound to light, or ocean waves to earthquakes, the transmission of energy by wave propagation is fundamental to almost every branch of physics. It is only through the understanding of what a wave is, that these phenomena can be described.

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What is a wave?

A wave is the transmission of energy via oscillations from one location to another without the net (overall) transfer of matter. The direction a wave travels is defined by the direction of the energy transmission. The oscillations that form a wave can either be perpendicular (transverse) or parallel (longitudinal) to the motion of the wave.

It is energy, not matter, that is transferred by a wave. Figure 1 shows the transfer of energy without the net transfer of matter within a transverse ocean wave. Even though the wave is moving to the left, the matter, including the ball, that makes up the wave is oscillating perpendicular to the wave direction (up and down) without being pushed horizontally.

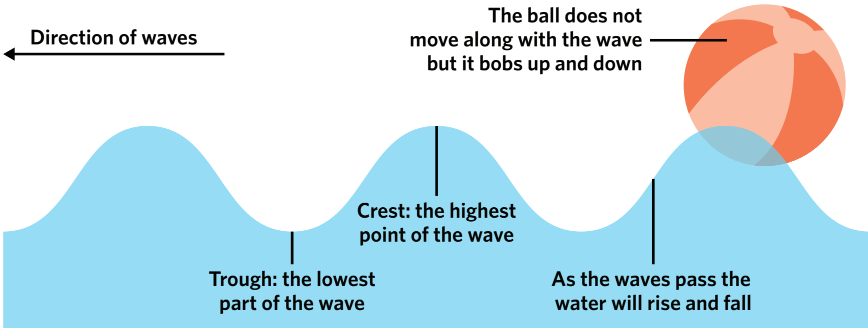


Figure 1 Water and a beach ball oscillate vertically as the wave moves

Figure 2 shows there is also no net transfer of matter within a longitudinal sound wave. Each air molecule vibrates about the same point, parallel to the direction of the wave (in this instance from left to right).

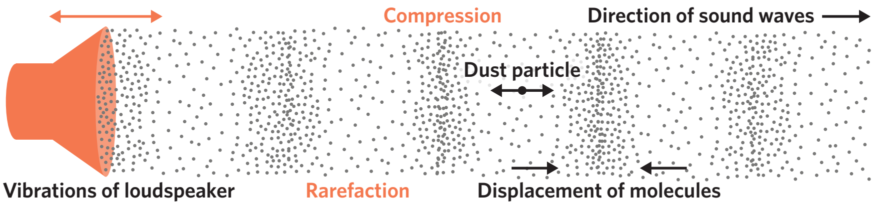


Figure 2 A dust particle within a sound wave oscillates back and forth

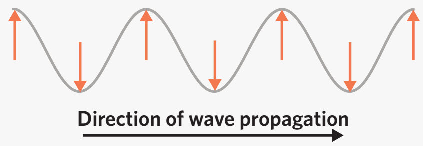
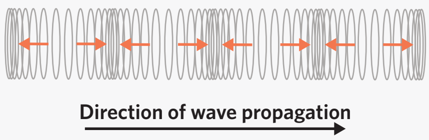
How do transverse and longitudinal waves differ?[1]

Waves can be distinguished by the direction of the oscillation in relation to the direction of their movement. Table 1 compares the properties of the two types of longitudinal and transverse waves.

KEEN TO INVESTIGATE?

[1] **What is a wave?**
Search YouTube: Physics - waves - introduction

Table 1 Transverse vs. longitudinal waves

	Transverse wave	Longitudinal wave
Diagram		
Movement of oscillations	Perpendicular to the direction of wave propagation. For a transverse wave travelling to the right, oscillations could occur in any perpendicular direction, such as up and down or into and out of the page, but not left and right.	Parallel to the direction of wave propagation. For a longitudinal wave travelling to the right, the particles in the medium must oscillate left and right. Longitudinal waves are also commonly referred to as compression waves.
Common examples	Waves in strings, electromagnetic waves, and water waves.	Sound waves, waves in springs, or the primary (P) waves in an earthquake.
Key features	Crests: points on a wave with maximum positive displacement. Troughs: points on the wave with maximum negative displacement.	Compressions: the points on a wave where particles are most closely grouped together (under the most pressure). Rarefactions: points where particles are most spread out (under the least pressure).

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Progress questions

Question 1

A point on a transverse wave will oscillate in which direction compared to the direction of the wave?

A. parallel

B. perpendicular

C. both A and B

Question 2

Which of the following is an example of a longitudinal wave?

A. a horizontal spring undergoing vertical oscillations

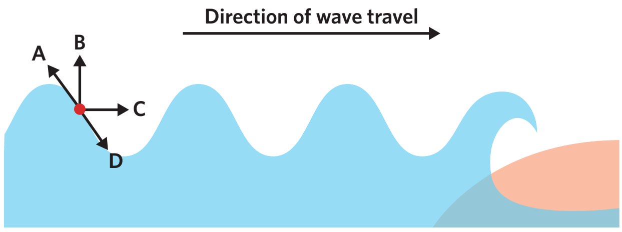
B. a violin string being plucked

C. a note from a speaker playing a song

D. a water ripple

Question 3

In which direction does the particle move at the instant shown: A, B, C or D?



Question 4

Sound is best described as a

A. longitudinal pressure wave transmitting air particles from a source to a receiver.

B. transverse pressure wave transmitting wave maxima from a source to a receiver.

C. longitudinal pressure wave transmitting energy from a source to a receiver.

D. transverse pressure wave transmitting energy from a source to a receiver.

VCAA 2016 exam Section B Detailed study 6 Q1

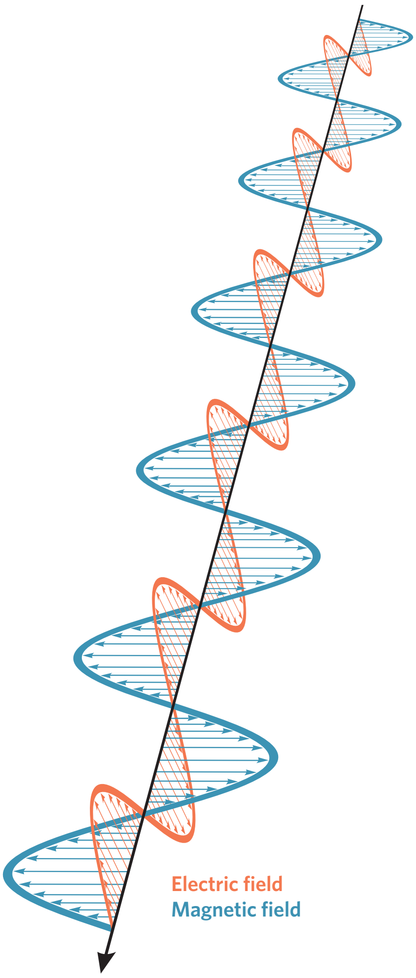


Figure 3 Oscillations of the electric and magnetic fields propagating through space

KEEN TO INVESTIGATE?

2 **How do electric and magnetic fields create waves?**
Search YouTube: Electromagnetic waves and the electromagnetic spectrum | physics

Mechanical and electromagnetic waves 1.1.1.2

There are two main categories of waves that this course will focus on: electromagnetic waves and mechanical waves. Electromagnetic waves are defined by the oscillations of the electromagnetic and magnetic fields while mechanical waves are the oscillations of particles with a medium.

Theory and applications

An electromagnetic wave is the transmission of light energy through oscillations within the electric and magnetic fields (see Figure 3)[2]. It is common to refer to electromagnetic waves as light, since the visible light that the human eye can see is an example of an electromagnetic wave.

How are electromagnetic waves distinct from mechanical waves?

An electromagnetic wave is a propagating oscillation of the electric and magnetic fields, whereas a mechanical wave is a propagating oscillation of the physical matter within a medium. Figure 4 shows a venn diagram of the main similarities and differences between these two types of waves

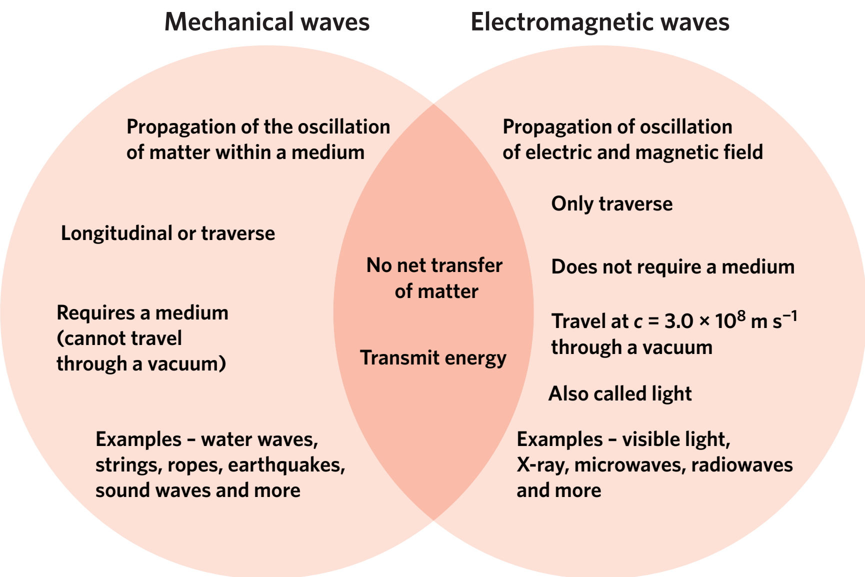


Figure 4 Venn diagram of similarities and differences

Examples of mechanical waves include sound waves (Figure 2), which transfers energy through the air (or another medium), a ripple in a pond (Figure 5(a)), which transfers energy through water, and an earthquake (Figure 5(b)) which transfers energy through the ground. In these examples, the particles oscillate about their mean (neutral) position; they do not travel with the wave as it propagates.

USEFUL TIP

It doesn't matter whether we are moving towards or away from an electromagnetic wave, it will always move at the same speed of 3.0×10^8 m s^{-1} through a vacuum.

Progress questions

Question 5

A mechanical wave can be best described as

A. the transmission of matter through a medium without the net transfer of energy.

B. the transmission of alternating electric and magnetic fields without the net transfer of matter.

C. the transmission of energy through a medium without the net transfer of matter.

D. the transmission of energy through a vacuum without the net transfer of matter.

Question 6

Which of the following is false about an electromagnetic wave?

A. They exist as the transfer of energy through the oscillation of matter.

B. They all travel at 3.0×10^8 m s^{-1} through a vacuum.

C. They are all transverse waves.

D. They do not require a material medium to propagate through.

Continues →

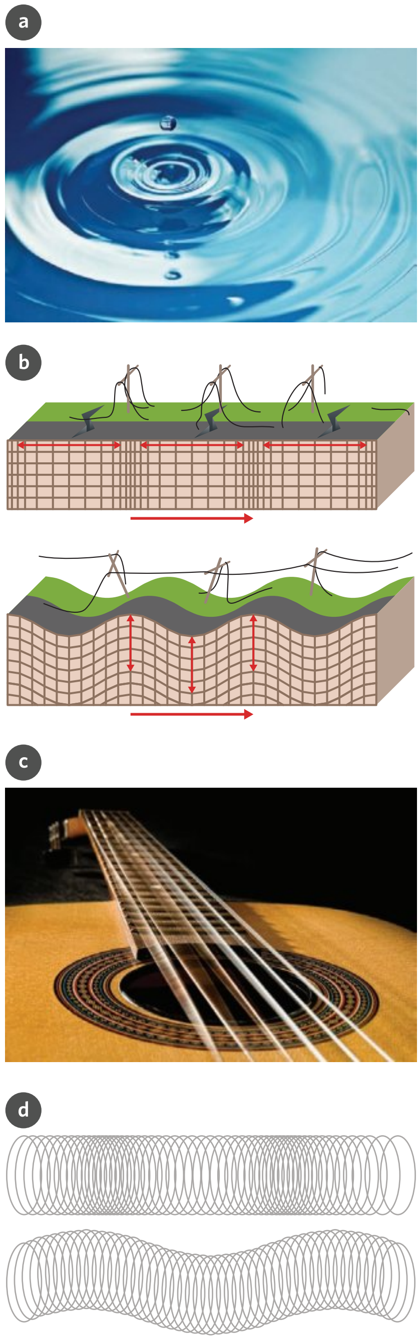


Figure 5 Examples of mechanical waves in **(a)** a pond, **(b)** an earthquake, **(c)** guitar string, and **(d)** a slinky.

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Question 7

Identify which of the following properties only apply to: (E) electromagnetic waves, (M) mechanical waves, or (B) both.

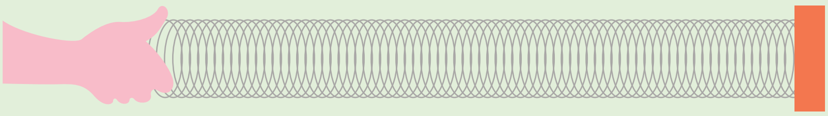
Propagation of an oscillation moving energy from one location to another	
Travel at a speed of $c = 3.0 \times 10^8$ m s^{-1} through a vacuum.	
Can be either transverse or longitudinal waves	
Require a medium to propagate	
Include: sound waves and ocean waves	
Also known as light	

Theory summary

- A wave is the transmission of energy via oscillations from one location to another without the net transfer of matter.
- All electromagnetic waves:
  - travel at the same speed in a vacuum known as the speed of light. The speed of light is denoted by the symbol 'c' which is commonly written as $c = 3.0 \times 10^8$ m s^{-1}.
  - are transverse waves. The oscillation of the electric and magnetic field is perpendicular to the direction that an electromagnetic wave moves.
  - do not require a medium to propagate through. Therefore they can travel through a vacuum such as deep space.
- All mechanical waves:
  - exist as the transfer of energy through matter which means they requirea medium to propagate (travel) through such as air or water.
  - can be longitudinal or transverse.

The content in this lesson is considered fundamental prior knowledge to light as a wave (Unit 4 AOS 1).

CONCEPT DISCUSSION



Think of a slinky (a stretchy spring). The slinky can support longitudinal waves and transverse waves. How must the slinky be shaken to produce transverse waves? How must the slinky be shaken to produce longitudinal waves?

Prompts:

- The oscillating movement of a longitudinal wave is in the direction of the wave motion.
- The oscillating movement of a transverse wave is perpendicular to the wave motion.
- A wave on a slinky moves in the direction that the slinky is aligned with.

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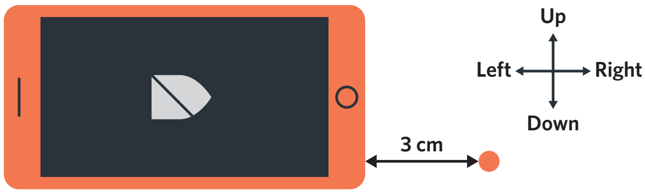
1A Questions

Mild 🌶 Medium 🌶🌶 Spicy 🌶🌶🌶

Deconstructed exam-style

Use the following information to answer questions 8–10.

Finn begins playing music out loud from his phone. The air particle shown (not drawn to scale) starts initially at rest 3 cm away from the phone speaker.



Question 8 (1 MARK) 🌶

The particle will oscillate

A. left and right.

B. up and down.

C. The particle will not oscillate as sound is not a mechanical wave.

Question 9 (1 MARK) 🌶

The particle will

A. oscillate back and forth while being pushed to the right in the wave direction.

B. be pushed to the right in the wave direction without oscillating.

C. oscillate back and forth about its initial position.

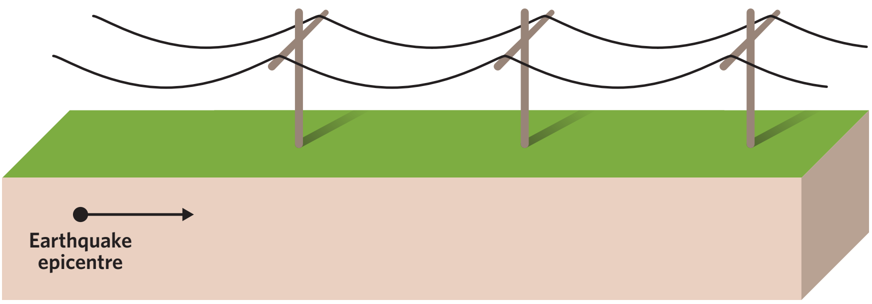
Question 10 (2 MARKS) 🌶🌶

Describe the resulting motion of this air particle in relation to its initial position.

Exam-style

Question 11 (1 MARK) 🌶

An earthquake is propagating primary waves through the ground in the direction as shown. Consider a series of power line poles in front of the epicentre.



Which of the following diagrams best describes the movement of the power line poles? Assume they will not fall over.

A.


B.

C.

D.

Adapted from VCAA 2018 exam Multiple choice Q10

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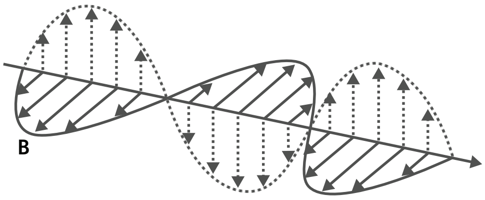
Question 12 (3 MARKS)

The image shows a representation of an electromagnetic wave.

a. Correctly label the electric field and direction of energy transfer on the electromagnetic wave shown. (2 MARKS)



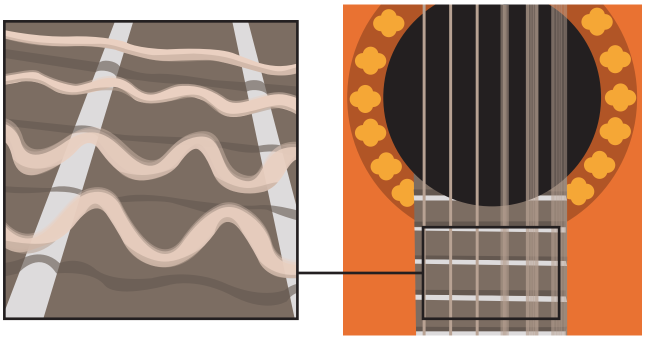
b. Assume the electromagnetic wave is travelling through a vacuum. At what speed would the wave pictured above be travelling at? Answer in metres per second ($m\ s^{-1}$). (1 MARK)

Adapted from VCAA 2020 exam Short answer Q14

Question 13 (2 MARKS)

A 0.60 m long guitar string (as pictured) is plucked, causing it to vibrate.

Is this wave longitudinal or transverse? Explain your answer.



Question 14 (1 MARK)

A star moving directly away from Earth and emits an electromagnetic wave. The speed of this electromagnetic wave is measured on Earth. Assume it is travelling through a vacuum.

Which one of the following is true?

A. The speed of the light is greater than $3.0 \times 10^8\ m\ s^{-1}$.

B. The speed of the light is less than $3.0 \times 10^8\ m\ s^{-1}$.

C. The speed of the light observed on earth is $c = 3.0 \times 10^8\ m\ s^{-1}$.

D. Not enough information is provided to answer the question.

Adapted from VCAA 2015 exam Section B Detailed Study 1 Q3

Key science skills

Question 15 (1 MARK)

The aim of darts is to hit the bullseye at the centre of the dartboard. Four darts players (A, B, C and D) each threw three darts. The results of their throws are shown.

Which one of the players produced a set of attempts that could be described as being precise but inaccurate?

A. player A

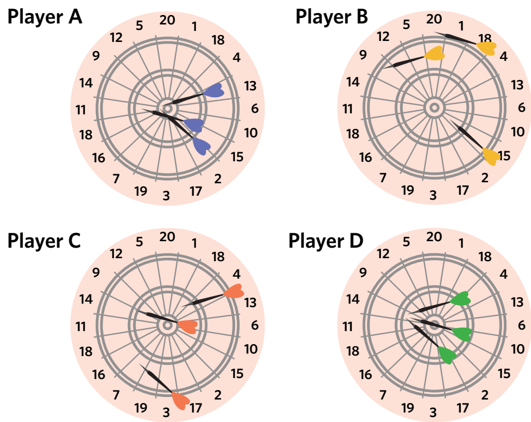
B. player B

C. player C

D. player D

VCAA 2020 exam Multiple choice Q1

FROM LESSON 11C



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1B Wave fundamentals

Image: Andrew Berezovsky/Shutterstock.com

Why do sound waves make the water bounce?

Knowledge of the properties of waves is important to be able to understand many aspects of the physical world including sound and light. All waves, including electromagnetic waves, can be defined by their properties. This lesson covers: identifying these properties, calculating them, and explaining why they are important.

STUDY DESIGN DOT POINTS

- identify the amplitude, wavelength, period and frequency of waves
- calculate the wavelength, frequency, period and speed of travel of waves using: $\lambda = \frac{v}{f} = vT$
- explain the wavelength of a wave as a result of the velocity (determined by the medium through which it travels) and the frequency (determined by the source)

1A 1B 1C 1D 1E

1.1.2.1 Wave properties

1.1.3.1 & 1.1.4.1 The wave equation

ESSENTIAL PRIOR KNOWLEDGE

1A Definition of a wave

1A Light and sound waves

11B Understanding units

See questions 1–3.

ACTIVITIES

Log into your Edrolo account for activities that support this lesson.

KEY TERMS AND DEFINITIONS

amplitude (waves) the magnitude of an oscillation's maximum value from the neutral point within a wave

crest a point on the wave where the amplitude is a maximum positive value

displacement the change in position of an object (vector quantity)

frequency the number of cycles completed per unit of time

period the time taken to complete one cycle

trough a point on the wave where the amplitude is a maximum negative value

wave cycle the process of a wave completing one full oscillation, ending up in a final configuration identical to the initial configuration

wavelength the distance covered by one complete wave cycle

wave speed the speed at which a wave transfers its energy through a medium

FORMULAS

- **frequency-period inverse relationship**
  $f = \frac{1}{T}$
- **wave equation (frequency)**
  $v = f\lambda$
- **wave equation (period)**
  $v = \frac{\lambda}{T}$

Wave properties 1.1.2.1

Four important properties of waves include: amplitude, wavelength, period, and frequency. They are essential to describing the behaviour of all waves.

Theory and applications

Even though light is an electromagnetic transverse wave and sound is a mechanical longitudinal wave, both types of waves are defined by the same properties. In order to describe the behaviour of light, sound, or any other wave, their properties (see Table 1) must first be identified.[1]

KEEN TO INVESTIGATE?

1 **What are the properties of a wave?**
Search YouTube: Wave motion | waves | physics

Table 1 Wave properties

Property	Representation	Units
Wavelength	λ	Length often in metres (m)
Frequency	f	Cycles per second often in Hz or s^{-1}
Period	T	Time often in seconds (s)
Amplitude	A	Displacement often in metres (m) **OR** pressure often in pascal (Pa)

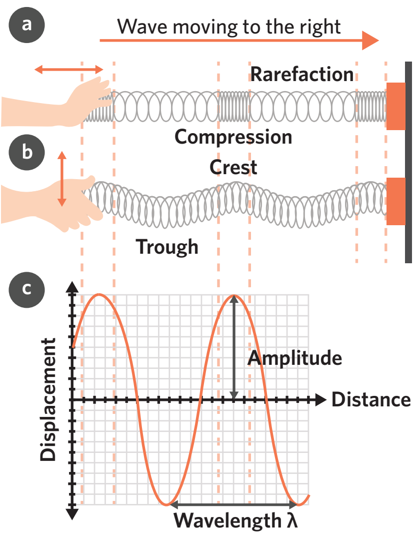

Figure 1 **(a)** A longitudinal wave and **(b)** a transverse wave. **(c)** Graph of either longitudinal or transverse wave with displacement on horizontal axis.

How are the properties of waves identified?

Wave properties are often given numerically and always with an accompanying unit. Quantities in physics only have meaning when in reference to units. In a question, always pay careful attention to the unit that puts the value into perspective.
E.g. Students measured the properties of a sound wave that has a wavelength $\lambda = 38$ cm, a frequency $f = 0.020$ MHz, and an amplitude of $A = 100$ Pa.

USEFUL TIP

The unit of the wavelength when referring to light is often given in nanometers (nm). A nanometer represents one billionth (10^{-9}) of a metre.

Period and frequency are mathematically related through the formula:

FORMULA

$$f = \frac{1}{T}$$

f = frequency (Hz or s^{-1})
T = period (s)

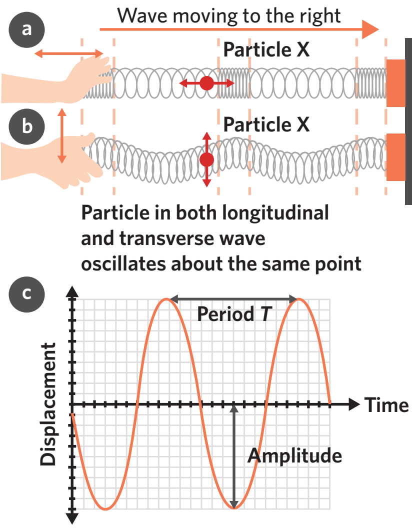

Figure 2 A particle moves **(a)** left/right in a longitudinal wave and **(b)** up/down in a transverse wave. **(c)** Graph of particle movement of either longitudinal or transverse wave with time on the horizontal axis.

This shows that frequency and period are inversely proportional. With an inverse relationship if frequency doubles then period will halve and vice versa. Frequency has two standard units which are both equivalent to each other ($1 \text{ Hz} = 1 \text{ s}^{-1}$), but Hertz (Hz) is more commonly used than per second (s^{-1}).

Transverse waves (e.g. light) and longitudinal waves (e.g. sound) can be graphed to show their properties.[2] Graphs can provide additional information depending on what is being represented on the horizontal or vertical axis.

To graph a wave with the horizontal axis (see Figure 1) as distance we must freeze a longitudinal or transverse wave at one point in time.

To graph a wave with time on the horizontal axis (see Figure 2) we must consider the movement of a single particle within that wave over a period of time. The particle will oscillate about the same location along the length of the wave. The particle moves perpendicular in a transverse wave and parallel in a longitudinal wave when compared to the direction of wave travel.

KEEN TO INVESTIGATE?

2 **How are transverse waves created?**
Search: Wave on a string simulation

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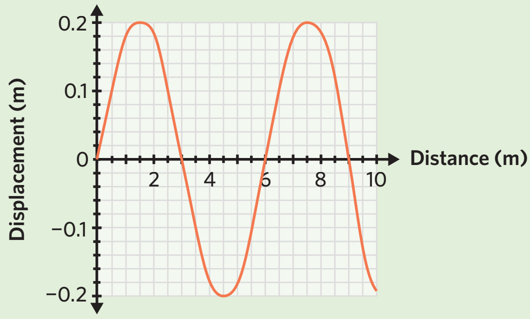
WORKED EXAMPLE 1

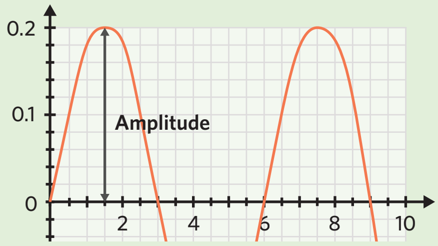
A wave is graphed at a single point in time.



a. Identify the amplitude. Make sure to use correct units in your answer.

The unit of the final answer must be the unit represented on the vertical axis which is metres (m).

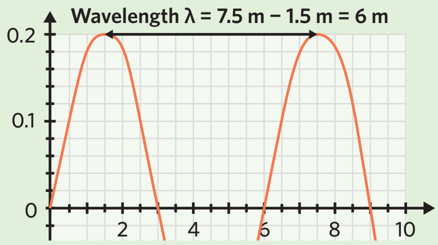
$A = 0.2$ m



b. Identify the wavelength. Make sure to use correct units in your answer.

The unit of the final answer must be the unit represented on the horizontal axis which is metres (m).

$\lambda = 6$ m



c. Find the period and calculate the wave's frequency.

The graph given has distance on its horizontal axis, therefore the period is unable to be found. Frequency is calculated from the period of the wave. As the period can't be found, neither can the frequency.

Why are wave properties so important?

The properties of a wave determines how they behave. They determine the speed, energy and many other characteristics a wave possesses. Note that a wave will have a greater energy if amplitude or frequency increases.

For electromagnetic waves the amplitude (also known as intensity) tells us how bright the light is. By knowing the wavelength and frequency of an electromagnetic wave, its characteristics and uses can be determined. For example low frequency wavelengths such as microwaves are used by smartphones for communication.

For sound, frequency tells us the pitch while amplitude represents the volume. Turning up the volume in the car is actually just increasing the amplitude of the sound waves being produced.

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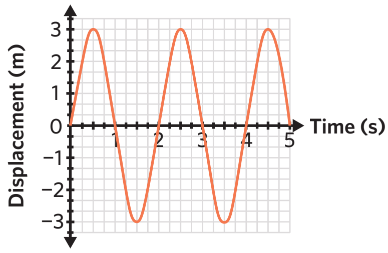
USEFUL TIP

There are many other types of waves besides electromagnetic and sound but the focus of a majority of questions throughout the course will be in terms of light and sound.

Progress questions

Use the following graph to answer questions 1–3.

The graph shows a transverse wave over time.



Question 1

What does the horizontal axis represent?

A. time in seconds

B. period in seconds

C. displacement in metres

D. pressure in pascal

Question 2

Identify the period and calculate the frequency of the wave.

A. $T = 1$ s and $f = 1$ Hz

B. $T = 2$ s and $f = \frac{1}{2}$ Hz

C. $T = 3$ s and $f = \frac{1}{3}$ Hz

D. $T = 6$ s and $f = \frac{1}{6}$ Hz

Question 3

Identify the wavelength.

A. $\lambda = 2$ m

B. $\lambda = 3$ m

C. $\lambda = 4$ m

D. Unable to be identified from graph

Question 4

What is the physical effect of increasing the amplitude of an electromagnetic wave?

A. increase in volume

B. increase in brightness

C. decrease in pitch

D. change of colour

The wave equation 1.1.3.1 & 1.1.4.1

The physical properties of the medium through which a wave travels determines its speed and the source of the wave determines its frequency. Wavelength is determined by its relationship to frequency and wave speed through the wave equation.

Theory and applications

The speed and frequency of a wave are both determined by external factors. In order to change their values these external factors must also change.

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How does the medium determine the wave-speed?

Wave speed is the speed at which the wave transfers its energy through a medium from one place to another. It is determined by the physical properties of the medium in which it travels (e.g. material, density, and temperature) (see Table 2 and 3). Even the speed of light is changed by the medium through which it travels as seen in Table 2.

Table 2 Electromagnetic wave speed through different materials.

Material	Electromagnetic wave speed
Nothing	3.0×10^{8} m s^{-1}
Glass	1.97×10^{8} m s^{-1}
Diamond	1.24×10^{8} m s^{-1}
Water	2.26×10^{8} m s^{-1}

Table 3 Sound wave speed through different materials.

Material	Sound wave speed
Air at sea level	340 m s^{-1}
Air at high altitude	303 m s^{-1}
Water	1482 m s^{-1}
Steel	5960 m s^{-1}

MISCONCEPTION

'The speed of a wave is the speed of an individual particle.'

Wave speed is the speed at which the crests and troughs, or compressions and rarefactions, move. An individual particle within the wave can be moving, faster, slower or not at all without actually affecting the speed of the wave.

How does the source determine the frequency?

Wave frequency will be determined by how fast the source of the wave is vibrating/oscillating. The faster the source is vibrating the higher the frequency of a wave. Take sound for example, a speaker vibrating slower will produce a sound at a lower frequency. Light is another example, the faster an atom vibrates, such as when it gets hotter, the higher the frequency electromagnetic wave it will produce.

USEFUL TIP

Don't forget that frequency and period are linked through an inverse relationship. This means that the source will also determine the period of a wave. The faster the source vibrates the higher the frequency and the lower the period will be.

Progress questions

Question 5

What could a student do to change the wave speed along a rope?

A. Change the frequency of wave generation.
B. Use a rope with different physical properties.
C. Change the period of wave generation.
D. Increase the amplitude of the waves.

Question 6

A particle begins to vibrate at a faster rate than before. The electromagnetic wave the atom produces will be

A. a higher frequency than before.
B. a lower frequency than before.
C. the same frequency as before.
D. a higher amplitude than before.

How do the speed and frequency determine wavelength?

Wavelength can be found using speed and frequency through the wave equation. This equation relates the three quantities and holds for all types of waves including light.

FORMULA

$$v = f\lambda$$

v = wave speed (m s^{-1})
f = frequency (Hz or s^{-1})
λ = wavelength (m)

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USEFUL TIP

Velocity is defined by how fast something moves (speed) and in what direction it moves. When referring to *v* in this chapter concerning waves, only the speed is considered.

The wave equation using period instead of frequency, given $f = \frac{1}{T}$, takes the following form:

FORMULA

$$v = \frac{\lambda}{T}$$

v = wave speed (m s^{-1})
λ = wavelength (m)
T = wave period (s)

WORKED EXAMPLE 2

A wave of frequency 48 Hz is travelling along a string at a speed of 24 m s^{-1}. Calculate the wavelength, λ.

Step 1

Identify the frequency and velocity of the wave, and the equation that relates these variables.

$f = 48$ Hz, $v = 24$ m s^{-1}, $\lambda = ?$

$v = f\lambda$

Step 2

Substitute values into the equation and solve for wavelength λ. Pay attention to the correct units and significant figures.

$24 = 48 \times \lambda$

$\lambda = \frac{24}{48} = 0.50$ m

Progress questions

Question 7

Identify the speed that light travels through a vacuum in kilometres per second (km s^{-1}).

A. 300 km s^{-1}

B. 300 000 km s^{-1}

Question 8

A loudspeaker emits a sound of frequency 30 Hz. The speed of sound in air in these conditions is 330 m s^{-1}. Which one of the following best gives the wavelength of the sound?

A. 30 m

B. 11 m

C. 3.3 m

D. 0.091 m

VCAA 2015 exam Detailed Study 6 Q1

Question 9

Which of the following will occur when the frequency of a wave is doubled?

A. The amplitude will double.

B. The speed will double.

C. The wavelength will double.

D. The period will halve.

Continues →

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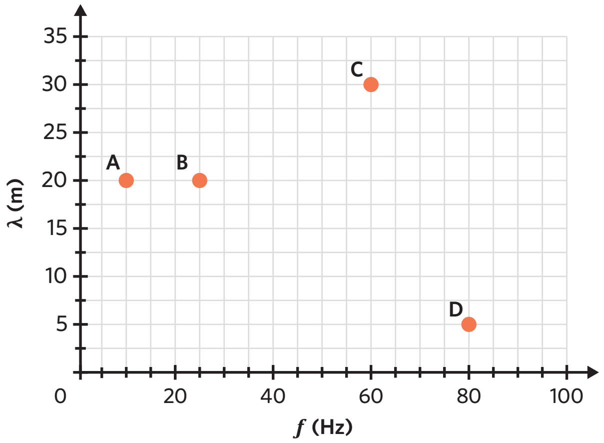
Question 10

Which of the four waves has the greatest speed?



Theory summary

- The properties that waves have that determine their behaviour are:
  - frequency, period, wavelength, and amplitude.
  - the properties are found by graphing the wave.
- All waves can be represented by a graph.
  - Graphs showing the wave at a single point in time will have distance as its horizontal axis.
    - Such graphs are used to find wavelength and amplitude.
  - Graphs showing a particle in the wave over a period in time will have time as its horizontal axis.
    - Such graphs are used to find period, frequency, and amplitude.
- Wave speed is determined by the medium through which the wave travels.
- Wave frequency is determined by the source of the wave.
- $v = f\lambda$ relates frequency and wavelength to wave speed.
- $v = \frac{\lambda}{T}$ relates wavelength and period to wave speed.

Table 4 Which property can be found from a graphed wave?

Graph type	Amplitude	Wavelength	Period	Frequency
Displacement distance	✓	✓	✗	✗
Displacement time	✓	✗	✓	✓ using $f = \frac{1}{T}$

The content in this lesson is considered fundamental prior knowledge to light as a wave (Unit 4 AOS 1).

CONCEPT DISCUSSION

Discuss the difference between wave speed and the frequency of a wave. Does both or just one affect wavelength? If so, how?

Prompts:

- What is wave speed and what determines its value?
- What is frequency and what determines its value?
- Is there a mathematical relationship that relates frequency and wave speed to wavelength?

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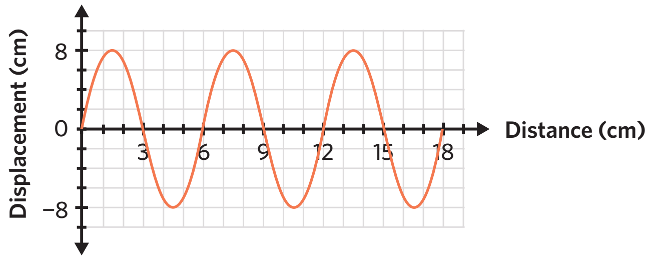
1B Questions

Mild Medium Spicy

Deconstructed exam-style

Use the following information to answer questions 11–14.

The diagram shows part of a travelling wave. The wave propagates with a speed of 18 m s^{-1}.



Question 11 (1 MARK)

What unit is represented on the horizontal and vertical axis?

A. mm

B. cm

C. m

Question 12 (1 MARK)

What is the wavelength?

A. 3 cm which is 0.03 m

B. 6 cm which is 0.06 m

C. 9 cm which is 0.09 m

D. 12 cm which is 0.12 m

Question 13 (1 MARK)

Which equation allows us to find frequency from wave speed and wavelength?

A. $v = f\lambda$

B. $v = \frac{\lambda}{T}$

C. $f = \frac{1}{T}$

Question 14 (3 MARKS)

Identify the amplitude and calculate the frequency of the wave.

Adapted from 2021 VCAA exam Multiple choice Q13

Exam-style

Question 15 (2 MARKS)

A set of speakers at a school assembly are driving sound waves at a frequency of 135 Hz. Calculate the resulting wavelength in metres (m), assuming the speed of sound in air is 340 m s^{-1}.

Adapted from 2018 VCAA exam Short answer Q11a

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Question 16 (5 MARKS)

The two graphs were generated from a longitudinal wave in a spring that is travelling horizontally to the right. Take displacement to the right as positive.

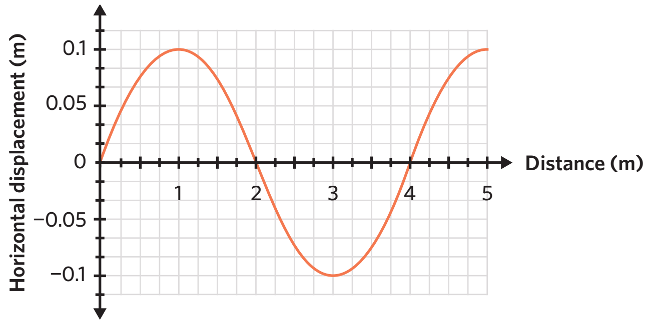
a. Which graph relates to the whole spring, and which specifically relates to one point of the spring? (1 MARK)

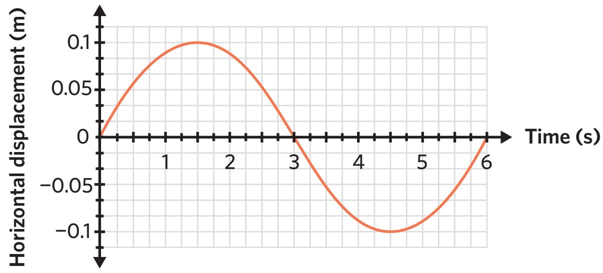
b. What is the amplitude of the wave? (1 MARK)

c. What is the wavelength of the wave? (1 MARK)

d. What is the period of the wave? (1 MARK)

e. What is the frequency of the wave? (1 MARK)





Question 17 (2 MARKS)

A cruise ship's instruments determine the time between the crests of a series of massive waves is $T = 30.0$ s and the distance between them, or wavelength, is $\lambda = 500$ m.

a. Calculate the speed the wave is travelling in m s^{-1}. (1 MARK)

b. Calculate the frequency of the wave in Hz. (1 MARK)

Question 18 (2 MARKS)

Students are using a microwave oven to reheat their food.

Take the speed of microwaves to be 3.0×10^8 m s^{-1}. The label on the microwave oven claims it produces microwaves of wavelength 0.040 m to 0.060 m.

a. Calculate the period of the 0.040 m microwaves. Give an answer in seconds. (1 MARK)

b. Identify whether electromagnetic waves with $\lambda = 0.040$ m or $\lambda = 0.060$ m have greater energy. (1 MARK)

Adapted from VCAA (NHT) 2018 exam Short answer Q11a

Question 19 (1 MARK)

Identify why increasing wave frequency does not increase wave speed.

Question 20 (4 MARKS)

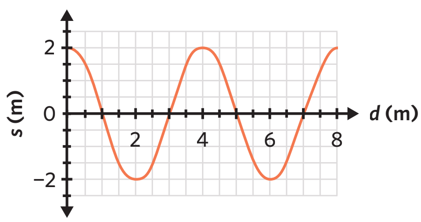
The two displacement-distance graphs represent a mechanical wave at two points in time.

a. Determine the wavelength of this wave. (1 MARK)

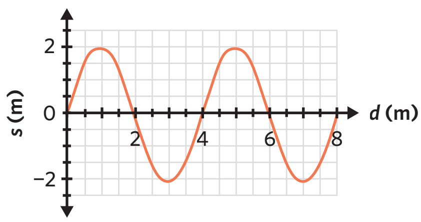
b. What is the lowest possible frequency of the wave? (2 MARKS)

c. What is the speed of the wave based on this frequency? (1 MARK)

$t = 0$ s



$t = 0.25$ s



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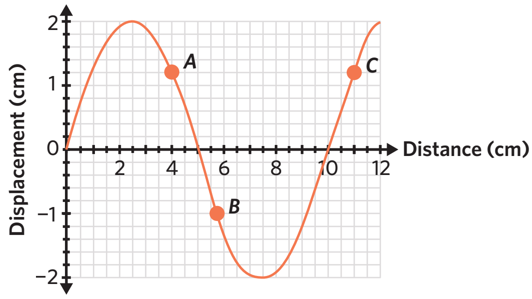
1B QUESTIONS

Question 21 (4 MARKS)

The following graph relates to a transverse wave in a string that is moving to the right.



a. In what direction (up, down, left, right) are the particles located at positions *A*, *B* and *C* moving at the instant shown? If a particle is not moving, write 'not moving'. (3 MARKS)

b. What will be the location of particle *A* after another period has passed? (1 MARK)

Question 22 (3 MARKS)

Mobile phones emit electromagnetic waves of around $f = 450 \times 10^6$ Hz.

Take the speed of light to be 3.0×10^8 m s^{-1}.

What is the wavelength of light produced by a mobile phone? Provide an answer in centimetres.

Question 23 (2 MARKS)

A student is using waves to determine the identity of an unknown gas.

They measure that the frequency of sound waves through the gas is 534 Hz and the wavelength is 0.500 m. Calculate the speed of the wave, and hence determine which gas the sound is passing through.

Gas	Speed of sound (m s^{-1})
Helium	1007
Krypton	221
Hydrogen	1270
Nitrogen	349
Oxygen	326
Carbon dioxide	267

Question 24 (2 MARKS)

Dominique is singing a note with a period of 0.005 s. She finds that the note is flat (the frequency is too low).

Explain whether she should make the period of the note longer or shorter to correct her pitch.

Key science skills

Question 25 (3 MARKS)

Izzy and Emma are using a technique called interferometry to each take 5 repeated measurements of the wavelength of a laser that has an actual wavelength of 695 nm.

Izzy takes the following measurements: 690 nm, 697 nm, 693 nm, 694 nm, 707 nm.

Emma takes the following measurements: 697 nm, 698 nm, 694 nm, 699 nm, 696 nm.

Identify and explain which set of results is more accurate and which set is more precise.

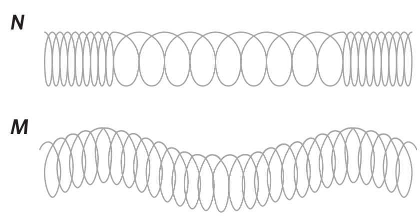
FROM LESSON 11C

Previous lessons

Question 26 (2 MARKS)

Which image shows an example of a transverse wave. Explain your answer.

FROM LESSON 1A



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1C Everyday electromagnetism

Image: Artstrov/Shutterstock.com

What type of everyday electromagnetic wave does this symbol represent?

Sunlight is just one type of electromagnetic wave (also called electromagnetic radiation) that is a part of a whole family of electromagnetic waves. This lesson introduces the concept of light emitted from the Sun as electromagnetic waves and discusses the properties and uses of other electromagnetic waves which are collectively called the electromagnetic spectrum.

STUDY DESIGN DOT POINTS

- describe electromagnetic radiation emitted from the Sun as mainly ultraviolet, visible and infrared
- compare the wavelength and frequencies of different regions of the electromagnetic spectrum, including radio, microwave, infrared, visible, ultraviolet, x-ray and gamma, and compare the different uses each has in society

1A 1B 1C 1D 1E

1.1.5.1 & 1.1.6.1 The electromagnetic spectrum

ESSENTIAL PRIOR KNOWLEDGE

1A Describe electromagnetism

1B Understand frequency and wavelength

See questions 4–5.

ACTIVITIES

Log into your Edrolo account for activities that support this lesson.

KEY TERMS AND DEFINITIONS

electromagnetic spectrum the range of all electromagnetic waves ordered by frequency and wavelength

radiation the transmission of energy in the form of electromagnetic waves or high-speed particles

The electromagnetic spectrum 1.1.5.1 & 1.1.6.1

All possible frequencies of electromagnetic waves comprise the electromagnetic spectrum. The different regions of the electromagnetic spectrum all have valuable uses within society.

Theory and applications

Many modern technologies, from mobile phones to medical equipment, as well the ability to see light, rely upon the electromagnetic spectrum. The electromagnetic spectrum is divided into regions defined by their frequency range as shown in Figure 1.

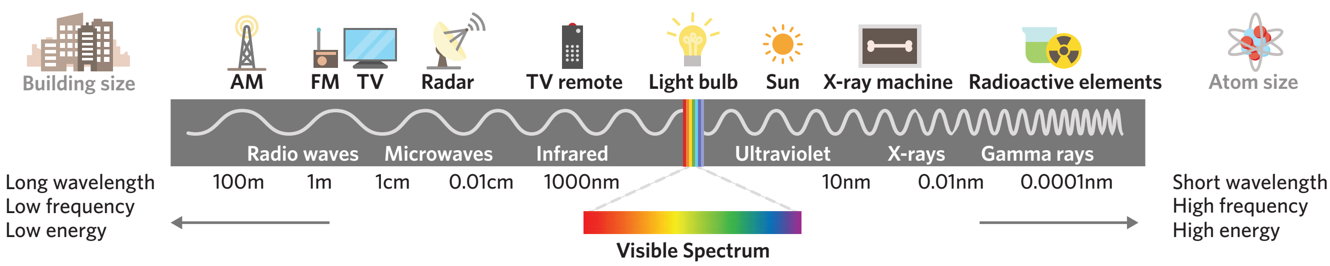

Image: VectorMine/Shutterstock.com

Figure 1 The electromagnetic spectrum

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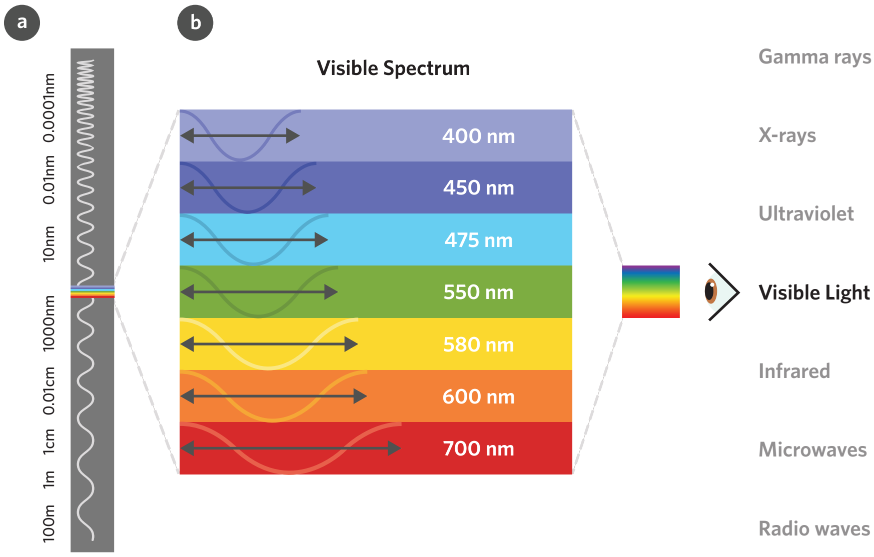
USEFUL TIP

It is common to refer to all types of electromagnetic radiation as 'light'. Light that we can see is called 'visible' light. This is a very small region of the entire spectrum.

The visible spectrum makes up a very small proportion of the electromagnetic spectrum. Although the human eye can distinguish about over a million different colours within this visible region, the other regions are invisible to the human eye. Figure 2(a) shows that only one small region of the electromagnetic spectrum (shown in Figure 2(b) with wavelengths between ≈ 390 nm and ≈ 780 nm) is visible light.



Images (left to right), udaix: VectorMinet/Shutterstock.com

Figure 2 The visible spectrum of electromagnetic radiation **(a)** and their wavelengths **(b)**

How do frequency and wavelength influence the properties of electromagnetic waves?

The Sun emits radiation mostly as infrared (≈ 50%), visible light (≈ 40%), and ultraviolet (≈ 10%). See Figure 3.

Electromagnetic radiation from the visible part of the spectrum is generally better than infrared at penetrating (transmitting) through the Earth's atmosphere.

The shorter wavelength, higher energy (blue) spectral region of the visible spectrum scatters as it passes through the atmosphere more than the longer wavelength, lower energy (red) spectral region. This causes the sky to appear blue and the Sun to appear yellow on Earth.

The more dangerous non-visible higher energy ultraviolet radiation (which has a higher frequency and shorter wavelength than visible light) is mostly absorbed by the ozone layer around the Earth, but some reaches the surface.

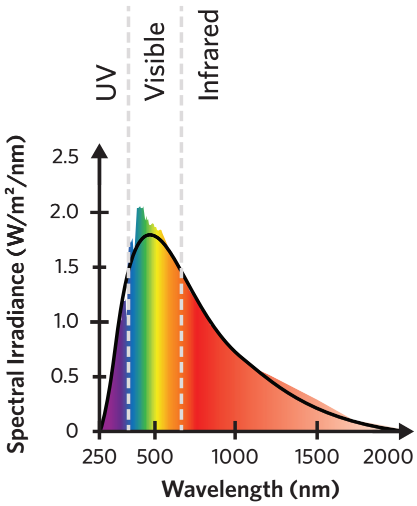


Figure 3 Graph showing the proportions of radiation emitted from the Sun

MISCONCEPTION

'All radiation is dangerous.'

Electromagnetic radiation makes up all of the waves of the electromagnetic spectrum, some of which are harmless to humans (e.g. visible light) and others that are very dangerous (e.g. gamma radiation).

Progress questions

Question 1

What determines the wave properties of electromagnetic waves?

A. wavelength and frequency

B. radiation and distance

Question 2

Which of the following statements about radio waves, microwaves, infrared, visible, ultraviolet, x-ray, and gamma rays is false?

A. They are all examples of electromagnetic waves.

B. They are all different with no shared properties.

C. They all exist on a spectrum and have some common properties.

Continues →

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Question 3

Why is the sky blue?

A. Because all the other colours except blue are absorbed by the atmosphere.

B. Blue light is scattered more than other colours because it travels as shorter, smaller waves.

Question 4

Rollo points an electromagnetic wave detector at the Sun. The detector picks up large amounts of infrared, visible light, and a moderate amount of ultraviolet radiation. Which is the best reason that he detects only very small amounts of light from the other parts of the spectrum?

A. Even though the Sun produces a large amount of all types of electromagnetic radiation, the atmosphere absorbs most of the light that is not infrared, visible or ultraviolet.

B. The Sun does not release other types of light.

C. The other types of radiation are mostly absorbed by other celestial bodies like Mercury, Mars, Venus, and the Moon.

D. The Sun mainly emits infrared, visible, and ultraviolet radiation.

How are the properties of electromagnetic waves utilised by society?

The following summarises the properties and uses of the seven regions of the electromagnetic spectrum in order of increasing frequency and increasing energy.

Radio waves

- Travel long distances uninterrupted due to their long wavelength.
- Diffract around obstacles like buildings and mountains and can reflect off the ionosphere to help travel long distances.
- Mostly used in radio and television communications (see Figure 4) where they are emitted by radio towers and picked up by antennae on devices such as car radios

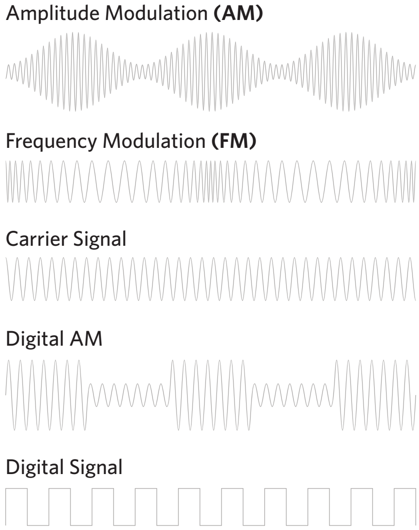

Image: Fouad A. Saad/Shutterstock.com

Figure 4 The different shapes of radio waves

Microwaves

- Used to heat food in microwave ovens.
- Also used for mobile phone signals, Wi-Fi and radar systems.
- Cosmic microwave background (CMB) radiation is electromagnetic radiation which was created in the early stages of the universe and continues to reach Earth, and provides strong evidence for the Big Bang Theory.

Infrared[1]

- All objects emit electromagnetic radiation due to the thermal vibration of charged particles. At temperatures for which life exists most of this radiation is infrared. For this reason thermal vision goggles use infrared and convert it to visible light to 'see' temperature – see Figure 5.
- When infrared radiation hits an object, it causes the particles in that object to vibrate so the object heats up. Radiator heaters and heating lamps use this principle.
- It is also used in some forms of signal transmission such as TV remote controls.

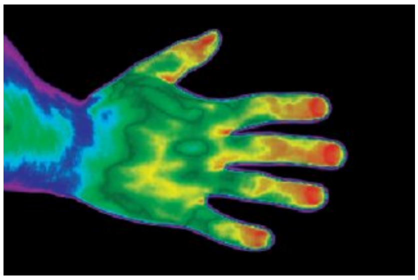

Image: pongpinun traisrisilp/Shutterstock.com

Figure 5 A thermal image

KEEN TO INVESTIGATE?

[1] **How does infrared help us at the scene of a crime?**
Search YouTube: Solving crime with infrared

Visible

- It allows humans (and many species) to see.
- When we see an object as coloured, the object is reflecting the wavelengths of the colour it appears to be and absorbing the complementary (all other) wavelengths (see Figure 6). White light contains all frequencies of visible light.
- Red is at the low frequency/long wavelength end of the visible spectrum and violet is at the high frequency/short wavelength end as shown in Figure 2.

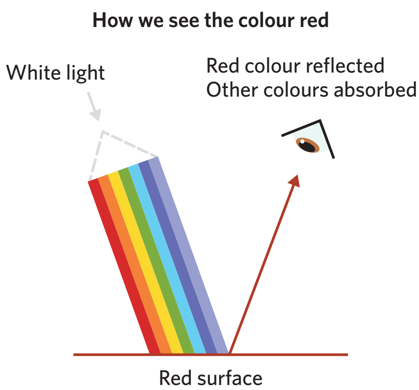

Image: udaix/Shutterstock.com

Figure 6 How we see colours

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KEEN TO INVESTIGATE?

[2] **Why does tonic water glow in the dark under UV light?**
Search YouTube: The world in UV

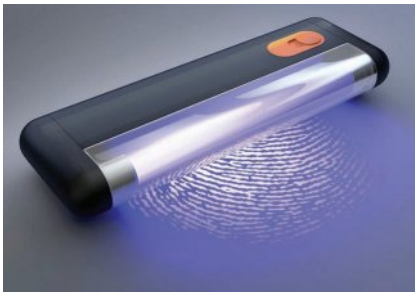

Image: imagineerinx/Shutterstock.com

Figure 7 Body oils fluoresce under UV

Image: Teo Tarras/Shutterstock.com

Figure 8 A medical x-ray image

MISCONCEPTION

'Radio waves are the sound from the radio.'

Radio waves are the electromagnetic wave that carries information between the radio antennas and the radio, the radio itself then transforms a radio wave into a sound wave.

Ultraviolet[2]

- Used in sterilisation processes and to cure (harden) different materials due to its high energy.
- Used in black lights (UV light bulbs) for forensic analysis (see Figure 7) as it causes other substances, including bodily fluids, to fluoresce (emit visible light).
- Produced along with visible light and infrared by the Sun.

X-ray

- High energy and highly penetrating.
- Useful for imaging bone structures as they pass easily through soft tissue (see Figure 8).
- Can damage the DNA in cells or even kill cells in significant doses.
- Produced by cosmic objects and used by astronomers to study those objects.

Gamma rays

- Higher energy, more penetrating, and more damaging than x-rays.
- Produced by nuclear reactions.
- Used in medicine to target and kill tumour cells but care must be taken to minimise damage to other cells.
- Produced by cosmic objects and used by astronomers to study those objects.

Progress questions

Question 5

Which of the following best gives the different regions of the electromagnetic spectrum in order from longest wavelength to shortest wavelength?

A. ultraviolet, visible light, infra-red, microwaves
B. microwaves, ultraviolet, visible light, infra-red
C. visible light, ultraviolet, infra-red, microwaves
D. microwaves, infra-red, visible light, ultraviolet

2018 VCAA (NHT) exam Section A Q15

Question 6

Moving along the entire electromagnetic spectrum from radio to gamma waves, which option correctly describes the way wavelength, frequency, and energy change?

	Wavelength	Frequency	Energy
A.	Decreases	Increases	Increases
B.	Increases	Decreases	Increases
C.	Increases	Increases	Decreases
D.	Decreases	Increases	Decreases

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Theory summary

- Electromagnetic radiation emitted from the Sun is mainly composed of ultraviolet, visible and infrared light.
- Figure 9 shows how the electromagnetic spectrum can be divided into spectral regions according to frequency and/or wavelength which determine their properties.

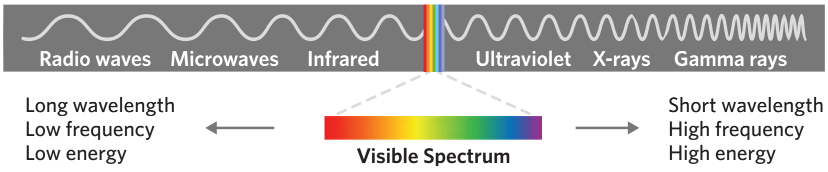

Image: MaciejForyszewski/Shutterstock.com

Figure 9 The electromagnetic spectrum

KEEN TO INVESTIGATE?

What electromagnetic waves are outside of our visible spectrum?
Search YouTube:
The Electromagnetic Spectrum

How do solar flares occur?
Search YouTube: A guide to solar flares

The content in this lesson is considered fundamental prior knowledge to light as a wave (Unit 4 AOS 1).

CONCEPT DISCUSSION

Radio waves and microwaves are used to communicate information, such as the information of a voice between mobile phones. Other regions of the electromagnetic spectrum could carry information in the same way. Discuss why visible light and gamma waves, for example, are not used in communication technology in the same way as radio waves and microwaves.

Prompts:

- What property must an information-carrying signal have in order to reach its destination?
- What are the properties of visible light or gamma waves, for example?

1C Questions

Mild 🌶 Medium 🌶🌶 Spicy 🌶🌶🌶

Deconstructed exam-style

Use the following information to answer questions 7–9.

A student was asked to design an experiment to investigate the light that is emitted from the Sun using a spectroscope. Some examples of spectroscopes are shown.

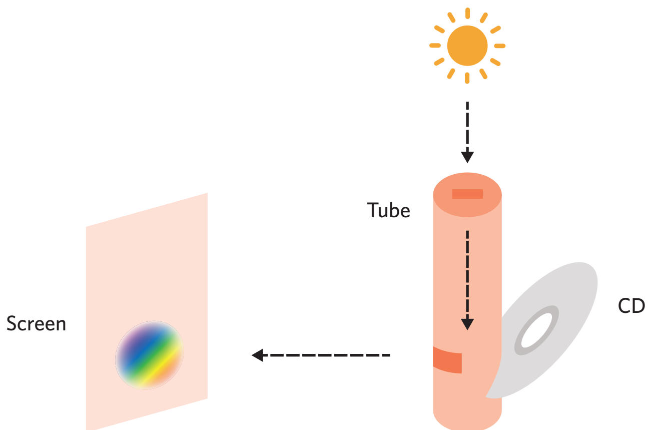

Image: Imfoto/Shutterstock.com

Question 7 (1 MARK) 🌶

Which of the following is not an important safety precaution that the student must follow?

A. Be careful not to touch hot surfaces that have been in the Sun.

B. Do not stand in the Sun for a prolonged period of time.

C. Only do this investigation on a very bright sunny day.

D. Point the spectroscope at reflected light from a white piece of paper.

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Question 8 (1 MARK)

Some spectroscopes might show black lines on the spectrum as shown. What do these black lines represent?

A. frequency of the light

B. wavelength of the light

C. all electromagnetic waves

D. absorbed light by the atmosphere

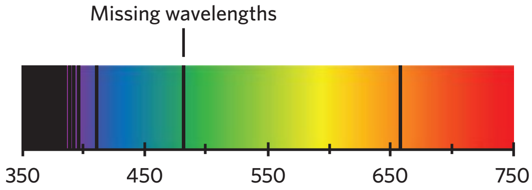


Image: pOrbital.com/Shutterstock.com

Question 9 (2 MARKS)

Describe the difference between ultraviolet and infrared light and give a possible reason why they are difficult to see through a spectroscope.

Exam-style

Question 10 (3 MARKS)

We can show how a radio transforms radio waves into sound as the translation of verbal language into sign language. As the presenter speaks, the interpreter translates the information into Auslan (sign language) so that deaf people can access the information.

Using the table, match the stages of translating verbal language into sign language with the stages of transforming a radio signal into sound (shown in an incorrect order).

Transforming a radio signal into sound	Translating verbal language into sign language
Radio emits sound	Presenter speaks
Radio station sends a radio wave signal	Translator hears the spoken words
Radio receives radio waves	Translator communicates in sign language

Image: Dave Hewison Photography /Shutterstock.com

Question 11 (1 MARK)

Order the following regions of the electromagnetic spectrum from longest wavelength to shortest wavelength.

orange light   x-rays   microwaves   radio   ultraviolet   infrared

Question 12 (1 MARK)

Order the following regions of the electromagnetic spectrum from highest energy to lowest energy.

red light   radio   ultraviolet   blue light   infrared   gamma

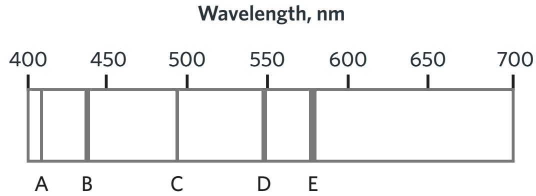
Question 13 (1 MARK)

The vertical lines in the diagram show the wavelengths of light which a mercury atom can emit (known as an emission spectrum). The following list gives the five visible colours that are emitted by the mercury atom.

yellow   green   blue-green   blue   violet

Identify which band (A, B, C, D or E) represents the green emission.

Adapted from VCAA 2018 exam Short answer Q19a



Key science skills

Question 14 (2 MARKS)

Students measure the wavelength of a red laser to be 658 nm. Express this wavelength in the appropriate SI unit to two significant figures.

FROM LESSON 11B

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Previous lessons

Question 15 (1 MARK)

When radiation from the Sun reaches the Earth's surface, it has to travel to the Earth's atmosphere and then through the atmosphere. Identify the property of electromagnetic waves that allows them to reach Earth's atmosphere from the Sun.

FROM LESSON 1A

Question 16 (1 MARK)

All waves of the electromagnetic spectrum in a vacuum have the same

A. energy.

B. speed.

C. wavelength.

D. frequency.

FROM LESSON 1A

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1D Refraction and reflection

STUDY DESIGN DOT POINT

- investigate and analyse theoretically and practically the behaviour of waves including:
  - refraction using Snell's Law: $n_1\sin(\theta_1) = n_2\sin(\theta_2)$ and $n_1v_1 = n_2v_2$
  - total internal reflection and critical angle including applications: $n_1\sin(\theta_c) = n_2\sin(90°)$

1A 1B 1C **1D** 1E

1.1.7.1 Refractive indices and light at boundaries

1.1.7.2 Snell's Law

1.1.7.3 Total internal reflection and critical angle

ESSENTIAL PRIOR KNOWLEDGE

- 1A Speed of light in a vacuum
- 1A Light as electromagnetic waves
- 1B Velocity and frequency of waves
- • Using $\sin(\theta)$ and $\sin^{-1}(a)$

See questions 6–9.

ACTIVITIES

Log into your Edrolo account for activities that support this lesson.

Image: LifeisticAC/Shutterstock.com

Why does light only shine out of the edges and the letters?

The understanding of light as electromagnetic waves can help explain how light behaves as it moves between different materials. This lesson discusses the behaviour of electromagnetic waves at boundaries between different materials, and how this behaviour is predicted and utilised for applications in everyday life.

KEY TERMS AND DEFINITIONS

angle of incidence the angle to the normal of a ray approaching a medium boundary

angle of reflection the angle to the normal of a ray reflected at a medium boundary

angle of refraction the angle to the normal of a ray refracted at a medium boundary

critical angle the angle above which total internal reflection occurs

normal an imaginary line perpendicular to the medium boundary at the point of incidence

refraction the change in direction of a wave moving between two mediums with different refractive indices

refractive index for a given medium, the ratio of the speed of light in a vacuum to the speed of light in that medium

total internal reflection the reflection of all incident light at a boundary between two mediums

transmission the transfer of wave energy through or between wave mediums

FORMULAS

- **refractive index**
  $n = \frac{c}{v}$
- **refractive index and wave speed**
  $n_1v_1 = n_2v_2$
- **Snell's Law**
  $n_1\sin(\theta_1) = n_2\sin(\theta_2)$
- **critical angle**
  $n_1\sin(\theta_c) = n_2$
- **wave equation (frequency)**
  $v = f\lambda$

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Refractive indices and light at boundaries 1.1.7.1

When light crosses a boundary between different mediums it can change speed. This change in speed causes it to refract (change direction - see Figure 1). The refractive index is a measure of the speed of light travelling through a specific medium. The greater the refractive index the slower light moves in that medium.

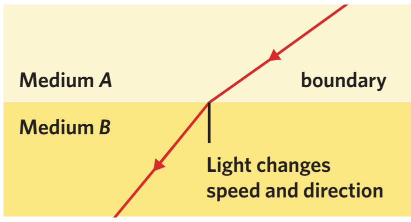

Figure 1 Refraction can occur when light changes speed.

Theory and applications

Light travels fastest through a vacuum because there is no matter for it to interact with. When light reaches a boundary between two mediums it can change both speed and direction of travel causing phenomena such as mirages and rainbows which are covered in Lesson 1E.

How is the refractive index of a medium determined?

The speed of light in a medium will depend on the physical characteristics of the medium (including temperature, density, and type of material) and the frequency of the light. The refractive index, n, is found from the ratio between the speed of light in a vacuum, c, and the speed of light in that medium, v.

FORMULA

$$n = \frac{c}{v}$$

n = refractive index of medium (no units)
c = speed of light in a vacuum (3.0×10^8 m s^{-1})
v = speed of light in medium (m s^{-1})

Because the speed of light never exceeds c, the minimum value for a refractive index is one ($n \geq 1$). The speed of light in air is very close to c so n_{air} is approximately equal to 1.00, whereas light travels slower in water which has refractive index $n_{\text{water}} = 1.33$.

From the definition of refractive index, the refractive indices and speeds of light in two different mediums can be related mathematically.

FORMULA

$$n_1 v_1 = n_2 v_2$$

n_1 = refractive index of first medium (no units)
v_1 = speed of light in first medium (m s^{-1})
n_2 = refractive index of second medium (no units)
v_2 = speed of light in second medium (m s^{-1})

WORKED EXAMPLE 1

Light in a glass block has a speed of 2.0×10^8 m s^{-1} and the speed of light in water is 1.15 times faster than light in the glass block.

a. Calculate the refractive index of the glass block.

Step 1

Identify wave speed and refractive index, and the formula that relates these variables.

$v_{glass} = 2.0 \times 10^8$ m s^{-1}, $c = 3.0 \times 10^8$ m s^{-1},
$n_{glass} = ?$

$n = \frac{c}{v}$

Step 2

Substitute values into the formula and solve for the refractive index of the glass block n_{glass}. Note the correct answer for the refractive index will not have any units.

$$n_{glass} = \frac{3.0 \times 10^8}{2.0 \times 10^8} = 1.50 = 1.5$$

Continues →

b. Calculate the refractive index of the water.

Step 1

Identify the wave speeds and refractive indices, and the formula that relates these variables.

$n_1 = n_{glass} = 1.5, v_1 = v_{glass} = 2.0 \times 10^8 \text{ m s}^{-1}$,
$n_2 = n_{water} = ?, v_2 = v_{water} = ?$

$n_1 v_1 = n_2 v_2$

Step 2

Calculate the speed of light in the water v_2. It is stated in the question that v_2 is 1.15 times faster than v_1.

$v_2 = v_1 \times 1.15 = 2.0 \times 10^8 \times 1.15$

$v_2 = 2.30 \times 10^8 = 2.3 \times 10^8 \text{ m s}^{-1}$

Step 3

Substitute values into the formula and solve for the refractive index of water n_2.

$1.5 \times 2.0 \times 10^8 = n_2 \times 2.3 \times 10^8$

$n_2 = \frac{1.5 \times 2.0 \times 10^8}{2.3 \times 10^8} = 1.30 = 1.3$

USEFUL TIP

Dividing $\frac{\textit{speed of light in the water}}{\textit{speed of light in the glass block}}$ can give an indication as to how many times faster light travels through the water than the glass.

Progress questions

Question 1

Higher refractive indices correspond to

A. lower speeds of light in a medium.

B. higher speeds of light in a medium.

Question 2

Which of the following statements is true?

A. $n = 1$ is the lowest possible value for a refractive index.

B. A vacuum has refractive index $n = 1$.

C. When light moves through a medium with refractive index $n = 1$, it is travelling at $3.0 \times 10^8 \text{ m s}^{-1}$.

D. All of the above

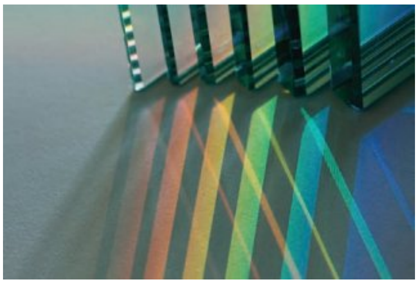

Image: noprati somchit/Shutterstock.com

Figure 2 Reflection and refraction often occur at the same time

How does light behave at boundaries between mediums?

How light moves as it changes between mediums depends on the refractive indices of those mediums as well as the angle that it arrives at the boundary between them. We use the refractive indices and the angle it arrives at the boundary to predict:

- which direction the light will move in,
- at what angle the light will deviate.

Whenever light hits a boundary between two mediums, some of the light will reflect back into the medium it is travelling in as shown in Figure 2. Light that is transmitted from one medium into another may refract (change direction). This is caused by light slowing down or speeding up as it travels between the mediums.

The angles of incidence (θ_i), reflection ($\theta_{reflect}$), and refraction (θ_r), are always measured between the relevant ray of light and the normal. Light will always be reflected at the same angle to the normal as it was incident ($\theta_i = \theta_{reflect}$). The amount and direction light will refract depends on the ratio between the refractive indices of the two mediums.

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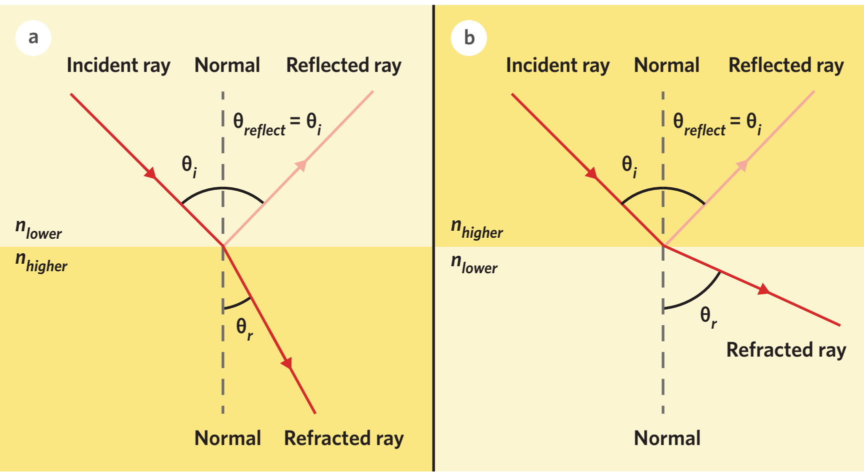


Figure 3 Rays of light at a boundary where the light is moving into **(a)** a slower medium and **(b)** a faster medium.

When light travels from its current medium into one with a higher refractive index, as in Figure 3(a), it:

- bends towards the normal,
- therefore the angle of refraction θ_r will be less than the angle of incidence θ_i.

When light travels from its current medium into one with a lower refractive index, as in Figure 3(b), it:

- bends away from the normal,
- therefore the angle of refraction θ_r will be greater than the angle of incidence θ_i.[1]

An easy way to see refraction in action is to put a pencil partially into a glass of water. Due to the refraction of the light coming off the pencil at the air-water boundary, the pencil will appear bent or disjointed, as shown in Figure 4.

MISCONCEPTION

'If the incident light travels in the direction normal to the boundary, crossing the boundary will have no effect on it.'

Light crossing the boundary at an angle of incidence of 0° means that it will not change direction, however its speed (and therefore its wavelength) will still be affected by changing medium. When passing between mediums, the frequency of light will be unchanged.

KEEN TO INVESTIGATE?

[1] **Why does light bend when it enters glass?**
Search YouTube: Why does light bend when it enters glass?

Image: Kuki Ladron de Guevara/Shutterstock.com

Figure 4 Refraction makes a pencil in water appear disjointed.

Progress questions

Question 3

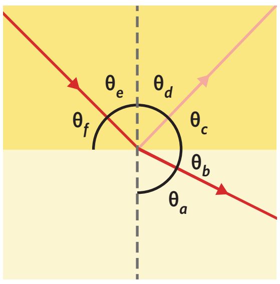
Light will reflect

A. only when light hits a shiny surface, such as a mirror.

B. whenever light reaches the boundary between two different mediums.

Question 4

Which option correctly identifies the angles of incidence, reflection and refraction in the diagram?



	Angle of incidence	Angle of reflection	Angle of refraction
A.	θ_a	θ_b	θ_c
B.	θ_e	θ_d	θ_a
C.	θ_f	θ_c	θ_b
D.	θ_e	θ_d	θ_c

Continues →

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Question 5

Which of the following statements is correct?

A. Light bends towards the normal whenever it enters a medium with a high refractive index.

B. Light bends away from the normal whenever it enters a medium with a high refractive index.

C. Light bends towards the normal whenever it passes from a lower refractive index medium to a higher refractive index medium.

D. Light bends towards the normal whenever it passes from a higher refractive index medium to a lower refractive index medium.

Snell's Law 1.1.7.2

Snell's Law gives a formula for light passing between mediums, relating the refractive indices of each medium with the angle of incidence and angle of refraction.

Theory and applications

We use Snell's Law to calculate the direction light, compared to the normal, will move after travelling through the boundary between mediums. Snell's Law has a wide range of applications in optics, the branch of physics that studies the behaviour of light, helping construct cameras, eyeglasses and contact lenses.

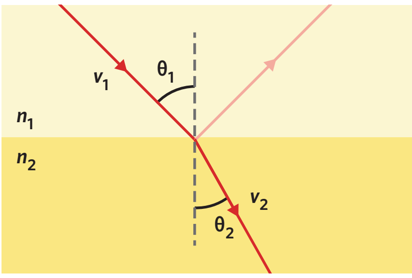


Figure 5 Snell's Law at a boundary between two mediums.

How is Snell's Law used to calculate refraction?

The angle of refraction is related to the incident angle and the refractive indices of the boundary medium by Snell's Law. The relationship between these four values is shown in Figure 5.

FORMULA

$$n_1\sin(\theta_1) = n_2\sin(\theta_2)$$

n_1 = refractive index of first medium (no units)
θ_1 = angle to the normal in first medium (°)
n_2 = refractive index of second medium (no units)
θ_2 = angle to the normal in second medium (°)

One of the primary applications of Snell's Law is in the making of eyeglasses. By manipulating the shape and thickness of the glass lenses, the direction that the light travels towards the eye can be altered. This means that glasses can be made to correct inaccuracies in the way the eyes focus light.[2]

Images appear blurry when the rays of light coming off them are focused at a point that is not on the retina, as shown in Figure 6(a). Optometrists use Snell's Law to calculate the exact shape and thickness of lenses to change the direction of incoming light, such that the eye refracts the rays to focus exactly onto the retina, shown in Figure 6(b).

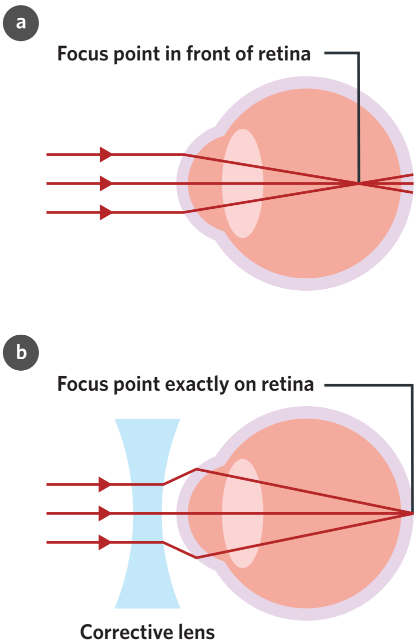


Figure 6 **(a)** Light incorrectly focused by the eye, and **(b)** correctly focused with a corrective lens.

KEEN TO INVESTIGATE?

[2] **Why does a convex lens magnify an image?**
Search YouTube: Lenses and virtual images explained

WORKED EXAMPLE 2

A ray of light passes from air ($n = 1.00$) to water ($n = 1.33$). If the incident angle of the ray is 43.0°, calculate the angle of refraction.

Step 1

Identify the refractive indices and angles of incidence and refraction, and Snell's Law which relates these variables. Note that the incident ray in this case refers to the light while it is travelling through the air.

$n_1 = n_{air} = 1.00$, $n_2 = n_{water} = 1.33$, $\theta_1 = \theta_{air} = 43.0°$, $\theta_2 = \theta_{water} = ?$

$n_1 \sin(\theta_1) = n_2 \sin(\theta_2)$

Step 2

Substitute values into Snell's Law and solve for the light ray's angle of refraction in water θ_2. Ensure that the calculator and the unit of the final answer is in degrees (°).

$1.00 \times \sin(43.0°) = 1.33 \times \sin(\theta_2)$

$\theta_2 = \sin^{-1}\left(\frac{1.00 \times \sin(43.0°)}{1.33}\right) = 30.84 = 30.8°$

Progress questions

Question 6

A ray of light passes from glass ($n = 1.50$) into an unknown medium ($n = ?$). The angle of incidence is $\theta_i = 45.0°$ and an angle of refraction is $\theta_r = 50.0°$. What is the refractive index of the unknown medium?

A. 1.38

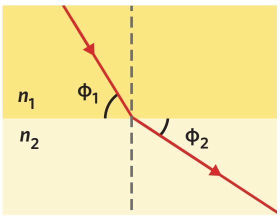
B. 1.63

C. 1.35

D. 1.67

Question 7

Which of the following relationships between the four labelled variables is correct?



A. $n_1 \sin(\phi_1) = n_2 \sin(\phi_2)$

B. $n_2 \sin(\phi_1) = n_1 \sin(\phi_2)$

C. $n_1 \sin(90 - \phi_1) = n_2 \sin(90 - \phi_2)$

D. $n_2 \sin(90 - \phi_1) = n_1 \sin(90 - \phi_2)$

USEFUL TIP

All the angles used in refraction formulas must be angles between a ray of light and the normal. If given an angle ϕ between a ray of light and the boundary, we can find the angle between the ray and the normal by using $\theta = 90 - \phi$ in calculations instead.

Total internal reflection and critical angle 1.1.7.3

The critical angle is the incident angle at which the refracted angle is 90°. Light with an incident angle greater than the critical angle will be totally internally reflected.

Theory and applications

It is possible for light to be refracted at a 90 degree angle away from the normal, or even for it to become impossible for light to be transmitted through a boundary. These phenomena, critical angle and total internal reflection, allow for gemstones to sparkle and for the construction of edge-lit LED panels.

Why does the critical angle only exist sometimes and how is it determined?

When light hits a boundary between the medium it is travelling through and one with a lower refractive index, it bends away from the normal (provided $\theta_i \neq 0°$). As a result, the angle of incidence can be increased to a point where the angle of refraction reaches 90°. The incident angle at which this occurs is called the critical angle, and is depicted in Figure 7.

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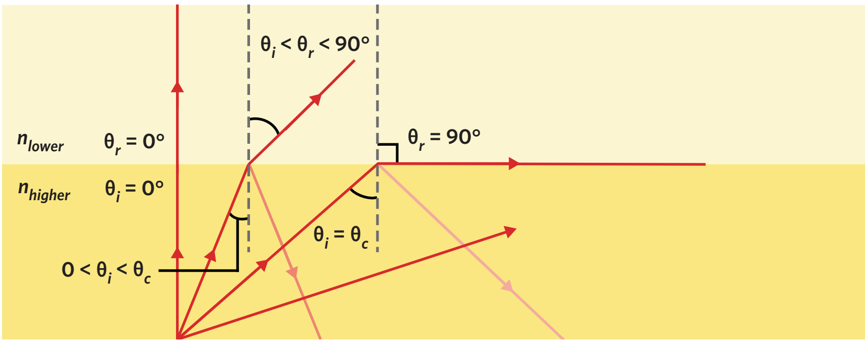

Figure 7 Formation of a critical angle

The critical angle exists when light hits a boundary to a medium with a lower refractive index. If it reaches a boundary between its current medium and one with a higher refractive index then the refracted ray would bend towards the normal, and so the angle of refraction cannot reach 90° since $\theta_i > \theta_r$.

To find the critical angle θ_c using Snell's Law, we assume that $\theta_1 = \theta_c$ and $\theta_2 = 90°$. Since $\sin(90°) = 1.00$, Snell's Law can be rewritten to find the critical angle as:

STRATEGY

The formula $n_1\sin(\theta_c) = n_2$ is an official VCAA formula, however it assumes that the light is moving from medium 1 towards medium 2. In critical angle calculations, always ensure that n_1 corresponds to the medium light is initially moving through.

FORMULA

$$n_1\sin(\theta_c) = n_2$$

n_1 = refractive index of first medium (no units)
θ_c = critical angle between the medium (°)
n_2 = refractive index of second medium (no units)

Rearranging for θ_c:

$$\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$

See Table 1 for the critical angles for yellow light travelling in various materials reaching a boundary with air. Note that materials with lower refractive indices have higher critical angles in air.

Table 1 The critical angle and refractive index of yellow light at the boundary with air at 20°C.

Material	Critical angle at boundary with air	Refractive index
Distilled water	48.6°	1.33
Table salt	41.8°	1.50
Glass	37.0° to 41.1°	1.52 to 1.66
Diamond	24.4°	2.42

WORKED EXAMPLE 3

What is the critical angle for light passing from oil into air, given that $n_{oil} = 1.46$ and $n_{air} = 1.00$?

Step 1

Identify the refractive indices and the formula that relates refractive indices to critical angle. Ensure that the medium assigned to n_1 is the source (incident) medium for this calculation.

$n_1 = n_{oil} = 1.46$, $n_2 = n_{air} = 1.00$, $\theta_c = ?$

$n_1\sin(\theta_c) = n_2$

Step 2

Substitute values into the formula and solve for the critical angle θ_c.

$1.46 \times \sin(\theta_c) = 1.00$

$\theta_c = \sin^{-1}\left(\frac{1.00}{1.46}\right) = 43.23 = 43.2°$

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Why does total internal reflection occur and how is it useful?

If the angle of incidence is greater than the critical angle (i.e. $\theta_i > \theta_c$), then the angle of refraction will be greater than 90°, so the light cannot be transmitted and will remain in its initial medium. This is known as total internal reflection, and is shown in Figure 8.

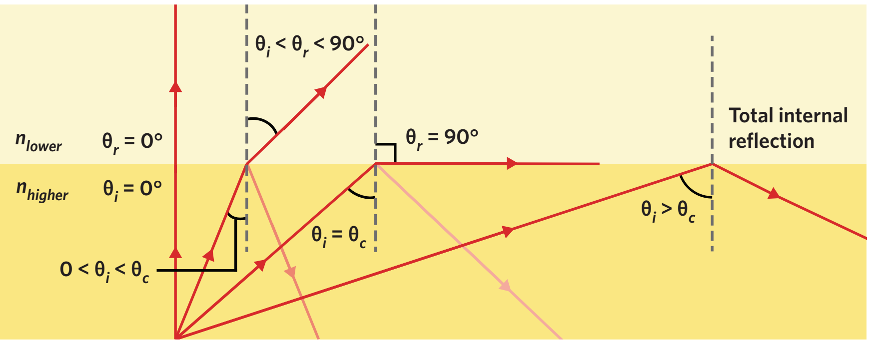

Figure 8 Increasing angle of incidence beyond the critical angle

A common instance of total internal reflection is the sparkling of gemstones (see Figure 9). Gems are cut in specific ways such that incoming light will be totally internally reflected many times before leaving the gem (usually through the top section), giving it a sparkly appearance. Diamonds have a particularly high refractive index of over 2.4 (and therefore low critical angle) so they are especially good at this.[3]

Total internal reflection is also used to make edge-lit LED signs, like the exit sign shown at the start of this lesson. Light is shone into a thin glass panel at an angle such that it will totally internally reflect off the inside surfaces, and only leave the panel through the edges or through a design etched on the surface. This way the panel glows only in certain parts, and appears transparent in others.

MISCONCEPTION

'Total internal reflection happens because light is refracted into its initial medium.'

Total internal reflection occurs because at angles greater than the critical angle, it is impossible for light to transmit and refract into the other medium, and so all light is reflected..

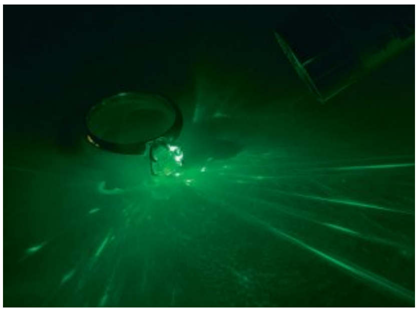

Figure 9 Total internal reflection inside a gemstone

KEEN TO INVESTIGATE?

[3] **What does it look like to shine a laser into a diamond?**
Search YouTube: 5 Total internal reflection in diamond

Progress questions

Question 8

A ray of light is travelling through water ($n = 1.33$) and hits a boundary between the water and air ($n = 1.00$). Which statement, if any, reflects what will occur at the boundary.

A. The critical angle exists and total internal reflection will occur.
B. The critical angle exists and total internal reflection might occur.
C. The critical angle does not exist and total internal reflection will not occur.
D. None of the above

Question 9

Which of the following correctly describes why total internal reflection occurs?

A. Because the light hits a highly reflective surface, such as a mirror.
B. Because the angle of refraction would be over 90 degrees, the light refracts back into its initial medium.
C. Because the angle of refraction would be over 90 degrees, the light cannot be transmitted into the second medium and thus all light is reflected into its initial medium.
D. Because light always reflects at a boundary between mediums.

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Theory summary

- Refractive index is the ratio of speed of light in a vacuum to speed of light in a medium.
- At a boundary between mediums, light always reflects and can also be transmitted.
- The angle of reflection always equals the angle of incidence.
- Snell's Law mathematically describes the refraction of waves at a boundary.

The decision flowchart in Figure 10 shows outcomes for different instances of light hitting a boundary, including direction of refraction, critical angle, and total internal reflection.

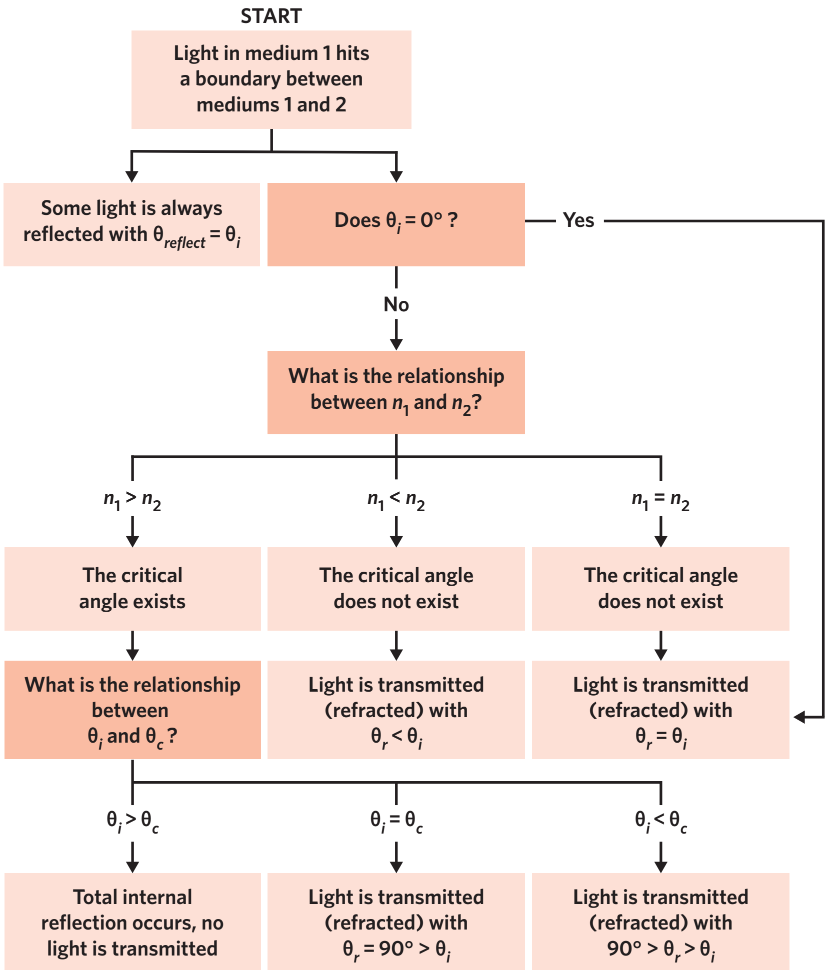


Figure 10 Decision flow chart for light at boundaries

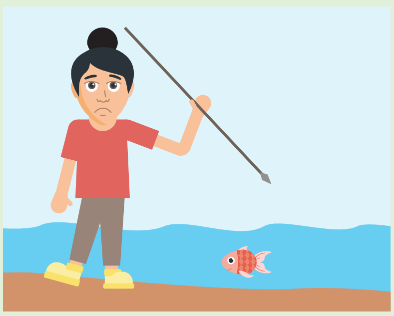
KEEN TO INVESTIGATE?

How can we make things appear invisible?
Search YouTube: A real invisibility shield how does it work?

STRATEGY

Use Figure 10 to determine how light will move at a boundary given certain parameters, or alternatively if the light's movement is already known use Figure 10 to determine the relationships between parameters that result in that outcome.

CONCEPT DISCUSSION



Sunny is standing in a lake to go spear fishing. There is a fish nearby her that is effectively motionless, and she is able to throw her spear in a perfectly straight line. However, whenever she throws her spear at the fish it always misses and travels above the fish instead.

Discuss with reference to refraction, why despite throwing her spear directly towards where she sees the fish, Sunny does not spear it.

Prompts:

- How does the light travel from the fish to Sunny's eyes?
- How does this differ from the paths light takes from objects in air to people's eyes?

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1D Questions

Mild 🌶 Medium 🌶🌶 Spicy 🌶🌶🌶

Deconstructed exam-style

Use the following information to answer questions 10–13.

A light wave is travelling in a body of saltwater, which is enclosed in a plastic container. The wavelength and frequency of a light wave in saltwater are 510 nm and 4.085×10^{14} Hz. Take $c = 3.00 \times 10^{8}$ m s^{-1}.

Question 10 (1 MARK) 🌶

What is the speed of the light wave in saltwater?

A. 3.00×10^{8} m s^{-1}

B. 2.08×10^{8} m s^{-1}

C. 2.25×10^{8} m s^{-1}

Question 11 (1 MARK) 🌶

What is the refractive index of the saltwater?

A. 1.33

B. 1.00

C. 1.44

Question 12 (1 MARK) 🌶

If light travelling in medium 1 hits a boundary between mediums 1 and 2, what condition must be met for the critical angle to exist?

A. $n_1 > n_2$

B. $n_1 < n_2$

C. No condition must be met.

Question 13 (4 MARKS) 🌶🌶🌶

What range of values can the refractive index of the plastic take such that it is possible for total internal reflection to occur?

Exam-style

Question 14 (1 MARK) 🌶

The refractive index of polycarbonate is 1.60. Calculate the speed of light in polycarbonate.

Question 15 (1 MARK) 🌶

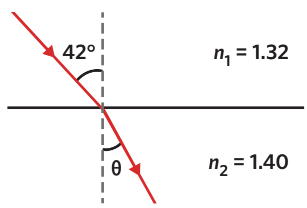
The desired critical angle for an optical fibre with $n_{core} = 1.7$ is 48°. What refractive index would the cladding of the fibre need in order to achieve this critical angle?

Question 16 (2 MARKS) 🌶

A ray of light passes through the boundary between air ($n = 1.00$) and glass. The incident angle is 45.0° and the refracted angle is 30.0°. Calculate the refractive index of the glass.

Question 17 (2 MARKS) 🌶

A ray of light is observed to bend when passing between two transparent liquids. Calculate the angle of refraction of the ray if it has an incident angle of 42.0°.



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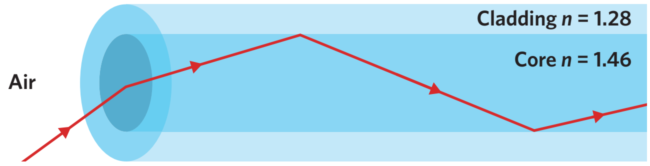
Question 18 (2 MARKS)

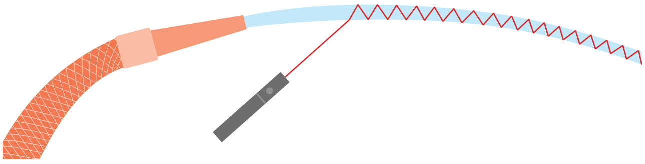
An optical fibre has a core with a refractive index of 1.46 and a cladding with a refractive index of 1.28. Calculate the critical angle inside the optical fibre.

Adapted from VCAA 2018 exam Short answer Q12b



Question 19 (2 MARKS)

A laser light passes into and is then guided by the stream of a hose. Explain how it is possible for the stream to guide the light.



Question 20 (2 MARKS)

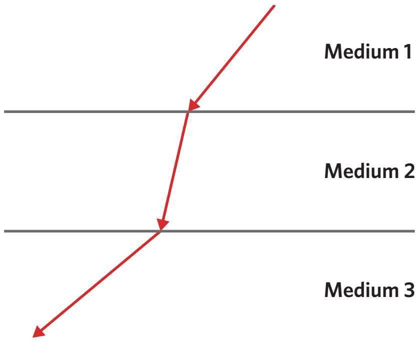
A glass fibre has a critical angle of 50° in air. Will total internal reflection still be possible inside the fibre if it is placed in a tub of water with $n = 1.33$? Assume the refractive index of air is 1.00.

Question 21 (1 MARK)

A monochrome light ray passes through three different mediums, as shown in the diagram. Assume that v_1 is the speed of light in Medium 1, v_2 is the speed of light in Medium 2, and v_3 is the speed of light in Medium 3. Which one of the following would best represent the relative speeds in the mediums?

A. $v_1 > v_2 > v_3$
B. $v_1 > v_3 > v_2$
C. $v_3 > v_2 > v_1$
D. $v_3 > v_1 > v_2$

VCAA 2019 exam Multiple choice Q9

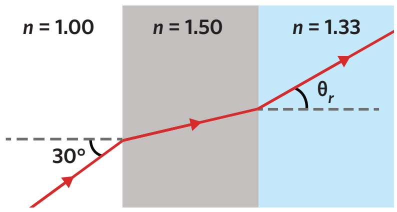


Question 22 (3 MARKS)

The speed of a ray of light passing between two mediums with unknown refractive indices increases by a factor of 1.2. If the ray of light has a refracted angle of 60°, what is the incident angle?

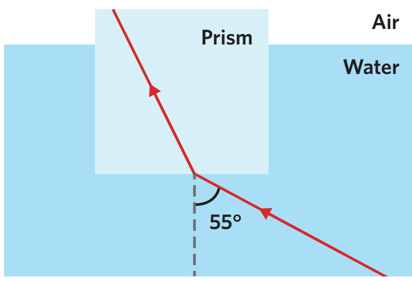
Question 23 (3 MARKS)

A light ray passes from air ($n = 1.00$) into a glass cube ($n = 1.50$) and then into a liquid ($n = 1.33$). The boundaries between the mediums are parallel. Calculate the magnitude (in degrees) of the difference between the initial incident angle of 30° and the final refracted angle.



Question 24 (4 MARKS)

A cubic prism is floating in water and has a refractive index such that $v_{prism} = 0.80 \times v_{water}$ and $v_{prism} = 0.60 \times v_{air}$. A monochromatic light ray from the water hits the prism at 55° to the normal. Determine whether the ray will be totally internally reflected the next time it reaches a boundary, assuming the next boundary is on the opposite face of the prism. Do not assume values for the refractive indices of air or water.



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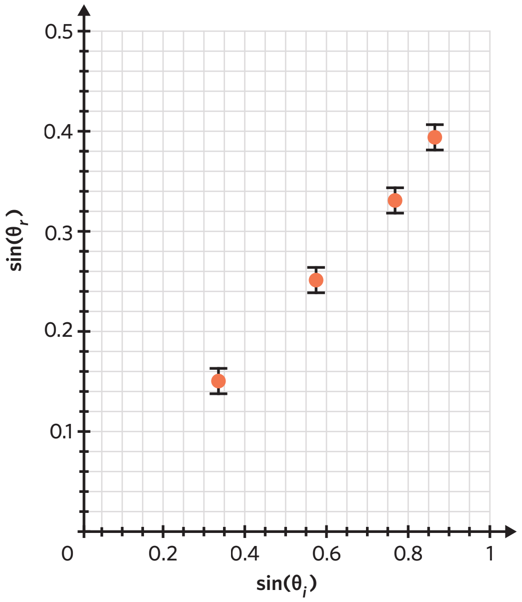
Key science skills

Question 25 (7 MARKS)

A scientist is analysing the diamond engagement ring given to them by their fiancé. They vary the incident angle of a 540 nm green laser light and record the refracted angle after it moves from air ($n = 1.00$) into the diamond. Real diamonds have refractive indices above 2.80.

a. What are the dependent and independent variables in this experiment? Also name one controlled variable in this experiment. (3 MARKS)

b. The scientist plots the results. Calculate the gradient of the line of best fit. (2 MARKS)



c. Use the value of the gradient to determine whether the diamond analysed is real. (2 MARKS)

FROM LESSONS 11A & 11E

Previous lessons

Question 26 (3 MARKS)

Frequency and wavelength are both properties of waves. Briefly describe each of these and identify which of these is only determined by the wave source.

FROM LESSON 1B

Question 27 (1 MARK)

Which of the following statements about electromagnetic waves is true?

A. X-rays have longer wavelengths than wavelengths in the ultraviolet region.

B. The Sun releases mostly waves in the ultraviolet part of the spectrum.

C. X-rays are higher energy electromagnetic waves than all other electromagnetic waves, apart from gamma rays.

D. Radio waves and infrared waves have the same frequency.

FROM LESSON 1C

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1E White light and optical phenomena

STUDY DESIGN DOT POINTS

- investigate and explain theoretically and practically colour dispersion in prisms and lenses with reference to refraction of the components of white light as they pass from one medium to another
- explain the formation of optical phenomena: rainbows; mirages
- investigate light transmission through optical fibres for communication

1A 1B 1C 1D 1E

- 1.1.8.1 White light and colour dispersion
- 1.1.9.1 Rainbows
- 1.1.9.2 Mirages
- 1.1.10.1 Optical fibres

ESSENTIAL PRIOR KNOWLEDGE

- 1C The electromagnetic spectrum
- 1D Behaviour of light at boundaries
- 1D Total internal reflection and critical angle

See questions 10–12.

ACTIVITIES

Log into your Edrolo account for activities that support this lesson.

Why do we see the top of the ships twice?

Reflection and refraction of light can lead to a range of phenomena especially when they interact with the human eye. For example, the dispersion of white light through prisms and other phenomena; rainbows and mirages.

Light phenomena are not only beautiful or occasionally confusing but also help Australians access films and games from overseas through fibre optic cables laid on the ocean floor.

KEY TERMS AND DEFINITIONS

cladding layer of a lower refractive index material forming a protective coating around the inner core of a fibre optic cable

dispersion the separation of white light into its constituent colours due to the different refractive indices for different frequencies (colours) of light in a given medium

fibre optic cable a single cable containing one or more optical fibres encased in cladding to protect it from the environment

illusion a deceptive or misinterpreted sensory experience

mirage an optical illusion caused by the refraction of light rays due to changes in air temperature and pressure

optical fibre a glass fibre that utilises total internal reflection to transmit light over long distances

rainbow an arch of colours caused by the dispersion of the Sun's light through water in the atmosphere

White light and colour dispersion 1.1.8.1

White light is not a particular colour or frequency of light, but a combination of the continuous visible spectrum of electromagnetic radiation. We perceive this combination of colours as white light and can observe a spectrum when we separate the light through a prism or lens.

Theory and applications

The way that white light splits into its constituent frequencies as it travels through a prism is called dispersion (see Figure 1).

Image: Mila Drumeva/Shutterstock.com

Figure 1 When white light is dispersed through a prism, a rainbow is observable

How does dispersion occur?

Instead of thinking about all the colours of light as it travels through a prism, let's consider red (λ ≈ 700 nm) and violet (λ ≈ 380 nm) waves as the frequencies of these colours are the extremes of the visible spectrum (see Figure 2(a)).

When white light is shone onto the prism, this effect is seen across the whole spectrum as each of the colours have different frequencies (see Figure 2(b)).

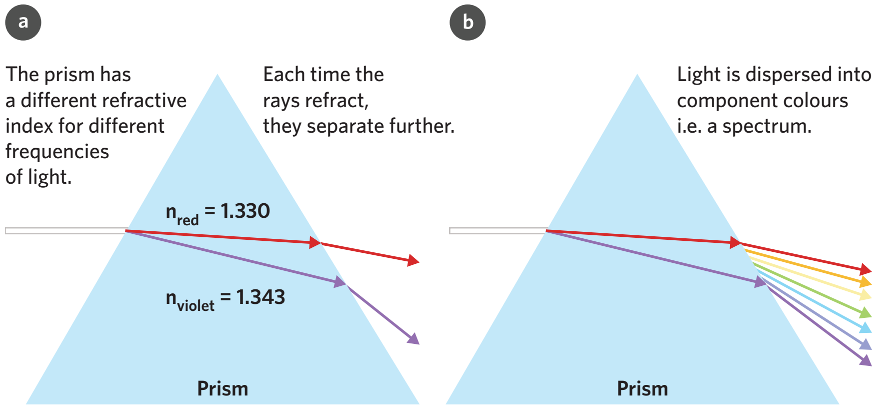

Figure 2 **(a)** Red and violet waves being refracted through a prism. **(b)** White light being dispersed into its component colours.

From Lesson 1D, we know that it is the speed of the light that changes as we enter a new medium. The refractive index of the prism is dependent upon the frequency of the light. This results in different angles of refraction for the components of white light that transmit through the prism.[1]

KEEN TO INVESTIGATE?

[1] **How do the different indexes of refraction impact the dispersed light?**
Search: Dispersion of light simulation

Progress questions

Question 1

White light is

A. a single frequency of light.

B. visible light waves with extremely high intensity.

C. the full, continuous electromagnetic spectrum.

D. the full, continuous spectrum of visible light.

Question 2

Which colour of light will refract to a greater extent when entering the prism?

A. orange light

B. green light

C. blue light

Question 3

For which colour of light will the medium have the highest refractive index?

A. orange light

B. green light

C. blue light

Lenses also disperse white light into a spectrum in the same way that it is dispersed for a prism, with some examples shown in Figure 3. This is an important factor to consider when designing the lenses used in scientific instruments and cameras.

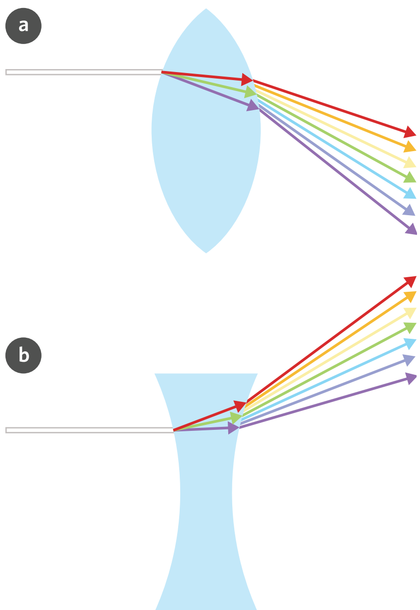

Figure 3 White light dispersion through **(a)** a convex lens and **(b)** a concave lens.

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Rainbows 1.1.9.1

Rainbows are an optical phenomenon caused by the dispersion of white light by water droplets in the atmosphere.

Theory and applications

Rainbows are an application of dispersion and reflection where sunlight disperses through numerous raindrops, acting as prisms and reflecting this dispersed sunlight towards an observer's eyes.

How are rainbows formed?

Rainbows are only visible when the following conditions are met:

- the Sun is behind the observer,
- there are water droplets in the air,
- the observer is far enough away from the water droplets,
- sufficiently bright sunlight reaches the water droplets to disperse and reflect light into the observer's eyes.

Much like Figure 2, we can analyse the dispersion of white light through a raindrop by looking at the extreme ends of the visible spectrum of light, red light and violet light (see Figure 4). The other colours fall between.

MISCONCEPTION

'Total internal reflection always occurs within the raindrop.'

Most light that travels into a raindrop is lost back to the environment and only a small proportion of it reaches our eyes as a rainbow. This is because the internal reflection that is required for a rainbow to form is not total.

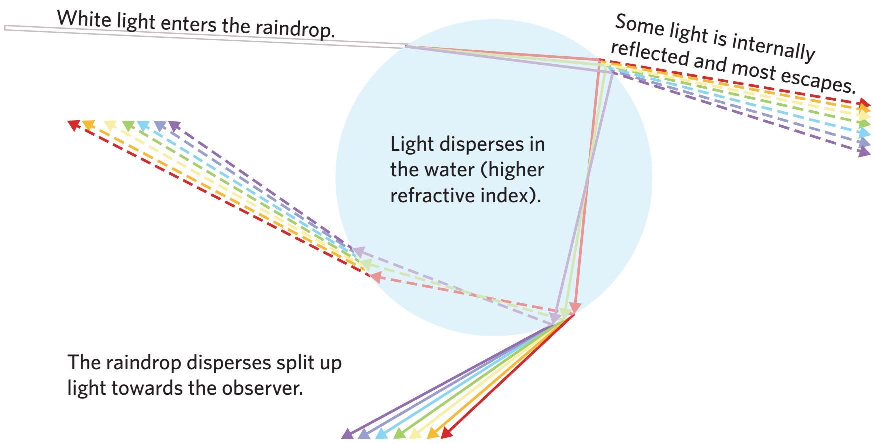

Figure 4 Dispersion and refraction of sunlight through a raindrop

Each droplet in a rainbow disperses the whole spectrum of white light into a cone; however, the observer is so far away from the rainbow itself we do not see the whole rainbow from each raindrop. Every drop instead reflects one colour, dependent on its location, into our eye. The combination of potentially millions of raindrops each sending a single colour to our eyes is the rainbow (see Figure 5).

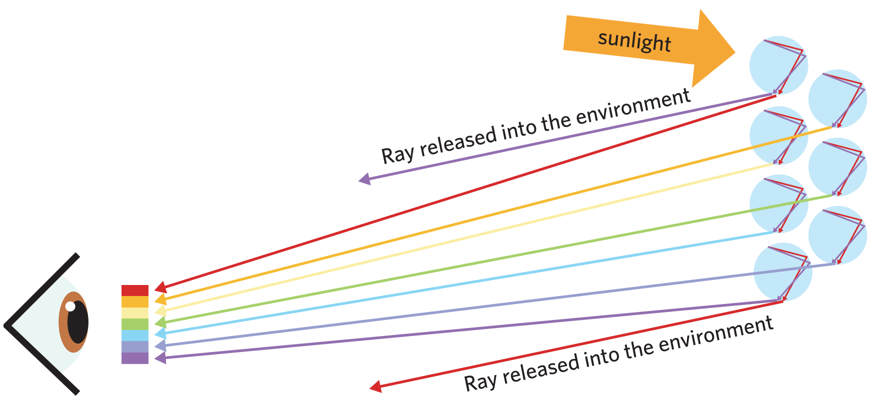

Figure 5 Model of each raindrop's contribution to the rainbow

The combination of thousands of raindrops lead to a continuous spectrum of light being seen instead of seven blocks of colour.

In Figure 5, note that the raindrop reflecting red light is on top and violet on the bottom due to the different angles they refract from the raindrop. The different angles they disperse from the raindrops lead to the order we see the rainbow.

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As we move towards or away from the rainbow, our angle to the rainbow changes meaning that different colours of light will reach our eyes from raindrops in similar locations.[2]

KEEN TO INVESTIGATE?

[2] **What occurs in a raindrop during the formation of a rainbow?**
Search: Rainbow formation simulation

Progress questions

Question 4

Are the orange and green colours in a rainbow likely to have reached an observer's eyes from the same raindrop?

A. Yes, they could be from the same raindrop.

B. No, they can not be from the same raindrop.

C. There is no way of knowing if they are from the same raindrop or not.

Question 5

According to the rainbow's observer, is a raindrop reflecting green likely to be above or below a raindrop reflecting red light?

A. There is no way of knowing which raindrop would be above or below the other.

B. Green is more likely to be above red.

C. Red is more likely to be above green.

Mirages 1.1.9.2

Mirages are an optical phenomena that occur as light travels through air that has a range of temperatures and densities. They allow us to see the sky and the clouds on the road as if it was a mirror.

Theory and applications

Mirages occur only when the air has a range of temperatures between our eyes and the object we are looking at. Surfaces that easily heat up, such as roads or deserts, transfer that heat energy to the air above. This creates a gradient of both air density and temperature above the road (see Figure 6).

Image: simoncritchell/Shutterstock.com

Figure 6 The road is reflecting the sky due to the mirage.

How are mirages formed?

Air's refractive index will be higher the more cold and dense it is. As light moves through air with this gradient of refractive indices its speed will change according to Snell's Law. This causes the light to refract and change direction. When the light refracts enough towards an observer's eyes, as shown in Figure 7, a mirage occurs.

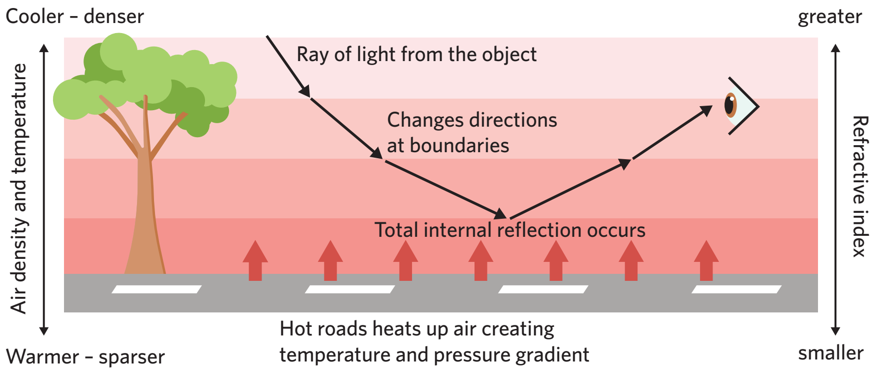

Figure 7 A model representing how mirages occur

The appearance of a reflection of cars or the sky or on the road is an optical illusion created because our brains assume all light travels in straight lines. In Figure 8, the red ray represents the light reflected from the top of the tree.

By extending a ray on the same angle as when it entered the eye, in the opposite direction, we see the tree reflected below where the actual object resides.[3]

KEEN TO INVESTIGATE?

[3] **What is a mirage?**
Search YouTube: What is a mirage?

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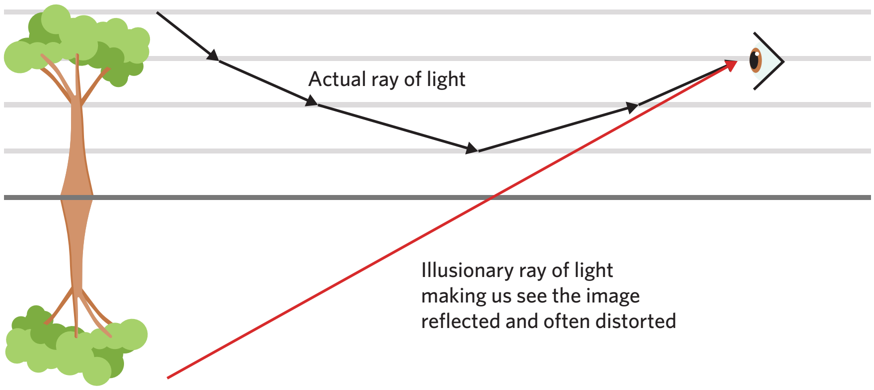


Figure 8 The ray of light that creates the illusion

Note that Figure 7 and 8 are models, which are limited, and cannot represent all the physics that goes into a mirage. Importantly, rays that travel through the temperature gradient change speed, and therefore bend, continuously with the change in temperature until either total internal reflection occurs or the light bends enough to turn into the observer's eye. The limitations of models are covered in Chapter 11.

Progress questions

Question 6

As the temperature of the air increases, its refractive index

A. decreases.

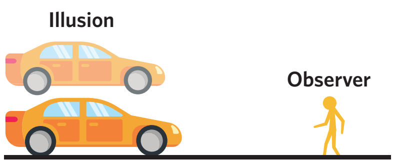
B. increases.

Question 7

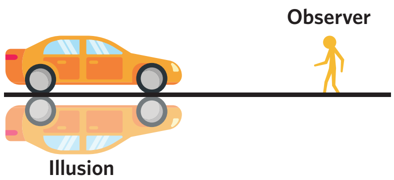
A person is observing a car drive down a road on a hot day.

Considering that the road is hot and the conditions for a mirage are met, which of the following illusions are most likely?

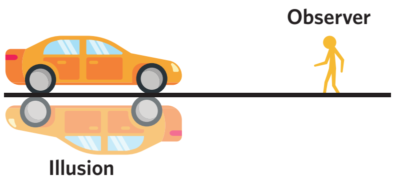
A.



B.



C.



Optical fibres 1.1.10.1

Optical fibres utilise total internal reflection to efficiently transport light through a cable from one location to another.

Theory and applications

Large fibre-optic cables, made up of bundles of optical fibres, running along the ocean floor and between continents form the backbone of the internet and all other telecommunications.

Why do we use fibre-optic cables to communicate?

When light in the optic fibre hits the lower refractive index cladding it undergoes total internal reflection (see Figure 9). The light repeatedly reflects from one side to the other along the length of the tube. As total internal reflection occurs, little light is absorbed or lost at each reflection point. This allows information to travel efficiently over long distances within optical fibres.

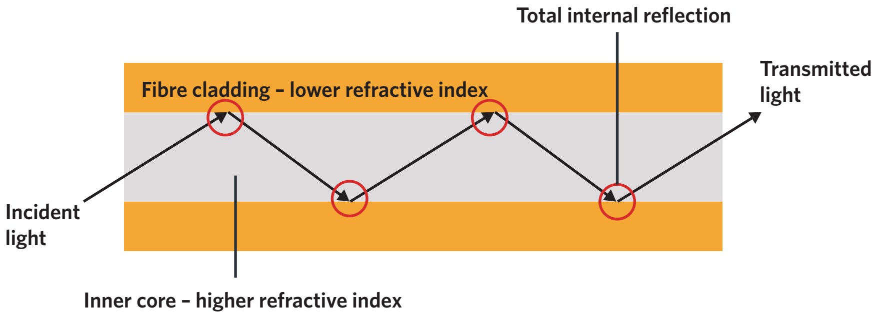


Figure 9 The anatomy of an optical fibre and where total internal reflection occurs

As fibre-optic cables can transfer data using a large range of frequencies, they can transfer more data than other technologies with smaller frequency bands. This allows fibre optics to be a powerful tool for transferring large amounts of data quickly and efficiently. A 10-Gbps (gigabit per second) connection can transmit any of the following per second:

- Video and audio from 16 TV channels
- Over 1000 e-books
- 130 000 audio channels

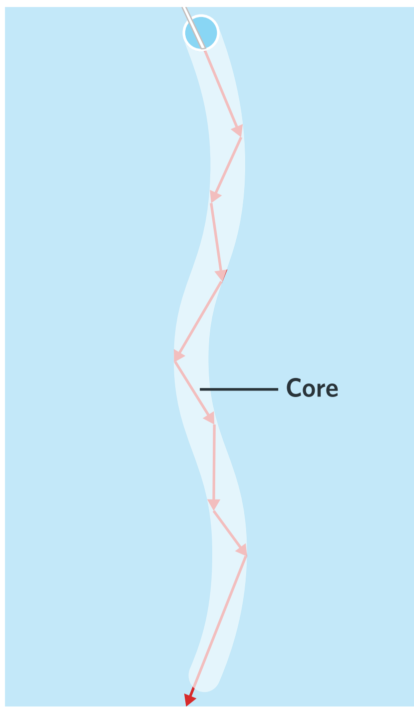


Figure 10 Light moving through an optical fibre as it bends

Progress questions

Question 8

If the fibre cladding had a higher refractive index than the inner core, could the fibre optic cable work as designed?

A. No, it would be impossible for total internal reflection to occur.

B. Yes, as total internal reflection would still occur.

Question 9

Which property of optical fibres makes them ideal for transmitting data? **(Select all that apply)**

I. can process lots of data

II. minimal loss of data over long distances

III. small size

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Theory summary

- White light is the human brain's way of interpreting the continuous spectrum of light entering the eye simultaneously.
- Dispersion is the phenomenon of white light being spread into a spectrum of its constituent frequencies.
- The combination of dispersion, refraction, and reflection cause other optical phenomena (see Table 1).

Table 1 Dispersion, refraction, reflection and their inclusion in other phenomena

Phenomena	Dispersion	Refraction	Total internal reflection
Rainbows	✓	✓	✗
Mirages	✗	✓	✓
Fibre optic cables	✗	✗	✓

CONCEPT DISCUSSION

Image: Shimon Bar/Shutterstock.com

The patch of sky between a primary (bottom) and secondary rainbow (top) is called Alexander's band. Notice how, compared to the light below the primary rainbow, Alexander's band is less bright. Discuss possible reasons as to why the light below the primary rainbow is more bright than the light between the primary and secondary rainbows.

Prompts:

- When light refracts through water, what direction does it bend?
- In what direction is the sunlight coming from?
- When light refracts through a raindrop, some of it is reflected elsewhere. Could this affect how bright light is above or below the rainbow?

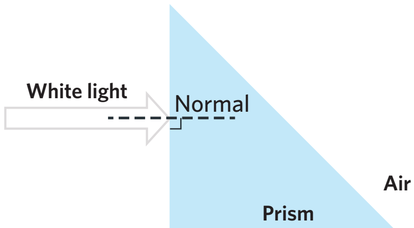
1E Questions

Mild 🌶 Medium 🌶🌶 Spicy 🌶🌶🌶

Deconstructed exam-style

Use the following information to answer questions 10-12.

White light is incident on a prism with a refractive index higher than the air. It first hits the prism parallel to the normal.



Question 10 (1 MARK) 🌶

As the light enters the prism will it disperse or refract?

A. Yes, as white light enters a prism it will disperse and refract.

B. Yes, the prism has a higher refractive index than the air so it will refract but not disperse.

C. No, the white light will neither disperse nor refract as the incident light is parallel to the normal.

D. There is not enough information to be able to determine what will happen.

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Question 11 (1 MARK)

After the light travels through the prism, what happens to the light as it passes through the boundary between the prism and the air?

A. The already dispersed light will disperse further.

B. The light will disperse.

C. The light will return to being white light.

D. There is not enough information to be able to determine what will happen.

Question 12 (4 MARKS)

Explain what happens to the white light as it passes into and out of this prism.

Exam-style

Use the following information to answer questions 13 and 14.

Fibre-optic cables allow the transfer of information over incredibly long distances with little to no loss of information or energy.

Question 13 (1 MARK)

Identify which light phenomenon allows this to occur.

Question 14 (1 MARK)

Which property of the structure of optical fibres allow this to occur?

A. The outer cladding is made of a reflective material causing it to reflect along the entire length of the fibre.

B. The inner cladding is exposed to the air. As air has a lower refractive index than the cladding it allows total internal reflection to occur.

C. The outer cladding has a higher refractive index than the inner cladding.

D. The inner cladding has a higher refractive index than the outer cladding.

Question 15 (3 MARKS)

Describe why rainbows are not as bright as the Sun despite consisting of light reflected from the Sun.

Question 16 (3 MARKS)

Light inside diamonds is totally internally reflected off multiple surfaces, giving diamonds their famous shine. The shine of diamonds also exhibits multiple colours when a white light is incident on the diamond.

Explain why diamonds exhibit a colourful shine, justifying your response with relevant theory.

Question 17 (4 MARKS)

Katya sees a rainbow form in front of her. Her friend Mo remarks that it must be possible to reach the end of the rainbow but Katya disagrees. Explain whether Katya or Mo is correct using the theory of the creation of a rainbow.

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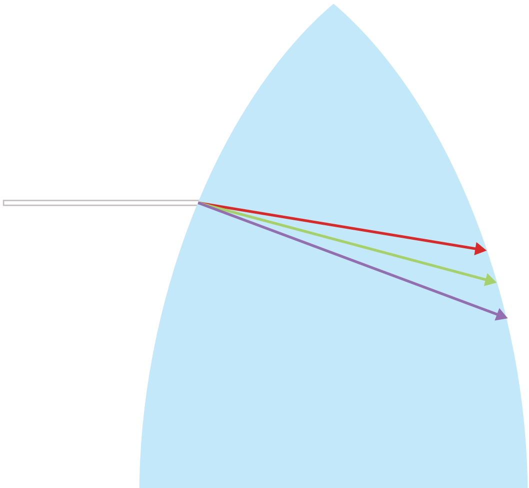
Question 18 (4 MARKS)

The diagram shows red, green, and violet light passing through a convex lens.



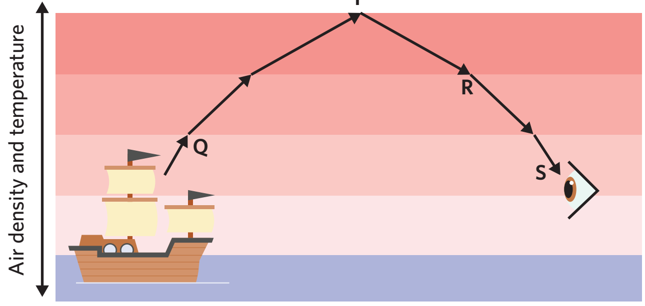
a. What can be concluded about how the refractive index of the lens changes based on the frequency of light? (2 MARKS)

b. Draw arrows to show the path of the red, green and violet light after exiting the lens. (2 MARKS)

Use the following information to answer questions 19–21.

There are two types of mirages, inferior and superior. Superior mirages (displayed in the diagram) occur only when the air's temperature increases with height whereas inferior mirages occur when the air's temperature decreases with height. Superior mirages often occur when the surface is cooler than the air, for example a cold ocean.

A superior mirage occurs due to similar processes to inferior mirages.



Question 19 (1 MARK)

At which point on the graph does total internal reflection occur?

A. P

B. Q

C. R

D. None of the above.

Question 20 (1 MARK)

Is the refractive index higher at point P or point S?

Question 21 (3 MARKS)

Explain where the 'mirage' or illusory image will form and why it will form there in the case of a superior mirage.

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Key science skills

Question 22 (4 MARKS)

Toni Stark is investigating the effect of lens shape on colour dispersion. She shines white light through a glass lens and records the distance between the dispersed red and violet light. She then replaces the glass lens with a plastic lens that has greater curvature, and repeats the measurements.

a. Is this a valid scientific experiment? Explain why or why not. (2 MARKS)

b. Suggest a change to the experimental design in order to make the results more valid. Justify your answer. (2 MARKS)

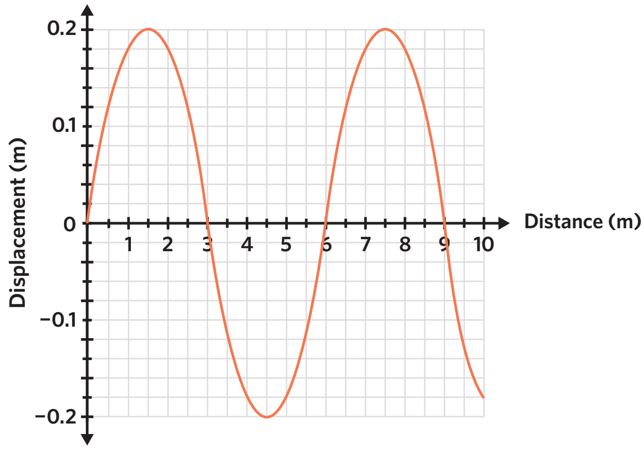
FROM LESSON 11C

Previous lessons

Question 23 (2 MARKS)

Determine the amplitude and wavelength of this mechanical wave.

FROM LESSON 1B



Question 24 (1 MARK)

A string is being plucked at 10 Hz, producing waves of wavelength 0.15 m. What is the period of these waves?

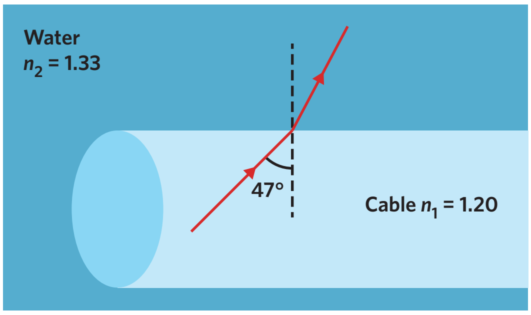
FROM LESSON 1B

Question 25 (2 MARKS)

The diagram shows light in a cable that is submerged in water.

With respect to the normal, at what angle would the light refract when leaving the cable?

FROM LESSON 1D



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Chapter 1 review

Mild 🌶 Medium 🌶🌶 Spicy 🌶🌶🌶

These questions are typical of 40 minutes worth of questions on the VCE Physics Exam.

Total marks: 30

Section A

All questions in this section are worth one mark.

Unless otherwise indicated, the diagrams in this book are not drawn to scale.

Question 1 🌶

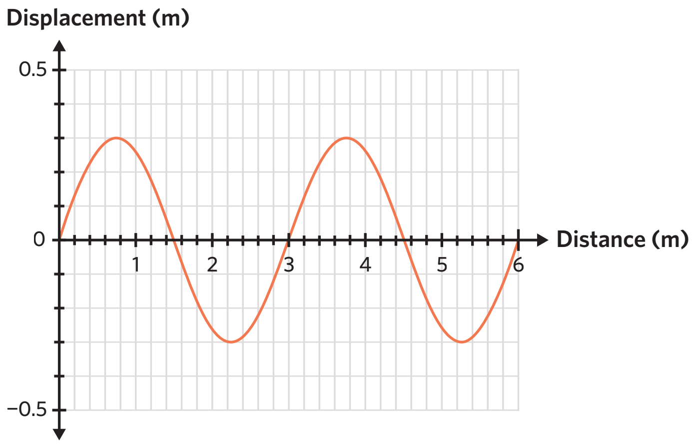
Which option best identifies the properties of the wave?

A. wavelength = 6 m, amplitude = 0.3 m, frequency = 3 Hz

B. wavelength = 3 m, amplitude = 0.3 m, frequency = 0.33 Hz

C. wavelength = 3 m, amplitude = 0.25 m, frequency = 3 Hz

D. wavelength = 3 m, amplitude = 0.3 m, frequency unknown



Question 2 🌶

Which of the following gives the order of light from shortest to longest wavelength?

A. radio, infrared, blue, green, red

B. blue, green, red, infrared, radio

C. radio, infrared, red, green, blue

D. infrared, radio, red, green, blue

Question 3 🌶🌶

Which of the following options lists the regions of electromagnetic spectrum from the fastest to slowest waves in a vacuum?

A. gamma rays, x-rays, ultraviolet, visible, infrared, microwaves, radio waves

B. radio waves, microwaves, infrared, visible, ultraviolet, x-rays, gamma rays

C. They all travel at random speeds and therefore it is impossible to rank them.

D. They all travel at the same speed.

Question 4 🌶🌶

Determine which of these wavelengths is not a component of white light.

A. infrared

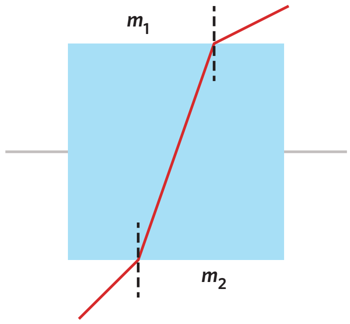
B. red

C. green

D. blue

Question 5

A glass block ($n = 1.50$) and a bowl of water ($n = 1.33$) are being used in a refraction experiment. The medium surrounding the experiment is air ($n = 1.00$). The student conducting the experiment records a diagram of the experiment, in which light travels from medium 1 (m_1), to the glass block, to medium 2 (m_2). What can be concluded about the experimental setup?



- **A.** The glass block is fully submerged in water.
- **B.** The glass block is only surrounded by air.
- **C.** The glass block is partially submerged in water.
- **D.** Unable to conclude any of the above statements.

Section B

In questions where more than one mark is available, appropriate working must be shown.

Unless otherwise indicated, the diagrams in this book are not drawn to scale.

Question 6 (1 MARK)

Identify two properties common to all electromagnetic waves.

Question 7 (1 MARK)

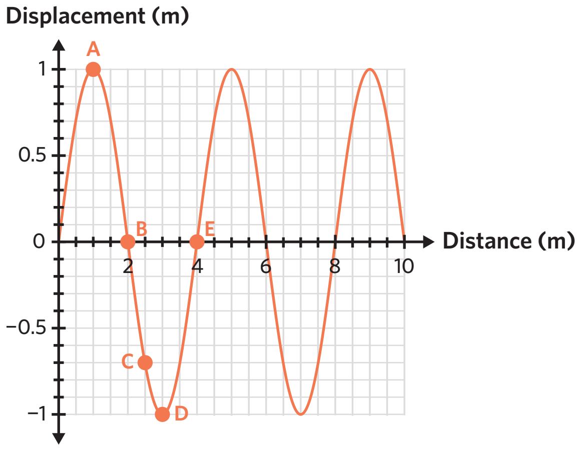
A light-year is the distance light travels in a year and is a common unit of measurement to use when describing astronomical scales. Assuming that an average year has 365 days, convert 0.75 light-years to metres.

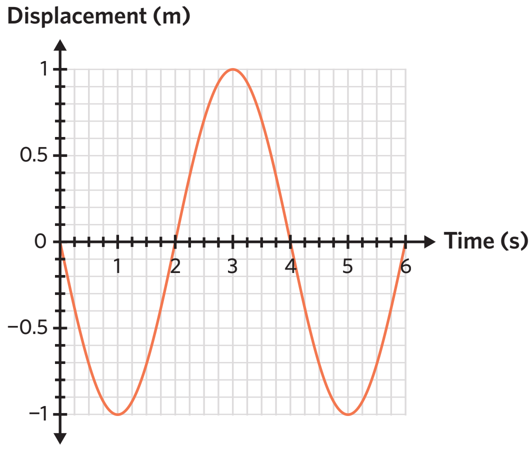
Question 8 (2 MARKS)

Two media have refractive indices of 1.30 and 1.40. Determine the ratio of the speed in the higher refractive index medium to the speed in the lower refractive index medium. Express your answer in decimal form.

Question 9 (7 MARKS)

The two graphs represent the characteristics of the same transverse wave travelling along a rope. The displacement-distance graph depicts the rope at $t = 0$ s. The displacement-time graph represents a single particle on the rope.





- **a.** Calculate the speed of the wave. (2 MARKS)
- **b.** In which direction (up, down, left, or right) is particle C moving at the instant shown? (1 MARK)
- **c.** Which particle (A, B, C, D or E) could the displacement-time graph represent? (1 MARK)
- **d.** Draw the displacement-distance graph at $t = 1.0$ s. (3 MARKS)

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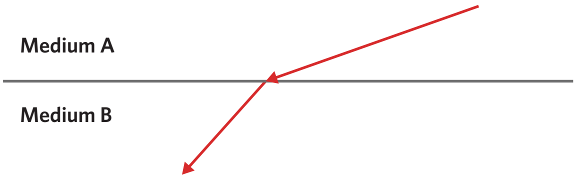
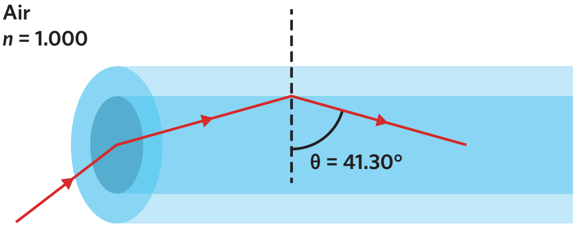
Question 10 (3 MARKS)

Students observe a light ray moving between medium A and medium B. What can be concluded about the refractive indices of the two media? Would this conclusion be impacted if the ray passed through this boundary in the opposite direction?



Question 11 (3 MARKS)

Students are experimenting with an optical fibre and a selection of monochromatic lasers of different colours.



Colour	Red	Yellow	Green	Blue	Violet
Refractive index in fibre optic cable	1.509	1.511	1.513	1.517	1.521

a. Describe the conditions, with reference to refractive indices and the angle of incidence, required for total internal reflection to occur in an optic fibre. (2 MARKS)

b. If the light was directed so that it travelled directly along the centre of the cable and did not touch the edge, which of the five colours would reach the end of the cable first? (1 MARK)

Question 12 (5 MARKS)

When sunlight travels through a raindrop, it splits into its constituent parts.

a. Identify and describe the phenomenon that splits white light into its constituent colours when it travels through a medium. (2 MARKS)

b. Explain why more than one raindrop is required to create a rainbow. (3 MARKS)

Question 13 (3 MARKS)

An observer is standing some distance away from a tree. Suppose that the air is cold at the middle height of the tree, and the air gets gradually warmer at heights lower and higher than this. Explain whether it would be possible for the observer to see a mirage above and/or below the tree.

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2

CHAPTER 2

Thermodynamics principles

STUDY DESIGN DOT POINTS

- convert between Celsius and kelvin scales
- describe temperature with reference to the average translational kinetic energy of the atoms and molecules within a system:
  - distinguish between conduction, convection and radiation with reference to heat transfers within and between systems
  - explain why cooling results from evaporation using a simple kinetic energy model
- investigate and analyse theoretically and practically the energy required to:
  - raise the temperature of a substance: $Q = mc\Delta T$
  - change the state of a substance: $Q = mL$

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LESSONS

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2A Temperature fundamentals

Image: Mandy Creighton/Shutterstock.com

STUDY DESIGN DOT POINTS

- convert between Celsius and kelvin scales
- describe temperature with reference to the average translational kinetic energy of the atoms and molecules within a system:
  - distinguish between conduction, convection and radiation with reference to heat transfers within and between systems
  - explain why cooling results from evaporation using a simple kinetic energy model

2A 2B 2C

1.1.12.1 The kinetic theory of matter

1.1.11.1 Temperature scales

ACTIVITIES

Log into your Edrolo account for activities that support this lesson.

Why does popcorn pop?

Temperature is a concept we are familiar with in our everyday lives, but what is the physical difference between a hot object and a cold object? This lesson will establish the kinetic theory of matter, which is a foundation of thermodynamics (the study of heat flow and its effects), and use this theory to explain the fundamentals of temperature.

KEY TERMS AND DEFINITIONS

energy a quantity describing the ability to cause a physical change (scalar)

internal energy the total energy associated with the random motion of particles and the interactions between the particles within a system

kinetic energy the energy associated with the motion of an object

particle a small, discrete object

potential energy the energy associated with the position of an object in the presence of a force that could move the object

state of matter the physical property of an object being either a solid, liquid, or a gas

system a collection of interacting particles or objects

temperature a measure of the average translational kinetic energy of the particles in a system (scalar)

thermal energy the kinetic energy associated with the movement of microscopic particles

thermal equilibrium the state of two (or more) systems having the same temperature so that there is no net flow of thermal energy from one system to the other

FORMULA

- **converting Celsius to kelvin**
  $T_K = T_{°C} + 273.15$

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The kinetic theory of matter 1.1.12.1

The kinetic theory of matter states that all matter consists of very small particles that are in constant motion. The small-scale behaviour of these particles can explain the large-scale behaviour of solids, liquids, and gases.

Theory and applications

When ice melts into water, it takes on different physical properties, such as the ability to flow and change its shape. The kinetic theory of matter provides an explanation for this, as well as many other processes that we will encounter in Chapters 3 and 4.

How can we describe the states of matter?

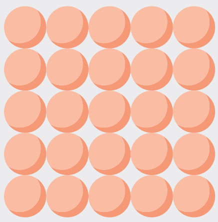
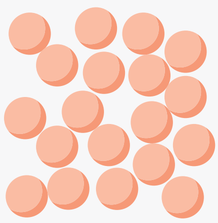
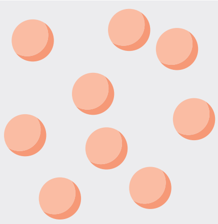
We usually treat objects as a single entity. We do this because objects, such as a single football, look and feel as though they are not made up of smaller parts. However, the kinetic theory of matter states that matter is made of small particles (atoms and molecules). These particles are constantly jiggling, in a state of random disordered motion.

There are three common states of matter: solid, liquid and gas.[1] The relationship between the arrangement/motion of the particles in each state of matter and the properties of each state are shown in Table 1.

KEEN TO INVESTIGATE?

1 **What happens to particles as heat is added?**
Search YouTube: States of matter – Atomic bonding simulation

Table 1 Properties of the states of matter

State of matter	Particle diagram	Particle arrangement	Particle motion	Properties of object	Example
Solid		• Stuck close together • Regular pattern	• Vibrate about a fixed point • No overall movement	• Fixed volume • Fixed shape	Ice  Image: Valentyn Volkov/Shutterstock.com
Liquid		• Close together • Random arrangement	• Free to move around each other • Random collisions	• Fixed volume • Shape can change to fit container	Water  Image: Cozine/Shutterstock.com
Gas		• Far apart • Random arrangement	• Free to move at high speed • Random collisions	• Volume and shape can change to fill a container	Steam  Image: naibank/Shutterstock.com

Progress question

Question 1

When water boils at 100°C, it changes state from a __________ (liquid/gas) to a __________ (solid/gas). The volume __________ (stays the same/changes to fit the container it's in), and inside, the atoms are __________ (more spread out/closer together). The speed of the atoms themselves __________ (increases/decreases) and the atoms tend to __________ (move and collide randomly/vibrate about a fixed point).

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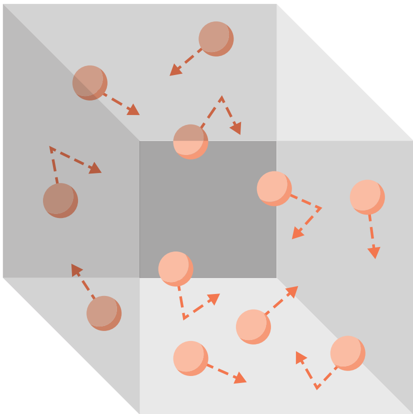

Figure 1 Atoms in an object have translational kinetic energy.

How can we analyse the internal energy within a system?

We can consider the internal energy of a system to consist of two types of energy:

- kinetic energy (KE), due to the random disordered motion of all the particles in the system (see Figure 1), and
- potential energy (PE), due to the interactions between the particles in the system.

Figure 2 illustrates how internal energy can be broken down into kinetic energy and potential energy, and how kinetic energy can be further broken down.

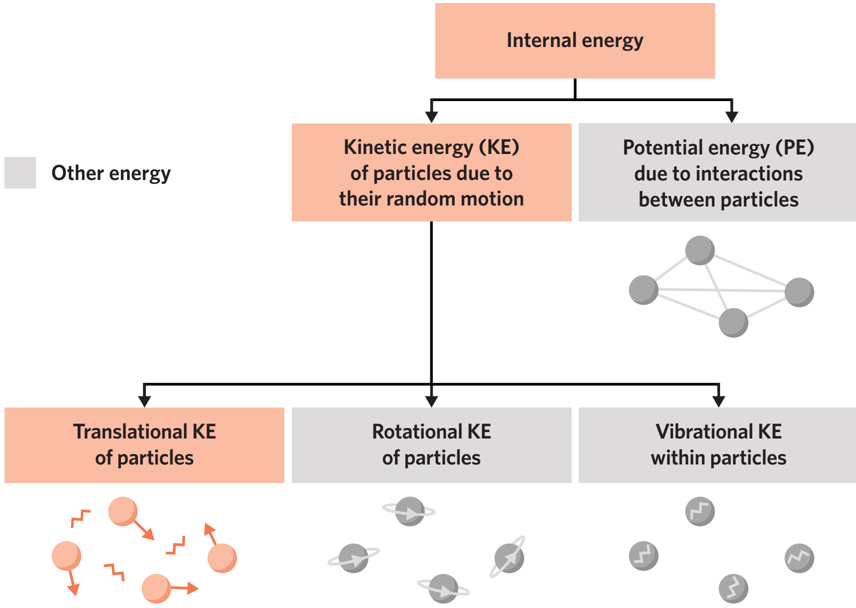

Figure 2 The internal energy of a system

Kinetic energy is the energy of motion. A car has greater kinetic energy when it is driving faster compared to when it is driving slower. Similarly, a system of particles has greater internal kinetic energy when the particles are moving faster compared to when they are moving slower.

This kinetic energy can be further divided into categories according to the different types of motion of the particles:

- translational motion of particles,
- rotational motion of particles, and
- vibrational motion within the particles.

The translational kinetic energy is of particular interest as it relates to the temperature, which will be explained later in the lesson.

The more kinetic energy an object's atoms have, the hotter the object is and the more it expands, as shown in Figure 3.

When cooking popcorn, the kernels heat up and the water inside expands (due to the water molecules increasing their translational kinetic energy and spreading apart), therefore creating pressure. Eventually the pressure gets too much for the starch walls of the shell to withstand, causing the shell to give way and the starch on the interior to burst out and expand.

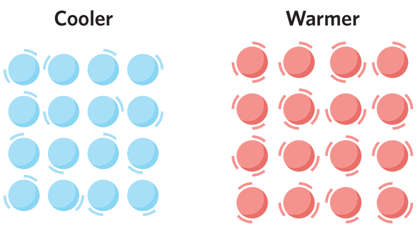

Figure 3 The more translational kinetic energy an atom has, the hotter the object.

MISCONCEPTION

'Internal energy is the same as temperature.'

Two systems can be at different temperatures but have the same internal energy (and vice versa).

Progress questions

Question 2

Which of the following best describes internal energy?

A. the energy associated with the random disordered motion of atoms and molecules

B. the energy associated with the temperature of each atom and molecule

Continues →

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Question 3

Which of the following best describes the type(s) of energy that make up internal energy?

A. the energy due to the overall movement of the system

B. kinetic energy of atoms/molecules and potential energy due to interactions between atoms/molecules

Question 4

If a patch of sand at the beach is at a higher temperature than the sea water, we can conclude that the __________ (average/total) __________ (internal/translational kinetic/potential) energy of the particles that make up the sand is greater than that of the molecules that make up the water.

USEFUL TIP

It is important to recognise that temperature measures the average translational kinetic energy because, at any instant in time, the particles within a system will have a range of speeds, and hence a range of kinetic energies.

Temperature scales 1.1.11.1

Temperature is a measure of the average translational kinetic energy of the particles within a system. Two systems are in thermal equilibrium when they have the same temperature.

Theory and applications

We know that when a substance heats up, it expands. As the fluid inside a thermometer (usually alcohol dyed red or blue) heats up, it expands and rises, to a level which we associate with a temperature scale.

How can we measure temperature?

Degrees Celsius (°C) is the common unit used for everyday temperature measurements in most countries, including Australia. However, the unit kelvin (K) is more commonly used by scientists and is the SI unit for temperature measurements.[2]

The Celsius scale bases the freezing point of water at 0°C and the boiling point at 100°C.

The Kelvin scale is an absolute scale. This means that a zero on the Kelvin scale represents the lowest temperature possible, which we call absolute zero. This is where the kinetic energy of atoms inside a system is zero, or at the point which all atomic movement stops.

- The Celsius scale defines this as −273.15°C.
- The Kelvin scale defines this as 0 K.

The coldest known place in the Universe is the Boomerang Nebula, which has a temperature of 1 K.

The size of one kelvin is the same as the size of one degree Celsius. That is, a temperature increase of 1 K is the same as an increase of 1°C. See Figure 4.

MISCONCEPTION

'Heat and temperature are the same.'

Heat is a measure of the transfer of thermal energy, whereas temperature is the measure of the average kinetic energy of the atoms, or the hotness or coldness of an object. We measure heat in joules, whereas we measure temperature in degrees Celsius or kelvin (we will go more in depth on this in Lesson 2B).

FORMULA

$$T_K = T_{°C} + 273.15$$

T_K = Temperature in kelvin (K)
$T_{°C}$ = Temperature in degrees Celsius (°C)

USEFUL TIP

When stating a temperature measurement using SI units, we do not include the word 'degrees'. A measurement of 50 K is stated as 'fifty kelvin' (rather than 'fifty degrees kelvin').

KEEN TO INVESTIGATE?

2 **What is temperature?**
Search: What exactly is temperature?

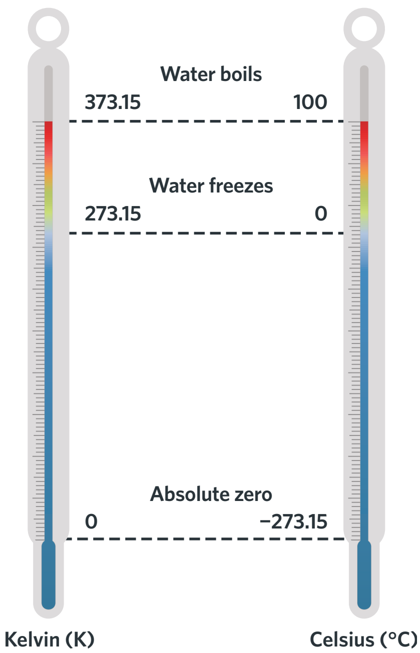

Figure 4 The Kelvin scale and the Celsius scale in comparison

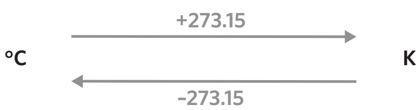

Figure 5 Converting temperature measurements

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Progress questions

Question 5

The atoms and molecules in __________ objects are constantly moving.

A. very hot

B. all

Question 6

The lowest possible temperature is __________ K, which is equivalent to __________°C.

A. 0, −273.15

B. −273.15, 0

Question 7

A change in temperature, ΔT, of 175 K is equivalent to

A. (175 − 273.15)°C.

B. (175 + 273.15)°C.

C. 175°C.

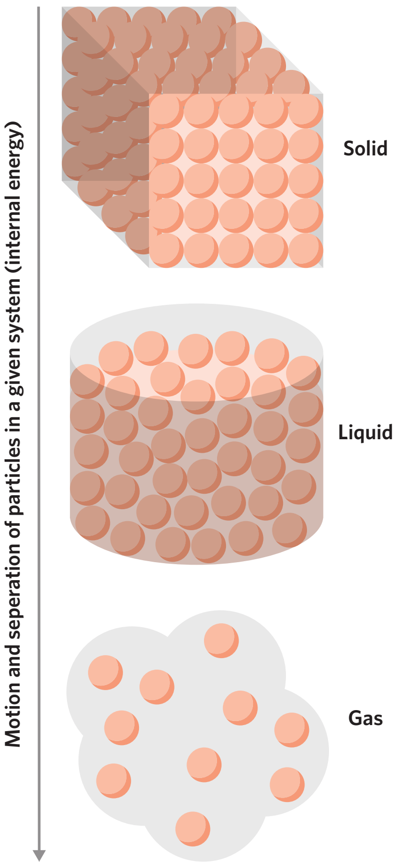
Question 8

Which of the following correctly converts 80°C to an absolute temperature?

A. 80 + 273.15 = 353.15 K

B. 80 − 273.15 = −193.15 K

Theory summary



- The kinetic theory of matter states that all matter consists of particles (molecules or individual atoms) that are constantly moving in a random and disordered way.
- Internal energy describes the energy associated with the motion and interactions between the particles that make up a system. This is also known as thermal energy.
- Internal energy consists of various types of kinetic energy and potential energy.
  - The proportion of each type depends on the substance.
- Temperature is a measure of the average translational kinetic energy of the particles in a system.
  - As temperature increases, the particles move faster and further apart.
- Two systems are in thermal equilibrium when they have the same temperature.
- The SI unit for temperature is the kelvin (K). Temperature is also commonly measured in degrees Celsius (°C).
  - The lowest possible temperature is 0 K (−273.15°C).
  - An increase in temperature of 1 K corresponds to an increase of 1°C.

Table 2 Physical properties of the three states of matter

	Solid	Liquid	Gas
Shape	Fixed	Not fixed	Not fixed
Volume	Fixed	Fixed	Not fixed

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CONCEPT DISCUSSION

If you pour milk into a very hot cup of tea, the milk will quickly diffuse (mix) throughout the tea. If you pour milk into a cold cup of tea, the milk will not diffuse as quickly. Discuss the reason for this difference.

Prompts:

- What do you think causes a substance to diffuse throughout another substance?
- What is the relationship between the temperature of a system and the motion of its particles?
- How could this behaviour affect the rate of diffusion?

Image: StudioByTheSea/Shutterstock.com

2A Questions

Mild 🌶 Medium 🌶🌶 Spicy 🌶🌶🌶

Deconstructed exam-style

Use the following information to answer questions 9–11.

A physics teacher is holding a hot cup of coffee in her hand as she marks exams. She is so busy marking the exams that she forgets to drink the coffee and, eventually, the cup of coffee reaches thermal equilibrium with her hand.

Question 9 (1 MARK) 🌶

What is temperature a measure of?

A. how hot each particle in a system is

B. the total kinetic energy of a system

C. the internal energy of a system

D. the average translational kinetic energy of the particles in a system

Question 10 (1 MARK) 🌶

What does it mean for the teacher's hand to be in thermal equilibrium with the cup of coffee?

A. There is no force between the hand and the cup of coffee.

B. The hand and the cup of coffee are at the same temperature.

C. The particles in the hand and the cup of coffee have stopped moving.

D. The temperatures of the hand and the cup of coffee add to zero.

Question 11 (3 MARKS) 🌶🌶

Describe how the average translational kinetic energy of the particles in the teacher's hand compares with the average translational kinetic energy of the particles in the cup of coffee throughout the process of reaching thermal equilibrium.

Exam-style

Question 12 (1 MARK) 🌶

The surface of the planet Venus maintains a nearly constant temperature of 735 K. Convert the temperature of the surface of Venus to degrees Celsius.

Question 13 (2 MARKS) 🌶

The surface of the planet Mercury can reach temperatures as high as 450°C during the day, and as low as −170°C at night. This large variation occurs because Mercury does not have an atmosphere to trap the thermal energy during the night.

a. Convert the minimum night-time temperature on Mercury to kelvin. (1 MARK)

b. Calculate the temperature range (the difference between the maximum and minimum temperatures) of the surface of Mercury. Provide your answer in kelvin. (1 MARK)

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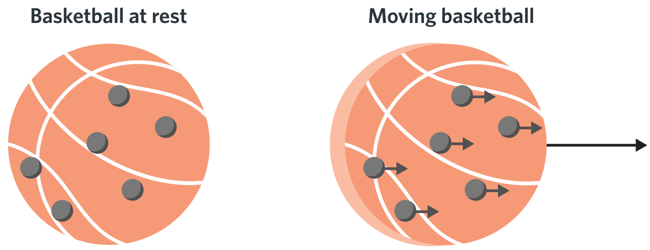
Question 14 (2 MARKS)

The surface of the planet Mars reaches a maximum temperature of 20°C during the day and a minimum of −125°C during the night. Compare the average translational kinetic energy of the atoms and molecules on the surface of Mars during the day with their average translational kinetic energy during the night. Justify your answer.

Question 15 (3 MARKS)

After reading about the relationship between temperature and energy, Archie states that a fast-moving basketball must have a higher temperature than a stationary basketball. Evaluate Archie's statement. Justify your response.



Question 16 (2 MARKS)

A backyard pool and an Olympic swimming pool (which is much larger than the backyard pool) are both at a temperature of 26°C.

a. Compare the internal energy of the water in the backyard pool with the internal energy of the water in the Olympic pool. (1 MARK)

b. Compare the average translational kinetic energy of the water molecules in the backyard pool with the average translational kinetic energy of the molecules in the Olympic pool. (1 MARK)

Question 17 (3 MARKS)

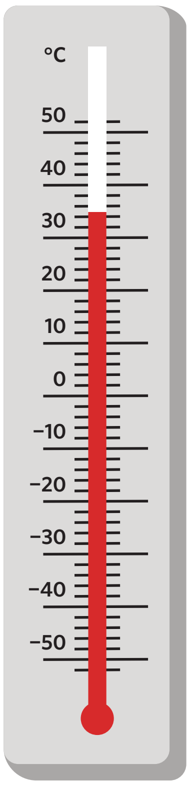
With reference to the relationship between macroscopic (large-scale) physical properties and molecular motion, explain why it is possible to pour water into a bottle and fill it up but it is not easy to do this with ice.

Key science skills

Question 18 (6 MARKS)

A class conducts an experiment in which a beaker of oil is heated and the temperature is measured each minute.

a. What is the absolute uncertainty of the thermometer shown? (1 MARK)



b. The data collected is shown in the table. (5 MARKS)

Time (mins)	0	1	2	3	4
Temp (°C)	15	23	30	38	44

Graph the data on a set of axes. Include:

- an appropriate scale, labels, and units for each axis.
- uncertainty bars for the temperature.
- a line of best fit.

FROM LESSONS 11C & 11D

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Previous lessons

Question 19 (2 MARKS)

By first expressing each value in the appropriate SI unit, order the following wavelengths from highest energy to lowest energy.

49 nm 75 mm 520 μm 410 nm 570 nm

FROM LESSON 1C

Question 20 (3 MARKS)

a. It takes 8 minutes and 19 seconds, on average, for light to travel from the Sun to Earth. Calculate the average distance between the Sun and Earth. (2 MARKS)

b. The sun emits photons over the full range of the electromagnetic spectrum. Sort the following types of electromagnetic waves from lowest frequency to highest frequency:

ultraviolet visible light x-rays gamma rays microwaves

FROM LESSON 1E (1 MARK)

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2B How thermal energy moves

STUDY DESIGN DOT POINT

- describe temperature with reference to the average translational kinetic energy of the atoms and molecules within a system:
  - distinguish between conduction, convection and radiation with reference to heat transfers within and between systems
  - explain why cooling results from evaporation using a simple kinetic energy model

2A 2B 2C

- 1.1.12.2 Heat
- 1.1.12.3 Conduction
- 1.1.12.4 Convection
- 1.1.12.5 Thermal radiation

ESSENTIAL PRIOR KNOWLEDGE

1C Electromagnetic waves
2A Internal energy
See questions 13–14.

ACTIVITIES

Log into your Edrolo account for activities that support this lesson.

Image: AppleZoomZoom/Shutterstock.com

Why do hot air balloons rise?

In the previous lesson, we learned about temperature and internal energy, but how does the energy associated with temperature get from one place to another? How does this explain why metal feels so cold on a chilly day? To answer these questions, this lesson introduces heat as a physical quantity, and explores the three types of heat transfer.

KEY TERMS AND DEFINITIONS

convection the transfer of heat through the bulk movement of matter

convection cell a cyclical flow of fluid caused by differences in temperature and hence fluid densities

density mass per unit volume; a measure of how closely packed matter is

fluid a substance that flows; a liquid or gas

heat energy that flows between systems due to a difference in temperature

medium a physical substance through which energy (e.g. heat or sound) travels

thermal conduction the transfer of heat through direct contact

thermal contact two systems are in thermal contact if heat can transfer between them

thermal radiation the transfer of heat in the form of electromagnetic radiation

vacuum a region that does not contain matter

FORMULA

- **heat flow rate of conduction**
  $\frac{Q}{t} \propto \Delta T$

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Heat 1.1.12.2

For two systems in thermal contact, there is a net flow of heat from the hotter (higher temperature) system to the colder (lower temperature) system. This is called heat transfer, and occurs faster when the difference in temperature between the systems is greater.

Theory and applications

We feel a burning sensation when we touch a hot pan not because of the temperature of the metal, but because heat transfers from the hot pan to our cool hand. If heat didn't flow from hot to cold, we'd be able to pick up the pan without suffering any burns.

How can we describe heat with reference to temperature?

Heat, written as Q, is thermal energy that flows from one system to another.

- Heat is measured in joules (J) since it is energy.
- Two objects are in thermal contact if heat can flow from one object to the other.
- Heat is not temperature.[1]

Once two systems reach the same temperature, they are in thermal equilibrium. There is no net heat transfer between systems in thermal equilibrium.

We can model energy transfers between substances as two connected containers of fluids. The flow of energy can be modelled as liquid flowing through a pipe connecting the containers. Just as heat flows from the hotter system to the colder system, liquid flows from the container filled to a greater height to the one filled to a lower height. They will eventually reach the same temperature, or height, see Figure 1.

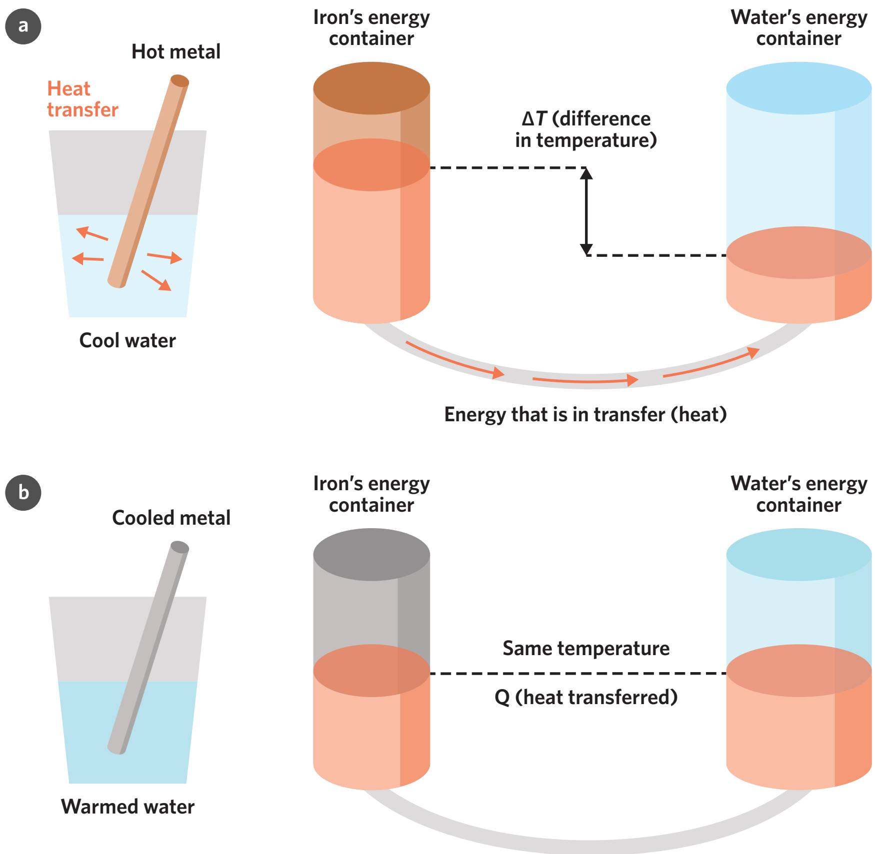

Figure 1 **(a)** The hot metal transfers energy to the cool water in the bucket. **(b)** The two systems after thermal equilibrium has been reached.

KEEN TO INVESTIGATE?

1 **What is the difference between heat and temperature?**
Search YouTube: Misconceptions About Temperature

MISCONCEPTION

'Heat is a property of an object.'

An object can't have heat. For example, a hot pot full of food cannot have heat, instead it has thermal energy which relates to temperature. Heat is the energy that flows between the stove and the pot. Therefore, we cannot have a change in heat (ΔQ) because heat (Q) itself is the change.

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2B THEORY

Progress questions

Question 1

Heat is flowing from System A to System B. Which of the following statements is false?

A. System B is gaining internal energy.

B. The two systems are in thermal equilibrium.

C. Energy is flowing between the systems.

D. System B is colder than System A.

Question 2

A small mug of boiling water is placed inside of a jug of cold water. They both have the same amount of internal energy. Which of the following statements is true?

A. No net heat transfer will occur because the internal energy of the system is constant.

B. The temperatures of the two containers of water are different, meaning there would be a net transfer of heat between the two.

Conduction 1.1.12.3

Conduction is a form of heat transfer between systems that is due to collisions between their particles, which can occur for all phases of matter (solids, liquids, and gases).

Theory and applications

When we touch an object, we might believe that we are feeling the temperature of the object, but in reality we are feeling the energy transfer between the object and our hands (which is related to a difference in temperature, see Figure 2). This is an example of a type of heat transfer called conduction.

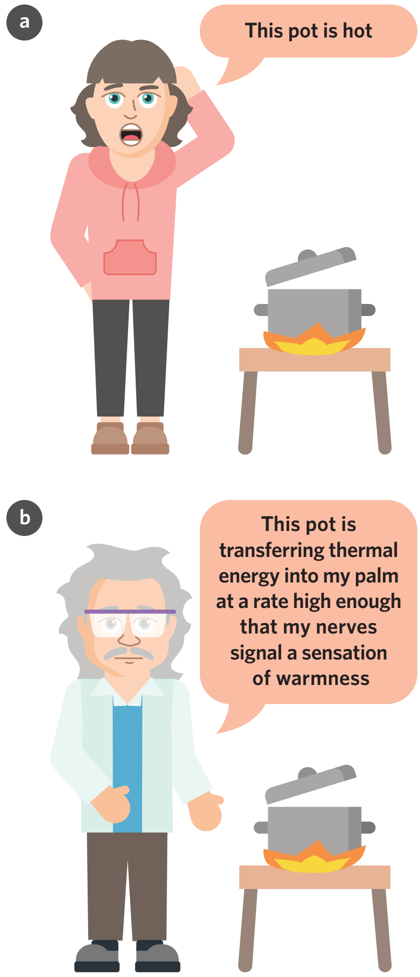

Figure 2 **(a)** The everyday (incorrect) explanation vs **(b)** the scientific explanation for why hot objects feel 'hot'.

KEEN TO INVESTIGATE?

[2] **How does energy flow between objects?**
Search: 'Energy Forms and Changes' simulation

How is heat transferred through conduction?

Conduction between two systems only occurs when:

- they are in physical contact, and
- they are at different temperatures.

For example, an electric stovetop works by using conduction to transfer heat from the hot cooktop to the base of a pot or pan.[2]

The heat transfer rate (measured in J s^{-1}) between two systems due to conduction is directly proportional to their difference in temperature.

FORMULA

$$\frac{Q}{t} \propto \Delta T$$

Q = net heat transferred (J)
t = time taken for transfer (s)
ΔT = magnitude of difference in temperature between the two systems (K or °C)

This means the heat transfer rate, $\frac{Q}{t}$, changes proportionally as ΔT changes. For example, if the difference in temperature between two objects halves, the heat flow rate will also halve.

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WORKED EXAMPLE 1

A hot rod of iron is placed in a container of water. Initially, the iron transfers 360 J to the water every 0.500 seconds. The water is at a temperature of 20°C, while the iron is at 820°C.

a. Calculate the initial heat transfer rate between the metal and the water, $\frac{Q}{t}$.

Step 1

Identify heat transferred and the time for transfer.

$Q = 360$ J, $t = 0.500$ s

Step 2

Substitute values given in the question into the equation for heat transfer rate and solve for heat transfer rate.

Note that the unit for the heat transfer rate will be J s^{-1}.

$$\frac{Q}{t} = \frac{360}{0.500}$$

$$\frac{Q}{t} = 720.0 = 720 \text{ J s}^{-1}$$

b. After a period of time, the water is at 40°C and the iron is at 120°C. What is the new rate that heat flows?

Step 1

Identify all relevant values.

$T_{initial\ iron} = 820°C$, $T_{initial\ water} = 20°C$,

$T_{final\ iron} = 120°C$, $T_{final\ water} = 40°C$, $\frac{Q}{t}_{initial} = 720 \text{ J s}^{-1}$

Step 2

Find the temperature difference between the iron and water, both before and after the period of time.

Since we are just looking for the difference, we do not need to convert to kelvin.

$$\Delta T_{before} = T_{initial\ iron} - T_{initial\ water} = 820 - 20 = 800°C$$

$$\Delta T_{after} = T_{final\ iron} - T_{final\ water} = 120 - 40 = 80°C$$

Step 3

Divide the final temperature difference by the initial temperature difference to find the ratio of final to initial temperature difference.

So ΔT has changed by a factor of $\frac{80}{800} = \frac{1}{10}$.

Step 4

Substitute into the equation. The factor that heat flow, $\frac{Q}{t}$, changes by is the factor ΔT changes by, which is $\frac{1}{10}$ in this case.

$$\frac{Q}{t} = \frac{1}{10} \times 720$$

$$\frac{Q}{t} = 72.0 = 72 \text{ J s}^{-1}$$

The rate of conduction also depends on the area of contact through which the conduction occurs – the rate of conduction is greater when this area is greater.

As we learned in Lesson 2A, temperature is a representation of the average translational kinetic energy (the vibration) of particles in a system. When two systems are in physical contact, particles where they touch collide and exchange translational kinetic energy (see Figure 3).

- In each collision, translational kinetic energy is usually transferred from the particle with more translational kinetic energy to the particle with less translational kinetic energy (like the opening break in a game of pool shown in Figure 4).
- Over time, energy transfers from the higher temperature system to the lower temperature system.

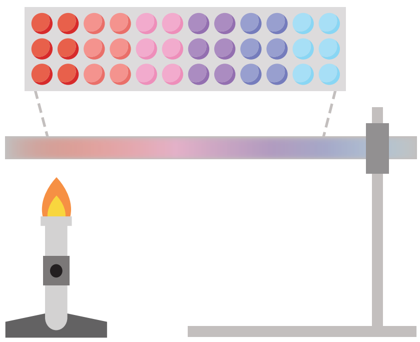

Figure 3 Heat transfers energy from the left to the right through collisions.

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Image: Gencho Petkov/Shutterstock.com

Figure 4 The opening 'break' shot in a game of pool is similar to the translational kinetic energy of atoms.

KEEN TO INVESTIGATE?

[3] **What is conduction?**
Search YouTube: Physics – Heat Transfer – Conduction

Due to their differing atomic and molecular structures, some materials and substances will be better conductors than others.

- Something that is good at conducting heat is called a good thermal conductor.
- Something that is bad at conducting heat is called a good thermal insulator.
- A list of common conductors and insulators is shown in Table 1.

A good thermal conductor will transfer heat faster, both within itself and to other systems. Pure metals are good conductors because the atoms are close together and they have free-moving electrons. This is why metals feel very cold on cold days and very hot on hot days, they transfer heat rapidly to or from our skin.

The opposite is true for thermal insulators: they transfer heat slowly. Air is an example of a good insulator. Its particles are spaced out and do not collide very often, so the rate that heat is transferred is very slow. A vacuum is the ideal insulator since there are no particles available to have collisions.[3]

Table 1 Examples of good thermal conductors and insulators

Good thermal conductors	Good thermal insulators
Gold	Wood
Copper	Air
Steel	Most plastics
Diamond (best known thermal conductor)	Wool (largely because it traps air)

Progress questions

Question 3

Which statement best describes thermal conduction?

A. a heat transfer that occurs when particles emit radiation by accelerating

B. a heat transfer that occurs when particles exchange energy through collisions

C. a heat transfer that occurs when particles move around a fluid and change the distribution of energy

Question 4

Fill in the gaps in the following paragraph to describe the process of conduction.

When two systems at different __________ (temperatures/internal energies) are __________(separated/in contact), __________(cold/heat) flows from one system to the other due to conduction. This means that the __________ (heat/internal energy) of each system is changing.

Question 5

Fill in the gaps in the following paragraph to describe why we will usually feel warmer under a blanket.

We feel warmer under a blanket, because the rate of heat __________(loss/gain) from our body decreases. The amount of __________ (heat/coldness) that flows from our bodies to the colder surroundings is reduced because blankets are good __________(conductors/insulators/radiators).

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Convection 1.1.12.4

Convection is a form of heat transfer within a fluid that is due to the overall movement of matter between hotter regions and colder regions.

Theory and applications

A hotter substance will generally rise above a cooler substance due to convection. This is a key factor to consider when designing air conditioners, hot air balloons, and more, which all rely on convection to function.

How is heat transferred through convection?

According to the kinetic theory of matter, a higher temperature means that particles have greater average translational kinetic energy. This additional kinetic energy means that particles at higher temperatures tend to have more space between them: this decreases the density of the material. Fluid with higher density sinks and displaces the less dense fluid, pushing the less dense fluid upwards.

- Convection only occurs in fluids (substances that flow).
- Convection can be natural or forced.

Figure 5 shows natural convection where a fluid is constantly heated from the bottom.

- The colder fluid is denser, so sinks and pushes up the hotter fluid.
- The hotter fluid cools down as it rises by transferring heat to its cooler surroundings, increasing in density and falling back down to the bottom.
- If the heating persists, particles continue rising and falling in convection cells.

When we heat up the air inside of a hot air balloon, convection causes it to rise above the cooler outside air, due to its lower density. This provides an overall lift force which is strong enough to lift an entire balloon and basket. Once the air cools down, it becomes denser and falls to where it is then heated up again, and the cycle continues.

Convection cells are cyclical flows of fluid caused by ongoing convection. The formation of convection cells explains why indoor heaters are often located close to the floor.

- As shown in Figure 6, the heater draws in cooler air from below and blows out hot air upwards, which cools across the top of the room, falls, and is drawn back to the heater. In this way, thermal energy from the heater is transferred around the room.

Forced convection is any fluid flow that transfers thermal energy where the heating itself does not drive the flow. This implies that another energy source must drive the flow such as a fan blowing air or a spoon mixing a cup of tea. This can transfer heat from anywhere in the fluid, not just from the bottom. For example, if a heater was placed at the top of a room, a built-in fan could convect heat away by blowing hot air downwards, as shown in Figure 7.

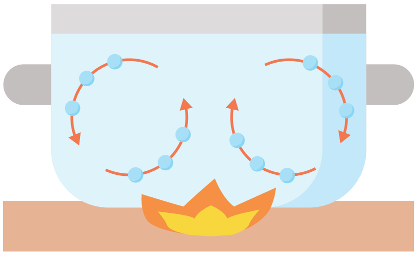

Figure 5 Water particles in a pot that is heated at its base. The arrows represent convection cells.

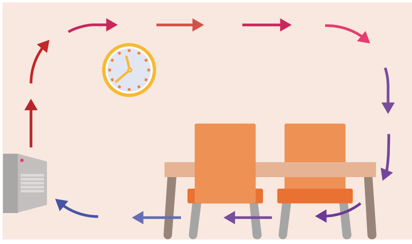

Figure 6 A convection cell formed by a heater

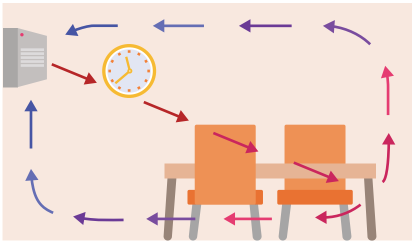

Figure 7 Forced convection by a heater with a fan can heat a room from above.

Progress questions

Question 6

Fill in the gaps in the following paragraph to describe convection.

Convection is a method of heat transfer used when transferring heat through regions of __________ (solids/fluids/empty space) which are at __________ (different temperatures/the same temperature). Fluids with higher temperatures will naturally __________ (rise above/fall below) those with lower temperatures. This is because a fluid with a higher temperature is __________ (more dense/less dense).

Question 7

Convection cells are best described as:

A. cells which provide heat energy through contact.

B. cyclical flows of fluid caused by ongoing convection.

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2B THEORY

Thermal radiation 1.1.12.5

Thermal radiation is a form of heat transfer that is due to the emission and absorption of energy as electromagnetic radiation.

Theory and applications

Thermal radiation is emitted by all objects with a temperature above absolute zero (0 K). Radiation is the heat transfer responsible for the warmth we feel from the Sun (see Figure 8).

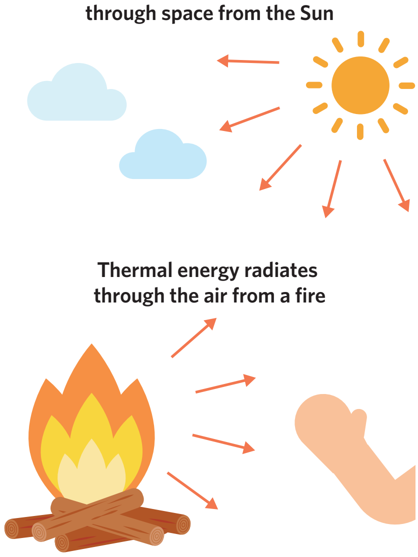


Figure 8 Thermal energy can be transferred to us through both the air and the vacuum of space.

How is heat transferred through thermal radiation?

Charged particles emit electromagnetic radiation whenever they accelerate. When the charged particles inside atoms (protons and electrons) accelerate while vibrating or colliding (due to the random motion associated with thermal energy), some of their translational kinetic energy is transformed into electromagnetic radiation. This causes a decrease in the internal energy and temperature of the emitting substance.

When radiation meets an object or substance, it is transmitted, reflected, and/or absorbed (see Figure 9).

- Transmission means the radiation continues through the object.
- Reflection means the radiation bounces off the object and continues to travel in a different direction.
- Absorption means the particles in the object receive the energy from the radiation.
  - The particle's energy increases, equal to the energy of the absorbed radiation, and therefore the temperature of the object increases.
  - The radiation ends its journey, completing the heat transfer.

The percentage of radiation that is transmitted, reflected, and absorbed by an object depends on the material of the object.

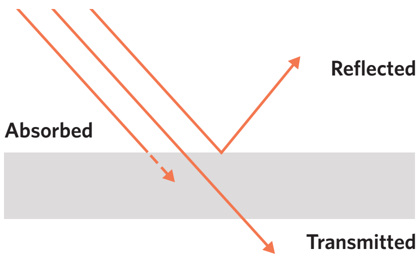


Figure 9 Absorption, transmission, and reflection of electromagnetic waves

MISCONCEPTION

'Thermal radiation requires a medium to transfer heat.'

Electromagnetic waves do not require matter in order to transfer energy, in this case heat. This is how the Sun's energy is able to reach Earth through the vacuum of space.

Progress questions

Question 8

We generally feel cooler in the shade. Why is this?

A. We give off more heat in the shade, and thus cool down quicker.

B. We are shielded from the wind, and thus convection, when we stand in the shade.

C. Shadows transfer coldness to us.

D. Less thermal radiation from the Sun reaches us in the shade.

Question 9

Which statement best describes thermal radiation?

A. a heat transfer that occurs when particles absorb radiation emitted from the collision of other particles

B. a heat transfer that occurs when particles absorb radiation emitted from the vibration of other particles

C. Both of the above

Theory summary

- Heat is thermal energy that transfers between two systems.
  - Objects at the same temperature do not have a net flow of heat.
- Heat transfers take three different forms:

	In what situations it occurs	What it is	Medium required?	Matter transferred?	Energy transferred?
Conduction	When two systems are physically touching and within systems	Particles collide with each other across the contact surface or within the system, transferring their thermal energy.	✓	✗	✓
Convection	In fluids	Particles move around the fluid, carrying their energy with them.	✓	✓	✓
Radiation	In all systems, but is more significant for hotter objects	Charged particles transform thermal energy into electromagnetic radiation (thermal radiation) as they accelerate.	✗	✗	✓

- The heat transfer rate for conduction is related to the difference in temperature: $\frac{Q}{t} \propto \Delta T$.
- For a given fluid, colder fluid is denser than hotter fluid, so colder fluid sinks and hotter fluid rises.
- Convection cells form due to convection and represent the path fluid takes.
- Radiation can be transmitted, reflected, and/or absorbed when interacting with matter.
- The three forms of heat transfer can be seen in Figure 10:

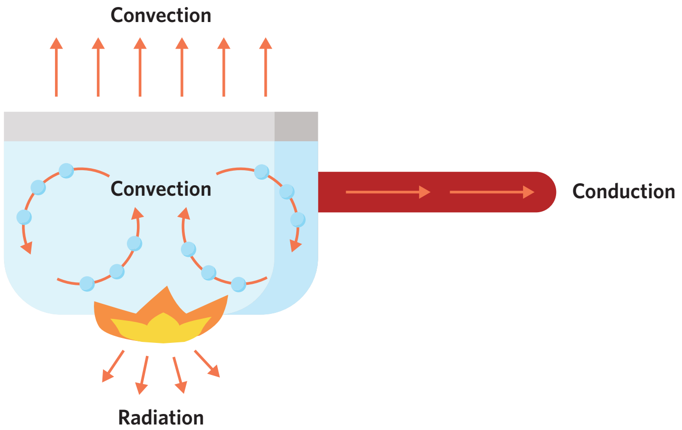


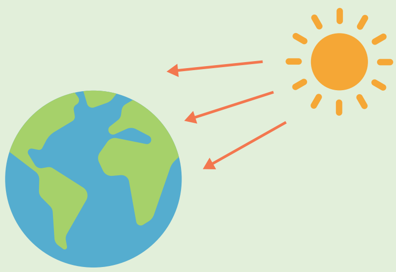
Figure 10 The methods of heat transfer

CONCEPT DISCUSSION

Electromagnetic radiation from the Sun travels through the vacuum of space before travelling through our atmosphere. Discuss how energy from the Sun could, after travelling to Earth via radiation, later undergo conduction and convection (in either order).

Prompts:

- What kinds of substances on Earth undergo convection?
- What happens to a particle after it absorbs energy? How does this differ between solids, liquids, and gases?



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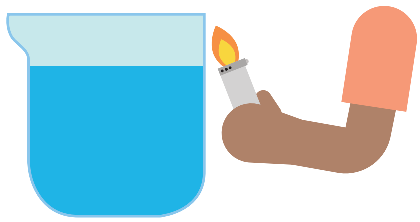
2B Questions

Mild Medium Spicy

Deconstructed exam-style

Use the following information to answer questions 10-12.

Thomas and Sabrina are debating whether the fluid in a beaker continuously heated from its top will undergo convection. Thomas says that whenever heat is constantly applied to a fluid, convection cells form. Sabrina says that convection cells will not form due to how the fluid is being heated.



Question 10 (1 MARK)

Which is the best description of the process of heating by natural convection?

A. Thermal energy moves through the contact between hot and cold regions.

B. Vibrations of particles cause collisions which spread thermal energy.

C. Hot fluids and cold fluids mix evenly and reach thermal equilibrium.

D. Colder fluids, which are more dense, sink, and hotter fluids, which are less dense, rise.

Question 11 (1 MARK)

Which direction does heat tend to flow during the process of natural convection?

A. up

B. down

C. left

D. right

Question 12 (3 MARKS)

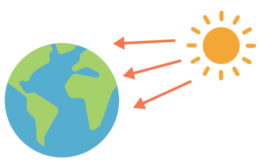
Who is correct? Explain your answer.

Exam-style

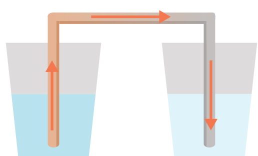
Question 13 (1 MARK)

Which of the following options depict convection cells?

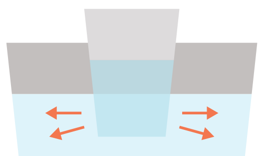
A.



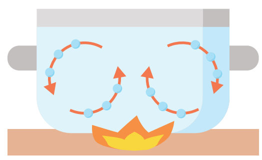
B.



C.



D.



Question 14 (1 MARK)

A wet bird is losing 100 J of energy every second due to conduction with the air. How much energy would it transfer through conduction every second if the temperature difference between itself and the air increased by a factor of 1.5?

A. 200 J

B. 150 J

C. 100 J

D. 50.0 J

Question 15 (3 MARKS)

Zev is applying an ice pack to his sore head. By first identifying the heat transfer that is occurring, explain how the ice pack cools Zev's head down.

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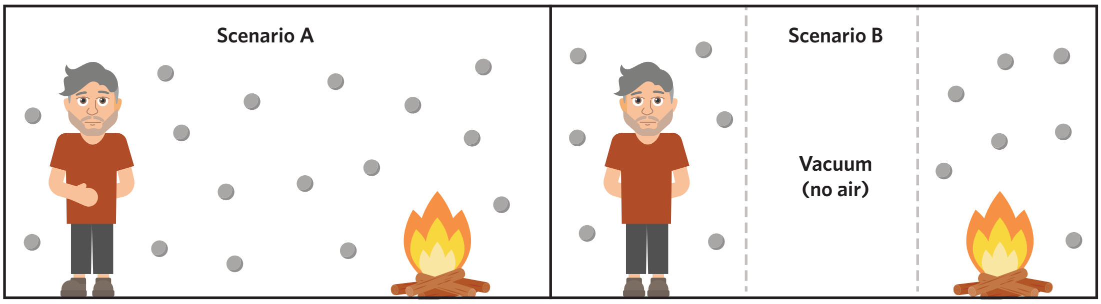
Question 16 (3 MARKS)

An oven mitt at 300 K is in direct contact with a hot plate at 340 K, and heat is transferring between them at a rate of 80 J s^{-1}. What difference in temperature would cause the rate to halve to 40 J s^{-1}?

Question 17 (2 MARKS)

Jim is standing by a campfire, as seen in scenario A. He wonders whether he would heat up if there was no air between him and the campfire, as seen in scenario B.

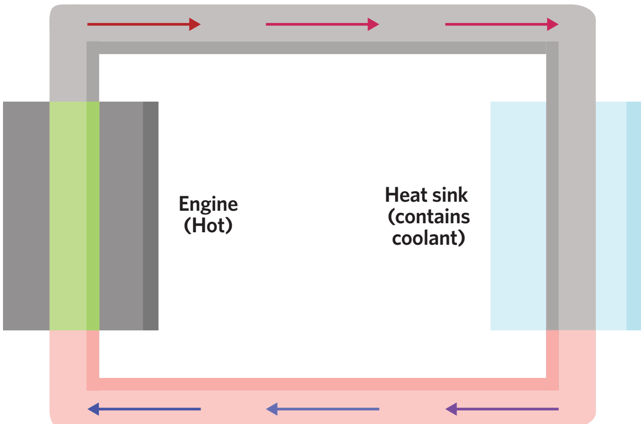


a. Will Jim feel the warmth of the campfire in scenario B? (1 MARK)

b. Jim now wants to cook some marshmallows. He notices it is much quicker to cook his marshmallows above the fire than to its side. Identify the heat transfer responsible for this difference. (1 MARK)

Question 18 (3 MARKS)

Car engines cool down by circulating liquid coolant, transferring energy by conduction and convection. The coolant absorbs heat from the engine, and a fan cools down the coolant in a 'heat sink'. The diagram shows a simplification of the cooling system of a car engine.



a. The engine piping (green) can be made of aluminium or plastic. Which would be better at transferring heat from the engine to the coolant? (1 MARK)

b. Suppose we want to limit the amount of energy transferred between the coolant and its surroundings while it travels to the engine. Should plastic or aluminium be used for this piping (pink)? Justify your answer with relevant theory. (2 MARKS)

Question 19 (3 MARKS)

A block of rubber and a block of wood have been placed in thermal contact. As a result, the internal energy of the wood has begun to increase. Assume the blocks are not in thermal contact with any other objects.

a. Before the two objects were placed in thermal contact, was the rubber hotter or colder than the wood? (1 MARK)

b. The two blocks are exchanging heat only through conduction. Use a relevant mathematical relation to explain why there will no longer be a net flow of heat between the blocks once they reach thermal equilibrium. You do not need to refer to the kinetic theory of matter. (2 MARKS)

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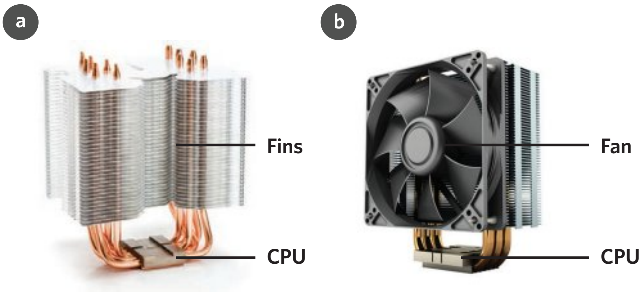
Question 20 (5 MARKS)

Computers cool down their central processing unit (CPU) by placing ‘heat sinks’ on them, which absorb heat from the CPU through conduction. An engineer is trying to optimise her computer’s cooling by keeping its heat sink cool.



Images (left to right): Draw05, NosorogUA/Shutterstock.com

a. The heat sink has thin fins that are designed to create a high surface area. Given that this heat sink cools down as a result of thermal conduction with the air, what purpose would this serve? (3 MARKS)

b. The engineer’s computer still overheats, so she looks for a new solution. Inspired by how car engines cool down, she attaches a fan to her heat sink, which blows air onto the fins. The CPU no longer overheats. Describe how the heat is moved away from the fins in this setup, making sure to describe the role of the fan. (2 MARKS)

Key science skills

Question 21 (2 MARKS)

A scientist wants to calculate the total rate that heat flows out of a campfire by adding the rates of conduction, convection, and thermal radiation.

	Conduction	Convection	Thermal radiation	Total rate
Heat flow rate (kJ s^{-1})	0.3	5.7	4.502	?

a. What will be the number of significant figures for the total rate? (1 MARK)

b. If the scientist wanted to calculate the total heat, Q, emitted over $t = 5.0$ seconds with the formula $Q = total\ rate \times t$, how many significant figures would Q have? (1 MARK)

FROM LESSON 11B

Previous lessons

Question 22 (4 MARKS)

By referencing the frequency and wavelength of the waves, describe the difference between infrared waves and ultraviolet waves. Include an example of where these waves can be found in everyday life in your answer.

FROM LESSON 1C

Question 23 (3 MARKS)

Aidan makes rings out of silver. In order to cast the rings, he needs to melt the silver using a furnace. The melting point of silver is 961.8°C, but his furnace only works in kelvin.

a. Convert 961.8°C to kelvin. (1 MARK)

b. Explain how the average kinetic energy and the total internal energy of the silver atoms change as the metal melts. (2 MARKS)

FROM LESSON 2A

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2C How heat affects temperature

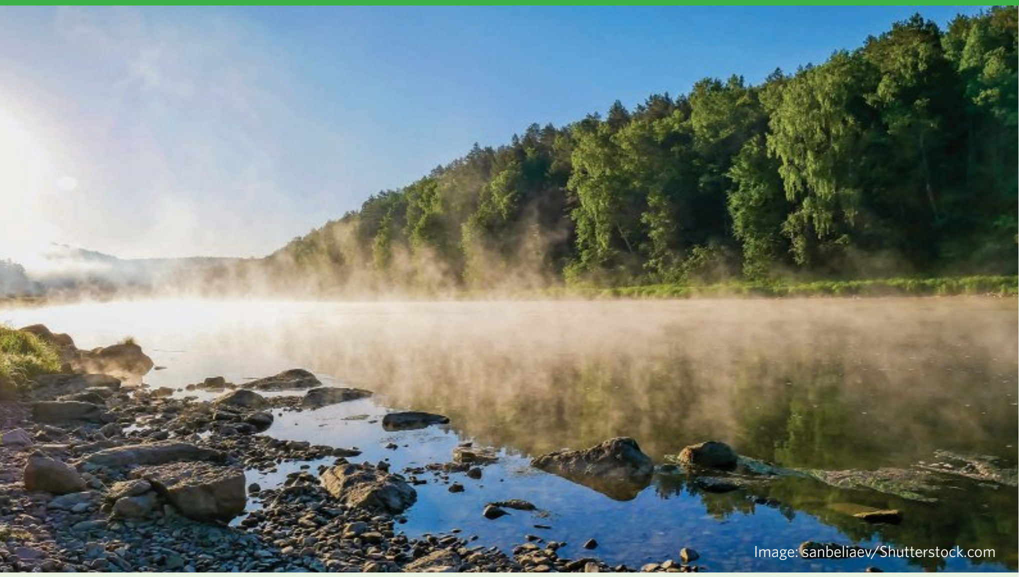

Image: sanbeliaev/Shutterstock.com

How does evaporation occur without boiling?

This lesson will build on the concepts of heat and temperature established in Lessons 2A and 2B to present a quantitative relationship between them. Understanding this relationship will help to explain how we experience temperature in our everyday lives.

KEY TERMS AND DEFINITIONS

boil to convert a substance from liquid to gas at its boiling point

condense to convert a substance from gas to liquid

evaporate to convert from liquid to gas only at the liquid's surface due to high-energy particles in the liquid escaping

freeze to convert a substance from liquid to solid at its freezing point

latent heat the heat absorbed or released to change the state of a substance

melt to convert a substance from solid to liquid

specific heat capacity the heat per unit of mass needed to increase the temperature of a substance by one kelvin (or degree Celsius)

latent heat of fusion the heat per unit of mass required to convert a given substance from a solid into a liquid

latent heat of vaporisation the heat per unit of mass required to convert a given substance from a liquid into a gas

state change the process of changing between different states of matter

FORMULAS

- **specific heat capacity**
  $Q = mc\Delta T$
- **latent heat**
  $Q = mL$

STUDY DESIGN DOT POINTS

- describe temperature with reference to the average translational kinetic energy of the atoms and molecules within a system:
  - distinguish between conduction, convection and radiation with reference to heat transfers within and between systems
  - explain why cooling results from evaporation using a simple kinetic energy model
- investigate and analyse theoretically and practically the energy required to:
  - raise the temperature of a substance: $Q = mc\Delta T$
  - change the state of a substance: $Q = mL$

2A 2B 2C

1.1.13.1 Specific heat capacity

1.1.13.2 Latent heat

1.1.12.6 Evaporative cooling

ESSENTIAL PRIOR KNOWLEDGE

2A Temperature scales

2B Conduction

See questions 15–16.

ACTIVITIES

Log into your Edrolo account for activities that support this lesson.

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Specific heat capacity 1.1.13.1

All substances have a specific heat capacity, which is a measure of the heat needed to change the temperature of one kilogram of the substance by one kelvin (or one degree Celsius). A substance with a low specific heat capacity changes temperature more readily compared to a substance with a high specific heat capacity.

Theory and applications

Cooking oil will get hotter on a stove faster than the same quantity of water. A smaller volume of oil will get hotter faster than a larger volume of oil. These observations suggest that the change in temperature of a substance depends on the substance itself, as well as the mass of that substance.

KEEN TO INVESTIGATE?

1 **What is specific heat capacity?**
Search YouTube: Specific Heat Capacity Matter Physics

How can we quantify the energy it takes to heat a substance up?

Specific heat capacity,[1] c, measures the heat transfer per unit of mass that is required to change the temperature of a substance:

$$c = \frac{\text{heat transferred}}{\text{mass} \times \text{change in temperature}} = \frac{Q}{m\Delta T}$$

This equation (see formula triangle in Figure 1) is more commonly expressed as follows.

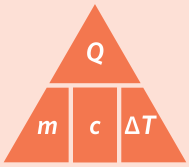

Figure 1 The formula triangle for specific heat capacity

FORMULA

$$Q = mc\Delta T$$

Q = heat transferred (J)
m = mass (kg)
c = specific heat capacity (J kg^{-1} K^{-1})
$\Delta T = T_f - T_i$ = change in temperature (K)

USEFUL TIP

A negative value of Q indicates heat is released rather than absorbed.

Consider Figure 2:

- The greater the increase in temperature of a given object, the greater the heat required: $Q \propto \Delta T$. See Figure 2(a).
- The greater the mass of a given substance (and hence the more particles within it), the greater the heat required to increase its temperature by a given amount: $Q \propto m$. See Figure 2(b).

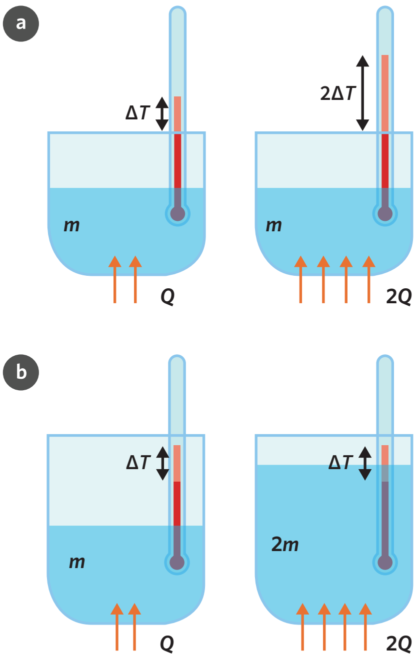

Figure 2 Proportional relationships between **(a)** heat energy, **(b)** mass, and the change in temperature

Table 1 shows the approximate specific heat capacities of some common substances. Note that the specific heat capacity of a given substance is different for different states of matter (e.g. water compared to ice).

Table 1 Some common substances and their (approximate) specific heat capacities in increasing order

Substance	Specific heat capacity, c (J kg^{-1} K^{-1})
Iron	0.45×10^3
Air	1.0×10^3
Steam	2.0×10^3
Ice	2.1×10^3
Cooking oil	2.8×10^3
Water	4.2×10^3

Different substances store their internal energy in different proportions. This means that some substances, those with higher specific heat capacities, do not change temperature as easily as others for a given heat exchange.

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USEFUL TIP

Ensure you use the term 'specific heat capacity' when discussing this topic, as 'heat capacity' is a different physical quantity and is not included in VCE Physics.

WORKED EXAMPLE 1

A pot of water is being heated up to cook pasta.

For this question, take the specific heat capacity of water to be 4186 J kg^{-1} K^{-1}.

a. How much energy is required to increase the temperature of 0.50 kg of water by 15°C?

Step 1

Identify relevant values and the relevant equation.

Remember that a change of 15°C is equal to a change of 15 K.

$m = 0.50$ kg, $c = 4186$ J kg^{-1} K^{-1}, $\Delta T = 15°C = 15$ K, $Q = ?$

$Q = mc\Delta T$

Step 2

Substitute relevant values into the specific heat capacity equation and solve for Q.

$Q = 0.50 \times 4186 \times 15$

$Q = 31\,395 = 3.1 \times 10^4$ J

b. After the pasta is cooked, the water cools down. What is the final temperature (in °C) when 0.50 kg of water at an initial temperature of 30°C releases 5000 J of thermal energy?

Step 1

Identify relevant values and the relevant equations.

Treat the heat released as a negative quantity.

$Q = -5000$ J, $m = 0.50$ kg, $c = 4186$ J kg^{-1} K^{-1}, $T_i = 30°C$

$T_f = ?$

$Q = mc\Delta T$

$\Delta T = T_f - T_i \Rightarrow T_f = T_i + \Delta T$

Step 2

Substitute and solve for T_f by first solving for ΔT.

$-5000 = 0.50 \times 4186 \times \Delta T$

$\Delta T = -2.389 \text{ K} = -2.389°C$

$T_f = T_i + \Delta T = 30 + (-2.389)$

$T_f = 28°C$

Progress questions

Question 1

It takes 1000 J to increase the temperature of a particular brick by 10 K.
How much heat energy is required to increase the temperature of an identical brick by 20 K?

A. 500 J

B. 2000 J

Continues →

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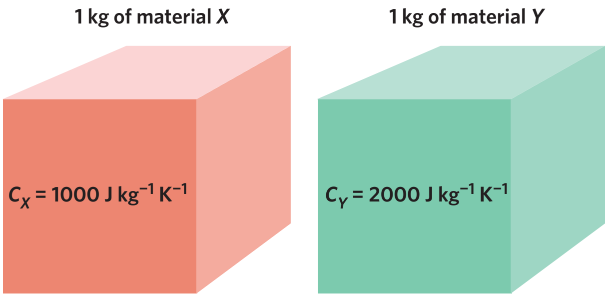
Use the following information to answer questions 2 and 3.

Consider a one kilogram block of material *X* and a one kilogram block of material *Y*, with specific heat capacities as shown in the diagram.



Question 2

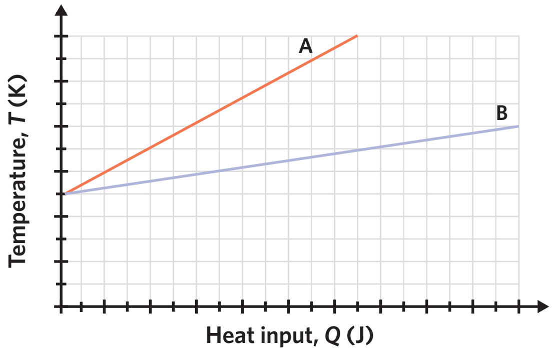
If 100 J of heat is absorbed by each block, which block (*X* or *Y*) will increase its temperature more?

Question 3

Which block (*X* or *Y*) must release more heat to decrease its temperature from 20 K to 10 K?

Question 4

The graph shows how temperature varies for equal masses of two materials (A and B) that have the same initial temperature as they are heated.



Which material has the higher specific heat capacity?

A. material A

B. material B

Latent heat 1.1.13.2

Latent heat is the energy that is absorbed or released when a substance undergoes a change in state. The temperature stays constant while the substance undergoes the state change.

Theory and applications

Water and steam can both exist at 100°C, but steam has a higher internal energy due to its state change.

How can we quantify the energy it takes for a state change to occur within a substance?

In Lesson 2A, we learned that:

- the particles in a gas have more freedom to move compared to the particles in a liquid,
- the particles in a liquid have more freedom to move compared to the particles in a solid,
- for a given material and mass, there is more potential energy stored in the gaseous state compared to the liquid state, and
- for a given material and mass, there is more potential energy stored in the liquid state compared to the solid state.

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A solid must absorb thermal energy when it melts into a liquid, and a liquid must release thermal energy when it freezes into a solid, due to the difference in potential energy between these two states. These transitions are represented in Figure 3.

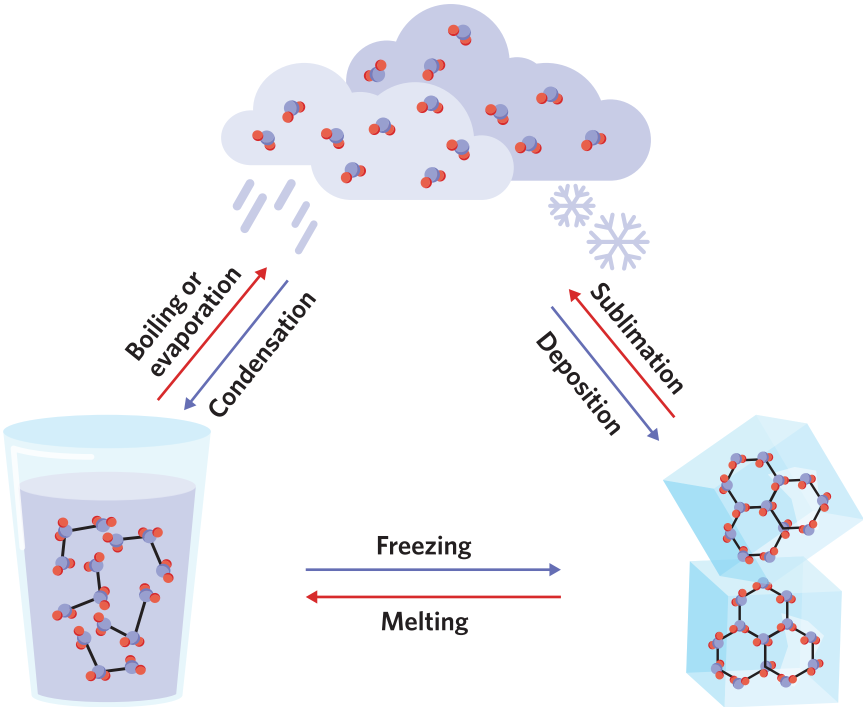

Figure 3 The transitions between states of matter

The temperature remains constant during transitions between states. The energy that is absorbed or released during these transitions is called latent heat, which means hidden heat.[2] Latent heat is 'hidden' as potential energy, used to break or create bonds between atoms required to change the state of matter. Latent heat has no effect on the translational kinetic energy (temperature) of the particles.

KEEN TO INVESTIGATE?

2 **How can we visualise latent heat?**
Search YouTube: Latent heat matter physics

Heating curves can be used to graph and visualise the amount of energy required to cause a state change and to increase the temperature of a given substance.

- Figure 4 shows the heating curve of 1 kg of ice transitioning to water and then to steam. From the graph, we can see that as more heat is absorbed, the temperature of the substance increases, except whilst undergoing a state change.
- The state must change before the temperature of a given substance can change further.
- The amount of thermal energy that must be absorbed to boil a liquid into a gas is exactly the same as the thermal energy that is released when the gas condenses (the same relationship is true for melting and freezing).

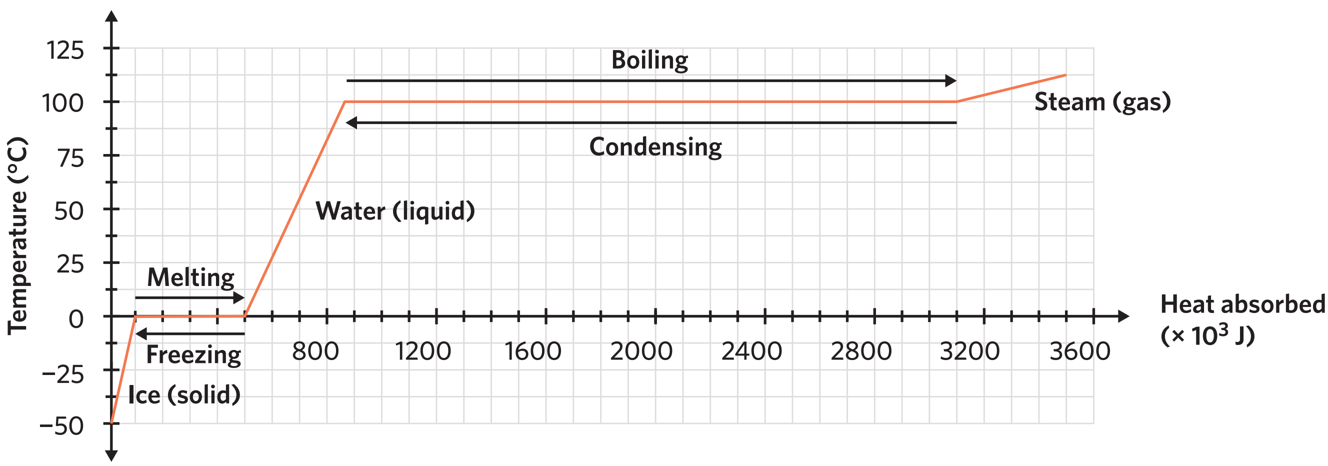

Figure 4 A heating curve for 1 kg of water

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The amount of heat that is added or removed during a transition between states is given by the following formula (see Figure 5):

FORMULA

$$Q = mL$$

Q = heat transferred (J)
m = mass (kg)
L = latent heat (J kg^{-1})

USEFUL TIP

For calculations involving heat transfer, we treat heat absorbed as a positive quantity and heat released as a negative quantity. Hence, when a substance condenses from a gas to a liquid or freezes from a liquid to a solid, the latent heat is a negative quantity.

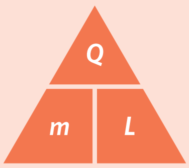

Figure 5 The formula triangle for latent heat

Table 2 shows the latent heat values for various materials. The latent heat for a transition between a solid and a liquid is referred to as 'the latent heat of fusion', and between a liquid and a gas is called 'the latent heat of vaporisation'.

Table 2 Some common substances and their (approximate) latent heat values at standard atmospheric pressure

Substance	Latent heat of fusion, L_f (J kg^{-1}) for solid-liquid transitions	Latent heat of vaporisation, L_v (J kg^{-1}) for liquid-gas transitions
(Ethyl) alcohol	1.1×10^5	8.6×10^5
Carbon dioxide	1.8×10^5	5.7×10^5
Iron	2.8×10^5	63×10^5
Oxygen	0.14×10^5	2.1×10^5
Water	3.3×10^5	23×10^5

WORKED EXAMPLE 2

Nadia is in the arctic and requires liquid water and steam for an experiment, but she can only use 2.0 kg of ice.

For this question, take the latent heat of fusion for water to be 3.34×10^5 J kg^{-1}, the latent heat of vaporisation for water to be 2.26×10^6 J kg^{-1}, and the specific heat capacity of water to be 4186 J kg^{-1} K^{-1}.

a. Calculate how much heat must be provided to melt 2.0 kg of ice at 0°C.

Step 1

Identify relevant values and the relevant formula.

$m = 2.0$ kg, $L_f = 3.34 \times 10^5$ J kg^{-1}, $Q_{Lf} = ?$

Melting (converting solid to liquid) relates to the latent heat of fusion.

$Q_{Lf} = mL_f$

Step 2

Substitute and solve for Q_{Lf}.

$Q_{Lf} = 2.0 \times 3.34 \times 10^5$

$Q_{Lf} = 6.68 \times 10^5 = 6.7 \times 10^5$ J

b. Calculate how much heat must be provided to boil 2.0 kg of water at 100°C.

Step 1

Identify relevant values and the relevant formula.

$m = 2.0$ kg, $L_v = 2.26 \times 10^6$ J kg^{-1}, $Q_{Lv} = ?$

Boiling (converting liquid to gas) relates to the latent heat of vaporisation.

$Q_{Lv} = mL_v$

Step 2

Substitute and solve for Q_{Lv}.

$Q_{Lv} = 2.0 \times 2.26 \times 10^6$

$Q_{Lv} = 4.5 \times 10^6$ J

Continues →

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c. Calculate the total thermal energy required to convert 2.0 kg of ice at 0°C to steam at 100°C.

Step 1

Identify the total amount of heat (the sum of: the heat absorbed to melt the ice, the heat absorbed to warm the water from 0°C to 100°C, and the heat required to boil the water).

$Q_{tot} = Q_{Lf} + Q_{water} + Q_{Lv}$

Step 2

Calculate the heat required to warm the water.

$Q_{water} = mc\Delta T$

$Q_{water} = 2.0 \times 4186 \times (100 - 0)$

$Q_{water} = 8.4 \times 10^5$ J

Step 3

Solve for Q_{tot} (the latent heat for the two changes of state have been calculated in part a and part b).

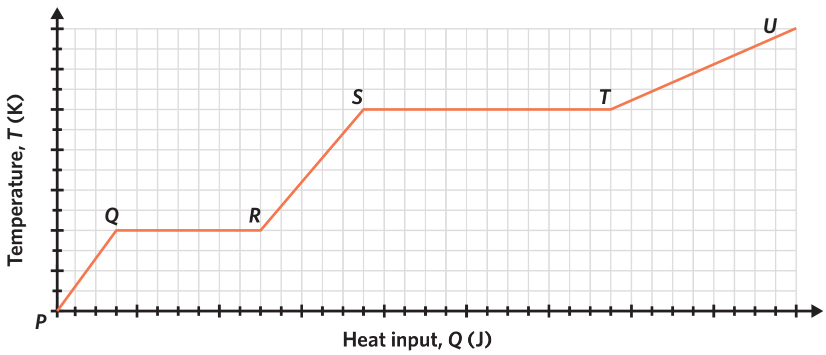
$Q_{tot} = 6.7 \times 10^5 + 8.4 \times 10^5 + 4.5 \times 10^6$

$Q_{tot} = 6.01 \times 10^6 = 6.0 \times 10^6$ J

Progress questions

Question 5

The graph shows the heating curve for a particular substance.



The process of condensing from gas to liquid is represented from __________ to __________.

A. *Q*, *R*

B. *S*, *T*

C. *U*, *T*

D. *T*, *S*

Question 6

As a substance melts from a solid to a liquid or boils from a liquid to a gas, heat is

A. released by the substance.

B. absorbed by the substance.

C. neither absorbed nor released.

Question 7

When a substance melts without a change in temperature, the heat is used to

A. increase only the kinetic energy of the particles in the substance.

B. increase only the potential energy of the particles in the substance.

C. increase both the kinetic energy and potential energy of the particles in the substance.

Continues →

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Question 8

As a substance condenses from a gas to a liquid, or freezes from a liquid to a solid, heat is

A. released by the substance.

B. absorbed by the substance.

C. neither absorbed nor released.

Question 9

As a substance melts from a solid to a liquid or boils from a liquid to a gas, the temperature of the substance

A. increases.

B. decreases.

C. stays constant.

Evaporative cooling 1.1.12.6

Evaporation occurs when the highest energy particles in a liquid escape from its surface. This reduces the average translational kinetic energy, mentioned in 2A, of the remaining particles, and the liquid is cooler as a result.

Theory and applications

When we are at the beach or a pool, we may notice that wind will make us feel a lot cooler if our skin is wet rather than dry. Sweating is an evolutionary mechanism that uses the same process to cool us down. This process is called evaporative cooling. In order to understand how evaporative cooling works, we need to have a clear understanding of what evaporation is.

How can we explain evaporative cooling?

Evaporation is the process of particles in a liquid escaping from the surface at a temperature below the boiling point. The particles that escape are in a gaseous state. This process occurs because higher-energy particles in the liquid constantly escape from its surface, as shown in Figure 6.

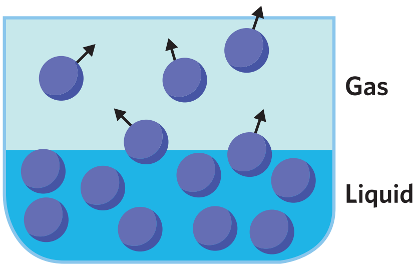

Figure 6 Evaporation occurs due to particles escaping from a liquid's surface.

The rate of evaporation is greater when:

- the temperature of the liquid is greater,
- the surrounding air is drier (lower humidity),
- air moves over the liquid surface, such as wind blowing (as it helps carry the escaped particles away),
- the surface area of the liquid is greater,
- the liquid has a lower boiling point and a lower latent heat of vaporisation, as the particles require less energy to escape.

Whenever a liquid evaporates, it cools its surroundings. Recall from 2A that temperature measures the average translational kinetic energy of a substance, because, at any instant in time, the particles within a system will have a range of kinetic energies. The process occurs as follows:

- Higher-energy particles escape from the liquid surface to the air through evaporation.
- The remaining particles in the liquid now have a lower average translational kinetic energy compared to before.
- This means the temperature of the liquid decreases, meaning more heat continues to be transferred from the surroundings to the liquid.

Evaporative cooling is used in some air conditioning systems by passing air through a damp mesh. However, this type of air conditioning is not effective in humid climates, as humidity slows the evaporation process.

USEFUL TIP

Boiling occurs when a liquid reaches a certain temperature (and pressure) that causes the particles in the entire substance to rapidly transition from a liquid arrangement to a gaseous arrangement, whereas evaporation only occurs at the surface of the substance.

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Progress question

Question 10

Which form of heat transfer is present between skin and water during the process of sweating to cool down?

A. convection

B. conduction

C. radiation

D. all of the above

Theory summary

- Temperature change is related to heat transfer by the formula $Q = mc\Delta T$.
  - c is the specific heat capacity, a measure of the heat transfer per unit of mass that is required to change the temperature of a substance by one kelvin.
- When heating up/cooling down, a substance with a higher specific heat capacity will:
  - absorb/release more heat per kelvin change in temperature (compared to an equal mass of a substance with a lower specific heat capacity).
  - change temperature by a smaller amount per joule of heat absorbed/released (compared to an equal mass of a substance with a lower specific heat capacity).
- Heat is absorbed whenever a solid turns to a liquid or a liquid turns to a gas.
  - Heat is released whenever the reverse processes occur.
  - This is called latent heat.
  - Latent heat is related to heat transfer by the formula $Q = mL$.
  - Temperature stays constant during these processes.
- Evaporative cooling occurs whenever a liquid evaporates from the surface of an object.
  - The highest energy molecules are carried away, decreasing the average translational kinetic energy and therefore reducing the temperature of the remaining liquid.
  - Substances with a lower latent heat of vaporisation and a lower boiling point tend to evaporate more quickly.

CONCEPT DISCUSSION

A burn caused by the steam from a kettle will generally be more severe than a burn caused by the boiling water in the kettle. Discuss why steam burns are usually worse than hot water burns, even when the temperatures of the steam and the liquid water are the same (100°C).

Prompts:

- What causes a burn (what physical process happens) and what makes one burn more severe than another?
- What is the physical difference between liquid water at 100°C and steam at 100°C?
- How does this affect the extent to which liquid water and steam can cause burns?

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2C Questions

Mild Medium Spicy

Deconstructed exam-style

Use the following information to answer questions 11–15.

100 g of water at an initial temperature of 12°C is cooled such that it releases 40 kJ of thermal energy to become ice. Take the specific heat capacity of water to be 4.2×10^3 J kg^{-1} K^{-1}, the specific heat capacity of ice to be 2.1×10^3 J kg^{-1} K^{-1}, and the latent heat of fusion for water to be 3.34×10^5 J kg^{-1}.

Question 11 (1 MARK)

Which option best describes the stages of cooling as the water turns into ice at a final temperature, T_f?

A. Water at 12°C cools to ice at T_f.

B. Water at 12°C cools to water at 0°C; ice at 0°C cools to ice at T_f.

C. Water at 12°C cools to water at 0°C; water at 0°C turns into ice at 0°C; ice at 0°C cools to ice at T_f.

D. Water at 12°C cools to water at T_f; ice at 0°C cools to ice at T_f.

Question 12 (1 MARK)

Which expression represents the energy (in joules) released as the water cools down to 0°C?

A. 100×4.2

B. $0.100 \times 4.2 \times 10^3 \times (0 - 12)$

C. $0.100 \times 2.1 \times (0 - 12)$

D. $100 \times 4.2 \times (273.15 + 12)$

Question 13 (1 MARK)

Which expression represents the change in the water's internal energy (in joules) during the freezing stage of the process?

A. -100×4.2

B. $-0.100 \times 4.2 \times 10^3$

C. $0.100 \times 3.34 \times 10^5 \times (0 - 12)$

D. $-0.100 \times 3.34 \times 10^5$

Question 14 (1 MARK)

Which expression represents the energy (in joules) transferred as the ice cools down from 0°C to its final temperature, T_f?

A. $0.100 \times 2.1 \times 10^3 \times (T_f - 0)$

B. $0.100 \times 4.2 \times 10^3 \times T_f$

C. $0.100 \times 2.1 \times 10^3 \times (0 - 12)$

D. $-100 \times 2.1 \times 10^3$

Question 15 (4 MARKS)

Calculate the final temperature of the ice.

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Exam-style

Question 16 (2 MARKS)

Calculate the heat absorbed by a graphite tennis racquet that has a mass of 0.30 kg when its temperature increases by 4.0°C. Take the specific heat capacity of graphite to be 7.2×10^2 J kg^{-1} K^{-1}.

Question 17 (2 MARKS)

The element in a toaster consists of 15.0 grams of nichrome wire. Electricity passing through the wire absorbs 5500 J of thermal energy to the wire in a short period of time. Take the specific heat capacity of nichrome to be 450 J kg^{-1} K^{-1}. Calculate the increase in temperature of the wire.

Question 18 (4 MARKS)

1.5 kg of oxygen is initially in a gaseous state at its boiling point (−183°C). Take the latent heat of fusion of oxygen to be 6.9×10^3 J kg^{-1} and the latent heat of vaporisation to be 1.1×10^5 J kg^{-1}.

a. Calculate the heat released as the oxygen condenses to liquid. (2 MARKS)

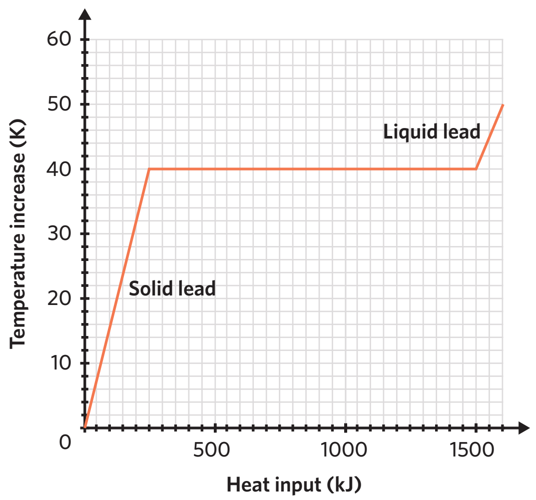
b. The total amount of heat released to the surroundings as the oxygen condenses and cools is measured to be 2.0×10^5 J. How much of this thermal energy was released as a result of cooling (as opposed to condensing)? (2 MARKS)

Question 19 (3 MARKS)

Xi and Ruth are heating a beaker that initially contains a mixture of ice and water. They measure the temperature throughout the process. They notice that the mixture has a temperature of 0°C at the beginning and that the temperature is still 0°C when the last bit of ice melts. Xi says that this means the internal energy of the contents of the beaker has not changed. Ruth says that the internal energy has increased. State who is correct and justify your answer with the appropriate physics principles.

Question 20 (8 MARKS)

The graph shows the heating curve for 5.0 kg of lead as it melts to a liquid.



a. Calculate the gradient of the section of the graph corresponding to the heating of solid lead. Provide your answer in K J^{-1} to two significant figures. (2 MARKS)

b. Using the data in the graph, calculate the specific heat capacity of solid lead. Provide your answer to two significant figures. (3 MARKS)

c. Use the graph to calculate the latent heat of fusion for lead. Provide your answer to two significant figures. (3 MARKS)

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Use the following information to answer questions 21–24.

Substance	Latent heat of fusion, L_f (J kg^{-1})	Latent heat of vaporisation, L_v (J kg^{-1})	Specific heat capacity, c (J kg^{-1} K^{-1})	Melting point (°C)	Boiling point (°C)
Liquid water	3.3×10^5	2.3×10^6	4.2×10^3	0	100
Glass	–	–	840	–	–
Rubbing alcohol	–	8.5×10^5	–	–	79

Question 21 (3 MARKS)

Explain, with reference to evaporation, the observation that rubbing alcohol cools your skin more quickly than water.

Question 22 (3 MARKS)

0.90 kg of ice at 0.0°C is provided with 4.0×10^5 J of heat so that it completely melts. Calculate the final temperature (in °C) of the water.

Question 23 (3 MARKS)

Calculate the increase in temperature of a 4.0 kilogram glass window when 50 grams of steam at 100°C condenses to water at 100°C on its surface. Assume there are no heat transfers other than from the steam to the glass.

Question 24 (5 MARKS)

200 g of ice at 0°C is added to 1.2 kg of water at 20°C in a thermally insulated container. Eventually the ice melts and thermal equilibrium is reached so there is only water in the container at a final temperature between 0°C and 20°C. What is the final temperature of the contents of the container?

Key science skills

Question 25 (8 MARKS)

Students conduct an experiment to measure the effect that known quantities of heat have on water. They heat 0.400 kg of water in a beaker and measure the temperature for every 10 kJ of heat that is added. They record the following data. Assume that the temperature measurements have an uncertainty of ±2°C, but the heat measurements are known to a high degree of accuracy.

Heat input (kJ)	0	10	20	30	40	50
Temperature (°C)	20	25	31	36	40	45

a. Plot the data on a graph with heat input on the horizontal axis and temperature on the vertical axis. Include axis labels (with units), an appropriate scale, uncertainty bars, and a line of best fit. (5 MARKS)

b. Use the gradient of the line of best fit to estimate the specific heat capacity of water. (3 MARKS)

FROM LESSONS 11D & 11E

Previous lessons

Question 26 (2 MARKS)

A ray of light passes through the boundary from water ($n = 1.33$) to glass. The incident angle is 60.0° and the refracted angle is 49.0°. Calculate the refractive index of the glass.

FROM LESSON 1D

Question 27 (4 MARKS)

Duncan is cooking soup in a pot on an electric cooktop. Identify and explain the two methods of heat transfer that move energy from the hotplate to the soup inside.

FROM LESSON 2B

Chapter 2 review

Mild Medium Spicy

These questions are typical of 40 minutes worth of questions on the VCE Physics Exam.

Total marks: 30

Section A

All questions in this section are worth one mark.

Unless otherwise indicated, the diagrams in this book are not drawn to scale.

Question 1

Which option is closest to a temperature of 1000 K?

A. 727°C

B. 1000°C

C. 1273°C

D. 1843°C

Question 2

Lloyd notices that, on a cold day, the tiles in his bathroom feel very cold under his feet. He puts on a pair of thick socks to stop his feet getting so cold. Which form of heat transfer do the socks affect the most in this situation?

A. conduction

B. convection

C. contact

D. radiation

Question 3

A laptop is in thermal equilibrium with a smartphone. The smartphone is at the same temperature as a tablet. Choose the statement that best describes this situation.

A. The laptop is at the same temperature as the smartphone.

B. There is no net heat transfer between the smartphone and the tablet.

C. The laptop is in thermal equilibrium with the tablet.

D. All of the above

Question 4

Which of the following statements is the best explanation for the reason why a beaker of water stays at a constant temperature while it is boiling due to a Bunsen burner flame?

A. The internal energy of the water stays constant during the process of boiling.

B. The heat is used to increase the potential energy of the particles in the water, while the average translational kinetic energy of the particles stays constant.

C. The water loses energy to its surroundings at the same rate as it absorbs energy from the flame.

D. The increase in kinetic energy of the particles is offset by a decrease in the potential energy of the particles.

Question 5

500 g of ice is added to 1.5 kg of warm water. Over a period of time, the ice transfers 9450 J of energy to the water. What was the magnitude of the temperature change of the water in degrees celsius? Take the specific heat capacity of water to be 4.2×10^3 J kg^{-1} K^{-1}.

A. 9.0°C

B. 3.0°C

C. 2.3°C

D. 1.5°C

Question 6

Which of the following is an example of convection?

A. holding heat packs in your pockets to warm up your hands

B. standing over a heater to warm up your hands

C. putting your hands in warm water to warm them up

D. holding your hands in the sun to warm them up

Question 7

An electric cooktop transfers 1400 J every second due to conduction to a pot. How much energy would it transfer through conduction every second if the temperature difference between the cooktop and the pot increased by a factor of 1.25?

A. 2800 J

B. 1750 J

C. 1400 J

D. 700 J

Section B

In questions where more than one mark is available, appropriate working must be shown.

Unless otherwise indicated, the diagrams in this book are not drawn to scale.

Question 8 (3 MARKS)

With reference to the kinetic theory of matter, explain why a pocket of warm air that is surrounded by cooler air will rise. Use this theory to explain how a hot air balloon rises.

Question 9 (5 MARKS)

A large goblet made of aluminium with a mass of 120 grams is at a temperature of 25.0°C. Chilled water at 5.0°C is poured into the goblet. In a short time, the goblet has cooled down to 10.0°C. Assume that the goblet and the water are an isolated system (so that there is no heat exchanged with the surrounding environment) and that heat is distributed evenly within each substance. Take the specific heat capacity of aluminium to be $c_{al} = 900$ J kg^{-1} K^{-1} and the specific heat capacity of water to be $c_w = 4.18 \times 10^3$ J kg^{-1} K^{-1}.

a. Calculate the amount of heat transferred from the goblet. (2 MARKS)

b. If the water has a temperature of 6.9°C when the goblet has reached 10.0°C, calculate the mass of the water that was poured into the goblet. Provide your answer in grams. (3 MARKS)

Question 10 (3 MARKS)

Tobias notices that wet skin feels much cooler when the wind blows compared to when the air is still. Use a simple kinetic energy model to explain this observation.

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Question 11 (4 MARKS)

A solid iron block with a mass of 10.0 kg is heated to its melting point of 1538°C, but is yet to change state. 3.00×10^6 J of heat is provided to the block. Use the data table provided to answer the following questions.

Specific heat capacity of solid iron	4.45×10^2 J kg^{-1} K^{-1}
Specific heat capacity of liquid iron	8.20×10^2 J kg^{-1} K^{-1}
Latent heat of fusion for iron	2.47×10^5 J kg^{-1}

a. Show that the amount of heat required to melt the iron block is 2.47×10^6 J. (1 MARK)

b. Calculate the final temperature of the liquid iron. (3 MARKS)

Question 12 (3 MARKS)

Mudbrick is a very dense material with a high specific heat capacity. Using thermodynamics principles and a relevant form of heat transfer, explain why mudbrick houses would be good insulators for summer, but not ideal for winter (for substantial differences in temperature).

Image: Andriy Blokhin/Shutterstock.com

Question 13 (5 MARKS)

A 2.00 kg solid mass of a substance with a specific heat capacity of 450 J kg^{-1} K^{-1} was melted and now has a temperature of 1.58×10^3 °C. Find the temperature, in kelvin, of the melting point of this specific substance if 5.96×10^5 J of energy was used in total from the beginning of the melting stage to the final temperature, and of that, 5.60×10^5 J of energy was used to cause the state change.

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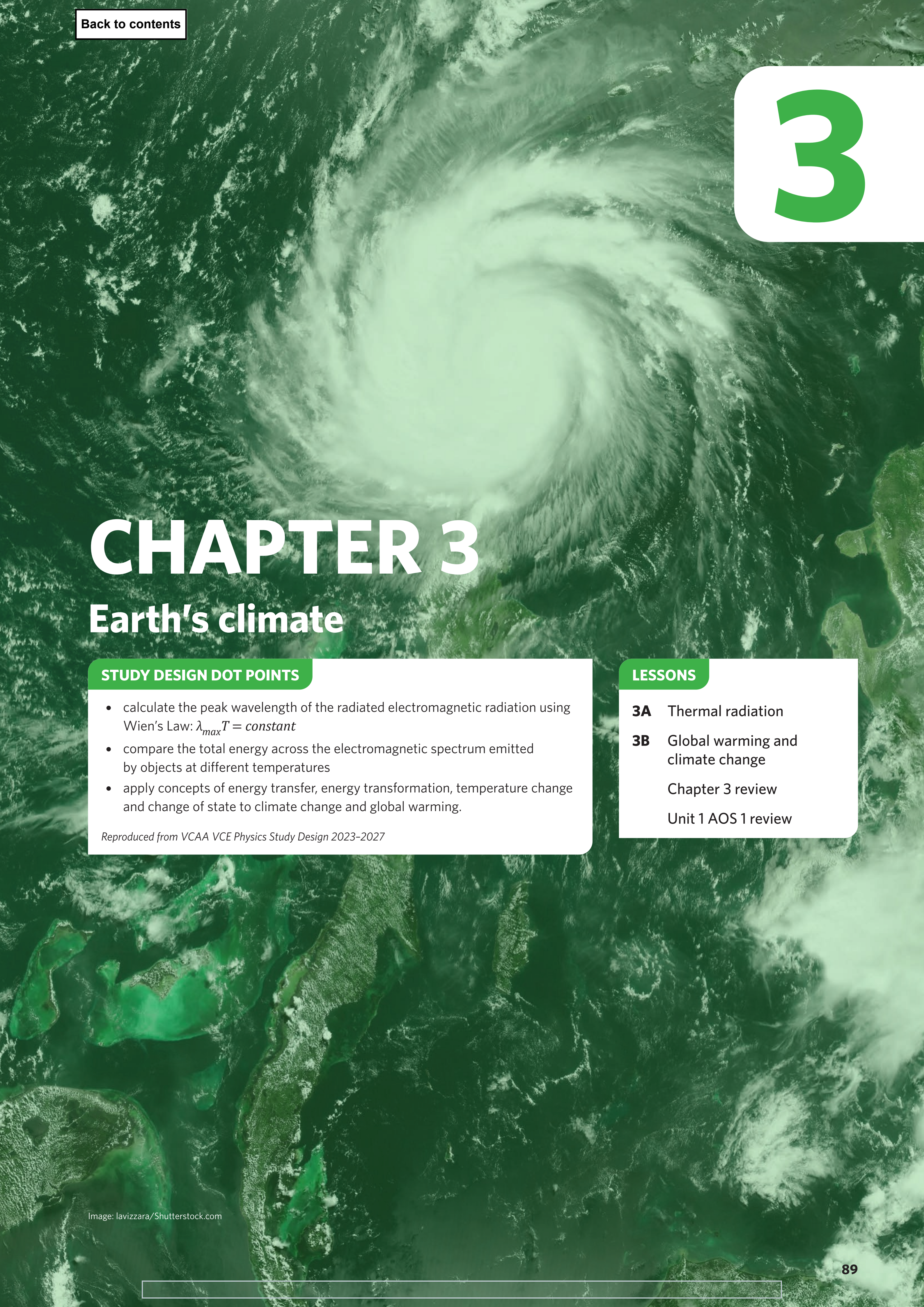

3

CHAPTER 3

Earth's climate

STUDY DESIGN DOT POINTS

- calculate the peak wavelength of the radiated electromagnetic radiation using Wien's Law: $\lambda_{max}T = constant$
- compare the total energy across the electromagnetic spectrum emitted by objects at different temperatures
- apply concepts of energy transfer, energy transformation, temperature change and change of state to climate change and global warming.

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LESSONS

Image: lavizzara/Shutterstock.com

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3A Thermal radiation

Image: ESA/Hubble & NASA, J. Kalirai

STUDY DESIGN DOT POINTS

- calculate the peak wavelength of the radiated electromagnetic radiation using Wien's Law: $\lambda_{max} T = constant$
- compare the total energy across the electromagnetic spectrum emitted by objects at different temperatures

3A — 3B

- **1.1.14.1** Wien's Law
- **1.1.15.1** Energy emitted at different temperatures

ESSENTIAL PRIOR KNOWLEDGE

1C The electromagnetic spectrum
2B Thermal radiation
- Inversely proportional relationships

See questions 17–19.

ACTIVITIES

Log into your Edrolo account for activities that support this lesson.

FORMULA

- **Wien's Law**
  $\lambda_{max} = \frac{b}{T}$

USEFUL TIP

All the questions in this lesson will assume the objects emitting thermal radiation are theoretical blackbodies.

Why are stars different colours?

As we learned in Lesson 2B, radiation is a form of heat transfer, while also a part of the electromagnetic spectrum. The emission of thermal radiation is why hot objects emit light and 'glow', and this principle can be used to work out the temperature of the stars.

KEY TERMS AND DEFINITIONS

intensity the measurable quantity of light

peak wavelength the wavelength of the highest intensity electromagnetic wave released as thermal radiation

Wien's Law 1.1.14.1

Wien's Law relates the temperatures of objects to the wavelength they most commonly emit as thermal radiation.

Theory and applications

We can use Wien's Law to determine the temperatures of astronomical objects such as distant stars and planets, assuming they are theoretical blackbodies. We now know that stars that appear more blue are hotter, and stars that appear more red are cooler.

How does temperature affect peak wavelength?

Every object, above 0 K, emits some sort of thermal radiation as a result of the kinetic energy of its atoms. This radiation occurs across the entirety of the electromagnetic spectrum but is most intense at a particular wavelength, depending on the object's temperature. This wavelength is called the peak wavelength.

Wien's Law is a mathematical relationship between the temperature of an object and the peak wavelength emitted by the object, assuming it is a blackbody.

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In the context of thermal radiation, a blackbody[1] is an object that:

- absorbs all incoming radiation; it does not reflect or transmit any radiation.
- emits the maximum amount of thermal radiation possible.

FORMULA

$$\lambda_{max} = \frac{b}{T}$$

λ_{max} = peak wavelength (m)
b = Wien's constant (2.898×10^{-3} m K)
T = temperature (K)

We can see in Figure 1 that hotter objects emit a greater proportion of radiation with shorter wavelengths compared to colder objects.

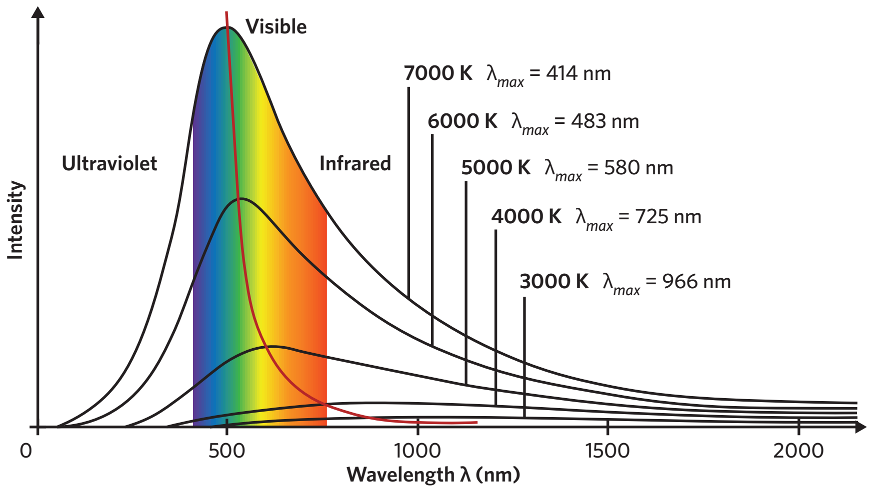


Figure 1 The intensities of the different wavelengths of light emitted by a blackbody at a given temperature

KEEN TO INVESTIGATE?

[1] **What is a blackbody?**
Search YouTube: Blackbody physics

USEFUL TIP

Note that the units for Wien's constant are metres-Kelvin, not millikelvin.

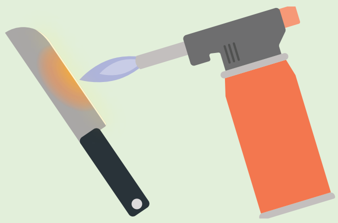
MISCONCEPTION

'Peak wavelength is the longest wavelength of light emitted.'

Peak wavelength is the wavelength of light at which the greatest proportion of radiation is emitted, the position of the peak of the intensity-wavelength graph.

WORKED EXAMPLE 1

A piece of steel is heated up with a blowtorch until it is melting and "white hot". The steel is found to be at 3700 K. Find the peak wavelength for this temperature. Take $b = 2.898 \times 10^{-3}$ m K.



Step 1

Identify the temperature of the steel, and the formula that relates it to peak wavelength.

$T = 3700$ K, $b = 2.898 \times 10^{-3}$ m K, $\lambda_{max} = ?$

$$\lambda_{max} = \frac{b}{T}$$

Step 2

Substitute relevant values into Wien's Law and solve for the peak wavelength.

$$\lambda_{max} = \frac{2.898 \times 10^{-3}}{3700} = 7.8324 \times 10^{-7} = 7.832 \times 10^{-7} \text{ m}$$

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Progress questions

Use the following information to answer questions 1 and 2.

Four identical objects are at different temperatures.

Object *S*	Object *T*	Object *U*	Object *V*
Temperature: 0 K	Temperature: 100 K	Temperature: 1000 K	Temperature: 10 000 K

Question 1

Which of the objects are releasing thermal radiation?

A. *U*, *V*

B. *T*, *U*, and *V*

C. all of the objects

Question 2

Which of the objects has the longest peak wavelength?

A. *T*

B. *U*

C. *V*

Question 3

Which of the following statements about an object emitting a peak wavelength of 650 nm is true? Note that 650 nm is within the visible spectrum of light.

A. It also emits wavelengths in the infrared and ultraviolet spectrums.

B. All the thermal radiation it emits is visible.

Question 4

What is the peak wavelength of an object glowing at 145 K?

A. 2.00×10^{-5} m

B. 2.00×10^{-2} m

Energy emitted at different temperatures 1.1.15.1

If two identical objects are at different temperatures, the hotter object has more energy to emit as radiation compared to the cooler object.

Theory and applications

The thermal energy emitted by the Sun as radiation is responsible for keeping the Earth warm enough for us to live on.

How does temperature affect emitted energy?

As temperature is a measure of the translational average kinetic energy of the atoms within an object, we know that hotter objects have more thermal energy. Similarly, hotter objects emit more energy as electromagnetic radiation, across the entire electromagnetic spectrum, than colder objects.[2]

KEEN TO INVESTIGATE?

[2] **How can we visualise the energy objects emit across the electromagnetic spectrum?**
Search YouTube: Intensity-wavelength graphs blackbody

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The thermal energy emitted by an object as radiation is proportional to the area under an intensity-wavelength graph for that object's temperature. In Figure 2, we see that an object at room temperature (300 K) is emitting energy at a lower intensity at each wavelength when compared to the filament of an incandescent bulb (3000 K). We expect to see this as the temperature of an object at 3000 K is much higher than one at 300 K.

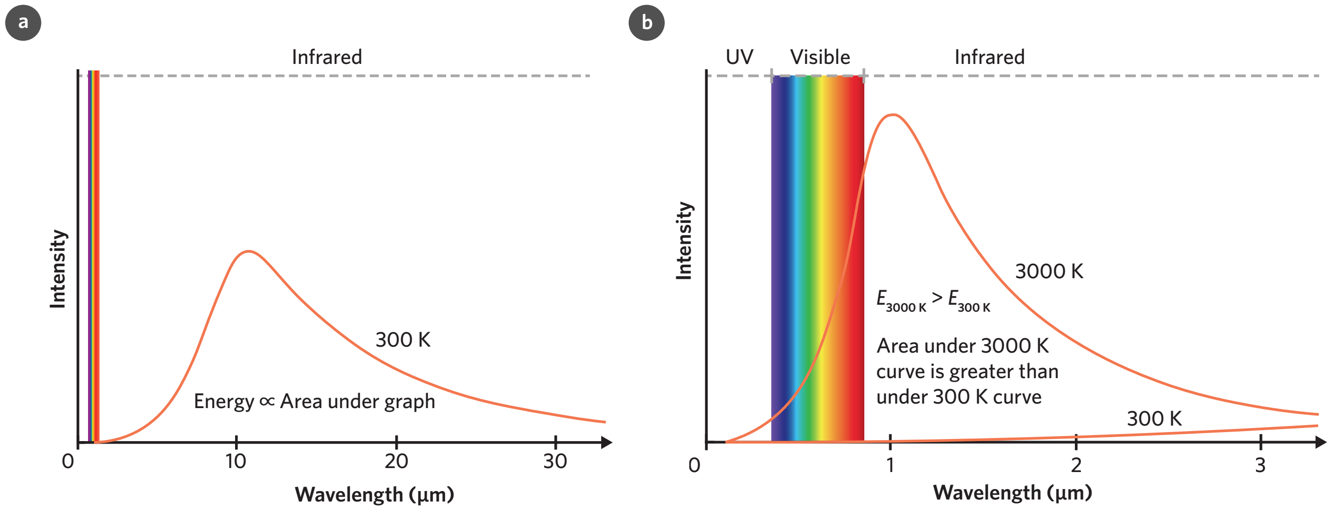

Figure 2 **(a)** The intensity-wavelength graph for an object at 300 K and **(b)** an object at 3000 K

Wien's Law calculates the peak wavelength of radiation emitted. So while an object will radiate more at the peak wavelength for that temperature, they can radiate any wavelength across the spectrum. From Figure 2(b), we see that the 3000 K object is emitting at a greater intensity of energy at every point when compared to the 300 K object, even at its peak.

Progress questions

Use the following information to answer questions 5 and 6.

Four identical objects are at different temperatures.

Object *S*	**Object *T***	**Object *U***	**Object *V***
Temperature: 0 K	Temperature: 100 K	Temperature: 1000 K	Temperature: 10 000 K

Question 5

Which object is releasing the most energy?

A. *S*

B. *T*

C. *U*

D. *V*

Question 6

Is there any wavelength where object *T* is releasing at a greater intensity of energy than object *U*?

A. Yes, the peak wavelength.

B. No, the much hotter object will release more energy at every wavelength.

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Theory summary

- All bodies radiate their heat as electromagnetic waves.
- Wien's Law is used to calculate the peak wavelength (the wavelength of maximum intensity) for a blackbody at any particular temperature.
  - $\lambda_{max} = \frac{b}{T}$, taking b as 2.898×10^{-3} m K
- As the temperature of an object increases:
  - The total energy across the entire electromagnetic spectrum radiated per second by the object increases.
  - The proportion of radiation that is short wavelength (high frequency, high energy) increases.
- Hotter objects emit more energy across the electromagnetic spectrum than cooler objects, if they have identical properties.

CONCEPT DISCUSSION

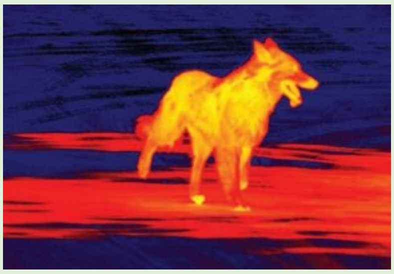


Image: Maximillian cabinet/Shutterstock.com

A thermographic camera can be used to create an image according to the infrared radiation emitted by an object. Regions that emit greater infrared radiation appear brighter, more yellow, than regions that emit less. Discuss how this could be used to spot warm blooded animals in the dark, and why certain areas of the body appear brighter than others.

Prompts:

- How does the temperature of a dog compare to its environment?
- Does a hotter or colder object emit more infrared radiation?
- Which areas of the body are likely warmer than others?

3A Questions

Mild / Medium // Spicy ///

Deconstructed exam-style

Use the following information to answer questions 7–10.

Mrs Beast is making a YouTube video cutting open objects using two different knives, made of copper and iron. They claim in the title the knives are at 1000°C, but in reality the copper knife is 560°C and the iron knife is 680°C.

Question 7 (1 MARK) /

What is the temperature of the two knives, in K?

A. $T_C = 560 + 273.15$, $T_I = 680 + 273.15$

B. $T_C = 560 - 273.15$, $T_I = 680 + 273.15$

C. $T_C = 560 + 273.15$, $T_I = 680 - 273.15$

D. $T_C = 560 - 273.15$, $T_I = 680 - 273.15$

Question 8 (1 MARK) /

Which knife will have a greater peak wavelength of emitted radiation?

A. They will have the same peak wavelength, as they are both metals.

B. The iron will have a longer peak wavelength, as it is hotter.

C. The copper will have a longer peak wavelength, as it is hotter.

D. The copper will have a longer peak wavelength, as it is cooler.

Question 9 (1 MARK)

Which expression will correctly calculate the difference in peak wavelength emitted by the two knives?

A. $\lambda_{max\ diff} = \frac{b}{560 + 273.15} - \frac{b}{680 - 273.15}$

B. $\lambda_{max\ diff} = \frac{b}{680 + 273.15} - \frac{b}{560 + 273.15}$

C. $\lambda_{max\ diff} = \frac{b}{560 + 273.15} - \frac{b}{680 + 273.15}$

D. $\lambda_{max\ diff} = \frac{b}{680 + 273.15} - \frac{b}{680}$

Question 10 (4 MARKS)

Calculate the difference in λ_{max} emitted by the two knives, in nanometres. Take Wien's constant, *b*, to be 2.898×10^{-3} m K.

Exam-style

Question 11 (2 MARKS)

Calculate the λ_{max} of a star with an average surface temperature of 7.0×10^{3} K. Take Wien's constant, *b*, to be 2.898×10^{-3} m K.

Question 12 (3 MARKS)

Jan makes a cup of tea on the bench, and forgets to drink it. How does the amount of thermal radiation emitted by the cup and the peak wavelength of radiation emitted by the cup of tea change over time?

Question 13 (5 MARKS)

Zayn is heating up a piece of metal. He finds, after a period of time, the metal changes colour from a "metallic silver" to red then bright white.

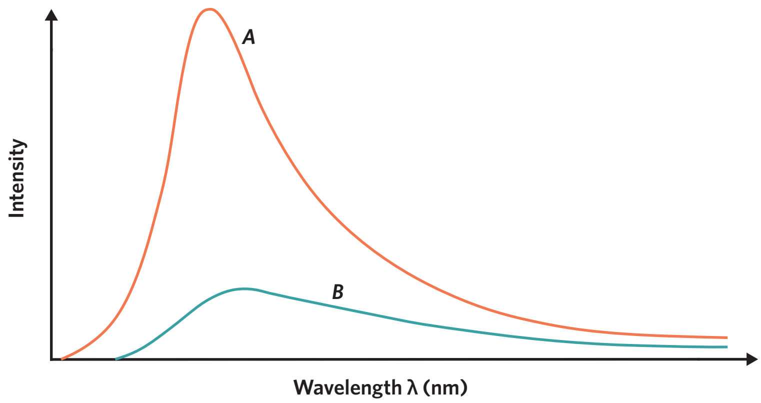
a. The change in the metal's colour can be considered to occur in two stages: From "metallic silver" to red and from red to white.

Explain the reasons for the colour change during these two stages, and describe how the intensity of light changes as the temperature increases. (3 MARKS)

b. Zayn finds that the most intensely emitted wavelength while the metal melts is 680 nm. Find the melting point of the metal in kelvin. Take Wien's constant, *b*, to be 2.898×10^{-3} m K. (2 MARKS)

Question 14 (6 MARKS)

The wavelength-intensity graph for two identical objects, object *A* and *B*, is provided.



a. Which object is at a higher temperature? Explain your answer using two features from the graph. (3 MARKS)

b. Draw how the intensity-wavelength graph of an object with a temperature in between objects *A* and *B* may look. (3 MARKS)

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Question 15 (5 MARKS)

A piece of glass has been heated to 1280°C and is glowing red.

a. Calculate the λ_{max} for a blackbody at the same temperature as this piece of glass. Take Wien's constant, b, to be 2.898×10^{-3} m K. (2 MARKS)

b. Explain why the piece of glass is glowing red, even though its λ_{max} is not in the visible range of the spectrum. (3 MARKS)

Question 16 (4 MARKS)

Luna and Selene are having a discussion about the amount of thermal radiation emitted by two objects at different temperatures. Luna claims that the cooler object will emit a greater amount of energy at its peak wavelength, and Selene claims the warmer object will emit a greater proportion of its energy at higher wavelengths than the cooler object.

Evaluate Luna and Selene's claims.

Question 17 (5 MARKS)

Two distant stars are observed through a telescope. One is a bright blue, and the other a bright red.

a. Explain, with reference to peak wavelength, why the two stars are different colours. Suggest qualitatively what the peak wavelength of each star may be. (3 MARKS)

b. The peak wavelength of the blue star is in the visible spectrum. Calculate the average temperature of the blue star. Take the wavelength of blue light to be 475 nm. (2 MARKS)

Key science skills

Question 18 (2 MARKS)

Stella and Asteri are taking measurements of the Sun's peak wavelength.

	λ_1 (nm)	λ_2 (nm)	λ_3 (nm)	λ_4 (nm)	λ_5 (nm)	λ_6 (nm)	λ_{avg}(nm)
Stella	646	810	401	711	526	276	562
Asteri	511	371	611	687	305	540	504

Compare the precision of Stella and Asteri's data.

FROM LESSON 11C

Previous lessons

Question 19 (3 MARKS)

The wavelength of a light wave in a medium with a refractive index, $n = 1.80$, is 880 nm. Calculate the frequency of this wave. Take the speed of light in a vacuum, c, to be 3.00×10^8 m s^{-1}.

FROM LESSON 1D

Question 20 (2 MARKS)

State the heat transfer that takes place as steam from a cup of coffee rises, and explain why this occurs.

FROM LESSON 2B

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3B Global warming and climate change

Why would Earth be frozen without any greenhouse gases?

This lesson will apply concepts of the interaction between thermal energy and electromagnetic radiation taught in the previous two chapters to understand global warming and climate change. Within our climate system, energy transforms between different types, transfers from one place to another, and causes water to change state.

STUDY DESIGN DOT POINT

- apply concepts of energy transfer, energy transformation, temperature change and change of state to climate change and global warming.

3A 3B

1.1.16.1 Earth's energy budget

1.1.16.2 Earth's energy imbalance

ESSENTIAL PRIOR KNOWLEDGE

2B Methods of heat transfer
2C Understanding thermal energy
3A Energy emitted at different temperatures

See questions 20–22.

ACTIVITIES

Log into your Edrolo account for activities that support this lesson.

KEY TERMS AND DEFINITIONS

albedo a measure of how much electromagnetic radiation an object reflects versus how much it absorbs

climate change a long-term change in weather patterns on the regional and global scale

climate system relationships and interactions between the atmosphere, oceans, snow, land surfaces, and all living organisms

energy transformation when energy changes from one form to another

global warming a long-term increase in the average global temperature of Earth's climate system since the industrial revolution due to human activities

Earth's energy budget 1.1.16.1

Climate change is the study of how, particularly through human activity, the distribution and flow of energy moving around our climate system is changing and the effects of those changes.

Theory and applications

Natural disasters, including cyclones, floods, droughts, and bushfires, all depend on the distribution and flow of energy within our climate. As the human impact on climate change worsens, so will the frequency and severity of natural disasters.

MISCONCEPTION

'Weather and climate are the same.'

Weather refers to local atmospheric conditions such as rain, snow, clouds, winds, floods and thunderstorms that occur over short periods of time (minutes/hours/days). On the other hand, climate refers to a region's or global average of atmospheric conditions such as temperature, humidity and rainfall patterns which occur over a long period of time (seasons/years/decades).[1]

KEEN TO INVESTIGATE?

1 **How does climate change differ from global warming?**
Search: Weather, global warming, and climate change

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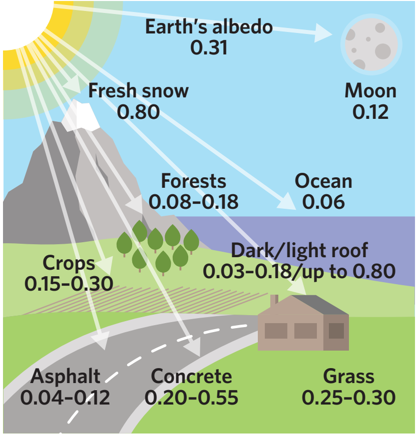

Figure 1 Albedo depends on the type of surface

How does Earth's climate system balance energy transfer, transformation, and change of state?

Energy that enters Earth's atmosphere comes from the Sun. For electromagnetic radiation to transform into another type of energy, such as heat, it must be absorbed by matter. The amount of absorbed energy is dependent on a planet's albedo. Earth's average albedo, approximately 0.30, means that 70% of the Sun's light is absorbed.

Every surface has a distinct albedo between 0 and 1, see Figure 1.

A surface with an albedo equal to:

- zero, is a completely black surface, absorbing all incident radiation.
- one, is a perfect mirror surface, reflecting all incident radiation.

The 70% of the Sun's electromagnetic radiation that is absorbed will transform into different forms of energy. Table 1 and Figure 2 describe the transformation, transfer, distribution and flow of energy throughout our climate system.

Table 1 Forms of energy within Earth's climate system

Form of energy	Impact	Explanation and examples
Thermal energy	Increasing air, water, and ground temperatures	Hot objects re-emit their energy, transforming it back into electromagnetic radiation which transfers energy equally in all directions including out to space and back down to Earth (see 'back radiation' Figure 2).
		Greenhouse gases provide the largest contribution to back radiation, trapping thermal energy within the atmosphere by absorbing infrared radiation emitted from the Earth's surface (see Figure 2).
Change of state of water	Evaporation of oceans, melting of ice/snow	Energy from evaporated water is transferred into the upper atmosphere through convection to form clouds. The presence of water vapour in the atmosphere drives cloud cover and therefore rain and snow patterns including blizzards, floods, and droughts.
		Water vapour in the atmosphere is a major greenhouse gas. Humid regions, such as tropical rainforests, have a large concentration of water vapour in the air, allowing them to better retain the Sun's heat at night.
		Melting of snow/ice leads to a change in global sea levels.
Kinetic energy	Winds (including cyclones), thermals, underwater currents, and ocean waves	Electromagnetic energy is transformed into kinetic energy through a temperature difference between two regions, driving convection.
		Waves, currents, thermals and winds transfer energy through convection in the direction they travel.
		Convection currents around the world greatly impact the condition of and differences between regional climates.

MISCONCEPTION

'Greenhouse gases are only produced by human activity.'

Greenhouse gases may come from human made or natural sources. Without naturally occurring greenhouse gases the climate would have an average temperature of around –18°C.

KEEN TO INVESTIGATE?

2 **What is Earth's energy budget?**
Search: What is Earth's energy budget?

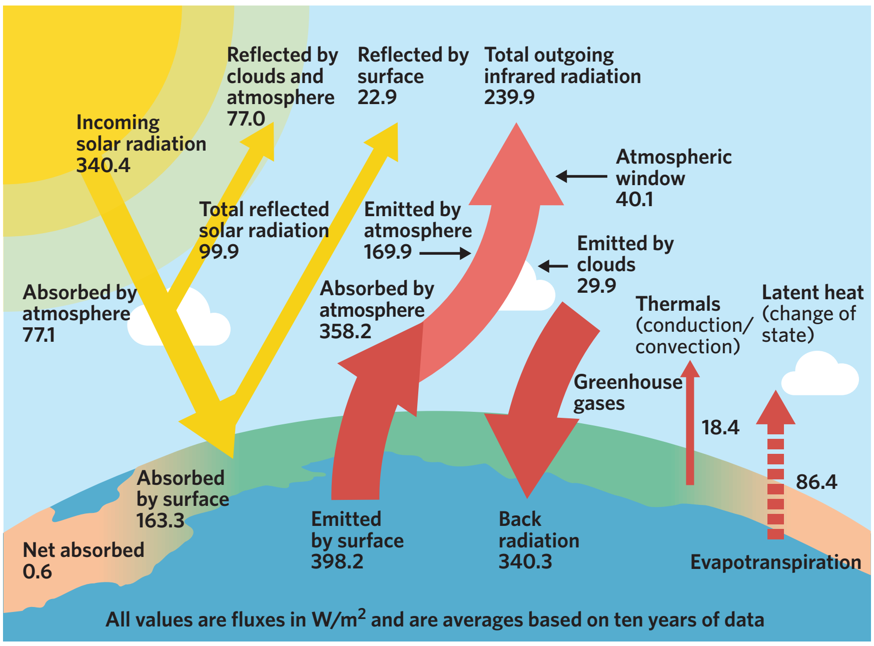

Figure 2 Earth's energy budget[2]

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How is human activity impacting Earth's climate?

Human activity is impacting climate systems in multiple ways, such as increasing greenhouse gas concentrations and changing the Earth's albedo. As the delicate balance of energy distribution and flow changes, so too will the climate. Precisely quantifying and predicting how the climate changes is a difficult task and is the focus of many scientists' research, such as those working at the Intergovernmental Panel on Climate Change (IPCC). Table 2 summarises part of the IPCC report on the effects of climate change in Australia.

MISCONCEPTION

'Global warming and climate change are exactly the same.'

Global warming and climate change are often used interchangeably but are not the same. Global warming specifically describes the long-term increase in average global temperature and is just one effect of climate change whereas climate change is a broad term that describes all the changes that occur to the climate due to human influence.

Table 2 Some effects of climate change in Australia based on the 6th IPCC report[3]

Consequence	Predicted changes	Reason		
Coral	High confidence in a significant change in the composition and structure of Australian coral reef systems.	Warming trend	Ocean acidification	Damaging cyclone
Mountain ecosystem	High confidence in the loss of mountain ecosystems and some native species in Australia.	Warming trend	Snow Cover	Drying trend
Floods	High confidence in an increase in frequency and intensity of flooding in Australia.	Extreme precipitation		
Droughts	High confidence in a decrease in freshwater in the southern parts of Australia.	Warming trend	Drying trend	
Heat waves	High confidence in increased death and infrastructure damage during heat waves.	Extreme temperature		
Wildfires	High confidence in increased wildfire infrastructure damages and risks to human life in Australia.	Warming trend	Extreme temperature	Drying trend
Coastal flooding	High confidence in an increasing risk to coastal buildings and low-lying ecosystems in Australia.	Sea level rise	Damaging cyclone	
Food production	High confidence in reduced food production in the Murray-Darling basin.	Warming trend	Extreme temperature	Drying trend

KEEN TO INVESTIGATE?

[3] **What are the impacts of climate change on Australia?**
Search: Australasia climate change report 25

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Progress questions

Question 1

Whenever radiation interacts with matter, including the atmosphere or the ground, some of the radiation will be __________ (reflected/convected), some will be __________ (induced/absorbed), and the rest will be __________ (enhanced (becomes more intense)/transmitted).

Question 2

Identify the following statements as true or false.

Statement	True/False
The energy driving winds, waves, and ocean currents comes from the Sun.	
Volcanoes are powered by solar energy, hence eruptions will become more common due to climate change.	
When solar electromagnetic energy is absorbed, it is transformed into a different type of energy.	
Greenhouse gases increase the amount of back radiation and therefore trap more heat in the atmosphere.	

Question 3

Thermals and water vapour move energy higher up in the atmosphere through

A. convection.

B. conduction.

C. radiation.

Earth's energy imbalance 1.1.16.2

Energy primarily enters and leaves Earth's climate system through electromagnetic radiation. When more energy enters than leaves, the globe's temperature increases.

Theory and applications

The imbalance between energy entering and leaving the Earth's climate system is causing a rise in average global temperatures. Many global agencies study, monitor and forecast these imbalances, as it is of fundamental concern to civilisation.

Why are global temperatures changing?

The Sun is very hot with a surface temperature around 5530°C. According to Wien's Law (see Lesson 3A), it emits a large amount of energy in the form of high energy, short wavelength electromagnetic radiation. Earth on the other hand is lower in temperature, and therefore emits lower energy, longer wavelength infrared electromagnetic radiation (see Figure 3).

MISCONCEPTION

'The climate has always changed therefore it can't be caused by human activity.'

Temperatures are rising at an unprecedented rate. The predicted rate of warming for the next century is 20 times faster than any other warming in the past two million years.[4]

KEEN TO INVESTIGATE?

[4] **How is today's warming different from the past?**
Search: How is today's warming different from the past?

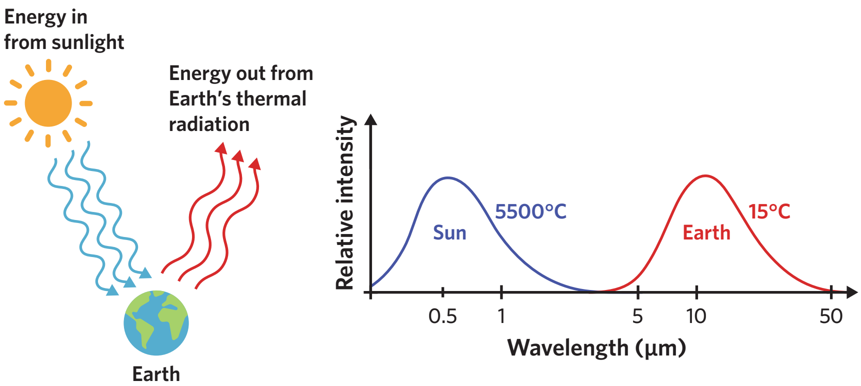

Figure 3 Earth absorbs short wavelength and emits long wavelength radiation

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When incoming solar energy and outgoing Earth energy is balanced, global temperatures will remain stable. However, if incoming energy increases, or outgoing energy decreases, there will be an energy imbalance causing warming. Global temperatures would continue to rise until the increased total energy emitted by a warmer planet is again in balance with absorbed solar energy. This can be shown by the following relationship.

Change in global temperatures is dependent on the difference between incoming solar energy and outgoing Earth energy.

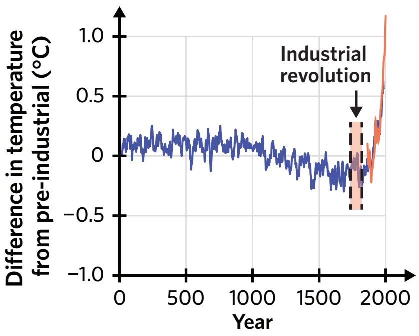

Figure 4 Global temperatures over 2000 years

How is human activity contributing to global warming?

Since the industrial revolution, the burning of fossil fuels causes the creation of more greenhouse gases than the environment is used to. This causes more thermal energy to be trapped in the atmosphere through back radiation thereby increasing the Earth's temperature (see Figure 4).

Global warming has increased due to many human influences, reducing the amount of energy that can escape our climate system. Every individual change to our climate system, whether or not human caused, can be quantified as to its effects on changing global temperatures (see Figure 5).

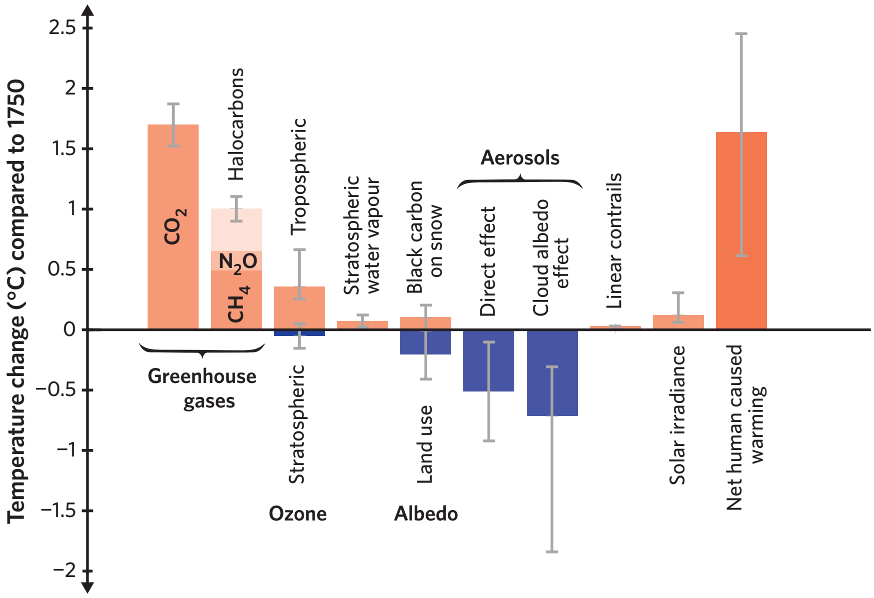

Figure 5 Contribution by variable to global warming in 2011

MISCONCEPTION

'Global warming is caused by increased solar activity.'

Although solar activity has increased slightly since pre-industrial times (see Figure 5), its effect on global temperatures are almost negligible when compared to humanities influence.

MISCONCEPTION

'Scientists' measurements of global temperatures are conflicting, invalid and do not follow predictions.'

An overwhelming majority (97%) of climate scientists agree on human activity as the primary cause of global warming and climate change. Data from respected scientific agencies including NASA, NOAA, Hadley and Berkeley Earth all record matching historical data showing an increase in global temperatures.

Progress questions

Question 4

Which of the following best describes incoming solar energy in terms of its source and its wavelength?

A. The Earth absorbs short wavelength electromagnetic radiation from the Sun.

B. The Earth absorbs long wavelength electromagnetic radiation from the Sun.

Question 5

If the Earth re-emits more radiation than it receives, then the Earth will

A. heat up.

B. remain at a constant temperature.

C. cool down.

Question 6

List the following variables in order of their effects on increasing global warming.

- Change in solar energy reaching Earth,
- Changing surface albedo,
- Changing ozone concentrations,
- Emitting other greenhouse gases,
- Emitting aerosols,
- Emitting CO_2.

Theory summary

- Climate change:
  - 70% of the Sun's energy is absorbed by Earth's climate system.
  - Absorbed energy is able to transform into different forms.
    - Some of the absorbed energy raises the surface, ocean and atmospheric temperatures.
    - Some of the energy absorbed by oceans and ice is used to change the state of water.
    - Some of the absorbed energy is transformed into kinetic energy driving the winds, waves, thermals and currents.
  - Human activity is interrupting the flow and distribution of energy in Earth's climate system causing regional and global changes to our climate.
- Global warming:
  - Change in global temperatures is dependent on the difference between incoming solar energy and outgoing Earth energy.
  - Earth is emitting less outgoing electromagnetic radiation due to human activity therefore causing global temperatures to rise.
  - Energy is primarily transferred into and out of Earth in the form of electromagnetic radiation.
    - Solar electromagnetic radiation is high energy, short wavelength and peaks in the visible light.
    - Earth radiation is low energy, long wavelength and peaks in the infrared.

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CONCEPT DISCUSSION

Imagine that suddenly the surface temperature of the Sun increases by a significant factor and starts to release much more energy. This energy would increase Earth's temperature but how long would it take? Discuss factors that might slow or speed up the time it would take for the Earth to increase in temperature.

Prompts:

- How much energy would be required to heat up earth by 1°C?
- How will the imbalance change with a hotter Sun?
- What might affect the amount of radiation Earth emits?

3B Questions

Mild Medium Spicy

Deconstructed exam-style

Use the following information to answer questions 7–9.

When the Earth and the Sun are in a relationship called radiative equilibrium, the temperature of both bodies are relatively stable even though the Earth is still receiving the Sun's radiation.

Question 7 (1 MARK)

When temperatures remain stable, which of the following is true?

A. Incoming solar energy is greater than outgoing Earth energy.

B. Incoming solar energy is less than outgoing Earth energy.

C. Incoming solar energy equals outgoing Earth energy.

Question 8 (1 MARK)

Which of the following is used to find if temperatures will increase, decrease or remain stable over time?

A. incoming solar energy plus outgoing Earth energy

B. incoming solar energy minus outgoing Earth energy

C. incoming solar energy multiplied by outgoing Earth energy

Question 9 (3 MARKS)

Explain the conditions required for radiative equilibrium to be reached.

Exam-style

Question 10 (4 MARKS)

Climate change and global warming have large consequences globally and regionally.

a. Identify four different consequences as a result of climate change. (2 MARKS)

b. Name two human impacts that are contributing to climate change and global warming. (2 MARKS)

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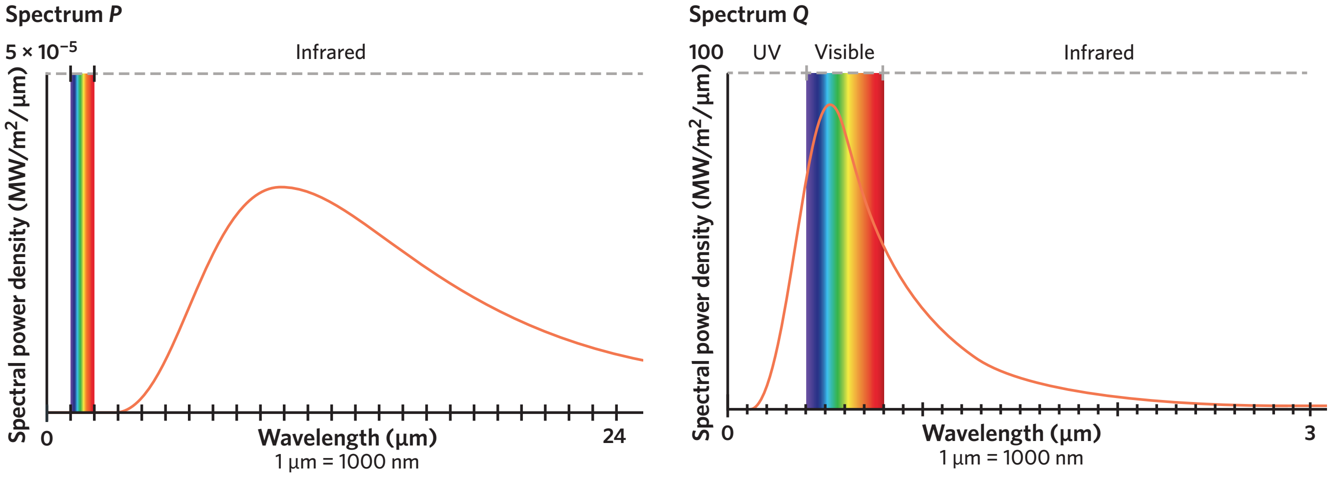
Question 11 (3 MARKS)

Scientists measure the energy emitted by the Sun and the Earth but forgot to label their graphs beyond *P* and *Q*.



a. Which graph represents the radiation the Sun emits and which graph represents the radiation that Earth emits? (1 MARK)

b. Based on the graph alone, what is the peak wavelength of the Sun's electromagnetic radiation? Give your answer in μm. (1 MARK)

c. Identify the method of heat transfer by which energy enters and leaves Earth's climate system. (1 MARK)

Question 12 (2 MARKS)

Explain why a decrease in energy leaving Earth's climate system leads to warming temperatures.

Question 13 (5 MARKS)

When sunlight reaches water, much of it is absorbed causing the water to evaporate.

a. How does water vapour transfer energy to the upper atmosphere? (2 MARKS)

b. Evaporation is the driving mechanism behind precipitation (rain). Changing evaporation patterns therefore also changes rainfall patterns.

Explain how changing evaporation patterns might affect the severity and frequency of droughts and floods. (3 MARKS)

Question 14 (5 MARKS)

Convection is a mechanism of energy transfer. The Gulf Stream is a large ocean current of warm water moving heat from the Caribbean on the equator up to Europe. This current is responsible for the significantly warmer climate in western Europe than eastern Europe.

a. Discuss the role of convection in moving energy around Earth's climate system. Refer to how the Gulf Stream current warms Europe in your answer. (3 MARKS)

b. Disrupting the movement of energy through the Gulf Stream current will cool down Europe's climate. Describe two possible consequences of disrupting the Gulf Stream current on Europe's climate. (2 MARKS)

Question 15 (5 MARKS)

Albedo describes the relationship between the amount of light absorbed and the amount reflected by a surface.

a. Explain how changing the Earth's albedo might affect the transformation of the Sun's electromagnetic energy into different forms. (2 MARKS)

b. Humans have cut down forests to be replaced with farm land. Farm land has a higher albedo (reflects more light) than forests. Only considering albedo, explain how this change would affect global temperatures. (3 MARKS)

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Key science skills

Question 16 (3 MARKS)

Endrico and Bronte are having a discussion about the scientific meaning of the word 'theory' with reference to global warming. Endrico tries to convince Bronte that a theory is the same as a hypothesis. Bronte claims that, in science, the term theory is only used when something has been repeatedly confirmed by experimental evidence.

Evaluate each of their claims.

FROM LESSON 11A

Previous lessons

Question 17 (2 MARKS)

On a bright day, the sun heats up a stretch of concrete. As the heat transfers to the air above the road, it becomes warmer than the air above it. Nadja is looking over the road. Could a mirage form in this context? Provide a reason for your answer.

FROM LESSON 1E

Question 18 (3 MARKS)

The surface of a building emits a peak wavelength of 9760 nm. Find the building's external temperature. Provide your answer in degrees Celsius. Take Wien's constant b to be 2.898×10^{-3} m K.

FROM LESSON 2C

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Chapter 3 review

Mild Medium Spicy

These questions are typical of 40 minutes worth of questions on the VCE Physics Exam.

Total marks: 30

Section A

All questions in this section are worth one mark.

Unless otherwise indicated, the diagrams in this book are not drawn to scale.

Question 1

If a distant star has a peak wavelength of 230 nm, what is its temperature? Assume the star is a blackbody and take Wien's constant, b, to be 2.898×10^{-3} m K.

A. 12 600 K

B. 10 000 K

C. 5700 K

D. 126 K

Question 2

Which of the following is not true about greenhouse gases?

A. Greenhouse gases trap the thermal radiation emitted by the Earth's surface.

B. Water vapour is one of the most potent greenhouse gases.

C. The burning of fossil fuels increases the amount of greenhouse gases in the atmosphere.

D. Greenhouse gases are present solely due to human activity.

Question 3

Which of the following is likely to have the greatest proportion of its emitted energy in the infrared region of the electromagnetic spectrum?

A. a metal ball heated until it is glowing red

B. the green flame from the burning of a particular chemical

C. a knife heated until it is glowing a bright yellow

D. the orange flames from a campfire

Question 4

The warming trend of the Earth's climate is not likely to

A. cause significant change to both coral and mountainous ecosystems.

B. decrease the frequency and severity of floods.

C. decrease the production of food.

D. increase the severity of many natural disasters, such as bushfires.

Question 5

The average temperature of the Moon increased for several years after the Apollo landings. It is suspected that astronauts disturbed the lunar soil – resulting in darker lunar soil covering the Moon's surface. This could have caused an increase in temperature by

A. decreasing the Moon's albedo.

B. increasing the Moon's albedo.

C. reducing the Moon's greenhouse effect.

D. enhancing the Moon's greenhouse effect.

Section B

In questions where more than one mark is available, appropriate working must be shown.

Unless otherwise indicated, the diagrams in this book are not drawn to scale.

Question 6 (5 MARKS)

The provided table shows the CO_2 released per kilometre and the annual fuel cost of three comparable vehicles. Currently, the electric vehicle is being powered by electricity mainly produced through the burning of fossil fuels.

Vehicle	CO_2 released due to electricity/fuel (g/km)	Annual fuel cost ($AUD)
Electric vehicle	169	789
Petrol vehicle	173	1625
Diesel vehicle	148	1061

a. If choosing a vehicle just by its current amount of CO_2 released, which vehicle is the best choice? (1 MARK)

b. If choosing a vehicle just by its annual fuel cost, which vehicle is the best choice? (1 MARK)

c. The CO_2 produced by electric vehicles is due to the burning of fossil fuels to charge the batteries. If the electricity was produced from sources with no net CO_2 emission, how would changing from a petrol vehicle to an electric vehicle change an individual's impact on global warming? (3 MARKS)

Question 7 (5 MARKS)

A light for a photography studio and a flashlight both send current through a high-resistance filament so that it reaches a high enough temperature to emit light. The radiation emitted by the studio light is a pure white colour, but the flashlight has a yellowish tinge.

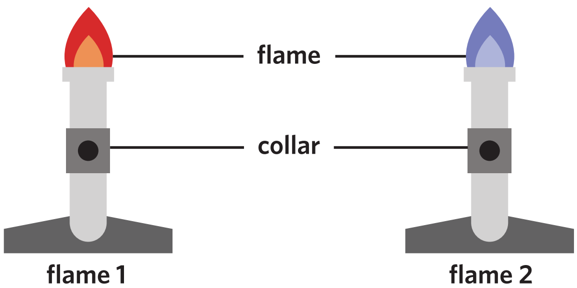
a. Which light is at a higher temperature? Justify your answer. (3 MARKS)

b. Before the flashlight is turned on it has a temperature of 20.0°C, but the label states that the operating temperature of the filament is 3500 K.

Calculate the peak wavelength of the light after it has reached operating temperature. Take Wien's constant, b, to be 2.898×10^{-3} m K and give your answer in nanometres. (2 MARKS)

Question 8 (9 MARKS)

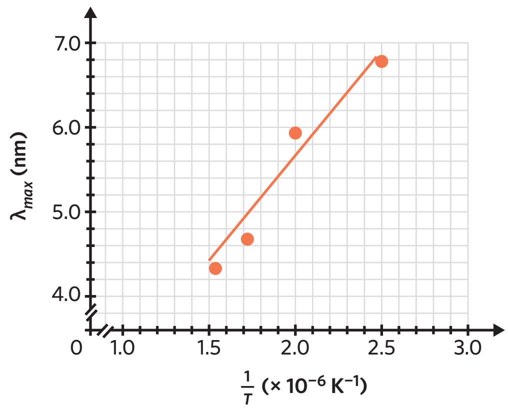
Two students are using bunsen burners to boil a small beaker of water, with one flame a bright blue whereas the other is a light red.



a. Explain which flame will boil the beaker of water quicker, with reference to the energy emitted by each flame. (3 MARKS)

b. The students are able to determine the average temperature of the flame for different wavelengths of light by recording how long the water takes to boil in each case. They produce the following λ_{max} vs. $\frac{1}{T}$ graph.

Determine the value of b, Wien's constant, from the students' results. (3 MARKS)



c. The values the students use for λ_{max} is estimated using an electromagnetic spectrum and visually determining where the peak wavelength of radiation emitted lies.

At which temperatures is this visual analysis least accurate? Explain your answer, comparing the true peak wavelength of light emitted to the observed peak wavelength of light emitted. (3 MARKS)

Question 9 (6 MARKS)

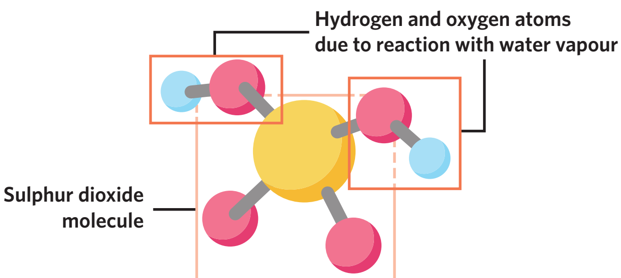
The following table outlines the difference in theoretical temperatures, ignoring the greenhouse effect, to actual recorded temperatures for planets in our solar system.

Planet	Theoretical temperature (°C)	Actual temperature (°C)	Increase
Venus	−41	4.7×10^2	1.2×10^3 %
Earth	−15	15	2.0×10^2 %
Mars	−65	−58	11 %

a. Explain how greenhouse gases in the Earth's atmosphere contribute to the greenhouse effect. (2 MARKS)

b. Use the above table to determine which planet experiences the greatest greenhouse effect? Suggest a reason for why this may be the case. (2 MARKS)

c. In the event of a major volcanic eruption, large amounts of sulphur dioxide are injected into the stratosphere in large smoke clouds. The sulphur dioxide reacts with water vapour in the air, producing long chain molecules that block incoming sunlight



Explain how the volcanic eruption could reduce the average temperature of the Earth. (2 MARKS)

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Unit 1 AOS 1 review

Mild Medium Spicy

These questions are typical of one hour's worth of questions on the VCE Physics Exam.

Total marks: 50

Section A

All questions in this section are worth one mark.

Unless otherwise indicated, the diagrams in this book are not drawn to scale.

Question 1

Which of the following gives the order of light from lowest to highest energy?

A. radio, infrared, blue, green, red

B. blue, green, red, infrared, radio

C. radio, infrared, red, green, blue

D. infrared, radio, red, green, blue

Question 2

Which of the following objects will release the most heat per unit change in temperature?

A. 1 kg of iron, with a specific heat capacity of 0.45×10^3 J kg^{-1} K^{-1}, being heated by a furnace.

B. 1 kg of cooking oil, with a specific heat capacity of 2.8×10^3 J kg^{-1} K^{-1}, being heated by an oven.

C. 1 kg of iron, with a specific heat capacity of 0.45×10^3 J kg^{-1} K^{-1}, being cooled by a freezer.

D. 1 kg of cooking oil, with a specific heat capacity of 2.8×10^3 J kg^{-1} K^{-1}, being cooled by a freezer.

Question 3

Which one of the following regions of the electromagnetic spectrum is emitted by the Sun, glowing a bright red, with the least intensity?

A. infrared

B. visible

C. x-ray

D. ultraviolet

Question 4

An ice cube, in a freezer, at a temperature of −6°C is losing thermal energy via conduction at a rate of 2 J s^{-1}. The rest of the inside of the freezer is at a temperature of −18°C. Ignore convection and radiation. When the ice cube's temperature is −12°C, the rate it will be losing heat due to conduction is closest to

A. 1 J s^{-1}.

B. 2 J s^{-1}.

C. 4 J s^{-1}.

D. 12 J s^{-1}.

Question 5

In which of the following situations is a mirage able to form?

A. An ocean with a temperature similar to that of the surrounding air.

B. A road on a hot day with surrounding air of equivalent temperature.

C. A warm lake with surrounding air that gradually warms with height from the ground.

D. A hot road with surrounding air that becomes less dense with height from the ground.

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Section B

In questions where more than one mark is available, appropriate working must be shown.

Unless otherwise indicated, the diagrams in this book are not drawn to scale.

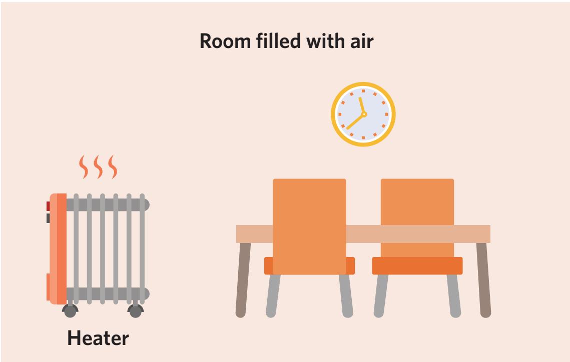
Question 6 (3 MARKS)

A chemist is trying to create a liquid that is effective at transferring energy through conduction, convection, and radiation. She can modify the liquid's reflectivity, thermal capacity, and viscosity (how easily the liquid flows). Which heat transfers will each of these three properties affect?

Question 7 (8 MARKS)

The provided diagram shows a hot electric heater (above room temperature) sitting in an otherwise empty, air-filled room.

a. On a copy of the provided diagram, sketch a convection cell that could be generated by the heater. (3 MARKS)

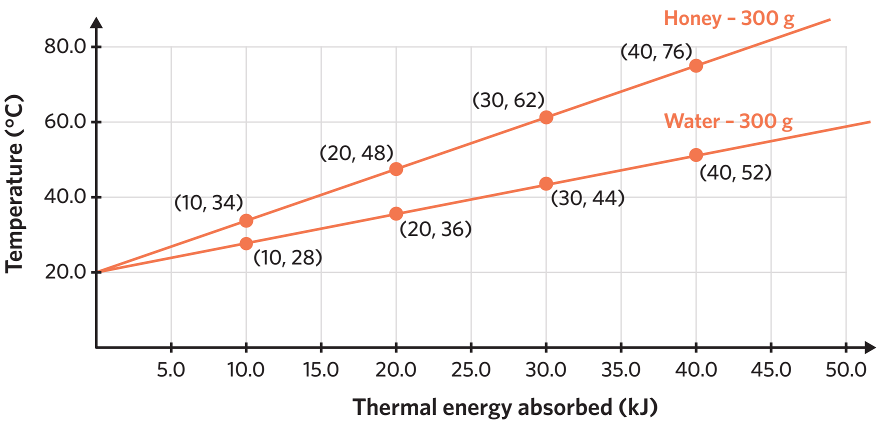


b. Compare the average translational energy of the particles inside the heater, and those in the room filled by air. Describe the energy transfers that take place over time between these particles and the overall effect on the temperature of the room. (3 MARKS)

c. Discuss why a heater is often placed close to ground level, whereas air conditioners are often placed above the ground. (2 MARKS)

Question 8 (5 MARKS)

Students are investigating the specific heat capacity of honey. They heat a 300 g sample of honey and a 300 g sample of water, and plot the samples' temperature against the calculated thermal energy absorbed by the samples.



Take the specific heat capacity of water to be $c_w = 4200\ \text{J kg}^{-1}\ \text{K}^{-1}$.

a. Calculate the specific heat capacity of the honey sample. Provide your answer in $\text{J kg}^{-1}\ \text{K}^{-1}$ to two significant figures. (3 MARKS)

b. The students now heat a new sample of water. The sample requires the same amount of energy to increase its temperature by one degree as the 300 g honey sample. Calculate the mass of this sample of water. (2 MARKS)

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Question 9 (11 MARKS)

The Australian summer of 2012–2013 was termed the 'Angry Summer' due to the overwhelming number of temperature records that were broken. The Angry Summer achieved a record 40.3°C for the hottest average temperature on a single day in Australia. However, this record was broken on a day in 2019 when Australia experienced an average temperature of 41.9°C. For this question, model Australia's temperature to be the same as its average temperature.

a. What impact does the greenhouse effect have on the amount of thermal energy retained by the Earth? How has this changed since the industrial revolution? (3 MARKS)

b. What effect does the construction of cities with an albedo lower than the environment they replaced have on the amount of thermal energy retained by the Earth? (1 MARK)

c. Calculate the peak wavelength of the radiation Australia emitted when its hottest average temperature was recorded. Give your answer in nanometres and assume Australia is a blackbody. (3 MARKS)

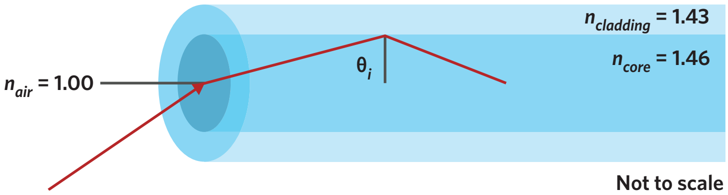
d. Using your answer to part **c**, draw an intensity-wavelength graph for the thermal radiation emitted by Australia. Values on the intensity axis are not required. (4 MARKS)

Question 10 (9 MARKS)

A student is experimenting with a green laser. The beam of light is shone through an optical cable. The refractive index of the core is 1.46, and the refractive index of the cladding is 1.43.

a. Calculate the frequency of the light beam travelling through air. Take the wavelength of green light to be 550 nm. (2 MARKS)

b. A student shines the green laser at a red bus. Does it absorb or reflect the light from the green laser? Explain your answer. (2 MARKS)



c. The incident light beam is at an angle, θ_i, of 75°. Will total internal reflection occur? (3 MARKS)

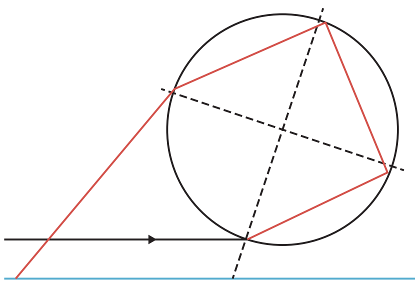
Adapted from VCAA 2007 Detailed Study 2 Q5

d. The student now decides to shine a ray of light through a block. It hits the top of the prism at an angle of 78° to the normal. The critical angle of the prism in air is 76°. An observer standing above the prism is shocked that they cannot see the light. Explain how this is possible. (2 MARKS)

Question 11 (9 MARKS)

a. Explain what happens when a beam of white light enters a raindrop. (3 MARKS)

b. When white light enters a raindrop, there may be two incidences of internal reflection. The path of the red component of light is shown. Explain how the refraction of light entering the raindrop would differ for the violet component of the visible spectrum of light. (3 MARKS)



c. Draw the path of the violet component of light inside the raindrop. (3 MARKS)

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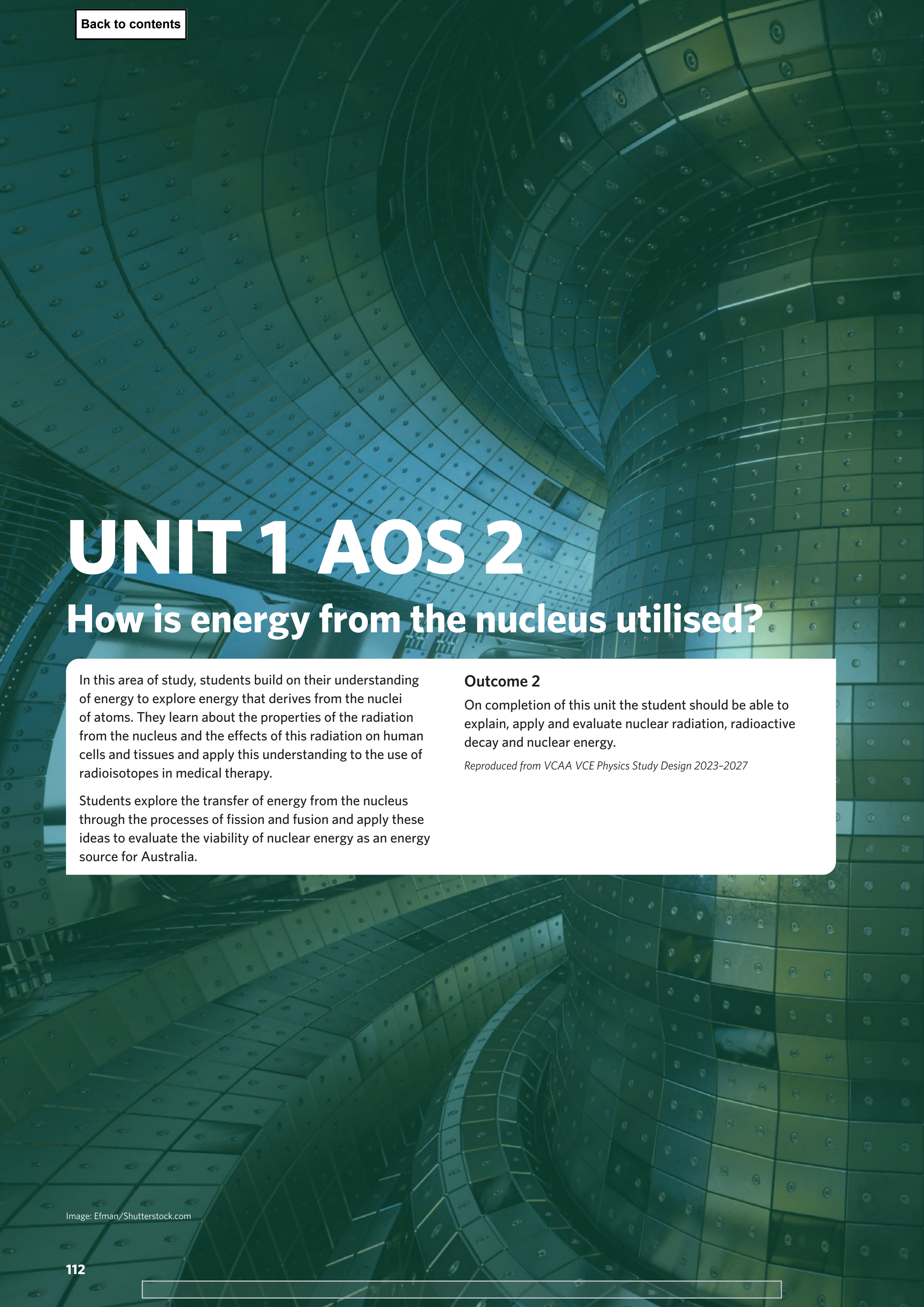

UNIT 1 AOS 2

How is energy from the nucleus utilised?

In this area of study, students build on their understanding of energy to explore energy that derives from the nuclei of atoms. They learn about the properties of the radiation from the nucleus and the effects of this radiation on human cells and tissues and apply this understanding to the use of radioisotopes in medical therapy.

Students explore the transfer of energy from the nucleus through the processes of fission and fusion and apply these ideas to evaluate the viability of nuclear energy as an energy source for Australia.

Outcome 2

On completion of this unit the student should be able to explain, apply and evaluate nuclear radiation, radioactive decay and nuclear energy.

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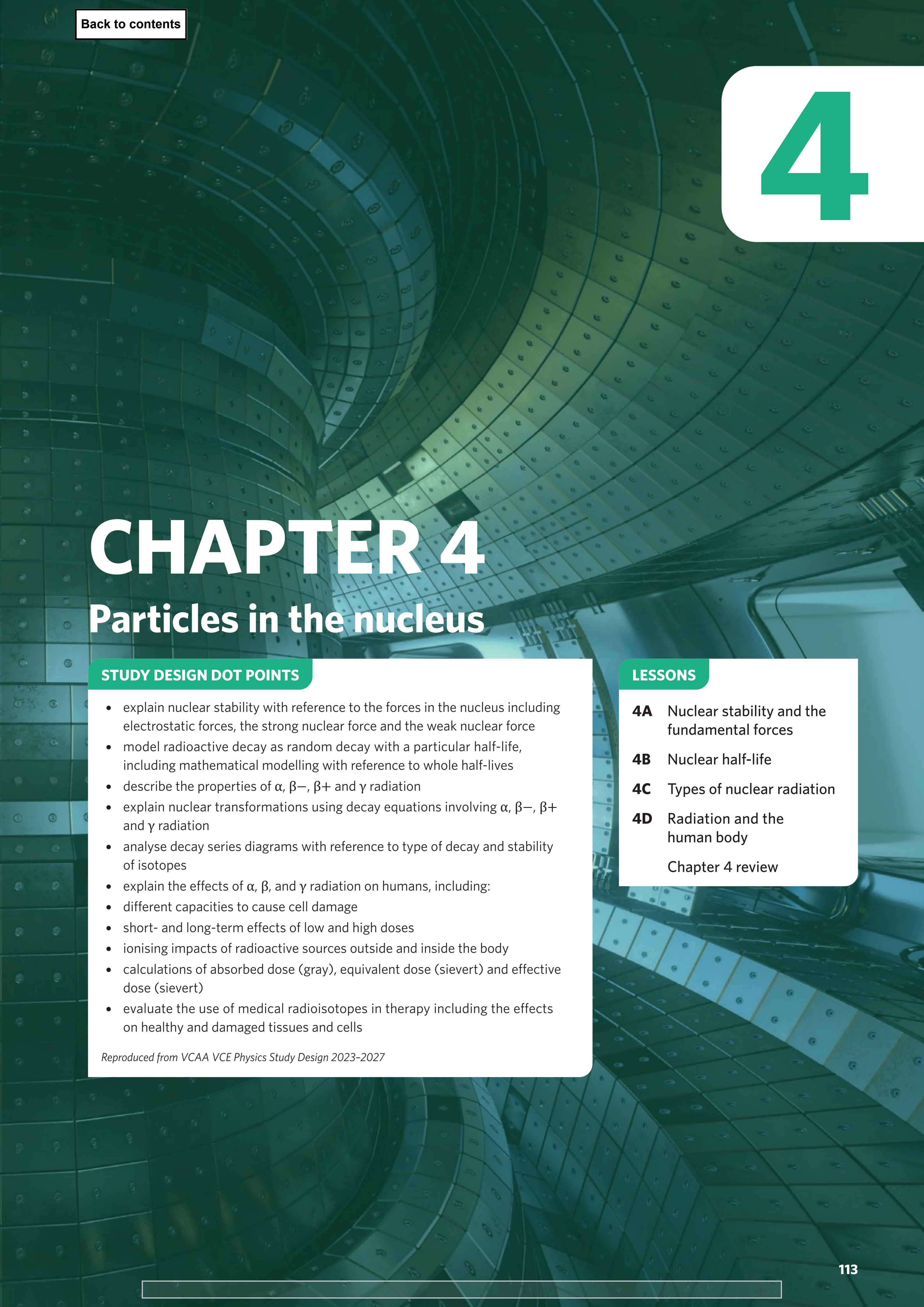

4

CHAPTER 4

Particles in the nucleus

STUDY DESIGN DOT POINTS

- explain nuclear stability with reference to the forces in the nucleus including electrostatic forces, the strong nuclear force and the weak nuclear force
- model radioactive decay as random decay with a particular half-life, including mathematical modelling with reference to whole half-lives
- describe the properties of α, β−, β+ and γ radiation
- explain nuclear transformations using decay equations involving α, β−, β+ and γ radiation
- analyse decay series diagrams with reference to type of decay and stability of isotopes
- explain the effects of α, β, and γ radiation on humans, including:
- different capacities to cause cell damage
- short- and long-term effects of low and high doses
- ionising impacts of radioactive sources outside and inside the body
- calculations of absorbed dose (gray), equivalent dose (sievert) and effective dose (sievert)
- evaluate the use of medical radioisotopes in therapy including the effects on healthy and damaged tissues and cells

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LESSONS

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4A Nuclear stability and the fundamental forces

STUDY DESIGN DOT POINT

- explain nuclear stability with reference to the forces in the nucleus including electrostatic forces, the strong nuclear force and the weak nuclear force

4A 4B 4C 4D

1.2.1.1 The fundamental forces

1.2.1.2 Nuclear stability

ACTIVITIES

Log into your Edrolo account for activities that support this lesson.

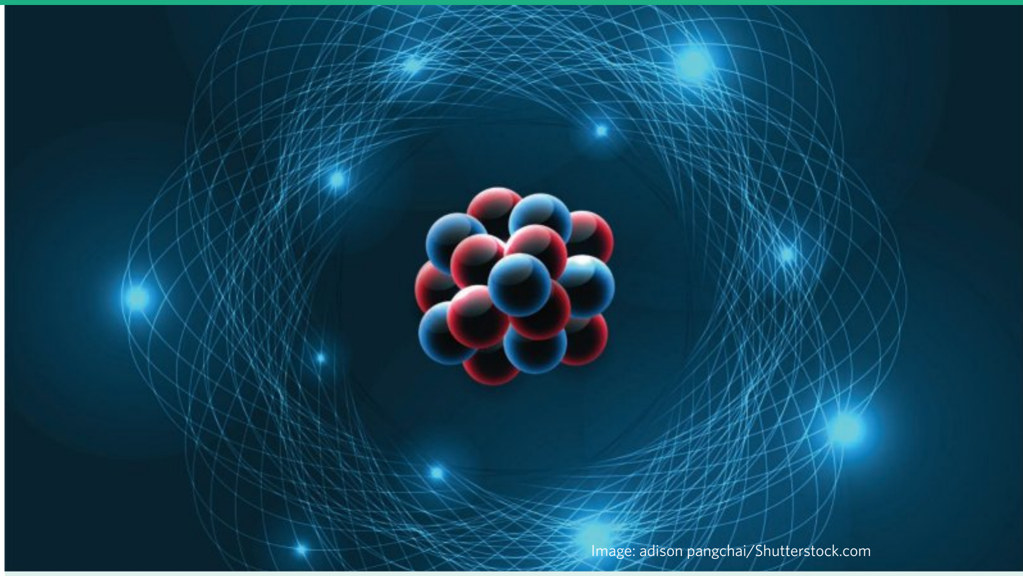

Image: adison pangchai/Shutterstock.com

How does an atomic nucleus stay together?

Nuclear stability underlies some of the most fundamental phenomena within the universe, including not only the existence of atoms but the energy generation inside stars. This lesson introduces the four fundamental forces and examines how the balance between forces within atomic nuclei determines their stability.

KEY TERMS AND DEFINITIONS

fundamental force a force that is irreducible, all other forces can be derived from the fundamental forces

isotope one of two or more possible forms of an atomic element, which will each have different masses and numbers of neutrons

neutron a subatomic particle found in the nucleus with no electric charge

nucleon a proton or a neutron found in an atom's nucleus

proton a subatomic particle found in the nucleus with positive electric charge

quark a type of fundamental particle which protons and neutrons are made of

radioactive decay the process of an atomic nucleus becoming more stable by losing energy and emitting particles or photons

radioisotope an isotope that will undergo radioactive decay

strong force the fundamental force that holds quarks together to form nucleons and that holds nucleons together within the nucleus

weak force the fundamental force responsible for beta decay by changing the properties of a quark

The fundamental forces 1.2.1.1

All forces can be reduced to the four fundamental forces. The fundamental forces most relevant to the atomic nucleus are the strong force, the weak force, and the electromagnetic force.

Theory and applications

While the gravitational force and the electromagnetic force can be observed in everyday life, the strong and weak forces only occur noticeably on subatomic (smaller than the size of an atom) scales. Understanding how the fundamental forces act on matter helps explain why atomic nuclei can be unstable.

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How do the fundamental forces act in atomic nuclei?

The fundamental forces all act in different ways on different particles and with different strengths, as introduced in Table 1.

Table 1 The four fundamental forces within atomic nuclei.

	Strong	Weak	Electromagnetic	Gravity
Relative strength (approximate)	1	10^{-6}	$\frac{1}{137}$	10^{-38}
Effective range	10^{-15} m (just over the radius of a nucleon)	10^{-18} m	∞	∞
Nuclear particles that experience the force	Quarks, nucleons	Quarks, nucleons	Electrically charged particles	All particles with mass
Attractive or repulsive	Repulsive and attractive	Neither	Repulsive and attractive	Attractive
Role within the atomic nucleus	Repulsive at very short distances: stops protons and neutrons from overlapping. Attractive at slightly larger distances: attracts quarks to one another which keeps nucleons intact and attracts them to one another.[1]	Causes beta decay, which is explained in Lesson 4C, in order to make unstable nuclei stable again.[2]	Repulsive for like charges: repels protons from one another.	Negligible

KEEN TO INVESTIGATE?

1 **How does the strong force keep the protons and neutrons together?**
Search YouTube: Strong interaction: the four fundamental forces of physics

2 **How does the weak force change a neutron to a proton?**
Search YouTube: Weak interaction: the four fundamental forces of physics

MISCONCEPTION

'The electrostatic force is a fundamental force.'

The electromagnetic force is a fundamental force, and the electrostatic and magnetic forces are its components. It is the electrostatic component that attracts/repels electrical charges from each other, and is the component which is most relevant in the nucleus.

Figure 1 shows the attractive and repulsive forces between nucleons within an atomic nucleus. The weak nuclear force is also present in the nucleus, however it is not shown on the diagram because it cannot be thought of as a "push" or a "pull". In real nuclei, the strong force attracts all nucleons that are close to each other, and the electrostatic force repels all protons in the nucleus from one another.

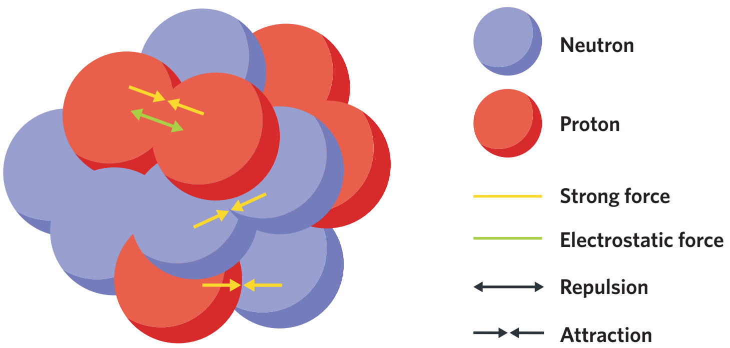

Figure 1 Attractive and repulsive forces in atomic nuclei

USEFUL TIP

The strong force attracting nucleons to each other is a residual effect of it attracting quarks to one another, since it will attract quarks in one nucleon to other quarks in nearby nucleons.

The strong and the weak nuclear forces are each vital for the universe and Earth to exist as it does. The strong force makes it possible for protons, neutrons, and atoms to exist in the first place, and the weak force makes it possible for the Sun and nuclear reactors to produce energy, which are concepts that will be explored in Chapter 5.

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Progress questions

Question 1

Circle the correct option for each blank.

The strong force is __________ (attractive/repulsive) at very short distances, and __________ (attractive/repulsive) at slightly longer distances. As a residual effect of holding together __________ (electrons/quarks), the strong force acts on __________ (quarks/nucleons).

Question 2

For each force, tick the properties it exhibits and cross the ones it doesn't.

	Acts on protons	Acts on neutrons	Acts noticeably at the human scale	Acts noticeably at the subatomic scale
Strong force				
Weak force				
Electromagnetic force				

Nuclear stability 1.2.1.2

A nucleus will be stable when the attractive strong force contribution is large enough to sufficiently counteract the repulsive electrostatic force contribution, and the nucleons do not have enough energy to undergo nuclear reactions.

Theory and applications

Nuclear stability is a balancing act between the strong and electrostatic forces, and is influenced by the ratio of protons and neutrons, as well as overall nucleus size. Nuclear stability and instability are utilised for dating artefacts (Lesson 4B), medical therapies (Lesson 4D), and nuclear energy (Lessons 5A, 5B).

How do the fundamental forces make nuclei stable or unstable?

A given atomic element can have several stable isotopes, which exist when the nuclei of these isotopes are not able to undergo nuclear reactions or decay without external influence.

We say nuclei are usually more stable the higher their binding energy per nucleon is, a concept which is explored in Lesson 5A. Isotopes will only ever spontaneously decay (to become a different element or isotope) if the decay would increase the overall binding energy. In general, the easier it is for an isotope to decay, the more unstable it is. The level of isotope stability is influenced by the attractive and repulsive forces in the nucleus, and the nuclear processes available to increase the overall binding energy, some of which are discussed in Lessons 4C and 5A.

Stable isotopes usually require the strong force to be slightly stronger than the electrostatic force within the nucleus. This means the nucleus is more attracted to itself than it is repelled by itself, and therefore has a higher binding energy per nucleon, making it less likely to decay.

MISCONCEPTION

'Stable nuclei and stable isotopes are the same thing.'

Sometimes an isotope will have a nucleus with a low binding energy per nucleon but require a high amount of external energy to undergo nuclear reaction, so the isotope is stable as it will not decay by itself.

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Isotopes with nuclei that have 20 or less protons are usually stable if they have an equal number of protons and neutrons. Table 2 gives the effect on the forces when an additional nucleon is added to an atomic nucleus with more than 20 protons. As shown, with higher numbers of protons, the nucleus will require more neutrons than protons to counteract the electrostatic repulsion and make the isotope stable.

Table 2 Effects of adding nucleons to atomic nuclei with more than 20 protons.

Particle added	Proton	Neutron
Change in electrostatic forces	Large additional repulsive force from electrostatic repulsion to all other protons in the nucleus	None
Change in strong nuclear forces	Small additional attractive force from strong force attraction to nucleons close to it	Small additional attractive force from strong force attraction to nucleons close to it
Overall effect on forces	Large increase in repulsive force within nucleus	Small increase in attractive force within nucleus

There are several factors that can make the nuclei of isotopes more unstable:

- Too many protons per neutron
  - The electrostatic force within the nucleus repelling the protons is stronger than the strong nuclear force binding the nucleons together.
- Too many neutrons per proton
  - When there are more neutrons in a nucleus, the neutrons need to exist in higher energy states which makes the nucleus more unstable.[3]
- Too big
  - When there are 84 or more protons in the nucleus, the electrostatic repulsive force is so significant the nucleus becomes inherently unstable. All isotopes of these unstable elements are radioisotopes.

The weak force makes atomic nuclei unstable by providing a process (beta decay) through which an isotope can decay to become more stable without attracting or repelling nuclei from one another. If the weak force did not exist, radioisotopes that decay via beta decay would not be able to anymore, and so would exist as stable isotopes.

Figure 2 illustrates the stability of isotopes on a graph of proton number (Z) versus neutron number (N). Notice that for the first twenty elements, the stable isotopes (those situated on the blue line) have roughly the same amount of neutrons (N) as protons (Z). Beyond this, isotopes begin to require a greater number of neutrons than protons to be stable.

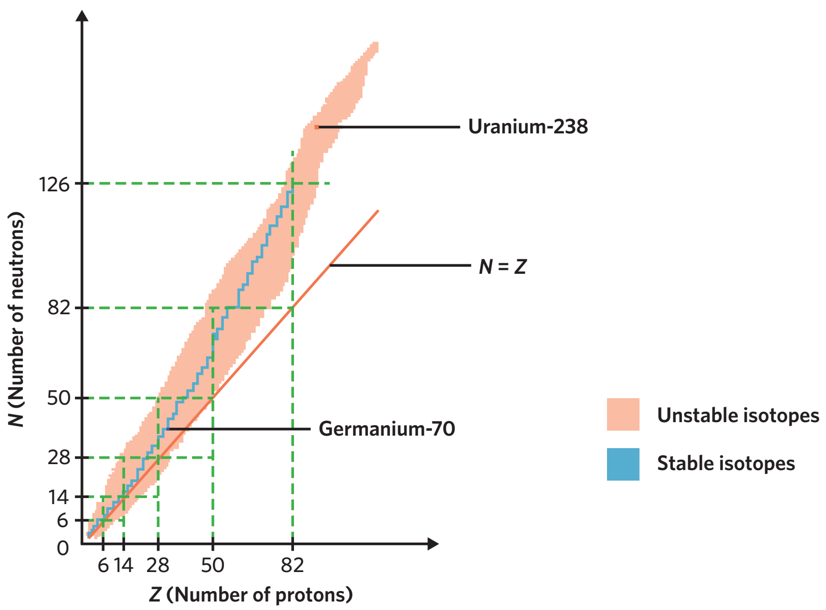

Figure 2 Stable and unstable isotopes of atomic elements

KEEN TO INVESTIGATE?

[3] **How does the number of protons and electrons impact stability?**
Search: Pauli exclusion principle hyper physics

STRATEGY

To identify whether specific isotopes are likely to be stable or unstable, it is useful to first identify how many protons they have in their nuclei. Then use the appropriate stability rules to determine stability.

STRATEGY

To locate a specific isotope in Figure 2 and diagrams like it, first identify how many protons it has and draw a vertical line from the x-axis at that number. Then identify how many neutrons it has and draw a horizontal line from the y-axis at that number, and the isotope will be located at the intersection of these two lines.

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Progress questions

Question 3

An atomic isotope is considered stable when

A. it has more than 20 protons.

B. its nucleus is unstable.

C. it will not spontaneously undergo nuclear reaction or decay.

D. it is possible for it to undergo nuclear reaction or decay.

Question 4

Adding a proton to an atomic nucleus with more than 20 protons

A. increases only the strong force.

B. increases only the electrostatic force.

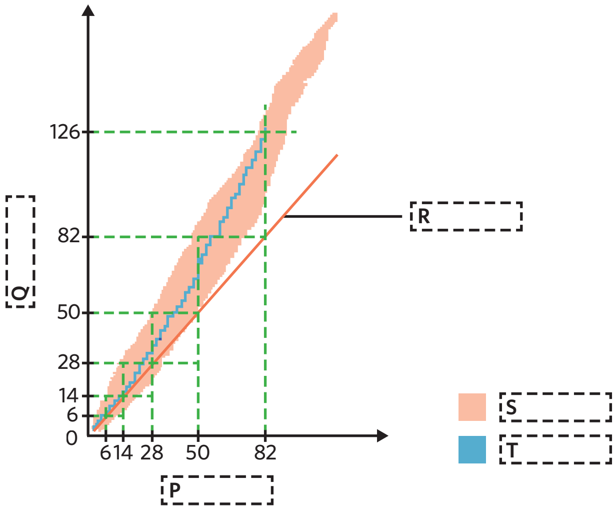
C. increases both the electrostatic and nuclear forces, but increases the electrostatic force more than the strong force.

D. has no effect on the forces in the nucleus.

Question 5

Match each label in the diagram with an option from the following list.

- stable isotopes
- unstable isotopes
- Z (number of protons)
- N (number of neutrons)
- $N = Z$ line



Theory summary

- There are four fundamental forces: the gravitational force, the electromagnetic force, the strong force, and the weak force.
  - The strong force holds together quarks within nucleons and holds together the nucleons within the nucleus.
  - The weak force acts on quarks and is responsible for beta decay.
  - The electromagnetic force acts on charged particles, it repels protons from each other.
  - The gravitational force is the weakest force and acts on particles with mass.
- Atomic nuclei are usually unstable because there is an imbalance between the attractive and repulsive forces acting within them.
- There are three main causes for nuclear instability:
  - having too many protons per neutron,
  - having too many neutrons per proton, and
  - being too large (having 84 or more protons).

KEEN TO INVESTIGATE?

Why is the weak force weak?
Search YouTube: Why is the weak force weak?

CONCEPT DISCUSSION

The strong force and the weak force are not easily observable in day to day life. Discuss the theoretical consequences of each of these forces not existing.

Prompts:

- Which particles does the strong force act on?
- What might happen with isotopes that use the weak force to decay?
- The weak force is responsible for the fusion of hydrogen into helium, which occurs in the Sun's core. What might happen if this fusion was not possible?

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4A Questions

Mild 🌶 Medium 🌶🌶 Spicy 🌶🌶🌶

Deconstructed exam-style

Use the following information to answer questions 6–8.

Carbon-12 is the most common isotope of carbon and has 6 protons and 6 neutrons. Thorium-232 is the most common isotope of thorium and has 90 protons and 142 neutrons.

Question 6 (1 MARK) 🌶

The primary requirement for stability for atoms with 20 or less protons is that

A. there needs to be more protons than neutrons.

B. there needs to be more neutrons than protons.

C. there needs to be approximately the same amount of protons and neutrons.

Question 7 (1 MARK) 🌶

The primary requirement for stability for atoms with 84 or more protons is that

A. there needs to be more neutrons than protons.

B. there needs to be approximately the same amount of protons and neutrons.

C. nonexistent, they are all inherently unstable.

Question 8 (4 MARKS) 🌶🌶

Identify whether these isotopes are likely to be stable or unstable and justify your answer.

Exam-style

Question 9 (3 MARKS) 🌶

Connect the following to their correct ending.

a.	Nuclei with 21-83 protons ●	● are inherently unstable.
b.	Nuclei with 20 or less protons ●	● require more neutrons than protons to be stable.
c.	Nuclei with 84 or more protons ●	● are usually stable if they have an equal number of protons and neutrons.

Question 10 (8 MARKS) 🌶🌶

Determine if these unknown isotopes are likely to be stable or unstable. Briefly justify your answer with reference to either stability rules or Figure 2.

a. An atom with 15 protons and 15 neutrons (2 MARKS)

b. An atom with 45 protons and 45 neutrons (2 MARKS)

c. An atom with 223 nucleons and 87 protons (2 MARKS)

d. An atom with 85 nucleons and 48 neutrons (2 MARKS)

Question 11 (2 MARKS) 🌶🌶

Explain why a nucleus with too many protons will be unstable.

Question 12 (2 MARKS) 🌶🌶

A given atomic element can have multiple isotopes, some of which may be radioisotopes that will radioactively decay. Explain the difference between the nuclear stability of a general isotope and a radioisotope.

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Question 13 (3 MARKS)

Jana and Genevieve, both keen physics students, are discussing the history of coins in their economics class. They are told that the most common isotope of gold (which has 79 protons) is an incredibly stable metal, which meant it was a good candidate for making coins.

Jana says that the nuclear stability of gold must be because the most common isotope of gold contains an equal number of protons and neutrons in the nucleus.

Genevieve counters that the number of protons and neutrons in the nucleus could not be the same if the gold isotope were stable.

Explain which student is correct and why.

Key science skills

Question 14 (4 MARKS)

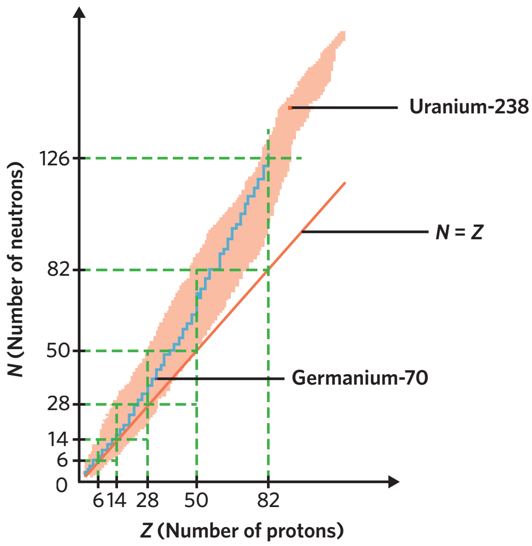
The nuclear stability diagram plots the possible isotopes of the elements by their numbers of neutrons and protons.

a. *Z* is on the horizontal axis of the graph. Identify the kind of variable (control, independent, dependent) normally on the horizontal axis. (1 MARK)

b. *N* is on the vertical axis of the graph. Identify the kind of variable (control, independent, dependent) normally on the vertical axis. (1 MARK)

c. Explain why it is most beneficial for the usability of the above diagram to have *Z* on the horizontal axis. (2 MARKS)

FROM LESSONS 11A & 11D



Previous lessons

Question 15 (4 MARKS)

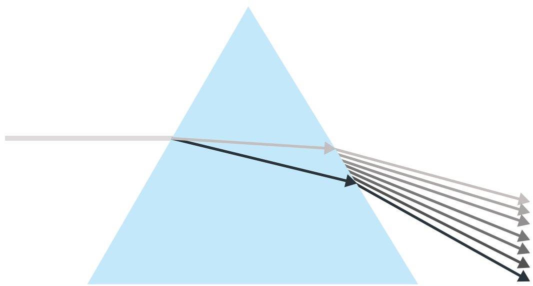
The diagram shows white light being split into its constituent colours by a prism.

a. Order the colours below as they would appear from bottom to top. Justify your answer. (2 MARKS)

green blue yellow red violet orange

b. Identify and describe the phenomenon that splits white light into its constituent colours when it travels through a prism. (2 MARKS)

FROM LESSON 1E



Question 16 (3 MARKS)

Visible light exists in a range of wavelengths from 380 nm to 720 nm.

Calculate the λ_{max} for a blackbody at 1420°C, taking Wien's constant to be $b = 2.898 \times 10^{-3}$ m K. Is this within the visible spectrum of light?

FROM LESSON 3A

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4B Nuclear half-life

Image: Xolodan/Shutterstock.com

How can we determine how old these bones are?

Every unstable isotope decays at a different rate. We can use simple mathematical models to calculate both how much of that isotope is remaining and how quickly it is decaying. This has a large range of applications, such as radiocarbon dating.

STUDY DESIGN DOT POINT

- model radioactive decay as random decay with a particular half-life, including mathematical modelling with reference to whole half-lives

4A 4B 4C 4D

1.2.2.1 Decay half-life

1.2.2.2 Modelling radioactive decay mathematically

ESSENTIAL PRIOR KNOWLEDGE

4A Nuclear stability

4A Radioisotopes

- Indices

See questions 23–25.

ACTIVITIES

Log into your Edrolo account for activities that support this lesson.

KEY TERMS AND DEFINITIONS

activity (radiation) the rate of radioactive decays per unit of time

half-life the time it takes for half of a radioactive sample to decay

FORMULAS

- **radioactive nuclei remaining**
  $N = N_0\left(\frac{1}{2}\right)^n$
- **radioactivity**
  $A = A_0\left(\frac{1}{2}\right)^n$

Decay half-life 1.2.2.1

A half-life is the time it takes for half of a substance to decay. It is used to describe the radioactive decay of unstable nuclei.

Theory and applications

Suppose we flip 100 fair coins, all with 'heads' facing up (see Table 1).

- The result of any individual coin flip is considered random with a 50% chance of being 'heads' and a 50% chance of being 'tails'.
- After flipping every coin, we can be confident that approximately 50 coins would land with 'tails' facing up.
- After flipping the remaining 'heads', we can be confident that 25 more would land with 'heads' facing up.

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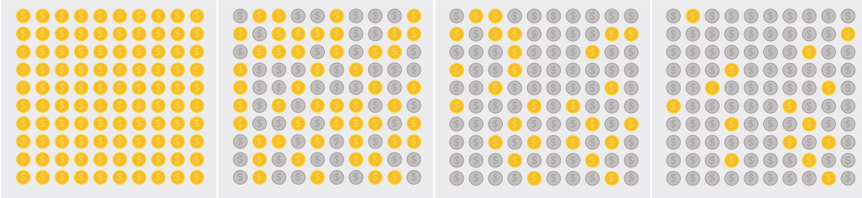
Table 1 Example of flipping 100 coins



Before first flip		After 1st flip		After 2nd flip		After 3rd flip	
Heads	Tails	Heads	Tails	Heads	Tails	Heads	Tails
100	0	50	50	26	74	13	87

What is a half-life?

In Lesson 4A, we learned that some nuclei are unstable and will decay into more stable products. The radioactive decay of unstable nuclei is similar to the coin-flip process in Table 1 because:

- The decay of any individual nucleus is a random process – it is unpredictable.
- The approximate number of nuclei that decay in a given period of time is proportional to the initial number of nuclei – it is predictable.

The half-life, $t_{1/2}$, is the time it takes for a substance to decay or decrease to half (50%) of its original amount.[1] This is shown graphically in Figure 1.

- A shorter half-life indicates the isotope decays faster and is more unstable.
- A longer half-life indicates the isotope decays slower and is less unstable.

Each radioactive substance has its own half-life. See Table 2 for examples.

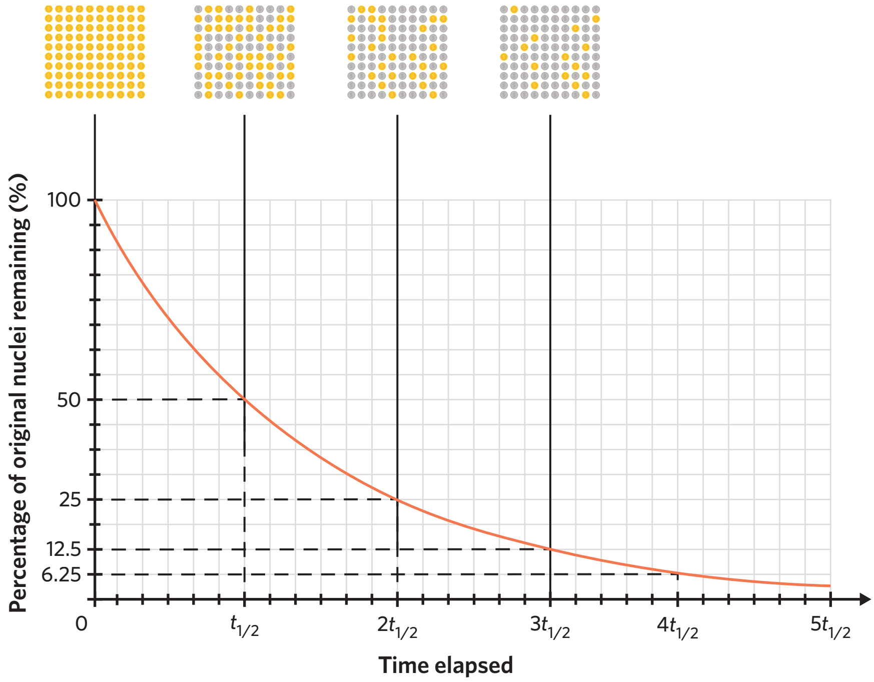


Figure 1 A graphical representation of radioactive decay

MISCONCEPTION

'When a radioisotope decays, it disappears.'

When a radioisotope decays, it loses some mass and decays into a more stable state, or in the case of a radionuclide, into a different atom. It does not disappear. This will be covered more in Lesson 4C.

KEEN TO INVESTIGATE?

[1] **How does the scale of the half-life impact the time it takes to decay?**
Search: Half-life simulation physics

Table 2 Some radioisotopes and their half-lives

Radioisotope	Half-life
Carbon-14	5730 years
Cesium-137	30 years
Iodine-131	8.0 days
Krypton-81m	13 seconds
Krypton-85	10.72 years
Plutonium-239	24 065 years
Polonium-214	0.00016 seconds
Rubidium-81	4.58 hours
Sodium-24	15 hours
Uranium-235	704 million years
Uranium-238	4.5 billion years

MISCONCEPTION

'Half-life is half the time it takes for all of a substance to decay.'

After one half-life, 50% of the initial substance remains and then, after a second half-life, 50% of that amount remains. That is, after two half-lives, 25% of the initial substance remains. See Figure 1.

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Progress questions

Use the following information to answer questions 1 and 2.

The half-life of substance X is one hour. Initially, there is 10 grams of substance X in a sample.

Question 1

How long does it take for all 10 grams of the substance to decay?

A. one hour

B. two hours

C. It might never completely decay.

Question 2

How much of substance X remains after two hours?

A. none

B. 2.5 grams

Modelling radioactive decay mathematically 1.2.2.2

The amount of a radioactive substance that remains after a given number of half-lives can be calculated using an exponential decay equation.

Theory and applications

Archaeologists use the half-life of radioactive carbon to calculate the age of archeological findings. This is called radiocarbon dating.[2]

KEEN TO INVESTIGATE?

[2] **How does radiocarbon dating work?**
Search YouTube: How does radiocarbon dating work?

How do we calculate how much of a substance remains after decay?

If N_0 is the number of nuclei in a radioactive substance at an initial time $t = 0$:

- after one half-life, the number of nuclei remaining would be $N = N_0 \times \frac{1}{2}$,
- after two half-lives, the number of nuclei remaining would be $N = \left(N_0 \times \frac{1}{2}\right) \times \frac{1}{2} = N_0 \times \left(\frac{1}{2}\right)^2$.

This process leads to the following formula for calculating the number of nuclei remaining after a whole number of half-lives.

FORMULA

$$N = N_0\left(\frac{1}{2}\right)^n$$

N = the remaining number of nuclei (no units)
N_0 = the initial number of nuclei (no units)
n = the number of half-lives since the initial measurement (no units)

Given that the mass of each atom is fixed for a given radioisotope, we can use a similar equation that relates the remaining mass (m) to the initial mass (m_0):

$$m = m_0\left(\frac{1}{2}\right)^n$$

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The number, n, of half-lives that have passed, ($t_{1/2}$), in a given time period, T, can be calculated according to the following equation:

FORMULA

$$n = \frac{T}{t_{1/2}}$$

n = the number of half-lives that have passed since the initial measurement (no units)
T = a given time period measured in a unit of time
$t_{1/2}$ = the half-life of a given isotope measured in the same unit of time

WORKED EXAMPLE 1

A sample of the artificial radioisotope sodium-24, which has a half-life of 15 hours, initially contains 16×10^{12} nuclei.

a. How many nuclei remain after 45 hours?

Step 1

Calculate how many half-lives have passed in 45 hours.

$T = 45$ hours, $t_{1/2} = 15$ hours

$n = \frac{T}{t_{1/2}} = \frac{45}{15} = 3.0$ half-lives

Step 2

Identify the initial number of nuclei, how many half-lives have passed, and the equation relating these variables.

$N_0 = 16 \times 10^{12}$, $n = 3.0$, $N = ?$

$N = N_0\left(\frac{1}{2}\right)^n$

Step 3

Substitute the initial number of nuclei into the decay equation to find the number of nuclei remaining.

$N = 16 \times 10^{12} \times \left(\frac{1}{2}\right)^{3.0}$

$N = 2.0 \times 10^{12}$ nuclei

b. How long does it take until 5.0×10^{11} nuclei remain?

Step 1

Identify the initial number of nuclei, the remaining number of nuclei, and the equation relating these variables.

$N_0 = 16 \times 10^{12}$, $N = 5.0 \times 10^{11}$, $\left(\frac{1}{2}\right)^n = ?$

$N = N_0\left(\frac{1}{2}\right)^n$

Step 2

Substitute the initial number of nuclei into the decay equation and solve for $\left(\frac{1}{2}\right)^n$.

$5.0 \times 10^{11} = 16 \times 10^{12} \times \left(\frac{1}{2}\right)^n$

$\left(\frac{1}{2}\right)^n = \frac{5.0 \times 10^{11}}{16 \times 10^{12}} = 0.03125$

Step 3

Repeatedly multiply $\frac{1}{2}$ with itself until we reach 0.03125 to determine the number of half-lives.

Alternatively use $n = \frac{\log(0.03125)}{\log(1/2)} = 5$. Logarithms are beyond the scope of VCE Physics but they can be used.

$0.03125 = \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} = \left(\frac{1}{2}\right)^5$

$\Rightarrow n = 5.0$ half-lives

Step 4

Convert the number of half-lives to the number of hours.

So it takes 5.0×15 hours $= 75$ hours.

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Progress questions

Question 3

Which of the following statements is true when describing the half-life for a given sample of a radioisotope?

A. The half-life depends on what the radioisotope is.

B. The half-life depends on how much of the substance there is.

C. The half-life changes as time passes.

Question 4

The half-life of a substance is 10 years. How many years does it take for that substance to make up one eighth $\left(\frac{1}{8}\text{th}\right)$ of its original mass?

A. 20 years

B. 30 years

C. 40 years

How do we calculate the rate a substance is decaying?

It is common to quantify the rate of radioactive decay at an instant in time by its 'activity', which measures the number of nuclei decaying per unit of time. The SI unit for activity is the becquerel (Bq), where 1 Bq = 1 nucleus decay per second. The activity is proportional to the amount of the substance remaining, which means we can use a similar formula to relate activity at any point in time to the initial activity.[3]

KEEN TO INVESTIGATE?

[3] **What is a half-life?**
Search YouTube: Radioactive decay and half-life

FORMULA

$$A = A_0\left(\frac{1}{2}\right)^n$$

A = the activity at a given time (Bq)
A_0 = the initial activity (Bq)
n = the number of half-lives since the initial measurement (no units)

WORKED EXAMPLE 2

A sample of the artificial radioisotope technetium-99, which has a half-life of 6 hours, has an initial activity of 8000 Bq. Determine the activity of the sample after one full day.

Step 1

Calculate how many half-lives elapsed in 24 hours.

$T = 24$ hours, $t_{1/2} = 6$ hours

$n = \frac{T}{t_{1/2}} = \frac{24}{6} = 4$ half-lives

Step 2

Identify the initial activity of the sample, the number of half-lives that have passed, and the equation relating these variables.

$A_0 = 8000$, $n = 4$

$A = A_0\left(\frac{1}{2}\right)^n$

Step 3

Substitute the initial activity into the activity equation to find the activity of the sample by the end of the day.

$A = 8000 \times \left(\frac{1}{2}\right)^4$

$A = 500 = 5 \times 10^2$ Bq

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Progress questions

Question 5

Sample S and sample T of the same isotope have the same half-life. Sample S is twice as heavy as sample T. Which sample has higher activity?

A. sample S

B. sample T

Question 6

A substance has an activity of 10 Bq after 2 half-lives have passed. What is the initial activity of the substance?

A. 10 Bq

B. 20 Bq

C. 40 Bq

Theory summary

- The decay of an individual unstable nucleus is a random process, which means we cannot predict when it will occur.
- A half-life is a measurement of time. It is the time it takes for half of a radioactive sample to decay and it indicates how unstable a radioisotope is.
- The value of the half-life is fixed for each radioisotope.
- Activity measures the decay rate of a radioactive substance at an instant in time. It is measured in becquerels (Bq) where 1 Bq = 1 nucleus decay per second.
- After n half-lives have passed since an initial measurement:
  - The number of nuclei remaining is given by $N = N_0\left(\frac{1}{2}\right)^n$.
  - The activity is given by $A = A_0\left(\frac{1}{2}\right)^n$.

CONCEPT DISCUSSION

Consider a bottle that contains one litre of water that is being emptied at a constant rate of 100 mL per second. Discuss why the concept of a half-life (i.e. the time it takes for the volume of water to decrease by 50%) does not apply to this situation.

Prompts:

- How long does it take for the volume of water in the bottle to decrease to half of its original volume?
- How much additional time does it take for the volume of water to decrease to half of that volume?
- How does this rate of decrease compare to the decay of radioactive substances?

4B Questions

Mild 🌶 Medium 🌶🌶 Spicy 🌶🌶🌶

Deconstructed exam-style

Use the following information to answer questions 7–10.

A medical tracer that contains 24 milligrams of phosphorus-32 is stored at a hospital. After 28 days, only 6.0 milligrams of the original phosphorus-32 remains.

Question 7 (1 MARK) 🌶

What is 6.0 milligrams as a proportion of the original 24 milligrams?

A. 0.25

B. 0.75

C. 4.0

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Question 8 (1 MARK)

How many half-lives must elapse so that only 6.0 milligrams of the original phosphorus-32 remains?

A. 2.0

B. 3.0

C. 4.0

Question 9 (1 MARK)

Based on this data, which option is closest to the half-life of phosphorus-32?

A. 7.0 days

B. 14 days

C. 28 days

Question 10 (4 MARKS)

How many days will it take in total until only 1.5 milligrams of the original phosphorus-32 remains?

Exam-style

Question 11 (3 MARKS)

A radioactive sample has an initial mass of 0.840 grams.

a. What mass of the radioactive sample remains after three half-lives? (1 MARK)

b. What mass of the radioactive sample has decayed after four half-lives? (2 MARKS)

Question 12 (5 MARKS)

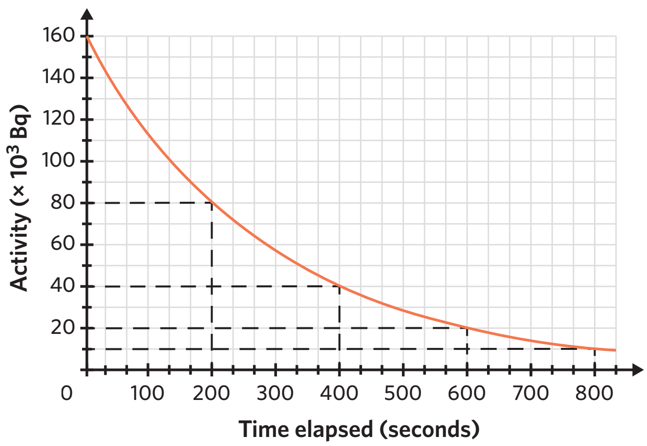
Iodine-131 has a half-life of 8.0 days. A sample of iodine-131 initially contains 5.0×10^{10} atoms.

a. Calculate the number of iodine-131 atoms that remain after 56 days. (2 MARKS)

b. Calculate how long it takes until only 6.25×10^9 iodine-131 atoms remain. Give your answer in days. (3 MARKS)

Question 13 (5 MARKS)

The graph shows the activity of an unknown radioisotope.



a. Use the graph to determine the half-life of the unknown radioisotope. (1 MARK)

b. Calculate the activity of the sample after 20 minutes. (2 MARKS)

c. If there were 40 grams of this sample to begin with, calculate the mass of the sample that remains after 400 seconds. Give your answer in grams. (2 MARKS)

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Question 14 (3 MARKS)

A sample of sodium-24, which has a half-life of 15 hours, has been left in a laboratory for 90 hours. At the present time, the activity of the sample is 5000 Bq. Calculate the activity of the sample when it was first put in the laboratory.

Question 15 (3 MARKS)

A sample of a radioisotope has decayed to a quarter of its original mass.

a. Compared to its original value, what is the fraction of the activity occurring at this point? (1 MARKS)

b. Explain how the fraction of the sample remaining relates to the activity. (2 MARKS)

Question 16 (5 MARKS)

Dr. Frankenfurter is testing the age of a mysterious human femur (thigh bone) they found digging a hole in their backyard. They found 0.15 μg of carbon-14, which has a half-life of 5730 years, in the bone. Initially, an adult human would have had 0.60 μg of carbon-14 in their femur.

a. Calculate how long it took for the carbon-14 in the femur to decay. (3 MARKS)

b. Does this time reflect the true age of the bone? Explain your answer. (2 MARKS)

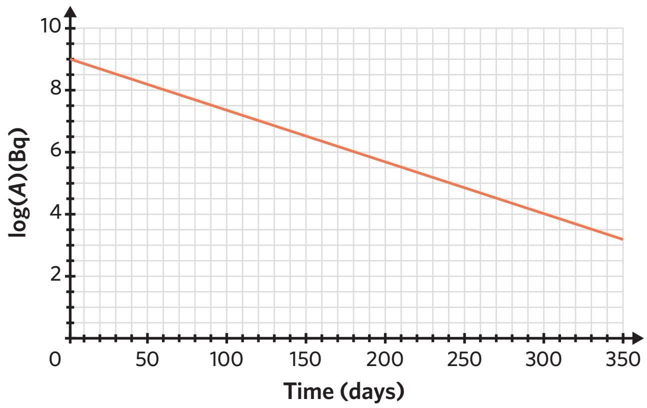
Question 17 (5 MARKS)

A 50 milligram sample of cobalt-60 decays so that only 12.5 milligrams remains after 10.6 years. How long will it take in total until only 6.25 milligrams of the original cobalt-60 remains?

Key science skills

Question 18 (5 MARKS)

Scientists use a Geiger counter to measure the activity of an unknown radioactive isotope over one year. They plot the natural logarithm of the activity $(\log(A))$ against time as shown.



a. Calculate the gradient of the graph. (2 MARKS)

b. It is known that the equation of the graph takes the form $\log(A) = -\frac{0.693}{t_{1/2}} \times t + 9$. Given that the equation of a straight line can be expressed in the form $y = mx + c$ where m is the gradient of the line, use the gradient calculated in part a to determine the half-life, $t_{1/2}$, of the substance to the nearest day. (3 MARKS)

FROM LESSONS 11D & 11E

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Previous lessons

Question 19 (3 MARKS)

Explain the similarities and differences between heat and temperature.

FROM LESSON 2A

Question 20 (3 MARKS)

Kyle claims that there is no scientific reason that the current shifts in the climate are caused by human activity as the climate has always gone through changes. Raveena disagrees, claiming that human activity is responsible for climate change including global warming. Evaluate if Raveena or Kyle's claims are correct and determine who is more correct. Explain your answer.

FROM LESSON 3B

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4C Types of nuclear radiation

STUDY DESIGN DOT POINTS

- describe the properties of α, β−, β+ and γ radiation
- explain nuclear transformations using decay equations involving α, β−, β+ and γ radiation
- analyse decay series diagrams with reference to type of decay and stability of isotopes

4A 4B 4C 4D

- 1.2.4.1 Nuclear decay equations
- 1.2.3.1 & 1.2.4.2 Alpha radiation
- 1.2.3.2 & 1.2.4.3 Beta radiation
- 1.2.3.3 & 1.2.4.4 Gamma radiation
- 1.2.5.1 Decay series diagrams

ESSENTIAL PRIOR KNOWLEDGE

4A Nuclear stability

4A Charges of protons and neutrons

See questions 26–27.

ACTIVITIES

Log into your Edrolo account for activities that support this lesson.

Image: luchschenF/Shutterstock.com

Why can radioactive uranium be kept in a plastic container?

The radioactive decay of unstable nuclei can be described through various nuclear decay equations. This lesson introduces the three main forms of radioactive decay (alpha radiation, beta radiation, and gamma radiation) and their properties, along with decay series diagrams.

KEY TERMS AND DEFINITIONS

alpha decay the process by which an unstable nucleus decays into a more stable nucleus by emitting an alpha particle

alpha particle a particle composed of two protons and two neutrons (the nucleus of a standard helium atom)

beta minus decay the process by which an unstable nucleus decays into a more stable nucleus by transforming a neutron into a proton and emitting an electron and an antineutrino

beta particle an electron (beta minus decay) or a positron (beta plus decay)

beta plus decay the process by which an unstable nucleus decays into a more stable nucleus by transforming a proton into a neutron and emitting a positron and a neutrino

daughter nuclide the nucleus remaining after radioactive decay occurs

gamma decay the process by which an excited nucleus decays into a more stable nucleus by emitting energy in the form of gamma rays

gamma rays high-energy photons

ionisation energy the energy required to remove an electron from an atom

ionising power the ability of a given type of radiation to cause another atom to lose electrons and become an ion

nuclide a nucleus with a specific number of neutrons and protons

parent nuclide the original nucleus before radioactive decay occurs

penetrating power an indicator of the extent to which a given type of radiation can penetrate matter before it loses its energy

radiation the transmission of energy in the form of electromagnetic waves or high-speed particles

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Nuclear decay equations 1.2.4.1

Chemical equations are a symbolic representation of a reaction that has taken place, showing both the products and reactants of the reaction.

Theory and applications

Nuclear decay can be represented through chemical equations, showing the change of a parent nuclide to a daughter nuclide, as it emits radiation.

How can equations be used to represent nuclear decay?

Atoms can be represented through nuclear notation, as in Figure 1. In this notation, the identity of an element is indicated by its chemical symbol as found on the periodic table of elements. For example, Au is the chemical symbol for gold.

- Z represents the number of protons in the nucleus. A represents the total number of protons and neutrons in the nucleus.
- N represents the number of neutrons in the nucleus. N is not shown in the standard nuclear notation, but can be calculated as $N = A - Z$.

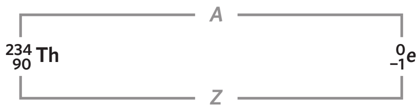

Figure 1 Nuclear notation of thorium-234 and an electron

Nuclear decay equations represent nuclear decay processes, of a general form shown in Figure 2. The parent nuclide, on the left-hand side of the equation decays into a daughter nuclide and other products on the right-hand side. In a nuclear decay process, the mass number and total charge are conserved.

Parent nuclide ⟶ Daughter nuclide + Other products

Figure 2 The general form of a nuclear decay equation

For ease of calculations, both charge and mass are standardised as unitless values, shown in Table 1.

Table 1 Standardised mass and charge of subatomic particles

Subatomic particle	Mass	Charge
Proton	1	+1
Neutron	1	0
Electron	0	−1
Positron	0	+1

USEFUL TIP

In all uncharged atoms, the number of protons is equal to the number of electrons.

Progress questions

Question 1

Identify what is the parent nuclide in the following alpha decay equation: $^{239}_{94}\text{Pu} \rightarrow {}^{235}_{92}\text{U} + {}^{4}_{2}\text{He}$.

A. $^{239}_{94}\text{Pu}$

B. $^{235}_{92}\text{U}$

C. $^{4}_{2}\text{He}$

Question 2

How many neutrons does $^{212}_{83}\text{Bi}$ contain?

A. 83

B. 129

C. 212

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Alpha radiation 1.2.3.1 & 1.2.4.2

When an atom with a heavy nuclide contains too many protons, it may undergo nuclear decay in the form of alpha radiation. This decay converts a parent nuclide into a daughter nuclide and an alpha particle, equivalent to a helium nucleus.

Theory and applications

Elements that undergo nuclear decay through alpha radiation can be used as a source of alpha particles. Alpha particles' ability to ionise air molecules and relatively low penetrating ability makes them useful in applications such as ionisation smoke alarms.

What are the properties of alpha radiation?

When considering the potential applications and dangers of different forms of radiation, a number of properties are considered:

- Alpha particles are relatively heavy, with an atomic mass of 4,
- travel around 5 to 7% of the speed of light,
- have a charge of +2, and
- are unable to penetrate a piece of paper.

The ionising power of alpha particles, due to their +2 charge, is utilised in the design of ionisation smoke detectors, as in Figure 3. As alpha particles collide with molecules in the air they remove electrons. These negatively charged electrons and positively charged air molecule ions create an electrical current in the detector. When smoke enters the detector, the collisions with air molecules are reduced, causing a reduction in current that triggers the alarm to beep.

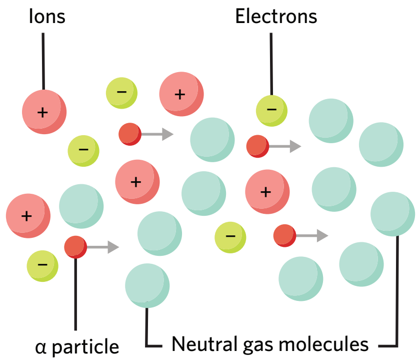
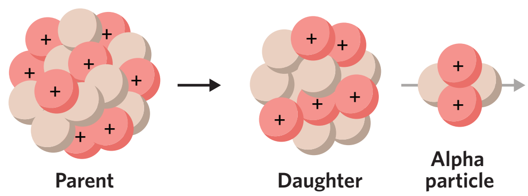


Figure 3 The ionisation of gas molecules by alpha particles

How can a decay equation be used to represent alpha decay?



$${}^{A}_{Z}X \longrightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He$$

Figure 4 Alpha decay

The daughter nuclide has:

- The daughter nuclide has an atomic number of two less than the parent nuclide, and
- an atomic mass of four less than the parent nuclide.
- Energy is released in the form of kinetic energy given to the products. (see Figure 4).

An example of the radioactive decay of uranium, which undergoes alpha decay, is:[1]

$${}^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}He$$

KEEN TO INVESTIGATE?

[1] **How does the number of nuclei impact the alpha decay rate?**
Search: Alpha decay simulation

STRATEGY

Always ensure the total atomic masses and total atomic numbers and charges are balanced on both sides when writing chemical equations.

Progress questions

Question 3

Identify which of the following is the daughter nuclide produced when ${}^{215}_{85}At$ undergoes alpha decay.

A. ${}^{211}_{83}At$

B. ${}^{211}_{83}Bi$

C. ${}^{213}_{83}Bi$

Continues →

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Question 4

A daughter nuclide $^{228}_{90}Th$ is produced through alpha decay. Identify which of the following was the parent nuclide.

A. $^{232}_{92}Th$

B. $^{228}_{92}U$

C. $^{232}_{92}U$

Beta radiation 1.2.3.2 & 1.2.4.3

When an atom contains too many protons or neutrons in its nucleus, it may undergo nuclear decay in the form of beta radiation. This occurs in order to move the atom closer to an optimal ratio of protons and neutrons.

Theory and applications

There are two types of beta decay: beta minus and beta plus decay. Beta minus decay converts a neutron in the parent nucleus into a proton in the daughter nucleus, whereas beta plus decay converts a proton in the parent nucleus into a neutron in the daughter nucleus.[2] These changes are caused by the weak nuclear force.

KEEN TO INVESTIGATE?

[2] **How does the number of nuclei impact the beta decay rate?**
Search: Beta decay simulation

What are the properties of beta radiation?

In beta decay, either an electron (in beta minus decay) or positron (beta plus decay) is emitted. Electrons and positrons are an example of antiparticles, particles which share the same properties, except have an opposite charge to one another. An electron has a charge of −1, whilst a positron has a charge of +1.

- Beta particles are relatively light, with a mass of 9.1×10^{-31} kg,
- can travel at speeds up to around 90% of the speed of light,
- have an ionising ability less than that of alpha particles, and
- have a greater penetrating power (due to their lower mass and greater speed).

In beta radiation, either an antineutrino ($\bar{v}$, emitted in beta minus decay) or neutrino (v, emitted in beta plus decay) is emitted too. Due to their relatively tiny mass and lack of electric charge, they can pass through matter largely without interaction.

How can a decay equation be used to represent beta decay?

Beta minus decay equation

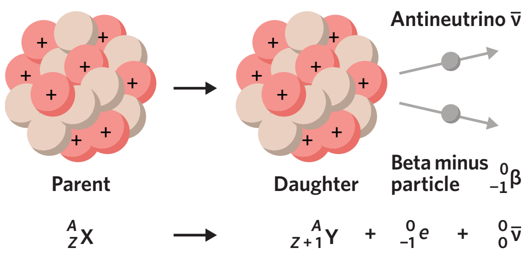

Figure 5 Beta minus decay

- The daughter nuclide has an atomic number of one more than the parent nuclide, and
- the same atomic mass as the parent nuclide.
- Energy is released in the form of kinetic energy given to the products (see Figure 5).

An example of a beta minus decay process is:

$$^{234}_{90}Th \rightarrow {}^{234}_{91}Pa + {}^{0}_{-1}e + {}^{0}_{0}\bar{v}$$

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4C THEORY

USEFUL TIP

Beta minus decay refers to the emission of a negatively charged particle – an electron. Beta plus decay refers to the emission of a positively charged particle – a positron.

Beta plus decay equation

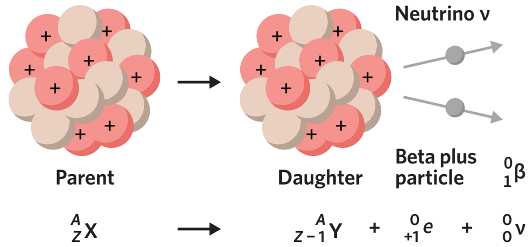

Figure 6 Beta plus decay

- The daughter nuclide has an atomic number of one less than the parent nuclide, and
- the same atomic mass as the parent nuclide.
- Energy is released in the form of kinetic energy given to the products (see Figure 6).

An example of a beta plus decay process is:

$$^{22}_{11}\text{Na} \rightarrow {}^{22}_{10}\text{Ne} + {}^{0}_{+1}e + {}^{0}_{0}\nu$$

WORKED EXAMPLE 1

$^{228}_{88}$Ra undergoes beta minus decay. What is the element of the daughter nuclide?

Step 1

Identify the general formula for beta minus decay.

$^{A}_{Z}\text{X} \rightarrow {}_{Z+1}^{A}\text{Y} + {}_{-1}^{0}e + {}^{0}_{0}\bar{\nu}$

Step 2

Substitute value for Z in formula to identify the number of protons of daughter nuclide.

$Z + 1 = 88 + 1 = 89$

Daughter has 89 protons.

Step 3

Find the element with atomic number 89 on the periodic table.

Daughter element is actinium.

Progress questions

Question 5

Identify which of the following is the daughter nuclide in the beta plus decay of $^{15}_{8}$O.

A. $^{14}_{7}$O

B. $^{15}_{7}$O

C. $^{15}_{7}$N

Question 6

Identify which of the following is the daughter nuclide in the beta minus decay of $^{3}_{1}$H.

A. $^{3}_{2}$H

B. $^{3}_{2}$He

C. $^{4}_{2}$He

Question 7

Which of the following decays emits negatively charged particles?

A. $^{238}_{92}\text{U} \rightarrow {}^{234}_{90}\text{Th} + {}^{4}_{2}\text{He}$

B. $^{234}_{90}\text{Th} \rightarrow {}^{234}_{91}\text{Pa} + {}_{-1}^{0}e + {}^{0}_{0}\bar{\nu}$

C. $^{22}_{11}\text{Na} \rightarrow {}^{22}_{10}\text{Ne} + {}_{+1}^{0}e + {}^{0}_{0}\nu$

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Gamma radiation 1.2.3.3 & 1.2.4.4

When a nucleus is in an excited state, it may undergo nuclear decay by emitting energy in the form of a gamma ray. Unlike other forms of radioactive decay, there is no change to the mass or charge from the parent nuclide to daughter nuclide.

Theory and applications

Gamma rays are high energy photons, and are most commonly emitted following a previous decay where the nuclide is left in an excited state. The high energy of gamma rays can be utilised in sterilisation processes, because of its ability to kill bacteria, as well as for medical purposes explored in Lesson 4D.

What are the properties of gamma radiation?

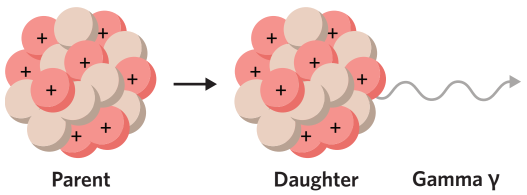
As gamma rays are a packet of excess energy, they have no mass or charge, and travel at the speed of light. This allows gamma rays to have a high penetrating power, and require dense material to be blocked.

MISCONCEPTION

'All forms of radiation are able to penetrate human skin and cause harm.'

Alpha particles are not able to penetrate skin, whereas most beta particles will be absorbed by the skin itself. Gamma radiation is able to pass through the entire body.

How can a decay equation be used to represent gamma decay?



$$^{A}_{Z}X \longrightarrow {}^{A}_{Z}X + {}^{0}_{0}\gamma$$

Figure 7 Gamma decay

- The daughter nuclide has the same atomic number as the parent nuclide, and
- the same atomic mass as the parent nuclide.
- Energy is released in the form of a gamma ray (see Figure 7).

An example of a gamma decay process is:

$$^{60}_{28}\text{Ni} \rightarrow {}^{60}_{28}\text{Ni} + {}^{0}_{0}\gamma$$

Progress questions

Question 8

How are the daughter nuclide and the parent nuclide different after gamma decay?

A. They are identical.

B. They have the same atomic number and mass, but the daughter nuclide contains less energy.

C. The daughter nuclide has a smaller mass than the parent nuclide.

Question 9

Identify which property of gamma rays means a denser material is required to stop them compared to alpha and beta radiation.

A. high penetrating power

B. high ionising power

C. no mass

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Decay series diagrams 1.2.5.1

As the daughter nuclide from a radioactive decay process is often radioactive itself, it will undergo further radioactive decay until a stable nuclide is produced. This sequence of radioactive isotopes is referred to as a decay series.

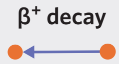
Theory and applications

A decay series diagram plots the nuclides formed in the successive decays of an unstable parent nuclide until the daughter nuclide is stable. This gives a visual of all the radioactive decays that have taken place. It can be used to predict the future decays of radioactive isotopes, as each atom has a unique decay series.

How can decay series diagrams be used to represent radioactive decay?

The process of repeated radioactive decay can be represented as a decay series diagram. We will primarily consider decay series diagrams that plot mass number against the number of protons, as in Figure 8, which shows the decay series of uranium-238. However, plotting the number of neutrons against the number of protons is also common.

Table 2 Decay series diagram representations

Type of decay	Proton change	Mass change	Decay series representation
Alpha decay	−2	−4	
Beta minus decay	+1	0	
Beta plus decay	−1	0	

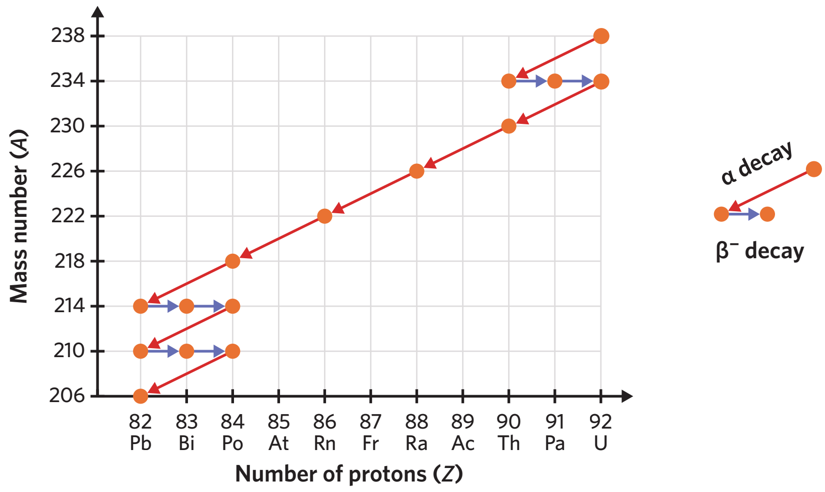


Figure 8 The decay series of uranium-238. The final daughter nuclide in the series is lead-206.

Geologists can use a technique called rock dating to estimate the age of rocks. This is done through analysing the proportion of a particular radioisotope present in a sample. They then refer to decay series diagrams and the half-lives of each radioisotope.

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Progress questions

Question 10

Which of the following describes why gamma decay is not represented on a decay series diagram?

A. As gamma decay only occurs at the end of the decay series.

B. As there is no change from parent to daughter nuclide with respect to mass or proton number.

Question 11

Using the decay series in Figure 8, determine whether the daughter nucleus is ever an astatine (At) nuclide.

A. No, there is no daughter nuclide in the series with 85 protons.

B. Yes, astatine is between lead and uranium so must be produced.

Theory summary

Three main forms of radioactive decay (alpha, beta and gamma) are explored, whose nuclear decay equations and properties are represented in Tables 3 and 4.

Table 3 Summary of different types of decay

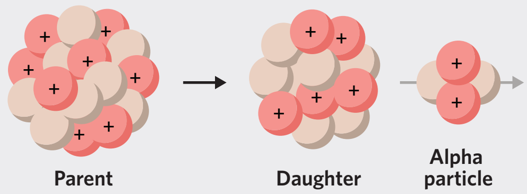
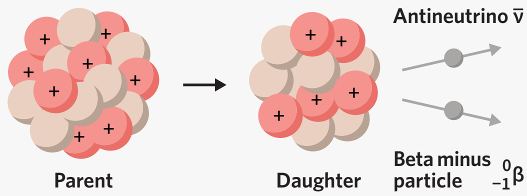
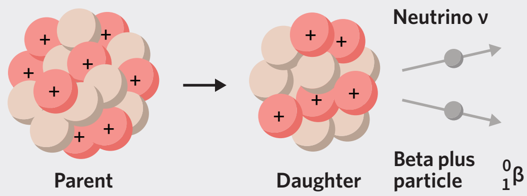
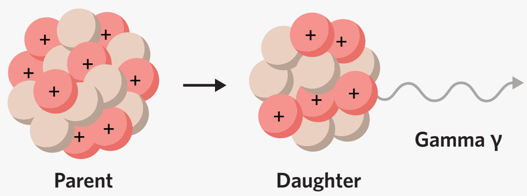
Decay Type	Radiation Emitted	Generic Equation	Model
Alpha decay	${}^{4}_{2}\alpha$	${}^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He$	
Beta− decay	${}^{0}_{-1}\beta$	${}^{A}_{Z}X \rightarrow {}_{Z+1}^{A}Y + {}^{0}_{-1}e + {}^{0}_{0}\bar{\nu}$	
Beta+ decay	${}^{0}_{+1}\beta$	${}^{A}_{Z}X \rightarrow {}_{Z-1}^{A}Y + {}^{0}_{+1}e + {}^{0}_{0}\nu$	
Gamma emission	${}^{0}_{0}\gamma$	${}^{A}_{Z}X \rightarrow {}^{A}_{Z}X + {}^{0}_{0}\gamma$	

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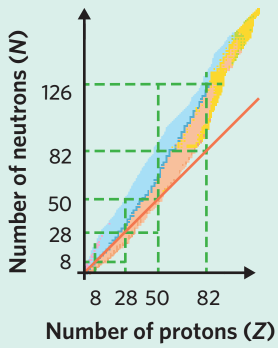
Table 4 Summary of primary radioactive decay products

	When emission occurs	Charge	Penetrating power	Ionising power	Speed (c)	Mass
Alpha particle	Heavy nuclides with too many protons	+2	Least	Greatest	~0.05–0.07	Heavy
Beta plus particle	Nuclides with too many neutrons	+1	Medium	Medium	~0.9	Light
Beta minus particle	Nuclides with too many protons	−1	Medium	Medium	~0.9	Light
Gamma ray	Excited nuclides	0	Greatest	Least	1	–

CONCEPT DISCUSSION



A valley of stability diagram shows a number of radioactive isotopes on a proton vs. neutron graph, along with a line with a 1:1 ratio of the two. It can be used to indicate the kind of decay that each radioactive nuclide undergoes. In the diagram shown here, each colour represents a different kind of decay.

Discuss which colour (out of blue, yellow and orange) represents which kind of decay (alpha, beta plus or beta minus) and why.

Prompts:

- Are the nuclides on the valley of stability line stable or unstable?
- Does beta plus decay or beta minus decay increase the number of protons in a nuclide?
- What kind of nuclides undergo alpha decay?

4C Questions

Mild Medium Spicy

Deconstructed exam-style

Use the following information to answer questions 12–15.

Thorium-232 is the most stable isotope of thorium, having a half-life of over 14 billion years. However, thorium-232 undergoes a series of radioactive decay reactions to eventually decay to a stable daughter nuclide. In its decay series, thorium-232 $\left({}^{232}_{90}\text{Th}\right)$ undergoes six alpha decays and four beta minus decays.

Question 12 (1 MARK)

Identify the atomic number, neutron number, and mass number of ${}^{232}_{90}\text{Th}$.

	Atomic number	Neutron number	Mass number
A.	90	232	142
B.	90	142	232
C.	232	90	142
D.	142	90	232

Question 13 (1 MARK)

Identify how the proton number changes between the parent nuclide and daughter nuclide under the different radioactive decay processes.

	Alpha decay	Beta plus decay	Beta minus decay
A.	−2	+1	−1
B.	−4	−1	−1
C.	−2	−1	+1
D.	−4	+1	+1

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Question 14 (1 MARK)

Identify how mass number changes between the parent nuclide and daughter nuclide under the different radioactive decay processes.

	Alpha decay	Beta plus decay	Beta minus decay
A.	−2	+1	−1
B.	−2	0	−1
C.	−4	0	0
D.	−4	+1	0

Question 15 (3 MARKS)

Identify the resulting daughter nuclide, using the data in the following table:

Element	Mercury (Hg)	Thallium (Tl)	Lead (Pb)	Bismuth (Bi)	Polonium (Po)
Atomic number	80	81	82	83	84

Exam-style

Question 16 (4 MARKS)

Finish the following decay equations by adding the appropriate particles (note that there can be more than one particle).

a. $^{14}_{6}C \rightarrow {}^{14}_{7}N +$ ________ (1 MARK)

b. $^{149}_{64}Gd \rightarrow {}^{145}_{62}Sm +$ ________ (1 MARK)

c. $^{137}_{56}Ba \rightarrow {}^{137}_{56}Ba +$ ________ (1 MARK)

d. $^{10}_{6}C \rightarrow {}^{10}_{5}B +$ ________ (1 MARK)

Use the following information to answer questions 17–19.

Periodic table of the elements

1 H 1.0 hydrogen																	2 He 4.0 helium
3 Li 6.9 lithium	4 Be 9.0 beryllium											5 B 10.8 boron	6 C 12.0 carbon	7 N 14.0 nitrogen	8 O 16.0 oxygen	9 F 19.0 fluorine	10 Ne 20.2 neon
11 Na 23.0 sodium	12 Mg 24.3 magnesium											13 Al 27.0 aluminium	14 Si 28.1 silicon	15 P 31.0 phosphorus	16 S 32.1 sulfur	17 Cl 35.5 chlorine	18 Ar 39.9 argon
19 K 39.1 potassium	20 Ca 40.1 calcium	21 Sc 45.0 scandium	22 Ti 47.9 titanium	23 V 50.9 vanadium	24 Cr 52.0 chromium	25 Mn 54.9 manganese	26 Fe 55.8 iron	27 Co 58.9 cobalt	28 Ni 58.7 nickel	29 Cu 63.5 copper	30 Zn 65.4 zinc	31 Ga 69.7 gallium	32 Ge 72.6 germanium	33 As 74.9 arsenic	34 Se 79.0 selenium	35 Br 79.9 bromine	36 Kr 83.8 krypton
37 Rb 85.5 rubidium	38 Sr 87.6 strontium	39 Y 88.9 yttrium	40 Zr 91.2 zirconium	41 Nb 92.9 niobium	42 Mo 96.0 molybdenum	43 Tc (98) technetium	44 Ru 101.1 ruthenium	45 Rh 102.9 rhodium	46 Pd 106.4 palladium	47 Ag 107.9 silver	48 Cd 112.4 cadmium	49 In 114.8 indium	50 Sn 118.7 tin	51 Sb 121.8 antimony	52 Te 127.6 tellurium	53 I 126.9 iodine	54 Xe 131.3 xenon
55 Cs 132.9 caesium	56 Ba 137.3 barium	57–71	72 Hf 178.5 hafnium	73 Ta 180.9 tantalum	74 W 183.8 tungsten	75 Re 186.2 rhenium	76 Os 190.2 osmium	77 Ir 192.2 iridium	78 Pt 195.1 platinum	79 Au 197.0 gold	80 Hg 200.6 mercury	81 Tl 204.4 thallium	82 Pb 207.2 lead	83 Bi 209.0 bismuth	84 Po (210) polonium	85 At (210) astatine	86 Rn (222) radon
87 Fr (223) francium	88 Ra (226) radium	89–103	104 Rf (261) rutherfordium	105 Db (262) dubnium	106 Sg (266) seaborgium	107 Bh (264) bohrium	108 Hs (267) hassium	109 Mt (268) meitnerium	110 Ds (271) darmstad	111 Rg (272) roentgenium	112 Cn (285) copernicium	113 Nh (280) nihonium	114 Fl (289) flerovium	115 Mc (289) moscovium	116 Lv (292) livermorium	117 Ts (294) tennessine	118 Og (294) oganesson

Lanthanoids	57 La 138.9 lanthanum	58 Ce 140.1 cerium	59 Pr 140.9 praseodymium	60 Nd 144.2 neodymium	61 Pm (145) promethi	62 Sm 150.4 samarium	63 Eu 152.0 europium	64 Gd 157.3 gadolinium	65 Tb 158.9 terbium	66 Dy 162.5 dysprosium	67 Ho 164.9 holmium	68 Er 167.3 erbium	69 Tm 168.9 thulium	70 Yb 173.1 ytterbium	71 Lu 175.0 lutetium
Actinoids	89 Ac (227) actinium	90 Th 232.0 thorium	91 Pa 231.0 protactinium	92 U 238.0 uranium	93 Np (237) neptunium	94 Pu (244) plutonium	95 Am (243) americium	96 Cm (247) curium	97 Bk (247) berkelium	98 Cf (251) californium	99 Es (252) einsteinium	100 Fm (257) fermium	101 Md (258) mendelevium	102 No (259) nobelium	103 Lr (262) lawrencium

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Question 17 (8 MARKS)

Fill in the blanks in the following decay equations with the appropriate daughter nuclide.

a. ${}^{175}_{78}\text{Pt} \rightarrow$ __________ $+ {}^{4}_{2}\text{He}$ (2 MARKS)

b. ${}^{228}_{88}\text{Ra} \rightarrow$ __________ $+ {}^{0}_{-1}e + {}^{0}_{0}\overline{\nu}$ (2 MARKS)

c. ${}^{23}_{12}\text{Mg} \rightarrow$ __________ ${}^{0}_{+1}e + {}^{0}_{0}\nu$ (2 MARKS)

d. ${}^{125}_{53}\text{I} \rightarrow$ __________ $+ {}^{0}_{0}\gamma$ (2 MARKS)

Question 18 (8 MARKS)

Fill in the blanks in the following decay equations with the appropriate parent nuclide.

a. __________ $\rightarrow {}^{22}_{10}\text{Ne} + {}^{0}_{0}\gamma$ (2 MARKS)

b. __________ $\rightarrow {}^{60}_{28}\text{Ni} + {}^{0}_{-1}e + {}^{0}_{0}\overline{\nu}$ (2 MARKS)

c. __________ $\rightarrow {}^{233}_{91}\text{Pa} + {}^{4}_{2}\text{He}$ (2 MARKS)

d. __________ $\rightarrow {}^{74}_{35}\text{Br} + {}^{0}_{+1}e + {}^{0}_{0}\nu$ (2 MARKS)

Question 19 (8 MARKS)

a. Write the equation for the alpha decay of ${}^{215}_{85}\text{At}$. (2 MARKS)

b. Write the equation for the beta plus decay of ${}^{64}_{29}\text{Cu}$. (2 MARKS)

c. Write the equation for the beta minus decay of ${}^{223}_{87}\text{Fr}$. (2 MARKS)

d. Write the equation for the gamma decay of ${}^{72}_{34}\text{Se}$. (2 MARKS)

Question 20 (8 MARKS)

Neptunium-237 $({}^{237}_{93}\text{Np})$ undergoes the following radioactive decays in sequence:

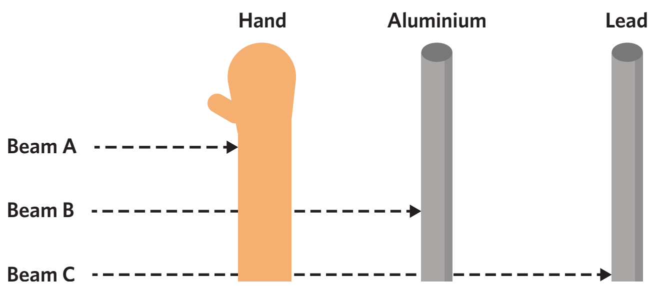
- 1 alpha decay
- 1 beta minus decay
- 2 alpha decays
- 1 beta minus decay
- 4 alpha decays
- 2 beta minus decays
- 1 alpha decay

a. Identify the stable nuclide product of this decay series. (3 MARKS)

b. Sketch the decay series diagram for neptunium-237. Plot the number of protons on the horizontal axis and the mass number on the vertical axis. (5 MARKS)

Question 21 (3 MARKS)

Identify the kind of radiation labelled Beam A, Beam B and Beam C, respectively.



Question 22 (3 MARKS)

Describe how alpha decay, beta minus decay, and beta plus decay would be represented on a decay series diagram that plotted the number of neutrons (vertical axis) against the number of protons (horizontal axis).

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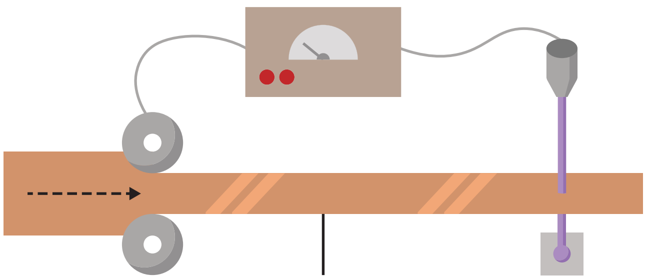
Question 23 (3 MARKS)

Ruby and Tom are discussing the design of an ionisation smoke detector. They are told the detector contains a small amount of radioisotope americium-241, a source of alpha particles. Ruby says that plastic can be used to contain the alpha particles in the detector. Tom counters that a more dense material, like lead, is necessary.

Discuss who is correct.

Question 24 (2 MARKS)

A plate roller is used to produce sheet metal of a desired thickness. By placing a source of beta particles below the sheet of metal, a detector can measure the number passing through. Explain how this design can be used to detect and adjust when the sheet metal being made is too thick.



Key science skills

Question 25 (3 MARKS)

The mass of an alpha particle is approximately 6.64466×10^{-27} kg. The kinetic energy of an alpha particle ejected during alpha decay is 5.00 MeV. Note that 1 eV= 1.602×10^{-19} J.

a. State the number of significant figures given in this mass value. (1 MARK)

b. Calculate the kinetic energy of the alpha particle in joules. (2 MARKS)

FROM LESSON 11B

Previous lessons

Question 26 (1 MARKS)

A change in temperature, ΔT, of 200°C is equivalent to:

A. (200 − 273.15) K

B. (200 + 273.15) K

C. 200 K

FROM LESSON 2A

Question 27 (2 MARKS)

Define the term isotope and distinguish between an isotope and a radioisotope.

FROM LESSON 4A

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4D Radiation and the human body

STUDY DESIGN DOT POINTS

- explain the effects of α, β and γ radiation on humans, including:
  - different capacities to cause cell damage
  - short- and long-term effects of low and high doses
  - ionising impacts of radioactive sources outside and inside the body
  - calculations of absorbed dose (gray), equivalent dose (sievert) and effective dose (sievert)
- evaluate the use of medical radioisotopes in therapy including the effects on healthy and damaged tissues and cells

4A 4B 4C **4D**

- **1.2.6.1** Ionisation impact and damage
- **1.2.6.2** Dose calculations and effects
- **1.2.7.1** Medical therapies

ESSENTIAL PRIOR KNOWLEDGE

4C Radiation penetrating power
4C Radiation ionising power
See questions 28-29.

ACTIVITIES

Log into your Edrolo account for activities that support this lesson.

Image: John Panella/Shutterstock.com

How can radiation be used to kill cancer cells?

The ionising properties of alpha, beta, and gamma radiation can have a wide range of effects on the human body. A radioisotope is capable of causing cell damage and cancer, but also diagnosing and treating it. Which effect it has depends on the length of time the body is exposed, the amount of radiation absorbed, and the source of the radiation.

KEY TERMS AND DEFINITIONS

absorbed dose radiation energy absorbed per kilogram of tissue
cancer harmful tumour caused by uncontrolled cell division
cell microscopic structure that makes up tissues
effective dose a measure of the biological impact of radiation
equivalent dose a measure of the organ-specific impact of radiation
ionising impact ability of ionisation to cause damage
medical radioisotope radioisotope used in diagnosis or treatment of illness
radiation weighting factor relative biological effect of radiation type
tissue group of specialised cells
tissue weighting factor relative danger of radiation absorption in a particular tissue

FORMULAS

- **absorbed dose**
  $D = \frac{E_r}{m}$
- **effective dose**
  $E = \sum(H \times w_t)$
- **equivalent dose**
  $H = D \times w_r$

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Ionisation impact and damage 1.2.6.1

The danger of radiation is its ability to cause cell damage through ionisation, and depends on how the radiation is absorbed by the person.

Theory and applications

In Lesson 4C we saw that different types of radiation have different ionising abilities (ability to remove electrons from atoms). Whether a radioactive source is outside or inside the human body helps to determine its potential damage. Ionisation of cells from outside the body requires penetration through the skin (see Figure 1), whereas ionisation of cells from within the body, due to an internal radiation source does not.

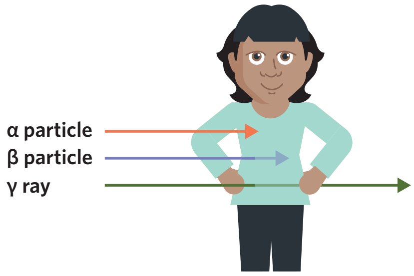

Figure 1 Penetration of radioactive sources from outside the body

How does the type and position of a radioactive source affect its potential to harm humans?

Table 1 Ability of radiation types to penetrate skin and ionising impact

Radiation	Penetrating power	Ability to penetrate skin	Ionising impact (radioactive source outside the human body)	Ionising impact (radioactive source inside the human body)
Alpha	Low	None	Low	High
Beta	Medium	Low	Medium	High
Gamma	High	High	High	Low

The ionising impacts of radioactive sources varies depending on how the radiation is absorbed, as summarised in Table 1. Alpha radiation, with a low penetrating power, only has an impact when absorbed from within the body. Beta radiation is able to ionise surface tissues, such as the skin and eye, when absorbed from outside the body. Gamma radiation is able to pass through skin undeflected, but is not as dangerous as other forms of energy when absorbed from within the body as it passes largely undeflected.

Radiation has the ability to either damage or kill human cells, through causing a change to the DNA structure in a molecule, which contains the information for a cell to perform its role in the body. The relative impacted areas from the radiation source and potential effect on cells are summarised in Table 2.[1]

Table 2 The ability of different radiation forms to damage cells

Radiation	Size of the area affected	Energy absorbed by cells	Relative damage	Potential effect
Alpha	Small number of cells	High	High	Cell death
Beta	More widely spaced	Medium	Medium	Severe cell damage or death
Gamma	Whole body	Medium	Low	Limited cell damage

MISCONCEPTION

'The only way to absorb radiation from inside the body is through eating a radioactive source.'

Radioactive sources can enter the body by a number of methods, including breathing or through open wounds.

KEEN TO INVESTIGATE?

[1] **How does radiation cause cell damage?**
Search: How does radiation affect humans (bioethics)?

Progress questions

Question 1

Which of the following radioactive sources has the most potential to cause harm, if outside the body?

A. alpha

B. beta

C. gamma

Continues →

4D THEORY

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Question 2

Which of the following radioactive sources has the most potential to cause harm, if inside the body?

A. alpha

B. beta

C. gamma

Question 3

What property of beta particles results in a greater affected area of cells when absorbed compared to alpha particles?

A. higher ionisation power

B. higher penetrating power

C. higher radiation weighting factor

Dose calculations and effects 1.2.6.2

Rather than trying to measure the potential danger of radiation travelling through the air, when the dosage is sufficient, we typically measure how dangerous radiation is by how badly it damages cells. There are three methods to measure the absorption of radiation in the body.

Theory and applications

The three dose calculations we will look at are: absorbed dose, equivalent dose and effective dose. Each measurement has different implications on short and long term effects, but are related to one another in the need to minimise dosage to minimise danger. A higher effective dose correlates to a higher risk of illness in that particular tissue, whereas a higher equivalent dose correlates to an overall higher risk of illness somewhere in the body.

How can radiation dosage be calculated?

Absorbed dose is a measure of the energy absorbed per kilogram of tissue. Absorbed dose, measured in gray (Gy), can be calculated using the equation:

USEFUL TIP

To differentiate between the energy absorbed from radiation and effective dose, we will represent radiation energy in this chapter as E_r.

FORMULA

$$D = \frac{E_r}{m}$$

D = absorbed dose (Gy)
E_r = energy absorbed (J)
m = mass (kg)

Equivalent dose is a measure of the biological damage of radiation on a particular tissue. Equivalent dose, measured in sievert (Sv), can be calculated using the equation:

FORMULA

$$H = D \times w_r$$

H = equivalent dose (Sv)
D = absorbed dose (Gy)
w_r = radiation weighting factor (no units)

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The radiation weighting factor compares the energy absorbed by cells for each different form of radiation. The values in Table 3 can be interpreted as saying that the absorbed dose of alpha is twenty times more damaging to cells than the same absorbed dose of beta or gamma radiation.

Table 3 Weighting factor of some radiation forms

Radiation	w_r
Alpha	20
Beta	1.0
Gamma	1.0

Effective dose is a measure of the potential for long term organ specific damage from the absorption of radiation. Effective dose, measured in sievert (Sv), can be calculated using the equation:

FORMULA

$$E = \sum(H \times w_t)$$

E = effective dose (Sv)
H = equivalent dose (Gy)
w_t = tissue weighting factor (no units)

USEFUL TIP

When the whole body is exposed to the same amount of radiation, the effective dose formula can be simplified to $E = H \times \sum w_t$, and when just one tissue is exposed to radiation it can be written as $E = H \times w_t$.

The tissue weighting factor is a measure of how sensitive an area of the body is to developing radiation poisoning . A tissue weighting factor of 0.10 means that if the whole body was radiated, that type of tissue would be responsible for 10% of the associated danger. Some common tissue weighting factors are summarised in Table 4.

Table 4 Weighting factor of some tissues

Tissue	w_t
Brain	0.010
Liver	0.040
Lung	0.12
Stomach	0.12

WORKED EXAMPLE 1

Determine the effective dose if a person's lungs and stomach are exposed to 0.40 Gy of alpha radiation. Take the tissue weighting factor of both the lungs and stomach to be 0.12.

Step 1

Identify the absorbed dose, radiation weighting factor, and equation relating these variables.

$D = 0.40$ Gy, $w_r = 20$, $H = ?$

$H = D \times w_r$

Step 2

Substitute values into the formula and solve for the equivalent dose.

$H = 0.40 \times 20$

$H = 8.0$ Sv

Step 3

As both the lung and stomach are exposed to the same dosage, find the combined tissue weighting factor.

$w_{t,\,stomach} = 0.12$, $w_{t,\,lung} = 0.12$

$\sum w_t = 0.12 + 0.12 = 0.24$

Continues →

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Step 4

Identify the equivalent dose, sum of the tissue weighting factors, and equation relating these variables.

$H = 8.0$ Sv, $\sum w_t = 0.24$, $E = ?$

$E = \sum(H \times w_t) = H \times \sum w_t$

Step 5

Substitute values into the formula and solve for the effective dose received.

$E = 8.0 \times 0.24$

$E = 1.9$ Sv

Progress questions

Question 4

A liver, of mass 1.5 kg, is exposed to 6.0 J of radiation. What is the absorbed dose of radiation?

A. 0.25 Gy

B. 1.5 Gy

C. 4.0 Gy

D. 6.0 Gy

Question 5

Which form of radiation exposure results in the greatest equivalent dose, is the same absorbed dose is received?

A. alpha

B. beta

C. gamma

Question 6

A person is shielded so that only their lungs absorb an equivalent dose of 6.0 mSv. Calculate the effective dose.

A. 0.072 mSv

B. 0.72 mSv

C. 2.4 mSv

D. 6.0 mSv

How does radiation affect the human body?

Being exposed to ionising radiation can have serious health risks. For absorbed doses below 1 Gy, it is unlikely the affected person will experience any short term effects. Between 1–3 Gy immediate health risks such as nausea or burns may be experienced, and with doses exceeding 10 Gy imminent death is likely. It is estimated that for dosages between 3.5 to 5 Gy, 50% of people exposed would eventually die from radiation inflicted injury.

It is difficult to use values for effective and equivalent doses to calculate the probability of illness, as there are a variety of factors that affect the onset of illness. The greatest long term danger of radiation absorption is an increase in cancer risk over time, along with a potential to pass down mutations to future generations.

MISCONCEPTION

'Radiation poisoning is a contagious disease.'

A person is only dangerous to be around if they are contaminated with radiation, that is if radiation sources are present on their body. If a person has been exposed but does not carry any radiation sources, they pose no danger.

Progress questions

Question 7

Which, if any, of the following are the likely long term observed effects of an absorbed dose of 15 Gy radiation?

A. cancer

B. mutation

C. lack of breathing

D. None of the above, death will probably occur due to short term effects.

Question 8

50 000 people are exposed to radiation of 5 Gy. How many are likely to survive the effects of exposure?

A. zero

B. approximately 25 000

C. all 50 000

Medical therapies 1.2.7.1

Radioactive isotopes are useful in both diagnosis and treatment of some medical conditions. It's a rapidly expanding field of research that has the ability to provide more accurate and personalised treatment plans for many diseases.

Theory and applications

The use of medical radioisotopes involves targeting affected areas of the body with radiation from radioisotopes. Although radiation can cause cancer, it can also be used to treat cancer, externally or internally, through its ability to damage malignant (harmful) cells.[2]

How are radioisotopes used in medical therapy?

Alpha radiation's high ionising impact and low penetrating power when inside the body, can be utilised to treat some cancerous tumours. The process, known as targeted alpha therapy, uses targeting alpha compounds (Figure 2) to emit alpha particles. These particles are able to directly kill cancerous cells, stopping them from reproducing without causing major harm to healthy body tissues. A common medical radioisotope that undergoes alpha decay is actinium-225.

Beta particles are able to penetrate slightly further than alpha particles, and can be useful in the design of radioactive seeds (see Figure 3). A source of beta particles, placed inside a capsule, is implanted in the body next to a targeted area. The beta particles are able to penetrate through the capsule's barrier to cause cell damage to the nearby tissues. There is some harm to healthy cells, as the beta particles have a mild penetrating ability, but it is generally limited. A common medical radioisotope that undergoes beta decay is iridium-192.

Unlike the other forms of radiation, gamma rays will travel through the whole body largely unaffected. This property is often utilised in imaging particular tissues or organs, and the rays are used to create an image of the region of interest (see Figure 4).

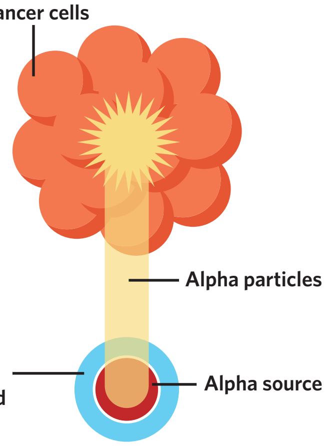

Figure 2 Targeting alpha compound incident on cancerous cells

KEEN TO INVESTIGATE?

[2] **How is radiation used in medicine?**
Search YouTube: Using radiation in medicine

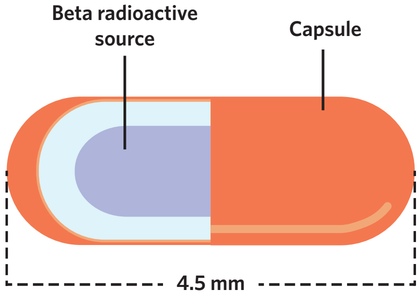

Figure 3 Radioactive seed design

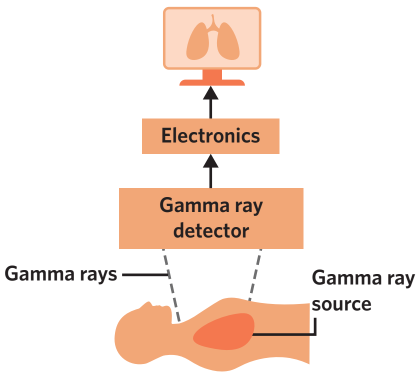

Figure 4 Gamma imaging

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Progress questions

Question 9

Why does targeted alpha therapy result in relatively mild side effects?

A. Healthy cells are damaged less.

B. The radioactive source is outside the body.

C. Cancer cells are only damaged by the radiation source, not killed.

Question 10

Which of the following would be a suitable capsule for a radioactive seed?

A. lead

B. thin metal

Question 11

Which property of gamma rays makes it unsuitable for direct treatment of cancer?

A. high penetrating power

B. high ionising power

C. lack of mass

D. lack of charge

Theory summary

Radiation	Relative ionising impact (source outside body)	Relative ionising impact (source inside body)	Capacity for cell damage	Example of medical application	Effects on healthy tissue
Alpha	Low	High	High	Targeted alpha therapy	Low
Beta	Medium	High	Medium	Radioactive seeds	Medium
Gamma	High	Low	Low	Gamma imaging	Low

- Potential short and long effects of radiation absorption depend on different measures of the dosage absorbed.
  - Absorbed dose is a measure of the radiation energy absorbed per kilogram of tissue:
    - it is calculated by $D = \frac{E_r}{m}$, and
    - correlates to short term impact as a result of radiation exposure.
  - Equivalent dose is a measure of the organ-specific impact of radiation:
    - it is calculated by $H = D \times w_r$, and
    - correlates to potential for organ-specific illness as a result of radiation exposure.
  - Effective dose a measure of the biological impact of radiation:
    - it is calculated by $E = \sum(H \times w_t)$, and
    - correlates to potential for long term biological impact as a result of radiation exposure.

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CONCEPT DISCUSSION

Discuss the difference between alpha and beta particles' ability to treat cancer, if situated on the cancerous tissue. Would both be acceptable treatments for the cancer? If so, why is targeted alpha particle therapy preferred?

Prompts:

- What is the capacity to cause cell damage of alpha and beta radiation?
- What is the affected area of cells for internal alpha and beta radiation sources?
- Is there a link between these properties and a preference for treatment?

4D Questions

Mild Medium Spicy

Deconstructed exam-style

Use the following information to answer questions 12–14.

Ava and Charlotte are exposed to 1.2 Gy of alpha radiation to the liver and 1.2 Gy of beta radiation to the stomach, respectively. The following table contains relevant data.

Person	Organ exposed	w_t	Radiation form	w_r
Ava	Liver	0.040	Alpha	20
Charlotte	Stomach	0.12	Beta	1.0

Question 12 (1 MARK)

Which, if any, of the following does the equivalent dose depend on?

A. radiation weighting factor
B. tissue weighting factor
C. time of radiation exposure
D. none of the above

Question 13 (1 MARK)

Which, if any, of the following does the effective dose depend on?

A. radiation weighting factor
B. mass of tissue where radiation is absorbed
C. tissue weighting factor
D. none of the above

Question 14 (4 MARKS)

Who is likely to have worse short term effects? Who is likely to have worse long term effects? Justify your answers using appropriate calculations.

Exam-style

Question 15 (1 MARK)

Which of the following shows the relationship between radiation weighting factors?

A. alpha = beta = gamma
B. alpha > beta = gamma
C. alpha < beta = gamma
D. alpha = beta < gamma

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Question 16 (1 MARK)

Which of the following shows the relationship between tissue weighting factors?

A. brain = liver = lung

B. brain > liver > lung

C. brain < liver < lung

D. brain = liver < lung

Question 17 (2 MARKS)

Why may different forms of radiation have different ionising impacts depending on whether the radioactive source is outside or inside the human body?

Question 18 (3 MARKS)

A particular beta seed emits 0.060 Gy of radiation incident on a person's stomach.

a. Calculate the effective and equivalent doses absorbed. (2 MARKS)

b. Comment on whether this radiation absorption is likely to have any short term effects on the person. (1 MARK)

Question 19 (2 MARKS)

A person was working with a radioactive source, encased in a plastic cube. Later, they noticed slight burns to their skin and irritation to the eyes, but no other effects. What is the most likely type of radiation that the source emits? Explain your choice.

Question 20 (4 MARKS)

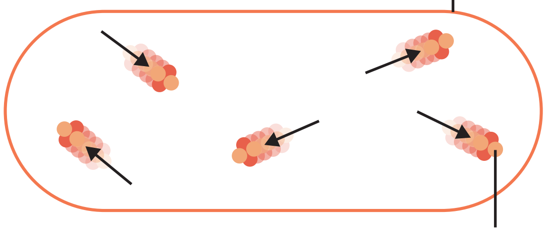
A radioactive seed is mistakenly created with polonium-210, which undergoes the following radioactive decay:

$^{210}_{84}Po \rightarrow ^{206}_{82}U + ^{4}_{2}He$.

a. Identify the type of decay this radioisotope undergoes. (1 MARK)

b. Explain why this is unlikely to effectively treat tumours, when placed inside a radioactive seed made with a perspex capsule (with a similar density to paper)? (2 MARKS)

c. What are the potential side effects of implanting this radioactive seed on nearby healthy tissue? (1 MARK)



Question 21 (5 MARKS)

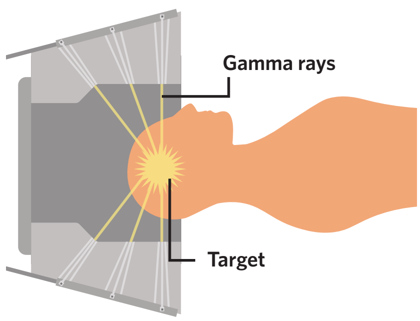
In the past, paint was created with a radium-base, a source of alpha particles. Two painters had opposing techniques to refine the tip of the brush, which was contaminated by the radium. Davide would lick the tip to create a sharp point, whereas Ekin-Su would use their hands.

a. Compare where the radioactive source is absorbed from by both painters. (2 MARKS)

b. Using your answer to part a, compare the short and long term risks of the radiation absorption of each painter. (3 MARKS)

Question 22 (4 MARKS)

A person undergoing gamma imaging to create an image of their brain ($w_{t, brain} = 0.010$) is exposed to a uniform effective dose of 3.4×10^{-2} Sv. What is the absorbed dose of radiation, and is this a realistic value for a gamma imaging scan? Assume the absorption of radiation by the skin and skull is negligible.



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Key science skills

Question 23 (2 MARKS)

When measured using a digital instrument, the absorption dose from a beta radiation source is consistently found to be around 2 Gy. People near the source do not experience any noticeable short term effects. Identify what type of error might be causing the higher than expected values, and suggest a likely reason the measuring instrument is inaccurate.

FROM LESSON 11C

Previous lessons

Question 24 (1 MARK)

Two rubber balls of different sizes in identical surroundings are conducting heat to their surroundings at different rates. Choose the option below that reflects what we can tell about their temperatures.

A. The two balls are at equal temperatures.

B. The two balls are at different temperatures.

C. It is impossible to determine whether they are at equal or different temperatures.

FROM LESSON 2B

Question 25 (2 MARKS)

A radioactive sample has a half-life of 7 hours, and has been left for 4 days. If 8.2 milligrams of the substance is left, what is the initial mass of the substance?

FROM LESSON 4B

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Chapter 4 review

Mild Medium Spicy

These questions are typical of 40 minutes worth of questions on the VCE Physics Exam.

Total marks: 30

Section A

All questions in this section are worth one mark.

Unless otherwise indicated, the diagrams in this book are not drawn to scale.

Question 1

Which of the following properties are not exhibited by the strong force?

A. It acts over large distances compared to the other fundamental forces.

B. It acts between nucleons.

C. It acts between quarks.

D. It can be attractive.

Question 2

When an atom undergoes β^- decay

A. it loses one of the electrons surrounding its nucleus.

B. the mass number decreases by 1 and the atomic number stays the same.

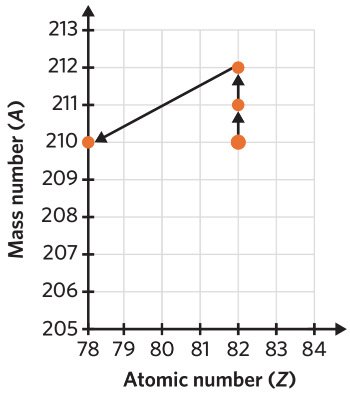
C. the mass number increases by 1 and the atomic number stays the same.

D. the mass number stays the same and the atomic number increases by 1.

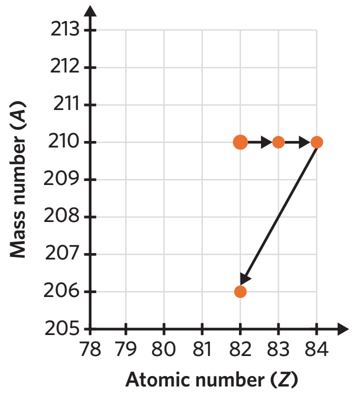
Question 3

The atomic number of lead is 82. Lead-210 is a radioactive isotope that decays by two β^- emissions followed by an α emission. Which of the following graphs best represents this decay process?

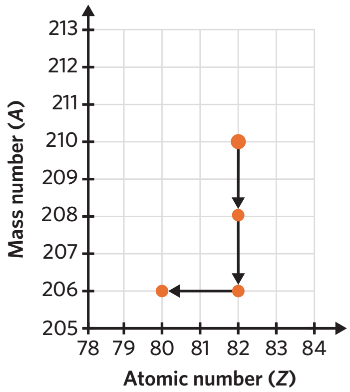
A.



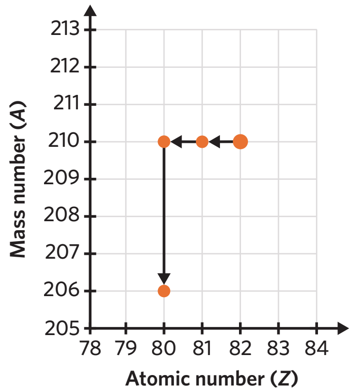
B.



C.



D.



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Question 4

A substance has a half-life of 10 years. How long does it take for the activity of the substance to decrease by 75% from its original value?

A. 7.5 years

B. 13.3 years

C. 15 years

D. 20 years

Question 5

A source of radiation is outside the human body. Choose the answer that lists the ionising impact of each type of radiation from most to least dangerous.

A. alpha, beta, gamma

B. beta, gamma, alpha

C. gamma, beta, alpha

D. gamma, alpha, beta

Section B

In questions where more than one mark is available, appropriate working must be shown.

Unless otherwise indicated, the diagrams in this book are not drawn to scale.

Question 6 (3 MARKS)

Any nucleus with 84 protons (corresponding to polonium) or more is unstable (radioactive). Explain what makes a nucleus stable and why large nuclei tend to be less stable than small nuclei.

Question 7 (2 MARKS)

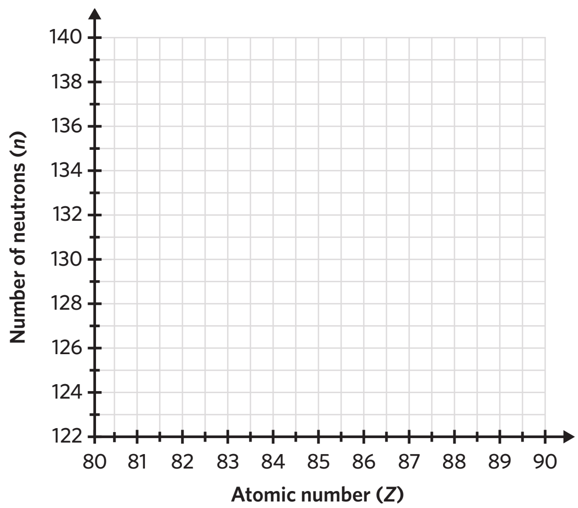
Identify which of the naturally occurring forms of radiation results in the nucleus becoming smaller. Describe the changes to the nucleus that occur when this radiation is emitted.

Question 8 (4 MARKS)

Radon has an atomic number of 86. Radon-222 is a radioactive isotope which decays by:

- two α emissions,
- followed by two β^- emissions,
- followed by one α emission,
- followed by two β^- emissions,
- followed by one α emission.

On a set of axes like the one provided, show this decay series. Note that in this case the vertical axis shows the number of neutrons (rather than the mass number).



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Question 9 (4 MARKS)

In each part of this question an incomplete decay equation is shown. Complete the equations, including the missing mass numbers.

a. $^{?}_{19}\mathrm{K} \rightarrow {}^{40}_{18}\mathrm{Ar} + \ldots$ (2 MARKS)

b. $^{218}_{85}\mathrm{At} \rightarrow {}^{?}_{83}\mathrm{Bi} + \ldots$ (2 MARKS)

Question 10 (4 MARKS)

The activity of a radioactive sample at 12 pm is 1600 Bq. The activity of the sample decreases to 200 Bq by 6 pm on the same day. What will the activity be at 10 pm?

Question 11 (3 MARKS)

Explain why alpha radiation is preferred over gamma or beta radiation for targeted treatment of cancerous tumours.

Question 12 (5 MARKS)

Anastasia's brain receives a dose of 3.1 Gy of gamma radiation, while Maksim's liver receives a dose of 2.6 Gy of alpha radiation. The following table contains relevant data.

Organ exposed	w_t	Radiation form	w_r
Brain	0.010	Alpha	20
Stomach	0.12	Beta	1.0
Lung	0.12	Gamma	1.0

a. Anastasia's brain has a mass of 1.12 kg. Calculate the amount of gamma radiation energy that her brain absorbs in joules. (1 MARKS)

b. Calculate the effective dose that Anastasia absorbs. Give your answer in Sv. (2 MARKS)

c. Who is likely to have worse short term effects? Justify your answer. (2 MARKS)

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5

CHAPTER 5

Atomic energy

STUDY DESIGN DOT POINTS

- explain, qualitatively, nuclear energy as energy resulting from the conversion of mass
- explain fission chain reactions including:
  - the effect of mass and shape on criticality
  - neutron absorption and moderation
- compare the processes of nuclear fusion and nuclear fission
- explain, using a binding energy curve, why both fusion and fission are reactions that release energy
- investigate the viability of nuclear energy as an energy source for Australia.

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LESSONS

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5A Nuclear energy

STUDY DESIGN DOT POINTS

- explain, qualitatively, nuclear energy as energy resulting from the conversion of mass
- compare the processes of nuclear fusion and nuclear fission
- explain, using a binding energy curve, why both fusion and fission are reactions that release energy

5A 5B

1.2.8.1 Mass-energy equivalence

1.2.10.1 Nuclear fusion and nuclear fission

1.2.11.1 Binding energy curves

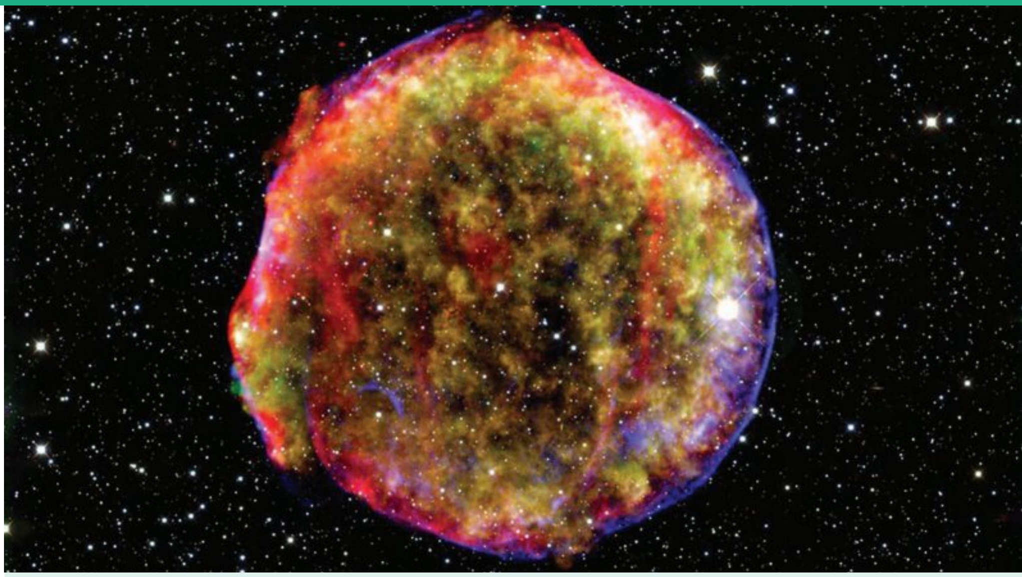
ESSENTIAL PRIOR KNOWLEDGE

4A Forces within atomic nuclei

See question 30.

ACTIVITIES

Log into your Edrolo account for activities that support this lesson.



Why do stars die?

Energy and mass are equivalent, and are linked by perhaps the most famous equation in physics, $E = mc^2$. This relationship suggests that a tremendous amount of energy could be released from the conversion of a small amount of mass. This lesson explores this mass-energy equivalence and how it underpins the processes of nuclear fusion and fission. It introduces the concept of binding energy and details how this concept explains energy release in nuclear reactions.

KEY TERMS AND DEFINITIONS

binding energy the total energy required to split a nucleus into its constituent nucleons

free nucleon a nucleon that is not bound to any other nucleons

mass defect the difference in mass between a nucleus and its constituent nucleons

nuclear fission the process of splitting a single nucleus into several smaller nuclei

nuclear fusion the process of forcing several smaller nuclei together to form a single larger nucleus

product a substance that is formed as the result of a reaction

reactant a substance present at the start of a reaction and is involved in the reaction

Mass-energy equivalence 1.2.8.1

Mass and energy are equivalent to each other and are related by $E = mc^2$.

Theory and applications

Understanding the equivalence between mass and energy explains how the mass of atomic nuclei can differ from the total mass of their nucleons, and how nuclear reactions can release energy.

How are energy and mass equivalent?

Anything with mass has an inherent energy proportional to its mass. This relationship reveals that there is a tremendous amount of energy contained in small amounts of mass. If a single gram of matter is converted entirely into energy, it would release 9.0×10^{13} J, or enough energy to power 4000 homes for a year.

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This mass-energy equivalence also means that when energy is added to an object, its mass increases. For objects in everyday life, this mass difference is so tiny that it is negligible, however when considering extremely small objects such as atoms and subatomic particles, the mass difference becomes noticeable.

The most fundamental example of matter being converted to energy is the formation and splitting of atoms.

- To separate a nucleus into its nucleons, we need to add energy to the nucleus to overcome the strong force.
- Therefore by mass-energy equivalence, the free nucleons have more energy (and therefore more mass) than the bound nucleus.
- This means the nucleus of an atom will be lighter (less massive) than the total mass of the protons and neutrons that form the nucleus.

For example, a helium nucleus has a mass of about 99.2% of the combined masses of 2 protons and 2 neutrons (see Figure 1).

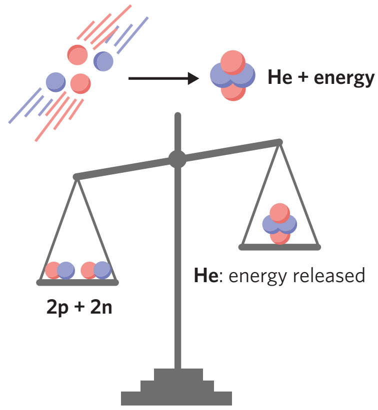

Figure 1 The mass of a helium nucleus compared to the mass of its nucleons

This difference in mass is known as the mass defect and is equivalent to the energy released when the nucleus is formed. In nuclear reactions, if the sum of the masses of the reactants (mass before the reaction) is different to the sum of the masses of the products (mass after the reaction), there must have been a conversion between mass and energy.

Progress questions

Question 1

A reaction occurs where there is a difference in mass between the reactants and products. Choose the correct statement.

A. Some of the mass of the reactants must have been converted into energy.

B. Some of the energy of the reactants must have been converted into mass.

C. There must have been a conversion between mass and energy, but we do not have enough information to tell which direction this conversion went.

D. Mass and energy cannot be converted, such a reaction is impossible.

Question 2

An atomic nucleus will always have

A. less mass than the sum of its nucleons' masses.

B. more mass than the sum of its nucleons' masses.

Nuclear fusion and nuclear fission 1.2.10.1

Nuclear fusion and fission are both processes that change atomic nuclei into different nuclei. Both processes typically lead to a decrease in mass and a release of energy.

Theory and applications

Nuclear fusion and fission are each capable of producing large amounts of energy. Fusion is the process that stars use to generate energy, while fission is used in nuclear power plants to generate electricity.

How does nuclear fusion occur?

Nuclear fusion is a reaction that involves combining (or fusing) two or more lighter nuclei into a single heavier nucleus. For such a reaction to occur, the reactant nuclei must be forced extremely close together in order to reach a point where the strong force overcomes the electrostatic forces.

Forcing nuclei so close together typically requires extremely energetic conditions, meaning very high temperatures, immense pressures, or commonly a combination of both. For example, the core of the Sun, where the Sun's fusion reactions take place, has a temperature of 1.57×10^7 K and a pressure of roughly 2.7×10^{11} times that of the air on the surface of Earth.

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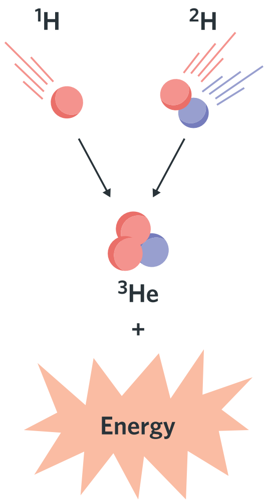

Figure 2 The fusion of two hydrogen isotopes forming a helium nucleus

Fusion reactions occur continuously within stars over their lifetimes. The energy this provides allows these highly energetic conditions to continue, creating the conditions for further fusion reactions, and sustaining the star. For most of a star's life, these reactions will be the fusion of two hydrogen isotopes into helium, a process shown in Figure 2.

As the hydrogen becomes more scarce, stars may continue to fuel themselves through the fusion of increasingly heavier elements. Since the Sun is releasing energy, it is actually losing mass over time, approximately 1.89×10^{17} kg per year. The formation of much heavier elements uses up energy, and can be explained by the binding energy curves shown later in this lesson.

Progress questions

Question 3

The main force that must be overcome to cause a fusion reaction is

A. the strong force.

B. the electrostatic force.

Question 4

Choose the correct statement out of the following.

A. Fusion reactions can only produce energy overall.

B. Fusion reactions can only use up energy overall.

C. Fusion reactions can produce or use up energy overall.

D. Fusion reactions do not consume or generate energy overall.

How does nuclear fission occur?

Nuclear fission is the process of splitting a nucleus into two or more smaller nuclei. The fission of a stable atom requires an initial input of energy to overcome the strong force binding the nucleus together. After this input of energy, the electrostatic force repelling the protons is the dominant force, and the nucleus splits into two or more smaller nuclei.

USEFUL TIP

Nearly all fission reactions will result in two product nuclei of slightly different sizes. However, occasionally three or more nuclei can be produced.

The most common mechanism to begin a nuclear fission reaction is to bombard a heavy nucleus with neutrons, which supply the initial energy required to overcome the strong force. The nucleus will 'capture' the neutron and the additional energy will force the nucleons apart enough for the nucleus to split. Often fission reactions will produce free neutrons, which can then go on to trigger other fission reactions. Figure 3 shows the fission reaction for a uranium-235 atom, which is used in nuclear power plants.

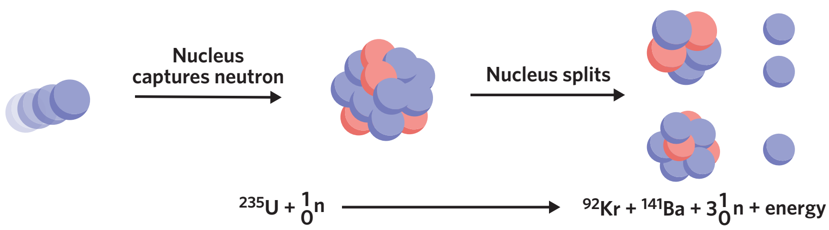

Figure 3 Uranium-235 capturing a neutron and undergoing fission

Unlike nuclear fusion, the necessary conditions for fission are currently easily achievable on Earth.[1] This allows nuclear fission to be controlled and harnessed for the production of electricity in nuclear power plants.

KEEN TO INVESTIGATE?

1 **Why can't we use nuclear fusion to generate power?**
Search YouTube: Why don't we have nuclear fusion power yet?

Progress questions

Question 5

The main force that must be overcome to cause a fission reaction is

A. the strong force.

B. the electrostatic force.

Question 6

Fill in the blanks to correctly describe the processes of nuclear fusion and fission.

Nuclear __________ (fusion/fission) is the process of several smaller nuclei being forced together and forming a new, __________ (smaller/larger) nucleus. This requires a __________(high/low) pressure or temperature in the environment. Nuclear __________ (fusion/fission) is the process of splitting a larger nucleus into several smaller nuclei, and often includes __________ (protons/neutrons) as additional products.

Binding energy curves 1.2.11.1

The binding energy of a nucleus is the energy required to break a nucleus into its constituent neutrons and protons. The binding energy curve shows how the number of nucleons in a nucleus affects how tightly bound it is.

Theory and applications

Binding energy can be used as an indicator of which fission and fusion reactions will release energy, and which will not.

Why can both fusion and fission reactions release energy?

For a stable atom to be completely separated into unbound nucleons, we must add energy to the nucleus to overcome the strong nuclear force holding the nucleus together. This energy is known as the binding energy and it is the energy equivalent to the mass defect in the formation of the atom. Since a bound nucleus will always be lighter than its component nucleons, the binding energy will always be positive.

A binding energy curve plots the binding energy of nuclei against the number of nucleons within the nucleus. As shown in Figure 4, the vertical axis will typically show the binding energy per nucleon, rather than the total binding energy. Binding energy curves like this have a peak at nickel-62.

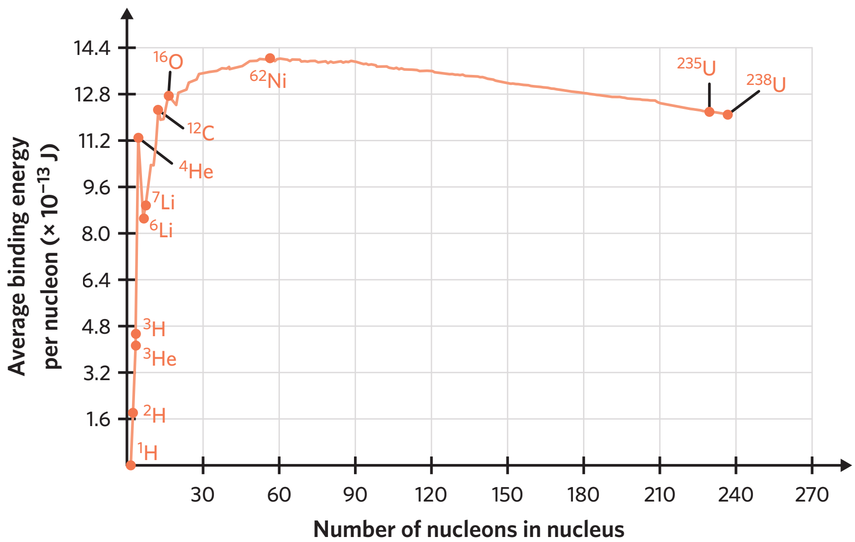

Figure 4 Binding energy curve

MISCONCEPTION

'Mass defect and binding energy are the same thing.'

Mass defect and binding energy are related by $E = mc^2$, so knowing one tells us the other, but mass defect is a mass quantity and binding energy is an energy quantity.

The total binding energy of the products minus the total binding energy of the reactants is equal to the energy released in the nuclear reaction. We can write this as:

$$energy\ released = BE_{products} - BE_{reactants}$$

Any reaction in which the products have a greater total binding energy than the reactants will release energy. This means that both nuclear fusion and fission can release energy, as shown in Table 1.

Table 1 Fission and fusion reactions at different locations on the binding energy curve

Reactant and product location(s) on binding energy curve	Left of Ni-62	Left of Ni-62	Right of Ni-62	Right of Ni-62
Reaction type	Fission	Fusion	Fission	Fusion
Location of product(s) on binding energy curve	Left of reactants	Right of reactants	Left of reactants	Right of reactants
Binding energy of products	Usually lower than reactants	Usually higher than reactants	Usually higher than reactants	Usually lower than reactants

The outcome of this is shown in Figure 5, with fusion reactions typically releasing energy for nuclei left of Ni-62, and fission reactions typically releasing energy for nuclei right of Ni-62.[2]

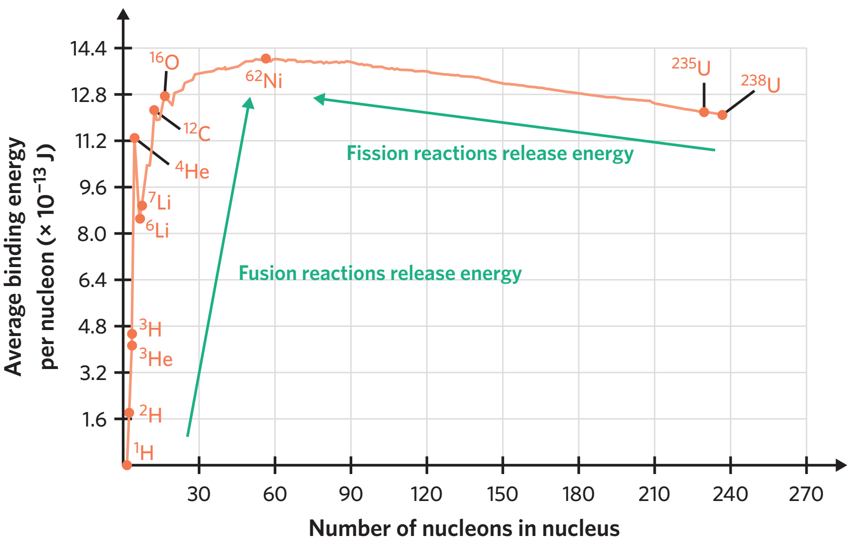

Figure 5 Binding energy curve and reactions that release energy

Progress questions

Question 7

Which of the following can binding energy, or the binding energy curve, be used to describe? **(Select all that apply)**

I. How tightly bound atomic nuclei are.

II. How much lighter atomic nuclei are compared to the sum of the masses of their constituent nucleons.

III. The proportion of protons and nucleons in atomic nuclei.

IV. Whether atomic nuclei are more likely to undergo fission or fusion reactions.

MISCONCEPTION

'Binding energy is energy stored in the nucleus that is released in nuclear reactions.'

Binding energy describes the energy released when a specific nucleus is created from individual nucleons. It is not a stored quantity but a property of a nucleus.

USEFUL TIP

Fission and fusion reactions can still occur even if they do not release energy, it just requires an extreme amount of energy to trigger them.

KEEN TO INVESTIGATE?

[2] **Why does binding energy increase and then decrease along a curve?**
Search YouTube: Cassiopeia project fission and fusion

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Theory summary

- Mass and energy are equivalent and related by the equation $E = mc^2$.
- Mass defect is the difference between the mass of an atom and the sum of the mass of its constituent nucleons. It is the mass equivalent of binding energy.
- Nuclear fusion is the process of forcing light nuclei to combine into a single larger nucleus, typically requiring immense temperatures and pressures.
- Nuclear fission is the process of splitting a larger nucleus into smaller nuclei.
- The binding energy of a nucleus is the energy required to completely separate it into its constituent nucleons, it is a measure of how tightly bound that nucleus is.
- A binding energy curve shows the binding energy per nucleon versus the number of nucleons in the atom.
  - If a nuclear reaction results in energy being released, the products must have a higher position on the binding energy curve.
  - A fusion reaction will have products to the right of the reactants.
  - A fission reaction will have products to the left of the reactants.

CONCEPT DISCUSSION

Stars are fuelled by the fusion of nuclei within their cores. As stars age, they burn increasingly heavy fuel, potentially all the way up to iron and nickel at the end of their lives. The formation of nuclei that are more massive than nickel requires cataclysmic events, such as supernovas or merging neutron stars.

Discuss why stars produce heavier elements as they age, but only up to around iron and nickel. What might happen once they run out of this less massive fuel? Consider why producing elements heavier than those found in stars requires the most energy-intense environments in the universe.

Prompts:

- Why would stars preferentially burn hydrogen until it is exhausted before moving on to increasingly heavier elements?
- What is special about the nuclei of elements such as iron and nickel, which would explain why stars do not produce heavier elements?
- How does the energy released in nuclear fusion change once the nuclei get bigger than nickel-62?

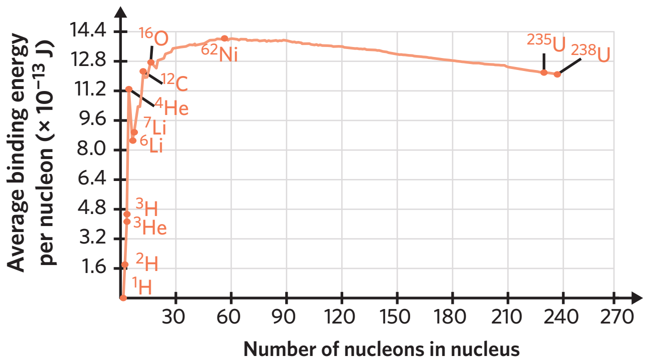
5A Questions

Mild Medium Spicy

Deconstructed exam-style

Use the following information to answer questions 8–11.

An example of a fusion reaction that releases energy is $^{3}_{1}H + ^{1}_{1}H \rightarrow ^{4}_{2}He$.



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Question 8 (1 MARK)

Which is closest to the binding energy per nucleon of $^{4}_{2}He$?

A. 4.0×10^{-12} J

B. 11×10^{-13} J

C. 11×10^{-11} J

D. 21 J

Question 9 (1 MARK)

Which is closest to the binding energy per nucleon of $^{3}_{1}H$?

A. -4.5×10^{-13} J

B. 0 J

C. 4.5×10^{-13} J

D. 15×10^{-12} J

Question 10 (1 MARK)

What is the total binding energy of a free nucleon (proton or neutron)?

A. 0 J

B. 1.20×10^{-12} J

C. 7.39×10^{-12} J

D. 1.51×10^{-11} J

Question 11 (4 MARKS)

Using values from the binding energy curve, explain why this specific reaction releases energy.

Exam-style

Question 12 (8 MARKS)

For each of the following statements, state whether it applies to nuclear fusion, nuclear fission or both.

a. The total number of nucleons remains unchanged. (1 MARK)

b. Small nuclei are forced together, forming a single heavier one. (1 MARK)

c. There may be a net energy release. (1 MARK)

d. A large nucleus is split into several smaller ones. (1 MARK)

e. The individual products are less massive than the individual reactants. (1 MARK)

f. The reaction is the source of energy for stars. (1 MARK)

g. The total binding energy may be greater after the reaction. (1 MARK)

h. The reaction can currently be harnessed for efficient energy generation. (1 MARK)

Question 13 (1 MARK)

What is the value of x in the following reaction? (How many neutrons are released as products in this reaction?)

$^{237}_{93}Np + ^{1}_{0}n \rightarrow ^{159}_{63}Eu + ^{71}_{28}Ni + ^{4}_{2}He + x^{1}_{0}n$

A. 1

B. 2

C. 3

D. 4

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Question 14 (2 MARKS)

Nuclear fusion and nuclear fission are both examples of nuclear reactions that can release energy. This energy release results from a difference in binding energy between the reactants and the products.

a. How does the total binding energy of the products of a nuclear fission reaction which released energy compare to the binding energy of the reactant nucleus? (1 MARK)

b. How does the binding energy of the product of a nuclear fusion reaction compare to the total binding energy of the reactant nuclei? (1 MARK)

Question 15 (3 MARKS)

All stars use the fusion of hydrogen into helium to release energy, but the reaction pathway will depend on the size of the star. Small stars use the proton-proton chain, while larger stars will predominantly use the CNO cycle. Both pathways have the same net reaction, so the initial reactants and the final products are the same.

How would you expect the energy released to compare between these two processes?

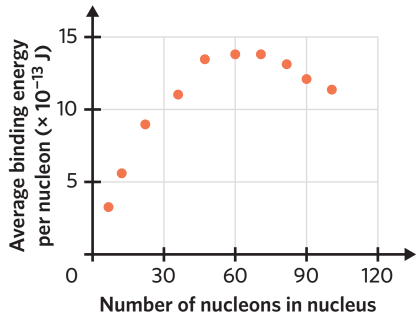
Key science skills

Question 16 (2 MARKS)

A group of students were investigating the relationship between the size of an atom and the average binding energy. They obtained the data points plotted in the following graph.

Advise the students whether it would be appropriate to fit a line of best fit to the data. Justify your response.

FROM LESSON 11E



Previous lessons

Question 17 (2 MARKS)

With reference to the appropriate form of heat transfer, explain why air conditioning systems are generally placed at a high position in buildings (high on the wall or on the ceiling, for example).

FROM LESSON 2B

Question 18 (3 MARKS)

Ernest and William are conducting an experiment to examine the effects of gamma radiation. William suggests that they should use an aluminium casing to protect the equipment from alpha and beta radiation, but Ernest argues that nothing more than a sheet of paper is necessary. Who is correct? Discuss your response.

FROM LESSON 4C

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5B Fission


Image: DanielRam/Shutterstock.com

STUDY DESIGN DOT POINTS

- explain fission chain reactions including:
  - the effect of mass and shape on criticality
  - neutron absorption and moderation
- investigate the viability of nuclear energy as an energy source for Australia.

5A 5B

1.2.9.1 Criticality and neutrons

1.2.12.1 The viability of nuclear energy

ESSENTIAL PRIOR KNOWLEDGE

5A Fission reactants and products

- Surface area of shapes

See questions 31–32.

ACTIVITIES

Log into your Edrolo account for activities that support this lesson.

Is nuclear energy a viable energy source for Australia?

The energy released from the nucleus in fission reactions has been utilised on a wide scale, initially for nuclear bombs and then for energy generation in nuclear power plants. This lesson discusses factors affecting the fission chain reactions underlying these technologies, and introduces arguments around the viability of nuclear energy as a potential energy source for Australia.

KEY TERMS AND DEFINITIONS

control rod a rod used in fission reactors to help control fission chain reactions

criticality the state of a fissile mass where the number of fission reactions occurring remains constant

fissile capable of sustaining a fission chain reaction

fissile mass a mass made out of or containing fissile material

neutron moderation the process of reducing the speed (and hence kinetic energy) of neutrons

neutron moderator a material capable of neutron moderation through collisions with neutrons

neutron multiplication factor at a point in time, the average number of neutrons per fission reaction that will cause further fission reactions

subcriticality the state of a fissile mass where the number of fission reactions occurring is decreasing

supercriticality the state of a fissile mass where the number of fission reactions occurring is increasing

Criticality and neutrons 1.2.9.1

The propagation of fission chain reactions is affected by factors such as the mass and shape of fissile masses, as well as neutron absorption and moderation.

Theory and applications

Being able to describe and control fission chain reactions is crucial to the design and operation of fission power plants.

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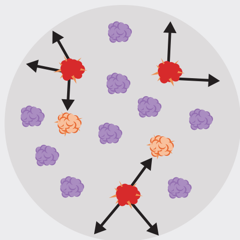
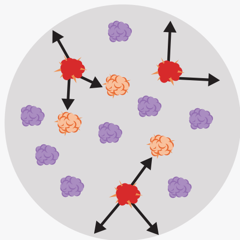
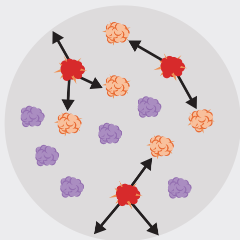
How are fission chain reactions described?

Fission reactions can have free neutrons as reactants and products, which means that the neutrons produced in one fission reaction can go on to trigger other fission reactions. This allows fissile nuclei to create fission chain reactions, with each fission reaction potentially causing other fission reactions.

When we talk about fission chain reactions, it is useful to talk about the neutron multiplication factor, k. For a given fissile mass, this number describes the average number of neutrons from each fission reaction that will cause further fission reactions. In other words, it is the average number of additional fission reactions that each fission reaction will cause.

Table 1 shows the relationship between fission chain reactions, the neutron multiplication factor, and the terminology used to describe them. It also gives diagrams of what different neutron multiplication factors can look like for chain reactions. See Figure 1 for a legend relating to the diagrams throughout this lesson.

Table 1 Description of fission chain reactions in a fissile mass

Number of fission reactions per unit time	Neutron multiplication factor	State definition	Example diagram
Decreasing	$k < 1$	Subcritical	
Remaining constant	$k = 1$	Critical	
Increasing	$k > 1$	Supercritical	

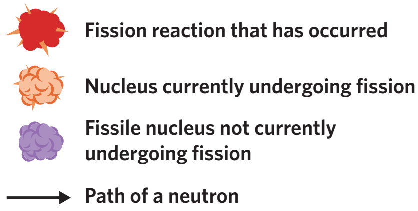


Figure 1 Legend for fission chain reaction diagrams

MISCONCEPTION

'A fissile mass being critical is dangerous.'

A fissile mass being critical simply means that the fission chain reaction is being sustained without growing or shrinking, it is often the desired state of operation in nuclear fission reactors. Uncontrollable supercriticality poses the greatest danger.

USEFUL TIP

The criticality (and k value) of a fissile mass will change with time. This is because the fission reactions will decrease the amount of available fissile material, decreasing k. It may also be affected if the energy released by the reactions causes the shape of the fissile mass to change.

The criticality of a fissile mass depends on how easy it is for neutrons from one fission reaction to go on and cause additional fusion reactions. Nuclear fission reactors need to be able to control the fission chain reactions and the criticality of their fuel, and will make it subcritical, critical, or supercritical depending on the needs of the reactor at the time.

Progress questions

Question 1

The neutron multiplication factor, k, can describe

A. the average number of additional fission reactions that each fission reaction triggers.

B. how the number of fission reactions (per unit time) is changing.

C. whether a fissile mass is subcritical, critical, or supercritical.

D. all of the above

Continues →

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Question 2

If a fissile mass is critical, this means that

A. the number of reactions (per unit time) is increasing.

B. it is going to explode.

C. each fission reaction will trigger on average exactly one additional fission reaction.

How do mass and shape affect fission chain reactions?

Changing the mass of a fissile mass will affect its criticality as:

- there is more fissile material available,
- which increases the chance that neutrons will be captured (and trigger fission reactions) instead of escaping.
- Therefore k increases.

This effect is shown in Figure 2, which compares fissile masses that contain different amounts of fissile material.

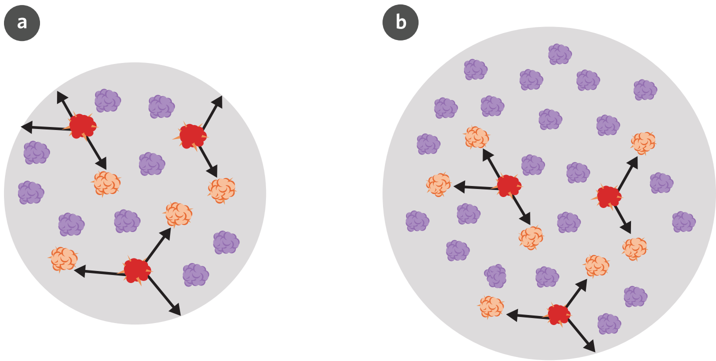

Figure 2 Fission chain reactions in **(a)** smaller and **(b)** larger fissile masses

MISCONCEPTION

'If k increases, that means the number of reactions is increasing.'

This is not the case when k remains below 1 ($k < 1$). As the mass is subcritical while $k < 1$, a higher value for k means that the overall number of reactions is still decreasing, but is decreasing more slowly than for a lower value of k.

Varying the shape of a fissile mass can change the criticality state as it may change the amount of neutrons that escape from the mass, which cannot then cause fission reactions.

Decreasing the surface area of a mass means that:

- on average, neutrons will have to travel further through fissile material to escape (since there is a smaller area to escape from).
- This increases the chance that neutrons will be captured (and trigger fission reactions) before escaping.
- Therefore k increases.

The shape which has the lowest surface area for any given volume is a sphere, so making a fissile mass more spherically shaped will increase its neutron multiplication factor. A visual of this is shown in Figure 3, which compares fissile masses in low and high surface area shapes.

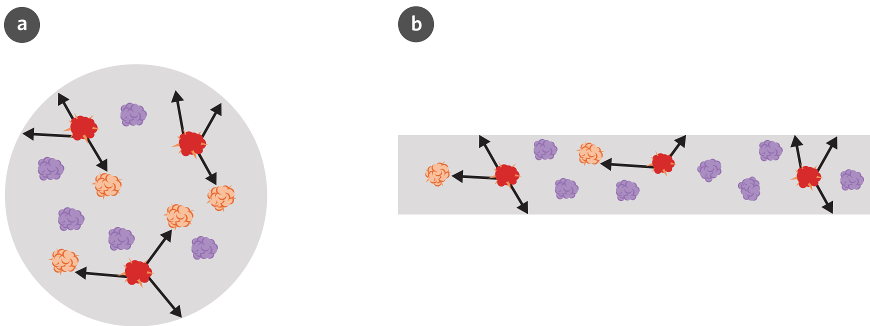

Figure 3 Fission chain reactions in **(a)** spherical and **(b)** slab fissile masses

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Progress questions

Question 3

Decreasing the mass of a fissile mass will mean there is ___________ (more/less) fissile material available to capture neutrons, so the neutron multiplication factor will ___________ (increase/decrease).

Question 4

Increasing the surface area of a fissile mass will mean there is a ___________ (larger/smaller) area which neutrons can escape through. Neutrons will be ___________ (more/less) likely to be captured instead of escaping, and therefore the neutron multiplication factor will ___________ (increase/decrease).

How do neutron absorption and moderation affect fission chain reactions?

Neutron absorption is the process where non fissile material absorbs neutrons produced by fission reactions, which reduces the availability of neutrons that could cause further fission reactions. In nuclear fission reactors, neutron absorption is managed by control rods, which are made of materials capable of absorbing neutrons without undergoing nuclear reaction.

Inserting a control rod into a fissile mass means:

- neutrons are more likely to be absorbed by the rod before they can be captured (and trigger fission reactions).
- Therefore *k* decreases.

Inserting more control rods, and inserting them further into a fissile mass, will make the chain reaction more difficult to propagate (decreasing *k*). Figure 4 compares fission chain reactions in fissile masses with and without a control rod present.

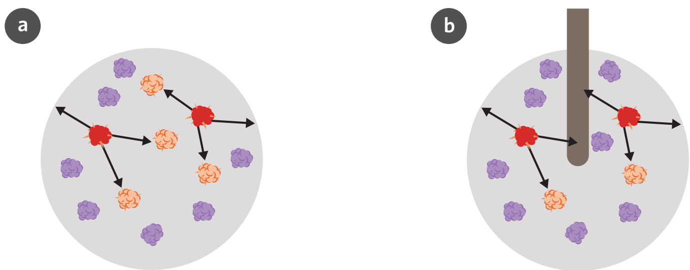

Figure 4 Fission chain reactions **(a)** without and **(b)** with a control rod inserted

The faster a neutron is moving, the more difficult it is for fissile nuclei to capture them. The neutrons produced in fission reactions generally move too fast to be captured and cause fission before they escape the fissile mass. For this reason, nuclear reactors place neutron moderators in and around fissile material to help propagate the fission chain reaction.

When a fast neutron collides with a neutron moderator, it is not captured but its energy is reduced by the collision. Through additional collisions, fast neutrons can be slowed enough where they are more easily captured by fissile nuclei, and can therefore more easily propagate the fission chain reaction, as shown in Figure 5.

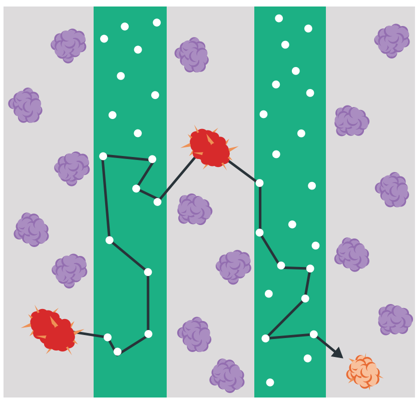

Figure 5 Neutron moderation through collisions with particles in a fission chain reaction

USEFUL TIP

Neutron moderators are often distributed throughout fissile material, to make it easier for neutrons to collide with them.

Progress questions

Question 5

Neutron absorption decreases the neutron multiplication factor because

A. neutrons bounce off control rods which makes it harder for them to get to fissile nuclei.

B. control rods absorb neutrons that might otherwise trigger fission reactions.

Continues →

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Question 6

Which of the following is correct about neutron moderation?
(Select all that apply)

I. It helps propagate fission chain reactions by slowing neutrons down through collisions.

II. Fast neutrons are unlikely to be captured by fissile nuclei, so neutron moderation helps propagate fission chain reactions.

III. Since slow neutrons have less energy to trigger fission reactions, neutron moderation hinders fission chain reactions.

IV. Fission chain reactions are possible without neutron moderators present.

The viability of nuclear energy 1.2.12.1

Nuclear energy has a variety of advantages and disadvantages with respect to environmental, social, and economic sectors.

Theory and applications

Assessing various pros and cons of nuclear energy in the Australian context provides insight into its viability as an energy source within the country. Three major areas to consider are its potential impact on the environment, people and communities, and the economy.

How can nuclear energy production impact the environment?

The impact of nuclear power plants on the environment can be mostly attributed to three factors: fuel and sourcing, greenhouse gas emissions, and waste and handling. Table 2 presents some considerations on each of these topics around nuclear energy and its impact on the environment.

Table 2 Arguments regarding nuclear energy's environmental impact

Issue	Argument against nuclear energy	Argument for nuclear energy	Important considerations
Fuel sourcing	Poses a risk to the environment through its potential to contaminate the environment and damage ecosystems, if managed irresponsibly.[1]	Poses little risk to the environment if managed responsibly.[2]	
Greenhouse gas emissions	Nuclear energy generation produces more greenhouse gases than renewables.[3]	Nuclear energy generation produces less greenhouse gases than fossil fuels, and a comparable amount to renewables.[4]	Values depend on assumed emissions for fuel sourcing, plant operation, plant decommissioning, etc.[5]
Nuclear waste handling	Handled incorrectly, nuclear waste can escape into and contaminate the environment, damaging ecosystems.[6, 7]	Handled correctly, nuclear waste poses almost no risk to the environment.[8]	

KEEN TO INVESTIGATE?

1. **How might nuclear fuel sourcing place the environment at risk?**
Search: APH uranium mining environmental impacts
2. **Why is nuclear fuel sourcing not a risk to the environment?**
Search: WNA environmental aspects uranium mining
3. **Does nuclear power produce more greenhouse gases than renewables?**
Search: ISA pdf report nuclear energy greenhouse gases
4. **Do nuclear power and renewables produce comparable amounts of greenhouse gases?**
Search: Carbon brief nuclear low footprint
5. **How are greenhouse gas estimates calculated?**
Search: The conversation nuclear zero emission
6. **How might nuclear waste be an environmental risk?**
Search: Conserve energy dangers nuclear waste
7. **How might nuclear waste affect ecosystems?**
Search: The conversation nuclear waste Fukushima
8. **How are current nuclear waste solutions effective?**
Search: World nuclear waste myths and realities

USEFUL TIP

If looking for a particular piece of information in a long document or article, try seeing if the information is summarised in the introduction, abstract, summary, or conclusion. The table of contents may also indicate which section of the document this information is contained in.

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How can nuclear energy production impact people and communities?

The predominant factors influencing the impact nuclear energy generation has on communities are the placement and management of the nuclear power plants and nuclear fuel and waste. The security risks related to nuclear energy are also an important area of analysis. Table 3 presents some arguments on these topics around nuclear energy's social impact.

Table 3 Arguments regarding nuclear energy's sociocultural impact

Issue	Argument against nuclear energy	Argument for nuclear energy	Important considerations
Nuclear site placement near communities	May cause serious health effects for people nearby in the case of mismanagement, accidents, or attacks.[9]	Operating normally, nuclear sites pose no health risk to people nearby.[10]	The placement of fuel sourcing sites, nuclear plants, and nuclear waste sites all have to be considered. Health effects from nuclear accidents may not become apparent for decades (and thus might be underreported).
Impact on aboriginal communities	Nuclear sites may be placed on aboriginal lands against the wishes of the traditional owners, and potentially damage/destroy the land.[11]	Nuclear sites can be chosen with respectful collaboration with indigenous peoples, and it is important we consider the perspectives of and benefits to other communities as well.[12]	The placement of fuel sourcing sites, nuclear plants, and nuclear waste sites all have to be considered.
Security risks	Nuclear energy programs increase security risks, such as those of nuclear proliferation[13] and nuclear terrorism.[14]	Promoting nuclear energy doesn't increase the security risks associated with nuclear proliferation, as there are safeguards in place to counteract any risk.[15]	The risks associated with nuclear proliferation are somewhat disputed. Certain groups may (to a degree) argue it is beneficial.

How can nuclear energy production impact the economy?

The economic effects of nuclear power production stem from the costs of producing nuclear power and the subsequent impact on energy prices. The cost of energy is also influenced by how reliable its production is, which is related to a concept called grid inertia. Table 4 presents some arguments on these topics concerning nuclear energy's economic impact.

Table 4 Arguments regarding nuclear energy's economic impact

Issue	Argument against nuclear energy	Argument for nuclear energy	Important considerations
Energy cost	Nuclear energy is expensive to produce, and will not reduce the cost of energy.[16] Investing in it is a waste of money.[17]	Nuclear energy is cheap to produce, and could reduce the cost of energy.[18, 19]	Values depend on assumptions of the costs of fuel, labour, construction, etc. over the lifetime of the plant.

KEEN TO INVESTIGATE?

[9] **What are the health risks of nuclear accidents near communities?**
Search: FPCJ health effects Hasegawa pdf

[10] **What are the safety precautions taken around nuclear sites?**
Search: IAEA what makes nuclear safe

[11] **How can nuclear sites harm indigenous communities?**
Search: The conversation Yeelirrie uranium indigenous

[12] **How can nuclear sites be placed in cooperation with (indigenous) communities?**
Search YouTube: Nuclear waste land indigenous

[13] **Why might nuclear energy contribute to nuclear proliferation?**
Search: Belfer centre spreading temptation pdf

[14] **Why might nuclear energy be a terrorism risk?**
Search YouTube: Greatest threat nuclear terrorism

[15] **How is nuclear proliferation prevented?**
Search: Science daily nuclear proliferation

[16] **What are the commercial prospects for nuclear energy in Australia?**
Search: NFCRC tentative findings pdf

[17] **Why might nuclear energy not be commercially viable?**
Search: Renew economy nuclear profitable

[18] **Why should we consider nuclear energy for cheaper energy?**
Search: AFR Mundine nuclear dismiss

[19] **Why might the Australian energy economy need nuclear energy?**
Search: Nuclear for climate least cost carbon

KEEN TO INVESTIGATE?

20 **Why are renewables' low inertia not an issue?**
Search: NREL inertia power grid

21 **Why might renewables' low inertia be an issue?**
Search YouTube: The problem with renewables

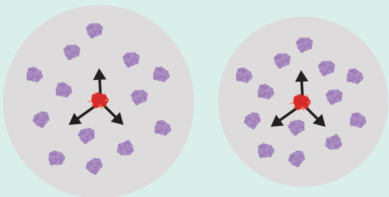
Table 4 Continued

Issue	Argument against nuclear energy	Argument for nuclear energy	Important considerations
Power grid composition	While renewables have low inertia they also reduce the need for inertia, so high inertia energy sources like nuclear are needed less.[20]	Nuclear energy has high inertia, so as renewables replace fossil fuels, it may be needed to provide reliability in the power grid.[21]	

Theory summary

- Criticality describes a state of a fissile mass where each fission reaction will on average trigger exactly one other fission reaction.
- The neutron multiplication factor, k, specifies how a fission chain reaction grows:
  - $k < 1$ means the fissile mass is subcritical, the reaction is shrinking,
  - $k = 1$ means the fissile mass is critical, the reaction is being sustained without growing, and
  - $k > 1$ means the fissile mass is supercritical, the reaction is growing.
- Adding fissile material to a fissile mass will increase k.
- Reducing the surface area of a fissile mass (making it more spherical) will increase k.
- Neutron absorption rods decrease the number of available neutrons to propagate the chain reaction, which decreases k.
- Neutron moderators slow neutrons down to make them more likely to propagate the chain reaction, which increases k.
- The viability of nuclear energy as an energy source for Australia is a disputed topic and is influenced by possible environmental, social, and economic impacts.

CONCEPT DISCUSSION



We know that on their own, both the amount of available fissile material and the shape it is kept in affect the neutron multiplication factor. Discuss what effect changing the density of the fissile nuclei (i.e. how close together they are) could have on the fission chain reaction and neutron multiplication factor of a fissile mass.

Prompts:

- If the nuclei are packed more closely together, how does the size of the gaps between them change?
- Would smaller gaps make it easier or more difficult for neutrons to escape without capture?

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5B Questions

Mild Medium Spicy

Deconstructed exam-style

Use the following information to answer questions 7–10.

A new nuclear energy company designs a fission power plant that operates without the use of control rods. They justify this to their investors by saying that in the absence of these control rods, they will be able to produce electricity at an ever increasing rate and dominate the energy market.

Question 7 (1 MARK)

What role do control rods play in fission chain reactions?

A. They slow neutrons down to help the chain reaction propagate.

B. They absorb neutrons to make it more difficult for the chain reaction to propagate.

C. They speed up neutrons to give more energy to the chain reaction.

Question 8 (1 MARK)

Why are control rods important in the operation of nuclear reactors?

A. The fission chain reaction would not propagate without them.

B. They can decrease the neutron multiplication factor of the fissile fuel, and their use is the most efficient method of doing so.

C. They are not important in this context.

Question 9 (1 MARK)

Which of the following are possible outcomes of a fissile mass going highly supercritical with no fast way to reduce its neutron multiplication factor? **(Select all that apply)**

I. The mass eventually brings itself back to criticality or subcriticality.

II. The mass causes a nuclear meltdown, potentially damaging its environment.

III. The mass will not change and will forever be supercritical.

Question 10 (3 MARKS)

Using your understanding of control rods and criticality, predict the possible outcomes if this plant were to become operational.

Exam-style

Question 11 (5 MARKS)

For each of the following statements, state whether they are true or false.

a. Control rods make it less likely that neutrons will be captured by fissile nuclei. (1 MARK)

b. Adding fissile material to a mass will increase the neutron multiplication factor. (1 MARK)

c. Removing fissile material from a mass will always make the mass subcritical. (1 MARK)

d. Most neutrons from fission reactions would be captured by fissile nuclei without the presence of neutron moderators. (1 MARK)

e. Decreasing the surface area of a fissile mass makes it harder for neutrons to escape without capture. (1 MARK)

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5B QUESTIONS

Question 12 (1 MARK)

What effect will inserting a neutron absorbing rod (control rod) into a fissile mass have on its neutron multiplication factor?

Question 13 (2 MARKS)

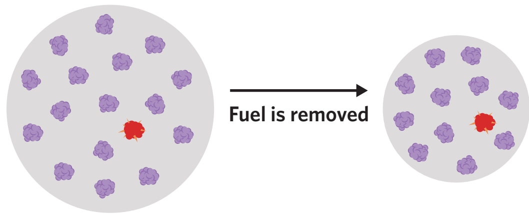
Describe what it means for a fissile mass to be in a critical state, and give a property of fissile masses that affect their criticality.

Question 14 (3 MARKS)

A fissile mass is sustaining a fission chain reaction at a critical level. Explain why, without external influence, the mass will eventually become subcritical.

Question 15 (6 MARKS)

Fissile fuel in a nuclear reactor is operating in a supercritical state. Some of the fuel is removed, but the shape of the fissile mass is kept the same.



a. Will the mass be supercritical, critical, or subcritical after the fuel is removed? Give a reason for your answer. (3 MARKS)

b. Instead suppose that the mass was initially in a critical state before the fuel was removed. Would it be supercritical, critical, or subcritical after the fuel is removed? Give a reason for your answer. (3 MARKS)

Question 16 (3 MARKS)

Two scientists, Julia and Aftyn, are discussing the design of a new nuclear power plant. Julia says that they should have designed it so that while in the reactor, the fissile fuel would be shaped as a thin slab so less fuel is required. Aftyn counters that for less fuel to be required, it should actually be shaped more spherically. Evaluate who is correct and why.

Key science skills

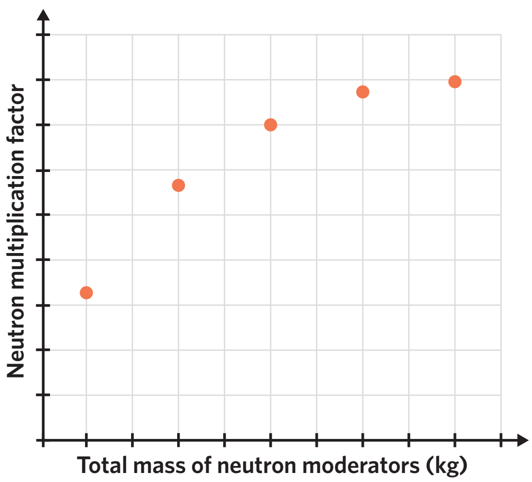
Question 17 (5 MARKS)

Scientists are conducting an experiment to try and establish a relationship between the use of neutron moderators and the neutron multiplication factor. They take measurements of the neutron multiplication factor of fissile masses that have different amounts of neutron moderating materials present.

a. Identify the independent and dependent variables in this experiment. (2 MARKS)

b. The data the scientists obtain is shown in the following plot.

Would it be appropriate for them to draw a line of best fit? Give a reason for your answer. (2 MARKS)



c. The scientists realise they were not consistent in the way that they arranged the fissile material and neutron moderators. State which type of error is this likely to have caused. (1 MARK)

FROM LESSONS 11A, 11C, & 11D

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Previous lessons

Question 18 (2 MARKS)

The difference in temperature between object A and object B is initially 400 K. After a period of time, the difference in temperature is only 100 K. By what factor has the rate of heat transfer $\frac{Q}{t}$ changed?

FROM LESSON 2B

Question 19 (1 MARK)

Using the information from the table provided, which of the following changes to a radioactive source will reduce the equivalent dose absorbed by a person nearby a radioactive source? Assume the absorbed dose of radiation does not change.

Radiation type	w_r
Alpha	20
Beta	1.0
Gamma	1.0

A. changing from a source of beta particles to a source of gamma rays

B. changing from a source of beta particles to a source of alpha particles

C. changing from a source of gamma rays to a source of alpha particles

D. changing form a source of alpha particles to a source of gamma rays

FROM LESSON 4D

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Chapter 5 review

Mild 🌶 Medium 🌶🌶 Spicy 🌶🌶🌶

These questions are typical of 40 minutes worth of questions on the VCE Physics Exam.

Total marks: 30

Section A

All questions in this section are worth one mark.

Unless otherwise indicated, the diagrams in this book are not drawn to scale.

Question 1 🌶

Which kind of nuclear reaction is the reaction ${}^{3}_{2}X + {}^{20}_{10}Y \rightarrow {}^{23}_{12}Z$?

A. fusion

B. fission

C. alpha decay

D. none of the above

Question 2 🌶

Which of the following is not a major factor in the viability of nuclear energy in Australia?

A. the location of potential nuclear power plants

B. the possible impact of nuclear material on the environment

C. whether it is possible to harness fission reactions for nuclear energy

D. how profitable nuclear energy might be

Question 3 🌶

The neutron multiplication factor

A. measures the number of free neutrons in a fissile mass.

B. is equal to 1 for a supercritical mass.

C. increases for a fissile mass if more control rods are inserted into it.

D. increases with the availability of fissile material.

Question 4 🌶🌶

Which of the following statements about binding energy is correct? **(Select all that apply)**

I. It is the energy required to separate one nucleon from an atomic nucleus.

II. It is stored inside the nucleus of an atom.

III. It can be plotted against nucleon number on a binding energy curve to compare nucleus stability.

IV. none of the above

Question 5 🌶🌶

Which of the following is incorrect about fission chain reactions? **(Select all that apply)**

I. They propagate by neutrons from previous reactions triggering new ones.

II. Any material that can undergo fission can sustain a fission chain reaction.

III. They release more energy per nucleon than a typical fusion reaction.

IV. Neutron multiplication factor is used to quantify their growth.

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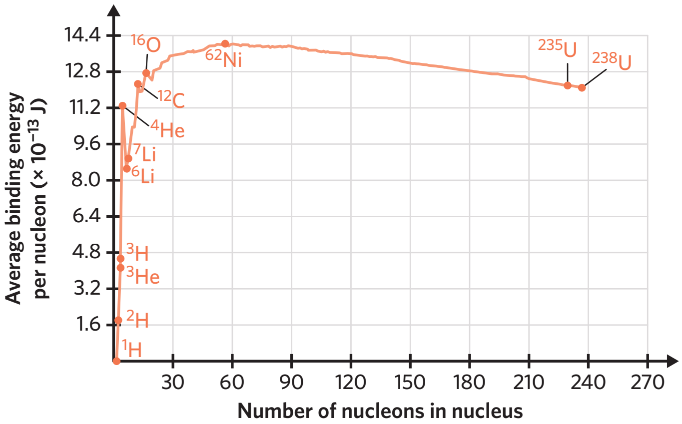
Question 6

The diagram shows the binding energy per nucleon against nucleon number.



Which one of the following statements regarding nuclear fusion and fission is incorrect?

A. Nuclear fusion generally occurs between multiple light nuclei and nuclear fission generally occurs for a single heavy nucleus.

B. The fission of 1 gram of uranium-235 will release more energy than the fusion of 1 gram of ^{2}H.

C. The energy release per nucleon for fusion reactions is generally greater than the energy release per nucleon for fission reactions.

D. In both fusion and fission reactions, the total mass of the products may be less than the total mass of the reactants.

Section B

In questions where more than one mark is available, appropriate working must be shown.

Unless otherwise indicated, the diagrams in this book are not drawn to scale.

Question 7 (2 MARKS)

Describe the difference between subcriticality and supercriticality, in reference to fission chain reactions.

Question 8 (3 MARKS)

Atomic nuclei are always less massive than the total mass of their constituent nuclei, a concept known as mass defect.

a. Why does mass defect occur? Reference mass-energy equivalence in your answer. (2 MARKS)

b. State how mass defect and nuclear binding energy are related. (1 MARK)

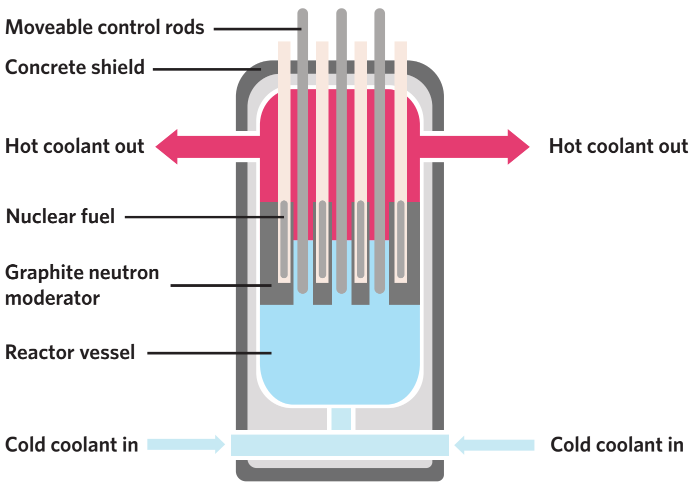
Question 9 (3 MARKS)

This diagram shows the components of a nuclear fission reactor.

a. State which labelled part of the reactor absorbs neutrons. (1 MARK)

b. State which labelled part of the reactor slows down neutrons. (1 MARK)

c. State why neutrons need to be slowed down in fission reactors. (1 MARK)



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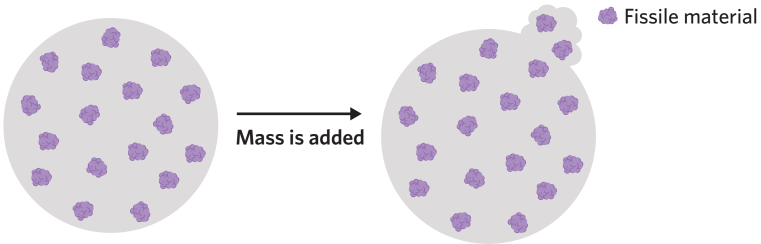
Question 10 (4 MARKS)

Two physics students, Aphisit and Lynn, are talking about nuclear energy. They have access to a sample of $^{62}_{28}Ni$. Aphisit says that they should fission their $^{62}_{28}Ni$ sample to release energy. Lynn counters that fusing $^{62}_{28}Ni$ with itself would produce more energy than fissioning it. State whether each student is correct and why.

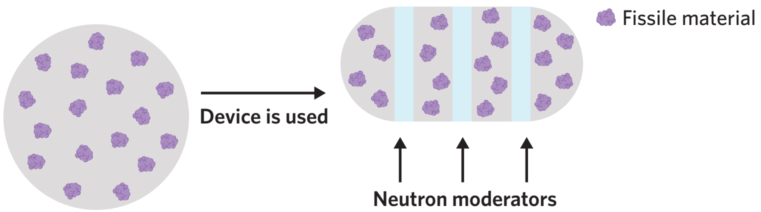
Question 11 (6 MARKS)

Two scientists, Siena and Ayrton, are trying to determine the best way to control the neutron multiplication factor of fissile masses. They have three identical fissile masses, which are shaped as spheres.

a. Siena takes the first mass and adds additional fissile material to it, as shown in the given diagram. The arrangement of the original fissile material does not change, but with the addition of the new material, the mass is no longer spherical. Explain what effect this would have on the neutron multiplication factor, with reference to the paths of neutrons. (2 MARKS)



b. Ayrton takes the second mass to a device which adds neutron moderators into the material. Unfortunately, he doesn't realise that the device flattens the mass a bit, making it less spherical. Evaluate whether Ayrton, drawing a conclusion from the result of this experiment, is likely to over or underestimate the effect of neutron moderation on neutron multiplication factor, given that it still increases overall. (4 MARKS)



Question 12 (6 MARKS)

A scientific organisation develops a way to harness fusion reactions to produce energy, in such a way that they generate more energy than is required to trigger them. This organisation is looking to break into the energy market and compete against traditional fission energy generation.

a. A competing company tries to profit off this discovery by taking the new technology and using it to fuse $^{4}_{2}He$ and $^{78}_{34}Se$, in an attempt to produce energy. Evaluate whether or not this will produce the desired results. (4 MARKS)

b. Another company proposes that by mixing fusion and fission fuel, the energy produced by the fusion can be used to propagate a fission chain reaction. State whether or not this assertion is correct and give a reason for your answer. (2 MARKS)

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Unit 1 AOS 2 review

Mild Medium Spicy

These questions are typical of one hour's worth of questions on the VCE Physics Exam.

Total Marks: 50

Section A

All questions in this section are worth one mark.

Unless otherwise indicated, the diagrams in this book are not drawn to scale.

Question 1

Which of the following best gives the different types of radiation in order from greatest ionising ability to least ionising ability?

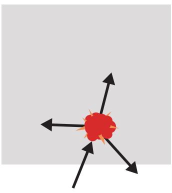
A. alpha radiation, beta radiation, gamma radiation

B. gamma radiation, beta radiation, alpha radiation

C. beta radiation, alpha radiation, gamma radiation

D. alpha radiation, gamma radiation, beta radiation

Use the following information to answer questions 2 and 3.



Legend

Path of a neutron

Nuclear reaction/decay

Question 2

Which of the following types of nuclear reaction/decay is depicted in the given diagram?

A. beta decay

B. fusion

C. fission

D. alpha decay

Question 3

Assume the mass in the diagram is critical. Which of the following sets of changes could potentially keep the mass at critical?

A. increasing the mass and making it more spherical

B. decreasing the mass and inserting a control rod

C. introducing a neutron moderator and decreasing the surface area

D. inserting a control rod and making it more spherical

Question 4

1.54×10^3 g of rubidium-81 is left out after an experiment. Calculate the amount of the sample left after 45 minutes. The half-life of rubidium-81 is 4.58 hours.

A. 1.37×10^3 g

B. 1.53×10^3 g

C. 1.57 kg

D. 1.97 kg

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Question 5

In order to study the blood flow in a patient's veins, a doctor decides to examine the emission of radioactive particles when a radioactive source is carried around the body. Which of the following would be an appropriate choice of radioactive source?

A. a targeting alpha particle compound absorbed in the blood from within the body

B. a source of beta particles absorbed in the blood from outside the body

C. a gamma ray source absorbed in the blood from within the body

D. a gamma ray source absorbed in the blood from outside the body

Section B

In questions where more than one mark is available, appropriate working must be shown.

Unless otherwise indicated, the diagrams in this book are not drawn to scale.

Question 6 (5 MARKS)

a. Describe the process of nuclear fusion. Refer to the reactants, products, and how the reaction occurs in your answer. (3 MARKS)

b. Identify one difference between fission and fusion reactions. (1 MARK)

c. Identify one difference between fission and fusion reactions, other than their reactants and products. (1 MARK)

Question 7 (8 MARKS)

Axel is investigating the radioactive substances erbium-160 and phosphorus-32. Axel was able to find out that the half-life of erbium-160 is 1.19 days, and he is running some tests to determine the half-life of phosphorus-32.

a. The activity of a particular sample of erbium-160, as measured with a Geiger counter, was initially 1.28×10^4 Bq. Calculate how long Axel would have to wait until the activity dropped below 1.0×10^2 Bq. Give your answer in days. (3 MARKS)

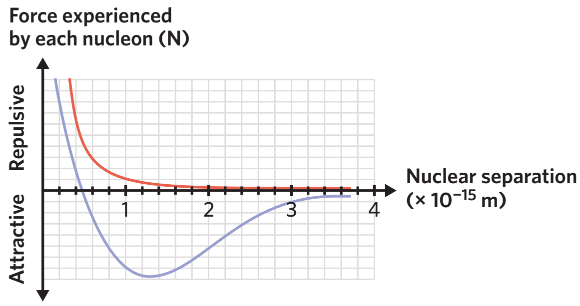
b. The sample of phosphorus-32 initially weighs 60.0 milligrams, and after 23.0 days only 15.0 milligrams remain. Calculate the half-life of phosphorus-32. Give your answer in hours. (3 MARKS)

c. After his experiments with the radioactive substances, Axel feels confident enough to put his findings into a report. In one part of his report, Axel states that the basic principle behind the concept of a half-life is that "if you have two radioactive nuclides, after one half-life one of them will decay. As such, half of a radioactive substance will decay after one half-life." Explain why Axel's statement is incorrect. (2 MARKS)

Question 8 (3 MARKS)

The diagram shows how the strength of the strong nuclear force and electrostatic force acting between two nucleons changes with their separation. The forces are repulsive above the horizontal axis and attractive below it.

State which curve corresponds to which fundamental force in the nucleus. Explain how these two fundamental forces change as the nuclear separation increases.



Question 9 (5 MARKS)

a. Through repeated α and β^- decays only, an actinium-227 nucleus (atomic number 89) decays to a lead-207 nucleus (atomic number 82). Calculate the number of α particles and the number of β^- particles emitted in this decay chain. (3 MARKS)

b. Draw a decay series diagram for this decay. Assume that actinium-227 undergoes all forms of alpha decay before undergoing beta decay. (5 MARKS)

Question 10 (10 MARKS)

A smoke alarm is not properly installed, and the radioactive source inside falls out of the casing. Jurgen, the owner of the house with a mass of 75.0 kg, picks up the source without realising the potential danger that may be caused.

a. Jurgen absorbs 10.0 J of radiation, but experiences an effective dose of 2.7 Sv. Determine the type of radioactive source inside the smoke alarm. Take the radiation weighting factor of alpha decay to be 20, and beta and gamma as 1.0. (5 MARKS)

b. With reference to penetrating ability, are the particles emitted by the radioactive source in the smoke alarm likely to have any noticeable health effect on the owner of the house? (2 MARKS)

c. Jurgen does not want the source of radioactive particles to go to waste. Their neighbour, the resident vet, is able to convert the source of particles into a suitable medical compound. Leo the Lion is suffering from a tumour on their stomach, and is in need of urgent treatment.

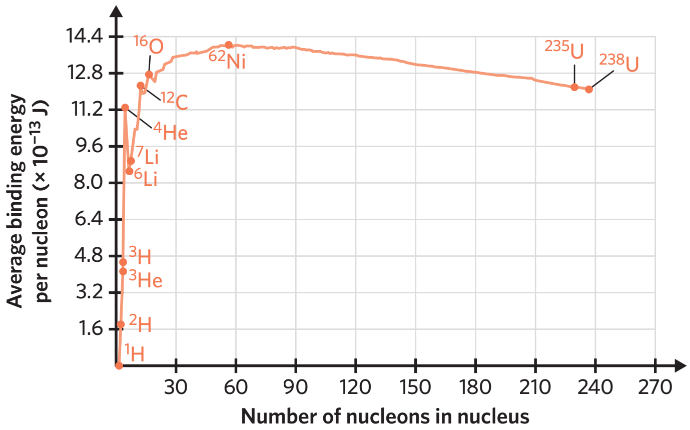
Explain how the vet could use the radioactive source to treat Leo. What effect is this likely to have on the cancerous cells and nearby healthy cells? (3 MARKS)

Question 11 (11 MARKS)

Australia decides that it wants to trial nuclear energy as an energy source, but only wants to use reactors that operate at subcriticality for safety reasons. It is proposed that these reactors should use uranium-235 as fuel. One nucleus of uranium-235 has a mass of 3.902×10^{-25} kg. Take the average mass of a uranium-235 nucleon to be 1.674×10^{-27} kg.

a. Explain why the mass of uranium-235's nucleus is less than the mass of its constituent nucleons when they are unbound. (3 MARKS)

b. Use the binding energy curve to explain why the fission of uranium releases energy. (3 MARKS)



c. Describe how neutron moderation helps propagate fission chain reactions. (2 MARKS)

d. A device is included in the nuclear reactor which constantly fires neutrons at the mass of fissile fuel. What effect would this machine have on the number of fission reactions in the fissile mass? Also explain what effect it would have on the neutron multiplication factor. (3 MARKS)

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UNIT 1 AOS 3

How can electricity be used to transfer energy?

Modelling is a useful tool in developing concepts that explain physical phenomena that cannot be directly observed. In this area of study, students develop conceptual models to analyse electrical phenomena and undertake practical investigations of circuit components. Concepts of electrical safety are developed through the study of safety mechanisms and the effect of current on humans. Students apply and critically assess mathematical models during experimental investigations of DC circuits. They explore electrical safety and the use of transducers to transfer energy in common devices.

Outcome 3

On completion of this unit the student should be able to investigate and apply a basic DC circuit model to simple battery-operated devices and household electrical systems, apply mathematical models to analyse circuits, and describe the safe and effective use of electricity by individuals and the community.

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6

CHAPTER 6

Electricity and circuits

STUDY DESIGN DOT POINTS

- apply concepts of charge (Q), electric current (I), potential difference (V), energy (E) and power (P), in electric circuits
- analyse and evaluate different analogies used to describe electric current and potential difference
- investigate and analyse theoretically and practically electric circuits using the relationships: $I = \frac{Q}{t}$, $V = \frac{E}{Q}$, $P = \frac{E}{t} = VI$
- justify the use of selected meters (ammeter, voltmeter, multimeter) in circuits
- model resistance in series and parallel circuits using:
  - current versus potential difference (I-V) graphs
  - resistance as the potential difference to current ratio, including $R = constant$ for ohmic devices
  - equivalent resistance in arrangements in
    - series: $R_{equivalent} = R_1 + R_2 + ... + R_n$ and
    - parallel: $\frac{1}{R_{equivalent}} = \frac{1}{R_1} + \frac{1}{R_2} + ... + \frac{1}{R_n}$
- calculate and analyse the equivalent resistance of circuits comprising parallel and series resistance
- compare power transfers in series and parallel circuits

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LESSONS

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6A Fundamentals of electricity

Image: Sergei Prokhorov/Shutterstock.com

STUDY DESIGN DOT POINTS

- apply concepts of charge (Q), electric current (I), potential difference (V), energy (E) and power (P), in electric circuits
- analyse different analogies used to describe electric current and potential difference
- investigate and analyse theoretically and practically electric circuits using the relationships:

  $I = \frac{Q}{t}$, $V = \frac{E}{Q}$, $P = \frac{E}{t} = VI$
- justify the use of selected meters (ammeter, voltmeter, multimeter) in circuits

6A 6B 6C 6D 6E

1.3.1.1 Electric circuits

1.3.1.2 & 1.3.3.1 Electric quantities

1.3.2.1 Circuit analogies

1.3.4.1 Measuring electrical quantities

ESSENTIAL PRIOR KNOWLEDGE

4A The electrostatic force

See question 33.

ACTIVITIES

Log into your Edrolo account for activities that support this lesson.

Why can birds sit on power lines and not get electrocuted?

Electricity plays an important role in our day to day lives; it powers our lights, charges our phones, and even powers some of our cars. This lesson will introduce fundamental quantities in the study of electricity: charge (Q), current (I), potential difference/voltage (V), electric energy (E), and electric power (P). Understanding these quantities and the relationships between them is essential to understanding electric circuits.

KEY TERMS AND DEFINITIONS

charge a fundamental property of subatomic particles responsible for electric interaction

charge carrier a charged particle that contributes to an electric current

conventional current the (hypothetical) direction of flow of positive charge

current (electric) the rate of movement of charge with respect to time, requiring the movement of charged particles

direct current (DC) electric current that flows in one direction around a circuit

electric potential energy potential energy due to the separation of charge

potential difference the difference in electric potential energy per unit charge between two points

power the rate of change of energy with respect to time

voltage see potential difference

FORMULAS

- **potential difference**

  $V = \frac{E}{Q}$
- **electric current**

  $I = \frac{Q}{t}$
- **power**

  $P = \frac{E}{t}$
- **electric power**

  $P = VI$

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Electric circuits 1.3.1.1

Electric circuits are closed loops that allow electricity to flow. Circuits and their components enable us to use electricity in many different ways.

Theory and applications

An electric circuit is a loop of connected electrical components. If there is a break in the connection, electricity will not flow. Representing circuits with circuit diagrams helps in understanding and analysing circuits.

How are electric circuits represented visually?

In circuit diagrams, electrical components are represented by unique symbols, and the lines that join them represent electric wires. Figure 1(a) shows a real circuit and circuit diagram for a cell (DC voltage source) and light bulb connected by a wire. In Figure 1(b), a switch has been added to the circuit so the light can be turned on and off.

Table 1 gives some common electrical components and the circuit symbols used to represent them in diagrams, which will be discussed throughout Chapter 6.

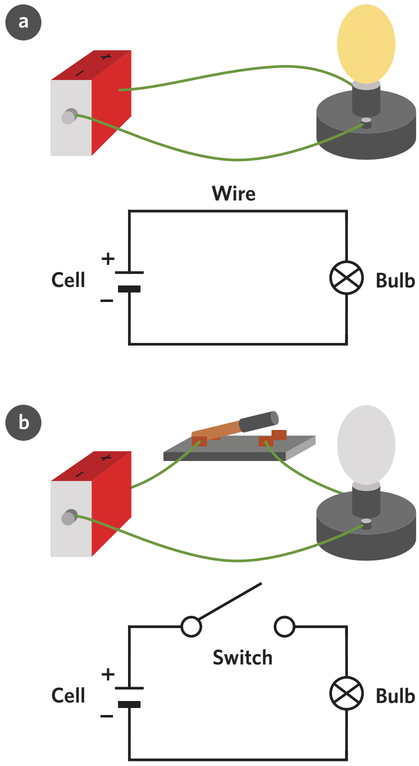
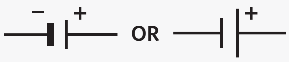
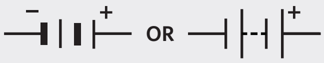
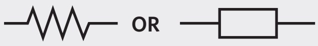
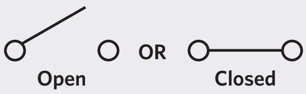


Figure 1 Electric circuits and their corresponding diagrams **(a)** without and **(b)** with a switch

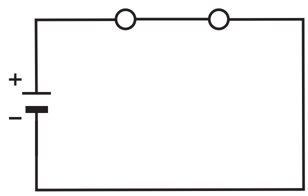
Table 1 Circuit components and their symbols

Circuit component	Circuit symbol
Wire	
Cell (a type of DC voltage source)	
Battery (a series of cells, which is also a DC voltage source)	
A general DC voltage source	
Resistor	
Light bulb	
Switch	
Voltmeter	
Ammeter	

Progress questions

Question 1

Which of the following electrical components are present in the given circuit?
(Select all that apply)



I. switch
II. ammeter
III. cell
IV. wire

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Electrical quantities 1.3.1.2 & 1.3.3.1

The quantities of electric charge (Q), potential difference (V), current (I), energy (E), and power (P), are important in our understanding of electric circuits.

Theory and applications

Understanding electrical quantities and the relationships between them can be used to conduct circuit analysis, and look at the operation of specific electrical components.

How does charge (Q) describe electricity?

Electric charge, Q, is a fundamental property of particles (such as protons and electrons) that is responsible for all electric interactions. Charge is measured in coulombs (C) and can be either positive or negative. Charge cannot be passed between particles, created or destroyed. It can only be carried through space by the movement of the particles themselves.

The term electricity is a general term used to refer to the physical interactions associated with the presence or movement of charge.[1]

KEEN TO INVESTIGATE?

1 **What is electric charge and how does electricity work?**
Search YouTube: Mechatronics electric charge works

USEFUL TIP

Since 'electricity' is a general term for anything to do with electric charge, avoid using this term when describing specific physical quantities.

Static electricity is the stationary separation or imbalance of electric charge in an object. Some physical interactions can move the charged particles in a material. For example, rubbing a balloon on human hair transfers electrons from the hair onto the rubber balloon. This gives the balloon a net negative charge and the hair a net positive charge, so the hair is attracted to the balloon as shown in Figure 2.

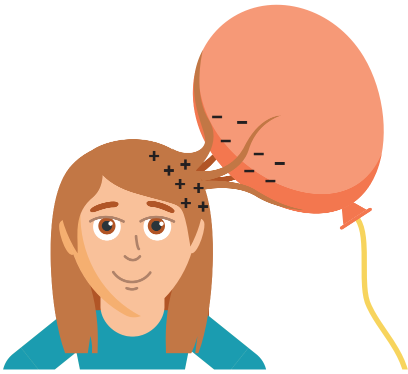

Figure 2 Static electricity on human hair and a balloon

Progress questions

Question 2

Which of the following statements correctly describes electric charge?

A. It is a fundamental property of particles.

B. It cannot be created or destroyed.

C. It can be positive or negative.

D. all of the above

How does potential difference (V) describe electricity?

Due to the electrostatic force, charges attract and repel each other without contact. This means that depending on the position of a charge relative to other charges, it has the potential to gain energy when other charges push or pull it.

The potential of a charged particle to gain energy due to other charges is called electric potential energy. The difference in electric potential energy per coulomb between two locations is called the potential difference, V. The symbol 'ε' can also be used to represent potential difference.

Potential difference can be related to electric potential energy and charge using the following formula, or the formula triangle shown in Figure 3.

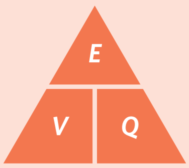

Figure 3 Formula triangle for potential difference

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FORMULA

$$V = \frac{E}{Q}$$

V = potential difference (V or J C^{-1})
E = difference in electric potential energy of a charge between two locations (J)
Q = the charge moved between the two locations (C)

USEFUL TIP

The terms voltage and potential difference have the same unit (V) as they represent the same thing, and will be used interchangeably in Edrolo and VCE Physics.

Ideal sources of potential difference, like cells, batteries, and certain power supplies, provide the same potential difference no matter what circuit they are applied to. The potential difference only depends on the source.

One of the common sources of potential difference in electric circuits is a cell. Cells use chemical reactions to separate positive and negative charges, giving them electric potential energy and therefore creating a potential difference. This is shown in Figure 4.

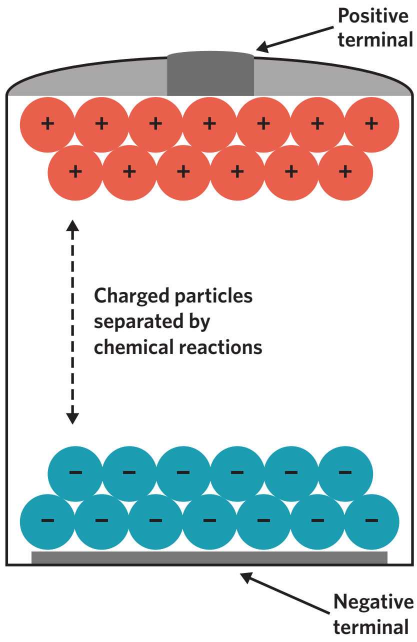

Figure 4 Charge separation in a cell

WORKED EXAMPLE 1

When an electron with charge -1.6×10^{-19} C is held at location X, away from a positively charged particle, the electron has 3.4×10^{-18} J of electric potential energy. When the electron is at location Y, closer to the positive particle, it has 1.0×10^{-18} J of electric potential energy.

a. Determine the potential difference from X to Y.

Step 1

Calculate the difference in electric potential energy between X and Y for the proton, using the values given in the question.

$E = 1.0 \times 10^{-18} - 3.4 \times 10^{-18}$

$E = -2.4 \times 10^{-18}$ J

Step 2

Identify the charge that this difference in electric potential energy corresponds to, and the formula that relates these variables.

$Q = -1.6 \times 10^{-19}$ C, $E = -2.4 \times 10^{-18}$ J, $V = ?$

$V = \frac{E}{Q}$

Step 3

Substitute values into the formula and solve for potential difference.

$V = \frac{-2.4 \times 10^{-18}}{-1.6 \times 10^{-19}} = 15.0 = 15$ V

b. If a particle with charge 1.0 C was moved from location Y to location X, what would be the change in its electric potential energy?

Step 1

Identify the charge and the potential difference, and the formula that relates these variables. Note that the potential difference from Y to X will be the negative of the potential difference from X to Y.

$Q = 1.0$ C, $V = -15$ V, $E = ?$

$V = \frac{E}{Q}$

Step 2

Substitute values into the formula and solve for difference in electric potential energy.

$-15 = \frac{E}{1.0}$

$E = (-15) \times 1.0 = -15.0 = -15$ J

Progress questions

Question 3

Potential difference is

A. the difference in electric potential energy between two locations.

B. the difference in electric potential energy per coulomb between two locations.

C. unrelated to electric potential energy.

D. not described correctly by any of the above.

Question 4

A particle with electric charge of 2.0 C moves across a potential difference of 10 V. What is its change in electric potential energy?

A. 20 C

B. 5.0 C

C. 100 C

D. 0 C

How does current (*I*) describe electricity?

When a potential difference is provided to an electric circuit, it causes an electric current, *I*, to flow. The current at a point is the rate that charge flows past that point, and can be calculated using the following formula or the formula triangle in Figure 5. Current is measured in Amperes (A).

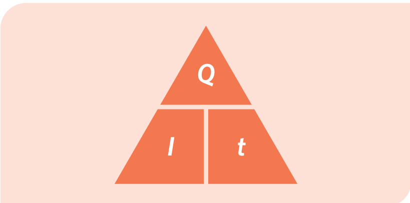

Figure 5 Formula triangle for electric current

FORMULA

$$I = \frac{Q}{t}$$

I = current through component (A or C s^{-1})
Q = amount of charge that flowed through component (C)
t = time taken for the charge to flow through (s)

WORKED EXAMPLE 2

When a battery is connected to a circuit containing a light bulb, 2.0 C passes through the filament in 0.50 s.

a. Determine the current through the filament.

Step 1

Identify charge and time, and the formula that relates these variables.

$Q = 2.0$ C, $t = 0.50$ s, $I = ?$

$I = \frac{Q}{t}$

Step 2

Substitute values into the formula and solve for current.

$I = \frac{2.0}{0.50} = 4.00 = 4.0$ A

b. How much charge would pass through the filament in 10 s if the current remained the same?

Step 1

Identify current and time, and the formula that relates these variables.

$I = 4.0$ A, $t = 10$ s, $Q = ?$

$I = \frac{Q}{t}$

Step 2

Substitute values into the formula and solve for charge.

$4 = \frac{Q}{10}$

$Q = 4.0 \times 10 = 40.0 = 40$ C

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The moving charged particles causing the current are called charge carriers. If a circuit is not closed (for example, if a switch is open) then current will not flow, as the charge carriers have nowhere to go.

The most common form of electric current is the flow of electrons through metallic wires.

- Electrons are repelled from the negative terminal of a voltage source, as like charges repel, and electrons are attracted towards the positive terminal of a voltage source, as opposite charges attract.
- Electrons are free to move in metallic wires.
- Therefore the electrons travel from the negative terminal to the positive terminal, as shown in Figure 6.

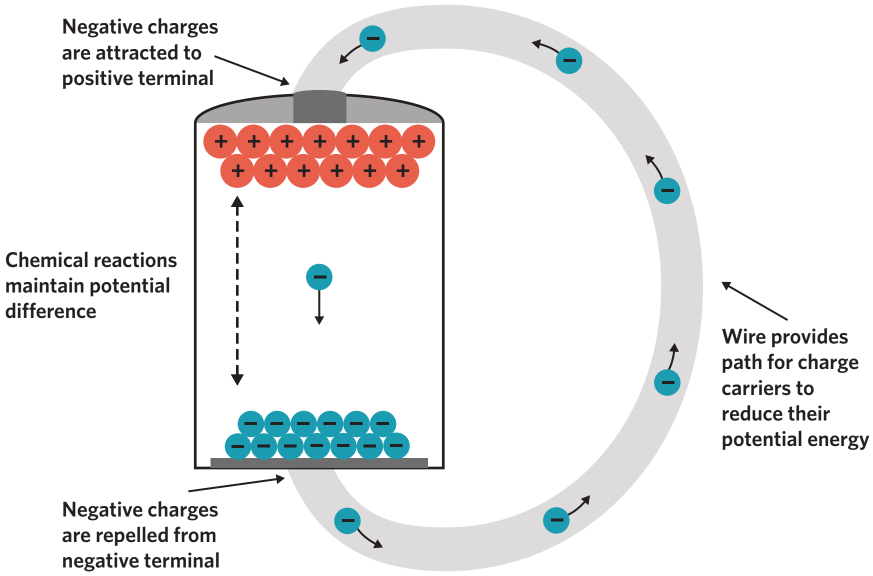

Figure 6 A potential difference provided by a voltage source driving a current

While the rate of electrons around a circuit is actually very slow (in a 4.0 mm^2 copper wire carrying a current of 10 A the electrons only travel 0.2 mm per second), all of the electrons within the circuit start moving almost instantly when the circuit is closed, so the electric signal travels from one terminal to the other very quickly.

Progress questions

Question 5

Which of the following best describes the flow of current in an electric circuit?

A. Charge flowing around a circuit is passed from particle to particle.

B. Charged particles physically flowing around a circuit.

C. The separation of charged particles between two points in a circuit.

D. The force pushing or pulling charged particles around a circuit.

Question 6

A total charge of 10 C moves through a point over 2.0 s. What is the current at that point?

A. 20 A

B. 5.0 A

C. 8.0 A

D. 10 A

Continues →

MISCONCEPTION

'Charge carriers are "used up" in a circuit as they carry their current.'

Charge carriers (like electrons) are not "used up" in a circuit. They transfer their potential energy to the circuit components, but will still remain in the circuit.

USEFUL TIP

By convention, the direction of current is considered to be the direction that positive charge would flow (conventional current) instead of the direction that negative charge flows (electron current). Figure 7 depicts the difference between these. Conventional current is always used unless otherwise stated.

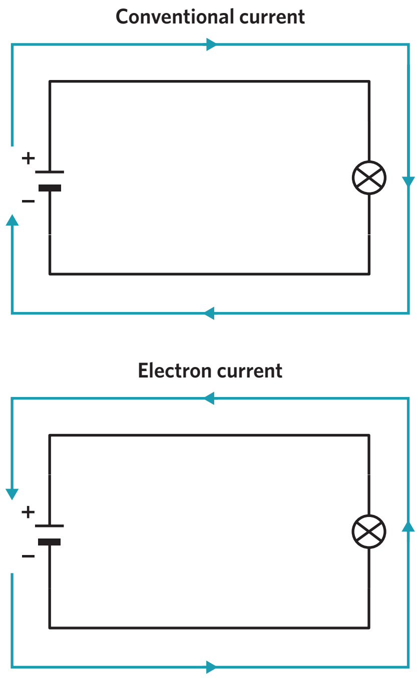

Figure 7 Conventional and electron current directions in a circuit

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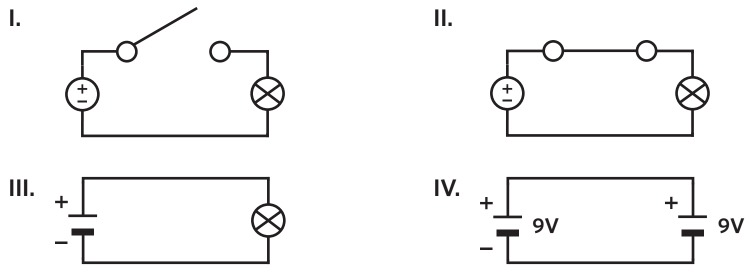
Question 7

In which of the following circuits would an electric current be flowing?
(Select all that apply)



How does power (P) describe electricity?

Electric potential energy can be transformed into other forms of energy like light, thermal energy, movement, and sound by electrical components.

Electric circuits usually involve the transformation of energy between various forms. Figure 8 shows how the chemical energy stored inside a battery is used to create a potential difference, giving electric potential energy to charge carriers in the wire, which is then transformed by the light bulb into light and thermal energy.

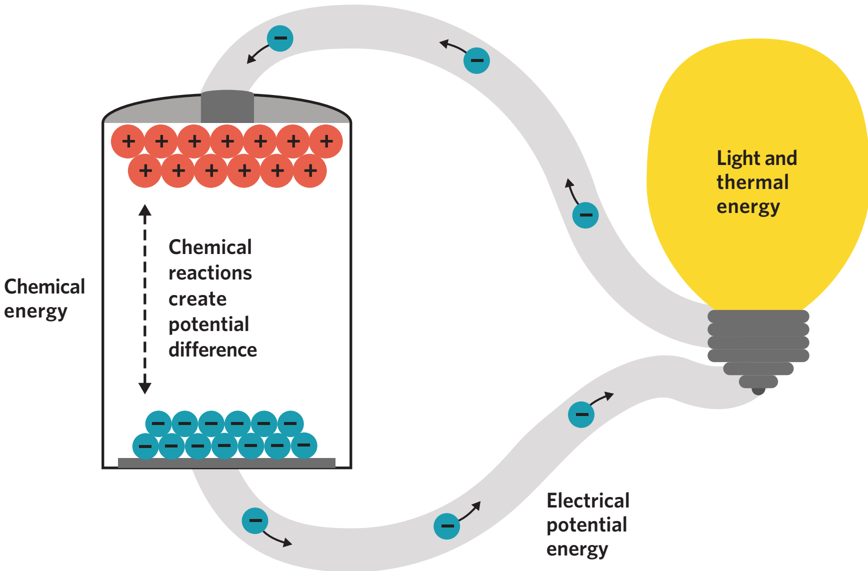


Figure 8 The transformations of energy in a circuit with a light bulb

Power, P, is the rate of transfer of energy with respect to time, and can be calculated using the following formula or the formula triangle in Figure 9. The total amount of power delivered to a circuit is always equal to the total amount that is consumed by the circuit components. Power is measured in Watts (W).

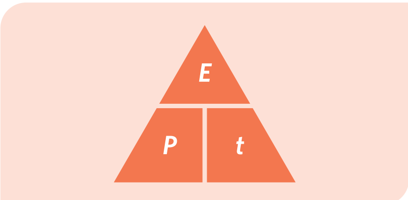


Figure 9 A formula triangle for power

FORMULA

$$P = \frac{E}{t}$$

P = power (W or J s^{-1})
E = energy delivered/consumed (J)
t = time (s)

We can formulate another expression for power. Working in SI units:

- Potential difference is the number of joules per coulomb ($J\ C^{-1}$) across a section.
- Current is the number of coulombs per second ($C\ s^{-1}$) passing through a section.
- So multiplying potential difference, V, by current, I, gives us the number of joules per second consumed in a section, which is the power, P. This relationship is shown explicitly in the following formula and the formula triangle in Figure 10.

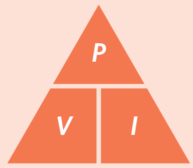


Figure 10 An alternate formula triangle for electric power

FORMULA

$$P = VI$$

P = power (W or $J\ s^{-1}$)
V = potential difference (V)
I = current (A)

STRATEGY

When calculating power from current and voltage, make sure the current and voltage being used correspond to the component, or components, the power is being calculated for.

WORKED EXAMPLE 3

Students are investigating an electric circuit.

a. It is found that a battery transfers 10 J of electric potential energy to the circuit in 5 s. Determine the average power delivered by the battery.

Step 1

Identify the energy transferred and the time taken to transfer, and the formula that relates these variables.

$E = 10$ J, $t = 5$ s, $P = ?$

$P = \frac{E}{t}$

Step 2

Substitute values into the formula and solve for power.

$P = \frac{10}{5}$

$P = 2.0 = 2$ W

b. During operation, the potential difference across a lightbulb in the circuit is 10 V and a current of 0.10 A is passing through it. Determine the average power consumed by the light bulb.

Step 1

Identify potential difference and current, and the formula that relates these variables.

$V = 10$ V, $I = 0.10$ A, $P = ?$

$P = VI$

Step 2

Substitute values into the formula and solve for power.

$P = 10 \times 0.10 = 1.00 = 1.0$ W

c. If the battery is the only source, are there any other components in this circuit, other than the lightbulb, that consume power? Assume the connecting wires do not consume power. Explain your answer.

[Yes, there are components in the circuit other than the lightbulb.[1]][Total power delivered is not equal to the total power consumed by the lightbulb.[2]][Since all of the battery's power is not being consumed by the lightbulb, there must be other components in this circuit consuming this power.[3]]

- I have explicitly addressed there must be other components in the circuit.[1]
- I have used the relevant theory: difference between power delivered and consumed.[2]
- I have referenced that this difference must be due to consumption by other components.[3]

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Progress questions

Question 8

An electrical component has a voltage across it of 5.0 V, and a current through it of 0.50 A. How much power is being delivered to it?

A. 1.0 W

B. 4.5 W

C. 0 W

D. 2.5 W

Question 9

A battery is connected to a closed circuit.

Which of the options best describes the energy and power delivered by the battery over 5 minutes? Note that the battery usually lasts for several hours.

	Energy	Power
A.	The rate of energy delivered to the circuit with respect to time	The energy used by the circuit
B.	The total energy stored inside the battery	The rate energy is delivered to the circuit with respect to time
C.	The energy from the battery transferred to the circuit over the 5 minutes	The rate energy is delivered to the circuit with respect to time

Circuit analogies 1.3.2.1

Some common circuit analogies are those of loops of water and highways.

Theory details

Using analogies for electrical circuits can make understanding circuits and electrical quantities more intuitive, by relating them to everyday concepts.

How can the hydraulic circuit analogy be used to understand electric circuits?

A common analogy for an electric circuit is a loop of pipes with flowing water. Figure 11 represents an electric circuit with a source, switch, wires, and a power consuming component. Table 2 shows how components of the hydraulic circuit represent components of an electric circuit.

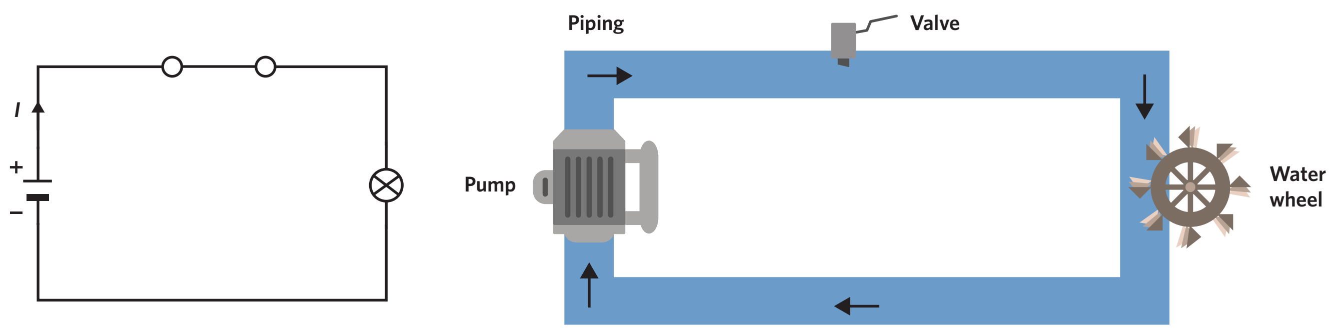

Figure 11 The hydraulic circuit analogy for a circuit containing a voltage source, switch, wires, and a power-consuming component

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Table 2 Electric circuit components in the hydraulic circuit analogy

Hydraulic component	Electric component	Notes
Water pump	Potential difference source (cell, power supply, etc.)	The water pump pushes water around a hydraulic circuit, like a potential difference source drives an electric current.
Piping	Wires	Provides a path for water/charge carriers to flow.
Valve	Switch	Determines whether or not water/current can flow around the circuit
Water wheel	Power consuming component	Uses the energy supplied by the pump/potential difference source.

This analogy models the following key electrical concepts:

- how the potential difference source drives a current through a circuit,
- current requires the physical movement of charge carriers,
- how components transform energy.

How can the highway analogy be used to understand electric circuits?

Another analogy used to understand electric circuits is a loop of one way road filled with cars. Figure 12 represents an electric circuit with a source, wires, and switch. Table 3 shows how different elements on this highway represent components of electric circuits.

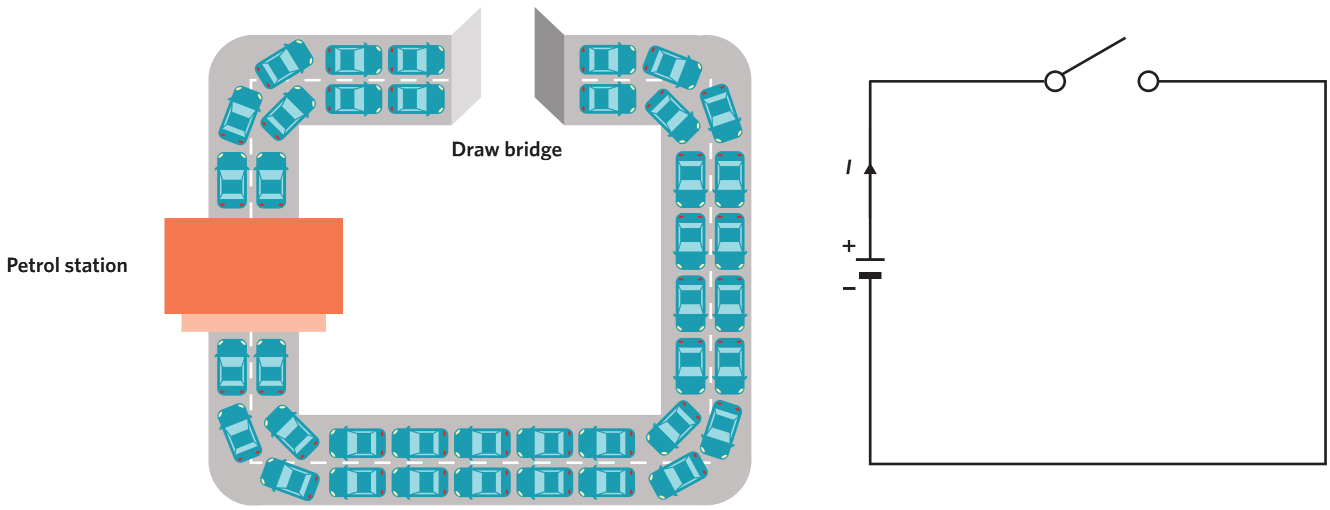

Figure 12 The highway analogy for a circuit with a voltage source, wires, and switch

Table 3 Electric circuit components in the highway analogy

Highway component	Electric component	Notes
Petrol station	Potential difference source	Provides energy to push the cars/charge carriers around the loop.
Roads	Wires	Provides a path for cars/charge carriers to flow.
Draw bridge	Switch	Determines whether or not cars/charge carriers can move around the loop.

This analogy models the following key electrical concepts:

- how voltage sources provide energy to a circuit,
- that current requires the physical movement of charge carriers,
- that current moves through the whole circuit simultaneously.

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Progress questions

Question 10

Fill in the blanks in the following paragraph.

In the hydraulic circuit analogy, the __________ (water/pipes) represents the charge carriers. The pump, analogous to a voltage source, provides it with __________ (charge/energy), which is then transferred to the __________ (water wheel/valve) as it passes through. This is analogous to the delivery of energy to a __________ (power-consuming component/switch).

Question 11

Fill in the blanks in the following paragraph.

In the highway analogy, the __________ (cars/petrol) represent the charge carriers. The petrol station, analogous to a voltage source, provides them with __________ (charge/energy). Since the cars are so close together, for them to move __________ (all/some) of them have to move at once. This is similar to how, in a circuit, charge carriers move simultaneously.

Measuring electrical quantities 1.3.4.1

To measure electrical quantities, specialised equipment must be used in specific configurations.

Theory and applications

When performing real-world circuit analysis, measuring electrical quantities can indicate whether components and circuits are operating as intended, or be used to obtain other electrical information.

How are voltage and current measured in electric circuits?

A voltmeter is used to measure potential difference. To measure the potential difference between two locations, one probe of the voltmeter must be connected to each location, as shown in Figure 13. This is known as a parallel connection, and the voltmeter's reading is a measurement of the potential difference across the probed locations.

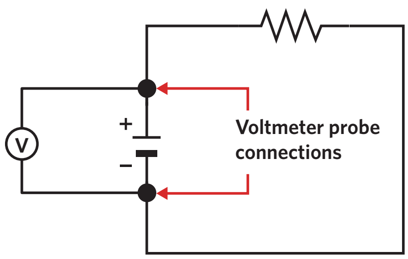

Figure 13 Using a voltmeter to measure the potential difference across a cell in a circuit

An ammeter is used to measure current. To measure the current through a component, the ammeter must be connected end-to-end in the circuit either before or after the component, as shown in Figure 14. This is known as a series connection. The ammeter's reading is a measurement of the electric current through the ammeter.

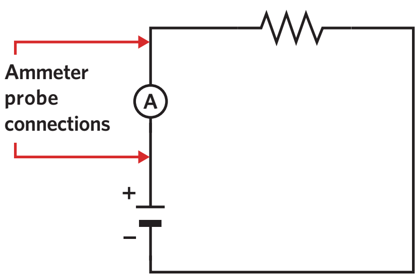

Figure 14 Using an ammeter to measure the current through a cell in a circuit

Devices that can be used to measure a range of electrical quantities are called multimeters. To measure a quantity with a multimeter, select the desired quantity on the meter and connect the probes to the circuit the same way a regular meter (a voltmeter or ammeter, for example) would be connected for that quantity, as shown in Figure 15.

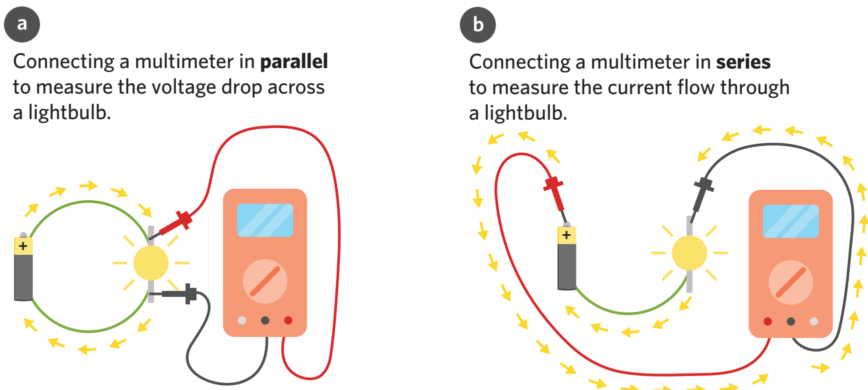

Figure 15 Using a multimeter to measure **(a)** voltage and **(b)** current across a component

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Progress questions

Question 12

Which of the following correctly describes the electrical quantities that each meter measures?

	Ammeter	Voltmeter	Multimeter
A.	Potential difference	Potential difference, current	Current
B.	Potential difference, current	Current	Potential difference
C.	Current	Potential difference	Potential difference, current

Question 13

Which of the following correctly describes how each meter should be connected to a circuit to measure the desired quantity?

	Ammeter	Voltmeter	Multimeter
A.	Series	Parallel (potential difference), series (current)	Parallel
B.	Series	Parallel	Parallel (potential difference), series (current)
C.	Series (potential difference), parallel (current)	Series	Parallel

Theory summary

- Electric circuits are closed conducting loops.
- Five key electrical quantities: charge, potential difference, current, energy, and power, have properties given in the following table.

Electrical quantity	Formula	Units	Additional notes
Charge		C	A fundamental property of particles.
Electric potential energy		J	Supplied by voltage sources, consumed by electrical loads.
Potential difference	$V = \frac{E}{Q}$	V or J C^{-1}	Also referred to as voltage.
Current	$I = \frac{Q}{t}$	A or C s^{-1}	Driven by potential difference, is not "used up" around a circuit.
Power	$P = \frac{E}{t} = VI$	W or J s^{-1}	

- The hydraulic circuit and highway analogies reinforce key electrical concepts.
- Voltmeters measure voltage, and should be connected in parallel across the locations they are measuring.
- Ammeters measure current, and should be connected in series with the part of the circuit they are measuring.
- Multimeters can measure voltage or current, and should be connected in parallel to measure voltage and series to measure current, in the same way a voltmeter or ammeter would be.

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The content in this lesson is considered fundamental prior knowledge to generation of electricity and transmission of electricity (Unit 3 AOS 3).

CONCEPT DISCUSSION

Two batteries with the same milliamp hour (mA h) rating are being used to power two circuits. Circuit *X* draws twice as much current from its battery compared to Circuit *Y*. Discuss what electrical quantity a mA h rating measures, and explain why the two batteries will run out at different times.

Prompts:

- What equation relates the two quantities of milliamp (mA) and hours (h)?
- How does the current in a circuit relate to how quickly a battery will run out of charge?

6A Questions

Mild 🌶 Medium 🌶🌶 Spicy 🌶🌶🌶

Deconstructed exam-style

Use the following information to answer questions 14-17.

When welding metal, large amounts of energy are required to heat the metal. A particular weld takes 2.0 s and uses 400 kJ of energy. The potential difference of the voltage source in the welder is 40 kV. There is only one power consuming component in the welding equipment.

Question 14 (1 MARK) 🌶

Which equation correctly relates potential difference, energy, and charge?

A. $V = \frac{E}{Q}$

B. $V = EQ$

C. $V = \frac{Q}{E}$

D. $\mathrm{E} = \frac{Q}{V}$

Question 15 (1 MARK) 🌶

Which equation correctly relates power, energy, and time?

A. $P = VI$

B. $t = PE$

C. $P = \frac{E}{t}$

D. $E = \frac{P}{V}$

Question 16 (1 MARK) 🌶

Which statement correctly describes power in an electrical circuit, assuming wires do not consume power?

A. Some power will be consumed by electrical loads, some will dissipate as energy is destroyed.

B. If there is only one electrical load, it will consume all the power in the circuit.

C. If there is only one electrical load, it will not consume any power.

D. none of the above

Question 17 (4 MARKS) 🌶🌶🌶

Determine the power delivered to the load in the welding equipment, per coulomb of charge that moved through it.

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Exam-style

Question 18 (2 MARKS)

Determine the electric potential energy of a 3.0 C charge after it passes through a 5.0 V phone charger.

Question 19 (6 MARKS)

An electric drill that consumes 220 W of power is driven by a 20 V ideal battery.

a. What is the operating current of the drill? (2 MARKS)

b. Jane uses the drill for 12 s to create a hole. How much energy is delivered by the battery to the drill in this period? (2 MARKS)

c. How many electrons pass through a single point in the drill's circuit during the 12 s? The magnitude of an electron's charge is $e = 1.6 \times 10^{-19}$ C. (2 MARKS)

Question 20 (2 MARKS)

Circuit analogies use real life objects and concepts to represent components or processes that function similarly in electric circuits.

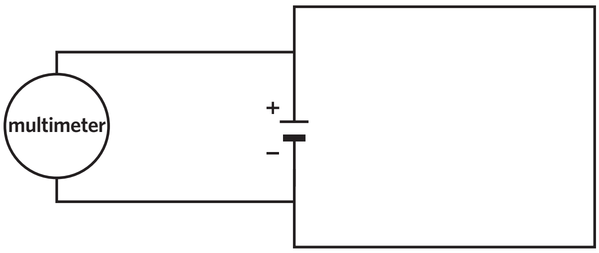
a. Along a closed loop of road, a camera is installed that records how many cars are moving past it at a given time. In the highway analogy, cars are analogous to charge carriers. What would be the analogous electric circuit component for this camera? (1 MARK)

b. In a hydraulic circuit, the pump is removed and replaced with a much stronger pump. What would this be analogous to in an electric circuit? (1 MARK)

Question 21 (2 MARKS)

Two circuits have multimeters connected to them, as shown in the following diagram. Determine which electrical quantity they should be measuring in each circuit.

a.



(1 MARK)

b.

(1 MARK)

Question 22 (3 MARKS)

Determine the voltage supplied to a light bulb that uses 3.6 kJ of energy every hour and draws 2.0 A of current.

Question 23 (3 MARKS)

Describe the flow of energy from the battery and through the circuit shown in the diagram. Make sure to reference where energy is stored, transferred, and transformed.

Question 24 (6 MARKS)

A cell delivers 10 W of power to an electrical component. The component is replaced with a different device that uses 20 W of power when connected to the cell.

a. Determine the time it would take for the replacement component to use the same amount of energy as the first component would in 8.0 s. (3 MARKS)

b. Compare and explain the voltage and current across/through each component. Justify your answer by referencing a property of an ideal source of potential difference. (3 MARKS)

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Question 25 (2 MARKS)

A common cause of power blackouts is a flashover, which occurs when electricity arcs through the air between power lines and surrounding objects. A particular arc lasts 0.50 s and delivers 500 MJ of energy to the ground. Determine the amount of charge transferred from the power line by this arc if the power line voltage is 66 kV.

Question 26 (3 MARKS)

Josie and Kendall are debating how electric current flows. Josie states that current can flow without the physical movement of particles, while Kendall states that current requires the physical movement of charged particles. Who is correct – Josie or Kendall? Explain your answer.

Question 27 (4 MARKS)

A fibre-optic transmission line has a length of 3.0 km. The material in the line causes the power to be halved for each kilometre it travels along it. The minimum power that can be detected clearly by the receiver is 2.0 μW. The laser at the other end only operates with a current of 4.0 mA. Calculate the minimum voltage required in the laser for the signal to be clearly received.

Adapted from VCAA 2011 Exam 2 Detailed study 2 Q12

Key science skills

Question 28 (5 MARKS)

Cici T. Vee records the current passing through her security camera network at a range of power settings.

Power (W)	Current (mA)
20	94
30	120
50	225
100	420

a. Plot Cici's data on a power vs current graph. Include a line of best fit. (3 MARKS)

b. Using the graph, determine the voltage at which the camera network is operating. (2 MARKS)

FROM LESSONS 11D & 11E

Previous lessons

Question 29 (5 MARKS)

An unknown liquid is found to have a specific heat capacity of 6.3×10^3 J kg^{-1} K^{-1}.

a. Calculate the energy it would take to increase the temperature of 1.2 kg of this liquid from 20°C to 40°C. (2 MARKS)

b. The specific heat capacity of water is 4200 J kg^{-1} K^{-1}. A kilogram of water and a kilogram of the unknown liquid are heated to 50.0°C and are left to cool. Assuming both release heat at the same rate, which do you expect to reach room temperature first? Explain your answer. (3 MARKS)

FROM LESSON 2C

Question 30 (1 MARK)

Which of the following statements correctly describes the binding energy curve?

A. Binding energy per nucleon increases as nucleon number increases.

B. Binding energy per nucleon decreases as nucleon number increases.

C. Binding energy per nucleon generally increases as nucleon number increases until Ni-62, after which it generally decreases.

D. Binding energy per nucleon generally decreases as nucleon number increases until Ni-62, after which it generally increases.

FROM LESSON 5A

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6B Resistance and Ohm's Law

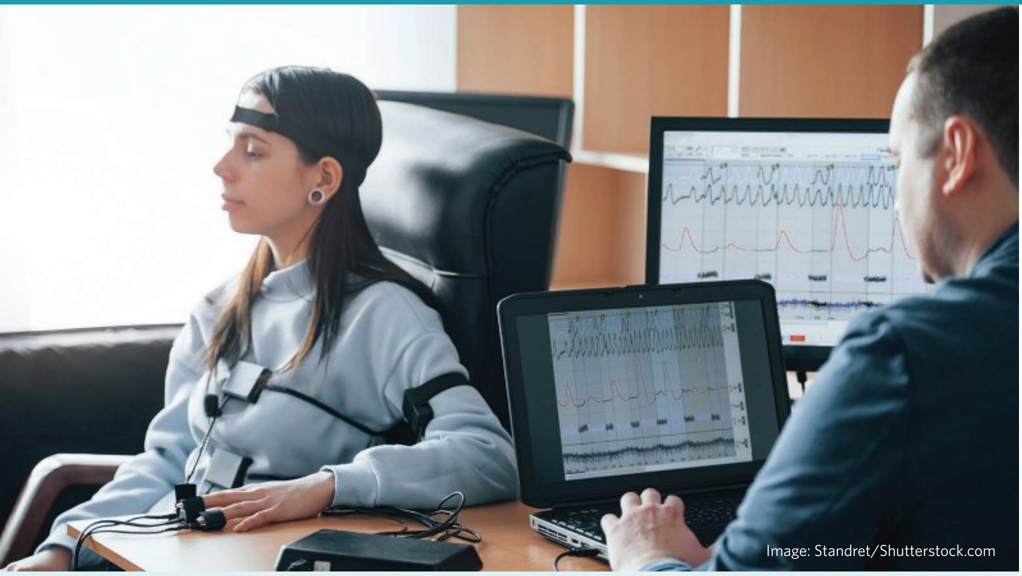

Image: Standret/Shutterstock.com

How is emotional response measured in polygraph tests?

How electrical circuits are constructed affects how voltage and current are distributed across them, which in turn affects how energy is carried through the circuit. This lesson will introduce the electrical quantity of resistance, as well as Ohm's Law, an important equation that links potential difference, resistance, and current. Ohm's Law is an important tool for understanding the circuits explored in Chapters 6 and 7.

STUDY DESIGN DOT POINT

- model resistance in series and parallel circuits using:
  - current versus potential difference (*I*-*V*) graphs
  - resistance as the potential difference to current ratio, including *R* = *constant* for ohmic devices

6A 6B 6C 6D 6E

1.3.6.1 Electrical resistance

1.3.6.2 Ohm's Law

ESSENTIAL PRIOR KNOWLEDGE

6A Current and voltage

See question 34.

ACTIVITIES

Log into your Edrolo account for activities that support this lesson.

KEY TERMS AND DEFINITIONS

ohmic device an electrical component that has a constant resistance for all voltages

resistance (electrical) a measure of an object's opposition to the flow of electric current

resistor an ohmic device with a fixed resistance that opposes the flow of electric current and causes a drop in voltage

FORMULAS

- **Ohm's Law**
  $V = IR$
- **electric power**
  $P = VI = I^2R = \frac{V^2}{R}$

Electrical resistance 1.3.6.1

Electrical resistance describes how difficult it is for current to flow through an electrical component. An object's resistance is determined by the material it is made from and the geometry of the object.

Theory and applications

Knowledge of resistance allows electrical components to be crafted with particular specifications, depending on how circuits are intended to function, and is useful in conducting circuit analysis.

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What is electrical resistance?

Electrical resistance, R (measured in Ohms Ω), is a measure of an object's opposition to the flow of current. It depends on the material that the object is made of, as well as the size and shape of the object.

Resistors are electrical components with a fixed resistance that are used in a circuit to limit and control the flow of current,[1] which is often necessary to prevent damage to the circuit components. They convert the electric potential energy of charge carriers flowing through them into thermal energy, and are often made from long coils of wire or materials such as carbon and metal oxide films.

It is helpful to model other electrical components like lightbulbs, heaters, and even devices like phone chargers as resistors for the purposes of circuit analysis. Resistors can be recognised in physical circuits by their colour bands that denote their resistance value, as shown in Figure 1. In circuit diagrams, resistors may be represented using either of the two symbols in Figure 2.

KEEN TO INVESTIGATE?

[1] **Why do resistors decrease current in adjacent parts of the circuit?**
Search YouTube: Does current decrease as it passes through a resistor?

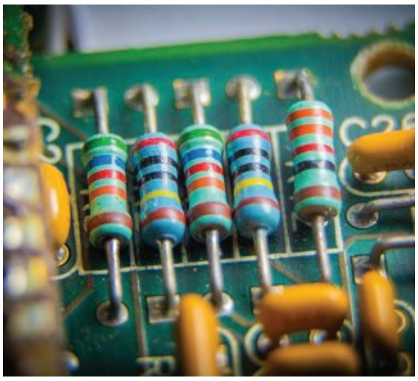

Image: TonStocker/Shutterstock.com

Figure 1 Resistors in a circuit

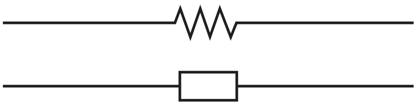

Figure 2 Resistor circuit symbols

Progress questions

Question 1

Which of the following statements about resistance is correct?
(Select all that apply)

I. Resistance is a measurement of how much an object resists the flow of current.

II. Resistance is a measurement of how much a material resists the flow of current.

III. If an object has a high resistance then current flows through it easily.

IV. An object's resistance depends on its material as well as its shape and size.

Question 2

Which of the following statements about a resistor is incorrect?

A. A resistor dissipates energy in the form of thermal energy.

B. A resistor adds energy to a circuit.

C. A resistor limits the flow of current in a circuit.

D. A resistor reduces the rate of movement of charge.

Ohm's Law 1.3.6.2

Ohm's Law relates the voltage and current across an electrical component to that component's electrical resistance.

Theory and applications

Ohm's Law can be used to analyse a variety of electrical circuits and determine any of voltage, current, and resistance (provided the other two quantities are known). This method of analysis can be used to measure indicators of emotional or psychological state.

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How are voltage, current, and resistance related?

Figure 3 shows Ohm's Law as a formula triangle.

FORMULA

$V = IR$

V = potential difference (V)
I = current (A)
R = resistance (Ω)

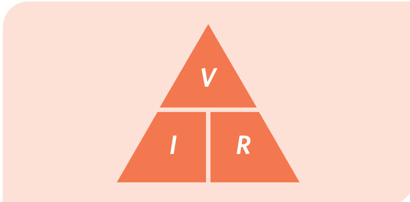


Figure 3 The formula triangle for Ohm's Law

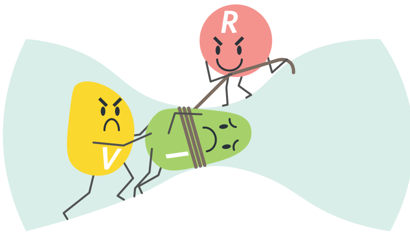


Figure 4 An illustrative representation of Ohm's Law

Note that the relationship between current and potential difference described by Ohm's Law is positive and linear. This means that if a higher potential difference is applied across a resistor, a higher current will flow. Figure 4 gives an illustration of how the quantities in Ohm's Law relate to one another.

Ohm's Law can be rearranged to give $R = \frac{V}{I}$, which shows that the resistance of a component will be the ratio of the potential difference across the component to the current flowing through it.

An ohmic device is an electrical component that has a constant resistance for all voltages, so regardless of the voltage or current through it, it will have the same resistance. Resistors and wires are ohmic devices. Despite often being modelled as resistors, many light bulbs such as LEDs are non-ohmic devices.

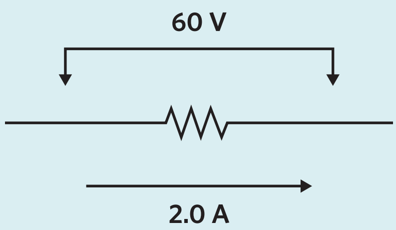
Ohm's Law is used to measure electrodermal activity, or skin conductance, by applying a voltage across a section of human skin and measuring the current passing through to detect minute changes in the resistance of the skin. Skin conductance is affected by emotional state, and so it is sometimes used (along with other measurements) in psychological studies and polygraph tests as an indicator of emotional response.

USEFUL TIP

Ohm's Law can be used to derive alternative expressions for electrical power. Substituting $V = IR$ and $I = \frac{V}{R}$ into $P = VI$, we obtain $P = I^2R$ and $P = \frac{V^2}{R}$.

WORKED EXAMPLE 1

When a potential difference of 60 V is applied across a resistor, a 2.0 A current is measured to pass through it.



a. Determine the resistance of the resistor.

Step 1

Identify the potential difference and current flowing through the circuit, and Ohm's Law that relates these variables.

$V = 60$ V, $I = 2.0$ A, $R = ?$

$V = IR$

Step 2

Substitute values into the formula and solve for resistance.

$60 = 2.0 \times R$

$R = \frac{60}{2.0} = 30\ \Omega$

b. Assuming the resistor is an ohmic device, what potential difference would drive a current of 0.50 A through the resistor?

Step 1

Identify the resistance and current flowing through the resistor, and Ohm's Law that relates these variables.

$I = 0.50$ A, $R = 30\ \Omega$, $V = ?$

$V = IR$

Step 2

Substitute values into the formula and solve for potential difference.

$V = 0.50 \times 30$

$V = 15$ V

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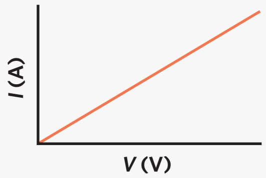
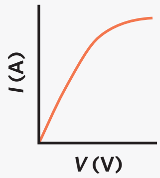
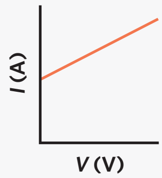
Collecting and plotting data on the current through an electrical component for various voltages gives an *I-V* graph, or a current-voltage graph. These can be used to determine the component's resistance at various voltages as well as whether or not it is ohmic.

Rearranging Ohm's Law into the form $I = \frac{V}{R}$ shows that an *I-V* graph for an ohmic device will have gradient $\frac{1}{R}$, since voltage is the independent variable (plotted on x-axis) and current the dependent variable (plotted on y-axis). Table 1 gives examples of *I-V* graphs for ohmic and non-ohmic devices, and the features of each.

USEFUL TIP

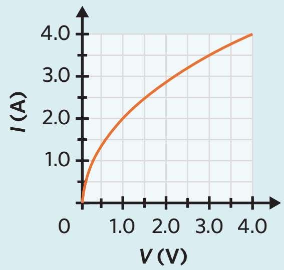
The *I-V* graph for an ohmic device will always pass through the origin, since when $V = 0$, Ohm's Law gives $IR = 0$. R is constant and non-zero so it must be that $I = 0$ when $V = 0$.

Table 1 *I-V* graphs for ohmic and non-ohmic devices

Device type	Ohmic	Non-ohmic
Example graphs		 
Graph features	Linear (constant gradient) and passes through the origin	Non-linear (varying gradient) or does not pass through the origin

WORKED EXAMPLE 2

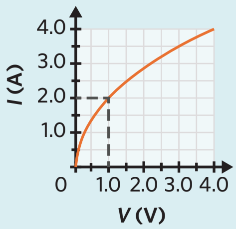
The *I-V* graph for an electrical component is shown. Determine the resistance of the electrical component when a potential difference of 1.0 V is applied across it.



Step 1

Identify the relevant point on the graph to obtain the current when $V = 1.0$ V.

When $V = 1.0$ V, $I = 2.0$ A



Step 2

Identify the potential difference and current flowing through the resistor, and Ohm's Law that relates these variables.

$V = 1.0$ V, $I = 2.0$ A, $R = ?$

$V = IR$

Step 3

Substitute values into the formula and solve for resistance.

$1.0 = 2.0 \times R$

$R = \frac{1.0}{2.0} = 0.50\ \Omega$

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Progress questions

Question 3

A resistor, with resistance $R = 6.0\ \Omega$, has a current $I = 1.5$ A flowing through it. What is the potential difference across the resistor?

A. 9.0 V

B. 4.0 V

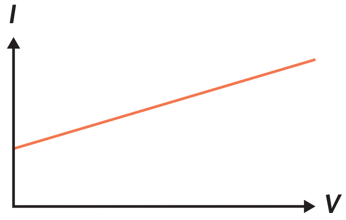
C. 5.0 V

D. 0 V

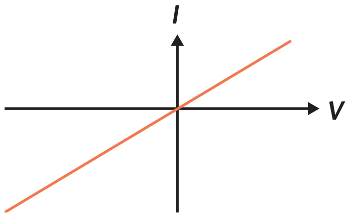
Question 4

Which of the following *I*-*V* graphs represent an ohmic device?
(Select all that apply)

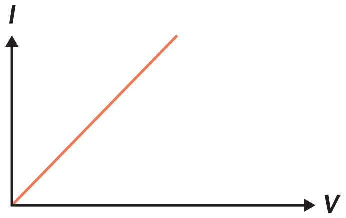
I.



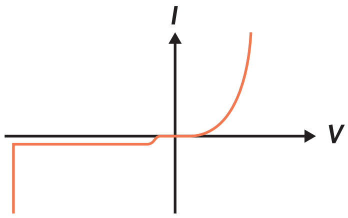
II.



III.



IV.



Theory summary

- Resistance, *R*, is a measure of how much an object opposes the flow of electric current.
  - Resistance depends on an object's material and geometry.
- Resistors are electrical components used to add resistance to a circuit.
  - Resistors dissipate thermal energy.
- Ohm's Law, $V = IR$, describes the relationship between voltage, current and resistance
- Ohmic devices have a constant resistance for all voltages.
- Resistance is the ratio of current to potential difference, $R = \frac{I}{V}$.
  - *I*-*V* graphs of ohmic devices have a constant gradient, $\frac{1}{R}$, and pass through the origin.
  - *I*-*V* graphs of non-ohmic devices have a varying gradient and may not pass through the origin.

KEEN TO INVESTIGATE?

What does Ohm's Law look like for individual electrons?

Search: Hyperphysics microscopic view of Ohm's Law

The content in this lesson is considered fundamental prior knowledge to generation of electricity and transmission of electricity (Unit 3 AOS 3).

CONCEPT DISCUSSION

Under certain conditions, it is possible to make superconducting components, electrical components that have zero resistance. Using Ohm's Law, predict what the voltage drop across and power used by a superconducting component would be. What might happen if we constructed electrical loads or wires only out of superconductors?

Prompts:

- If $V = IR$ and $R = 0\ \Omega$ for a component, what will the voltage drop across the component be?
- If $P = IV$ and $V = 0$ V across a component, what will the power used by the component be?
- If electrical components do not use any power, how might they operate?

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6B Questions

Mild Medium Spicy

Deconstructed exam-style

Use the following information to answer questions 5–8.

Students are provided with an unknown resistor that has a constant resistance for all potential differences. The students are instructed to plot an *I*-*V* graph for the resistor.

Question 5 (1 MARK)

What is a device that has a constant resistance for all potential differences called?

A. constant current device

B. non-ohmic device

C. ohmic device

D. constant voltage device

Question 6 (1 MARK)

Which of the following best describes the gradient of an *I*-*V* graph for such a device?

A. negative and constant

B. positive and constant

C. positive and varying

D. negative and varying

Question 7 (1 MARK)

Which, if any, of the following are true for *I*-*V* graphs of ohmic devices?

A. must be a horizontal line

B. must pass through the origin

C. must not pass through the origin

D. none of the above

Question 8 (3 MARKS)

Sketch an *I*-*V* graph for this resistor. Your graph does not need to include values, but axis labels and appropriate units should be included.

Exam-style

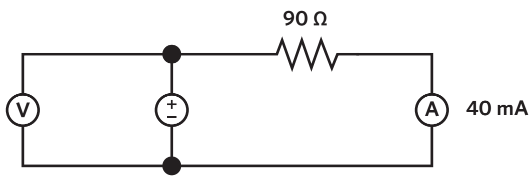
Question 9 (2 MARKS)

When a 12 V potential difference is applied across a resistor, it drives a current of 0.20 A. Determine the resistor's resistance.

Question 10 (2 MARKS)

A current of 40 mA is measured by the ammeter in the circuit shown.

Determine the potential difference that will be measured by the voltmeter.



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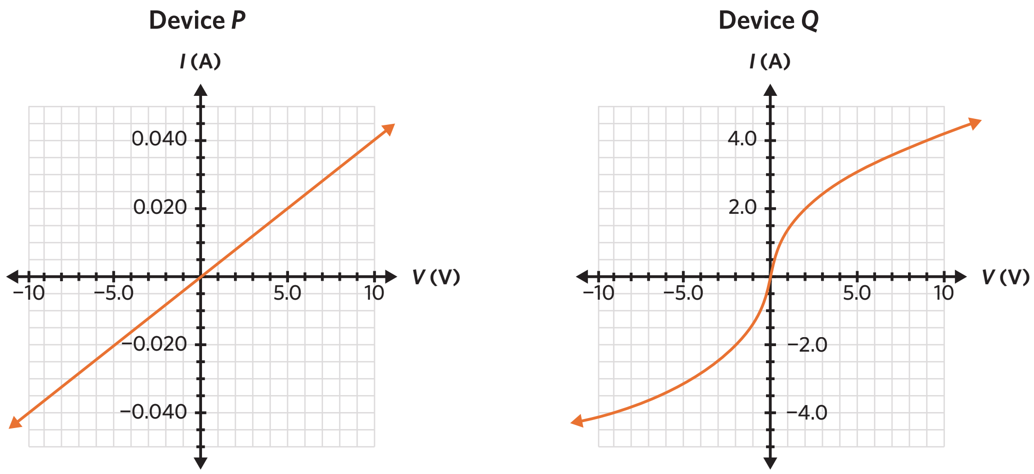
Question 11 (5 MARKS)

I-V graphs are produced for two electrical devices *P* and *Q*.



a. Which of the devices is ohmic? (1 MARK)

b. Use the graph for device *P* to determine its resistance. (2 MARKS)

c. Use Ohm's Law to determine the resistance of device *Q* when the voltage applied is 5.0 V. (2 MARKS)

Question 12 (2 MARKS)

A component of a circuit has a resistance of 12 μΩ.

Determine the current when a potential difference of 900 V is applied across the component.

Question 13 (3 MARKS)

When an ohmic device with resistance *R* is connected to an ideal source with potential difference *V*, a current of *I* flows through it.

a. If the potential difference were to triple what would the resulting current be? (1 MARK)

b. If the resistance were to double, what would the current across the device be? (1 MARK)

c. If the resistance were to double, what would the potential difference across the device be? (1 MARK)

Question 14 (4 MARKS)

Students set up four different circuits, and the information in the following table is obtained from each. Use Ohm's Law to determine the missing value for each circuit.

	Circuit 1	Circuit 2	Circuit 3	Circuit 4
Potential difference	12 V		5.4 V	9.6 V
Current	6 A	30 mA		320 mA
Resistance		44 Ω	9 Ω	

Question 15 (3 MARKS)

3.0 A of current flows through an ohmic phone charger when an ideal 60 V source is connected. Determine the current that would flow through the charger if it was connected to an ideal 45 V source.

Question 16 (4 MARKS)

Two students Max and Daisy are constructing circuits in their physics class, and they are each using different types of resistors. Max says that his resistors will have a higher resistance than Daisy's because they are made out of a material with higher resistivity. Daisy replies that that is not necessarily the case, because the geometry of their resistors is also different. Explain who is correct and why.

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Key science skills

Question 17 (6 MARKS)

Elle Ektrik is experimenting with two resistors of unknown resistance. She produces the following data with a high level of confidence:

	Current (mA)	
Voltage (V)	**Resistor 1**	**Resistor 2**
1.5	70	40
3.0	160	80
4.5	230	110
6.0	280	150

a. Plot the data on an *I*-*V* graph. Be sure to include axis labels, appropriate units, and lines of best fit. Label each line of best fit with the corresponding resistor number. (5 MARKS)

b. Without using calculations, determine which resistor has a greater resistance. (1 MARK)

FROM LESSONS 11D & 11E

Previous lessons

Question 18 (1 MARK)

In which region of the electromagnetic spectrum do objects at room temperature radiate the most?

FROM LESSON 3A

Question 19 (3 MARKS)

A new nuclear plant is being designed, and some nuclear scientists are being consulted about the design of the reactor. It can either be designed to hold fissile masses in the shapes of spheres or thin cylinders. Which of these shapes would require less fissile fuel to reach a state of criticality? Justify your answer.

FROM LESSON 5B

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6C Series circuits

Image: Maria Kozharskaya/Shutterstock.com

How does current flow through a set of string lights?

In this lesson we will introduce the series (end to end) connection of components and the equivalent resistance these components provide. Using this, we will analyse how voltage, current and power behave in a series circuit.

STUDY DESIGN DOT POINTS

- model resistance in series and parallel circuits using:
  - current versus potential difference (I–V) graphs
  - resistance as the potential difference to current ratio, including $R = constant$ for ohmic devices
  - equivalent resistance in arrangement in series: $R_{equivalent} = R_1 + R_2 + ... + R_n$ and parallel: $\frac{1}{R_{equivalent}} = \frac{1}{R_1} + \frac{1}{R_2} + ... + \frac{1}{R_n}$
- compare power transfers in series and parallel circuits

6A 6B 6C 6D 6E

1.3.6.3 Equivalent resistance in series circuits

1.3.10.1 Current, voltage, and power in series circuits

KEY TERMS AND DEFINITIONS

equivalent resistance the effective resistance when two or more resistive components are treated as one component

series circuit an electric circuit that has only series connections

series connection a connection of components from end to end

ESSENTIAL PRIOR KNOWLEDGE

6A Electric circuit diagrams
6A Electric power
6B Resistance and Ohm's Law
11D Proportional variables

See questions 35–38.

FORMULAS

- **electric power**
  $P = VI$
- **Ohm's Law**
  $V = IR$
- **equivalent series resistance**
  $R_{equivalent} = R_1 + R_2 + ... + R_n$

ACTIVITIES

Log into your Edrolo account for activities that support this lesson.

Equivalent resistance in series circuits 1.3.6.3

A series circuit contains components that are all connected end to end. The equivalent resistance of series resistors is the sum of their individual resistances.

Theory and applications

Equivalent resistance is a useful tool in analysing series circuits, and building complex circuits with multiple components.

How can we determine the equivalent resistance in series circuits?

Components in series are connected end to end, either directly or by conducting wires. When all the components in a circuit are connected by a single pathway, this is called a series circuit. Figure 1 shows two examples of series circuits.

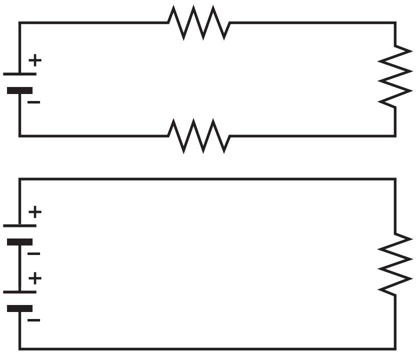


Figure 1 Two series circuits

The particular arrangement of the electrical components in a series circuit does not affect the behaviour of the circuit. When solving problems with complex series circuits, reordering components can help to make circuits appear more familiar, as seen in Figure 2.

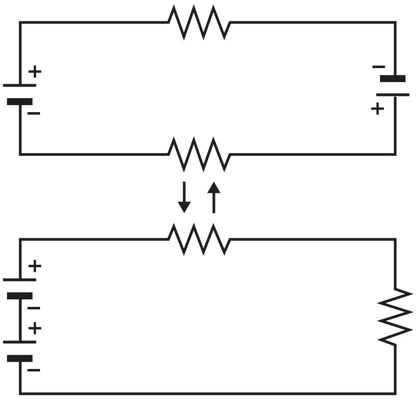


Figure 2 Alternative arrangements for series circuits

For resistors in series, the equivalent resistance is equal to the sum of each individual resistance, and can be used to simplify the resistive components of the circuit as one single resistance. In Figure 3, R_1, R_2 and R_3 are combined so the circuit has one equivalent resistor, R_{eq}.

FORMULA

$$R_{equivalent} = R_1 + R_2 + \ldots + R_n$$

$R_{equivalent}$ = equivalent series resistance (Ω)

$R_1, R_2, \ldots, R_n$ = individual resistance of component n (Ω)

USEFUL TIP

In this book, we will use R_T to refer to the equivalent resistance of all components (that do not supply voltage) in a circuit. We will use R_{eq} to refer more generally to equivalent resistance of any given group of components.

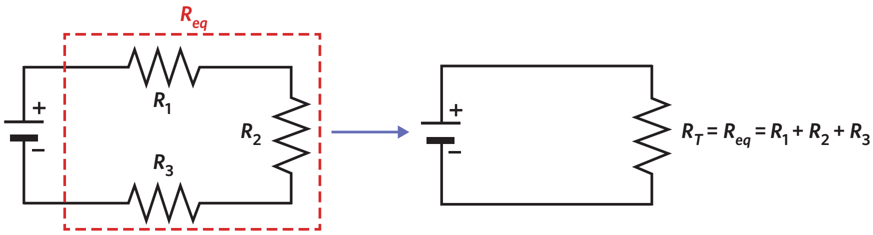
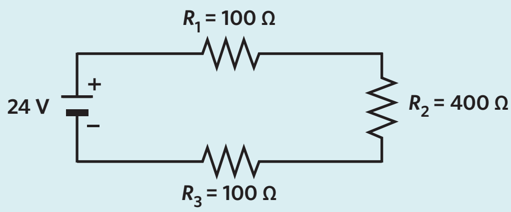


Figure 3 Replacing three resistors in series with one equivalent resistance

WORKED EXAMPLE 1

An ideal cell is delivering power to a series circuit containing three resistors. Determine the equivalent resistance of the three resistors.



Step 1

Identify the resistance of each of the circuit components, and the equation that relates them.

$R_1 = 100\ \Omega$, $R_2 = 400\ \Omega$, $R_3 = 100\ \Omega$, $R_{eq} = ?$

$R_{eq} = R_T = R_1 + R_2 + R_3$

Step 2

Substitute the values in and solve for the equivalent resistance of the three resistors in the circuit.

$R_T = 100 + 400 + 100 = 600\ \Omega$

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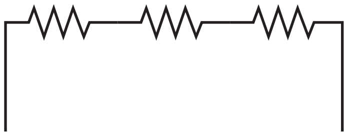
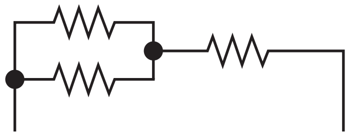
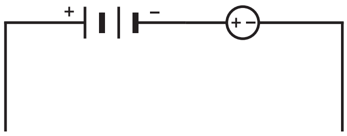
Progress questions

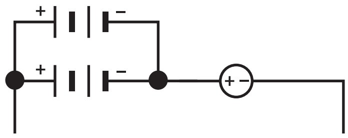
Question 1

Which of the following sets of components are connected only in series?
(Select all that apply)

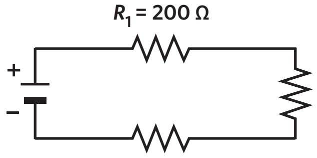
I.


II.


III.


IV.


Use the following information to answer questions 2 and 3.



Question 2

What is the equivalent resistance of the circuit?

A. 200 Ω

B. 450 Ω

C. 340 Ω

D. 1050 Ω

Question 3

What is the equivalent resistance of resistors R_2 and R_3?

A. 50 Ω

B. 200 Ω

C. 850 Ω

D. 1050 Ω

Current, voltage, and power in series circuits 1.3.10.1

Series circuit analysis allows us to predict the behaviour of series circuits. We will use Ohm's Law to investigate the relationship between current, voltage, and power in series circuits. Series connections for voltage sources are used in battery powered toys and decorative string lights so they receive a higher voltage.

Theory and applications

We can use series circuit analysis as a foundation for more complex circuits and to gain an understanding of how everyday electrical items work.

How are current and voltage modelled in series circuits?

In a series circuit there is only one path for current to flow. This means that the current is equal at all points around a series circuit, as demonstrated in Figure 4. As we learnt in Lesson 6A, this is similar to how the flow rate of water in a loop of pipe is the same at all points around the pipe.

MISCONCEPTION

'Current is "used up" as it travels through a series circuit.'

If this were the case, two identical light bulbs connected in series would have different brightnesses within the same circuit. Current is supplied equally to all components in a series circuit.

The current in a series circuit is determined by the total voltage being supplied, V_T, and the equivalent resistance of the whole load, R_T, using Ohm's Law.

$$I = \frac{V_T}{R_T}$$

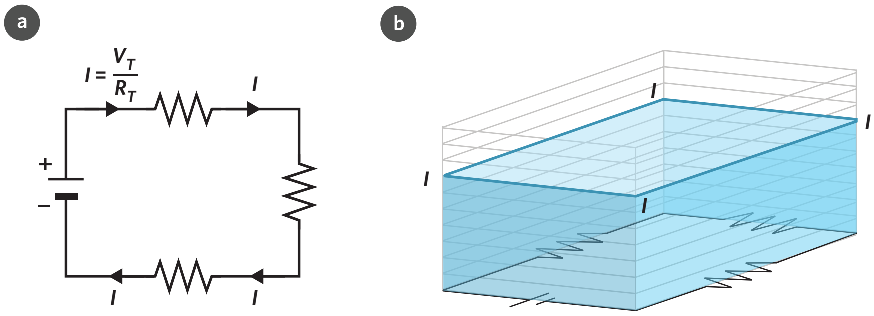


Figure 4 (a) A series circuit and (b) the current around the circuit.

KEEN TO INVESTIGATE?

1 **How does voltage change throughout a series circuit?**
Search YouTube: Series circuits explained

Voltage, unlike current, is not constant at all points throughout a series circuit, see Figure 5.[1]

- The voltage supplied to a series circuit, V_T, is the sum of the voltages supplied by each voltage source in the circuit.
- The voltage drop across the entire load is the sum of the voltage drops across each component in the load,

$$V_{load} = V_1 + V_2 + \ldots + V_n.$$

- The voltage drop across the load of the circuit is always equal to the voltage supplied. $V_{load} = V_T$
- We can use the equation $I = \frac{V_T}{R_T}$ to determine current in the circuit.

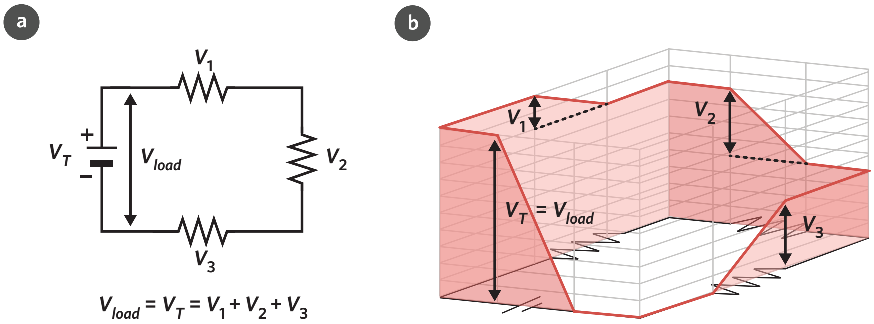


Figure 5 (a) A series circuit and (b) the changes in voltage around the circuit.

The voltage drop across any load component can be found with Ohm's Law:

$$V_n = IR_n.$$

As the current is the same through each load component, the voltage drop across each component is proportional to its resistance.

$$V_n \propto R_n$$

This means that in a series circuit with multiple components, there will be a greater voltage drop across the higher resistance components.

USEFUL TIP

$\propto$ means there is a linear relation between two values. If $a \propto b$ then we say a is proportional to b.

STRATEGY

When calculating the voltage drop across a single component in a series circuit, make sure that the answer is smaller or equal to the supply voltage, and follows the proportional relationship between resistance and voltage $V_n \propto R_n$.

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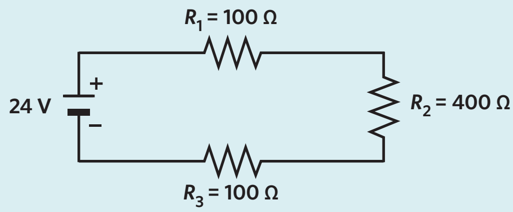
WORKED EXAMPLE 2

An ideal cell is delivering power to a series circuit containing three resistors which have an equivalent resistance of 600 Ω.



a. What is the voltage drop across this equivalent resistance?

Step 1

Identify that the voltage drop is equal to the total voltage supplied.

$V_{load} = V_T = V_{cell} = 24$ V

The voltage drop across the equivalent resistance is 24 V.

b. What is the current through the cell?

Step 1

Identify total voltage and resistance, and the equation that relates these variables.

Note that R_T was found in Worked Example 1.

$V_T = 24$ V, $R_T = R_{eq} = 600$ Ω, $I = ?$

$V_T = IR_T$

Step 2

Substitute known values into the equation and solve for current.

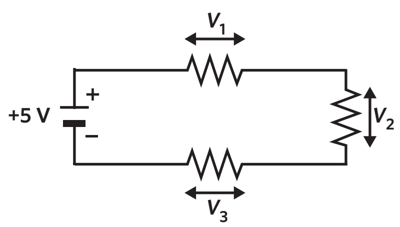
$24 = I \times 600$

$I = \frac{24}{600} = 0.0400 = 4.0 \times 10^{-2}$ A

Progress questions

Question 4

Which of the following equations is true for this circuit?



A. $V_1 = 5$ V

B. $V_1 = V_2 = V_3 = 5$ V

C. $V_1 + V_2 = 5$ V

D. $V_1 + V_2 + V_3 = 5$ V

How is power calculated in a series circuit?

In series circuits, the total power delivered by sources is equal to the total power used by the load.

$$P_T = V_T I = V_1 I + V_2 I + \ldots + V_n I$$

When determining the power delivered or used by a single component, the corresponding voltage value must be used in the power equation, see Figure 6.

STRATEGY

- When calculating the power supplied to a series circuit, use the voltage provided by the battery or cell.
- When calculating the power used by a resistor, use the voltage drop that occurs across that resistor.

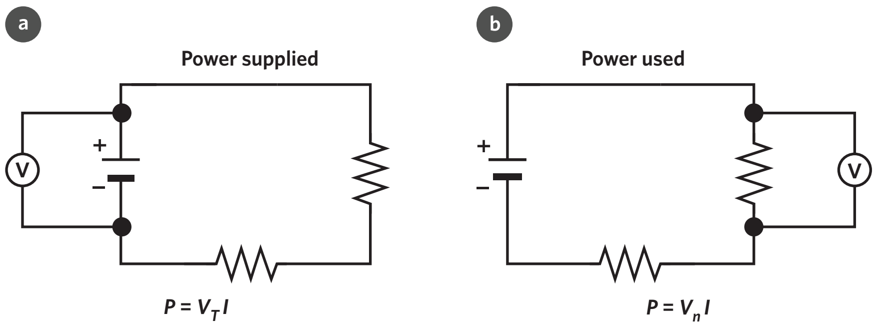


Figure 6 Voltmeters measuring power **(a)** supplied and **(b)** used by a resistor in a series circuit.

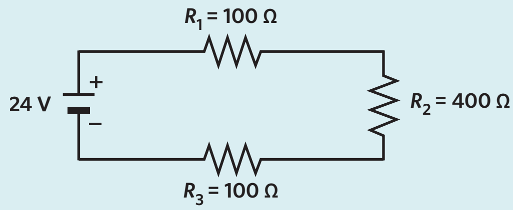
When we add more resistance to a series circuit, we decrease the current through the circuit since the supplied voltage remains constant and $V = IR$. Therefore, adding resistance causes the amount of power delivered to and used by a circuit to decrease, as $P = VI$.

USEFUL TIP

Adding more components/devices in series causes the power used by each device to drop. This decrease in power can cause lights to be dimmer. A drop in power is often undesirable, so series circuits are not always the best choice when designing electrical systems.

WORKED EXAMPLE 3

An ideal cell is delivering power to a series circuit containing three resistors which have an equivalent resistance of 600 Ω. The circuit has a current of 0.040 A. What is the power being dissipated by the resistor R_3?



Step 1

Identify current and resistance for R_3, and Ohm's Law which relates them.

Remember that current through R_3 is the same as through the whole circuit.

$I = 0.040$ A, $R_3 = 100$ Ω, $V_3 = ?$

$V_3 = IR_3$

Step 2

Substitute known values and calculate V_3.

$V_3 = 0.040 \times 100$

$V_3 = 4.00 = 4.0$ V

Step 3

Identify the current and voltage for R_3, and the power equation that relates these variables.

$V_3 = 4.0$ V, $I = 0.040$ A, $P_3 = ?$

$P_3 = V_3 I$

Step 4

Substitute known values and calculate P_3.

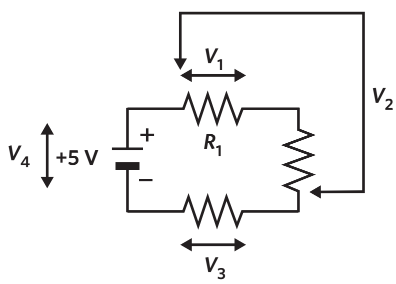
$P_3 = 4.0 \times 0.040$

$P_3 = 0.160 = 0.16$ W

Progress questions

Question 5

Which of the four voltages shown below should be used when calculating the power used by resistor R_1?



A. V_1

B. V_2

C. V_3

D. V_4

Question 6

Adding more components to a series circuit will increase the total power transferred to the circuit.

A. True

B. False

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Theory summary

- Components in series are connected end to end.
- Series circuits only contain series connections.
- The equivalent resistance of resistors in series is the sum of their individual resistances.
  - $R_{equivalent} = R_1 + R_2 + ... + R_n$
- Current is equal at all points in a series circuit.
  - The supply voltage and total equivalent resistance of a circuit determines the current.
- The total voltage supplied to a series circuit is the sum of all voltage sources' individual voltages, and is equal to the voltage dropped across the total load.
- Voltage drop across each series component is proportional to its resistance: $V_n \propto R_n$
- The power used by series circuits decreases as more components (and hence more resistance) are added.

KEEN TO INVESTIGATE?

How do string lights work in series when one light is blown?
Search YouTube: Are Christmas lights connected in series or parallel?

The content in this lesson is considered fundamental prior knowledge to generation of electricity and transmission of electricity (Unit 3 AOS 3).

CONCEPT DISCUSSION

When we measure the current across a component, an ammeter is connected in series with that component. However, an ammeter has a resistance, which we would expect to affect the operation of the circuit. Discuss the requirement for the ammeter resistance in order for its measurement to accurately represent the component current if the ammeter were not present.

Prompts:

- What is the equivalent resistance of two resistors in series when one resistor has a much greater resistance than the other?
- For the resistance to be similar with and without the ammeter connected, would the ammeter need to have a much higher or much lower resistance than the component?

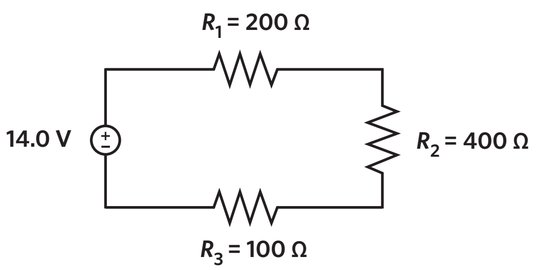
6C Questions

Mild Medium Spicy

Deconstructed exam-style

Use the following information to answer questions 7–10.

Students are experimenting with the series circuit shown.



Question 7 (1 MARK)

What is the equivalent resistance of the three resistors?

A. 57 Ω

B. 400 Ω

C. 700 Ω

D. 1400 Ω

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Question 8 (1 MARK)

What is the current through R_3?

A. 14 mA

B. 20 mA

C. 140 mA

D. 200 mA

Question 9 (1 MARK)

What is the voltage drop across R_3?

A. 1.40 V

B. 2.00 V

C. 14.0 V

D. 20.0 V

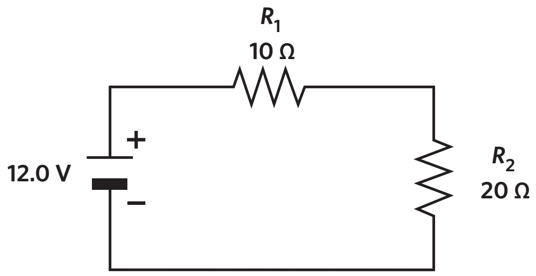
Question 10 (4 MARKS)

Determine the power dissipated by R_3.

Exam-style

Question 11 (3 MARKS)

An ideal cell provides 12 V to the series circuit shown.

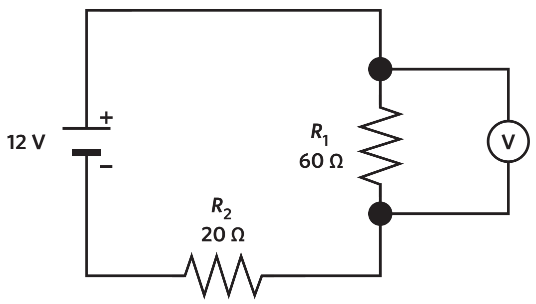


a. Determine the current through the circuit. (2 MARKS)

b. Determine the voltage drop across R_2. (1 MARK)

Question 12 (3 MARKS)

What is the reading on the voltmeter in this series circuit?



Adapted from VCAA 2016 exam Short answer Q7

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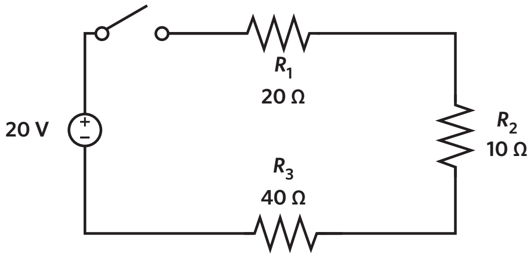
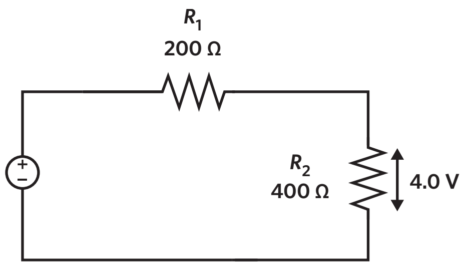
Question 13 (1 MARK)

Determine the power dissipated by the resistor R_2 in the circuit shown.



Question 14 (3 MARKS)

Determine the voltage supplied to this circuit. The voltage drop across R_2 is 4.0 V.

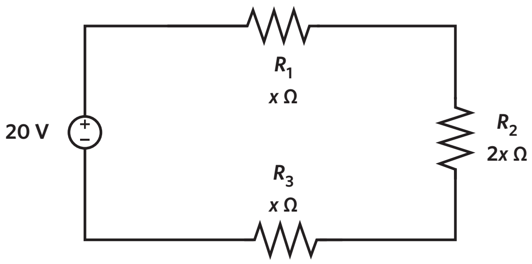


Question 15 (3 MARKS)

Sione and Bruno are debating the effect of adding resistive components on the current flow in a series circuit. Sione says that adding components will decrease the current, whereas Bruno says that it will increase the current. Evaluate these claims and state who is correct.

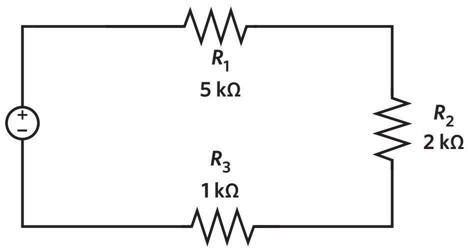
Question 16 (3 MARKS)

A 20 V DC source is connected to the circuit shown. Determine the voltage drops across each of R_1, R_2, and R_3.



Question 17 (2 MARKS)

A power source delivers 10 W to this series circuit. Determine the power dissipated by R_3 to three significant figures.



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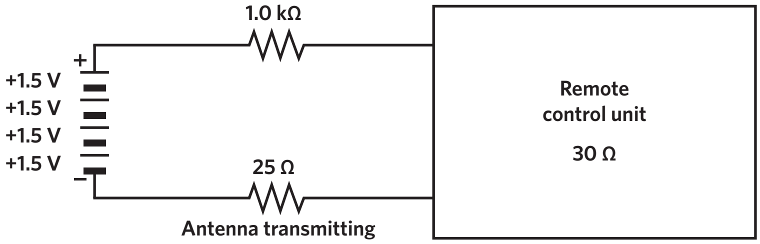
Question 18 (9 MARKS)

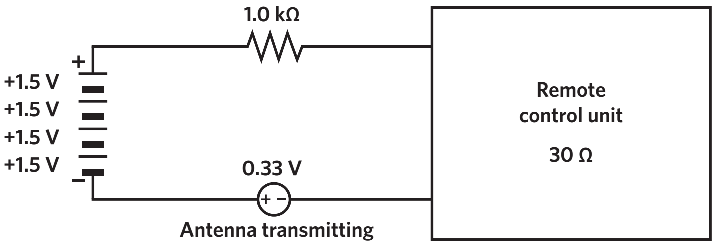
Four 1.5 V AA cells are powering the circuit of a remote controlled toy. In this configuration, the toy's antenna is transmitting information. The remote control unit will overheat if a current greater than 7.00 mA flows through it.



a. Will the unit overheat in the configuration shown? (3 MARKS)

b. The 1.0 kΩ resistor stops working and needs to be replaced. Four replacement resistors are available with resistances of 800 Ω, 810 Ω, 820 Ω, or 830 Ω. Determine the resistor with minimum resistance that will prevent the control unit from overheating. (3 MARKS)

c. When the antenna is receiving information, it can be modelled as a 0.33 V DC voltage source rather than a resistor, as shown.



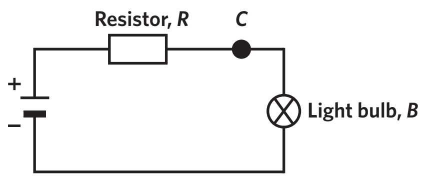
What is the power delivered to the circuit by the antenna? Give your answer in mW. (3 MARKS)

Question 19 (4 MARKS)

Students are modelling the effect of the resistance of electrical cables, *C*, on the transmission of electrical power. Their circuit is set up as the following:

Describe the effects of introducing a second resistor at point *C* on the brightness of the light bulb, *B*, with reference to power.

Adapted from VCAA 2020 exam Short answer Q18



Key science skills

Question 20 (2 MARKS)

Mahua is investigating the effect of increasing resistance on power delivery in series circuits. She connects an ideal cell to an increasing number of resistors, each having equal resistance. Each time Mahua connects another resistor, she records the current through the circuit once and proceeds with adding the next resistor. Explain how a change to Mahua's experiment could decrease the effect of random error on her results.

FROM LESSON 11C

Previous lessons

Question 21 (2 MARKS)

A sample of lead is heated to 1700°C and is glowing red. By modelling the sample as a black body, calculate the λ_{max} of the radiation emitted. Take Wien's constant b to be 2.89×10^{-3} m K.

FROM LESSON 3A

Question 22 (2 MARKS)

Determine the voltage supplied to a light bulb that uses 7.2 kJ every hour and draws 1.0 A of current.

FROM LESSON 6A

6D Parallel circuits

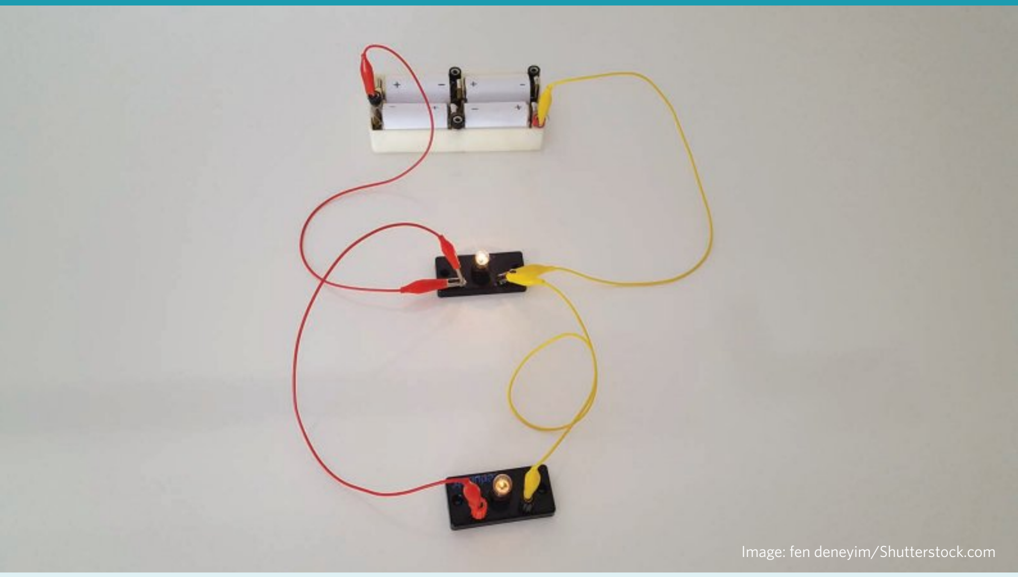


Image: fen deneyim/Shutterstock.com

STUDY DESIGN DOT POINTS

- model resistance in series and parallel circuits using:
  - current versus potential difference (I–V) graphs
  - resistance as the potential difference to current ratio, including R = constant for ohmic devices
  - equivalent resistance in arrangement in series: $R_{equivalent} = R_1 + R_2 + ... + R_n$ and parallel: $\frac{1}{R_{equivalent}} = \frac{1}{R_1} + \frac{1}{R_2} + ... + \frac{1}{R_n}$
- compare power transfers in series and parallel circuits

6A 6B 6C 6D 6E

1.3.6.4 Equivalent resistance in parallel circuits

1.3.10.2 Current, voltage, and power in parallel circuits

Why is one bulb dimmer than the other in this circuit?

As well as being able to be connected in series, electrical components can be connected in parallel. Parallel circuits have important uses in household circuits and electronic devices. In this lesson we will analyse parallel connections and how voltage, current, resistance, and power behave in a parallel circuit.

KEY TERMS AND DEFINITIONS

branch the circuit connections between two nodes

node the intersection point in a circuit where current changes direction

parallel circuit an electric circuit that has only parallel connections

parallel connection an arrangement where multiple components connect the same two points so there are multiple alternative pathways for current to flow

FORMULAS

- **equivalent parallel resistance** $\frac{1}{R_{equivalent}} = \frac{1}{R_1} + \frac{1}{R_2} + ... + \frac{1}{R_n}$
- **Ohm's Law** $V = IR$
- **electric power** $P = VI$

ESSENTIAL PRIOR KNOWLEDGE

6A Current and voltage

6A Electric power

6B Resistance

6C Series circuits analysis

See questions 39–42.

ACTIVITIES

Log into your Edrolo account for activities that support this lesson.

Equivalent resistance in parallel circuits 1.3.6.4

A parallel circuit contains branches that are all connected to the same points, providing multiple pathways for current to flow. The equivalent resistance of a parallel circuit decreases as more branches are added.

Theory and applications

Parallel circuits have a different arrangement to series circuits as they contain distinct branches. This means there are multiple paths for current to flow. This affects our analysis of electricity throughout the entire circuit.[1]

KEEN TO INVESTIGATE?

[1] **Interested in creating a parallel circuit?**
Search: 'Circuit Construction Kit' simulation

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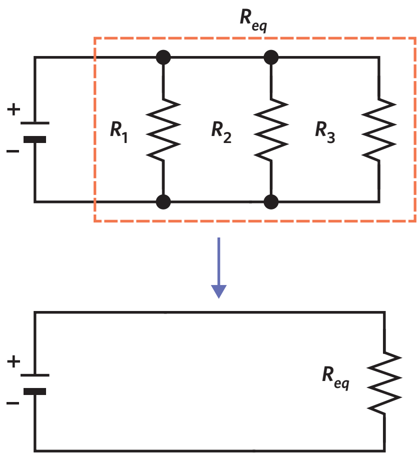
USEFUL TIP

The equivalent resistance of multiple branches must be less than the lowest resistance of any of the individual branches, that is, $R_{eq} < R_{smallest}$. This may be used to check your calculations of equivalent resistance, to ensure they are less than the smallest resistance.



$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Figure 2 Replacing several parallel resistors with one series resistor of equivalent resistance

STRATEGY

When calculating the equivalent resistance of two parallel resistors, the formula $\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}$ can be rearranged to give $R_{eq} = \frac{R_1 R_2}{R_1 + R_2}$.

This can potentially be used to make the calculation easier.

How can we determine equivalent resistance in parallel circuits?

Components in parallel are connected with common nodes to form multiple pathways for current to flow. A node is an intersection point along a circuit joining two or more pathways for current, called branches. When all the branches in a circuit are connected in parallel, it is called a parallel circuit.

Parallel circuits differ from series circuits in that there is more than one path for current to flow. Figure 1 shows two examples of parallel circuits and their multiple branches.

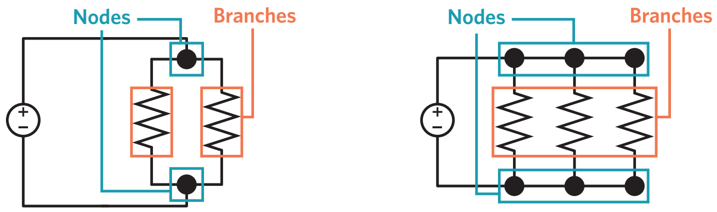


Figure 1 Two parallel circuits with nodes and branches highlighted

To analyse parallel circuits, it is important that we find the equivalent resistance, R_{eq}, of multiple parallel resistors.

FORMULA

$$\frac{1}{R_{equivalent}} = \frac{1}{R_1} + \frac{1}{R_2} + \dots + \frac{1}{R_n}$$

$R_{equivalent}$ = equivalent parallel resistance (Ω)

$R_1, R_2, \dots R_n$ = individual resistances of branches 1, 2, … *n* (Ω)

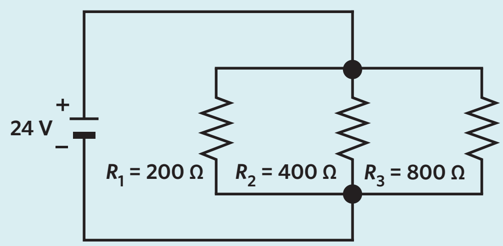
The equivalent resistance for components connected in parallel represents the resistance of a single pathway that would have the same effect (causing the same amount of current to flow as the parallel components). This is shown in Figure 2.

The equation for equivalent resistance in a parallel circuit shows us that the equivalent resistance will decrease as more branches are added in parallel.

- By adding more branches, we are creating additional paths for charge carriers to flow through, making it easier for current to flow through the circuit.
- Using the hydraulic circuit analogy from Lesson 6A, this is similar to parallel water pipes. The more pipes there are connecting two points, the more space there is for the water to flow through, making it easier for more water to flow.

WORKED EXAMPLE 1

An ideal 24 V cell is delivering power to a parallel circuit containing three resistors, as shown in the given diagram.



Determine the equivalent resistance of the circuit.

Step 1

Identify the resistances of the individual branches, and the parallel equivalent resistance formula that relates these variables.

$R_1 = 200\ \Omega$, $R_2 = 400\ \Omega$, $R_3 = 800\ \Omega$,

$R_{eq} = R_T = ?$

$$\frac{1}{R_{eq}} = \frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Step 2

Substitute values into the formula and solve for the equivalent resistance.

$$\frac{1}{R_T} = \frac{1}{200} + \frac{1}{400} + \frac{1}{800}$$

$$R_T = \frac{1}{\frac{1}{200} + \frac{1}{400} + \frac{1}{800}} = 114.3 = 114\ \Omega$$

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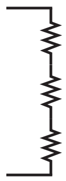
Progress questions

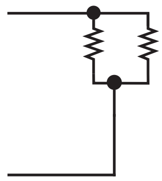
Question 1

Which of the following sets of components are connected only in parallel? **(Select all that apply)**

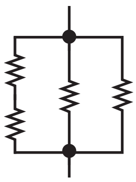
I.



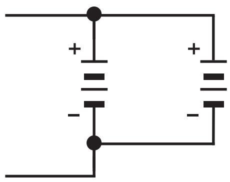
II.



III.



IV.



Question 2

What impact will adding branches to a parallel circuit have on equivalent resistance?

A. The equivalent resistance increases as the number of branches increases.

B. The equivalent resistance decreases as the number of branches increases.

Question 3

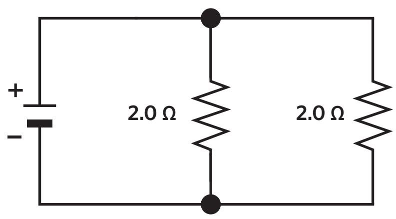
What is the equivalent resistance of this parallel circuit?

A. 0.25 Ω

B. 0.50 Ω

C. 1.0 Ω

D. 4.0 Ω



Current, voltage, and power in parallel circuits 1.3.10.2

The different paths available for current to flow in a parallel circuit means that we need to analyse the flow of current, voltage drop, and power differently compared to that of series circuits.

Theory and applications

Parallel circuits behave very differently to series circuits. We will use Ohm's Law to determine the relationship between the current, voltage and power for individual branches within a parallel circuit, as well as around the whole parallel circuit.[2]

KEEN TO INVESTIGATE?

[2] **How do parallel circuits work?**
Search YouTube: Current and voltage in parallel circuits demonstration

How are current and voltage modelled in parallel circuits?

Recall from Lesson 6A that voltage relates to the energy per unit of charge ($V = \frac{E}{Q}$).

In parallel circuits:

- The voltage drop across all parallel branches is the same, and is equal to the supply voltage V_T.
- Although the voltage will remain constant, the total current will decrease after splitting up from a node (intersection point).

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MISCONCEPTION

'The voltage across each component is the same in a parallel circuit.'

The voltage across each branch, not component, is the same in a parallel circuit. Figure 3(a) only displays one resistor per branch, however there may be parallel circuits with multiple components in each branch. In this case, the total voltage would be divided amongst these components.

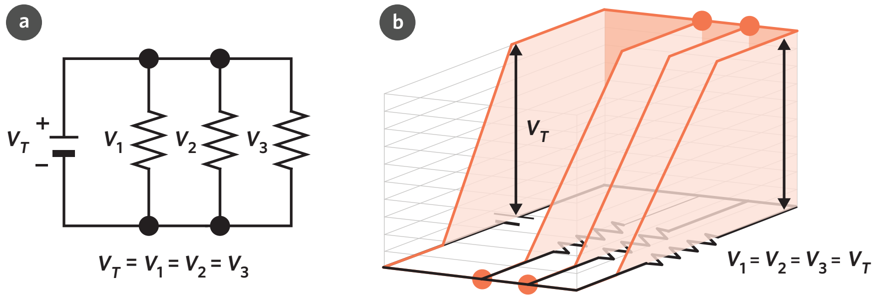


Figure 3 (a) A parallel circuit and (b) the changes in voltage around the circuit

Like in series circuits, the total current provided to a parallel circuit by its source is given by Ohm's Law: $I_T = \frac{V_T}{R_T}$. Knowing this:

- the total current in a parallel circuit will increase with a greater supplied voltage and;
- decrease with a greater equivalent resistance (as R_T is found using R_{eq} in a parallel circuit).

However, in a parallel circuit there are multiple paths for the current to flow, and so the current is split between each branch. The sum of the currents flowing into a node must always be equal to the sum of the currents flowing out of a node, as shown in the examples in Figures 4 and 5.

$$I_{in} = I_{out}$$

This is similar to the flow of water at a junction of parallel pipes. The total water entering a junction must equal the total water leaving the junction.

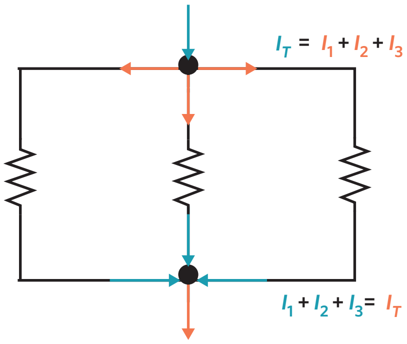


Figure 4 Equivalence of currents flowing into (blue) and out of nodes (orange).

USEFUL TIP

When calculating the current through individual branches of a parallel circuit, make sure that each current:

- is smaller than the total current, and
- satisfies the Ohm's Law calculation for that branch.

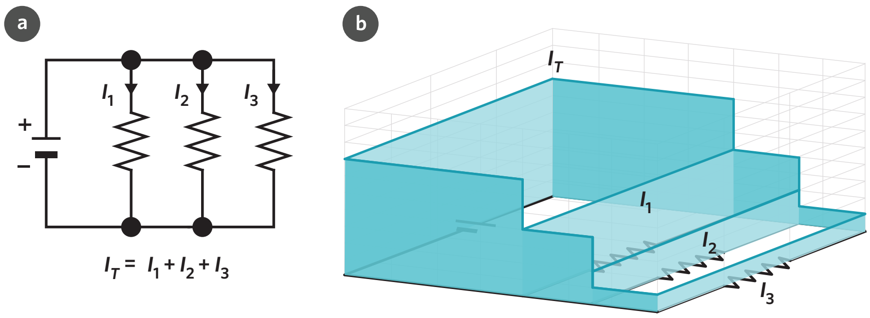
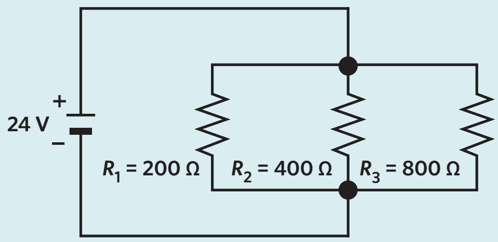


Figure 5 (a) A parallel circuit and (b) the associated current around the circuit.

WORKED EXAMPLE 2

An ideal 24 V cell is delivering power to a parallel circuit containing three resistors with an equivalent resistance of 114 Ω.



a. What is the current through the cell?

Step 1

Identify the relevant voltage and resistance values for the relevant current, and Ohm's Law which relates these variables.

$V_T = 24$ V, $R_{eq} = R_T = 114$ Ω, $I_T = ?$

$V_T = I_T R_T$

Step 2

Substitute values into the formula and solve for the total current.

$24 = I_T \times 114$

$I_T = \frac{24}{114} = 0.211 = 0.21$ A

Continues →

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b. What is the current through R_2?

Step 1

Identify the voltage and resistance across R_2, and Ohm's Law which relates these variables. Note that the supply voltage will be equal to the voltage across each branch.

$V_2 = V_T = 24$ V, $R_2 = 400\ \Omega$, $I_2 = ?$

$V_2 = I_2 R_2$

Step 2

Substitute values into the formula and solve for the total current through R_2.

$24 = I_2 \times 400$

$I_2 = \frac{24}{400} = 0.0600 = 0.060$ A

Progress questions

Question 4

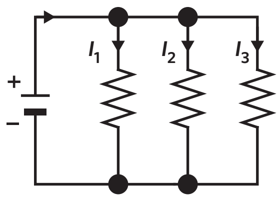
There is a different voltage drop across each branch of a parallel circuit.

A. True

B. False

Question 5

In the parallel circuit shown below, use Ohm's Law to investigate the current in the middle branch, and identify which equation is correct.



A. $I_2 = \frac{V_T}{R_2}$

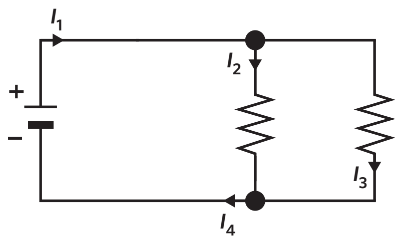
B. $I_2 = \frac{V_T}{R_3}$

C. $I_2 = \frac{V_T}{R_1}$

D. $I_2 = \frac{V_T}{R_T}$

Question 6

Which of the following equations is true for this circuit?



A. $I_1 = I_2 = I_3 = I_4$

B. $I_1 + I_2 = I_3 + I_4$

C. $I_1 = I_2 + I_3 = I_4$

D. $I_1 - (I_2 + I_3) = I_4$

How is power calculated in parallel circuits?

Just like in series circuits, in parallel circuits, the total power delivered by a source is equal to the total power used by the load.

$$P_T = V_T I_T = V_T I_1 + V_T I_2 + \ldots + V_T I_n$$

When determining the power delivered or used in parallel circuits, the corresponding current value must be used in the power equation.

Table 1 explains the effect of adding additional branches to a parallel circuit on the total resistance, voltage, current, and power of the circuit.

STRATEGY

- When calculating the power supplied to a parallel circuit, use the total current through the circuit.
- When calculating the power used across a branch, use the current through that individual branch.

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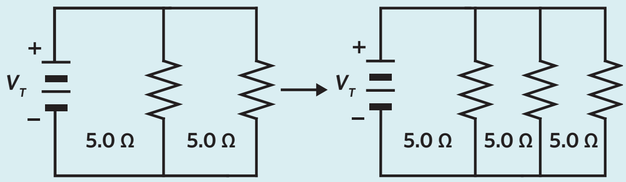
Table 1 Impact of increasing the number of branches in a circuit

Quantity	Effect	Explanation
Resistance	Decrease ↓	An increase in the amount of pathways for current to flow creates more 'options' for current to flow through, decreasing the overall resistance.
Voltage	Constant —	Voltage is determined by the power source and is not impacted by increasing the amount of branches.
Current	Increase ↑	According to Ohm's Law ($V = IR$), as voltage is constant and resistance decreases, current must increase.
Power	Increase ↑	Increasing the number of components increases the number of opportunities for power loss. Alternatively, by the definition of power ($P = IV$), the increase in total current must translate to an increase in total power consumption for a constant voltage supply.

WORKED EXAMPLE 3

The number of branches of a parallel circuit is increased, as shown in the diagram, for a fixed voltage supply of 10 V. The resistance of each branch is 5.0 Ω. The old circuit had an equivalent resistance of 2.5 Ω, and the new circuit has an equivalent resistance of 1.7 Ω.



a. Calculate the total current in the new circuit. Compare with the total current in the old circuit.

Step 1

Identify the relevant resistance values for the new circuit, and Ohm's Law that relates these variables.

$V_{new} = V_{supply} = 10$ V, $R_{new} = 1.7$ Ω, $I_{new} = ?$

$V_{new} = I_{new}R_{new}$

Step 2

Substitute values into Ohm's Law and solve for the total current in the new circuit.

$10 = I_{new} \times 1.7$

$I_{new} = \frac{10}{1.7} = 5.88 = 5.9$ A

Step 3

Identify the relevant voltage and resistance values for the old circuit, and Ohm's Law that relates these variables.

$V_{old} = V_{supply} = 10$ V, $R_{new} = 1.7$ Ω, $I_{new} = ?$

$V_{old} = I_{old}R_{old}$

Step 4

Substitute values into Ohm's Law and solve for the total current in the new circuit.

$10 = I_{old} \times 2.5$

$I_{old} = \frac{10}{2.5} = 4.00 = 4.0$ A

Step 5

Compare the two current values.

$5.9 \text{ A} > 4.0 \text{ A} \Rightarrow I_{new} > I_{old}$

The total current in the new circuit is greater than the total current in the old circuit.

Continues →

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b. Calculate the power consumed by the new circuit. Compare with the power consumed by the old circuit.

Step 1

Identify the relevant voltage and current values for the new circuit, and the power formula that relates these variables.

$V_{new} = 10$ V, $I_{new} = 5.9$ A, $P_{new} = ?$

$P_{new} = I_{new}V_{new}$

Step 2

Substitute values into the formula and solve for the total power consumption of the new circuit.

$P_{new} = 5.9 \times 10 = 59$ W

Step 3

Identify the relevant voltage and current values for the old circuit, and the power formula that relates these variables.

$V_{old} = 10$ V, $I_{old} = 4.0$ A, $P_{old} = ?$

$P_{old} = I_{old}V_{old}$

Step 4

Substitute values into the formula and solve for the total power consumption of the old circuit.

$P_{old} = 4.0 \times 10 = 40$ W

Step 5

Compare the two power values.

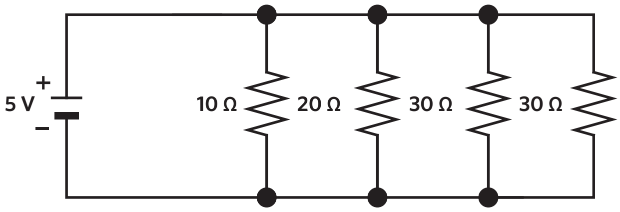
$59 \text{ W} > 40 \text{ W} \Rightarrow P_{new} > P_{old}$

The power consumed by the new circuit is greater than the power consumed by the old circuit.

Progress questions

Question 7

Which of the following statements about this circuit is incorrect?



A. The sum of the currents through each resistor is equal to the current through the cell.

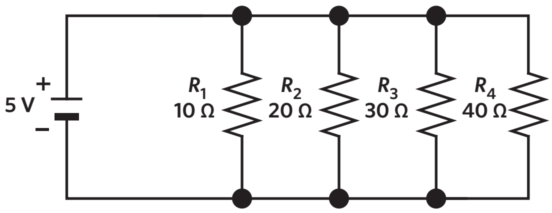
B. The voltage drop across both 30 Ω resistors is equal.

C. The current through the 10 Ω resistor would be larger than the current through the 20 Ω resistor.

D. The voltage drop across each resistor is proportional to their resistance.

Question 8

List the four resistors below in an increasing order of the power they consume.



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Theory summary

- Components in parallel are connected side by side with a common node at each end.
- The equivalent resistance of resistors in parallel is given by:
  - $\frac{1}{R_{equivalent}} = \frac{1}{R_1} + \frac{1}{R_2} + \dots + \frac{1}{R_n}$
- The voltage drop over parallel branches is always equal.
- The current splits through each branch of a parallel circuit and is calculated using Ohm's Law.
  - Lower resistance branches will carry a larger current, as $I_n = \frac{V_T}{R_n}$.
  - At a node, the incoming current is always equal to the outgoing current.
- The power used by parallel circuits increases as more branches are added or when resistance is lowered.

CONCEPT DISCUSSION

Image: Suradech Prapairat/Shutterstock.com

Jack is looking to watch some TV after a taxing day at work, only to find his TV will not turn on. He notices that this problem only persists when the other major appliances, such as the microwave or refrigerator, are turned on. Jack remembers that the electrician who installed his wiring used a 'series arrangement.'

Discuss, with reference to types of circuits, how the wiring in his house may have been better arranged to provide sufficient power to the TV.

Prompts:

- Is the television receiving enough energy to turn on?
- How does a series circuit affect voltage?
- Which appliances are located closer to the power source in the house?

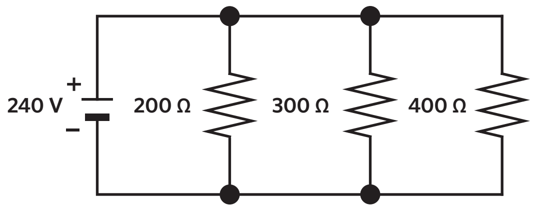
6D Questions

Mild Medium Spicy

Deconstructed exam-style

Use the following information to answer questions 9–12.

A 240 V DC power source is being used to run a set of appliances wired in parallel. Assume each appliance can be modelled as a resistor.



Question 9 (1 MARK)

What is the voltage across the 300 Ω resistor?

A. 240 V

B. 120 V

C. 80 V

D. 60 V

Question 10 (1 MARK)

Which of the following equations could be used to find the total current provided by the source?

A. $240 = I_T \times 300$

B. $80 = I_T \times 900$

C. $240 = I_T \times R_T$

D. $80 = I_T \times R_T$

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Question 11 (1 MARK)

Which of the following equations could be used to find the current through the 300 Ω resistor?

A. $240 = I_{300\,\Omega} \times 300$

B. $80 = I_{300\,\Omega} \times 900$

C. $240 = I_{300\,\Omega} \times R_T$

D. $80 = I_{300\,\Omega} \times R_T$

Question 12 (4 MARKS)

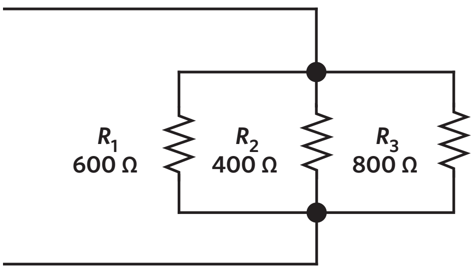
Using calculations, determine what percentage of the total power delivered by the source is consumed by the 300 Ω resistor.

Exam-style

Question 13 (4 MARKS)

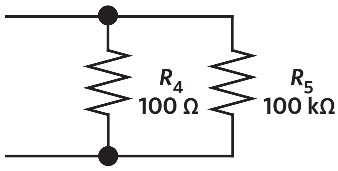
Determine the equivalent resistance of the following systems of parallel resistors.

a.



(2 MARKS)

b.



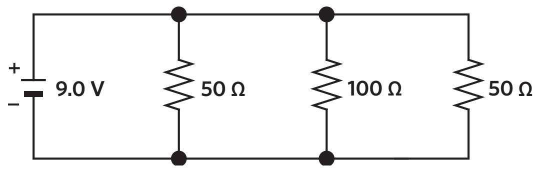
(2 MARKS)

Question 14 (4 MARKS)

The given diagram depicts a parallel circuit.

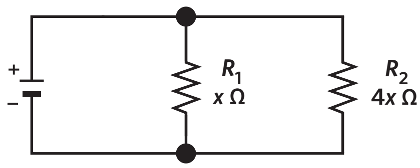
a. Determine the total current in this parallel circuit. (2 MARKS)

b. Determine the current passing through the 100 Ω resistor. (2 MARKS)



Question 15 (2 MARKS)

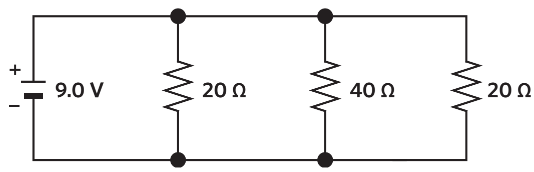
The total current provided to this parallel circuit by the ideal DC source is 5.0 A. Calculate the current passing through R_2.



Question 16 (5 MARKS)

a. Determine the total power dissipated by this parallel circuit. (3 MARKS)

b. Determine the power dissipated by the two 20 Ω resistors. (2 MARKS)



Question 17 (2 MARKS)

Joanne is comparing different sets of decorative lights and wants to choose the lights with the lower power consumption. The two sets of lights contain different numbers of identical bulbs which have the same electrical characteristics and are connected in parallel. Explain whether Joanne should choose the set with more or fewer lights.

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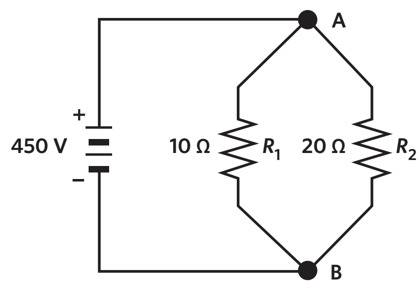
Question 18 (7 MARKS)

a. Does the circuit have a series or parallel configuration? Justify your response. (2 MARKS)

b. Calculate the equivalent resistance of the circuit. (2 MARKS)

c. Determine the power loss across R_2. (3 MARKS)



Question 19 (3 MARKS)

An engineer is tasked with constructing a radio tuning circuit and requires a 200 Ω resistor. However, the only resistors available are one each of a 100 Ω, a 400 Ω, a 600 Ω, a 1000 Ω, and a 1200 Ω resistor. Design a parallel combination of resistors that the engineer can use to create an equivalent resistance of 200 Ω. Justify your response with a calculation.

Key science skills

Question 20 (3 MARKS)

Rahj conducts an investigation where he measures the total current supplied by a voltage source to a parallel circuit as different numbers of 1 kΩ resistors are connected. Identify the independent variable, the dependent variable, and a controlled variable in this experiment.

FROM LESSON 11A

Previous lessons

Question 21 (3 MARKS)

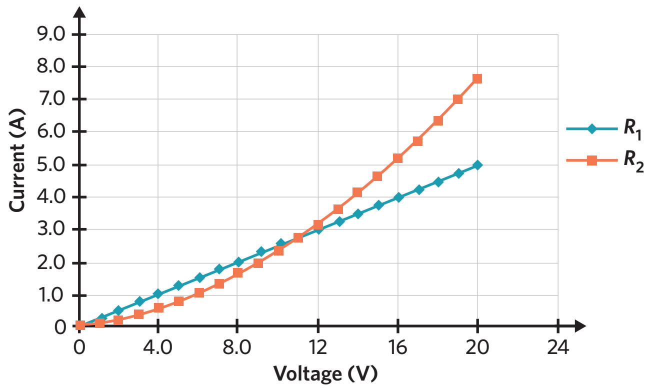
With reference to energy balance, explain why the industrial revolution led to a rapid increase in the globe's average temperature?

FROM LESSON 3B

Question 22 (5 MARK)

For their science project, Rebecca conducts an experiment to determine the influence of a changing voltage supply on the current.

Two circuits, each containing a resistor and variable power supply, are compared side by side. The effect of the changing supply voltage on the current is noted and graphed below.



a. In their report, Rebecca solely uses Ohm's Law to justify the positive common positive trend of both graphs. Explain, with reference to non-Ohmic resistors, why Rebecca is not correct. (3 MARKS)

b. Determine the resistance of R_1. (2 MARKS)

FROM LESSON 6B

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6E Combination circuits

How are the lights in a car connected in a circuit?

Many real life circuits are made up of components in both series and parallel arrangements. This lesson explores the analysis of such circuits, commonly known as combination circuits.

STUDY DESIGN DOT POINT

- calculate and analyse the equivalent resistance of circuits comprising parallel and series resistance

6A 6B 6C 6D 6E

1.3.7.1 Combination circuits

ESSENTIAL PRIOR KNOWLEDGE

6A Current and voltage
6A Electric power
6B Resistance
6C Series circuits analysis
6D Parallel circuits analysis
See questions 43–47.

ACTIVITIES

Log into your Edrolo account for activities that support this lesson.

FORMULAS

- Ohm's Law
  $V = IR$
- electric power
  $P = VI = I^2R = \frac{V^2}{R}$
- equivalent series resistance
  $R_{equivalent} = R_1 + R_2 + ... + R_n$
- equivalent parallel resistance
  $\frac{1}{R_{equivalent}} = \frac{1}{R_1} + \frac{1}{R_2} + ... + \frac{1}{R_n}$

Combination circuits 1.3.7.1

Combination circuits contain both series and parallel connections. To solve problems with combination circuits, we have to apply equivalent resistance formulas and Ohm's Law at multiple stages.

Theory and applications

Many circuits in real life contain both series and parallel connections, as both connection types have particular advantages and disadvantages in different contexts.[1]

KEEN TO INVESTIGATE?

[1] **Interested in creating your own circuits?**
Search: 'Circuit Construction Kit' simulation

How do we analyse resistance in combination circuits?

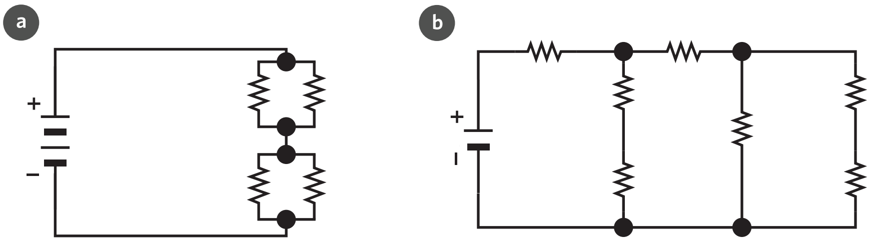

Figure 1 Two combination circuits

Combination circuits may consist of sets of parallel components connected in series, as shown in Figure 1 (a), or sets of series components connected in parallel, as shown in Figure 1 (b).

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USEFUL TIP

When writing out working for circuit analysis questions, it can be efficient to use the parallel symbol (||) between resistors to represent an equivalent parallel resistance. For example, writing $R_1||R_2$ is equivalent to writing $\frac{1}{\frac{1}{R_1}+\frac{1}{R_2}}$ or $\left(\frac{1}{R_1}+\frac{1}{R_2}\right)^{-1}$.

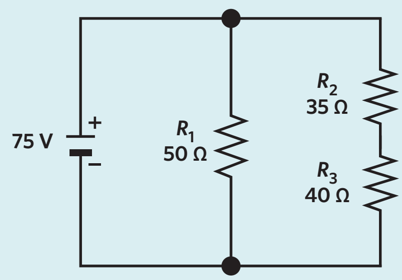
Many combination circuit questions require finding the total equivalent resistance of a circuit. To do this:

- find the equivalent resistance of small groups of components connected only in series or parallel,
- redraw the circuit with each of these groups drawn as a single equivalent resistor, and
- repeat these steps until the total equivalent resistance is found.

Ohm's Law and the electric power equations can be used with this total equivalent resistance to find the total current, voltage, and power for the circuit.

WORKED EXAMPLE 1

An ideal 75 V cell is delivering power to a parallel circuit containing three resistors in a combined series-parallel arrangement.



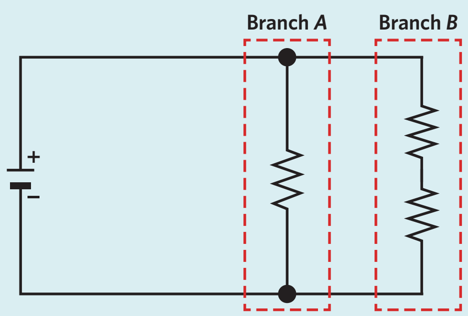
a. Determine the total resistance of the right branch.

Step 1

Define the left branch as branch *A* and the right branch as branch *B*. Identify the resistance values at branch *B* and appropriate series resistance formula.

$R_2 = 35\ \Omega$, $R_3 = 40\ \Omega$, $R_B = ?$,

$R_B = R_2 + R_3$



Step 2

Substitute values into the formula to solve for the resistance in branch *B*.

$R_B = 40 + 35 = 75\ \Omega$

b. Determine the total equivalent resistance of the circuit.

Step 1

Identify the equivalent resistance of each branch, and the parallel resistance formula that relates these variables.

$R_A = R_1 = 50\ \Omega$, $R_B = 75\ \Omega$, $R_T = R_{eq} = ?$

$$\frac{1}{R_T} = \frac{1}{R_{eq}} = \frac{1}{R_A} + \frac{1}{R_B}$$

Step 2

Substitute values into the formula and solve for the equivalent resistance.

$$\frac{1}{R_T} = \frac{1}{50} + \frac{1}{75}$$

$$R_T = \frac{1}{\frac{1}{50} + \frac{1}{75}} = 30\ \Omega$$

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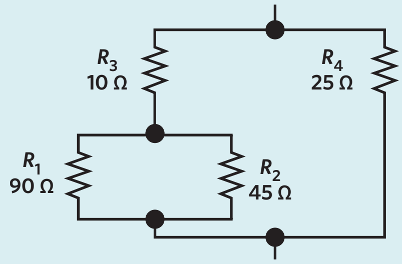
STRATEGY

Analysing combination circuits requires dividing the circuit into more manageable series or parallel components. These components can then be related to one another, and the circuit as a whole. This was done in Worked Example 1, in which only a series connection was initially considered and then related to the total equivalent resistance of the circuit.

WORKED EXAMPLE 2

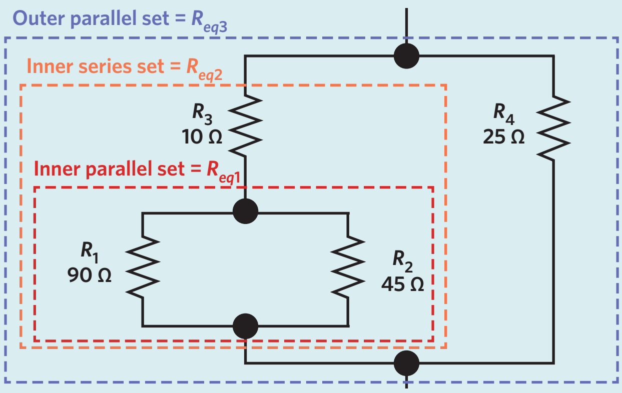
A circuit contains a rectangular section of four resistors in a combined series-parallel arrangement.

Determine the equivalent resistance of this component of the circuit.



Step 1

Identify the pairs of series and parallel resistors.



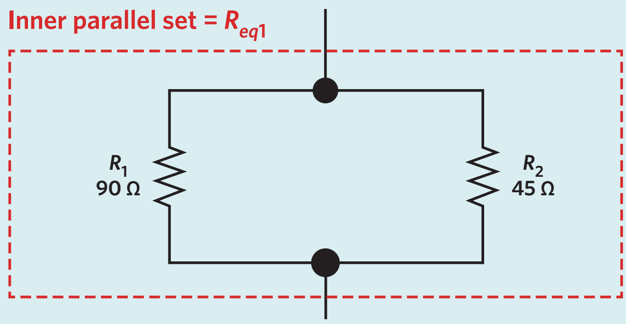
R_{eq1} (inner parallel set): consists of 90 Ω resistor and 45 Ω resistor connected in parallel

R_{eq2} (inner series set): consists of R_{eq1} and 10 Ω resistor connected in series

R_{eq3} (outer parallel set): consists R_{eq2} and 25 Ω resistor connected in parallel

Step 2

Identify R_1 and R_2, and the parallel equivalent resistance formula that relates these variables to R_{eq1}.



$R_1 = 90\ \Omega$, $R_2 = 45\ \Omega$, $R_{eq1} = ?$

$$\frac{1}{R_{eq1}} = R_1||R_2 = \frac{1}{R_1} + \frac{1}{R_2}$$

Step 3

Substitute values into the formula and solve for the resistance of the inner parallel set, R_{eq1}.

$$\frac{1}{R_{eq1}} = \frac{1}{90} + \frac{1}{45}$$

$$R_{eq1} = \frac{1}{\frac{1}{90} + \frac{1}{45}} = 30.0 = 30\ \Omega$$

Continues →

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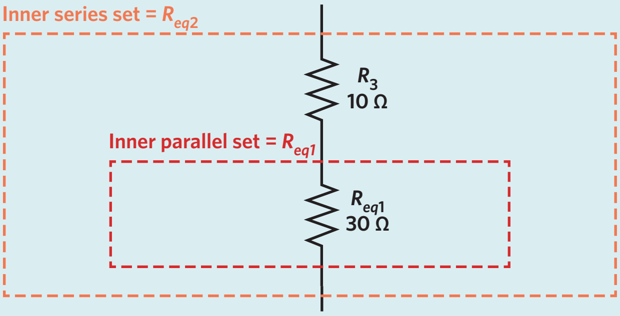
Step 4

Identify R_3 and R_{eq1}, and the series equivalent resistance formula that relates these variables to R_{eq2}.

$R_3 = 10\ \Omega$, $R_{eq1} = 30\ \Omega$, $R_{eq2} = ?$

$R_{eq2} = R_3 + R_{eq1}$



Step 5

Substitute values into the formula, and solve for the equivalent resistance of the inner series set, R_{eq2}.

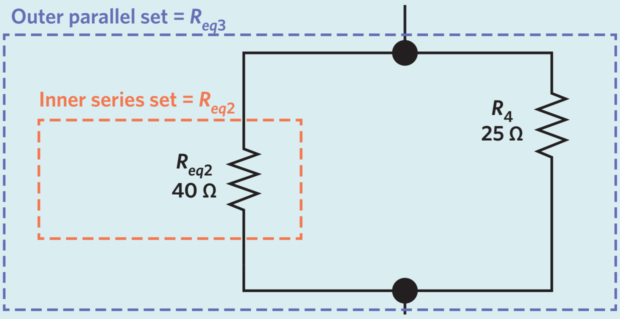
$R_{eq2} = 30 + 10 = 40\ \Omega$

Step 6

Identify R_{eq2} and R_4, and parallel equivalent resistance formula that relates these variables to R_{eq3}.

$R_{eq2} = 40\ \Omega$, $R_4 = 25\ \Omega$, $R_{eq3} = ?$

$$\frac{1}{R_{eq3}} = R_{eq2}||R_4 = \frac{1}{R_{eq2}} + \frac{1}{R_4}$$



Note: the rightward branch has only one resistor, so R_4 is the equivalent resistance of that branch.

Step 7

Substitute values into the formula, and solve for the equivalent resistance of the outer parallel series set, R_{eq3}.

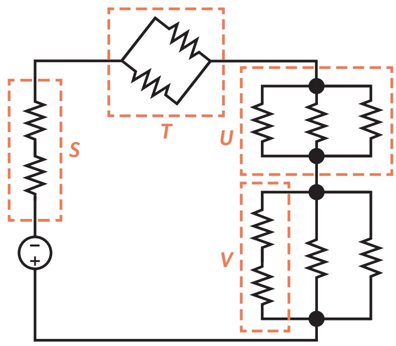
$$\frac{1}{R_{eq3}} = \frac{1}{40} + \frac{1}{25}$$

$$R_{eq3} = \frac{1}{\frac{1}{40} + \frac{1}{25}} = 15.3 = 15\ \Omega$$

Progress questions

Question 1

Identify the types of connections (series or parallel) for each labelled group of components S, T, U, and V in this combination circuit.



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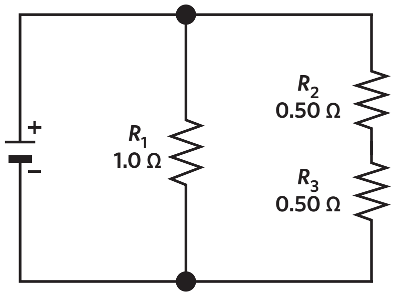
Question 2

What is the equivalent resistance of this circuit?

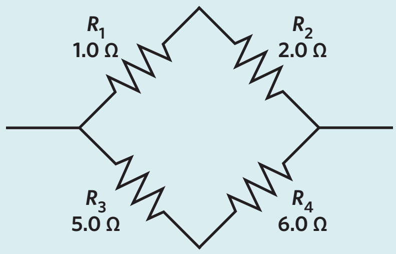
A. 0.50 Ω

B. 1.0 Ω



WORKED EXAMPLE 3

The circuit diagram shows a segment of a circuit.



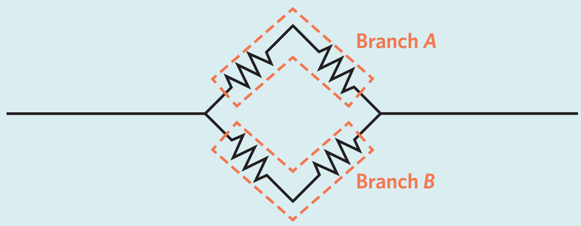
a. Identify the parallel and series connections in the circuit.

Step 1

Identify the conditions for series and parallel connections.

Series: current moves directly from one resistor to another

Parallel: current is split in two directions from a node



Step 2

Group resistors meeting these requirements.

R_1 and R_2 are in series (branch *A*), R_3 and R_4 are in series (branch *B*), and branch *A* and branch *B* are in parallel.

b. Calculate the equivalent resistance in the circuit.

Step 1

Consider the two separate series circuits.

Identify the resistance values and appropriate resistance formula.

$R_1 = 1.0\ \Omega$, $R_2 = 2.0\ \Omega$, $R_A = ?$

$R_A = R_1 + R_2$

Step 2

Substitute values in and solve for the equivalent resistance of branch *A*.

$R_A = 1.0 + 2.0 = 3.0\ \Omega$

Step 3

Identify R_3 and R_4, and the series equivalent formulas that relate these variables.

$R_3 = 6.0\ \Omega$, $R_4 = 5.0\ \Omega$, $R_B = ?$

$R_B = R_3 + R_4$

Step 4

Substitute values in and solve for the equivalent resistance of branch *B*.

$R_B = 6.0 + 5.0 = 11.0\ \Omega$

Continues →

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Step 5

Identify the resistance of each branch and the parallel equivalent resistance formula that relates these variables

$R_A = 3.0\ \Omega$, $R_B = 11.0\ \Omega$, $R_{eq} = ?$

$$\frac{1}{R_{eq}} = \frac{1}{R_A} + \frac{1}{R_B}$$

Step 6

Substitute values into the formula and solve for the equivalent resistance in the circuit.

$$\frac{1}{R_{eq}} = \frac{1}{3.0} + \frac{1}{11.0}$$

$$R_{eq} = \frac{1}{\frac{1}{3.0} + \frac{1}{11.0}} = 2.35 = 2.4\ \Omega$$

USEFUL TIP

Recall from Lesson 6A that the power equation can be represented in different ways in terms of the relevant variables of a given scenario. These are shown below:

$P = VI$ (excluding resistance)

$P = \frac{V^2}{R}$ (excluding current)

$P = I^2R$ (excluding voltage)

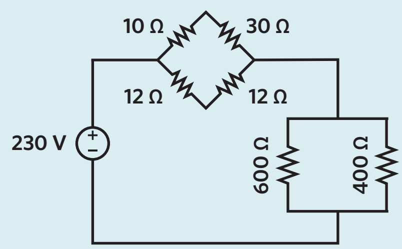
How do we analyse current, voltage, and power in combination circuits?

Combination circuit analysis often involves finding the current, voltage drop, and/or power for particular components within the circuit. To achieve this:

- if not provided, find the total current and voltage provided to the circuit using Ohm's Law and the total equivalent resistance.
- Split the equivalent resistance back into smaller groups of components and use Ohm's Law to calculate the current and/or voltage for these components.
- Continue to work backwards, splitting component groups until you can use Ohm's Law to determine the current and/or voltage for the specified component.
- Use the power equation with the current and voltage drop for the specific component if required.

WORKED EXAMPLE 4

An ideal 230 V is connected to a combined circuit composed of both parallel and series resistors, representing an electric heater circuit.

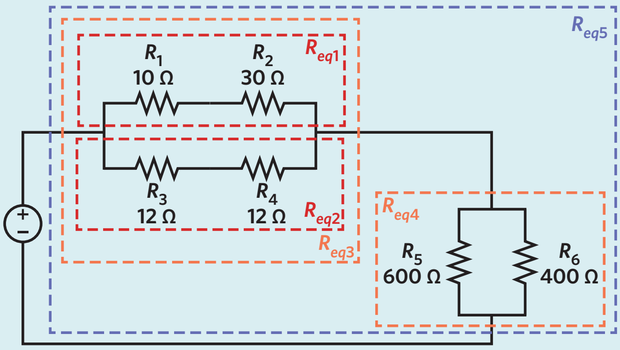


a. Determine the total power consumed by the electric heater circuit.

Step 1

Redraw the circuit in a more familiar shape, and identify the sets of series and parallel resistors.

It may be helpful to visualise a triangular arrangement as being rectangular.



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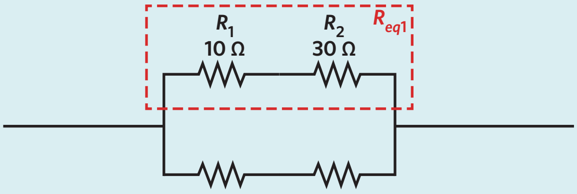
Step 2

Identity R_1 and R_2, and the series equivalent resistance formula that relates these variables.

$R_1 = 10\ \Omega,\ R_2 = 30\ \Omega,\ R_{eq1} = ?$

$R_{eq1} = R_1 + R_2$



Step 3

Substitute values into the formula and solve for the equivalent resistance of R_{eq1}.

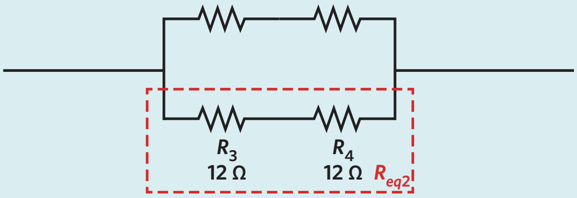
$R_{eq1} = 10 + 30 = 40\ \Omega$

Step 4

Identity R_3 and R_4, and the series equivalent resistance formula that relates these variables.

$R_3 = 12\ \Omega,\ R_4 = 12\ \Omega,\ R_{eq2} = ?$

$R_{eq2} = R_3 + R_4$



Step 5

Substitute values into the formula and solve for the equivalent resistance of R_{eq2}.

$R_{eq2} = 12 + 12 = 24\ \Omega$

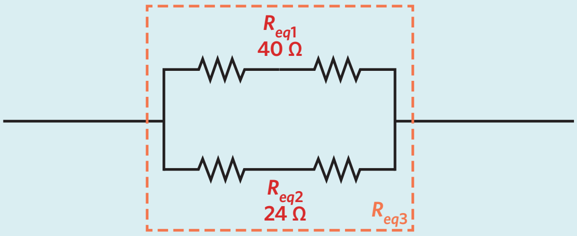
Step 6

Identify R_{eq1} and R_{eq2}, and the parallel equivalent resistance formula that relates these variables.

Circuit redrawn with equivalent resistors:

$R_{eq1} = 40\ \Omega,\ R_{eq2} = 24\ \Omega,\ R_{eq3} = ?$

$$\frac{1}{R_{eq3}} = \frac{1}{R_{eq1}} + \frac{1}{R_{eq2}}$$



Step 7

Substitute values into the formula and solve for the equivalent resistance of R_{eq3}.

$$\frac{1}{R_{eq3}} = \frac{1}{40} + \frac{1}{24}$$

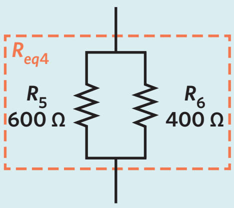
$$R_{eq3} = \frac{1}{\frac{1}{40} + \frac{1}{24}} = 15.0 = 15\ \Omega$$

Step 8

Identity R_5 and R_6, and the parallel equivalent resistance formula that relates these variables.

$R_5 = 600\ \Omega,\ R_6 = 400\ \Omega,\ R_{eq4} = ?$

$$\frac{1}{R_{eq4}} = \frac{1}{R_5} + \frac{1}{R_6}$$



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Step 9

Substitute values into the resistance formula to solve for the equivalent resistance of R_{eq4}.

$$\frac{1}{R_{eq4}} = \frac{1}{600} + \frac{1}{400}$$

$$R_{eq4} = \frac{1}{\frac{1}{600} + \frac{1}{400}} = 240.0 = 240\ \Omega$$

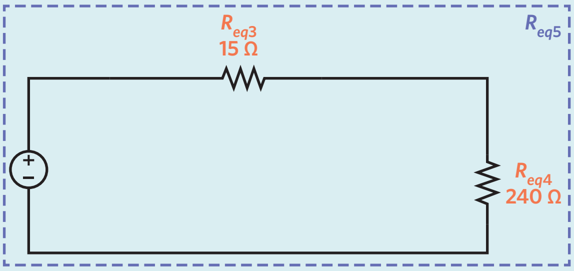
Step 10

Identity R_{eq3} and R_{eq4}, and the series equivalent resistance formula that relates these variables.

Circuit redrawn with equivalent resistors:

$R_{eq3} = 15\ \Omega$, $R_4 = 240\ \Omega$, $R_{eq5} = R_T = ?$

$R_T = R_{eq3} + R_{eq4}$



Step 11

Substitute values into the formula and solve for the total resistance in the circuit.

$R_T = 15 + 240 = 255\ \Omega$

Step 12

Identify total resistance and voltage, and the equations that relate these variables.

$R_T = 255\ \Omega$, $V_T = 230$ V, $P_T = ?$

$$P_T = \frac{{V_T}^2}{R_T}$$

Step 13

Substitute values into the power formula to solve for the total power consumed in circuit.

$$P_T = \frac{V^2}{R} = \frac{(230)^2}{255} = 207.4 = 207\ \text{W}$$

---

b. Determine the current through the 400 Ω (R_6) resistor in the electric heater circuit.

Step 1

Identify the total equivalent resistance and voltage, and the equation that relates these variables to find the total current.

$R_T = 255\ \Omega$, $V_T = 230$ V, $I_T = ?$

$V_T = R_T I_T$

Step 2

Substitute values into the formula and solve for the total current in the circuit.

$230 = 255 \times I_T$

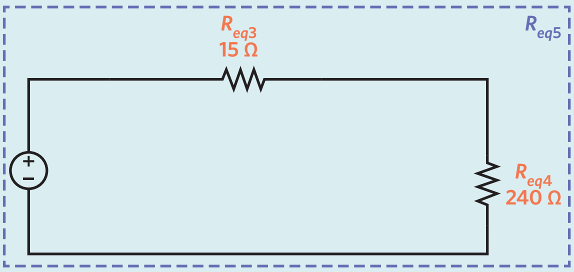
$$I_T = \frac{230}{255} = 0.9020 = 0.902\ \text{A}$$

Step 3

Split the equivalent resistance R_T into two groups, corresponding to each set of parallel components.

$I_T = 0.902$ A

$I_{eq4} = I_T = 0.902$ A



Since this is a series circuit, the current through both groups is equal to the total current calculated in part (a).

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Step 4

Identify R_{eq4} and the current through it, and Ohm's Law which relates these variables. Since the components within R_{eq4} are parallel, the voltage across it is also the voltage across R_6.

$I_{eq4} = 0.902$ A, $R_{eq4} = 240\ \Omega$, $V_6 = V_{eq4} = ?$

$V_6 = V_{eq4} = I_{eq4}R_{eq4}$

Step 5

Substitute values into the formula and solve for the voltage across R_6.

$V_6 = 0.902 \times 240 = 216.4 = 216$ V

Step 6

Identify R_6 and the voltage across it, and Ohm's Law which relates these variables.

$V_6 = 216$ V, $R_6 = 400\ \Omega$, $I_6 = ?$

$V_6 = I_6R_6$

Step 7

Substitute values into the formula and solve for the current through R_6.

$216 = I_6 \times 400$

$I_6 = \frac{216}{400} = 0.540$ A

Progress questions

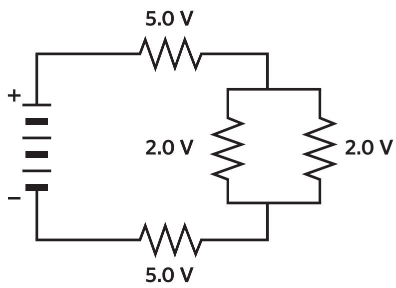
Question 3

For a given circuit, the power consumed was measured to be at 25 W, whilst a voltmeter measured total voltage of the circuit to be 5 V. What is the equivalent resistance of the circuit?

A. 0.2 Ω **B.** 1 Ω **C.** 4 Ω **D.** 5 Ω

Question 4

A combined parallel-series circuit is shown, alongside the voltage drop for each resistor. What is the total voltage of this circuit?



A. 6.5 V

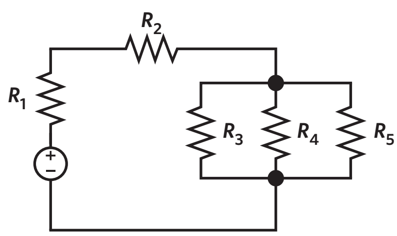
B. 11 V

C. 12 V

D. 14 V

Question 5

Simone has been asked to find the current passing through R_4. Number the actions below to create a step-by-step process for Simone to solve this problem.



Step no.	Action
	Find total equivalent resistance of the circuit.
	Find the equivalent resistance of the parallel resistors.
	Find the current passing through R_4 using Ohm's Law or $I_n \propto \frac{1}{R_n}$.
	Find the total current using Ohm's Law.

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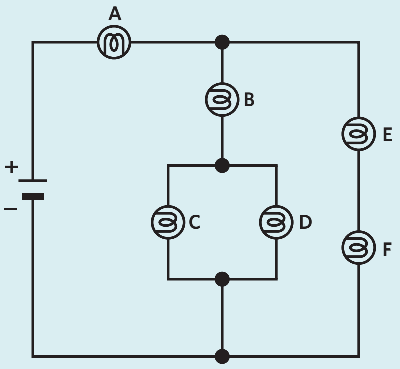
Theory summary

- Circuits often have components in a combination of series and parallel connections.
- To analyse combination circuits, we have to calculate equivalent resistances at multiple levels.
  - We start with small sections of the circuit which only contain one type of connection, and then 'replace' those sections with a single equivalent resistor.
  - A total equivalent resistance of a combination circuit can be found to use $V_T = I_T R_T$.
  - Solving for specific values of current and voltage requires working backwards from total values.

CONCEPT DISCUSSION



During a school lab, students design a circuit containing six light bulbs in a combined series-parallel arrangement, as shown in the diagram. All light bulbs have identical resistance. The students have a single open switch which they can use to place anywhere in the circuit, even in place of a light bulb.

The students aim to increase the brightness of light bulb A to maximum intensity. Discuss where the students should place the open switch for their objective to be fulfilled.

Prompts:

- Which variable does the intensity of the light bulb relate to?
- Does adding more resistors in parallel increase or decrease overall resistance? What about in series?
- How does the resistance of a component impact the power loss?

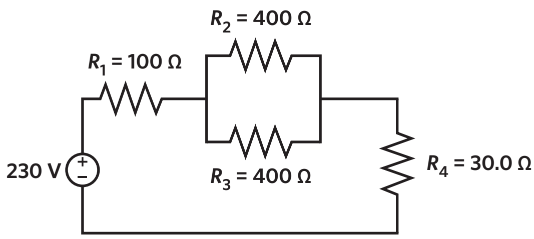
6E Questions

Mild Medium Spicy

Deconstructed exam-style

Use the following information to answer questions 6–9.

This electric circuit represents the internal circuitry of an appliance.



Question 6 (1 MARK)

Which of the following is closest to the equivalent resistance for the group of components containing R_2 and R_3 only?

A. 100 Ω

B. 200 Ω

C. 400 Ω

D. 800 Ω

Question 7 (1 MARK)

Which of the following is closest to the total equivalent resistance of the circuit?

A. 20.0 Ω

B. 230 Ω

C. 330 Ω

D. 930 Ω

Question 8 (1 MARK)

Which of the following statements about the appliance circuit is incorrect?

A. The current through R_4 is equal to $\frac{I_T}{R_4}$.

B. The current through R_4 is equal to I_T.

C. The voltage across R_4 is equal to $\frac{R_4}{R_T} \times V_T$.

D. The voltage across R_4 is equal to $I_T \times R_4$.

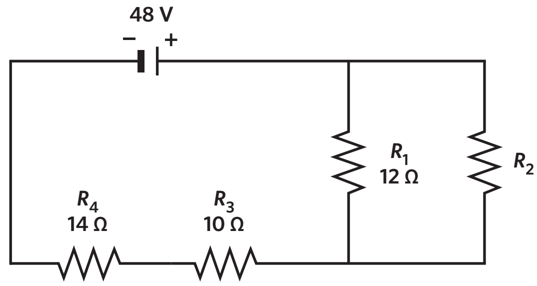
Question 9 (4 MARKS)

How much power is consumed by R_4?

Exam-style

Question 10 (5 MARKS)

1.0 A of current flows through R_1 in this combination circuit. Determine the resistance of R_2.

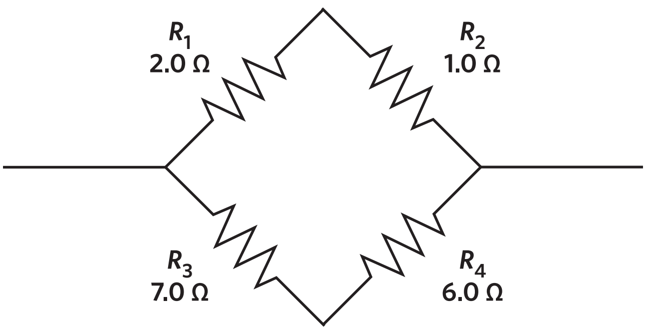


Question 11 (5 MARKS)

An electrical circuit contains a diamond-like resistor arrangement.

a. Find the equivalent resistance of this circuit. (2 MARKS)

b. Given that the circuit consumes 20 W of power, find the current through this circuit. (3 MARKS)



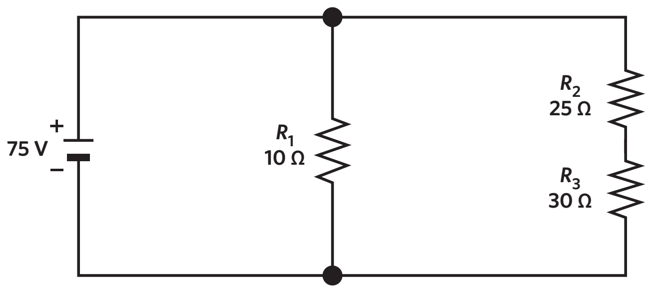
Question 12 (6 MARKS)

The combined parallel-series circuit containing three resistors is connected to a 75 V cell.

a. Calculate the equivalent resistance of the circuit. (2 MARKS)

b. Determine the total current in the circuit. (2 MARKS)

c. Calculate the voltage drop across resistor R_2. (2 MARKS)



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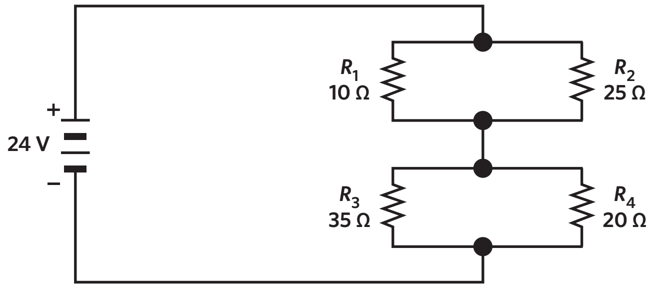
Question 13 (10 MARKS)

The parallel-series circuit shown displays a 24 V battery alongside four different resistors.



a. Determine the equivalent resistance of this circuit. (3 MARKS)

b. Calculate the total current across the circuit. (2 MARKS)

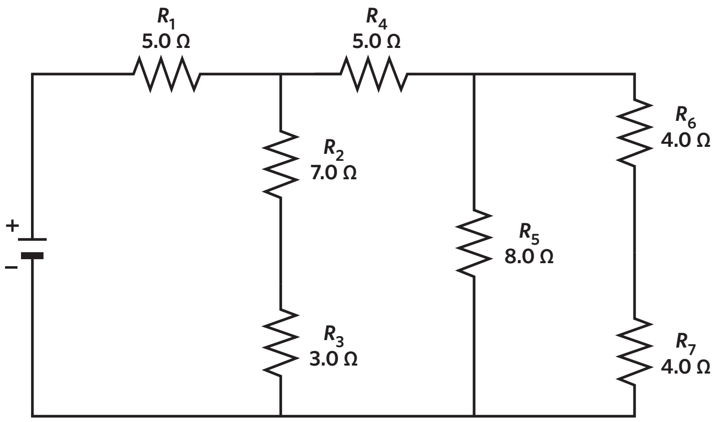
c. Calculate the current through resistor R_1. (2 MARKS)

d. Determine the ratio of the powers dissipated between resistor R_1 and resistor R_2. (3 MARKS)

Question 14 (6 MARKS)

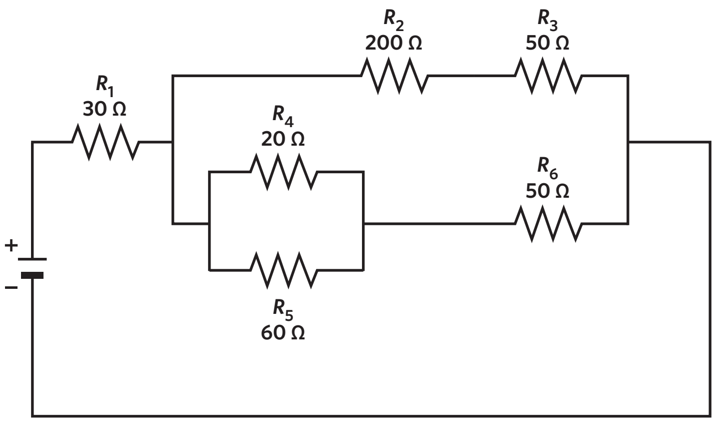
Determine the equivalent resistance of each combination circuit.

a.



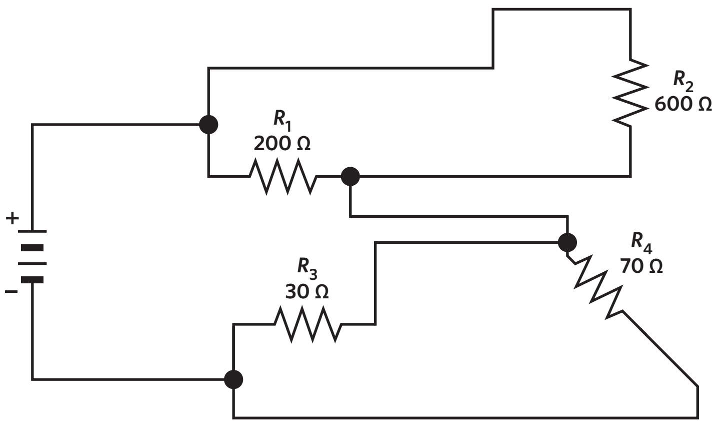
(2 MARKS)

b.



(2 MARKS)

c.



(2 MARKS)

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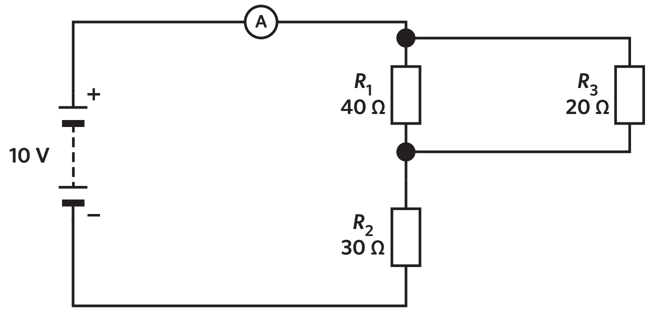
Question 15 (3 MARKS)

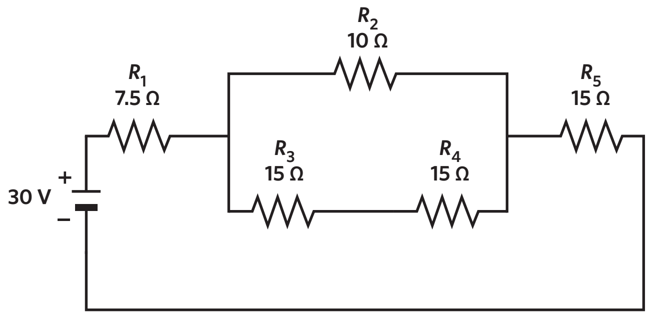
Janelle sets up the circuit shown in the diagram below. The circuit consists of a 10 V battery and three resistors, $R_1 = 40\ \Omega$, $R_2 = 30\ \Omega$ and $R_3 = 20\ \Omega$. What is the current through the ammeter A?

Adapted from VCAA 2009 Exam 1 Area of Study 2 Q3



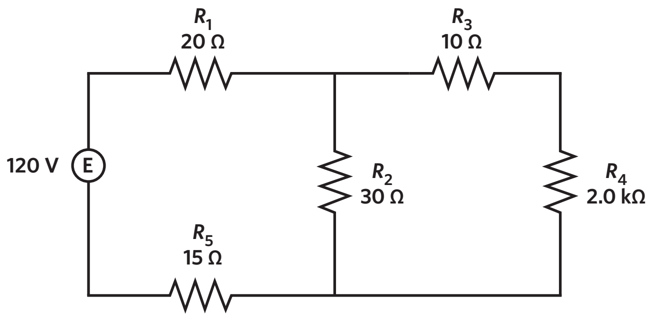
Question 16 (4 MARKS)

Determine the voltage drop across R_1 and R_4 in this combination circuit.



Question 17 (5 MARKS)

Which of the resistors in this combination circuit would consume the most power? Show your working.



Key science skills

Question 18 (3 MARKS)

Joanne has performed two experiments to determine the total current provided to a combination circuit. She records the following results:

	I_T (mA)				
Experiment 1	5.5	5.4	5.6	5.6	5.6
Experiment 2	5.8	5.1	5.9	5.9	5.5

The true value of I_T is known to be 5.5 mA.

Determine which experiment produced the more precise results, and which experiment produced the more accurate results. Explain your answer.

FROM LESSON 11C

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Previous lessons

Question 19 (2 MARKS)

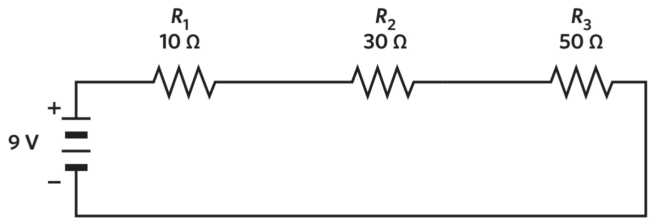
List two significant impacts of climate change Australia is currently experiencing, or expected to experience in the near future.

FROM LESSON 3B

Question 20 (2 MARKS)

Determine the total current in this series circuit.

FROM LESSON 6C



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Chapter 6 review

Mild 🌶 Medium 🌶🌶 Spicy 🌶🌶🌶

These questions are typical of 40 minutes worth of questions on the VCE Physics Exam.

Total marks: 30

Section A

All questions in this section are worth one mark.

Unless otherwise indicated, the diagrams in this book are not drawn to scale.

Question 1 🌶

Which of the following correctly describes how electrical quantities are affected by two conductive elements with different resistances in series or parallel?

	Series	Parallel
A.	power is split between the two	power is equal
B.	current is equal	potential difference is equal
C.	current is equal	potential difference is split between the two
D.	potential difference is equal	current is split between the two

Question 2 🌶🌶

The magnitude of the charge of an electron is 1.60×10^{-19} C. Using this information, the number of electrons flowing every second through a 45 W toaster that is connected to a 240 V power supply would be closest to

A. 1.2×10^{17}.

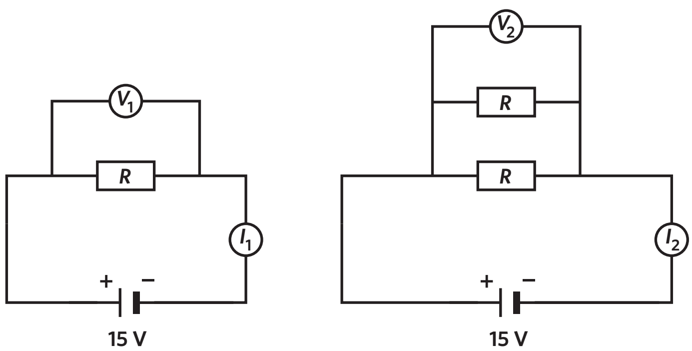
B. 1.2×10^{18}.

C. 3.3×10^{19}.

D. 2.8×10^{20}.

Question 3 🌶🌶

The following diagram depicts two simple circuits. In both circuits, R represents a resistor of identical resistance.



V_1 and V_2 are readings from ideal voltmeters. I_1 and I_2 are readings from ideal ammeters. Which one of the following statements is true?

A. $V_2 = V_1$ and $I_2 > I_1$

B. $V_2 = V_1$ and $I_2 < I_1$

C. $V_2 > V_1$ and $I_2 > I_1$

D. $V_2 > V_1$ and $I_2 < I_1$

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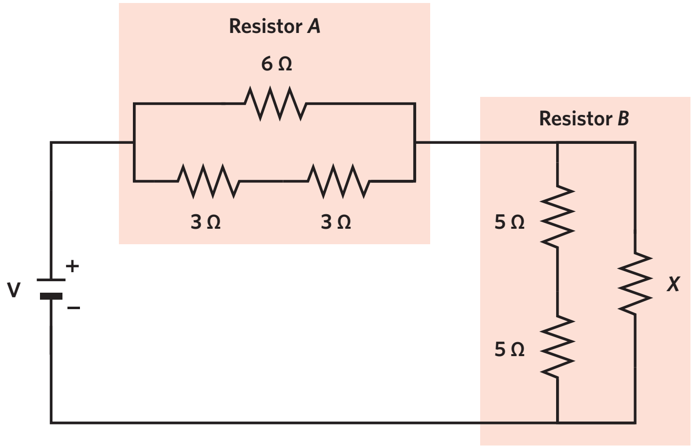
Use the following information to answer questions 4 and 5.

The provided diagram shows two sets of parallel resistors *A* and *B* in a combination circuit. *X* is a resistor with an unknown resistance.



Question 4

Which one of the following statements is true?

A. The equivalent resistance of *A* is 6.0 Ω.

B. The equivalent resistance of *A* is 12 Ω.

C. The equivalent resistance of *B* cannot exceed 10 Ω.

D. The equivalent resistance of *B* must be above 10 Ω.

Question 5

If the circuit has a total equivalent resistance of 11 Ω, which of the following is closest to the resistance of *X*?

A. 5.0 Ω

B. 10 Ω

C. 20 Ω

D. 40 Ω

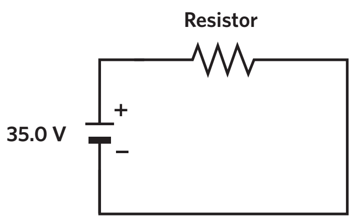
Section B

In questions where more than one mark is available, appropriate working must be shown.

Unless otherwise indicated, the diagrams in this book are not drawn to scale.

Question 6 (6 MARKS)

A new resistor is being tested by manufacturers. It has a resistance of 8.00×10^4 Ω. They place the resistor in the circuit shown in the provided diagram.



a. Calculate the power dissipated by the resistor. (3 MARKS)

b. A second identical resistor is placed in parallel with the resistor above. Calculate the current flowing in the circuit. (3 MARKS)

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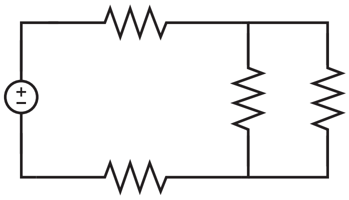
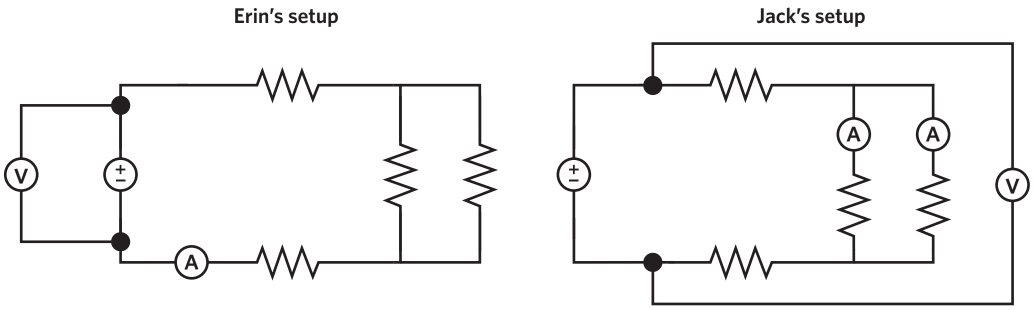
Question 7 (4 MARKS)

Students are attempting to determine the power usage of a circuit with unknown electrical quantities.



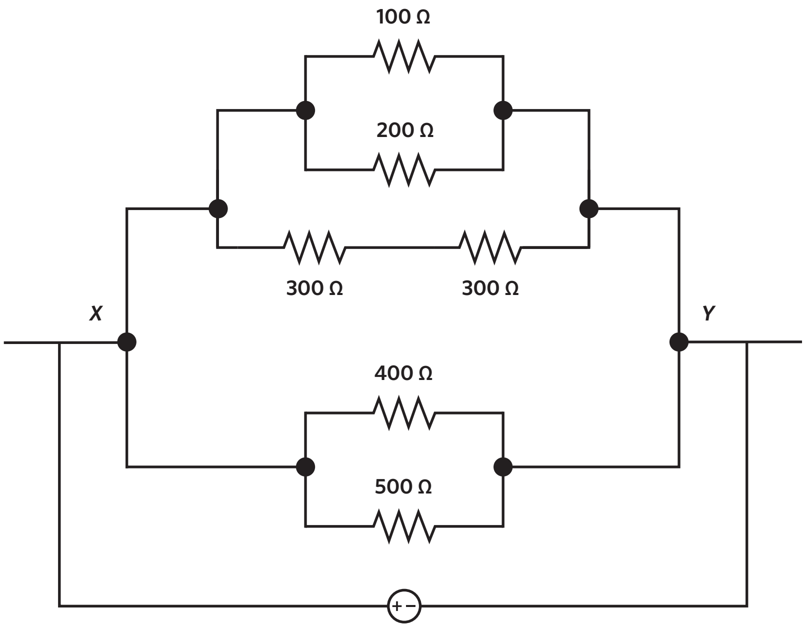
Erin believes that they can determine the power usage of the circuit by placing a voltmeter and ammeter as shown. Jack disagrees. He says that in order to know the total power they need to check the voltage and current across the entire circuit, and proposes a different circuit arrangement.



Which student's setup will allow them to determine the total power usage of the circuit? Explain your answer.

Question 8 (4 MARKS)

Calculate the equivalent resistance between *X* and *Y* for the following combination circuit.



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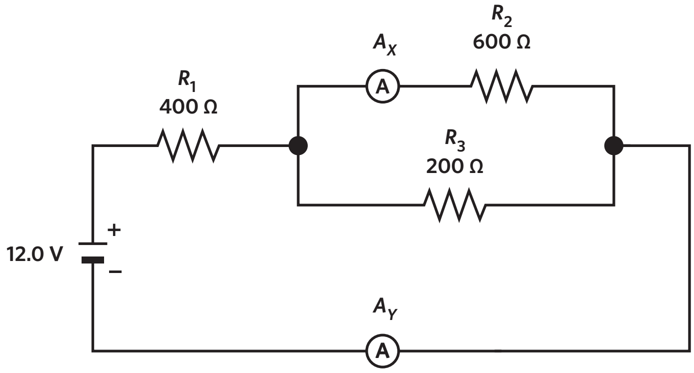
Question 9 (11 MARKS)

Consider the following circuit which shows three resistors wired to two ammeters and a 12.0 V power source.

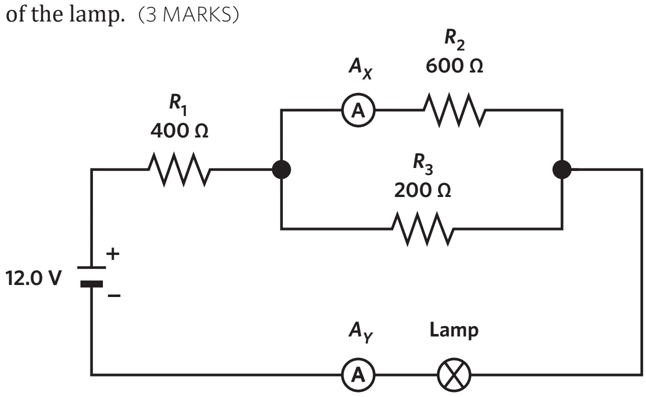


a. Calculate the ratio of the current through A_X to the current through A_Y. (2 MARKS)

b. Calculate the potential difference across R_1. (3 MARKS)

c. Calculate the power dissipated by R_3. (3 MARKS)

d. A lamp is inserted into the circuit in series with A_Y, which now reads 15 mA. Calculate the resistance of the lamp. (3 MARKS)



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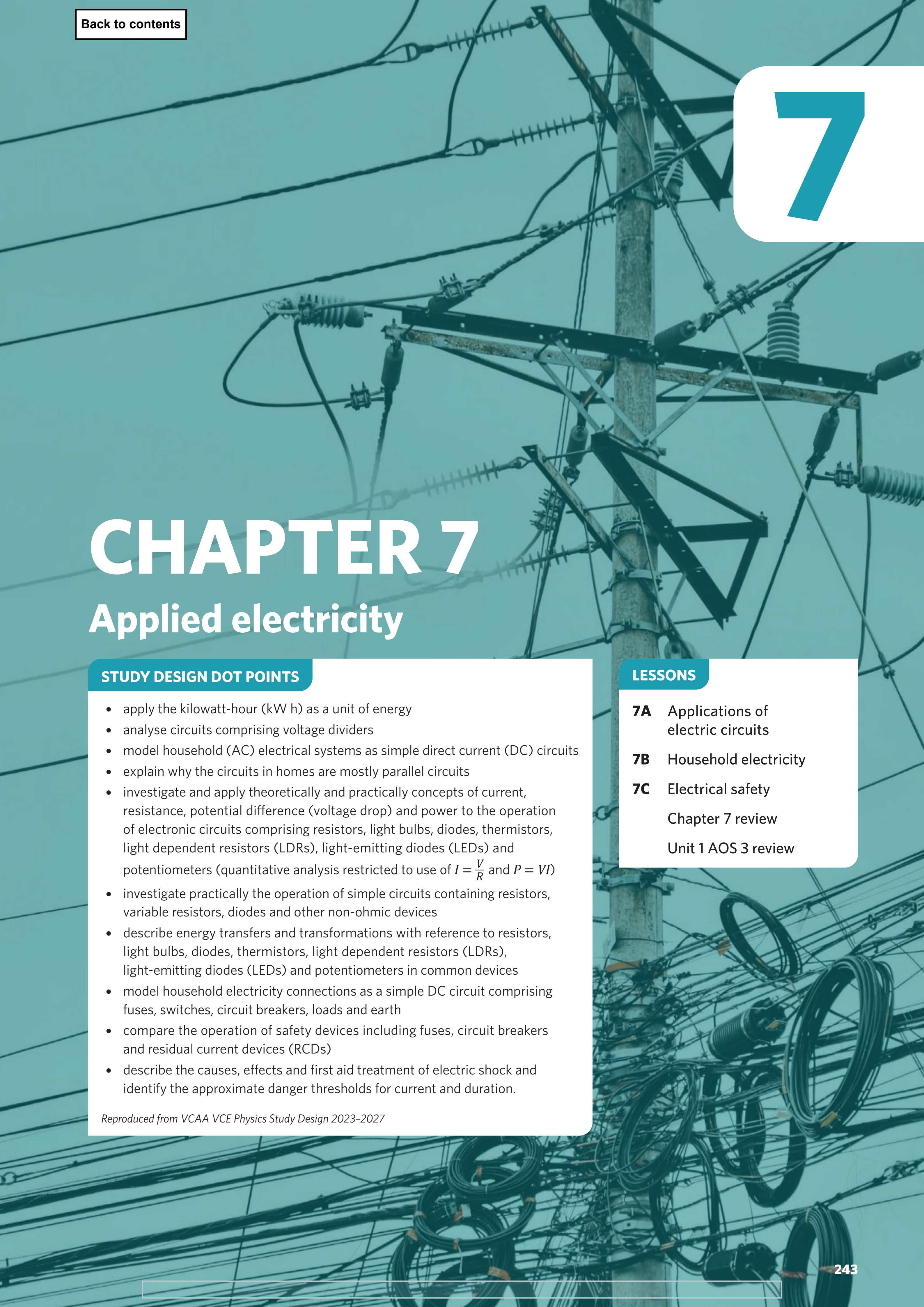

7

CHAPTER 7

Applied electricity

STUDY DESIGN DOT POINTS

- apply the kilowatt-hour (kW h) as a unit of energy
- analyse circuits comprising voltage dividers
- model household (AC) electrical systems as simple direct current (DC) circuits
- explain why the circuits in homes are mostly parallel circuits
- investigate and apply theoretically and practically concepts of current, resistance, potential difference (voltage drop) and power to the operation of electronic circuits comprising resistors, light bulbs, diodes, thermistors, light dependent resistors (LDRs), light-emitting diodes (LEDs) and potentiometers (quantitative analysis restricted to use of $I = \frac{V}{R}$ and $P = VI$)
- investigate practically the operation of simple circuits containing resistors, variable resistors, diodes and other non-ohmic devices
- describe energy transfers and transformations with reference to resistors, light bulbs, diodes, thermistors, light dependent resistors (LDRs), light-emitting diodes (LEDs) and potentiometers in common devices
- model household electricity connections as a simple DC circuit comprising fuses, switches, circuit breakers, loads and earth
- compare the operation of safety devices including fuses, circuit breakers and residual current devices (RCDs)
- describe the causes, effects and first aid treatment of electric shock and identify the approximate danger thresholds for current and duration.

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LESSONS

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7A Applications of electric circuits

STUDY DESIGN DOT POINTS

- analyse circuits comprising voltage dividers
- investigate and apply theoretically and practically concepts of current, resistance, potential difference (voltage drop) and power to the operation of electronic circuits comprising resistors, light bulbs, diodes, thermistors, light dependent resistors (LDRs), light-emitting diodes (LEDs) and potentiometers (quantitative analysis restricted to use of $I = \frac{V}{R}$ and $P = VI$)
- investigate practically the operation of simple circuits containing resistors, variable resistors, diodes and other non-ohmic devices
- describe energy transfers and transformations with reference to resistors, light bulbs, diodes, thermistors, light dependent resistors (LDRs), light-emitting diodes (LEDs) and potentiometers in common devices

ESSENTIAL PRIOR KNOWLEDGE

6A Current, voltage and power

6B Resistance and Ohm's law

6E Circuit analysis

See questions 48–50.

ACTIVITIES

Log into your Edrolo account for activities that support this lesson.

Image: Sergey Zolkin

How do street lamps turn on and off automatically?

Electric circuits are used all over the world to perform all kinds of jobs, from cooking food to flying planes. This lesson will explore the uses of voltage dividers, analyse non-ideal electrical component behaviour, and introduce diodes and advanced resistors to help understand how complex circuits work.

KEY TERMS AND DEFINITIONS

anode the electrode of a device conventional current flows into

cathode the electrode of a device conventional current flows out from

diode a semiconductor device which limits current flow to one direction

internal resistance the resistance associated with an electric power source

light-dependent resistor a variable resistor that decreases resistance as the intensity of light hitting its surface increases

light-emitting diode a diode that emits light when a potential difference is applied

potentiometer a variable resistor that changes resistance depending on the manual control of a sliding contact

thermistor a variable resistor that changes resistance with temperature

transducer a component or device that transforms energy between different forms

voltage divider a circuit with resistance that outputs a voltage smaller than its input voltage

FORMULA

- **voltage divider equation**

$$V_{out} = \frac{R_2}{R_1 + R_2} \times V_{in}$$

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Voltage dividers 1.3.8.1

Voltage dividers use the ratio of resistances between two resistors to output a desired voltage less than the input voltage.

Theory and applications

Voltage dividers are useful in obtaining different voltage levels from a common supply voltage. A voltage divider is typically used to change a large input voltage into a small output voltage.

How can we analyse circuits comprising voltage dividers?

Many complex circuits require different voltages to operate their various components. As such, it is often required to 'divide' a fixed input voltage into a smaller output voltage. The simplest method of achieving this is to use a voltage divider.

- A voltage divider consists of two resistors in series, with the output defined as the voltage across one of the resistors.
- Since the resistors are in series, the total input voltage is split between the resistors proportional to their resistances.

If we define R_2 as the output resistor (see Figure 1), then the formula for the output voltage is as follows:

FORMULA

$$V_{out} = \frac{R_2}{R_1 + R_2} \times V_{in}$$

V_{out} = output voltage (V)
R_2 = resistance of output resistor (Ω)
R_1 = resistance of non-output resistor (Ω)
V_{in} = input voltage (V)

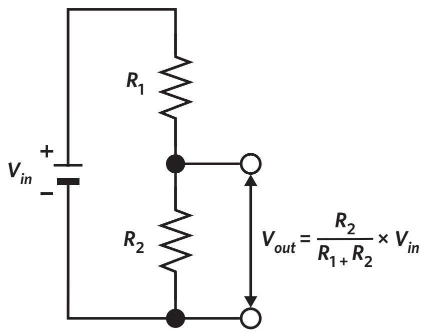
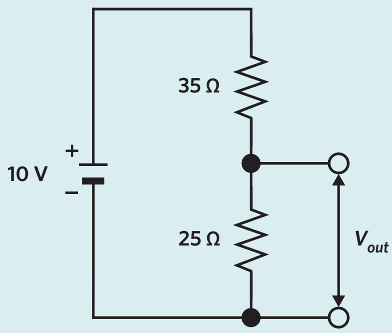


Figure 1 A voltage divider

WORKED EXAMPLE 1

A student designs the following electrical circuit as an introduction to voltage dividers. Determine the output voltage.



Step 1

Identify the relevant circuit components and the equation relating these variables.

$R_1 = 35\ \Omega$, $R_2 = 25\ \Omega$, $V_{in} = 10$ V, $V_{out} = ?$

$$V_{out} = \frac{R_2}{R_1 + R_2} \times V_{in}$$

Step 2

Substitute the relevant values into the equation and solve for the output voltage.

$$V_{out} = \frac{25}{35 + 25} \times 10 = 4.17 = 4.2 \text{ V}$$

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Progress questions

Question 1

A voltage divider has a 3.0 Ω and a 6.0 Ω resistor in series with a 12 V power supply. What is the output voltage across the 3.0 Ω resistor?

A. 3.0 V

B. 4.0 V

C. 6.0 V

D. 12 V

Question 2

A voltage divider has a 12 V power source and needs an output voltage of 8 V.

What ratio of $\frac{R_2}{R_T}$ is required?

A. $\frac{1}{3}$

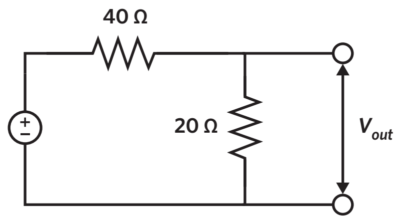
B. $\frac{2}{3}$

Question 3

Will the output voltage of this voltage divider be more than or less than half of the input voltage?

A. more than

B. less than



Behaviour of real electrical components 1.3.12.1 & 1.3.13.1

In Chapter 6, we analysed circuits with ideal sources and mainly ohmic components. However, real components have limitations that make their behaviour non-ideal.

Theory and applications

Light bulbs are often modelled in VCE physics as resistors with a constant resistance, however, light bulbs do not behave like this in real circuits. In reality, voltage and current sources, such as batteries, also have an associated internal resistance.

How can we model the behaviour of real electrical components, such as light bulbs?

Incandescent (filament) bulbs produce light by passing a current through the filament, causing it to heat up and glow. Resistance is dependent on temperature, so when the filament heats up, its resistance increases.

- When a small voltage is applied to an incandescent bulb, a small current flows, so the filament does not heat up significantly and the resistance remains small.
- As the voltage increases, the current increases and the filament heats up more, increasing the resistance.
- As the resistance is increasing with the applied voltage, the light bulb is a non-ohmic device.
- A possible graph of current (A) versus voltage (V) for a real incandescent light bulb is shown in Figure 2. Note that the graph is non-linear, therefore the light bulb is non-ohmic.

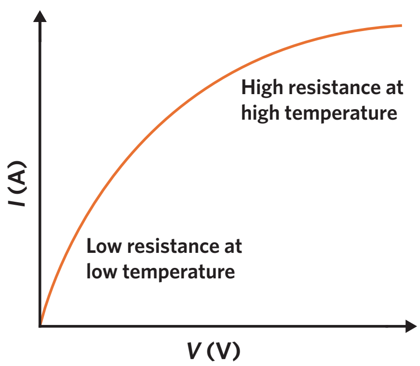


Figure 2 An *I*-*V* graph of an incandescent bulb

In previous lessons, we analysed circuits containing ideal sources that have no limitations on their outputs. Real sources, however, have an inherent internal resistance that affects the current and output voltage provided to a circuit. The internal resistance is modelled as a resistor, R_i, in series with the source, as shown in Figure 3.

The internal resistance of a power supply can have some significant effects on circuit behaviour, as the internal resistance increases the total equivalent resistance of the circuit:

- The voltage provided to the circuit (the load) is smaller than that of the ideal voltage source.
  - This effect is reduced when the load resistance is much greater than the internal resistance.
- The current provided by the source is reduced.
  - This effect is small when the load resistance is much greater than the internal resistance.

For our circuit to behave as we expect through calculations, we either need to know the internal resistance of the source and consider its effects, or ensure that our load resistance is large enough that the impacts of the internal resistance are negligible.

USEFUL TIP

The internal resistance of a source is usually quite small, for example, a 1.5 V AA cell might have an internal resistance between 0.1 Ω and 1 Ω.

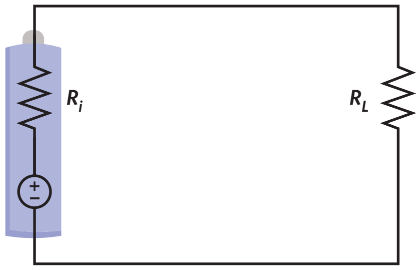
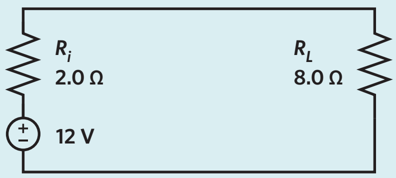


Figure 3 The ideal voltage source in series with an internal resistance, R_i

WORKED EXAMPLE 2

A DC voltage source, at 12 V, is being used to power a simple circuit consisting of an 8.0 Ω resistor. The source has an internal resistance of 2.0 Ω (R_i).



a. Determine the voltage provided to the load resistor, R_L.

Step 1

Identify the relevant values in the circuit and the equation relating these variables.

$V_{in} = 12$ V, $R_i = 2.0\ \Omega$, $R_L = 8.0\ \Omega$, $V_L = V_{out} = ?$

$$V_L = \frac{R_L}{R_i + R_L} \times V_{in}$$

Step 2

Substitute values into the equation and solve for V_L.

$$V_L = \frac{8.0}{2.0 + 8.0} \times 12$$

$$V_L = 9.60 = 9.6 \text{ V}$$

b. Determine the difference in current in the load, considering the circuit with and without internal resistance.

Step 1

Identify the relevant values in the circuit and the relevant equation relating these variables.

$V_{in} = 12$ V, $R_i = 2.0\ \Omega$, $R_L = 8.0\ \Omega$, $I_B = ?$, $I_A = ?$

Without R_i: $I_B = \frac{V_T}{R_T}$

With R_i: $I_A = \frac{V_T}{R_i + R_L}$

Step 2

Substitute and solve for the currents using Ohm's law, with the two total resistances and constant supply voltage.

$$I_B = \frac{V_T}{R_T} = \frac{12}{8.0} = 1.5 \text{ A}$$

$$I_A = \frac{V_T}{R_i + R_L} = \frac{12}{10.0} = 1.2 \text{ A}$$

Step 3

Find the difference between the currents with and without the internal resistance.

$$I_B - I_A = 1.5 - 1.2 = 0.3 \text{ A}$$

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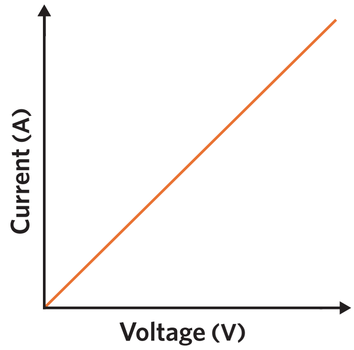
Progress questions

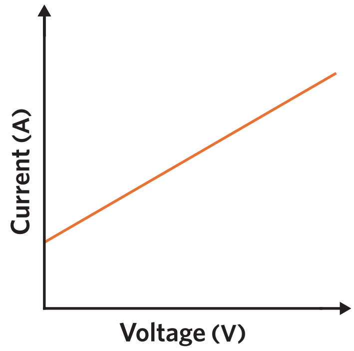
Question 4

Which of the following graphs could represent the current-voltage relationship of a real electrical component?

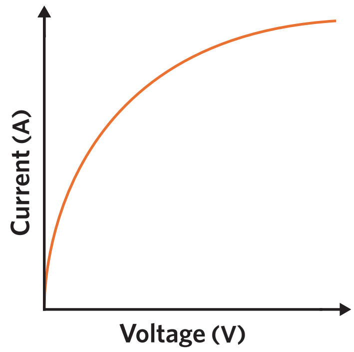
A.



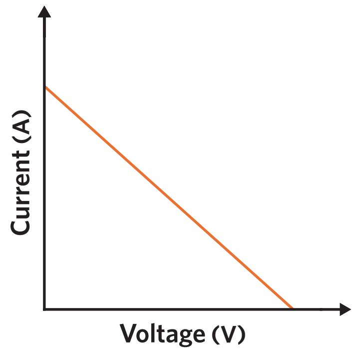
B.



C.



D.



Question 5

Fill in the gaps in the following paragraph about internal resistance.

The internal resistance of a source is an inherent property of ___________ (real/ideal) sources. It limits the ___________(maximum/minimum) current that can be provided by the source. When the load resistance is similar in magnitude to the internal resistance, there is a ___________ (negligible/significant) effect on the voltage supplied to the load due to the internal resistance.

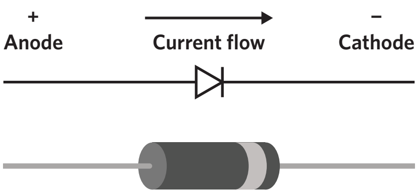


Figure 4 The circuit diagram symbol for a diode and a real diode

KEEN TO INVESTIGATE?

1 **How can we explain diodes?**
Search YouTube: Diodes explained

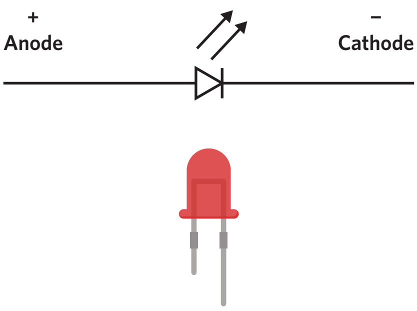


Figure 5 The circuit diagram symbol for an LED and a real LED

Diodes and light-emitting diodes 1.3.12.2

Diodes are semiconductor devices that only allow current to flow in one direction. Light-emitting diodes (LEDs) are a type of diode that produces light under a potential difference.

Theory and applications

By using LEDs as a light source over incandescent light bulbs, the amount of energy lost to heat is reduced. Because of their simple componentry, LEDs also last much longer than incandescent bulbs, therefore reducing waste.

How are diodes used in everyday electrical circuits?

Diodes are made from semiconductors -- materials like silicon that can be designed to allow current to flow in only one direction.[1] Due to the physical properties of the semiconductor materials, this junction only allows current to flow in one direction.

The circuit symbol for a diode (see Figure 4) indicates the direction that current can flow. Using conventional current (from positive to negative terminals), current can flow in the direction the 'arrow' of the diode symbol is pointing, see Figure 5.

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USEFUL TIP

We can think of the vertical line in the symbol of the diode as a wall stopping current from flowing in the opposite direction.

A light-emitting diode (LED) is a type of diode specifically designed to emit light when a potential difference is applied. It converts electric potential energy into light when electrons move across the semiconductor junction.

Like a regular diode, current can only flow one way through an LED, so the potential difference applied to the LED must be in the correct direction for the LED to light up, or the LED will not work.

USEFUL TIP

The anode of a real LED will be longer than the cathode so that it can be easily wired in the correct direction.

Diodes are used in circuits to ensure current only flows in one direction. This can be useful to protect sensitive components from backwards currents (current moving in the wrong direction) when sources are connected the wrong way.

- When analysing a circuit with a diode, start by checking whether any current will flow.
- If current is flowing, use the diode threshold voltage to determine the voltage drop for the rest of the circuit.

When a potential difference is applied to a diode that creates a current flow, there will be a voltage drop across the diode. This is known as the threshold voltage, V_t. We can use the *I-V* graph of a diode to find the threshold voltage, as shown in Figure 6.

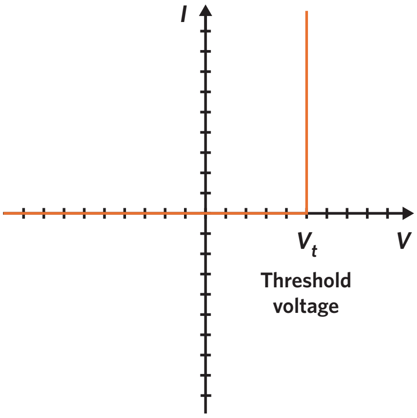

Figure 6 The *I-V* graph of a diode with ideal characteristics

USEFUL TIP

Most diodes have a small threshold voltage of around 0.7 V. Our analysis of diodes will be limited to ideal diodes, where once the threshold voltage is met, unlimited current can flow without affecting the voltage drop across the diode.

LEDs operate much the same as regular diodes in circuits, however they often have a much higher threshold voltage, commonly around 1.5 V–3 V. One important requirement when designing circuits that use LEDs is to limit the current passing through each LED. Too much current will cause an LED to burn out, so a current-limiting resistor must be placed in series with the LED to prevent failure, as shown in Figure 7.

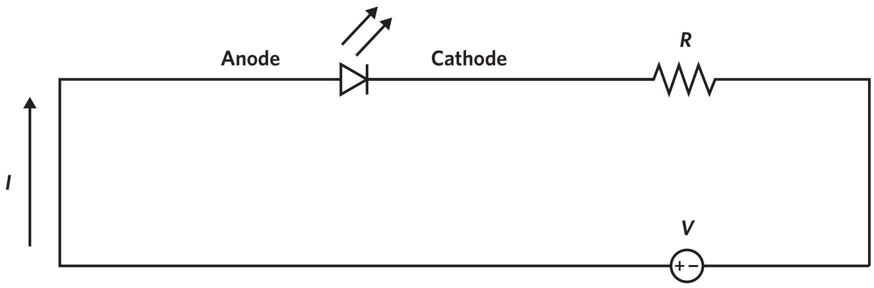

Figure 7 The use of a current-limiting resistor in an LED circuit

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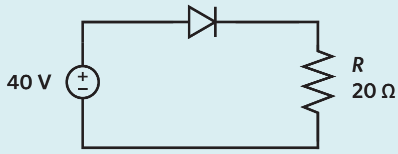
WORKED EXAMPLE 3

A diode is being used to protect a sensitive circuit from a backwards current when its source is connected the wrong way. The diode has a threshold voltage of 1.1 V.

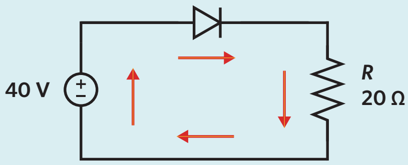


a. Determine whether current will flow in the circuit. Explain your answer.

Step 1

Identify which direction conventional current is flowing.

Conventional current flows from positive to negative.



Step 2

Identify whether the diode is facing the same direction as the current flow, and therefore whether current will flow in the circuit.

The 'arrow' of the diode is facing the same direction as the current flow, therefore current will flow through this circuit.

b. Determine the current through the diode when the source is connected as shown. Assume the diode in this circuit is an ideal diode.

Step 1

Identify the relevant circuit components and the equation relating these variables.

$V_T = 40$ V, $V_{diode} = 1.1$ V, $R = 20\ \Omega$, $V_R = ?$

$V_T = V_R + V_{diode}$

Step 2

Substitute the relevant values into the formula to find the voltage supplied to the resistor.

$40 = V_R + 1.1$

$V_R = 38.9$ V

Step 3

Use Ohm's law to find the current through the diode.

The current through the diode is equal to the current through the resistor.

$I_{diode} = I_R = \dfrac{V_R}{R}$

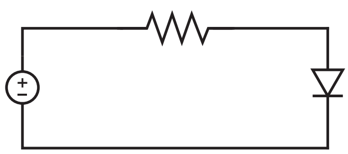
$I_{diode} = \dfrac{38.9}{20} = 1.95 = 2.0$ A

Progress questions

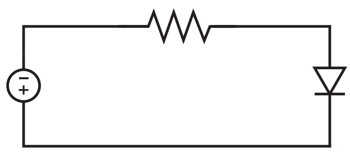
Question 6

In which of these four circuits will a current flow? **(Select all that apply)**

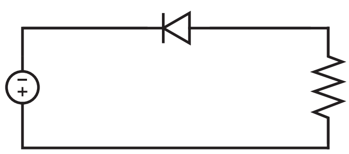
I.



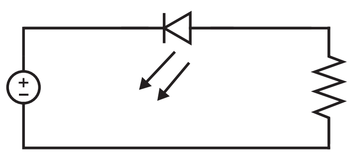
II.



III.



IV.



Question 7

A voltage source of 12 V is connected to a diode and a 4.0 Ω resistor in series. Determine the current through the diode given it has a threshold voltage of 1.3 V.

A. 3.0 A

B. 2.7 A

Advanced resistors 1.3.12.3 & 1.3.14.1

Advanced resistors respond to analogue control, or inputs like light intensity and temperature, to have a range of resistance values. Circuit components that transform energy from one form to another are known as transducers.

Theory and applications

Sensors used in our everyday lives often rely on advanced resistors such as thermistors and light-dependent resistors. For example, thermistors are used in thermostats to automatically regulate air-conditioning systems. Similarly, light-dependent resistors are often used in street lamps to turn them on and off automatically.

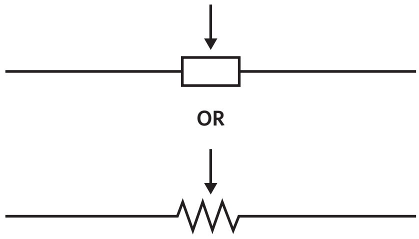


Figure 8 The circuit diagram symbols for a potentiometer

How do potentiometers work?

Potentiometers are electrical components that can have their resistance varied by manually moving a rotating or sliding contact (Figure 8). The potentiometer has a fixed length of resistive material, and the position of the contact determines how much of this length is active in the circuit. The length of a resistive material affects the total resistance of a component, so when the contact is moved to increase the length of resistive material being used, the potentiometer's resistance increases (see Figure 9). The length of the resistive material active is directly proportional to the amount of resistance.

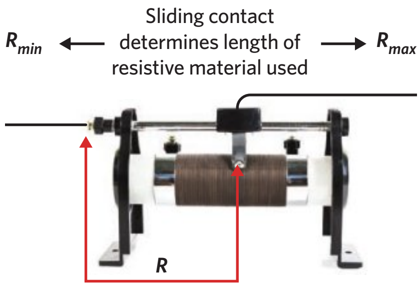


Figure 9 A potentiometer with a sliding contact

How do transducers work?

A transducer is any device that is designed to convert energy between different forms. An electric component, such as an LED, microphone, motor, or a circuit itself can be a transducer. Transducers are important in acting as sensors or outputs of a circuit. A common way that transducer circuits are constructed is using an advanced variable resistor in a voltage divider to transform an input energy – such as thermal energy or light - into an electric signal with electrical potential energy.

In such a voltage divider, an advanced variable resistor can be either the output resistor or the non-output resistor. Figure 10 is an example of using a thermistor as the non-output resistor.

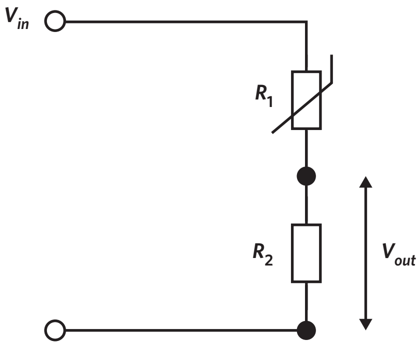


Figure 10 Using a thermistor in a voltage divider circuit as the other resistor

If we choose a thermistor whose resistance decreases with temperature, the voltage across the thermistor will drop, and therefore, the output voltage of the divider will increase. In this way, we have essentially created a digital thermometer. A switching circuit that turns on at a certain voltage can then be used to operate additional components when a certain temperature (and thus voltage) is reached. A transducer like this could be used as a temperature sensor in the control system of an air conditioner.

MISCONCEPTION

'When designing a voltage divider with a variable resistor, the variable resistor should always be the output resistor, R_2.'

The choice of the variable resistor as R_1 or R_2 depends on the characteristics of the variable resistor and the desired output voltage behaviour. Therefore either R_1 or R_2 can be the output resistor.

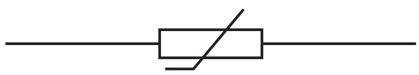


Figure 11 The circuit diagram symbol for a thermistor

How do thermistors work?

Thermistors (Figure 11) are variable resistors whose resistance varies with temperature. While all resistors are affected by temperature, thermistors are much more sensitive, so their resistance varies more significantly.

Thermistors can increase or decrease resistance with increasing temperature. The resistance of a thermistor at a specific temperature can be read from its resistance-temperature graph. For example, if we were told that the thermistor represented in Figure 12 was at 25 °C, we would use the graph to determine it has a resistance of 10 kΩ, shown by the green dotted lines.

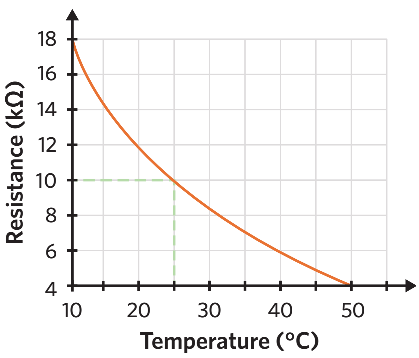


Figure 12 A resistance-temperature graph for a particular thermistor

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How do light-dependent resistors work?

Light-dependent resistors (LDRs), also known as photoresistors, are a type of variable resistor where the resistance decreases as the intensity of light hitting its sensitive surface increases (see Figure 13). They are commonly used in street lamps to automate turning them on and off.[2]

Similar to thermistors, a graph (in this case a resistance-light intensity graph) must be used to determine the resistance of an LDR for a given light intensity, see Figure 14.

KEEN TO INVESTIGATE?

[2] **How do street lamps work?**
Search YouTube:
LDRs and street lights

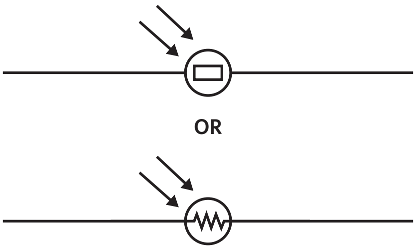


Figure 13 The circuit diagram symbols for a light-dependent resistor

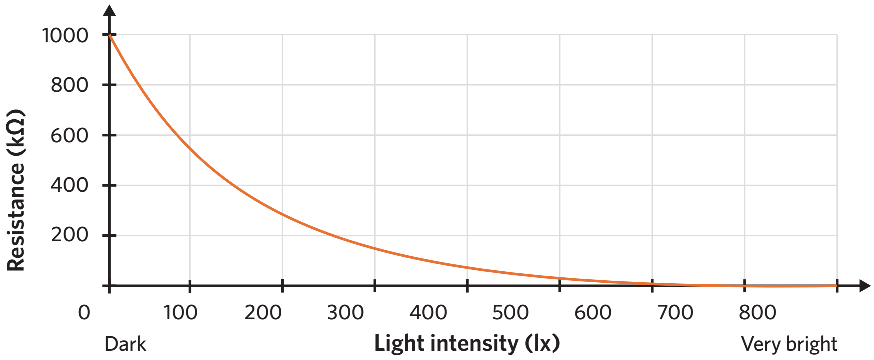
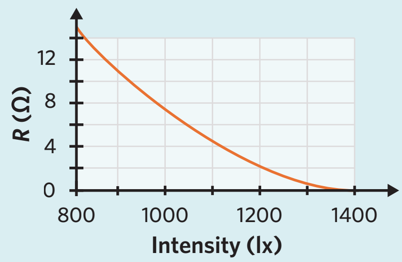


Figure 14 An example of a resistance-light intensity graph for a street light

WORKED EXAMPLE 4

A light intensity sensor is required to operate a street lamp.

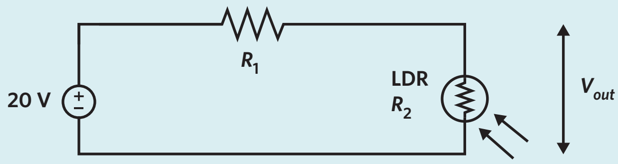
Design a voltage divider circuit consisting of an LDR with the resistance-intensity relationship shown in the graph below, another resistor (of any value), and a 20 V ideal source. The circuit should output 10 V when the light intensity is 1000 lux.



Step 1

Identify that the output voltage must decrease for greater light intensity, therefore R_2 must be an LDR. The decrease in resistance for greater intensity will cause a decrease in voltage dropped across it.

Circuit design:



Step 2

Identify the relevant circuit components and the equation relating these variables.

At 1000 lx:

$R_2 = 7.0\ \Omega$, $V_{out} = 10$ V, $V_{in} = 20$ V, $R_1 = ?$

$$V_{out} = \frac{R_2}{R_1 + R_2} \times V_{in}$$

Step 3

Substitute the values into the voltage divider equation and solve for R_1.

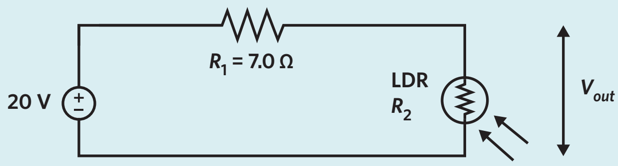
$$10 = \frac{7.0}{R_1 + 7.0} \times 20$$

$$R_1 = 7.00 = 7.0\ \Omega$$

Step 4

Redraw the electrical circuit, with the relevant labels.

Circuit design:



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Progress questions

Question 8

The resistance of a light-dependent resistor decreases as the intensity of light hitting its sensitive surface decreases.

A. True

B. False

Question 9

The relationship between the resistance of a potentiometer and the length along the potentiometer the centre contact sits is what kind of relationship?

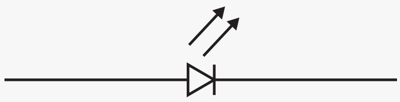
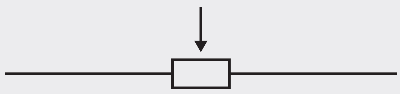
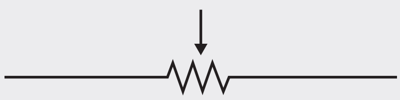
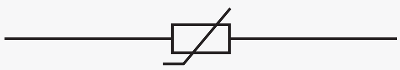
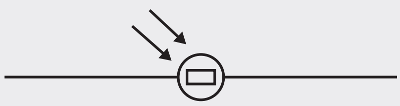
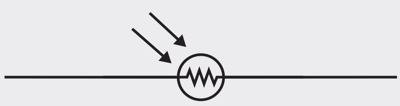
A. proportional

B. inversely proportional

C. exponential

Theory summary

- Voltage dividers use the ratio between two resistors to output a voltage that is smaller than the input voltage:
  - $V_{out} = \frac{R_2}{R_1 + R_2} \times V_{in}$
- Power sources have internal resistance which affects the voltage and current that can be provided to a circuit.
  - Internal resistance is modelled as a resistor, R_i, in series with the source.
- Light bulbs have a variable resistance that depends on the operating voltage.
- A summary of the advanced resistors this lesson covers is found in the following table:

Circuit component	Symbol	Description
Diode		A semiconductor device that only allows current to flow one way through it. A small voltage drop occurs across a diode.
Light-emitting diode (LED)		A type of diode that emits light when a forward voltage is applied. The current through an LED must be limited to avoid burning out.
Potentiometer	 OR 	A variable resistor whose resistance can be manually controlled by physically moving a contact along a resistive material.
Thermistor		A variable resistor whose resistance varies with temperature.
Light-dependent resistor (LDR)	 OR 	A variable resistor whose resistance varies depending on the amount of light hitting its light-sensitive surface.

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CONCEPT DISCUSSION

Image: Zakaria Zayane

Many new car models have headlights that turn on and off automatically. Discuss how this function is possible with the use of advanced resistors placed in series or parallel. Could any other functions of a car be automated with advanced resistors?

Prompts:

- Which resistor is used in situations with varying light intensity?
- Are these resistors used in series or parallel arrangements?
- What other functions does a car have that could be automated?
- Which of these could be automated with LDRs, thermistors and potentiometers?

7A Questions

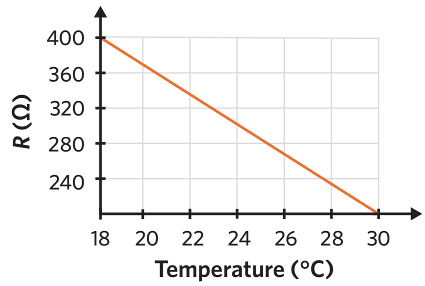
Mild Medium Spicy

Deconstructed exam-style

Use the following information to answer questions 10–13.

An engineer is designing the circuitry of an air conditioner. She has a 12.0 V source with an internal resistance of 1.00 Ω, a thermistor represented by the graph below, and a potentiometer with a range of 200–1000 Ω.

Thermistor properties



Question 10 (1 MARK)

What is the resistance of the thermistor at 24°C?

A. 200 Ω

B. 250 Ω

C. 300 Ω

D. 350 Ω

Question 11 (1 MARK)

If we want to create a voltage divider that increases the output voltage with temperature, should the thermistor be the output resistor R_2?

A. Yes

B. No

Question 12 (1 MARK)

To output a voltage of 5.00 V, the ratio $\frac{R_2}{R_1 + R_2}$ of a voltage divider with a 12.0 V source needs to be equal to:

A. $\frac{1}{2}$

B. $\frac{1}{3}$

C. $\frac{12}{5}$

D. $\frac{5}{12}$

Question 13 (4 MARKS)

Design a circuit using the circuit elements the engineer has available that will output a voltage of 5.00 V at 24.0°C, and above 5.00 V for temperatures above 24.0°C.

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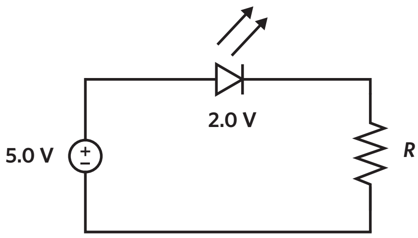
Exam-style

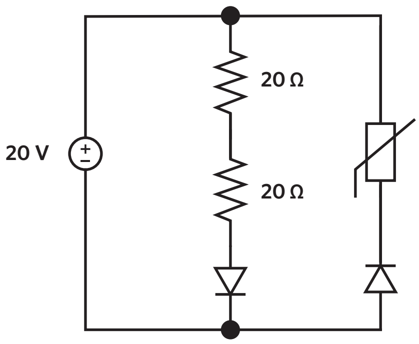
Question 14 (2 MARKS)

An LED has a threshold voltage of 2.0 V and a maximum current of 20 mA.
If it is powered by a 5 V source, determine the minimum resistance of R_1?



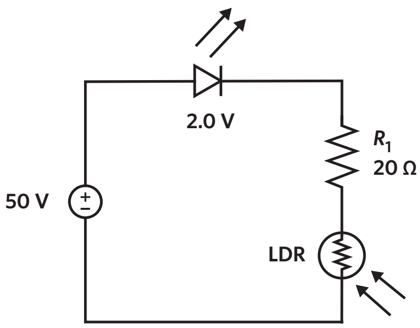
Question 15 (1 MARK)

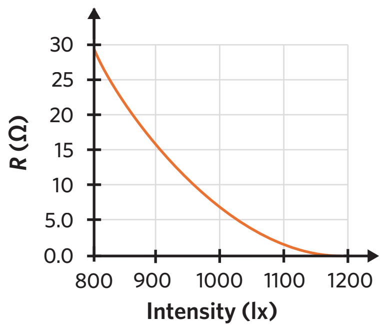
What is the current flowing through the thermistor in this combination circuit?

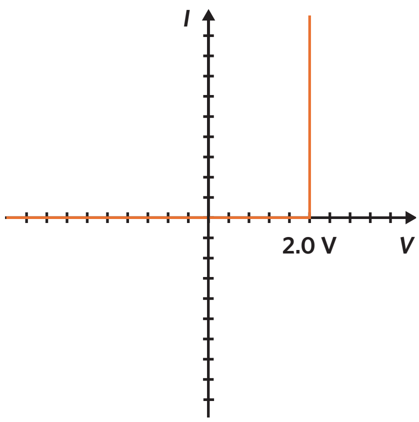


Question 16 (4 MARKS)

Determine the voltage drop across the LDR in this circuit when the light intensity is 900 lx.
The LDR and LED characteristics are represented by the graphs below.





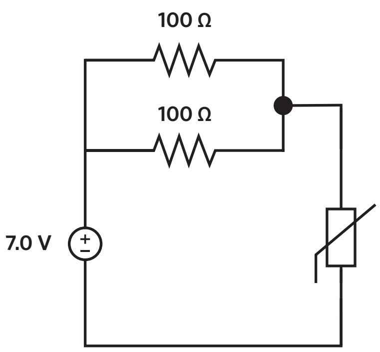


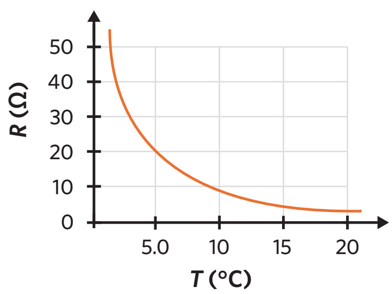
Question 17 (2 MARKS)

Explain the effect of an internal resistance on the voltage and current that can be provided by a voltage source, compared to if the source was ideal.

Question 18 (3 MARKS)

Determine the temperature of the thermistor in this circuit when a current of 100 mA is being provided by the source. The properties of the thermistor are shown in the graph below.





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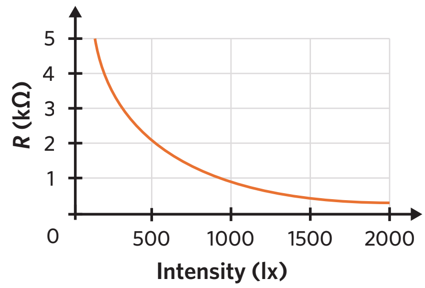
Question 19 (4 MARKS)

Design a voltage divider circuit using:

- a potentiometer with a range of 40–4000 Ω,
- a 300 V ideal power source,
- a LDR with the characteristics shown in the graph.

The circuit should output 100 V when intensity of light is 500 lx and the output voltage should decrease as light intensity decreases.



Key science skills

Question 20 (4 MARKS)

Mariam and Mateo are performing an experiment involving electric circuits. They are discussing what it means for an experiment to be valid. Mariam states that for an experiment to be valid, it needs to measure what it intends to measure. Mateo believes that it needs to be performed using a valid report template. Evaluate the two students' claims and list the stages of experimentation which affect validity.

FROM LESSON 11C

Previous lessons

Question 21 (2 MARKS)

Explain what would happen to Earth's climate if there were no greenhouse gases in our atmosphere.

FROM LESSON 3B

Question 22 (2 MARKS)

A particular light bulb is designed to draw 8.3 A when supplied by an ideal 12 V power supply. What resistance should be chosen for the light bulb?

FROM LESSON 6B

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7B Household electricity

How much energy do Victorians consume in a year?

The type of electricity delivered to a household is known as alternating current, which is different from the direct current we have encountered in previous lessons. In this lesson, we will learn how alternating current is different to direct current and how the wiring in household electrical systems accounts for its nature. We will also learn a new energy unit that is commonly used when measuring household energy consumption, the kilowatt-hour.

KEY TERMS AND DEFINITIONS

AC (alternating current) electricity electricity with a periodically alternating direction of current and voltage

active wire the wire at the end of an AC electrical system with a varying potential; this wire connects to the voltage supply

DC (direct current) electricity electricity with a constant direction of current and voltage

neutral wire the wire at the end of an AC electrical system that is fixed at zero volts

RMS (root-mean-square) a measure of a time-varying (such as AC) voltage or current. A constant DC voltage or current with the same value as the RMS would deliver the same average power

sinusoidal having the form of a sine wave

FORMULAS

- **RMS voltage**

  $V_{RMS} = \frac{1}{\sqrt{2}} V_{peak}$

- **RMS current**

  $I_{RMS} = \frac{1}{\sqrt{2}} I_{peak}$

STUDY DESIGN DOT POINTS

- model household (AC) electrical systems as simple direct current (DC) circuits
- explain why the circuits in homes are mostly parallel circuits
- apply the kilowatt-hour (kWh) as a unit of energy

7A — 7B — 7C

1.3.5.1 The kilowatt-hour

1.3.9.1 Alternating current

1.3.9.2 & 1.3.10.1 Household electrical systems

ESSENTIAL PRIOR KNOWLEDGE

6A Voltage
6A Current
6B Ohm's law
6C Series circuit analysis
6D Parallel circuit analysis

See questions 51–55.

ACTIVITIES

Log into your Edrolo account for activities that support this lesson.

The kilowatt-hour 1.3.5.1

A kilowatt-hour is a unit of energy. It is commonly used for measuring large quantities of energy, such as the amount of electrical energy used by a household over a period of time.

Theory and applications

On average, each Victorian household uses 1.66×10^{10} J of electricity per year. It is inconvenient to state such a large number when describing this quantity, rather we could state this quantity as 4.16×10^{3} kilowatt-hours, which is a much more quantifiable value.

How can we apply the kilowatt-hour as a unit of energy?

In Lesson 6A we learned that power is the rate of change of energy per unit of time, $P = \frac{E}{t}$, which we could write as $E = P \times t$. We also learned that the SI unit for measuring power is the watt, where one watt is equivalent to one joule per second ($1\ \text{W} = 1\ \text{J s}^{-1}$).

If an appliance operates with a power of one kilowatt (1000 W) for one hour (3600 s), then we could determine the amount of energy used by the appliance by

$$E = P \times t = 1000 \times 3600 = 3.6 \times 10^{6}\ \text{J}.$$

This quantity of energy is equivalent to one kilowatt-hour, see Figure 1.

$$1\ \text{kWh} = 3.6 \times 10^{6}\ \text{J}$$

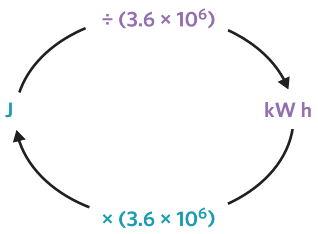

Figure 1 Conversion factor between kilowatt-hours and joules

MISCONCEPTION

'The kilowatt-hour is a measure of power.'

It is important to recognise that the kilowatt-hour measures the power consumed over a period of time, which is equivalent to energy with $E = P \times t$. It is most commonly used for measuring large quantities of electrical energy.

WORKED EXAMPLE 1

An electric oven operates with a power of 0.70 kW for 30 minutes while baking a cake.

a. Determine the amount of energy used by the oven, in kilowatt-hours.

Step 1

Identify the power used by the oven, the duration of time and the formula that relates these variables.

$P = 0.70\ \text{kW},\ t = \frac{30\ \text{min}}{60\ \text{min/h}} = 0.50\ \text{h}$

$E = P \times t$

As the answer is to be provided in kWh, it is simplest to use kilowatts for the power and hours for the time.

Step 2

Substitute relevant values into the formula and solve for E.

$E = 0.70 \times 0.50$

$E = 0.35\ \text{kWh}$

b. Determine the amount of energy used by the oven, in joules.

Step 1

Identify the energy used, kilowatt-hours, and the conversion to joules.

$E = 0.35\ \text{kW h},\ E = ?\ \text{J}$

$E\ (\text{J}) = 3.6 \times 10^{6} \times E\ (\text{kWh})$

Step 2

Calculate the energy used, in joules.

$E = 0.35 \times 3.6 \times 10^{6}$

$E = 1.26 \times 10^{6} = 1.3 \times 10^{6}\ \text{J}$

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Progress questions

Question 1

What does a kilowatt-hour measure?

A. energy

B. power

C. power per unit of time

Question 2

How much energy is used by an electric oven that operates at 3.0 kW for 2.0 hours?

A. 1.5 kWh

B. 6.0 kWh

Question 3

2.0 kWh is equivalent to

A. 5.6×10^{-7} J.

B. 1.8×10^{6} J.

C. 7.2×10^{6} J.

Alternating current 1.3.9.1

Household electrical appliances run on alternating current (AC), rather than direct current (DC) which we are used to working with in previous lessons. In this section we will explore methods of working with and understanding alternating current.

Theory and applications

AC describes electricity where the charges repetitively change direction. This means that the value of the voltage and the current changes from one instant to the next. We commonly use the root-mean-square value to compare AC quantities to DC quantities.

How do we define AC and DC power?

The electricity from a battery is DC because the electrons flow in a constant direction. To produce DC electricity, the potential difference between the two terminals of the battery is fixed. For example, for a 12 V battery, the positive terminal is always 12 V higher than the negative terminal, so that conventional current always flows from the positive terminal to the negative terminal.

If DC is like the teeth on a chainsaw, moving in one direction around a loop to cut through wood, then AC is like the teeth on a hand saw moving back and forth, see Figure 2.[1]

To produce AC electricity, the potential difference between the two ends of the circuit constantly changes.

- The active wire (also called the live wire) is the end of the circuit that connects to the AC voltage supply. It varies between a positive maximum value and a negative maximum value, due to the way the electricity is generated at the power station. In Australian households, the active wire varies between around +240 V and –240 V.
- The neutral wire is connected to the ground (the Earth), which is at 0 V.
- When the active wire is at +240 V, conventional current flows from the active wire through the circuit to the neutral wire. When the active wire is at –240 V, conventional current flows from the neutral wire through the circuit to the active wire, see Figure 3.

KEEN TO INVESTIGATE?

[1] **What is the difference between AC and DC?**
Search YouTube: Difference between AC and DC explained

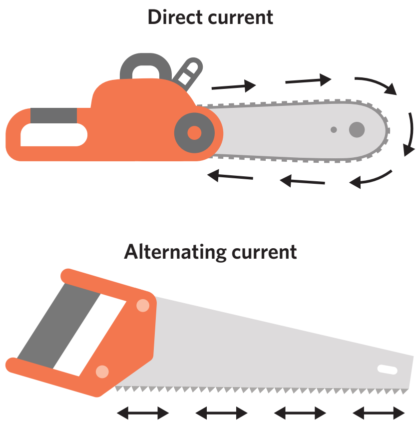

Figure 2 An analogy for the difference between direct current and alternating current

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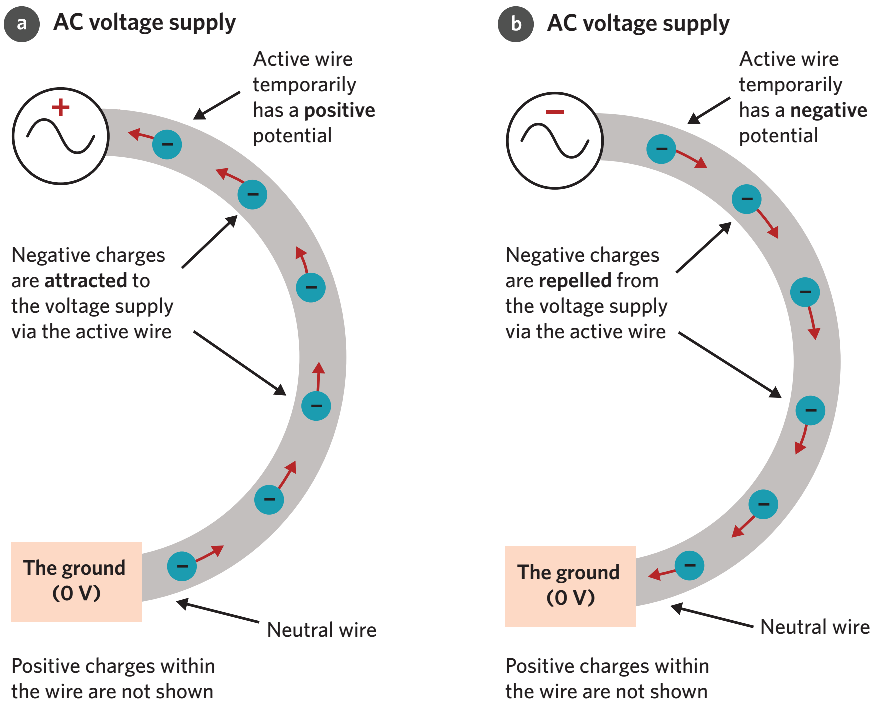

Figure 3 **(a)** When the active wire is at a positive potential, electrons flow towards it whereas in **(b)** the active wire is at a negative potential and so electrons flow away from it.

Progress questions

Question 4

Which of the following statements is true?

A. The direction of current constantly changes in an AC circuit.

B. In an AC circuit, conventional current always flows from the active terminal to the negative terminal.

C. In an AC circuit, conventional current always flows from the negative terminal to the positive terminal.

Question 5

Which of the following statements is true?

A. The 'active wire' is the name given to the positive terminal in an AC circuit and the 'neutral wire' is the name given to the negative terminal.

B. The 'active wire' is the name given to the negative terminal in an AC circuit and the 'neutral wire' is the name given to the positive terminal.

C. The active wire varies between having a positive potential and a negative potential. The neutral wire is fixed at 0 V.

USEFUL TIP

It is worth noting that, unlike a DC circuit, the path along which alternating current flows does not form a complete circuit because the active wire and the neutral wire lead to different places. However it is still common to refer to an AC system as a circuit[2].

KEEN TO INVESTIGATE?

[2] **How can we build simple AC circuits?**
Search: Circuit construction kit AC

How do we compare AC and DC power?

The voltage, and hence current, supplied to household electrical systems varies sinusoidally, as shown in Figure 4.

We often use the root-mean-squared (RMS) values of voltage and current to describe sinusoidal AC electricity. The RMS value is a fixed proportion of the peak value (as shown in Figure 4) which can be calculated as follows:

An RMS value has the same magnitude as the constant DC value that would deliver the same average amount of power. Consider a light bulb rated at 12 V.

- If we use a DC source, such as a battery, to supply power to the light bulb, we would require a constant 12 V source for the light bulb to operate properly.
- To deliver the same power to the same light bulb with an AC source, we require a 12 V RMS source (which has a peak value of 17 V to two significant figures).

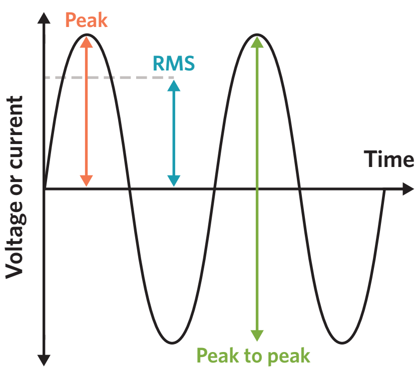

Figure 4 An AC voltage (or current) versus time graph

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FORMULA

$$V_{RMS} = \frac{1}{\sqrt{2}} V_{peak}$$

V_{RMS} = root-mean-square voltage (V)
V_{peak} = peak voltage (V)

FORMULA

$$I_{RMS} = \frac{1}{\sqrt{2}} I_{peak}$$

I_{RMS} = root-mean-square current (A)
I_{peak} = peak current (A)

STRATEGY

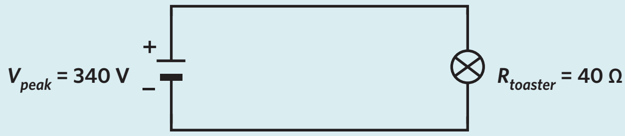
The equations that were introduced throughout Chapter 6 for DC electricity also apply to the RMS values of AC electricity. Whenever using these equations, always convert to RMS first!

USEFUL TIP

The RMS current or voltage will always be lower than the peak current or voltage. Use this to check whether the RMS values obtained make sense in a particular scenario.

WORKED EXAMPLE 2

The peak AC voltage delivered to a toaster is 340 V.
The resistance of the toaster is 40 Ω.



a. Determine the RMS voltage supplied to the toaster.

Step 1

Identify the peak AC voltage and its relationship to the RMS voltage.

$V_{peak} = 340$ V, $V_{RMS} = ?$

$V_{RMS} = \frac{1}{\sqrt{2}} V_{peak}$

Step 2

Substitute value for peak AC voltage into the equation and solve.

$V_{RMS} = \frac{1}{\sqrt{2}} \times 340 = 240.4 = 240$ V

b. Determine the RMS current supplied to the toaster.

Step 1

Identify the RMS voltage, resistance of the toaster and their relation to current through Ohm's law.

$V_{RMS} = 240$ V, $R = 40\ \Omega$, $I_{RMS} = ?$

$I_{RMS} = \frac{V_{RMS}}{R}$

Step 2

Substitute relevant variables into the equation and solve for current.

$I_{RMS} = \frac{240}{40} = 6.0$ A

c. Determine the constant DC voltage that would deliver the same average power.

Step 1

By definition, the RMS value of AC voltage is the same as the constant DC value that would deliver the same average power.

240 V DC

d. Calculate the average power delivered to the toaster.

Step 1

Identify the RMS current, RMS voltage and relevant formula relating these variables.

$V_{RMS} = 240$ V, $I_{RMS} = 6.0$ A, $P = ?$

$P = V_{RMS} I_{RMS}$

Step 2

Substitute relevant variables into the equation and solve for power delivered to the toaster.

$P = 240 \times 6.0$

$P = 1.4 \times 10^3$ W

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Progress questions

Question 6

The equivalent RMS value for AC voltage running with a peak voltage of 40 V is

A. 28 V.

B. 40 V.

C. 57 V.

Question 7

The power dissipated in a 30 Ω resistor if there is a peak voltage of 14 V AC running across it is

A. 3.3 W.

B. 6.5 W.

Household electricity systems 1.3.9.2 & 1.3.10.1

Household electrical systems use alternating current.[3] Most appliances and power points in households are wired in parallel. We can model these parallel circuits like simple DC circuits.

KEEN TO INVESTIGATE?

[3] **Why do we now use AC power in our homes?**
Search: Nikola Tesla explained in 16 minutes

Theory and applications

Household electricity systems are designed so that all appliances on the circuit can be switched on and off independently, without affecting other appliances on the circuit.

How are household electricity systems modelled?

The wiring for a typical household consists of:

- a distribution board (also called a switch box, fuse box, or panel board), to which the active and neutral supply wires are connected from power lines, and
- multiple parallel circuits called 'circuit rings'.

The distribution board includes:

- a main switch (which can disconnect the entire household electrical system),
- fuses or circuit breakers,
- residual current devices, and
- a meter.

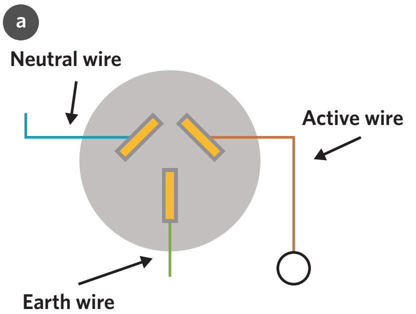
Each circuit ring is spread from the distribution board via a fuse or a circuit breaker.

- A circuit ring services a section of the house such as the lights in a given area or the power outlets. Within a circuit ring, individual appliances or power outlets are also connected in parallel.

The three types of wires in a household circuit are colour coded, shown in Figure 5:

- the active wire is brown,
- the neutral wire is blue, and
- the earth wire is green or green and yellow.

The role of fuses, circuit breakers, residual current devices, and the earth wire will be covered in Lesson 7C.



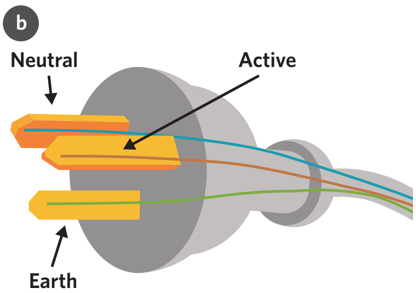


Figure 5 **(a)** A front-on and **(b)** a side on view of a household electricity plug

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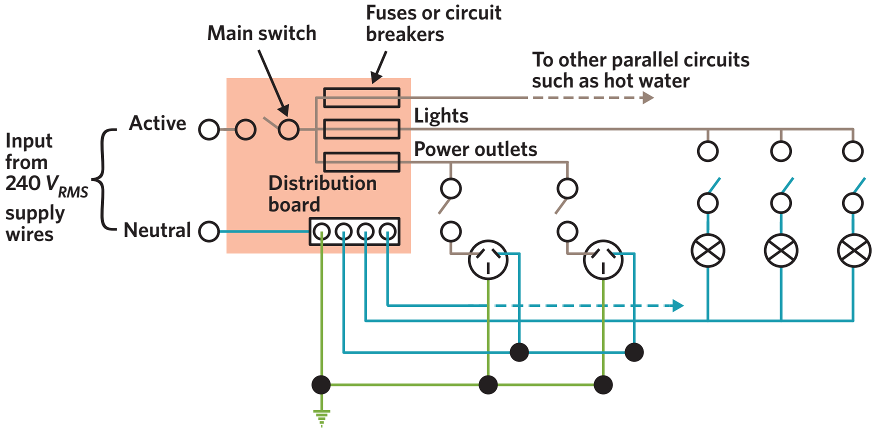

Figure 6 A household wiring diagram showing circuit rings for lights and power outlets

The majority of circuits in a household system are connected in parallel to allow individual appliances to be switched on or off without affecting the operation of other appliances. If there is a fault in one of the circuit rings (such as an open circuit breaker, which will be covered in Lesson 7C), then only appliances on that circuit ring will be affected but other circuit rings will not be affected.

While the nature of alternating current has some important differences to simple DC circuits, it is common to model AC household electrical systems as simple parallel DC circuits. Figure 7 shows a DC circuit model of the household wiring diagram in Figure 6.

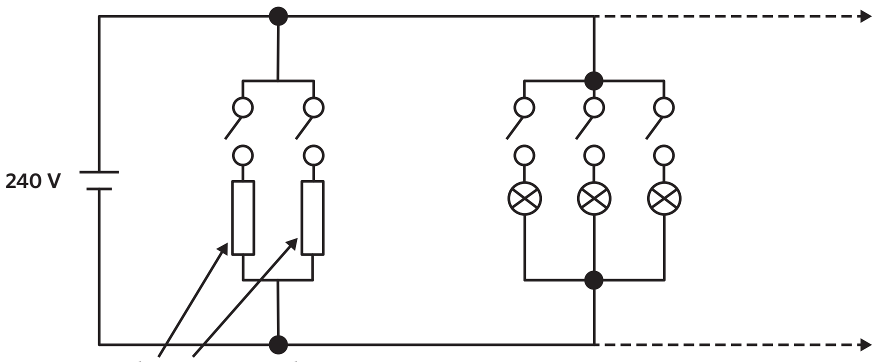

Figure 7 A simple DC circuit model of the household wiring shown in Figure 6

Progress questions

Question 8

Which of the following best explains why circuits in homes are mostly parallel circuits?

A. Parallel connections use less energy so they are cheaper and better for the environment.

B. Parallel circuits allow individual appliances to be switched on or off without affecting other appliances.

Question 9

The three wires used in a household circuit are colour-coded. Which row describes the correct colours?

	Active wire	Neutral wire	Earth wire
A.	Green	Brown	Blue
B.	Blue	Green	Brown
C.	Brown	Blue	Green

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Theory summary

- One kilowatt-hour is the amount of energy used by an appliance that consumes one kilowatt of power for one hour.
  - $1 \text{ kWh} = 3.6 \times 10^6 \text{ J}$
- For AC electricity:
  - The charges (electrons) constantly change direction.
  - An active wire varies between a positive potential and a negative potential while a neutral wire maintains a fixed potential of 0 V by connecting to the ground.
  - RMS values of AC voltage and current indicate the DC voltage or current that would deliver the same amount of power.
  - $V_{RMS} = \frac{1}{\sqrt{2}} V_{peak}$ and $I_{RMS} = \frac{1}{\sqrt{2}} I_{peak}$
- Household electrical systems use alternating current with most appliances connected to parallel circuits to allow their individual operation.
- The principles for analysing circuits that we learned in Chapter 6 apply to household (AC) electrical systems, so it is common to model them as simple DC circuits.

CONCEPT DISCUSSION

Image: Stasique/Shutterstock.com

In a household electrical system, appliances that convert electrical energy into another form of energy, such as thermal, sound or kinetic energy, generally run on AC.

Discuss how AC can transfer electrical energy from the source to the appliance, even though the individual charges (electrons) only move back and forth by very small distances. Use a hand saw as an analogy for AC electricity in your discussion.

Prompts:

- How does a hand saw cut through wood?
- What provides energy most immediately to the hand saw for it to cut through wood?
- How is electrical energy transformed into other types of energy, such as thermal energy in a toaster?
- Do charges need to move from the source to the appliance for this process to occur?

7B Questions

Mild Medium Spicy

Deconstructed exam-style

Use the following information to answer questions 10–13.

An electric heater has a resistance of 80 Ω. It is connected to an AC electrical system so that the peak voltage across it is 300 V. It operates for 4.0 hours.

Question 10 (1 MARK)

Which of the following is closest to the RMS voltage across the heater?

A. 212 V

B. 300 V

C. 424 V

D. 600 V

Question 11 (1 MARK)

How is the RMS voltage related to the power consumption of the heater?

A. $P = V_{RMS} \times R$

B. $P = V_{RMS} \times t$

C. $P = \frac{{V_{RMS}}^2}{R}$

D. $P = \frac{V_{RMS}}{I}$

Question 12 (1 MARK)

How is the energy use related to the power consumption and the time of operation?

A. $E = \frac{P}{t}$

B. $E = P \times t$

C. $E = P^2 \times t$

D. $E = \frac{t}{P}$

Question 13 (4 MARKS)

Calculate the energy used by the electric heater over this time. Provide your answer in kilowatt-hours.

Exam-style

Question 14 (3 MARKS)

A microwave oven heats a meal in 6.0 minutes and uses 0.16 kWh in that time.

a. Determine the power of the microwave oven in kilowatts. (2 MARKS)

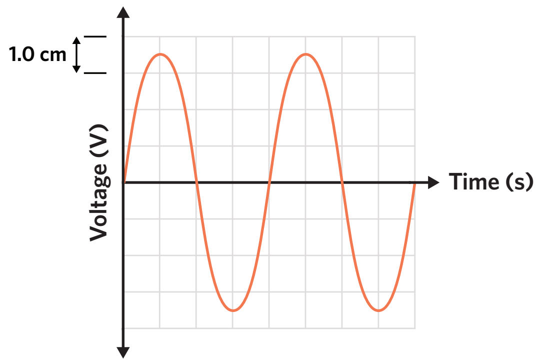
b. How much energy is used by the microwave oven over the 6.0 minute-period in joules? (1 MARK)

Question 15 (2 MARKS)

Rex is measuring the voltage from an AC signal generator using an oscilloscope, which produces the following output. The vertical scale is set to 0.40 V cm^{-1}.

Calculate the value of the constant DC voltage that would deliver the same power as this signal generator.

Adapted from 2010 VCAA Exam 1 Detailed study 3 Q4



Question 16 (2 MARKS)

The power outlets and fixed appliances in a household are usually connected in parallel. Explain how the operation of the lights in a household would be different if they were all connected in series.

Question 17 (5 MARKS)

An electric appliance with a resistance of 50 Ω uses an average of 242 W while operating on a household electrical system.

a. Show that the RMS current flowing through the appliance is 2.2 A. (2 MARKS)

b. Calculate the peak current flowing through the appliance. (1 MARK)

c. How much energy is used by the appliance if it is operating for 2.5 hours? Provide your answer in kilowatt-hours. (2 MARKS)

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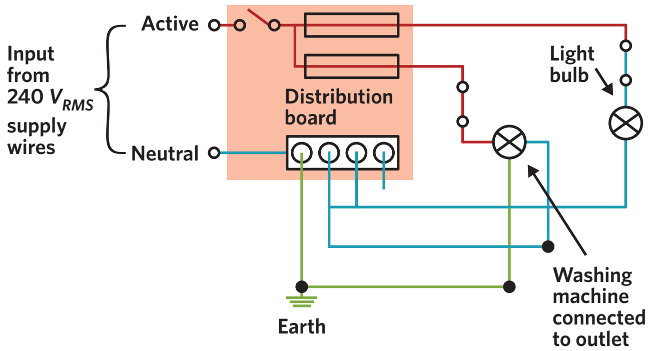
Question 18 (5 MARKS)

A household electrical system is supplied by 240 V_{RMS}. Within the system there is a 60 W lamp operating correctly and a washing machine that is connected to one of the power outlets as shown. For its current operation, the washing machine can be considered to have a resistance of 120 Ω. Assume there are no other electrical devices operating and ignore the resistance of the wires.



a. Draw a circuit diagram to model the household electrical system as a simple DC circuit. The washing machine should be represented with a resistor symbol. Include the relevant values provided. (2 MARKS)

b. Calculate the RMS value of the current flowing through the supply wires in this situation (3 MARKS)

Key science skills

Question 19 (4 MARKS)

Arden and Jacinta take measurements of the energy used by a kettle to boil 2.0 litres of water.

	Meas. 1	Meas. 2	Meas. 3	Meas. 4	Meas. 5
Jacinta's measurements (kWh)	0.15	0.23	0.25	0.19	0.19
Arden's measurements (kWh)	0.18	0.18	0.20	0.20	0.18

The true value for each measurement is 0.19 kWh.

a. Which set of data (Jacinta's or Arden's) is more accurate? Justify your answer. (2 MARKS)

b. Which set of data (Jacinta's or Arden's) is more precise? Justify your answer. (2 MARKS)

FROM LESSON 11C

Previous lessons

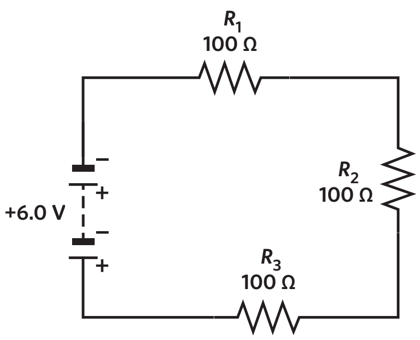
Question 20 (3 MARKS)

Would the iron isotope $^{52}_{26}Fe$ likely be stable or unstable? Justify your answer.

FROM LESSON 4A

Question 21 (7 MARKS)

Lawrence is analysing power loss in a basic series circuit. He begins with the following configuration:



a. Calculate the current across the resistor R_1. (2 MARKS)

b. Calculate the power dissipated across R_1. (2 MARKS)

c. Lawrence now removes resistor R_3 and reconnects the circuit. What is the power dissipated across R_1 in the new configuration? How does this compare to the old one? (3 MARKS)

FROM LESSON 6C

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7C Electrical safety

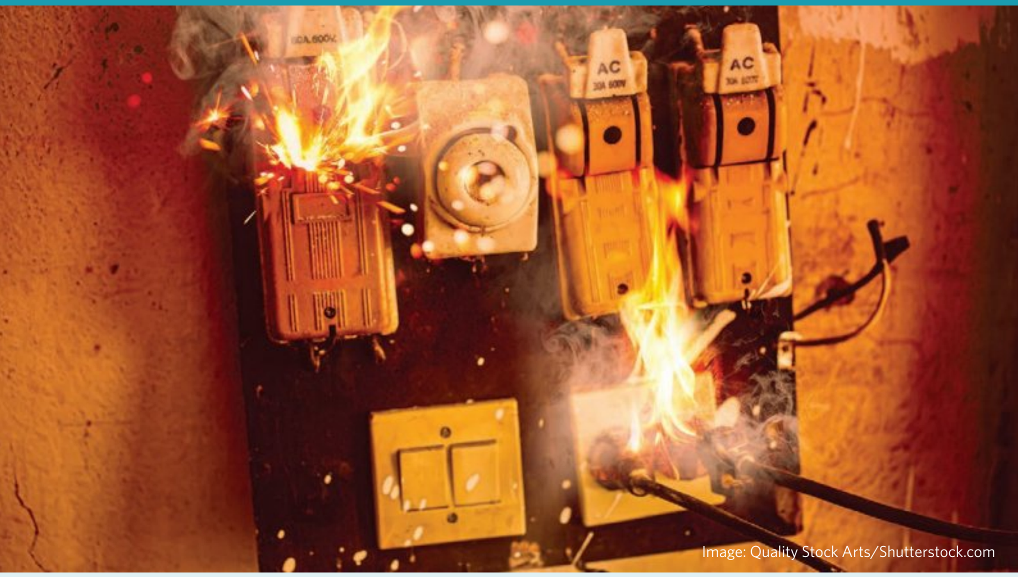
Image: Quality Stock Arts/Shutterstock.com

Why doesn't a high voltage determine the extent of an electric shock?

While electricity is an incredibly important feature of our modern lives, it also has the potential to cause great harm. This lesson will explore some of the common components used in household circuits to protect people from the risks associated with electricity, as well as describe the causes and potential effects of those risks.

KEY TERMS AND DEFINITIONS

circuit breaker a safety device that opens a resettable switch, causing a break in an electric circuit when too much current flows through it

earth wire provides a low-resistance path for current to flow from the outside of the appliance to the ground, in order to avoid an electric shock

electric shock the sensation and damage done when electric current flows through a person or other living thing

fuse a safety device that melts when too much current flows through it, causing a break in an electric circuit

load the amount of electrical energy consumed (in the form of a current) by a transducer

residual current device (RCD) a safety device that switches off a household electric circuit when it detects a difference between the current flowing in the active and neutral wires

short circuit a situation in which current flows through an unintended path with lower resistance, causing accidental contact between components

STUDY DESIGN DOT POINTS

- model household electricity connections as a simple DC circuit comprising fuses, switches, circuit breakers, loads and earth
- compare the operation of safety devices including fuses, circuit breakers and residual current devices (RCDs)
- describe the causes, effects and first aid treatment of electric shock and identify the approximate danger thresholds for current and duration.

7A 7B 7C

1.3.15.1 & 1.3.16.1 Safety features in household circuits

1.3.17.1 Electric shock

ESSENTIAL PRIOR KNOWLEDGE

6A Current
6C Series circuits
7B Household electrical systems
7B DC electricity
See questions 56–59.

ACTIVITIES

Log into your Edrolo account for activities that support this lesson.

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Safety features in household circuits 1.3.15.1 & 1.3.16.1

This section will explore the function of five common safety features in Australian household electrical circuits and appliances – fuses, circuit breakers, earth wires, double insulation and residual current devices. Figure 1 shows the basic setup of safety devices in homes.

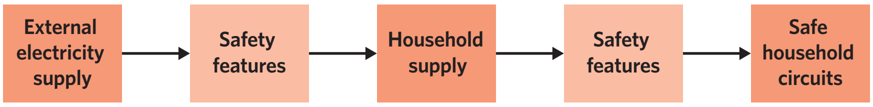

Figure 1 The basic setup of the electrical supply and safety in our homes.

Theory and applications

The electric circuits in a household must be able to safely deliver the required electrical energy for appliances and devices (the load) to convert into other useful forms of energy – such as light, heat and sound. Household circuit systems are designed to prevent wires from becoming overloaded.

How do fuses operate as a 'weak point' in a circuit?

The purpose of a fuse is to prevent overheating and damage to appliances caused by the current in a circuit exceeding a certain value. Fuses are a built-in 'weak point' that form part of the circuit. They consist of small tubes with a thin piece of wire through their centre, and a current rating (see Figure 2).

Image (top to bottom): Travis Mizuhata, nelikdulatov/ Shutterstock.com

Figure 2 Fuses can be made of either **(a)** glass or **(b)** plastic

Fuses operate based on two electrical principles:

- when a current flows through a wire, it produces heat, and
- the thinner the wire, the greater the heat produced.

The fuse will get hotter than the rest of the wires in the circuit. When too much current flows through the circuit (when it is overloaded), the fuse is designed to melt at or just below its current rating and break the circuit. This can ultimately prevent an electric fire.[1]

Figure 3 shows a fuse designed to protect a light bulb in a series circuit. The excessive current leads to a blown fuse, preventing any further damage to the light bulb.

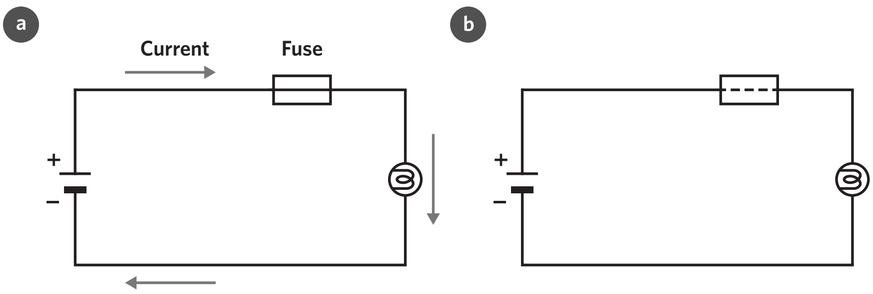

Figure 3 **(a)** A fuse-containing circuit and **(b)** a blown fuse prevents further damage to the light bulb.

Figure 4 shows the difference between a new fuse, melted fuse, and what can happen without a fuse.

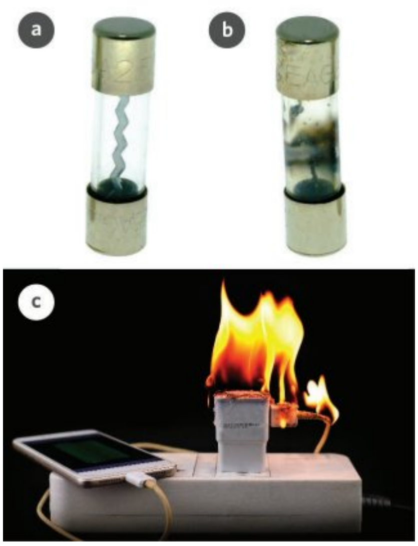

Image (top to bottom): NOPPHARAT539, Thichaa/ Shutterstock.com

Figure 4 **(a)** A working fuse, **(b)** a melted fuse due to an overload of current and **(c)** an electric device catching fire

MISCONCEPTION

'A fuse protects people from electric shock.'

The main function of a fuse is to prevent damage to appliances, not to safeguard a user from electric shock.

KEEN TO INVESTIGATE?

1 **How many Victorian house fires were preventable in 2017?**
Search: CFA preventable house fire statistics

Progress questions

Question 1

When a circuit containing a fuse is operating correctly,

A. current does not flow through the fuse.

B. the fuse forms part of the circuit.

Continues →

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Question 2

A fuse is designed to prevent

A. electric shock.

B. fires and damage to appliances.

Question 3

A fuse is not an effective protection against electric shock because

A. the current required by most appliances, which must also flow through the fuse, is greater than the amount required to cause electric shock.

B. there is usually some current left in a circuit, even when the circuit has opened, which can still cause electric shock.

How do circuit breakers operate in terms of opening the circuit?

Circuit breakers serve the same purpose as fuses: to prevent fires and damage to appliances. They have largely replaced fuses in household circuits because they do not melt like a fuse, they 'trip'. When this happens, the circuit breaker switch can be easily reset, as shown in Figure 5.

Circuit breakers for a given building are usually located in the circuit distribution board. These contain circuit breaker switches for the whole building, as well as for smaller sections of it, so that if a current surge is detected, electricity will only stop flowing to the parts of the building that are affected.

Circuit breakers cause a break in the circuit by automatically opening a switch when the current flowing through the circuit exceeds the rated value. This mechanical operation occurs due to the bimetal strips generating heat as they conduct electricity. If the current becomes too large for the rated circuit then the metals will expand, causing the bimetal strip to bend via a pivot mechanism that disconnects the contacts (see Figure 6).[2]

Image: Sutiwat Jutiamornloes/Shutterstock.com

Figure 5 Resetting a 'tripped' circuit breaker

KEEN TO INVESTIGATE?

[2] **How does a circuit breaker work in slow motion?**
Search YouTube: How does a circuit breaker work?

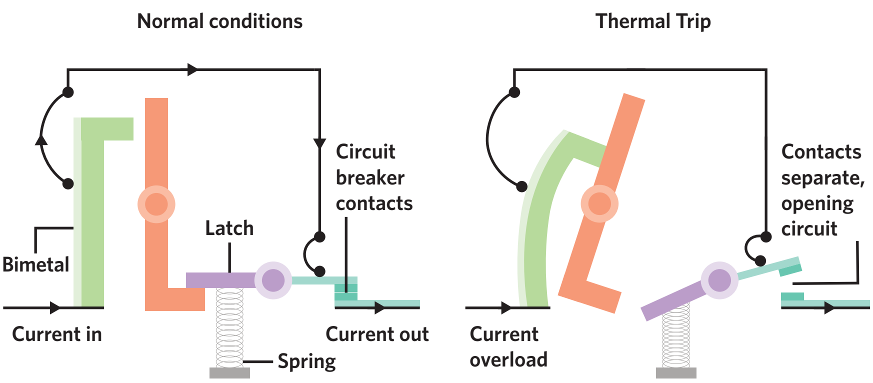

Figure 6 The mechanical operation of a circuit breaker

Although circuit breakers are much more practical than fuses because they can be reset, they still do not fully protect humans and appliances from the dangers of electricity.

Progress questions

Question 4

The main difference between a circuit breaker and a fuse is that

A. circuit breakers can be reset once they have been tripped.

B. circuit breakers open a circuit when too much current flows through the circuit.

Continues →

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Question 5

The mechanical movement of a circuit breaker is due to the electrical current producing

A. heat, which causes metals to expand.

B. a magnetic effect, which repels the contacts.

How can an earth wire prevent an electric shock?

An earth wire prevents current flowing to the wrong place and hence causing electric shock. However, an earth wire only protects against the specific risk posed by an active wire coming into contact with the metal exterior of an appliance. This is usually caused by a fault such as a cut or frayed wire.

The earth wire provides a direct connection from the metal exterior of an appliance to the ground, as shown in Figure 7, which has a voltage of zero.

If an active wire touches the exterior of the appliance, so that the exterior becomes active or live, the current will follow a path of least resistance (a short circuit). This will direct the current through the earth wire, which has a lower resistance than the person and appliance, and safely into the ground (see Figure 8).

Image: TS Photographer/Shutterstock.com

Figure 7 Earth wires are connected to the ground (the earth).

MISCONCEPTION

'An earth wire forms a part of every circuit.'

When the circuit is operating normally, current does not flow through the earth wire. It does not open the circuit or stop current flowing (like a circuit breaker) when there is a problem. It only redirects the current if it happens to flow through the metal exterior of an appliance or device.

MISCONCEPTION

'Short circuits are always paths of shorter length than the main circuit.'

Short circuits are paths that have a lower resistance than the main circuit, but are not necessarily shorter in length.

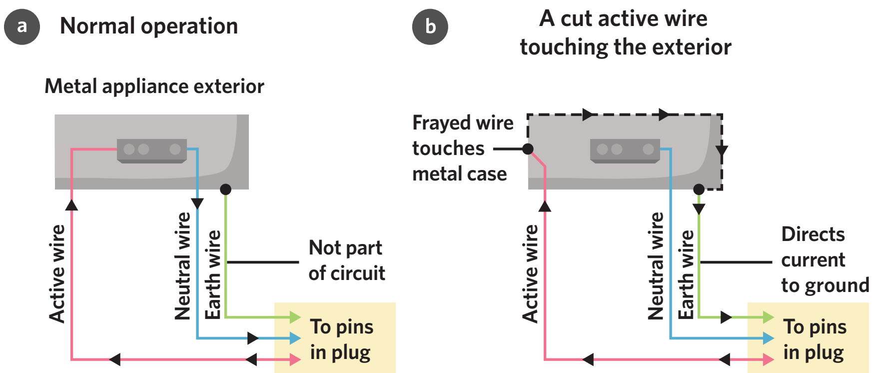

Figure 8 **(a)** Normal operation of earth wire and **(b)** earth wire redirecting loose current

Many modern appliances use double insulation as an alternative to an earth connection. This means they do not have the third earth pin on their electrical plugs (see Figure 9).

Image: Kitch Bain/Shutterstock.com

Figure 9 Two and three pin plug

USEFUL TIP

Double insulation allows for an additional barrier between the internal conducting wires and the environment. This means that even if the first inner layer of insulation fails and the conducting wires become exposed and touch an inner layer, then the current is still insulated by an outer non-conductive protective layer. This provides a physical barrier so that neither a person nor an object can become part of the circuit.

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Progress questions

Question 6

When a circuit is operating correctly,

A. current does not flow through the earth wire.

B. the earth wire forms part of the circuit.

Question 7

The main purpose the earth wire is to prevent

A. electric shock.

B. fires and damage to appliances.

How do residual current devices create open circuits?

A residual current device (RCD) (see Figure 10) serves a different purpose to fuses and circuit breakers. RCDs are designed to break the circuit when the current is flowing to the wrong place, rather than when too much current is flowing, in order to avoid electric shock.

Image: Kwangmoozaa/Shutterstock.com

Figure 10 A consumer unit containing many RCDs

During an electric shock, a current flows through a person instead of the neutral wire, as the person provides a lower resistance path. An RCD prevents this through the following steps:

1. The current flows in opposite directions in the active and neutral wires.
2. A magnetic field is produced when a current flows through a wire.
3. When the flow occurs in different directions opposing magnetic fields are produced.
4. Opposing magnetic fields cancel each other out so no overall magnetic field exists in the sensor.
5. The sensor switch allows a current to flow throughout the circuit.

An RCD 'trips' when a current has leaked from the active wire to the wrong place (see Figure 11).

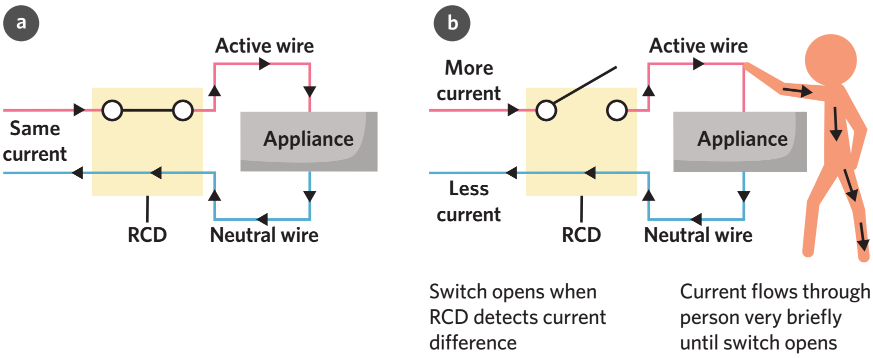

Figure 11 The feedback loop that triggers the RCD switch

MISCONCEPTION

'RCDs protect people from every type of electrical fault.'

RCDs are only useful if the current flows to Earth, not when a human is connected between the active and neutral wires.

The function of RCDs, can be summarised as follows:

- when a human or other conductive object touches the active wire, a current will flow through the human or object.
- This will then decrease the current in the active wire.
- An RCD detects the difference in current between the two wires through their magnetic fields. This triggers the circuit to open, breaking the circuit.

Progress questions

Question 8

A residual current device opens a circuit when

A. there is too much current flowing through the active and neutral wires.

B. the device detects different amounts of current in the active and neutral wires.

Question 9

The main purpose of an RCD and the earth wire is to prevent

A. electric shock.

B. fires and damage to appliances.

Question 10

If the current flowing through the active wire is greater than the current flowing through the neutral wire, it indicates that

A. current is flowing somewhere that it is not supposed to.

B. current is being used up by the appliance.

Electric shock 1.3.17.1

The severity of an electric shock through the body is determined by a multitude of factors. Depending on these factors, an electric shock can either be a minor jolt or a fatal catastrophe.

Theory and applications

Despite the safety precautions discussed in the previous section, electrical accidents still occur and pose a dangerous risk. In the case of electric shock, first aid protocol must be followed to ensure the safety of both the victim and the handlers.

USEFUL TIP

When dealing with electricity, make sure to keep yourself dry. The resistance of dry skin is between 100 000 Ω and 1 000 000 Ω, but it is reduced to around 1000 Ω when it is wet. This increases the current by a factor of around 100–1000.

KEEN TO INVESTIGATE?

[3] **Why is current dangerous?**
Search: Do amps or volts kill you?

Image: wellphoto/Shutterstock.com

Figure 12 An Automated External Defibrillator or AED

What are the effects of electric shock?

If a large current (approximately 100–500 mA) passes through the heart, it can cause the heart to beat irregularly for a prolonged time, persisting longer than the shock itself, known as 'ventricular fibrillation', which is potentially fatal.[3]

Even greater currents (approximately 5000 mA or 5 A) cause the heart and diaphragm to contract and remain contracted for the duration of the shock, so that blood will not circulate around the body and the person will not breathe in this time. Although dangerous for any significant duration, a very short pulse of a large current can be used to defibrillate the heart, and return it to a regular beating rhythm (see Figure 12).

A very small electric current can pass through the body harmlessly without being felt. Similarly, current that flows for less than about 0.1 seconds is typically harmless, even if the current is large. By contrast, a shock that lasts for about one second or more can cause severe harm.

Table 1 The effects of different amounts of current for a duration greater than ~0.1 seconds

Current (mA)	Effect on body
1	Can be felt minorly
5	Easily felt, harmless
10–50	Muscular contraction, cannot let go of electrical contact during shock, pain
100–200	Ventricular fibrillation possible, breathing upset or difficult, possibly fatal
500	Severe burns, ventricular fibrillation and defibrillation, unable to breathe, likely to be fatal

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Since the duration of an electric shock is an important factor in determining the severity, it is important to ensure that the person who has suffered the shock is no longer connected to the source (see Figure 13). If the person is still connected, it is dangerous to touch them. The electric circuit should be switched off and the person should be moved clear of the source using an object made of insulating material, such as plastic gloves.

An ambulance should be called straight away by dialling 000. In the case of an electric shock, a defibrillator may need to be used to get the person's heart beating normally again, and an artificial respirator may be used if they have stopped breathing. Normal first aid procedures should be followed while waiting for the ambulance to arrive.

MISCONCEPTION

'It takes large currents for an electrical shock to cause harm.'

Currents as low as 0.05 A (50 mA) can cause severe injury.

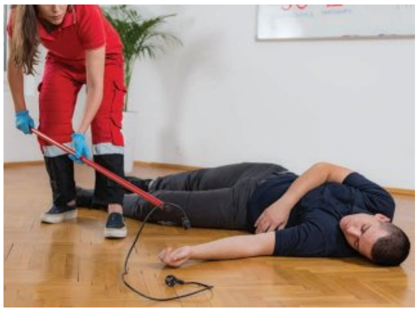


Image: Microgen/Shutterstock.com

Figure 13 An electrocuted person should never be touched

Progress questions

Question 11

What amount of current, measured in mA, could be fatal to a human?

A. 10

B. 100

Question 12

Which of the following measurements, by itself, would give the best indication of the severity of an electric shock?

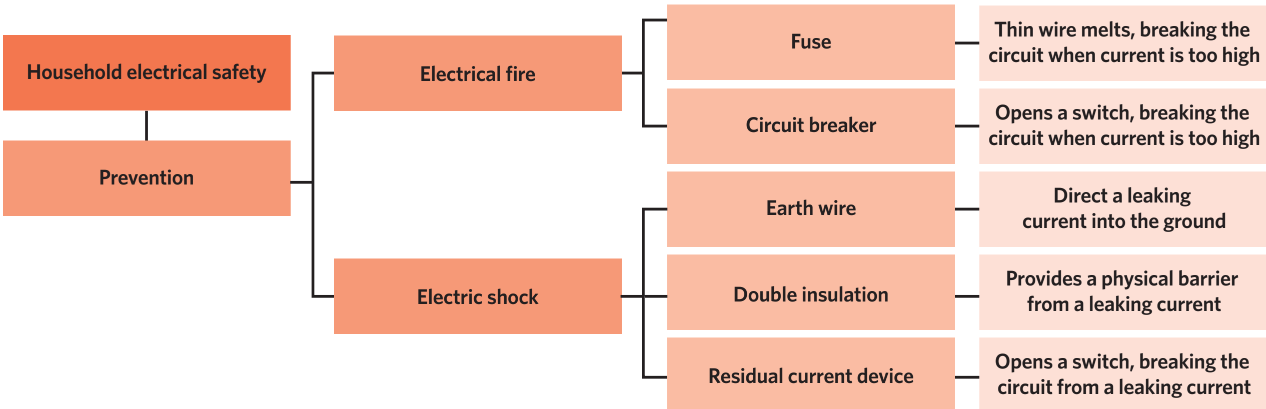
A. the voltage applied to the person

B. the amount of current flowing through the person

C. the resistance of the person

Theory summary

The following flowchart summarises common household electrical dangers and the operation of some safety devices in preventing such.



- The severity of an electric shock depends on the amount of current that flows through the person, the amount of time that it lasts, and the path that the current takes through the person.

CONCEPT DISCUSSION

Consider what would happen if the earth pin and the neutral pin were swapped in a power outlet, so that the appliance was wired between the active wire and the connection to the earth. Discuss whether the appliance will operate as normal and if there are any safety risks in this configuration.

Prompts:

- Does this configuration allow current to flow through the appliance?
- Will the currents in the active and neutral wires be the same?
- Are there any risks associated with the earth forming the endpoint of the circuit?

Image: Tiwat--T/Shutterstock.com

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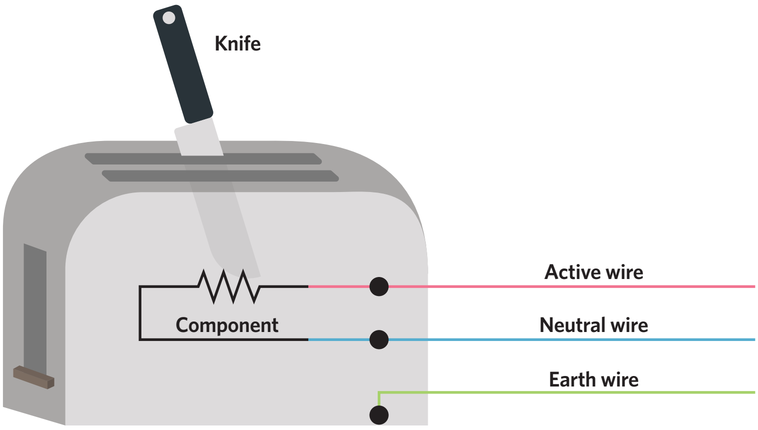
7C Questions

Mild Medium Spicy

Deconstructed exam-style

Use the following information to answer questions 13–17.

Regina tries to remove toast that is stuck in her toaster using a metal knife. She does this while the toaster is connected and switched on, which is a very dangerous thing to do. Her knife makes contact with one of the elements (a live wire) in the toaster, so that current flows through her body to the ground. The amount of current flowing through her body is no greater than the current flowing through the toaster when it is operating normally.



Question 13 (1 MARK)

Which of the following statements is true?

A. The exterior casing of the toaster is live.

B. The current is greater than the amount that the circuit is designed to carry.

C. Some or all of the current flowing along the active wire does not flow through the neutral wire.

Question 14 (1 MARK)

What causes a fuse or a circuit breaker to open a circuit?

A. too much current within the intended circuit

B. current leaving the intended circuit

C. a live exterior part of an appliance

Question 15 (1 MARK)

What causes current to flow along the earth wire?

A. too much current within intended the circuit

B. current leaving the intended circuit

C. a live exterior part of an appliance

Question 16 (1 MARK)

What triggers an RCD to open a circuit?

A. too much current within the intended circuit

B. current leaving the intended circuit

C. a live exterior part of an appliance

Question 17 (3 MARKS)

Identify which safety design is most likely to protect Regina from electric shock, and explain how it would do this.

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Exam-style

Question 18 (2 MARKS)

The active wire in an appliance that has a metal exterior case is damaged and is making contact with the case. Identify which electrical safety feature is designed to protect against the hazard caused by this particular situation and identify what the hazard is.

Question 19 (5 MARKS)

Polly understands that electric shocks are more severe when the current flowing through the person is greater. She also understands that a short circuit leads to a greater current flowing in the circuit. She concludes that short circuits must be a shock hazard.

a. Evaluate Polly's conclusion that a short circuit is a shock hazard. (3 MARKS)

b. Why is an RCD an ineffective safety feature for the risk posed by short circuits? (2 MARKS)

Question 20 (2 MARKS)

The picture shows an electrical safety device that is used in cars. What type of safety device would this be called and how does it operate?

Image: marekusz/Shutterstock.com

Question 21 (4 MARKS)

Current is flowing through the earth connection of a particular appliance. Explain whether, or under what conditions, each of the following safety features would cause a break in the circuit and what hazard the safety feature is designed to protect against

a. a fuse/circuit breaker. (2 MARKS)

b. an RCD. (2 MARKS)

Question 22 (2 MARKS)

Ruth connects a 9 V battery cell to a single light globe. The globe shines brightly and she measures a current greater than 1 A in the circuit. She understands that if 1 A flows through a human it can be deadly. However, she has also been told that touching the terminals of a 9 V battery cell will not cause a severe shock. Explain why touching a 9 V battery cell would not cause a severe shock even though the amount of current it provides to a light bulb could kill a human.

Key science skills

Question 23 (2 MARKS)

Some students are measuring the current rating of an electrical fuse that is well established to have a rating of 5.0 ± 0.2 A. They take five measurements, as follows: 5.4 A, 5.1 A, 5.5 A, 5.6 A, 5.9 A. If the manufacturer's rating is taken to be correct, what is the minimum error in the student's average measurement?

FROM LESSON 11C

Previous lessons

Question 24 (2 MARKS)

The nucleus of an atom is generally stable. Even when radioactive, nuclei are held together for some period of time. Explain the forces acting on the atomic particles that allows for overall stability until a nucleus eventually decays.

FROM LESSON 4A

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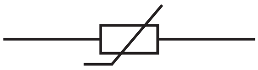
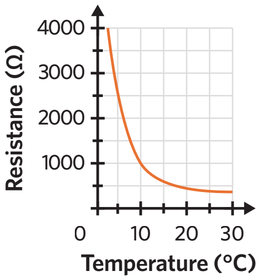
Question 25 (3 MARKS)

Tyson is installing a small refrigeration system into an esky so that the refrigerator motor turns on when the temperature is greater than 5°C. He builds the electric circuit from the following devices:

- a thermistor with the characteristics shown in the following graph,

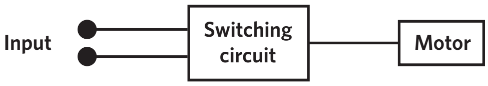




- a 12 V battery,

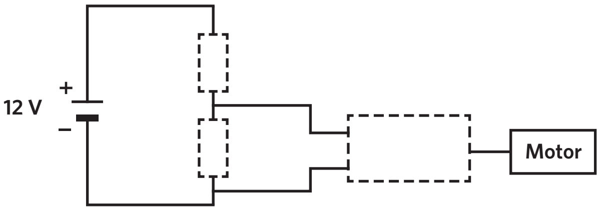
- one of the following resistors: 2500 Ω, 5000 Ω, 7500 Ω, and

- a switching circuit that turns on the refrigerator motor when the voltage across the input is greater than 8 V.



a. What is the resistance of the thermistor when the temperature is 5°C? (1 MARK)

b. Using the thermistor, the 12 V battery, and one resistor from the listed resistors, complete the circuit diagram shown below to produce a voltage greater than 8 V at the input of the switching circuit when the temperature is greater than 5°C. You must include the value of the resistor you have used in your diagram. (2 MARKS)



Adapted from VCAA 2011 Exam 1 Area of Study 2 Section A Q5–6

FROM LESSON 7A

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Chapter 7 review

Mild 🌶 Medium 🌶🌶 Spicy 🌶🌶🌶

These questions are typical of 40 minutes worth of questions on the VCE Physics Exam.

Total marks: 30

Section A

All questions in this section are worth one mark.

Unless otherwise indicated, the diagrams in this book are not drawn to scale.

Question 1 🌶

A set of six 120 W floodlights are left to run for 12.0 hours. Which is closest to the amount of energy they consume, in kWh?

A. 0.720 kWh

B. 1.44 kWh

C. 8.64 kWh

D. 5.20×10^3 kWh

Question 2 🌶

Consider a DC power supply that is operating at 100 V. An AC power supply that delivers the equivalent power would be one that

A. oscillates between −100 V and +100 V.

B. oscillates between 0 V and +100 V.

C. oscillates between 0 V and +141 V.

D. oscillates between −141 V and +141 V.

Question 3 🌶

The risk of an electrical shock cannot be prevented by

A. reducing the voltage across the points of contact.

B. the use of a residual current device (RCD).

C. the use of an earth pin at the device socket.

D. the use of a circuit breaker.

Question 4 🌶🌶

Yousef is investigating the simple lamp circuit shown in the diagram.

He notices that the voltage drop across the lamp was initially lower than he had calculated. Which one of the following factors best explains the phenomenon observed by Yousef?

A. internal resistance within the 12 V supply

B. more resistance in the light bulb than expected

C. the 12 V supply running out of charge

D. both A and B

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Question 5

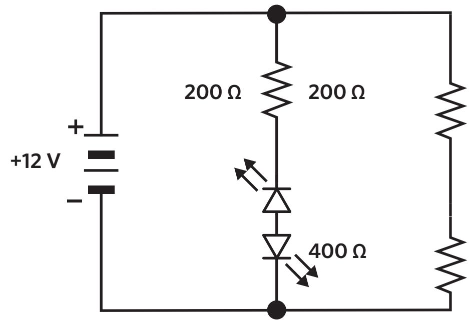
Which one of the following is closest to the current flowing through the 400 Ω resistor in the provided combination circuit?

A. 0 A

B. 20 mA

C. 30 mA

D. It depends on the characteristics of the LEDs.



Section B

In questions where more than one mark is available, appropriate working must be shown.

Unless otherwise indicated, the diagrams in this book are not drawn to scale.

Question 6 (3 MARKS)

The average cost of electricity for a given household is 36 cents per kWh. In a particular week, a toaster runs for a total of 3.0 hours and consumes enough electricity to cost the owner $12.50.

a. Use this information to calculate the average power used by the toaster. (2 MARKS)

b. Assuming the current remains constant, by what factor would the voltage across the toaster need to change in order for the weekly cost of the toaster to decrease by a factor of 4? (1 MARK)

Question 7 (6 MARKS)

Melike is investigating safety protections against short circuits that provide a path of zero resistance between the active and neutral wires. Evaluate the effectiveness of each of the following safety devices against the risks posed by a short circuit:

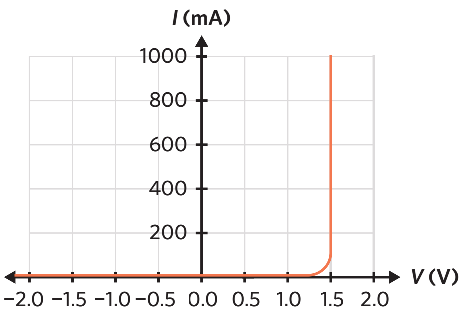
a. Residual current devices (RCDs) (2 MARKS)

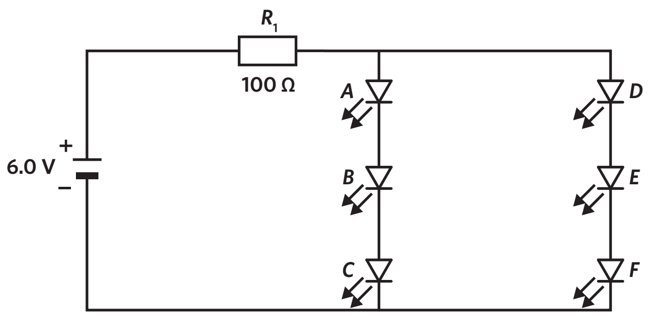
b. Circuit breakers (2 MARKS)

c. Earth wires (2 MARKS)

Question 8 (5 MARKS)

Richard wants to make a light display using a number of identical light-emitting diodes (LEDs). The *I*-*V* graph of these diodes is shown. Richard sets up a circuit involving these six identical LEDs (*A*–*F*).





a. What is the value of the current through R_1? (3 MARKS)

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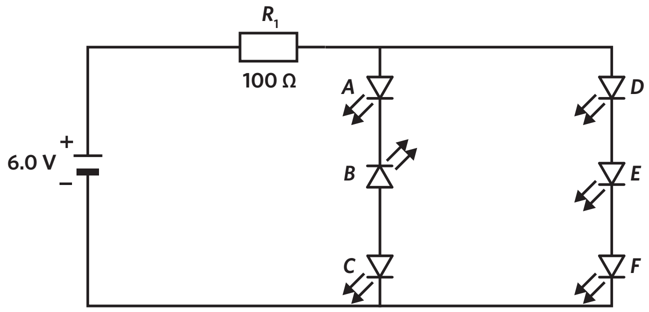
b. Richard later sets up the same circuit again, but this time accidentally connects LED *B* in reverse as shown in the provided diagram. Which of the LEDs (*A*–*F*) will be on and which of the LEDs will be off? (2 MARKS)



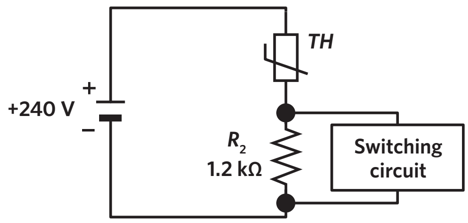
Adapted from VCAA 2009 Exam 1 Area of study 2 Section A Q4-5

Question 9 (3 MARKS)

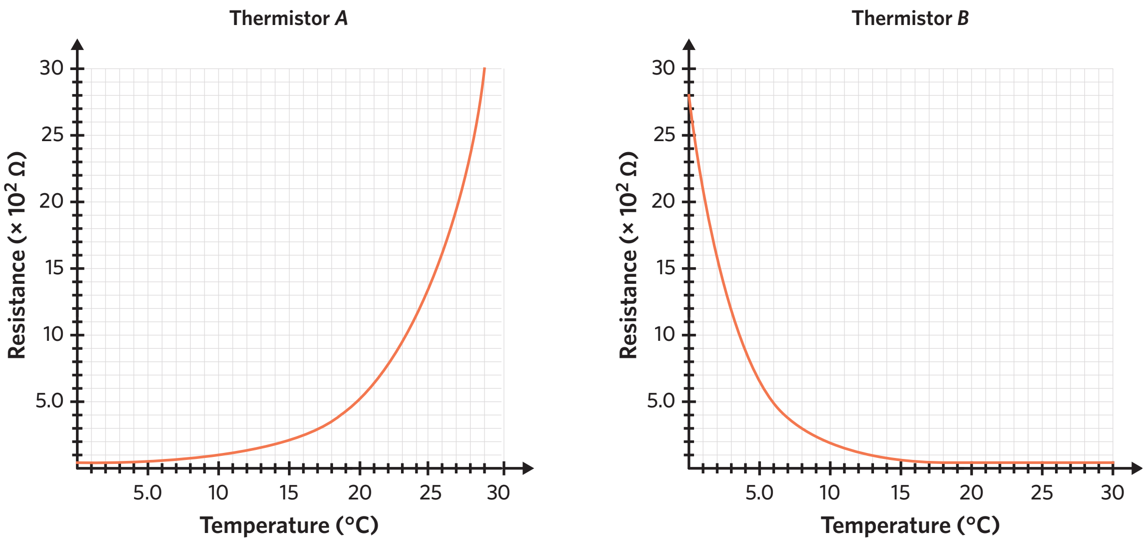
A set of Christmas lights have an equivalent resistance of 1.3 kΩ. They are connected to an AC electrical system so that the peak voltage across it is 250 V. The cost of electricity is \$0.36/kWh. Use this information to calculate the cost of running the Christmas lights overnight from 8 PM to 8 AM the next morning.

Question 10 (8 MARKS)

Shaquem, an apprentice electrician, is making a small circuit, shown in the diagram, to turn on a lighting system when the temperature rises above a certain value. To do this, he uses a thermistor (labelled *TH*). The circuit incorporates a switching circuit, that turns on the lighting system when the voltage across it is greater than or equal to a threshold voltage.



a. Shaquem can choose between two different thermistors to use in the circuit. They are represented by the two resistance-temperature graphs provided. However, he does not know which one describes the thermistor he should use in the circuit. Explain why *B* is the thermistor that he should use in this circuit. (2 MARKS)



b. Shaquem wants the lighting system to first turn on when the temperature is at 10°C. Calculate the threshold voltage for the switching circuit. Assume that the switching circuit has infinite resistance. (3 MARKS)

c. Shaquem uses a multimeter to determine that the resistance of the switching circuit is 2.4 kΩ. Determine the temperature of the thermistor to the nearest degree, if the current flowing through the 240 V source is 200 mA. (3 MARKS)

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Unit 1 AOS 3 review

Mild | Medium | Spicy

These questions are typical of one hour's worth of questions on the VCE Physics Exam.

Total Marks: 50

Section A

All questions in this section are worth one mark.

Unless otherwise indicated, the diagrams in this book are not drawn to scale.

Question 1

A Van de Graaff generator produces an electrostatic charge on a hollow metal sphere through the movement of a belt.

The belt can supply a positive charge to the dome at a rate of 500×10^{-6} C s^{-1}. The average electrical potential energy of each coulomb of charge in the dome is 1.2 kJ.

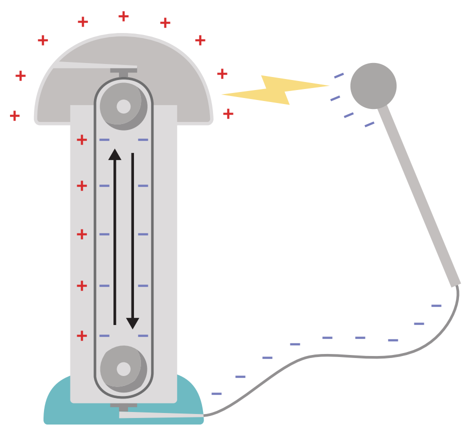
Which one of the following is closest to the voltage across the dome after the belt has been running for 1 minute?

A. 25 V

B. 1.2×10^3 V

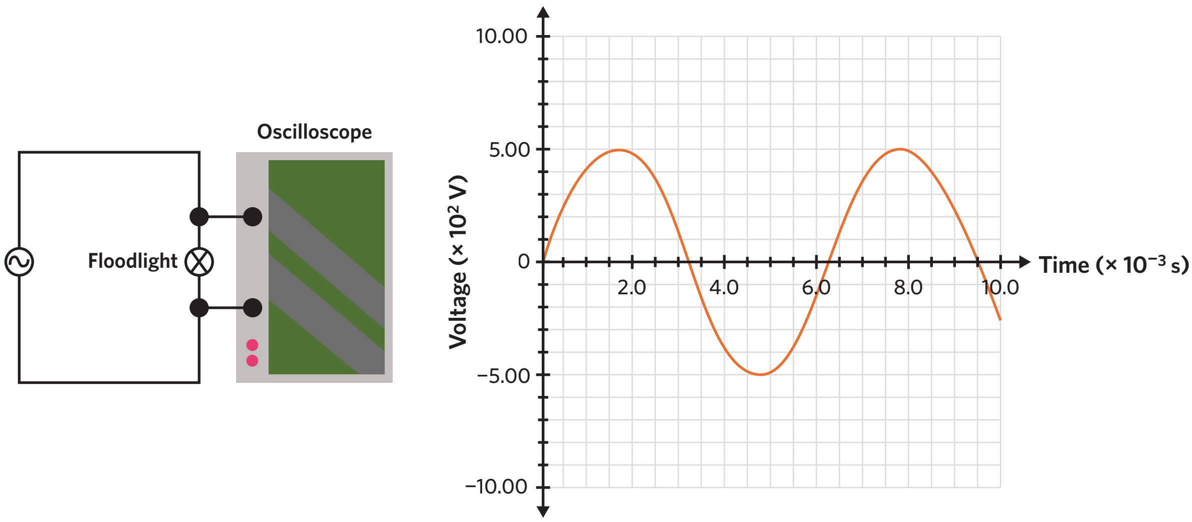
C. 10 kV

D. It is not possible for the voltage to be determined without further information.



Question 2

The provided diagram shows an AC supply being used to power a floodlight. An oscilloscope is attached to the circuit as shown and its output is included in the diagram.



The AC supply is to be replaced with a battery.

Which one of the following is closest to the voltage the battery would need to have for the floodlight to produce the same average brightness as it did with the AC supply?

A. 250 V

B. 354 V

C. 500 V

D. 707 V

Adapted from VCAA 2018 Exam Short Answer Q4

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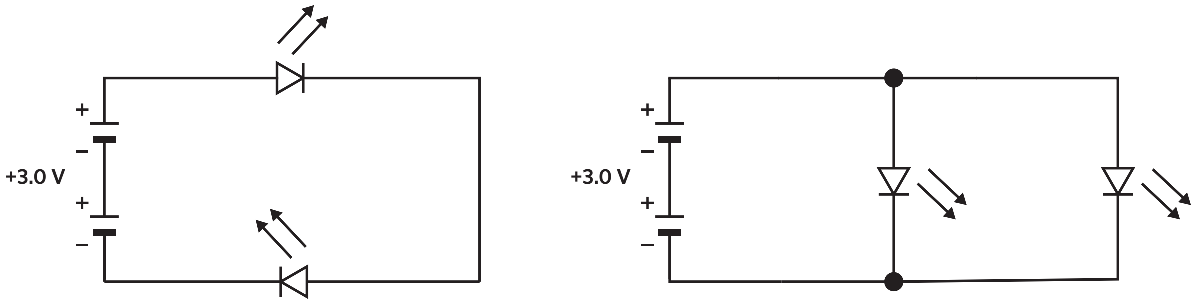
Question 3

Consider the following two circuits each consisting of two LEDs and a 3.0 V battery. In one of the circuits, the LEDs are wired in series, and in the other, they are wired in parallel. The threshold voltage of the LEDs is 3.0 V. Assume that the LEDs will not burn out.



Which one of the following statements is true regarding the circuits?

A. The LEDs will all shine with the same brightness.

B. The batteries in both circuits will last for the same amount of time.

C. The LEDs in series will shine brighter than the LEDs in parallel.

D. The LEDs in parallel will shine brighter than the LEDs in series.

Question 4

Which one of the following statements is incorrect about voltmeters, ammeters and multimeters?

A. A multimeter can be used to measure both current and voltage in a circuit.

B. A voltmeter needs to be wired in parallel to the part of the circuit it is measuring.

C. An ammeter needs to be wired in series to the part of the circuit it is measuring.

D. A multimeter needs to be wired in parallel when measuring both current and voltage.

Question 5

Which one of the following statements is incorrect about ohmic and non-ohmic devices?

A. For an ohmic device, the resistance is independent of the voltage or current of the circuit.

B. Examples of non-ohmic devices include both thermistors and light-dependent resistors.

C. A non-ohmic device is one for which we cannot use Ohm's law to calculate its current, voltage or resistance.

D. The gradient at any point of an *I*-*V* graph for an ohmic device is equal to the resistance.

Section B

In questions where more than one mark is available, appropriate working must be shown.

Unless otherwise indicated, the diagrams in this book are not drawn to scale.

Question 6 (3 MARKS)

Consider two 12.0 V batteries, one of which powers a 30.0 W lamp, and the other that powers a second lamp with unknown power usage.

a. How many electrons pass through the 30.0 W lamp per second? Take the magnitude of the charge of an electron as 1.6×10^{-19} C. (2 MARKS)

b. It takes three times as long for the second lamp to use the same amount of energy as the 30.0 W one does.

Calculate the power usage of the second lamp. (1 MARK)

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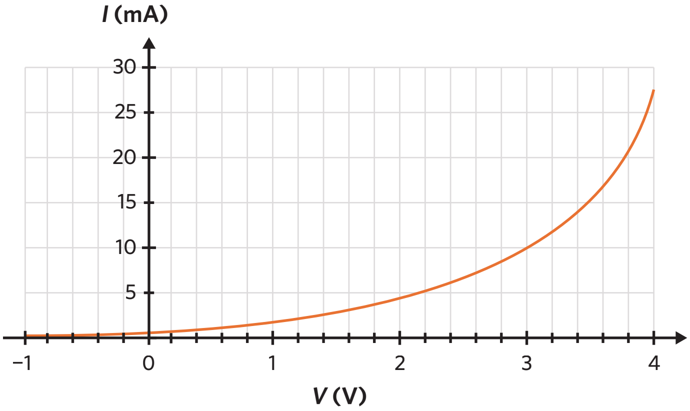
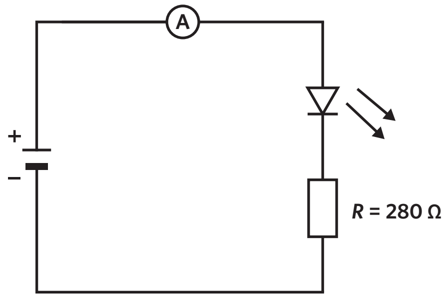
Question 7 (6 MARKS)

Carmen is experimenting with a light-emitting diode (LED). The LED's characteristics are shown in the provided diagram. He connects the LED to a circuit as shown in the provided diagram.





a. Based on the *I*-*V* graph, is the LED an ohmic or non-ohmic device? (1 MARK)

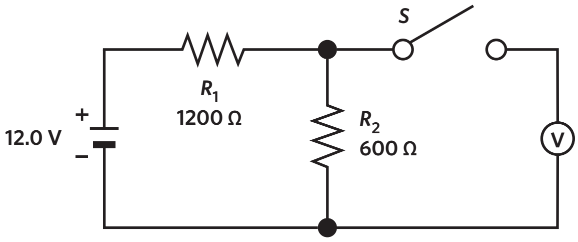
b. The current measured by the ammeter is 15 mA. Determine the voltage of the battery. (3 MARKS)

c. State the main energy transformation occurring in the LED and the resistor. (2 MARKS)

Adapted from 2013 VCAA exam Short Answer Q12

Question 8 (8 MARKS)

Timothy constructs the circuit shown in the provided diagram. The circuit consists of a 12.0 V battery, a 1200 Ω resistor, a 600 Ω resistor and a voltmeter.



a. What is the expected reading on the voltmeter when the switch *S* remains open? (1 MARK)

b. Timothy closes the switch *S*. What is the voltage that should now be measured by the voltmeter? (2 MARKS)

c. Timothy now replaces the voltmeter with a small 170 Ω motor that requires 4.0 V across it to run. Timothy swaps the resistor R_1 for a different resistor so that the motor can function.

What should the value of the resistor replacing R_1 be so that the motor functions correctly? (5 MARKS)

Adapted from 2014 VCAA exam Short Answer Q6

Question 9 (5 MARKS)

A family has moved into a new home and are having difficulties with the household electricity.

a. All the appliances in the house are wired in series with one another. Give two reasons for why this is a bad idea. (2 MARKS)

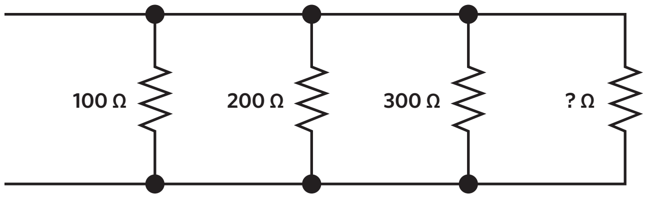
b. The family has noticed that the mains plugs for some old outdoor appliances do not have an earth pin and no double insulation, however they do not think this is a danger since the appliances draw a fairly low voltage. The family continues using the appliances outside, even when they are wet from the rain. Explain why the use of such appliances in these conditions increases the likelihood and severity of electric shock. (3 MARKS)

Question 10 (7 MARKS)

A student only has five 600 Ω resistors that they can use to build an electric cirtuit.

a. Sketch how they could connect some or all of the resistors to create a total resistance of 200 Ω. (3 MARKS)

b. The student wants to create an overall resistance of 75 Ω, and does this by putting four new resistors in parallel as shown. One of the resistor's values is unknown.



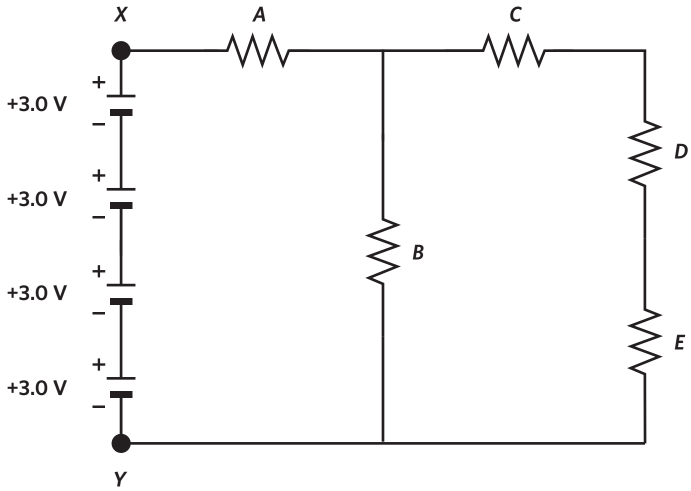
Calculate the equivalent resistance of the three known resistors in the circuit. (1 MARK)

c. Explain whether it is possible for the equivalent resistance of this circuit to be 75 Ω. (3 MARKS)

Adapted from 2013 VCAA exam Short Answer Q10

Question 11 (7 MARKS)

Five 8.00 Ω resistors are connected as shown, with four 3.0 V batteries in series across *XY*.



a. What is the current through resistor *B*? (3 MARKS)

b. What is the power dissipated in resistor *D*? (4 MARKS)

Adapted from 2011 VCAA Exam 1 Area of Study 2 Section A Q1–4

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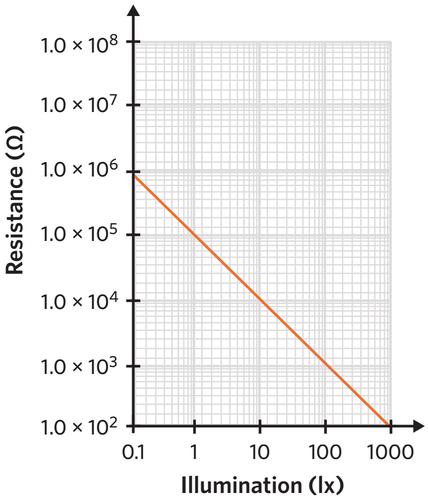
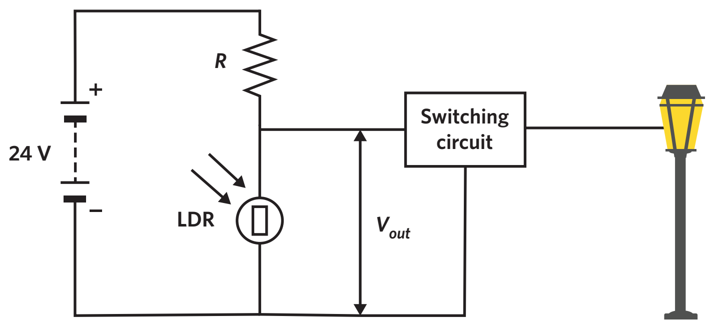
Question 12 (9 MARKS)

Randall wants to install some garden lights that will come on at sunset. A circuit will be used to control the lights. It consists of:

- a 24.0 V DC power source,
- a light-dependent resistor (LDR),
- a resistor *R*, and
- a switching circuit (an internal circuit that turns the lights on or off).

The resistance-illumination graph of the LDR and the setup of the circuit are shown in the provided diagrams.





a. The switching circuit turns the lights on when V_{out} is 6.0 V. Randall wants the lights to come on when the illumination has fallen to 10 lx.

What must the value of the resistor *R* be in the circuit to ensure the lights come on at 10 lx? (3 MARKS)

b. As sunset approaches, and the daylight decreases, does the value of V_{out} increase or decrease? Justify your answer. (3 MARKS)

c. Randall decides that he wants the lights to come on later (when there is less daylight). Should he increase or decrease the resistance *R* to achieve this? Explain your answer. (3 MARKS)

Adapted from 2010 VCAA Exam 1 Area of Study 2 Section A Q6–8

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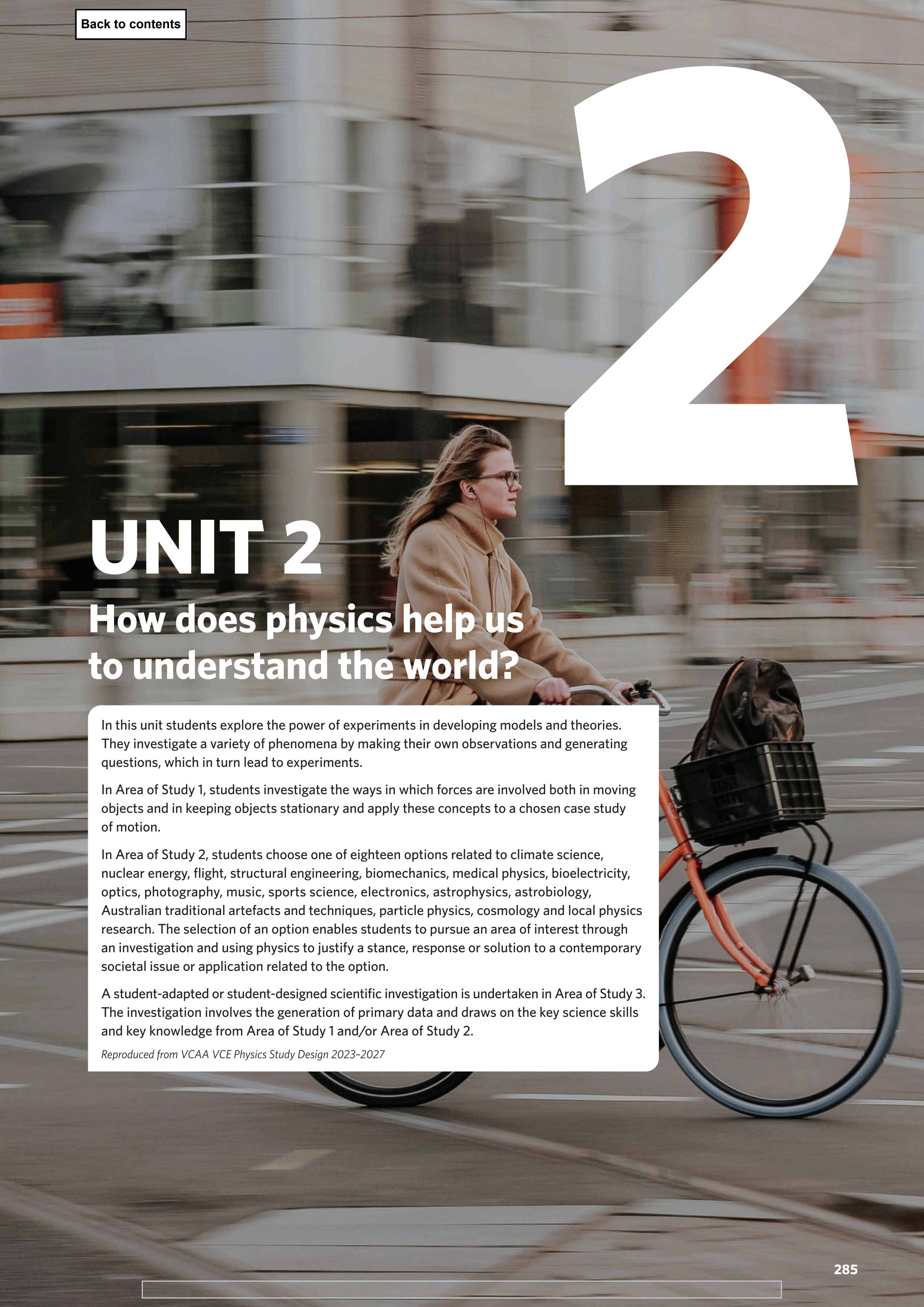

UNIT 2

How does physics help us to understand the world?

In this unit students explore the power of experiments in developing models and theories. They investigate a variety of phenomena by making their own observations and generating questions, which in turn lead to experiments.

In Area of Study 1, students investigate the ways in which forces are involved both in moving objects and in keeping objects stationary and apply these concepts to a chosen case study of motion.

In Area of Study 2, students choose one of eighteen options related to climate science, nuclear energy, flight, structural engineering, biomechanics, medical physics, bioelectricity, optics, photography, music, sports science, electronics, astrophysics, astrobiology, Australian traditional artefacts and techniques, particle physics, cosmology and local physics research. The selection of an option enables students to pursue an area of interest through an investigation and using physics to justify a stance, response or solution to a contemporary societal issue or application related to the option.

A student-adapted or student-designed scientific investigation is undertaken in Area of Study 3. The investigation involves the generation of primary data and draws on the key science skills and key knowledge from Area of Study 1 and/or Area of Study 2.

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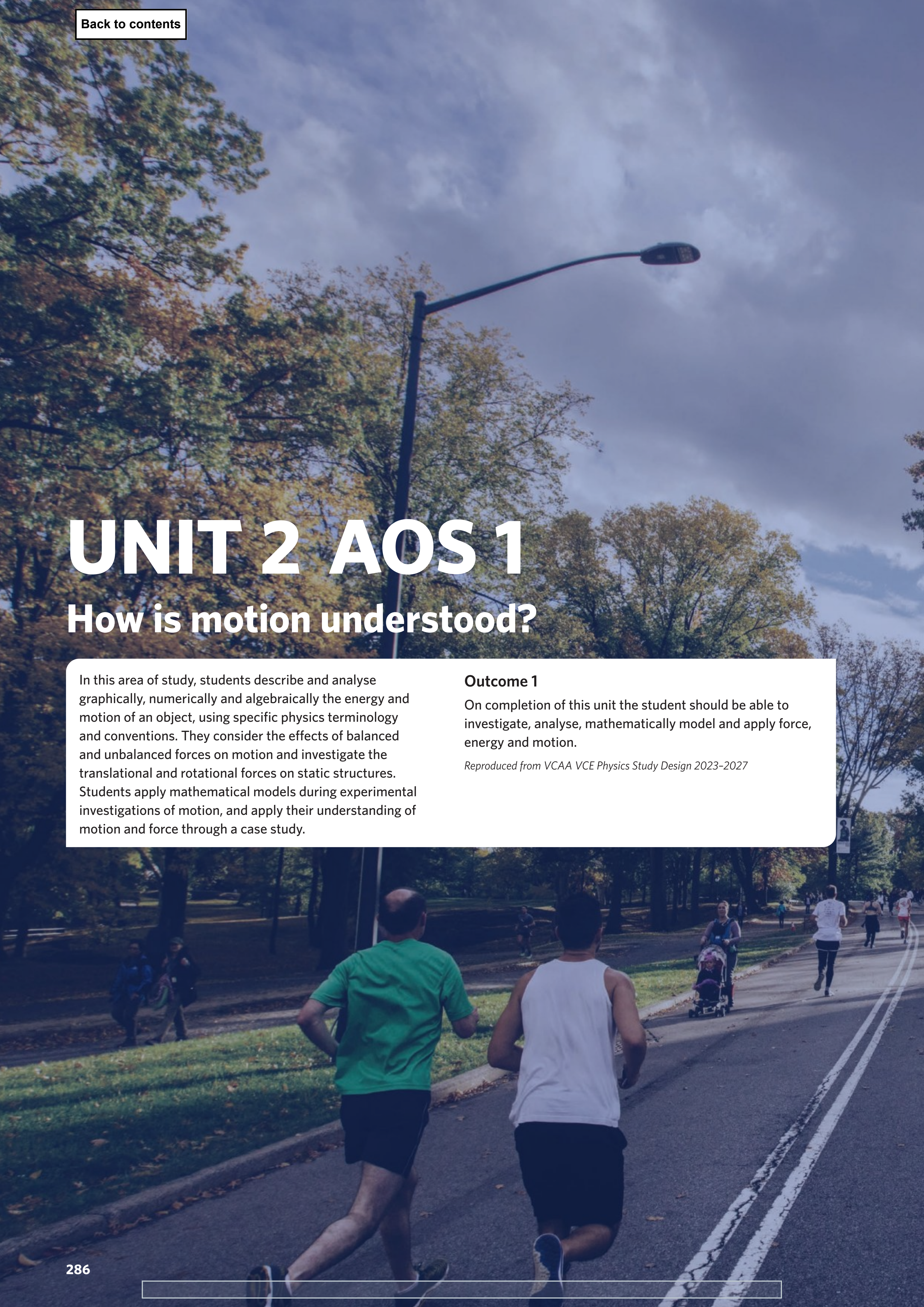

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UNIT 2 AOS 1

How is motion understood?

In this area of study, students describe and analyse graphically, numerically and algebraically the energy and motion of an object, using specific physics terminology and conventions. They consider the effects of balanced and unbalanced forces on motion and investigate the translational and rotational forces on static structures. Students apply mathematical models during experimental investigations of motion, and apply their understanding of motion and force through a case study.

Outcome 1

On completion of this unit the student should be able to investigate, analyse, mathematically model and apply force, energy and motion.

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8

CHAPTER 8

Kinematics

STUDY DESIGN DOT POINTS

- identify parameters of motion as vectors or scalars
- analyse graphically, numerically and algebraically, straight-line motion under constant acceleration: $v = u + at$, $v^2 = u^2 + 2as$, $s = \frac{1}{2}(u + v)t$, $s = ut + \frac{1}{2}at^2$, $s = vt - \frac{1}{2}at^2$
- analyse, graphically, non-uniform motion in a straight line

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LESSONS

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8A Describing motion


Image: Good Luck Photo/Shutterstock.com

STUDY DESIGN DOT POINTS

- identify parameters of motion as vectors or scalars
- analyse graphically, numerically and algebraically, straight-line motion under constant acceleration: $v = u + at$, $v^2 = u^2 + 2as$, $s = \frac{1}{2}(u + v)t$, $s = ut + \frac{1}{2}at^2$, $s = vt - \frac{1}{2}at^2$

8A 8B 8C

2.1.1.1 Scalars and vectors

2.1.2.1 Motion with constant velocity

2.1.2.2 Acceleration

ESSENTIAL PRIOR KNOWLEDGE

- Pythagoras' theorem
- Trigonometry

See questions 60–61.

ACTIVITIES

Log into your Edrolo account for activities that support this lesson.

How can speed cameras detect speeding?

Motion describes how objects navigate and interact with the space around them, and includes anything from driving a car, to walking down the street, to playing golf. Whilst we have an existing vocabulary for motion – speed, distance, time, etc. – this lesson will establish a formal language for describing movement of all kinds. We will look at the foundations of scalar and vector quantities and explore key terms like displacement, *s*, velocity, *v*, and acceleration, *a*.

KEY TERMS AND DEFINITIONS

acceleration the rate of change of velocity per unit time (vector quantity)
displacement the change in position of an object (vector quantity)
distance the total length of a given path between two points (scalar quantity)
scalar quantity a quantity that only has magnitude (size)
speed the rate of change of distance per unit time (scalar quantity)
vector quantity a quantity that has both magnitude (size) and direction
velocity the rate of change of displacement per unit time (vector quantity)

FORMULAS

- **speed**
  $speed = \frac{distance}{time}$
- **average velocity**
  $v_{avg} = \frac{\Delta s}{\Delta t}$
- **average acceleration**
  $a_{avg} = \frac{\Delta v}{\Delta t}$

Scalars and vectors 2.1.1.1

We interact with scalar and vector quantities almost everyday. Understanding the fundamentals of these can help us explain the physics behind motion in different dimensions.

Theory and applications

Scalar quantities are a type of measurement that associate a magnitude to something, giving us a description of the quantity's size. Some examples are length, time and money. Vectors are quantities that have both a magnitude (size) and a direction, giving us more information.

Why do we need scalar and vector quantities?

Vectors can be represented using arrows:

- The length of the arrow represents the quantity's magnitude.
- The direction in which the arrow is pointing represents the relative direction of the measurement.

Giving direction is important in navigation. Suppose, for instance, we are telling someone the location of a building from where we are standing. Telling them "the tuckshop is 100 metres away", gives them no sense of how to reach the location. Instead, by saying "the tuckshop is 100 metres to the left", informs them on which direction they should travel.

There are some points worth making with regard to how the direction is communicated:

- This direction can be communicated in many ways: cardinal directions (e.g. North), words like left and right, and angles given relative to a particular direction.
- When using vectors in one dimension, we will mostly use positive (+) and negative (−) signs to distinguish direction.

USEFUL TIP

For convention, the positive directions are usually taken as to the right and upwards. However, this can be changed for convenience depending on the situation.

Distance, *d*, describes the total length of a path that an object travels. Displacement, *s*, describes the change in position of an object from one point in time to another. While both have the SI unit metres (m), distance is a scalar quantity and displacement is a vector quantity. Since distance is a scalar quantity, it does not account for changes in direction.

Consider the hole of golf shown in Figure 1. Three shots were taken, as indicated by the black arrows. This route is much longer than the direct red arrow. Regardless of how we moved from point *A* (the tee) to point *B* (the hole), we only account for the net outcome of the movement when calculating displacement, whereas the distance travelled by the ball considers the unique path the object took.

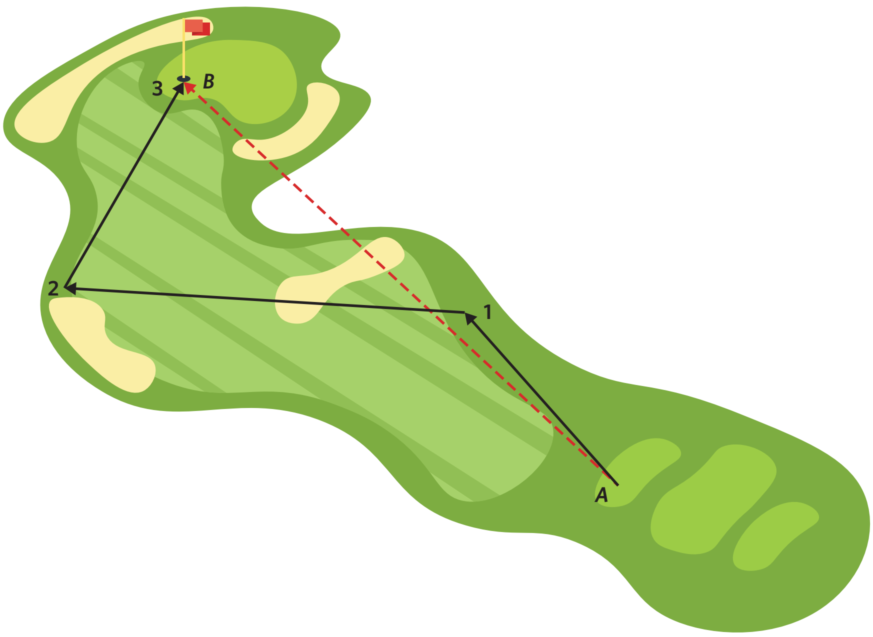

Figure 1 Depiction of how a golf hole was played

USEFUL TIP

Since displacement is a vector and distance is a scalar, the magnitude of displacement will always be less than or equal to the distance. Use this fact to check whether your answer makes physical sense when doing calculations.

How do we add and subtract vector quantities?

When operating with vectors, we can represent the operation geometrically to ensure we find the correct magnitude and direction. Because of this, we can see that the direction of the arrow, and not just its magnitude, is important.

To evaluate the sum of the vectors we can use the tip-to-tail method. When vector arrows are pointing in the same direction, we can draw the tail of one vector from the tip of another, shown in Figure 2.

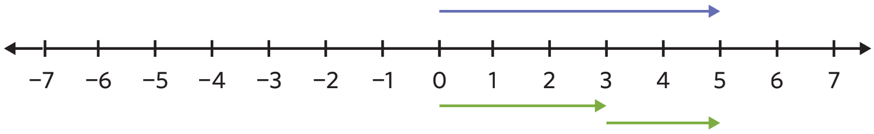

Figure 2 A number line demonstrating the addition of two vectors in the same direction.

We can also combine one-dimensional vectors when they do not point in the same direction. In Figure 3, the green arrow shows a movement of 3 units to the right, followed by a movement of 7 units to the left, in red. The blue arrow represents the displacement of 4 units to the left, or in the negative direction.

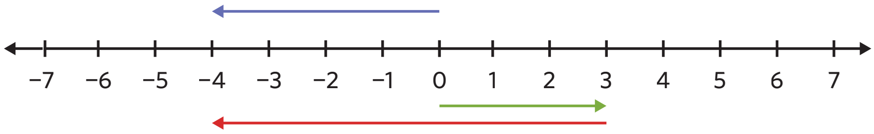

Figure 3 A number line demonstrating the addition of two vectors in different directions.

We can represent and combine two-dimensional vectors. We can think of two-dimensional vectors as being arrows on a Cartesian plane. As shown in Figure 4, a vector can be communicated either with:

- the components in the two perpendicular directions (x and y-directions) or
- a magnitude and an angle measured relative to a reference direction (such as the positive direction of the x-axis).

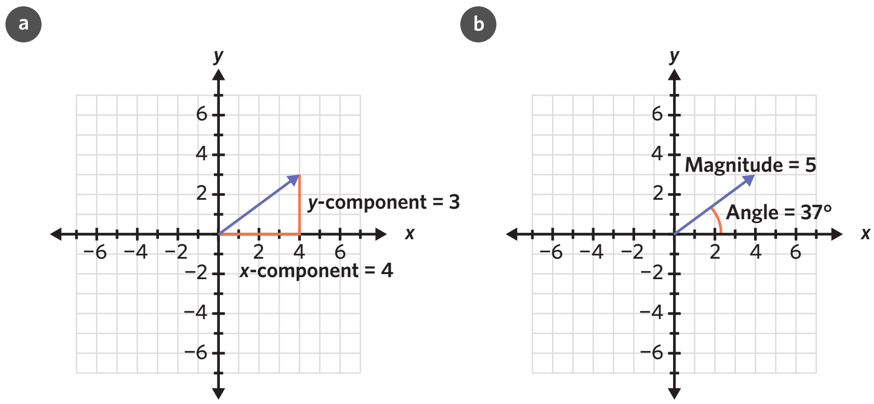

Figure 4 A vector can be represented by either **(a)** an x-component and a y-component, or **(b)** a magnitude and an angle.

Figure 5(a) shows two vectors, v_1 and v_2. We can again use the tip-to-tail method to add these two vectors. The result is shown by the orange vector in Figure 5(b).[1]

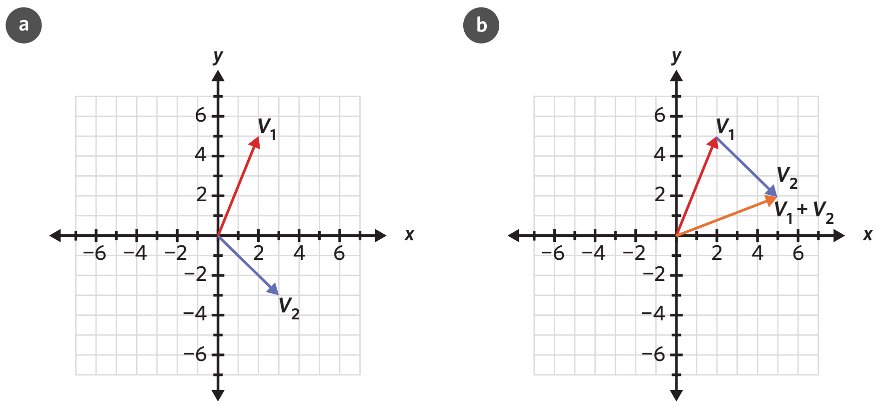

Figure 5 **(a)** Two vectors, v_1 and v_2 **(b)** being added using the tip-to-tail method.

KEEN TO INVESTIGATE?

[1] **How do we add and subtract vectors in two-dimensional?**
Search: Physics vector addition and subtraction simulation

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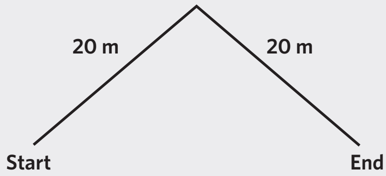
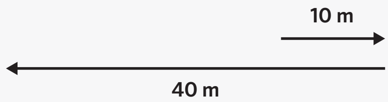
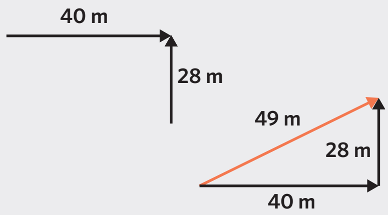
Table 1 A summary of scalars and vectors, and how to perform operations with each type of quantity.

Type of quantity	How to represent it	How to use in operations	Example
Scalars	Measurements of a certain size that we can linearly combine through addition, subtraction, multiplication or division	Substitute the magnitude into the operation.	 The total distance is: 20 + 20 = 40 m
Vectors	One-dimensional vectors – arrows that represent physical quantities applied in one dimension. Direction is commonly represented with positive and negative values.	Draw the vectors using the tip-to-tail method. For subtraction, flip the subtracted vector. Find the length and direction of the resultant arrow.	 The total displacement is: $10 + (-40) = 30$ m to the left.
	Two-dimensional vectors – arrows that represent physical quantities applied in two dimensions (such as up/down and left/right). Direction is commonly represented with an angle.	Draw the vectors using the tip-to-tail method. For subtraction, flip the subtracted vector. Find the length and direction of the resultant arrow.	 The total displacement, found using trigonometry, is 49 m 35° from the horizontal.

Progress questions

Question 1

Kenneth, having just purchased a new pair of sneakers, decides to go for a walk. He travels 8 km east and then 6 km north. He claims that from his starting point, his displacement is 14 km. Is he correct?

A. Yes, because displacement is given by the total length he has covered.

B. Partially, but he would have to include a direction because displacement is a vector.

C. No, because his direction has changed and he cannot simply add the two lengths.

Question 2

Zara walks around her neighbourhood in a perfect square where each side is 400 m long. She returns home so her displacement is zero. What distance did she travel?

A. 0 m

B. 400 m

C. 1600 m

D. We cannot calculate distance without speed.

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Motion with constant velocity 2.1.2.1

Speed and velocity can both be used to describe how fast something is moving, although depending on the motion, they produce different descriptions.

Theory and applications

When an object travels in a straight line and covers an equal distance each unit of time, we can say it has constant velocity. During this motion, acceleration is equal to zero.

In our vocabulary of describing motion, it will be important to define a term for how fast something is moving. A familiar concept may be speed, which is the rate of change of distance travelled per unit time.

- The SI unit for speed is metres per second ($m\ s^{-1}$).
- Speed is a scalar quantity.

To calculate the average speed of an object, we divide the distance travelled by the time taken.

$$speed = \frac{distance}{time}$$

STRATEGY

It is good practice to convert all measurements to SI units when analysing motion. A common conversion that will be required is between $km\ h^{-1}$ and $m\ s^{-1}$.

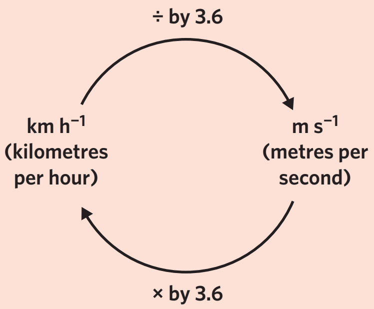

Figure 6 Converting between common speed/velocity units

How does velocity differ from speed?

Velocity is the rate of change of displacement per unit time.

- The SI unit for velocity is metres per second ($m\ s^{-1}$).
- Velocity is a vector quantity.

Suppose we are driving in a golf buggy and we drop a golf ball out the back of the buggy every second, as shown in Figure 7. In both Figure 7(a) and Figure 7(b) the balls land five metres apart in a straight line.

- The magnitudes of both the speed and velocity in Figure 7(a) are $5\ m\ s^{-1}$ since there is no change in the buggy's direction.
- By contrast, in Figure 7(b) the buggy follows a curved path. The magnitude of the average velocity is $5\ m\ s^{-1}$, however the average speed must be greater than $5\ m\ s^{-1}$ due to the greater distance travelled by the buggy along its curved path.

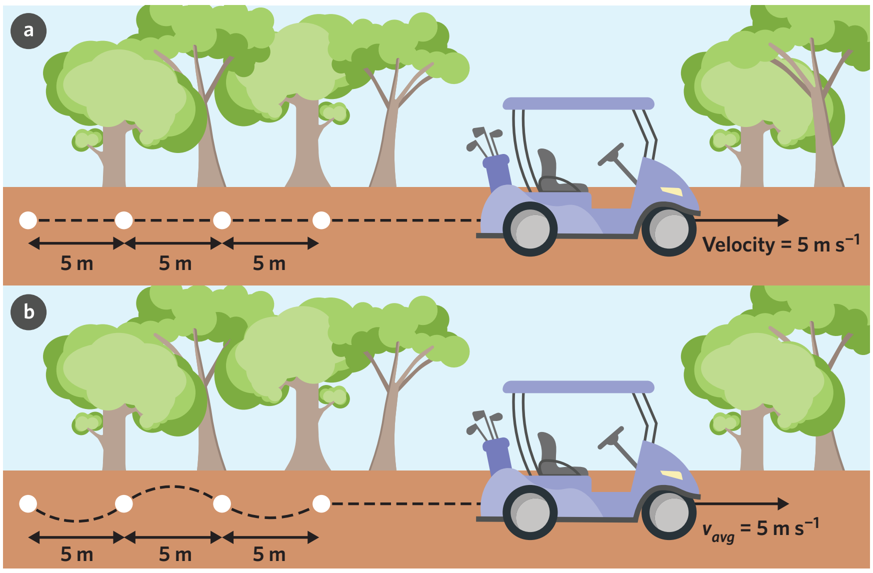

Figure 7 **(a)** A golf buggy travelling at a velocity of 5 ms^{-1}. **(b)** A golf buggy travelling with an average velocity of 5 ms^{-1}.

This allows us to make three observations:

- Velocity is a measure of how much an object is displaced (or displaces itself) per unit time
- A higher velocity corresponds to a greater displacement between consecutive golf balls when compared to a lower velocity.
- The displacement (spacing) between consecutive golf balls will be the same if the golf buggy is travelling at constant velocity.

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FORMULA

$$v_{avg} = \frac{\Delta s}{\Delta t} = \frac{s_2 - s_1}{t_2 - t_1}$$

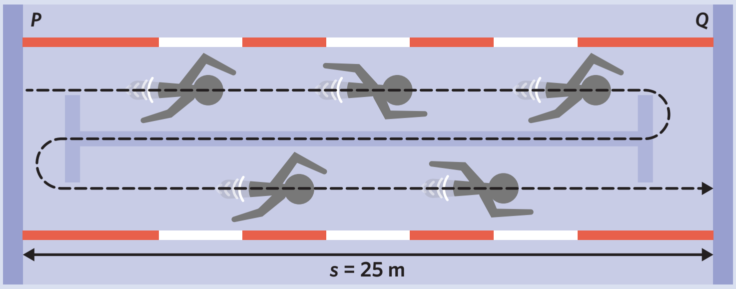
v_{avg} = average velocity (m s^{-1})
s_1 = displacement at t_1 (m)
s_2 = displacement at t_2 (m)
t_1 = start time (s)
t_2 = end time (s)

USEFUL TIP

Δ, called delta, is the symbol for change. For example, Δs refers to a change in displacement.

WORKED EXAMPLE 1

Sam swims three laps of a 25 m pool in 120 s, starting from one end, *P*, and swimming towards the other end, *Q*. Take to the right as positive.



a. Calculate Sam's average speed.

Step 1

Identify time, distance, average speed, and the formula that relates these variables.

Note that speed is a scalar quantity and distance can be found by summing all lengths that Sam swam.

$\Delta t = 120$ s, $distance = 3 \times 25 = 75$ m, $speed_{avg} = ?$

$speed_{avg} = \frac{distance}{\Delta t}$

Step 2

Substitute values into the formula and solve for average speed.

$speed_{avg} = \frac{75}{120} = 0.625 = 0.63$ m s^{-1}

b. Calculate Sam's average velocity.

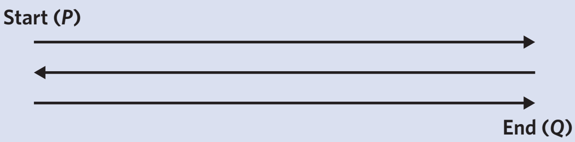
Step 1

Identify time, displacement and average velocity and the formula that relates these variables.

Note that velocity is a vector quantity and displacement can be calculated using *P* as s_1 and *Q* as s_2.

$\Delta t = 120$ s, $\Delta s = s_2 - s_1 = 25 - 0 = 25$ m, $v_{avg} = ?$

$v_{avg} = \frac{\Delta s}{\Delta t}$



Step 2

Substitute values into the formula and solve for average velocity, remembering to add direction.

$v_{avg} = \frac{25}{120} = 0.208 = 0.21$ m s^{-1} in the positive direction.

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WORKED EXAMPLE 2

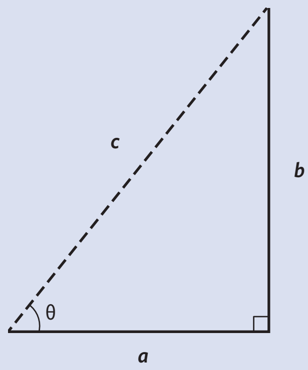
Imogen walks 3.5 km before turning 90 degrees and continuing for another 4.7 km. The whole trip takes her 1.3 hours.

Calculate the magnitude and direction of her average velocity in km h^{-1}.

Step 1

Identify the two sides of a right angle triangle and the formula for finding the hypotenuse.

Note: since velocity is a vector we need to find the displacement.



$a = 3.5$ km, $b = 4.7$ km, $c = ?$

$c = \sqrt{a^2 + b^2}$

Step 2

Substitute values and solve for the hypotenuse to get the displacement.

$c = \sqrt{3.5^2 + 4.7^2} = 5.86$ km

Step 3

Identify the opposite and adjacent sides, and the angle, and the formula that relates these variables.

$a = 3.5$ km, $b = 4.7$ km, $\theta = ?$

$\tan(\theta) = \frac{b}{a}$

Step 4

Substitute values and solve for the angle.

$\tan(\theta) = \frac{4.7}{3.5}$

$\theta = \tan^{-1}\left(\frac{4.7}{3.5}\right) = 53.3 = 53°$

Step 5

Identify displacement, time and average velocity, and the formula that relates these variables.

$s = 5.86$ km, $t = 1.3$ hours, $v_{avg} = ?$

$v_{avg} = \frac{\Delta s}{\Delta t}$

Step 6

Substitute values into the formula and solve for average velocity.

$v_{avg} = \frac{5.86}{1.3} = 4.50 = 4.5$ km h^{-1}, 53° from the horizontal

Progress questions

Question 3

In which of the following scenarios would the average speed and average velocity (calculated from start to finish) be different? **(Select all that apply)**

A. A 100 m runner starts the race, takes a 30 second break, then finishes the race.

B. A 400 m runner completes one full lap around the track.

C. A travelling tourist takes the round-trip train line from Paris to Rome and back.

Continues →

Question 4

A car is driving along a straight driveway to the right that is 10 m long.
If the car takes 4 seconds to get to the end, what is the average velocity?

A. 0.4 m s^{-1}
B. 2.5 m s^{-1}
C. 0.4 m s^{-1} right
D. 2.5 m s^{-1} right

Acceleration 2.1.2.2

Acceleration describes the changes in the magnitude or direction of velocity.

Theory and applications

In everyday language, we generally associate acceleration with 'speeding up or slowing down'. However, since velocity is a vector, acceleration can occur without the speed changing.

How do we use acceleration to describe changes in velocity?

Acceleration is a vector and can be described as the rate of change of velocity per unit time (how quickly velocity changes).

- The SI unit for acceleration is metres per second per second or metres per second squared (m s^{-2}).
- Acceleration occurs when there is a change in velocity, whether that is the magnitude or direction.
- The term deceleration can be used when the object slows down (speed decreases).

In Figure 7(a), the golf buggy travelled in a straight line with constant velocity (indicated by the golf balls) for each unit of time. This represented constant velocity. If velocity is visualised by the displacement between balls for each unit of time, then acceleration can be visualised by how this displacement changes from one unit of time to the next.

- In Figure 8(a), the golf buggy travels with an acceleration of 1 m s^{-2}.
- This means that for every second, the velocity of the cart increases by 1 m s^{-1}. After three seconds, Figure 8(b), the buggy has a velocity of 8 m s^{-1}.
- The increase in velocity causes the spacing between golf balls to increase.

MISCONCEPTION

'Negative acceleration means the object is decelerating.'

If an object is slowing down, it is decelerating. However, if an object has negative acceleration, it may be speeding up in the direction opposite to what is defined as positive.

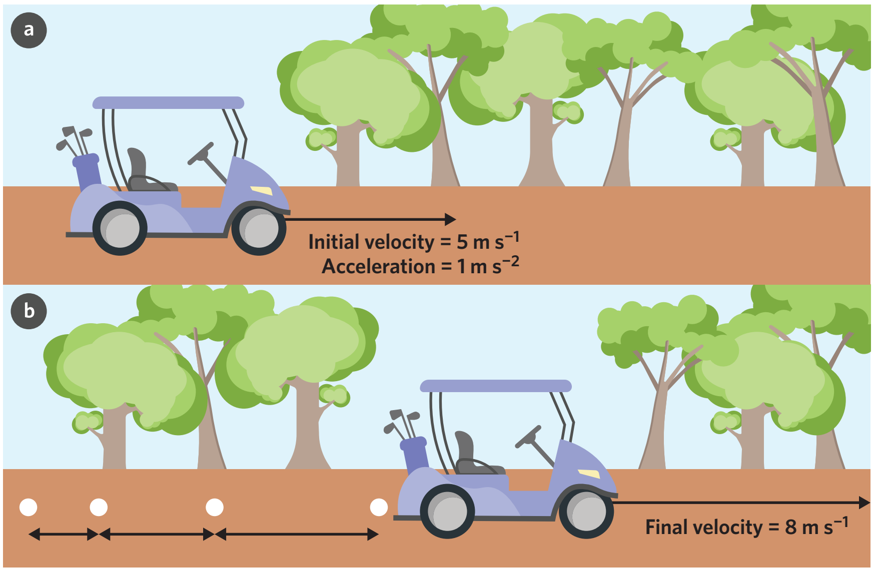


Figure 8 A golf buggy travelling with an acceleration of 1 m s^{-2} **(a)** initially and **(b)** after 3 seconds

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FORMULA

$$a_{avg} = \frac{\Delta v}{\Delta t} = \frac{v_2 - v_1}{t_2 - t_1}$$

a_{avg}= average acceleration (m s^{-2})
Δv= change in velocity (m s^{-1})
Δt= change in time (s)

WORKED EXAMPLE 3

Sonny is running a sprint race. He starts standing still and speeds up at a constant rate over the first four seconds to reach a velocity of 11.0 m s^{-1}. He maintains this velocity for seven seconds and then, having run out of energy, slows down at a constant rate over the next three seconds to a velocity of 7.0 m s^{-1} as he crosses the line. Take the direction Sonny is running as positive.

a. Calculate his acceleration for the first 4.0 s.

Step 1

Identify initial and final velocity and average acceleration over the first 4.0 s, and the formula that relates these variables.

$v_1 = 0$ m s^{-1}, $v_2 = 11.0$ m s^{-1}, $t_1 = 0$ s, $t_2 = 4.0$ s $a_{avg} = ?$

$$a_{avg} = \frac{\Delta v}{\Delta t} = \frac{v_2 - v_1}{t_2 - t_1}$$

Step 2

Substitute values into the formula and solve for the average acceleration.

$a_{avg} = \frac{11 - 0}{4.0 - 0} = 2.75 = 2.8$ m s^{-2} in the positive direction.

b. Calculate his acceleration for the period between 4 s and 11 s.

Step 1

Identify initial and final velocity and average acceleration over the seven second period, and the formula that relates these variables.

$v_1 = 11.0$ m s^{-1}, $v_2 = 11.0$ m s^{-1}, $t_1 = 4.0$ s, $t_2 = 11.0$ s
$a_{avg} = ?$

$$a_{avg} = \frac{\Delta v}{\Delta t} = \frac{v_2 - v_1}{t_2 - t_1}$$

Step 2

Substitute and solve for acceleration.

Note that $\Delta v = 0$. This means there is no change in velocity and no acceleration.

$a_{avg} = \frac{11 - 11}{11 - 4.0} = 0$ m s^{-2}

c. Calculate his acceleration for the final 3.0 s.

Step 1

Identify initial and final velocity and average acceleration over the last three seconds, and the formula that relates these variables.

$v_1 = 11.0$ m s^{-1}, $v_2 = 7.0$ m s^{-1}, $t_1 = 0$ s, $t_2 = 3.0$ s, $a_{avg} = ?$

$$a_{avg} = \frac{\Delta v}{\Delta t} = \frac{v_2 - v_1}{t_2 - t_1}$$

Step 2

Substitute and solve for acceleration, remembering to include direction.

$a_{avg} = \frac{7.0 - 11}{3.0 - 0} = \frac{-4.0}{3.0} = -1.33 = -1.3$ m s^{-2} in the positive direction (or 1.3 m s^{-2} in the negative direction).

It is important to note the following points:

- Knowing the acceleration does not tell us anything about the specific velocity of the object.
  - It simply tells us how the velocity changes between consecutive time intervals.
  - This means that two objects can have the same acceleration but different velocities and vice-versa.
- Since acceleration is independent from velocity in this way, we must remember that acceleration does not always occur in the direction of motion.

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Progress questions

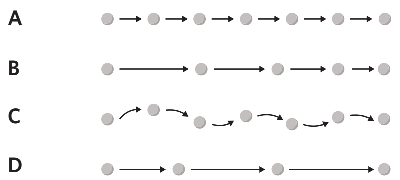
Question 5

Fill in the gaps in the following paragraph to correctly show the relationship between the variables of motion covered in this lesson.

__________ (displacement/velocity/distance) is a measure of the change in position of an object. The variable that measures how the displacement changes over time is __________ (acceleration/speed/velocity). Unlike __________ (speed/acceleration), this variable is a vector. In order to calculate the average acceleration, we divide the change in __________ (displacement/time/velocity) by the change in __________ (speed/time/displacement).

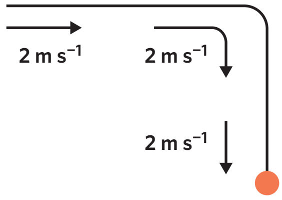
Question 6

This lesson explored a golf buggy dropping a golf ball behind it every second as it travelled along. Identify which of the following options represents the path of a golf cart with a non-zero initial velocity but a positive acceleration.



Question 7

An object travels with a speed of 2 m s^{-1} before turning right and continuing at the same speed. Acceleration is not present in this scenario. Is this statement true or false?



A. True

B. False

Theory summary

Table 2 Summary of scalar and vector quantities introduced in this lesson

Variable	Type of quantity	Definition	Equation
Distance, *d* (m)	Scalar	Length of the path travelled by an object.	–
Displacement, *s* (m)	Vector	Relative change in position of an object.	–
Speed, *v* (m s^{-1})	Scalar	Rate of change of distance per unit time.	$speed = \frac{distance}{time}$
Average velocity, *v* (m s^{-1})	Vector	Rate of change of displacement per unit time.	$v_{avg} = \frac{\Delta s}{\Delta t}$
Acceleration, *a* (m s^{-2})	Vector	Rate of change of velocity per unit time.	$a_{avg} = \frac{\Delta v}{\Delta t}$

- The direction of a vector can be communicated through words like 'left' or 'north', angles, or through a positive or negative sign.
- Constant velocity means that the rate at which the displacement of an object changes with respect to time is constant.
- Acceleration does not always occur in the same direction as motion.
  - Acceleration occurs whenever velocity changes, even if only the direction of the velocity changes.

KEEN TO INVESTIGATE?

How do speed cameras work?
Search YouTube: How do we know red-light and speed cameras work?

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CONCEPT DISCUSSION

Image: Waymo

Consider a car and a large truck stopped at a red light. When the light turns green and both vehicles start moving, we could reasonably expect the car to reach the next set of lights first because the car is 'faster', even though both vehicles reach (but do not exceed) the speed limit.

Discuss what we mean by 'faster' in this context and how this explains the expected observation from this scenario.

Prompts:

- If the car reaches the next set of lights before the truck, what can we say about the average speed of the car compared to the truck as they drive between the two sets of lights?
- How can we explain this, given that they both reach the same maximum speed?

8A Questions

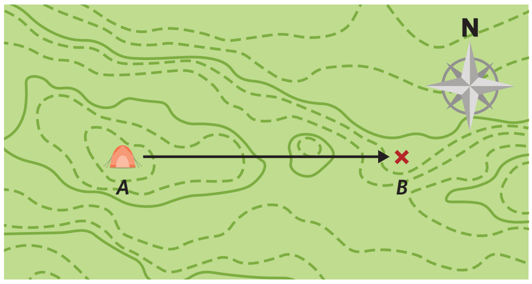
Mild 🌶 Medium 🌶🌶 Spicy 🌶🌶🌶

Deconstructed exam-style

Use the following information to answer questions 8–13.

Michael and Tara are going for a hike. They travel from their camp at point *A* to another campsite at point *B*.

- The journey takes 9.0 hours in total.
- They walk at an average velocity of 4.0 km h^{-1} up hills and 6.0 km h^{-1} on flat ground.
- They stop for a 1 hour break at some point in the hike.
- The distance they hike up hills is half the distance they hike on flat ground.



Question 8 (1 MARK) 🌶

We can split the journey up into two parts: the time spent walking up hills (t_{hills}) and the time spent walking on flat ground (t_{flat}). Which of the following gives the correct expression for t_{flat}?

A. $t_{flat} = \frac{40}{6.0}$

B. $t_{flat} = \frac{s_{flat}}{6.0}$

C. $t_{flat} = \frac{s_{flat}}{4.0 + 6.0} = \frac{s_{flat}}{10}$

D. There is not enough information to determine this.

Question 9 (1 MARK) 🌶

Which of the following is the correct calculation for t_{hills}?

A. $t_{hills} = \frac{40}{6.0} = 6.7$ hours

B. $t_{hills} = \frac{40}{4.0} = 10$ hours

C. $t_{hills} = \frac{s_{hills}}{4.0}$

D. There is not enough information to determine this.

Question 10 (1 MARK) 🌶

Which of the following correctly expresses the total time of the trip in terms of t_{flat} and t_{hills}?

A. $9.0 = t_{flat} - t_{hills}$

B. $9.0 = t_{hills} - t_{flat} - 1$

C. $9.0 = t_{hills} + t_{flat}$

D. $9.0 = t_{hills} + t_{flat} + 1$

Question 11 (1 MARK)

The question states that the distance they hike up hills is half the distance they hike on flat ground. Use this information to identify the equation below that correctly relates t_{flat} to s_{hills}.

A. $t_{flat} = \dfrac{2 \times s_{hills}}{6.0} = \dfrac{s_{hills}}{3.0}$

B. $t_{flat} = \dfrac{0.5 \times s_{hills}}{6.0} = \dfrac{s_{hills}}{12.0}$

Question 12 (1 MARK)

Using the equations from questions 8–11, what are the values of s_{hills} and s_{flat}?

A. 8.1 km, 16 km

B. 14 km, 27 km

C. 24 km, 48 km

D. 6.6 km, 13 km

Question 13 (5 MARKS)

Calculate the average velocity for the entire hike.

Exam-style

Question 14 (1 MARK)

A man runs with a constant velocity of magnitude of 5.0 m s^{-1} along a straight path. How long does it take for him to travel 100 m?

Question 15 (3 MARKS)

Jessica swims up and back along a 25 metre lap pool in 40 seconds.

a. What is her distance travelled? (1 MARK)

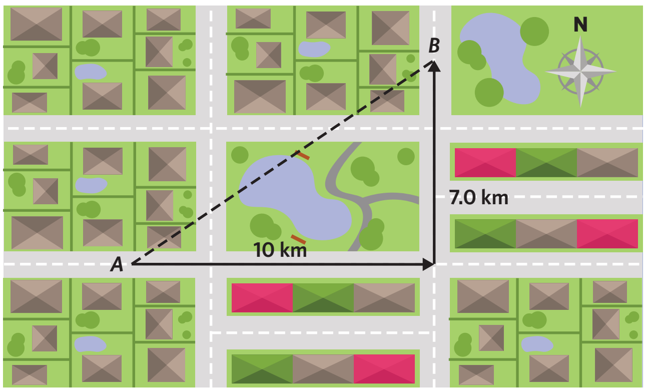
b. What is her displacement? (1 MARK)

c. What is her average velocity? (1 MARK)

Question 16 (3 MARKS)

Sarah goes for a walk as shown in the diagram.

If this journey takes Sarah 100 minutes, calculate the magnitude of her average velocity in km h^{-1} as she walks from *A* to *B*.



Question 17 (4 MARKS)

Describe the similarities and differences between velocity and speed, including reference to their magnitudes.

Question 18 (6 MARKS)

A cyclist rides north along a straight line for 4.3 km and it takes her 47 minutes. Without stopping she turns right and continues east for another 4.2 km, which takes her another 47 minutes to complete.

a. Calculate her displacement in km. (3 MARKS)

b. Calculate her average velocity in m s^{-1}. (3 MARKS)

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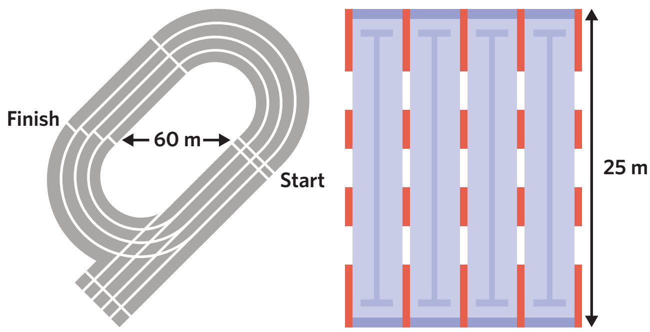
Question 19 (4 MARKS)

A swimmer and a runner were comparing their average speeds in their respective sports to see which was greater. The runner completes a 200 m race in 4 minutes. The displacement from start to finish is 60 m to the left. The swimmer completes a 25 m race with an average speed of 3.2 km h^{-1}.

a. Calculate which athlete has the greater average speed in m s^{-1}. (3 MARKS)

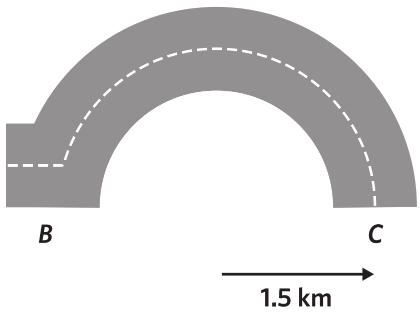
b. Calculate the average velocity of the runner in m s^{-1}. (1 MARK)



Question 20 (7 MARKS)

a. Consider the motion of the car between points B and C, with radius 1.5 km. Instead of a speed limit, there is an 'average velocity limit' of 100 km h^{-1} whilst rounding the bend BC. If it takes the driver 100 seconds to complete the turn, determine whether or not they will exceed the limit for the duration of the curve. (4 MARKS)

b. The reckless individual drives around the track from B to C at a constant speed. However, this is different to the magnitude of their average velocity over this stretch. Explain why this is, using calculations to support your answer. (3 MARKS)



Key science skills

Question 21 (5 MARKS)

We are provided with the following data points which describe the displacement of a car driving along a straight track of road for a given length of time:

Time (seconds)	0.80	1.4	6.0	9.0
Displacement (metres)	24.0	56.0	226	316

a. Plot the data on a graph of displacement against time. Include a line of best fit. (3 MARKS)

b. Calculate the gradient of your line of best fit. What does this gradient represent? (2 MARKS)

FROM LESSONS 11D & 11E

Previous lessons

Question 22 (2 MARKS)

Cobalt-60 is a commonly used source of radiation and has a half life of 5.27 years. Calculate how much of an 8.0 kg sample will remain after 31.62 years.

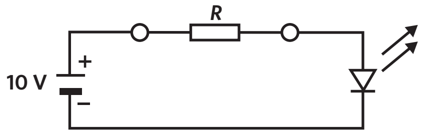
FROM LESSON 4B

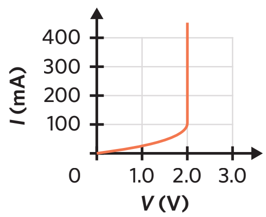
Question 23 (3 MARKS)

Some students build a circuit in order to power a light-emitting diode (LED).
The power is supplied by a 10 V battery and the power dissipated in the LED is 0.35 W.

Using the circuit diagram and the current-voltage characteristics for the LED shown, calculate the resistance of the resistor, *R*.

FROM LESSON 7A





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8B Graphing motion

How can we graph the motion of someone running around an athletics track?

In the previous lesson, we examined motion with constant velocity or acceleration. We will now move on to how we graph, and read graphs, of this type of motion. Graphing motion is the process of extrapolating relationships between displacement, velocity and acceleration so we can analyse and predict the behaviour of a moving object over a period of time.

STUDY DESIGN DOT POINTS

- analyse graphically, numerically and algebraically, straight-line motion under constant acceleration: $v = u + at$, $v^2 = u^2 + 2as$, $s = \frac{1}{2}(u + v)t$, $s = ut + \frac{1}{2}at^2$, $s = vt - \frac{1}{2}at^2$
- analyse, graphically, non-uniform motion in a straight line

8A 8B 8C

- 2.1.2.3 & 2.1.3.1 Displacement-time graphs
- 2.1.2.4 & 2.1.3.2 Velocity-time graphs
- 2.1.2.5 Acceleration-time graphs

ESSENTIAL PRIOR KNOWLEDGE

- 8A Vector and scalar quantities
- 8A Acceleration
- 11E Gradient between two points

See questions 62–64.

ACTIVITIES

Log into your Edrolo account for activities that support this lesson.

KEY TERMS AND DEFINITIONS

average acceleration the average rate of change of velocity per unit time over a given period (vector quantity)

average velocity the average rate of change of displacement per unit time over a given period (vector quantity)

gradient the slope of a graph

instantaneous acceleration the rate of change of velocity per unit time at a single instant in time (vector quantity)

instantaneous velocity the rate of change of displacement per unit time at a single instant in time (vector quantity)

FORMULAS

- **speed**
  $speed = \frac{distance}{time}$
- **average velocity**
  $v_{avg} = \frac{\Delta s}{\Delta t}$
- **average acceleration**
  $a_{avg} = \frac{\Delta v}{\Delta t}$

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Displacement-time graphs 2.1.2.3 & 2.1.3.1

Displacement-time graphs represent the displacement of an object over a particular time interval.

Theory and applications

The horizontal axis in displacement-time graphs represents the time, usually in seconds, whereas the vertical axis represents displacement, usually in metres. Recall from Lesson 8A, displacement is a vector quantity with both magnitude and direction.

How do we analyse displacement-time graphs?

Suppose we knew that a golf cart was travelling at a constant velocity and we recorded its displacement every 2 seconds. See Figure 1(a). We can then produce a linear relationship (straight line) between its displacement and time as shown in Figure 1(b).

If we want to know the displacement of the golf cart at any point in time, we would:

- find the time value on the horizontal axis,
- trace upwards until we meet the graph,
- trace across and read off the displacement value on the vertical axis.

This is shown by the dotted blue lines in Figure 1(b). At a time of 5 seconds the object has a displacement of 15 m, in the positive direction.

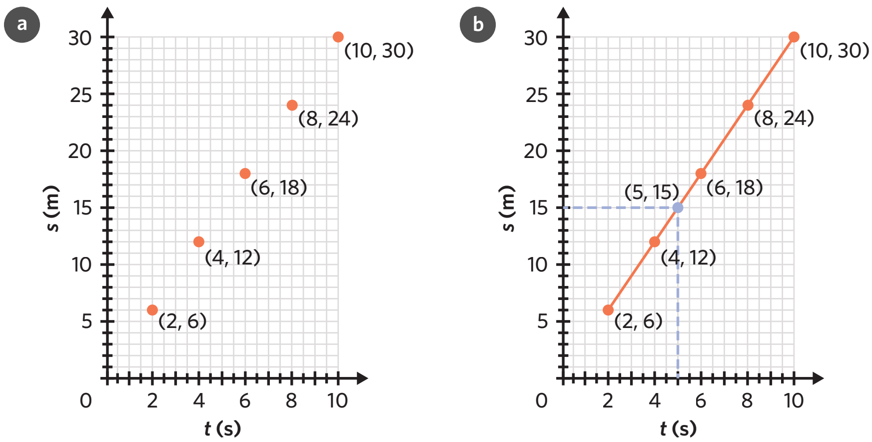

Figure 1 **(a)** The displacement of the object at 2 second intervals and **(b)** the line of best fit for these data points

In Figure 2, the gradient between the points (t_1, s_1) and (t_2, s_2) is given by $\frac{s_2 - s_1}{t_2 - t_1} = \frac{\Delta s}{\Delta t}$.

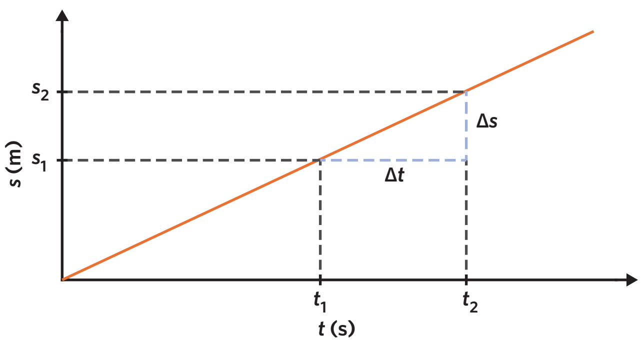

Figure 2 The gradient of a displacement-time graph gives the average velocity.

USEFUL TIP

In examples where the gradient is constant at all positions, the instantaneous velocity at any point will be equal to the average velocity between two points on the graph.

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Recall from Lesson 8A that this is equal to the average velocity $v_{avg} = \frac{\Delta s}{\Delta t}$. Because of this relationship, for objects with constant velocity, the gradient of the displacement-time graph must also be constant. The features of a displacement-time graph and their meaning are summarised in Table 1.

Table 1 Features of displacement-time graphs

Feature	Quantity	How to find
Individual point	Displacement at a particular time	Draw dotted line from a point to each axis and read off values
Area under the graph	×	×
Gradient between two points	Average velocity	$v_{avg} = gradient = \frac{s_2 - s_1}{t_2 - t_1} = \frac{\Delta s}{\Delta t}$

MISCONCEPTION

'Instantaneous and average values are the same.'

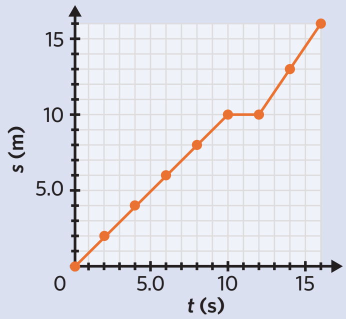
An instantaneous quantity is the value of a variable at a single point in time, for example the speedometer of a car. Average values require a calculation over a particular time, for example the total distance travelled by the car divided by the total time the journey took, and cannot be inferred at a single point in time.

A journey may be represented using a distance-time graph. If this is the case, then:

- an individual point will represent the object's distance travelled at a particular time,
- the gradient between two adjacent points will represent the magnitude of the velocity over that interval.

WORKED EXAMPLE 1

The displacement of a mini golf ball from the tee during a hole produces the following displacement-time graph.



a. What is the displacement of the golf ball after 10 seconds?

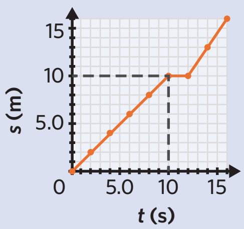
Step 1

Identify the type of graph, and its relationship to displacement.

The displacement can be determined by the value of the graph at a particular point.

Step 2

Identify the point on the graph when time is 10 seconds, and draw a dotted line to the vertical axis to read displacement.



At $t = 10$ s, $s = 10$ m in the positive direction.

Continues →

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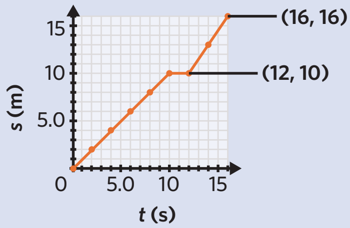
b. What is the average velocity of the golf ball between $t = 12$ s and $t = 16$ s?

Step 1

Identify the type of graph, and its relationship to average velocity.

A displacement-time graph's gradient is the average velocity.

$$v_{avg} = gradient = \frac{s_2 - s_1}{t_2 - t_1}$$



Step 2

Identify two points on the graph, and calculate the gradient of the line of best fit.

$$v_{avg} = \frac{s_2 - s_1}{t_2 - t_1} = \frac{16 - 10}{16 - 12} = 1.50 = 1.5 \text{ m s}^{-1}$$

in the positive direction

Progress questions

Question 1

In which of the following scenarios would the instantaneous and average velocities be the same at all times?

A. a train going at a constant speed in a straight line

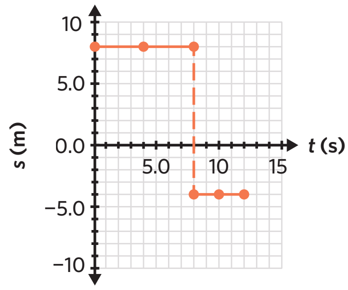
B. a car going at a constant speed around a corner

C. a person running a 100 m race from rest

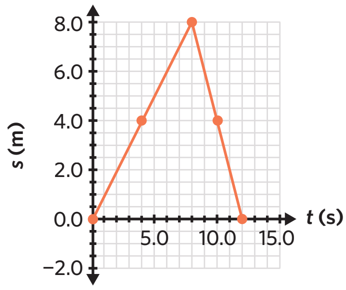
Question 2

A person walks at a constant velocity in the positive direction for 8 s, before turning around and running back to their original position at twice this speed. Which of the following displacement-time graphs may be produced from their motion? Assume the change in velocity at 8 s was instantaneous.

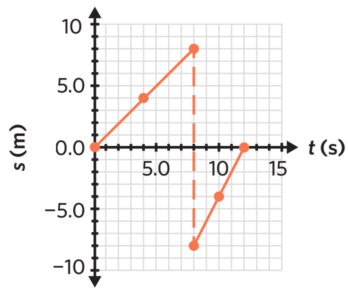
A.



B.



C.



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Velocity-time graphs 2.1.2.4 & 2.1.3.2

Velocity-time graphs represent the velocity of an object over a particular time interval.

Theory and applications

The horizontal axis in velocity-time graphs represents the time, usually in seconds, and the vertical axis represents velocity, usually in m s^{-1}. Recall from Lesson 8A, velocity is a vector quantity with both magnitude and direction.

How do we analyse velocity-time graphs?

A velocity-time graph is produced when we plot the instantaneous velocities of an object at each instant over a given time interval. For an object travelling at a constant velocity (when $a = 0$ m s^{-2}) this graph will be a horizontal line, as shown in Figure 3, as its velocity is not changing.

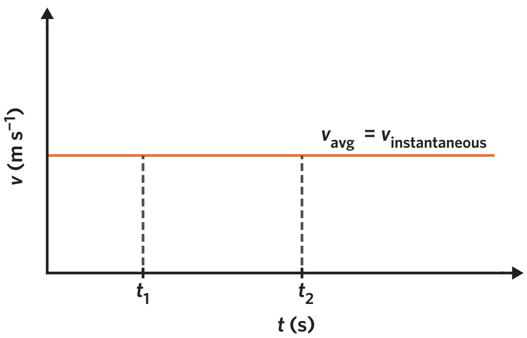

Figure 3 The velocity-time graph of an object travelling at a constant velocity.

The area under a velocity-time graph between two time values is equal to the change in displacement over that interval. The green area under the graph in Figure 4 is a rectangle with an area given by $l \times w = v \times \Delta t$. Comparing this to the equation for calculating velocity, $v = \frac{\Delta s}{\Delta t}$ rearranged to form $\Delta s = v \times \Delta t$, we can see that the area is equal to the change in displacement.

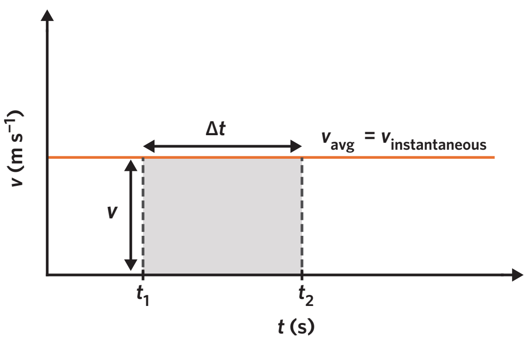

Figure 4 The area under a velocity-time graph gives the change in displacement.

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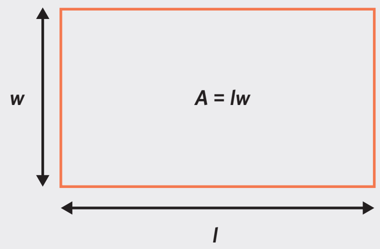
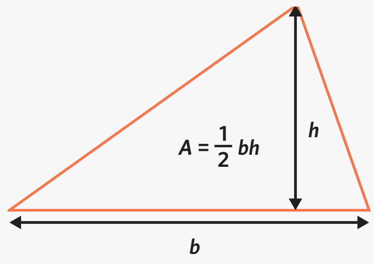
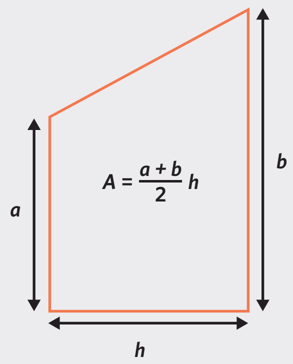
USEFUL TIP

Finding the area underneath a graph (between the graph and the *x*-axis) is an important skill in calculating many quantities in VCE Physics, including displacement from a velocity time graph. Table 2 summarises geometric methods of calculating the area under a graph.

Table 2 Finding the area of geometric shapes

Shape	Example	Formula
Rectangle		$A = l \times w$
Triangle		$A = \frac{1}{2} \times b \times h$
Trapezium		$A = \frac{(a+b)}{2} \times h$

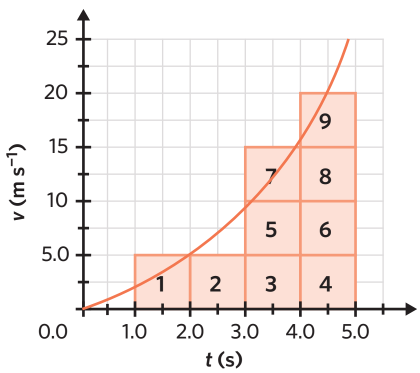


Figure 5 Counting the squares beneath a non-linear graph

STRATEGY

When the area under a non-linear graph is required, counting squares can be used to estimate the total area (see Figure 5):

1. Count the number of whole squares under the line.
2. For all remaining squares, use the following rule:
   - If exactly or more than 50% of a square is under the line, include the whole square (squares 1 and 7).
   - If less than 50% of a square is under the line, exclude the whole square.
3. Calculate the area of one square.
   - Here, each square has dimensions of $5.0 \text{ m s}^{-1} \times 1 \text{ s} = 5.0 \text{ m}$.
4. Multiply the total number of squares by the area of one square.
   - $\Delta s = 9 \times 5.0 = 45 \text{ m}$

For an object travelling with constant, non-zero acceleration, its velocity-time graph will be linear. In Figure 6, the gradient between the points (t_1, v_1) and (t_2, v_2) is given by $\frac{v_2 - v_1}{t_2 - t_1} = \frac{\Delta v}{\Delta t}$. This expression is equal to the formula for average acceleration, $a_{avg} = \frac{\Delta v}{\Delta t}$. As the acceleration is constant, the graph must be a straight line since the gradient must be equal between any two points.[1]

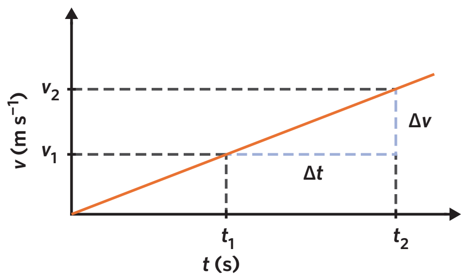


Figure 6 The gradient of a velocity-time graph is equal to the average acceleration.

Since displacement is a vector, and therefore can have a positive or negative sign, to calculate the change in displacement, we add the area above the horizontal axis and subtract the area below it (in Figure 7, $A_1 - A_2$). We refer to this as the signed area beneath the graph, as it accounts for whether the area is above or below the x-axis. As distance is a scalar quantity and therefore can only be positive, it will be equal to the sum of the areas (in Figure 7, $A_1 + A_2$).

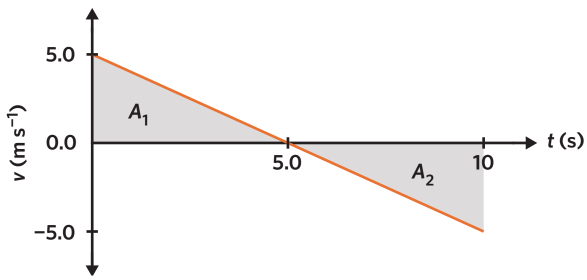


Figure 7 The change in displacement is equal to the area above the horizontal axis minus the area below the horizontal axis.

Consider a 400 metre race, where the runner will finish at the same point they started. The signed area under the corresponding velocity-time graph (the displacement) would be 0 m, but the total area underneath the graph (the distance travelled) would be 400 m. The features of a velocity-time graph and their meaning are summarised in Table 3.

Table 3 Features of velocity-time graphs

Feature	Quantity	How to find
Individual point	Velocity, at a particular time	Draw a dotted line from the point to each axis and read off values
Signed area under the graph	Displacement	Geometric methods (see Table 2) or counting squares
Total area under the graph	Distance travelled	Geometric methods (see Table 2) or counting squares
Gradient between two points	Average acceleration	$a_{avg} = gradient = \frac{v_2 - v_1}{t_2 - t_1} = \frac{\Delta v}{\Delta t}$

A speed-time graph may also be given, which has the same features as a velocity-time graph, but their equivalent scalar quantities:

- an individual point will represent the object's speed at that particular time,
- the total area underneath the graph will represent the distance travelled,
- the gradient between two points will be the magnitude of the average acceleration over that interval.

KEEN TO INVESTIGATE?

1 **What does the slope of a velocity-time graph represent?**
Search: Velocity vs time graphs

USEFUL TIP

The gradient of a linear velocity-time graph is equal to both the average acceleration and the instantaneous acceleration, the rate at which the velocity is changing at a single moment of time, as the acceleration is constant.

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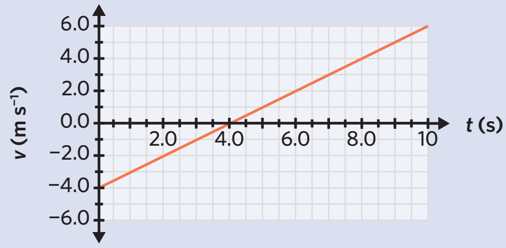
WORKED EXAMPLE 2

A soccer player during a match produces the following velocity-time graph for a given 10 second interval:



a. What is the magnitude of their average acceleration?

Step 1

Identify the type of graph, and its relationship to average acceleration.

A velocity-time graph's gradient is the average acceleration.

$a_{avg} = gradient = \frac{v_2 - v_1}{t_2 - t_1}$

Step 2

Identify two points on the graph, and calculate the average acceleration between those points.

$a_{avg} = \frac{v_2 - v_1}{t_2 - t_1} = \frac{6.0 - 0.0}{10 - 4.0} = 1.0 \text{ m s}^{-2}$

b. What is their change in displacement over the 10 seconds?

Step 1

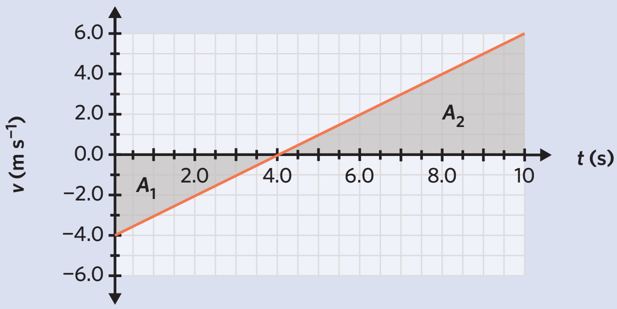
Identify the type of graph, and its relationship to change in displacement.

The signed area under a velocity time graph is the change in displacement.

$\Delta s = signed\ area\ under\ graph$

Step 2

Break the total area into two components, and calculate the area of each.



$\Delta s = (-A_1) + A_2 = \left(-\frac{1}{2} \times b_1 \times h_1\right) + \frac{1}{2} \times b_2 \times h_2$

Step 3

Substitute relevant values from the graph and solve for change in displacement.

$\Delta s = \left(-\frac{1}{2} \times 4.0 \times 4.0\right) + \left(\frac{1}{2} \times (10 - 4.0) \times 6.0\right) = 10 \text{ m}$

Change in displacement is 10 m in the positive direction.

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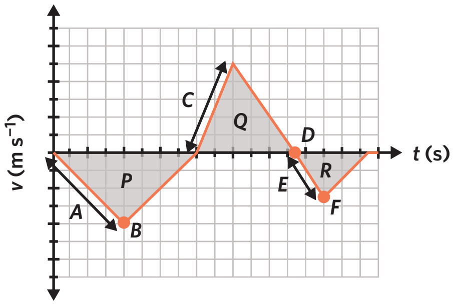
Progress questions

Use the following velocity-time graph to answer questions 3–4.



Question 3

Which of the following expressions involving the areas P, Q and R gives the correct value for the change in displacement over the entire time of motion?

A. $P - Q + R$

B. $Q - P - R$

C. $P + Q + R$

Question 4

Which of the following expressions involving the areas P, Q and R gives the correct value for the distance travelled over the entire time of motion?

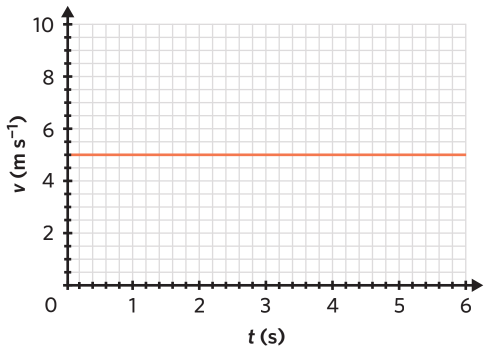
A. $Q - P + R$

B. $P + Q + R$

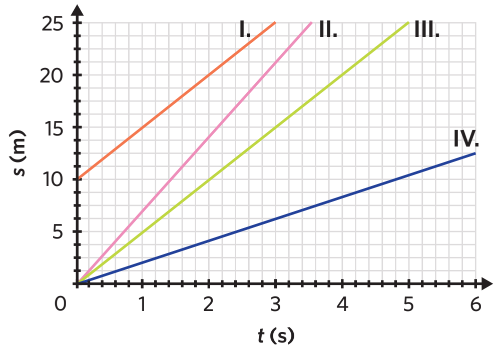
C. $Q - P - R$

Question 5

Consider the velocity-time graph shown below.

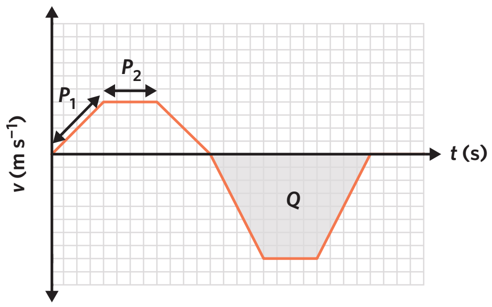


To which of the following lines on the displacement-time graph could this correspond? **(Select all that apply)**



Question 6

Consider the following velocity-time graph.



Which of the following statements are true for the velocity-time graph? **(Select all that apply)**

I. The instantaneous velocities over P_1 are all equal to the average velocity over that interval.

II. The instantaneous velocities over P_2 are all equal to the average velocity over that interval.

III. The magnitude of the shaded area Q represents the distance travelled over that time interval.

IV. The object is furthest away from its starting location over P_2.

Acceleration-time graphs 2.1.2.5

Acceleration-time graphs represent the acceleration of an object over a particular time interval.

Theory and applications

The horizontal axis in an acceleration-time graph represents the time, usually in seconds, and the vertical axis represents acceleration, usually in m s^{-2}. Note, acceleration is a vector quantity, with both magnitude and direction.

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8B THEORY

KEEN TO INVESTIGATE?

[2] **Why are acceleration-time graphs useful?**
Search: Acceleration vs time graphs

How do we analyse acceleration-time graphs?

If we consider the value of the instantaneous acceleration at every point in time, we can construct an acceleration-time graph, with the acceleration on the vertical axis and the time on the horizontal axis. For an object with constant acceleration, the acceleration-time graph will be a horizontal line as shown in Figure 8.[2]

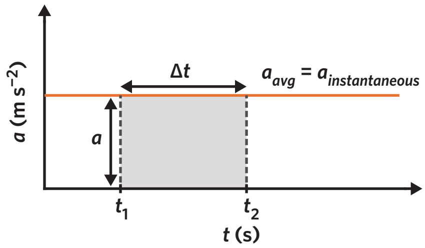

Figure 8 The area under an acceleration-time graph is equal to the change in velocity.

The key features of this graph to note are that:

- The gradient of the graph is zero, indicating constant acceleration.
- The average acceleration is equal to the instantaneous acceleration.
  - Both of these values are equal to the gradient of the object's velocity-time graph.
- The area under the line between t_1 and t_2 is equal to the change in velocity over that time interval.
  - The area is equal to $height \times width = a \times \Delta t = \Delta v$ which can be derived by rearranging the formula used to define acceleration, $a = \frac{\Delta v}{\Delta t}$.

Up to this point, we have only considered graphs of horizontal motion. However, we can also use them to model vertical motion. In Lesson 9A, we will see that all objects in free fall are subject to a constant acceleration due to gravity, g, which has a value of 9.8 m s^{-2} downwards close to the surface of the Earth. The features of an acceleration-time graph and their meaning are summarised in Table 4.

USEFUL TIP

Since average acceleration is equal to the gradient of the velocity-time graph, this means that the gradients of all velocity-time graphs for objects in free fall are equal to −9.8 (if the positive direction is taken as up), the acceleration due to gravity. Note that this assumes the graph is given in SI units of s and m s^{-1}.

Table 4 Features of acceleration-time graphs

Feature	Quantity	How to find
Individual point	Acceleration at a particular time	Draw a dotted line from the point to each axis and read off
Area under the graph	Change in velocity	Geometric methods (see Table 2) or counting squares
Gradient between two points	×	×

Progress questions

Question 7

Fill in the gaps in the following paragraph to describe the relationship between motion graphs:

The gradients of a velocity-time graph and a displacement-time are equal to the average __________ (velocity/acceleration/speed) and __________ (displacement/velocity/change in time) respectively. A negative acceleration __________ (has to/does not have to) correspond to a negative velocity on a velocity-time graph.

Continues →

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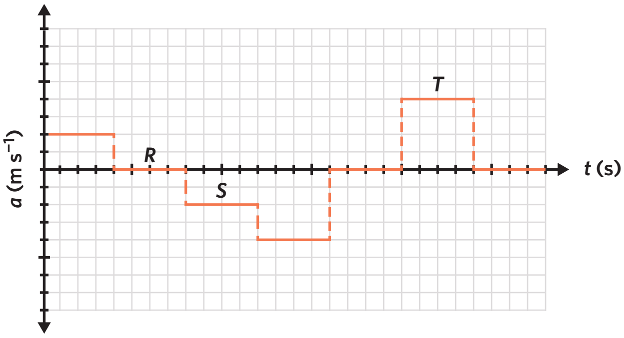
Question 8

Consider the following acceleration-time graph.



Which of the following statements are true for the acceleration-time graph? **(Select all that apply)**

I. The acceleration for interval *R* being equal to zero does not mean that the velocity at this moment must also be zero.

II. The acceleration at point *S* is negative, which means that the object is travelling backwards/in the negative direction.

III. The acceleration along interval *T* is positive, which means that the object will begin moving faster.

Theory summary

- It is important to distinguish between instantaneous and average measures of motion:
  - instantaneous velocity is equal to average velocity only if the acceleration is zero,
  - instantaneous acceleration is equal to average acceleration only if the acceleration is constant.

	Displacement-time graph	Velocity-time graph	Acceleration-time graph
Individual point	Displacement at a particular time	Velocity at a particular time	Acceleration at a particular time
Area under graph	✕	Distance travelled (total area) or displacement (signed area)	Change in velocity
Gradient of graph between two points	Average velocity	Average acceleration	✕

CONCEPT DISCUSSION

When an object falls from a great height on Earth, the magnitude of its downward acceleration is approximately equal to 9.8 m s^{-2}. However, repeated collisions with air molecules (commonly known as air resistance) as it falls will reduce the object's acceleration until it reaches 0 m s^{-2}. This is why there is a limit to the velocity at which objects can fall on Earth, otherwise known as terminal velocity.

Using this information, discuss what the acceleration-time graph and velocity-time graph of a basketball would look like if it were dropped from the top of a tall building and accelerated towards its terminal velocity.

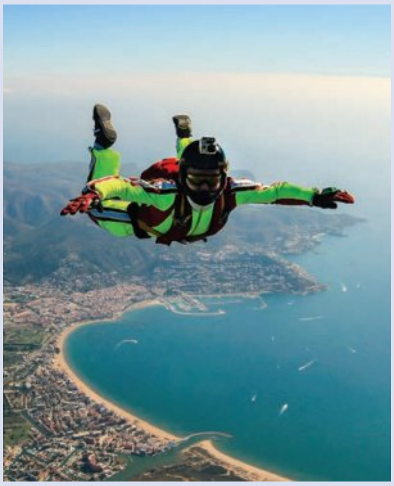


Image: ViktorKozlov/Shutterstock.com

Prompts:

- Is there a difference in the change in velocity during the initial few seconds of falling and the change in velocity near terminal velocity? How might we represent this on the velocity-time graph?
- If the velocity of an object is approaching a limit, what does this tell us about the magnitude of the acceleration at this limit?
- What is the relationship between the acceleration-time graph and the velocity-time graph?

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8B Questions

Mild Medium Spicy

Deconstructed exam-style

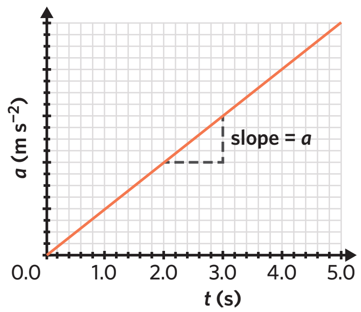
Use the following information to answer questions 9–13.

An F1 driver in the Australian Grand Prix starts the race from rest and accelerates along a straight section of the track at a constant rate of acceleration, a m s^{-2}.

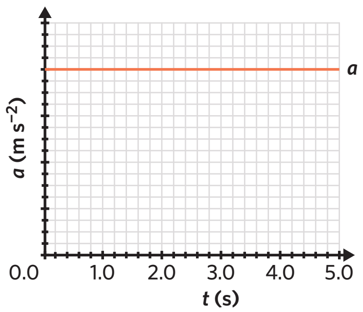
Question 9 (1 MARK)

Which of the following gives the acceleration-time graph over the first 5 seconds?

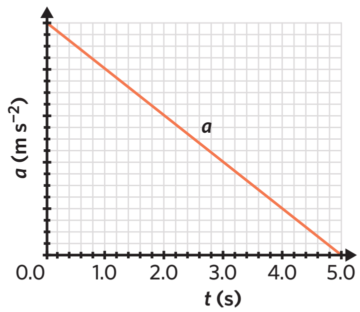
A.



B.



C.



Question 10 (1 MARK)

Which of the following expressions correctly calculates the change in velocity of the car over the first 5 seconds, in terms of a?

A. $\Delta v = \frac{1}{2} \times 5 \times a$

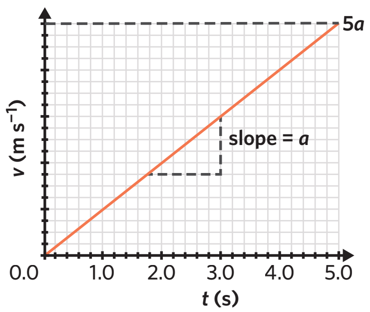
B. $\Delta v = \frac{1}{2} \times a^2$

C. $\Delta v = 5a$

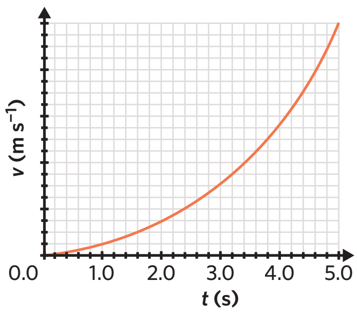
Question 11 (1 MARK)

Which of the following graphs correctly shows the velocity-time graph of the car?

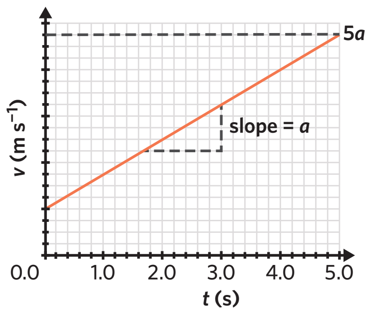
A.



B.



C.



Question 12 (1 MARK)

What is the displacement of the car in terms of a over the 5 seconds?

A. $\Delta s = 5a \times \Delta t = 25a$

B. $\Delta s = \frac{1}{2} \times 5a \times 5 = 12.5a$

C. $\Delta s = \frac{1}{2} \times (v_f + 5a) \times 5$

D. The displacement-time graph is parabolic, so we could only approximate the change in displacement.

Question 13 (4 MARKS)

Calculate the value of a so that the F1 driver covers the first 150 metres of the race in 5 seconds.

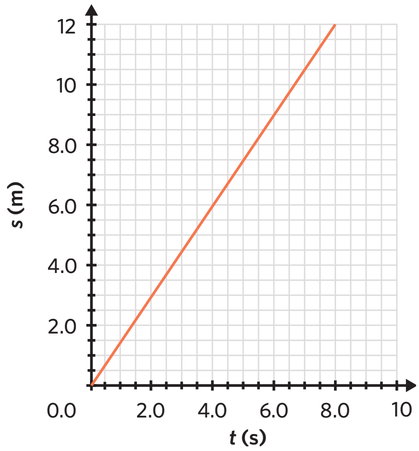
Exam-style

Question 14 (2 MARKS)

Consider the following displacement-time graph.

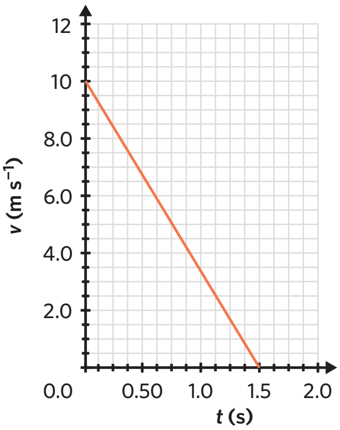
a. Calculate the magnitude of the average velocity. (1 MARK)

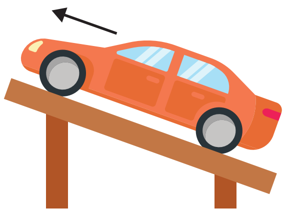
b. What is the magnitude of the instantaneous velocity at $t = 4.0$ s? (1 MARK)



Question 15 (3 MARKS)

Rachel's physics class is analysing the motion of model cars rolling up a ramp. The velocity-time graph of her car along the ramp is shown below:





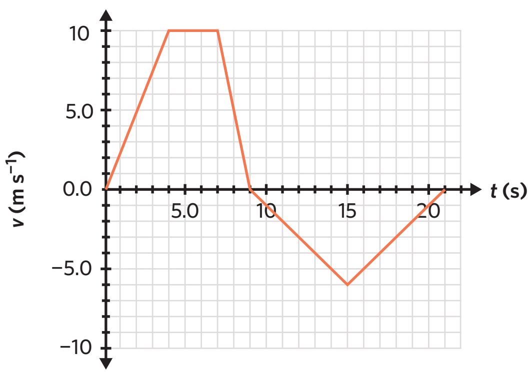
a. What is the magnitude of the car's acceleration? (1 MARK)

b. What is the change of the displacement of the car before it comes to a stop and starts to roll back down the ramp? (2 MARKS)

Question 16 (2 MARKS)

Kate is doing some warm-up runs along a straight track before her race. She sprints out, turns around, and then jogs back. Her velocity-time graph for one of these warm-up sprints is shown below.

By calculating her change in displacement, determine how far away Kate finishes from where she started.



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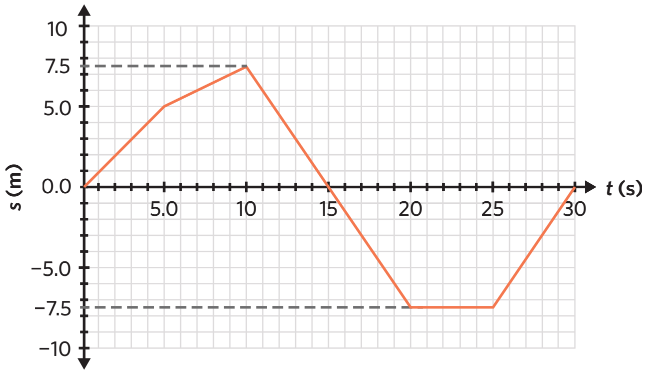
Question 17 (3 MARKS)

Dumbledore spends most of his days strolling back and forth in his office. Given his old age and his 'excitable' nature, his movement is fairly irregular and his displacement-time graph for a period of his day looks like this.

a. Calculate the magnitude of his average velocity from $t = 0.0$ to $t = 10$ seconds. (1 MARK)

b. Calculate the magnitude of his average velocity from $t = 0.0$ to $t = 30$ seconds. (1 MARK)

c. Calculate his average speed from $t = 0.0$ to $t = 30$ seconds. (1 MARK)

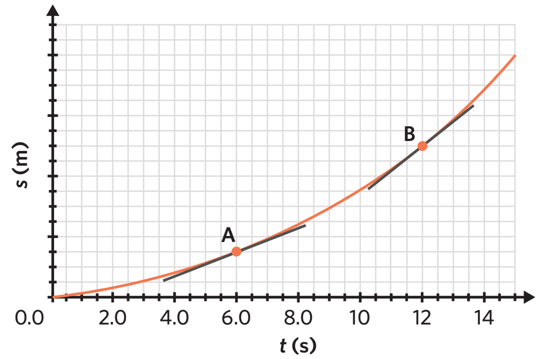


Question 18 (4 MARKS)

Tanya gets a new pair of rollerblades for Christmas and decides to roll down a steep hill. Her displacement-time graph can be modelled by the following parabola. Assume the acceleration is constant and she starts from rest.

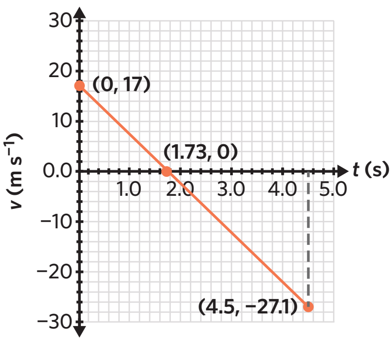
a. The slope of the curve (instantaneous velocity) at A ($t = 6.0$ s) is equal to 4.5 and at B ($t = 12$ s) is equal to 9.0. Use this information to sketch her velocity-time graph. (3 MARKS)

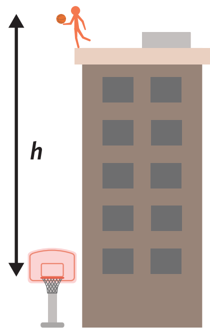
b. Hence calculate the magnitude of her change in displacement from point A to point B. (1 MARK)



Question 19 (2 MARKS)

Stevie is trying to make a basketball trick shot by shooting a ball upwards off the top of a tall tower. Use the velocity-time graph to calculate the height, *h*, from where the ball is released to the hoop below. Assume that air resistance was observed to be negligible and that the ball lands in the hoop 4.5 s after it was released. Take up to be positive.

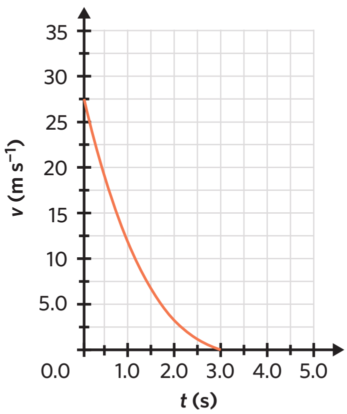




Question 20 (3 MARKS)

A car company is testing how well their new car can brake by having it decelerate from a high speed to stationary. Once the brakes are applied, the car needs to be able to stop over a maximum distance of 35 metres. The velocity-time graph of the car from its test is shown below.

By approximating the area under the curve, determine whether or not the car passed the test.



Question 21 (6 MARKS)

Joaquin is having a bike race with his friend Tony, and decides to give him a head start. Tony rides away at a constant velocity of 12.5 m s^{-1}. After 4.0 seconds, Joaquin begins to ride after him. He accelerates for 5.0 seconds at 3.0 m s^{-2}, before continuing on at a constant speed.

a. Draw the velocity-time graphs for both Joaquin and Tony on the one axis, across the first 14 seconds. (3 MARKS)

b. Use the graphs to calculate how long it takes before Joaquin catches up to Tony. (3 MARKS)

Question 22 (5 MARKS)

Lottie is trying to figure out how high she can throw a ball in the air. She throws the ball with an initial velocity of 14.0 m s^{-1}. Take acceleration due to gravity, g, to be −9.8 m s^{-2} and assume that the effects of air resistance are negligible.

a. Sketch a velocity-time graph to model Lottie's throw, until the ball reaches its maximum height. (3 MARKS)

b. Use the graph to calculate the maximum height of her throw. (2 MARKS)

Key science skills

Question 23 (4 MARKS)

Juzzy is using a speed-gun to calculate the acceleration of a car that is driving directly towards him. He records the following measurements:

Velocity (m s^{-1})	5.4	8.3	12.0	17.1	22.2
Time (s)	1.4	2.3	3.5	4.6	5.9

There is an uncertainty in the speed-gun of ± 1.5 m s^{-1}. Use the data points to plot a graph of velocity against time. Include a line of best fit.

FROM LESSON 11D

Previous lessons

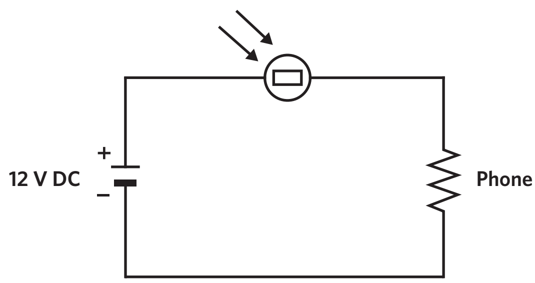
Question 24 (1 MARK)

What does the half-life of a radioactive sample represent?

FROM LESSON 4B

Question 25 (4 MARKS)

A young electrical engineer, Matt Amatix, is attempting to create a circuit that automatically charges his phone when the sunlight entering his room is at a certain intensity. He constructs a circuit with a light dependent resistor as shown in the diagram. The phone charges correctly when there is a voltage drop of exactly 5.0 V across it. The phone has a resistance of 4.0 Ω. The DC power supply provides 12 V.



a. What is the current flowing through the circuit when the charger operates correctly? (1 MARK)

b. Determine the resistance of the light dependent resistor for the phone charger to correctly operate. (3 MARKS)

FROM LESSON 7B

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8C The constant acceleration equations

Image: Bordovski Yauheni/Shutterstock.com

STUDY DESIGN DOT POINT

- analyse graphically, numerically and algebraically, straight-line motion under constant acceleration: $v = u + at$, $v^2 = u^2 + 2as$, $s = \frac{1}{2}(u + v)t$, $s = ut + \frac{1}{2}at^2$, $s = vt - \frac{1}{2}at^2$

8A 8B 8C

2.1.2.6 Constant acceleration equations

ESSENTIAL PRIOR KNOWLEDGE

8A Scalars and vectors
8A Acceleration
8B Velocity-time graphs
See questions 65–67.

ACTIVITIES

Log into your Edrolo account for activities that support this lesson.

What will the velocity of the car be when it reaches the end of the straight?

In the previous lesson, we learned how to analyse motion using graphs. However, motion can also be described by a series of equations. In this lesson we will derive and apply the constant acceleration equations, and investigate how they help us describe and predict motion.

KEY TERMS AND DEFINITIONS

constant acceleration acceleration that is constant in both magnitude and direction

FORMULAS

- **the constant acceleration equations**

$v = u + at$

$v^2 = u^2 + 2as$

$s = \frac{1}{2}(u + v)t$

$s = ut + \frac{1}{2}at^2$

$s = vt - \frac{1}{2}at^2$

- **speed**

$speed = \frac{distance}{time}$

- **average velocity**

$v_{avg} = \frac{\Delta s}{\Delta t}$

- **average acceleration**

$a_{avg} = \frac{\Delta v}{\Delta t}$

Constant acceleration equations 2.1.2.6

The five constant acceleration equations describe the motion of an object in terms of time, displacement, initial and final velocities, and acceleration. They can be used for both horizontal and vertical motion.

Theory and applications

The constant acceleration equations are a set of equations that allow us to mathematically describe motion, and relate to the linear shape of velocity-time graphs under constant acceleration.

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The equations will be expressed in terms of the following variables:

- s (m) – displacement from initial position (the change in position of an object)
- t (s) – the duration of acceleration (the difference between t_2 and t_1)
- a (m s^{-2}) – acceleration (the rate of change of velocity $a_{avg} = \frac{\Delta v}{\Delta t}$)
- u (m s^{-1}) – initial velocity (the velocity of the object at t_1)
- v (m s^{-1}) – final velocity (the velocity of the object at t_2)

USEFUL TIP

- t explicitly represents Δt, a change in time $t_2 - t_1$, however in VCE Physics it is generally written in its abbreviated form for clarity and conciseness.
- Many questions will explicitly state objects beginning from rest, that is $u = 0$.

Where do the constant acceleration equations come from?

Under constant acceleration, the graph of velocity against time will be linear, shown in Figure 1. The gradient of the line is given by $\frac{\Delta v}{\Delta t} = a$. Since $\Delta v = v - u$, we can rewrite this equation as $\frac{v - u}{\Delta t} = a$. Rearranging this to make v the subject will result in the first constant acceleration equation:[1]

$$v = u + at$$

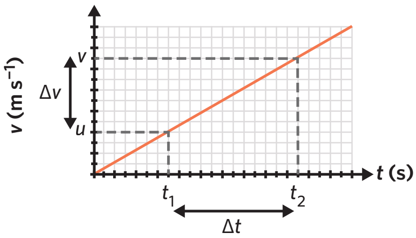

Figure 1 A velocity-time graph showing a change in velocity over a change in time

KEEN TO INVESTIGATE?

[1] **Does velocity keep increasing during free fall?**
Search YouTube: Free fall and terminal velocity

The second equation comes from calculating the area under this graph. From Lesson 8B, we know that the area from t_1 seconds to t_2 seconds is equal to the displacement of the object over that time period. The area in Figure 2 is given by the area of a trapezium, $A = \frac{1}{2}(a + b)h$, leading to the second constant acceleration equation:

$$s = \frac{1}{2}(u + v)t$$

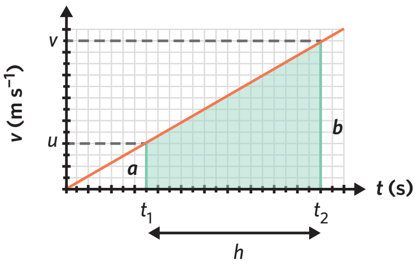

Figure 2 The green area is equal to the displacement, s.

The area under the graph can also be represented as the sum of a rectangle and a triangle, as shown in Figure 3. The total area or displacement is equal to the sum of A_1 and A_2.

- A_1 is a rectangle with $Area = length \times width = u(t_2 - t_1) = ut$
- A_2 is a triangle with $Area = \frac{1}{2} \times base \times height = \frac{1}{2} \times (t_2 - t_1) \times (v - u)$
  - Recall from the first constant acceleration equation that $(v - u) = at$
    $\Rightarrow A_2 = \frac{1}{2} \times t \times at = \frac{1}{2}at^2$

Therefore the displacement, s, will be given by the third constant acceleration equation:

$$s = ut + \frac{1}{2}at^2$$

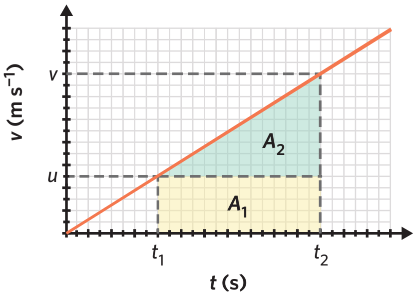

Figure 3 The area from Figure 2 can be split into a rectangle (A_1) and a triangle (A_2).

The same area we wish to calculate can also be expressed as the area of a large rectangle minus a smaller triangle.

- In Figure 4, the pink triangle has an area equal to A_2 from Figure 3, of $\frac{1}{2}at^2$,
- by subtracting this from the total area of the box $v \times t$, we obtain the green area found in Figure 2.

Therefore the displacement, s, will be given by the fourth constant acceleration equation:

$$s = vt - \frac{1}{2}at^2$$

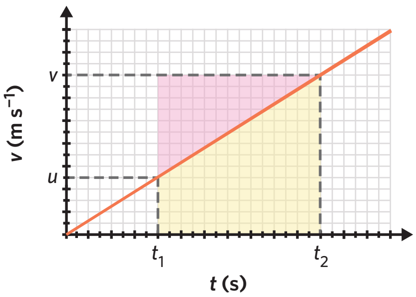

Figure 4 The displacement is the total area of the rectangle, vt, minus the pink area.

We can use these equations to derive the final constant equation.

- If $v = u + at$, then by squaring both sides of this equation we get $v^2 = (u + at)^2 = u^2 + 2uat + a^2t^2$.
- Then, by factoring $2a$ out from the last two terms on the right-hand side, we arrive at $v^2 = u^2 + 2a\left(ut + \frac{1}{2}at^2\right)$.
- Recognise that the expression in the brackets is equal to the right-hand side of the third constant acceleration equation, $s = ut + \frac{1}{2}at^2$.

STRATEGY

If the acceleration of an object is 0, as $u = v$, either $s = ut$ or $s = vt$ can be used to relate the remaining variables.

USEFUL TIP

Objects near the surface of the Earth accelerate downwards because of the force due to gravity. For vertical motion in VCE Physics, acceleration is given by $g = 9.8\ \text{m s}^{-2}$ downwards (or $-9.8\ \text{m s}^{-2}$ when upwards is defined as positive), unless otherwise specified.

By way of substitution, this leaves us with the final constant acceleration equation:

$$v^2 = u^2 + 2as$$

Progress questions

Question 1

Which of the following lists contains only correct constant acceleration equations?

A. $u^2 = v^2 + 2as, s = \frac{\Delta v}{\Delta t}, s = ut + \frac{1}{2}ta^2$

B. $v = u + at, s = ut - \frac{1}{2}at^2, v = usa^2 + t$

C. $s = \frac{1}{2}(u + v)t, v^2 = u^2 + 2as, s = ut + \frac{1}{2}at^2$

D. $s = u + at, s = \frac{1}{2}(u + v)t, t = va + us^2$

Question 2

In which of the following situations is constant acceleration present? Ignore the effects of air resistance.

A. A trolley is pushed with a varying force.

B. A ball is thrown in the air.

C. A skier going down a mountain occasionally applies extra force with their poles.

How do we use the constant acceleration equations?

STRATEGY

There are five variables we can be asked to calculate in motion problems:

- Each constant acceleration equation contains four of the five variables, with one missing.
- If we are given three variables and wish to find a fourth, there will be one appropriate equation we can use.
- Table 1 indicates the missing variable in each constant acceleration equation, and can be used to identify the relevant equation for a particular scenario:

Table 1 Missing variable in each constant acceleration equation

Constant acceleration equation	Missing variable
$v = u + at$	s
$s = ut + \frac{1}{2}at^2$	v
$s = vt - \frac{1}{2}at^2$	u
$v^2 = u^2 + 2as$	t
$s = \frac{1}{2}(v + u)t$	a

This process of selecting the appropriate equation for a particular scenario is shown in Figure 5.

- Example 1 – "A train leaves a station and accelerates at $5\ \text{m s}^{-2}$. How long does it take for the train to reach a speed of $100\ \text{m s}^{-1}$ given that it starts from rest?"
- Example 2 – "A ball is thrown upwards with an initial velocity, such that it takes 5 seconds for the ball to return to the point it started at. Calculate this initial velocity."

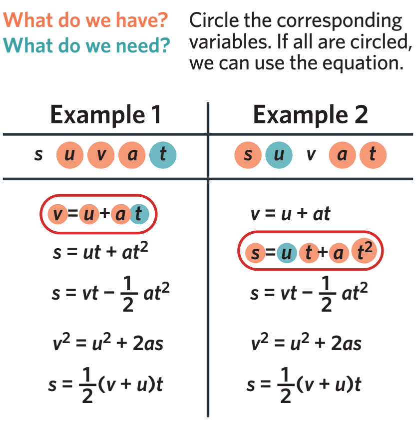

Figure 5 Two examples of finding the appropriate constant acceleration equation

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Remember that since displacement, velocity and acceleration are all vector quantities:

- they will all need to be acting in the same dimension, that is, either all of them vertically or all of them horizontally,
- a positive direction must be defined at the beginning of the question.

USEFUL TIP

In general, we define vectors pointing upwards or to the right to be positive, and vectors pointing downwards or to the left to be negative. However, it may be helpful in particular situations to do the opposite to make calculations more convenient by avoiding negative values. The most important thing is to be consistent with the choice.

WORKED EXAMPLE 1

A car, starting from a stationary position, accelerates up to a speed of 30.0 m s^{-1} over a period of 10.0 seconds. How far does it travel from its starting position during this time?

Step 1

Identify the relevant variables, and the appropriate constant acceleration equation relating these variables.

$u = 0$ m s^{-1}, $v = 30.0$ m s^{-1}, $t = 10.0$ s, $s = ?$

s u v a t

$v = u + at$

$s = ut + at^2$

$s = vt - \frac{1}{2}at^2$

$v^2 = u^2 + 2as$

$s = \frac{1}{2}(v + u)t$

$$s = \frac{1}{2}(v + u)t$$

Step 2

Substitute variables into the relevant constant acceleration equation and solve for displacement.

$$s = \frac{1}{2}(0 + 30.0) \times 10.0 = 150 \text{ m}$$

The car travelled 150 m from its starting position during this time.

WORKED EXAMPLE 2

A ball is thrown straight up in the air at an initial speed of 24.5 m s^{-1}. Use this information to calculate the maximum height of the ball. Take upwards as positive.

Step 1

Identify the relevant variables, and the appropriate constant acceleration equation relating these variables.

At its maximum height, the velocity is zero.

$u = 24.5$ m s^{-1}, $v = 0$ m s^{-1}, $a = -9.8$ m s^{-2}, $s = ?$

s u v a t

$v = u + at$

$s = ut + at^2$

$s = vt - \frac{1}{2}at^2$

$v^2 = u^2 + 2as$

$s = \frac{1}{2}(v + u)t$

$$v^2 = u^2 + 2as$$

Continues →

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Step 2

Substitute variables into the relevant constant acceleration equation and solve for displacement.

$0^2 = 24.5^2 + 2 \times (-9.8) \times s$

$s = \frac{0^2 - 24.5^2}{2 \times (-9.8)} = 30.6 = 31$ m

The ball reached a maximum height of 31 m above its starting point.

The constant acceleration equations can also be used to compare the motion of multiple objects over the same period. The time values used in both calculations must be the same.

WORKED EXAMPLE 3

Car A drives past a stationary Car B at 15 m s^{-1}. Car B instantly begins to accelerate at 5.0 m s^{-2}. Calculate how long it takes Car B to catch up to Car A.

Step 1

Identify the relevant variables for Car A, and the equation relating these variables.

As acceleration is 0, $s = ut$ or $s = vt$ can be used

$u_A = v_A = 15.0$ m s^{-1}, $t = ?$, $s_A = ?$

$s_A = u_A t$ or $s_A = v_A t$

Step 2

Substitute variables into the identified constant equation and solve for displacement.

$s_A = 15t$ m

Step 3

Identify the relevant variables for Car B, and the equation relating these variables.

$u_B = 0.0$ m s^{-1}, $a_B = 5.0$ m s^{-2}, $s_B = ?$

$s_B = u_B t + \frac{1}{2} a_B t^2$

Step 4

Substitute variables into the identified equation and solve for displacement.

$s_B = 0.0 \times t + \frac{1}{2} \times 5.0 \times t^2 = 2.5t^2$ m

Step 5

Equate the two displacements, and solve for time for Car B to catch Car A.

$s_A = s_B$

$15t = 2.5t^2 \Rightarrow 15 = 2.5t$

$t = \frac{15}{2.5} = 6.0$ s

It takes Car B 6.0 seconds to catch up to Car A.

USEFUL TIP

When using the constant acceleration equations which involve t^2 to find time, we may encounter a quadratic equation to solve. To avoid this, try using $v^2 = u^2 + 2as$ and then $v = u + at$ to solve for t instead. See the deconstructed exam-style question for an example.

Progress questions

Use the following information to answer questions 3–5.

A car takes 100 metres to decelerate from 25 m s^{-1} to a complete stop.

Question 3

Which of the following describes all of the known variables in this situation?

A. $s = 100$ m, $u = 25$ m s^{-1}

B. $s = 100$ m, $u = 25$ m s^{-1}, $v = 0$ m s^{-1}

C. $s = 100$ m, $v = 25$ m s^{-1}

D. $s = 100$ m, $v = 25$ m s^{-1}, $u = 0$ m s^{-1}

Continues →

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Question 4

Which of the following constant acceleration equations is applicable to find the acceleration of the car?

A. $v^2 = u^2 + 2as$

B. $s = vt - \frac{1}{2}at^2$

C. $s = \frac{1}{2}(u + v)t$

D. $v = u + at$

Question 5

Which of the following constant acceleration equations is best suited to find the time it takes for the car to come to a stop?

A. $v^2 = u^2 + 2as$

B. $s = vt - \frac{1}{2}at^2$

C. $s = \frac{1}{2}(u + v)t$

D. $v = u + at$

Theory summary

Under constant acceleration (including $a = 0$), the motion of an object in one dimension can be described by the constant acceleration equations.

- $s = \frac{1}{2}(u + v)t$
- $v = u + at$
- $s = ut + \frac{1}{2}at^2$
- $s = vt - \frac{1}{2}at^2$
- $v^2 = u^2 + 2as$

- Each equation contains four of the five possible motion variables. To determine which equation to use:
  - identify the variables given in the question,
  - identify the variable we are solving for,
  - find the constant acceleration equation that contains the four variables (and not the fifth variable).
- For vertical motion in VCE Physics, acceleration is given by $g = 9.8 \text{ m s}^{-2}$ downwards, unless otherwise specified.

KEEN TO INVESTIGATE?

Is gravity really constant for all bodies?
Search YouTube: The world's biggest vacuum

CONCEPT DISCUSSION

The Museum of Old and New Art (MONA) contains a water display where water droplets fall in patterns to produce different words. We can model each of the water drops as an object falling with constant acceleration, *g*. Discuss how the appearance of a given word will change as it moves from the top of the display to the bottom.

Prompts:

- What is the relative velocity of a water drop at the top of the word compared to one at the bottom?
- How does the velocity of a water drop change as it falls?
- Under constant acceleration, what is the relationship between displacement and velocity?

Image: Willowtreehouse/Shutterstock.com

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8C Questions

Mild Medium Spicy

Deconstructed exam-style

Use the following information to answer questions 6–11.

Jamieson is competing in his school's 3.0-metre diving competition. For his last dive, he is performing a forward somersault. The duration of the dive must be exactly 1.75 seconds or he will under- or over-rotate before hitting the water. He jumps upwards off the board with a vertical velocity of 6.0 m s^{-1} and takes *t* seconds to land in the pool. Take the upwards direction as positive.

Question 6 (1 MARK)

Which of the following correctly describes the acceleration during the jump?

A. 4.9 m s^{-2}

B. −4.9 m s^{-2}

C. 9.8 m s^{-2}

D. −9.8 m s^{-2}

Question 7 (1 MARK)

Which of the following correctly describes the initial velocity during the jump?

A. 0 m s^{-1}

B. 6.0 m s^{-1}

C. −6.0 m s^{-1}

D. 6.0 m s^{-2}

Question 8 (1 MARK)

Which of the following correctly describes the displacement of the diver as he hits the water?

A. 0 m

B. 3.0 m

C. −3.0 m

D. 6.0 m

Question 9 (1 MARK)

Which of the following constant acceleration equations could correctly calculate the velocity of the diver as they hit the water?

A. $v = u + at$

B. $s = ut + \frac{1}{2}at^2$

C. $s = vt - \frac{1}{2}at^2$

D. $v^2 = u^2 + 2as$

Question 10 (1 MARK)

Knowing the velocity of the diver when they hit the water, which of the following constant acceleration equations would be easiest to use to calculate the duration of the jump?

A. $v = u + at$

B. $s = ut + \frac{1}{2}at^2$

C. $s = vt - \frac{1}{2}at^2$

D. $v^2 = u^2 + 2as$

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Question 11 (4 MARKS)

Determine whether or not Jamieson performs the dive successfully. If not, determine whether he would over- or under-rotate.

Exam-style

Question 12 (2 MARKS)

Patricia, a drag-race enthusiast, is testing her new car down a straight road. Find the magnitude of her change in displacement if she starts from rest and finishes with a velocity of 45 m s^{-1} after 6.0 seconds.

Question 13 (2 MARKS)

A motorcyclist accelerates along a highway at a rate of 2.50 m s^{-2} for 10.0 seconds and finishes with a speed of 24.0 m s^{-1}. Calculate the distance the rider covers in this time.

Question 14 (3 MARKS)

Rico is throwing a ball up and down to herself. She tosses it up with an initial velocity of u m s^{-1}. The ball travels upwards, reaches its peak, and then falls back down again such that after 2.5 seconds, it has a velocity of 11 m s^{-1} downwards. Find u.

Question 15 (4 MARKS)

Pebbles is launching a water bomb attack out the window of her apartment onto a group of her unsuspecting friends 15 metres directly below her. One of the balloons hits her friends at a speed of 18 m s^{-1}. Pebbles claims that she did not throw the balloon out of the window, but instead dropped it after it slipped from her hands.

a. Use the information provided to calculate the magnitude of the initial velocity of the water balloon. (2 MARKS)

b. Hence explain whether or not Pebbles' claim is true (2 MARKS)

Question 16 (3 MARKS)

Santush is trying his hand at lawn bowls. The green is 40 metres in length. For this question, we will assume that the ball decelerates at a constant rate of 0.35 m s^{-2} due to friction from the grass. To win the game, Santush must have the ball stop right at the edge of the green. If the ball is in motion for 18 seconds, determine whether or not he will win the game. Show your working.

Question 17 (7 MARKS)

Mavis has stolen a painting from the nearby art gallery and is fleeing from the security on her motorbike at a constant speed of 54 km h^{-1}. On her way, she travels past a police officer in their car who takes 10 seconds to finish his doughnut and start the car before pursuing. He accelerates at 5.0 m s^{-2} for 4.0 seconds before maintaining a constant speed.

a. Calculate the time it takes for the police officer to catch Mavis. (5 MARKS)

b. Calculate how far away the police car is from his starting position when he catches her. (2 MARKS)

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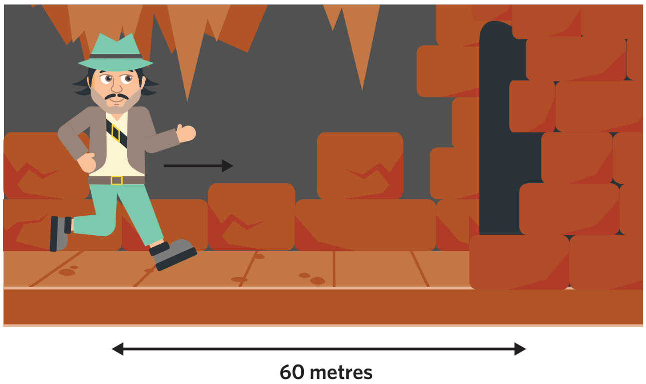
Question 18 (4 MARKS)

Zeviana Jones is in the depths of a Mayan temple searching for a priceless idol. He needs to make it down the 60 metre corridor and through the doorway to the treasure in 9.0 seconds before the floor on which he is running gives out and leaves him with no escape. He starts from rest and accelerates at a m s^{-2} for 3.0 seconds after which point he maintains a constant speed. What is the minimum magnitude of a he can have if he is to make it through the doorway in time?



Key science skills

Question 19 (7 MARKS)

A student is performing an experiment where she drops a ball from the second floor of her science building and uses speed gates placed at different heights to calculate the magnitude of the ball's velocity at given times. Some of the results are provided below.

Velocity (m s^{-1})	5.0	10	17	22	26
Time (s)	0.40	1.1	1.9	2.4	3.0

a. Sketch the graph of velocity against time, making sure to include a line of best fit. (3 MARKS)

b. Calculate the gradient of this line. (2 MARKS)

c. Identify if the data the student recorded is

i. primary or secondary. (1 MARK)

ii. qualitative or quantitative. (1 MARK)

FROM LESSONS 11A, 11D & 11E

Previous lessons

Question 20 (3 MARKS)

List one of the three types of radioactive decay that we can detect and identify its composition as well as its relative ionisation and penetration ability compared to the other forms of nuclear decay.

FROM LESSON 4C

Question 21 (2 MARKS)

Identify two factors that impact how severely a person is impacted by an electric shock.

FROM LESSON 7C

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Chapter 8 review

Mild 🌶 Medium 🌶🌶 Spicy 🌶🌶🌶

These questions are typical of 40 minutes worth of questions on the VCE Physics Exam.

Total marks: 30

Section A

All questions in this section are worth one mark.

Unless otherwise indicated, the diagrams in this book are not drawn to scale.

Use the following information to answer questions 1 and 2.

A man is standing on the edge of a 30 m tall bridge and throws a tennis ball vertically upwards with a speed of 15 m s^{-1}. Take the acceleration due to gravity, g, to be 9.8 m s^{-2}. Ignore the effects of air resistance.

Question 1 🌶

Which of the following is closest to the maximum height of the tennis ball above the ground?

A. 11 m

B. 30 m

C. 41 m

D. 74 m

Question 2 🌶

After reaching its maximum height, what is the speed of the tennis ball when it returns to the height it was thrown from?

A. 0 m s^{-1}

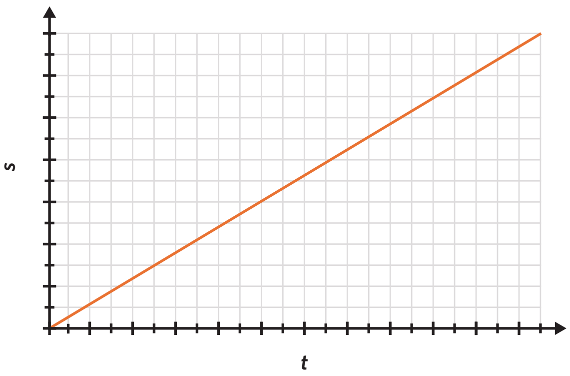
B. 8 m s^{-1}

C. 15 m s^{-1}

D. 16 m s^{-1}

Question 3 🌶

The provided displacement-time graph represents the motion of a toy car over a period of time.



Which of the following options correctly describes the velocity and acceleration of the toy car?

	Velocity	Acceleration
A.	Constant	Increasing
B.	Constant	Zero
C.	Increasing	Increasing
D.	Increasing	Constant

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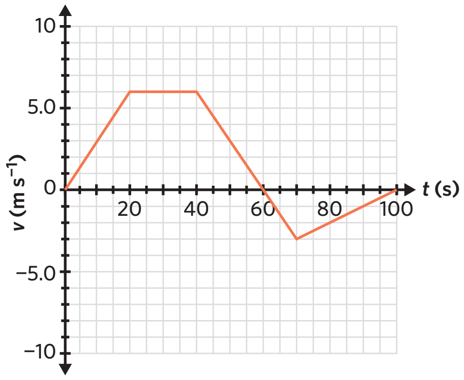
Use the following information to answer questions 4 and 5.

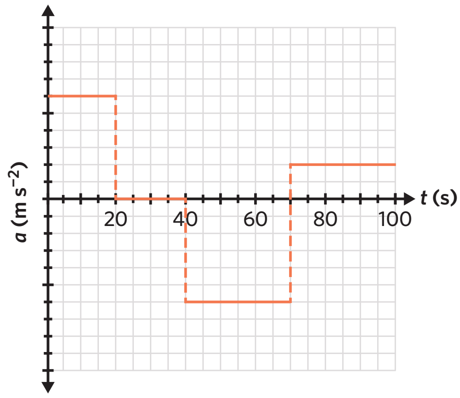
The provided velocity-time graph represents the motion of a runner along a straight track.



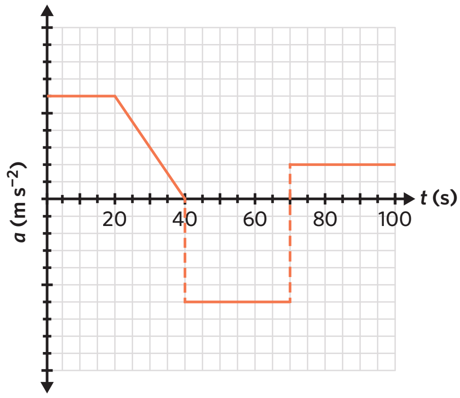
Question 4

Which of the following acceleration-time graphs best represents the motion of the runner?

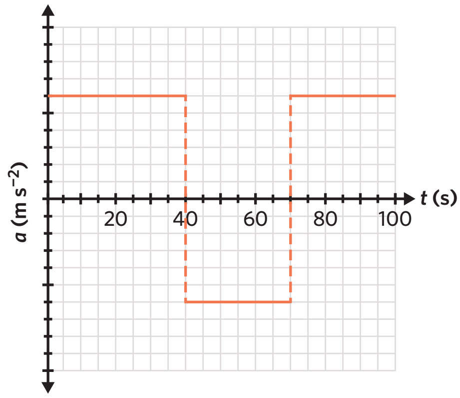
A.



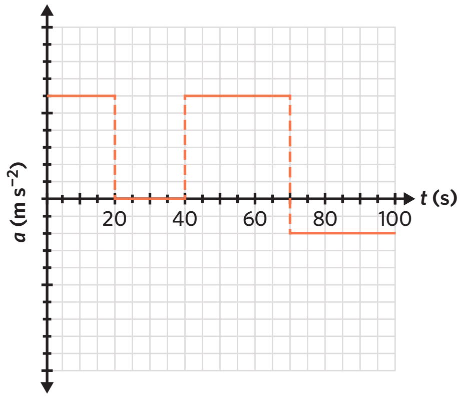
B.



C.



D.



Question 5

Using the velocity-time graph, which of the following best represents the magnitude of the displacement of the runner after 100 seconds?

A. 60 m

B. 180 m

C. 240 m

D. 300 m

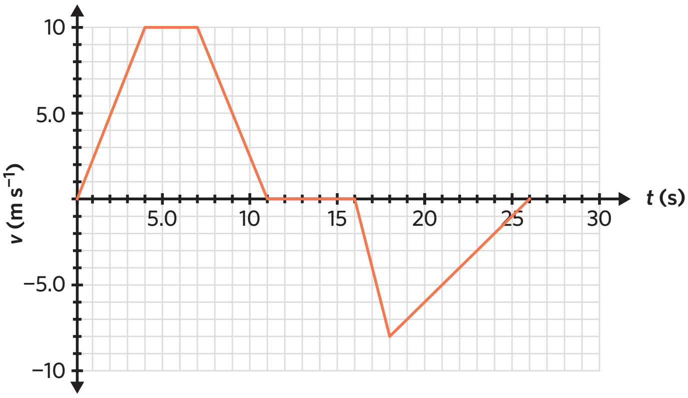
Section B

In questions where more than one mark is available, appropriate working must be shown.

Unless otherwise indicated, the diagrams in this book are not drawn to scale.

Question 6 (7 MARKS)

The provided graph shows how the velocity of a cyclist varied as they travelled along a straight stretch of road, where west is the positive direction on the y-axis.



a. Determine the magnitude and direction of the acceleration of the cyclist 9.0 seconds after they began riding. (2 MARKS)

b. Calculate the distance travelled by the cyclist over the 26-second journey. (2 MARKS)

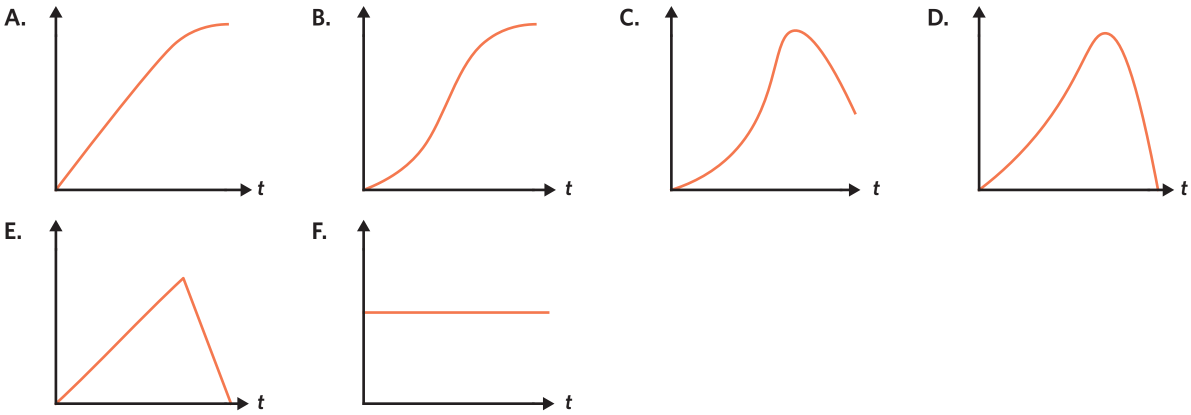
c. Find the magnitude and direction of the cyclist's final displacement from their starting position. (2 MARKS)

d. Determine the magnitude and direction of the average velocity of the cyclist over their journey. (1 MARK)

Question 7 (7 MARKS)

Whilst driving to school, a student who is late for their physics exam accelerates their car from rest over a distance of 300 m in 14.0 seconds. The student then sees a stop sign and applies the brakes, stopping the car in 7.50 seconds. Assume that both the acceleration and deceleration of the car are constant.

The provided graphs (A–F) show time on the horizontal axis and velocity or distance on the vertical axis.



a. Determine the magnitude of the acceleration of the car over the first 300 m. (2 MARKS)

b. Calculate the average speed of the car during the entire accelerating and decelerating period. (3 MARKS)

c. Which of the provided graphs (A–F) best represents the distance-time graph of the car during the accelerating and decelerating periods? (1 MARK)

d. Which of the provided graphs (A–F) best represents the velocity-time graph of the car during the accelerating and decelerating periods? (1 MARK)

Adapted from VCAA 2002 Exam 2 Q1-4

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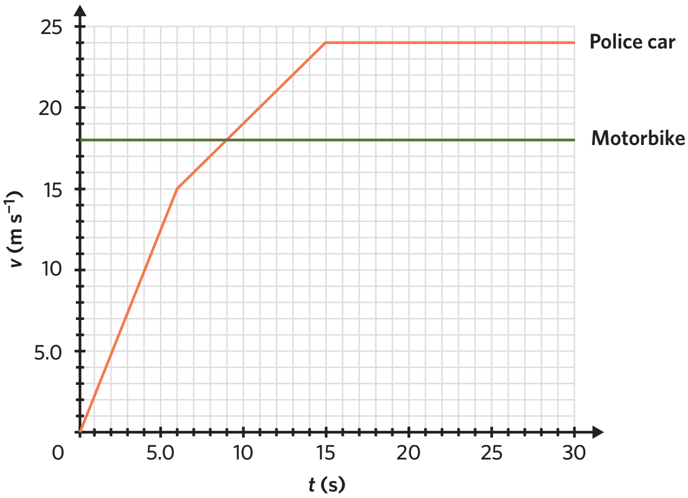
Question 8 (6 MARKS)

A motorbike speeds through a school zone at 18 m s^{-1} and passes a stationary police car at $t = 0$ s. The police car accelerates and attempts to catch up with the motorbike. The provided graph shows how the velocities of the police car and motorbike vary over time.



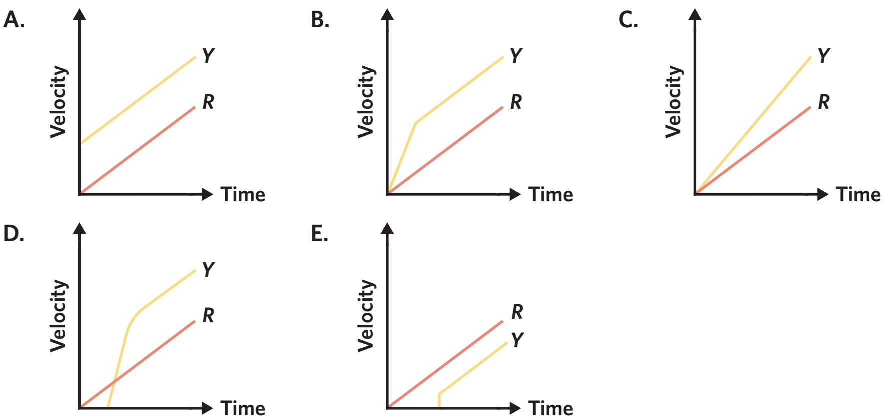
a. Determine the magnitude of the average acceleration of the police car over the first 10 seconds. (1 MARK)

b. How does the velocity and acceleration of the police car change at $t = 6$ s? (1 MARK)

c. Determine the time it takes for the police car to catch the motorbike from the time $t = 0$ s. (4 MARKS)

Question 9 (5 MARKS)

Two friends are at the top of an apartment building dropping water balloons on people who walk past. One friend drops a red water balloon from rest and 0.50 seconds later the other friend throws a yellow water balloon vertically downwards at 2.0 m s^{-1}. The apartment building is 20 m high. Take the acceleration due to gravity, g, to be 9.8 m s^{-2}. Ignore the effects of air resistance.



a. Which of the following velocity-time graphs (A–E) best represents the motion of the red water balloon (R) and the yellow water balloon (Y)? (1 MARK)

b. Determine which water balloon hits the ground first. Use calculations to support your answer. (4 MARKS)

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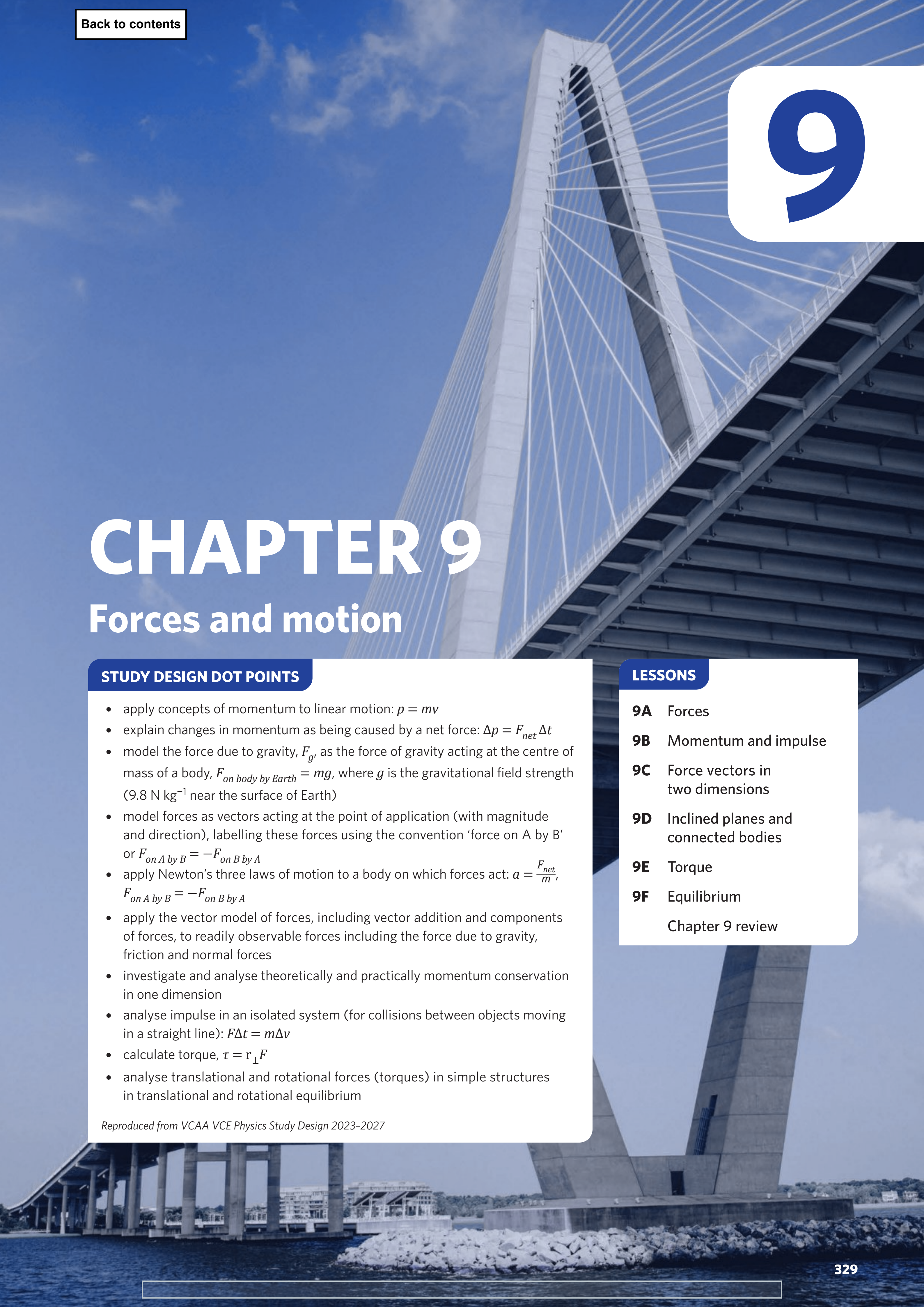

9

CHAPTER 9

Forces and motion

STUDY DESIGN DOT POINTS

- apply concepts of momentum to linear motion: $p = mv$
- explain changes in momentum as being caused by a net force: $\Delta p = F_{net} \Delta t$
- model the force due to gravity, F_g, as the force of gravity acting at the centre of mass of a body, $F_{on\ body\ by\ Earth} = mg$, where g is the gravitational field strength (9.8 N kg^{-1} near the surface of Earth)
- model forces as vectors acting at the point of application (with magnitude and direction), labelling these forces using the convention 'force on A by B' or $F_{on\ A\ by\ B} = -F_{on\ B\ by\ A}$
- apply Newton's three laws of motion to a body on which forces act: $a = \frac{F_{net}}{m}$, $F_{on\ A\ by\ B} = -F_{on\ B\ by\ A}$
- apply the vector model of forces, including vector addition and components of forces, to readily observable forces including the force due to gravity, friction and normal forces
- investigate and analyse theoretically and practically momentum conservation in one dimension
- analyse impulse in an isolated system (for collisions between objects moving in a straight line): $F\Delta t = m\Delta v$
- calculate torque, $\tau = r_{\perp}F$
- analyse translational and rotational forces (torques) in simple structures in translational and rotational equilibrium

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LESSONS

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9A Forces

STUDY DESIGN DOT POINTS

- model the force due to gravity, F_g, as the force of gravity acting at the centre of mass of a body, $F_{on\ body\ by\ Earth} = mg$, where g is the gravitational field strength (9.8 N kg^{-1} near the surface of Earth)
- model forces as vectors acting at the point of application (with magnitude and direction), labelling these forces using the convention 'force on A by B' or $F_{on\ A\ by\ B} = -F_{on\ B\ by\ A}$
- apply Newton's three laws of motion to a body on which forces act: $a = \frac{F_{net}}{m}$, $F_{on\ A\ by\ B} = -F_{on\ B\ by\ A}$

9A 9B 9C 9D 9E 9F

2.1.8.1 Newton's laws of motion
2.1.7.1 Representing forces
2.1.6.1 Force due to gravity
2.1.8.2 The normal force
2.1.7.2 The net force

ESSENTIAL PRIOR KNOWLEDGE

8A Vector and scalar quantities
8A Acceleration
See questions 68–69.

ACTIVITIES

Log into your Edrolo account for activities that support this lesson.

Image: wavebreakmedia/Shutterstock.com

Who will win the game of tug of war?

When we want to move something, we apply a force. In this lesson we will quantify and measure the effects of forces by introducing concepts of force vectors in one dimension, Newton's laws of motion, the gravitational force, and the normal force.

KEY TERMS AND DEFINITIONS

force a push or a pull with an associated magnitude and direction (vector quantity)

gravitational force the force experienced by an object due to the gravitational field of another object

net force the vector sum of all forces acting on an object (vector quantity)

Newton's first law states that an object will accelerate only if a non-zero net force (unbalanced force) acts upon it

Newton's second law states that the net force on an object is proportional to the object's acceleration and mass

Newton's third law states that for every force there is a reaction force of equal magnitude and opposite direction

normal force the contact force that acts between two objects with equal magnitude on each object and at right angles to the contact surfaces

FORMULAS

- **Newton's second law**
  $F_{net} = ma$
- **Newton's third law**
  $F_{on\ A\ by\ B} = -F_{on\ B\ by\ A}$
- **force due to gravity**
  $F_g = mg$
- **the net force**
  $F_{net} = F_1 + F_2 + F_3 + \ldots$

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Newton's laws of motion 2.1.8.1

A force is a push or a pull that has an associated magnitude and direction. Forces are responsible for causing changes in motion.

Theory and applications

Cars, bridges, aeroplanes, boats, skyscrapers, and many more technologies are designed through applying Newton's three laws to the concept of a force.[1, 2]

KEEN TO INVESTIGATE?

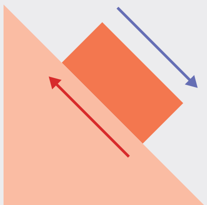
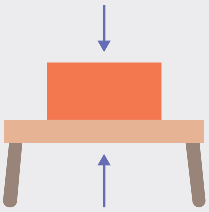
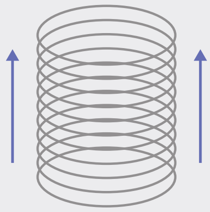
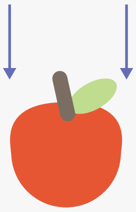
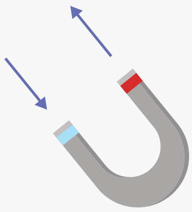
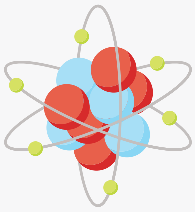
1 **How can we demonstrate Newton's three laws?**
Search: forces and motion interactive simulation

2 **What are Newton's three laws?**
Search YouTube: Newton's laws

What is a force?

In physics, a force, F, is a push or a pull that acts to cause a change in motion. Forces are vector quantities, having both magnitude and direction. The magnitude (strength) of a force is measured in newtons (N). There are many different types of forces that we can separate into contact and non-contact forces (see Table 1).

Table 1 Examples of contact and non-contact forces

Contact force	Friction force 	Normal force 	Spring force 
Non-contact force	Force due to gravity 	Magnetic force 	Electric force 

How does Newton's first law describe motion?

1. **Law of inertia** — A body will remain at rest, or moving at constant velocity, unless it is acted on by an unbalanced force.

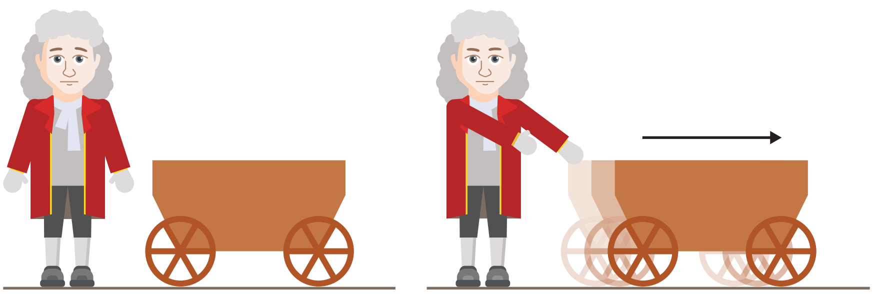


Figure 1 Newton's first law

If the net force acting on an object is zero, it will either remain at rest or continue moving in the same direction and speed (see Figure 1). This is known as the forces being in equilibrium. An important conclusion of the law is that an object will remain moving forever if it doesn't experience any forces.

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Progress questions

Question 1

Which of the following statements about a force is correct?

A. A force is a property of an object due to its motion.

B. A force must be present for an object to move.

C. A force is an action that can have an effect on the motion of a body.

D. A force is the energy of a body.

Question 2

How long does it take an object to stop moving when there are no forces acting on it?

A. instantly

B. never

C. Usually around five to ten seconds.

How does Newton's second law describe motion?

2.	**Law of force and acceleration**	The acceleration of an object is equal to the net force applied divided by the mass of the object.

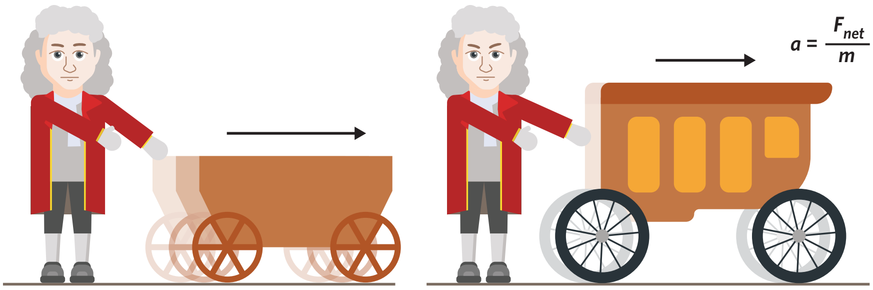

Figure 2 Newton's second law

An object of a larger mass will accelerate less than a smaller mass object when the same amount of force is applied (see Figure 2). Imagine how much easier it is to throw a light tennis ball compared to a heavy shot put.

Newton's second law is commonly written mathematically as:

FORMULA

$$F_{net} = ma$$

F_{net} = net force (N)
m = mass (kg)
a = acceleration (m s^{-2})

WORKED EXAMPLE 1

Determine the magnitude of acceleration of a 3.0×10^3 kg truck when a net force with a magnitude of 1.5×10^3 N is applied.

Step 1

Identify Newton's second law that relates these variables.

$F_{net} = 1.5 \times 10^3$ N, $m = 3.0 \times 10^3$ kg, $a = ?$

$F_{net} = ma$

Step 2

Substitute values into the formula and solve for the acceleration of the truck. Note the question only asks for the magnitude so we ignore the direction in our answer.

$1.5 \times 10^3 = 3.0 \times 10^3 \times a$

$a = 0.50$ m s^{-2}

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Progress questions

Use the following information to answer questions 3 and 4.

A plane has a mass of 600 kg. Its engines produce a net force of 6000 N pushing it north.

Question 3

What is the direction of the net force acting on the plane?

A. north
B. south
C. west
D. east

Question 4

What is the magnitude of the acceleration of the plane?

A. 0 m s^{-2}
B. 5.00 m s^{-2}
C. 10.0 m s^{-2}
D. 15.0 m s^{-2}

How does Newton's third law describe motion?

3. Law of action and reaction — For every action force, there is a reaction force of equal magnitude and opposite direction.

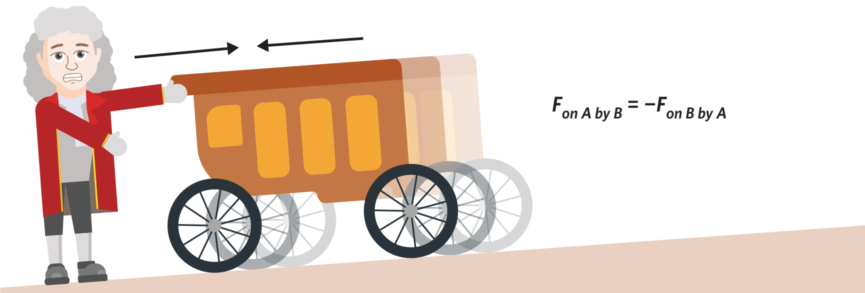

Figure 3 Newton's third law

For every action force applied on object A by object B, there will be a reaction force of equal magnitude and opposite direction on object B by object A (see Figure 3).

FORMULA

$$F_{on\ A\ by\ B} = -F_{on\ B\ by\ A}$$

$F_{on\ A\ by\ B}$ = force applied on object A by object B (N)
$F_{on\ B\ by\ A}$ = force applied on object B by object A (N)

USEFUL TIP

Note that the designation of a force being 'action' or a 'reaction' is arbitrary since they occur at the same time. The forces are an action-reaction pair.

An example of Newton's third law can be found in a rocket shown in Figure 4. The rocket exerts a force to accelerate the gases backwards $F_{on\ gases\ by\ rocket}$, causing the gases to exert a force of equal magnitude and opposite direction (forwards) on the rocket $-F_{on\ rocket\ by\ gases}$.

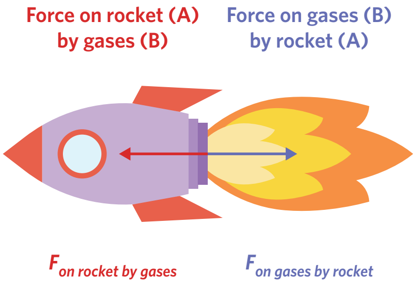

Figure 4 The action and reaction force pair between gases and a rocket

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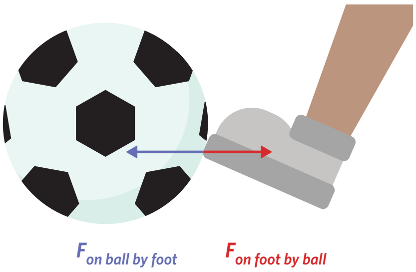


Figure 5 The action and reaction force pair between a ball and a foot

Another example is shown in Figure 5. The foot and the ball exert equal and opposite forces on each other. However, since the mass of the ball is much smaller than the combined mass of the foot and the person it is attached to, the magnitude of acceleration of the ball is much greater than that of the foot.

Progress questions

Question 5

Which of the following is an accurate description of Newton's third law?

A. If we push down on the floor the floor will push back up on us with an equal magnitude.

B. All forces acting on an object are balanced.

Question 6

In Figure 5, the force acting back on the foot is the same as the force on the ball. Why does the foot not go flying backwards like the ball?

A. The foot does not experience the same force as the ball.

B. The foot – which is connected to the person – is far heavier than the ball so does not experience such a large acceleration.

Representing forces 2.1.7.1

Force diagrams are drawn to show the direction, magnitude and location of a force acting upon an object.

Theory and applications

Drawing diagrams to represent forces is a key skill for all mechanical and structural engineering. Whenever analysing the movement and stability of any structure, like a bridge or a car, the first step is always to draw a force diagram.

How do we model forces acting on an object?

A force diagram (see Figure 6), sometimes called a free body diagram, is a representation of all the forces acting on an object. These diagrams help us visualise the directions and relative sizes of forces in order to analyse an object's movement.

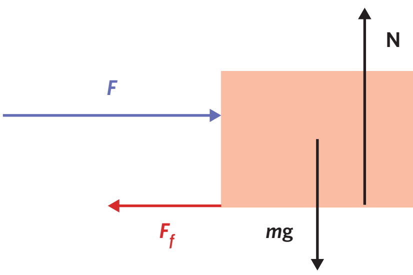


Figure 6 Drawing forces acting on a box.

Rules for drawing forces:

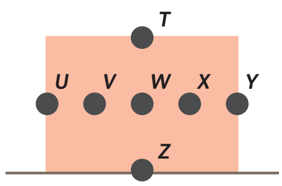
- Forces are always drawn as arrows.
- We draw forces as arrows which point in the direction that the force is acting.
- A force arrow always begins at the point where the force is acting.
- The relative length of the arrow indicates the magnitude of the force.

Progress questions

Use the following information to answer questions 7 and 8.

Two friends are exerting forces on a 5 kg block.

- Demi is exerting a 200 N force to the right acting on the right face of the block.
- Sharni is exerting a 100 N force to the left acting on the left face of the block.
- A force due to gravity and a normal force are acting on the block.



Continues →

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Question 7

At which of the points labelled (T–Z) should the force arrows for Demi's force, Sharni's force, the force due to gravity (mg), and the normal force (N) begin?

Question 8

How should the length of the force arrows for Sharni's and Demi's forces compare?

A. The arrow for Sharni's force should be longer than the arrow for Demi's force.

B. The arrow for Sharni's force should be shorter than the arrow for Demi's force.

C. The arrows should have equal length.

Force due to gravity 2.1.6.1

The force due to gravity attracts masses towards each other.

Theory and applications

If we were to remove air resistance from a room, a feather and a brick would fall at the same rate, despite the brick being heavier, due to the gravitational force being the only force acting on the objects.[3]

KEEN TO INVESTIGATE?

[3] **Would a bowling ball or a feather fall faster on the moon?**
Search YouTube: Brian Cox visits the world's biggest vacuum

How do we calculate the force due to gravity?

The gravitational field strength, g, helps us calculate the force due to gravity acting on an object.

- This quantity g is also known as the acceleration due to gravity.
- An object falling in Earth's gravitational field, with no other forces acting on it, will accelerate at 9.8 m s^{-2}.
- At the Earth's surface, the gravitational field strength is taken to be 9.8 N kg^{-1} or m s^{-2}.

We can replace acceleration (a) in Newton's second law with gravitational field strength (g) to calculate the force due to gravity.

FORMULA

$$F_g = mg$$

F_g = force due to gravity (N)
m = mass (kg)
g = gravitational field strength (9.8 N kg^{-1} or m s^{-2})

How do we model the force due to gravity acting on an object?

When drawing the force due to gravity, it must be drawn acting down towards the centre of the Earth from the object's centre of mass.

Newton's third law also applies to the gravitational force (see Figure 7). Hence, $F_{on\ car\ by\ Earth} = -F_{on\ Earth\ by\ car}$. Note that the force that the car is exerting on the Earth is also a gravitational force.

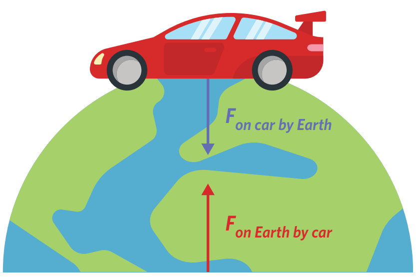

Figure 7 The action reaction gravitational force pair between a car and Earth

WORKED EXAMPLE 2

A 500 kg truck is driving down the highway.

a. What is the magnitude of the gravitational force acting on the truck?

Step 1

Identify the formula for force due to gravity. Note that unless otherwise explicitly stated in the question assume that $g = 9.8$ m s^{-2}.

$m = 500$ kg, $g = 9.8$ m s^{-2}, $F_g = ?$

$F = mg$

Step 2

Substitute the values into the equation and solve. Note that the question only asks for a magnitude so we do not have to give the direction of the force.

$F = 500 \times 9.8 = 4900 = 4.9 \times 10^3$ N

b. The truck is placed on the surface of Mars and experiences a gravitational force of 1.85×10^3 N. What is the magnitude of the gravitational field strength on the surface of Mars?

Step 1

Identify the formula for force due to gravity. Note that since the car is on Mars, *g*, will not be equal to 9.8 m s^{-1}.

$m = 500$ kg, $F_g = 1.85 \times 10^{-3}$ N, $g = ?$

$F = mg$

Step 2

Substitute the values into the equation, rearrange and solve for *g*.

$1.85 \times 10^3 = 500 \times g$

$g = \frac{1.85 \times 10^3}{500} = 3.70$ N kg^{-1} or m s^{-2}

Progress questions

Question 9

On the Moon, a hammer and a nail are dropped at the same time. Which object will reach the ground first?

A. hammer

B. nail

C. both will reach the ground at the same time

Question 10

A chair has a mass of 3.0 kg. What is the magnitude of the gravitational force acting on the chair? Assume $g = 9.8$ m s^{-2}.

A. 3.0 N

B. 9.8 N

C. 29 N

Question 11

Fill in the blanks to complete the paragraph.

When located in the Earth's __________ (atmosphere/gravitational field), bodies with __________ (solid centres/mass) experience a(n) __________ (attractive/repulsive) force towards the Earth due to __________ (gravity/contact with other objects). The force acts at the __________ (contact point/centre of mass) and in a direction pointing __________ (downwards/ towards the centre of Earth).

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The normal force 2.1.8.2

The normal force exists as a contact force between two objects pushing away from each other.

Theory and applications

The normal force is what prevents an object from falling through the ground. It is a concept that is essential to understand the movement of an object down an inclined plane (Lesson 9D).

How do we model the normal force acting on an object?

The normal force F_N is the contact force that pushes objects away from each other in a direction that is perpendicular (normal) to the contact surfaces.

- For an object stationary on flat ground, the normal force will act upwards counteracting the force of gravity. See Figure 8(a).
- For an object stationary on an incline, both the normal force and the frictional force will act to counteract the force of gravity. See Figure 8(b).
- An object in free fall will not have a normal force acting on it. See Figure 8(c).

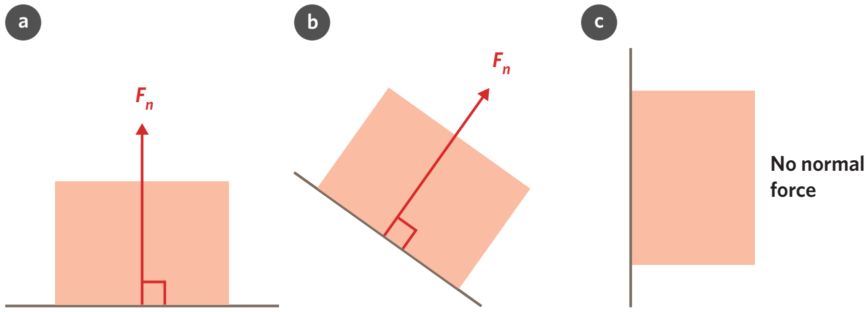


Figure 8 The normal force acting on a box **(a)** on flat ground, **(b)** on an incline, and **(c)** in free fall.

MISCONCEPTION

'According to Newton's third law, gravity and the normal force are an action reaction pair.'

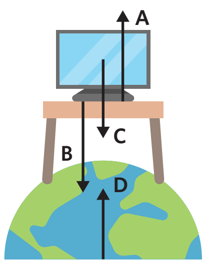
Note that the gravitational force on an object and the normal force on an object are not an action-reaction pair. Since both forces are acting on the same object, these forces cannot be an action-reaction pair. The action-reaction pair is the two normal (or contact) forces.

Progress questions

Question 12

Complete the included table to correctly label the diagram.

Force due to gravity on the object by Earth	
Force due to gravity on Earth by the object	
Normal force on the table by the object	
Normal force on the object by the table	



Question 13

Which of the following statements about the normal force is false?

A. The normal force is equal and opposite to the force due to gravity.

B. The normal force acts perpendicular to the surface of the object creating the force.

C. The normal force is a type of contact force.

Question 14

A lift is accelerating downwards at 2 m s^{-2}. The normal force acting on people in the lift will

A. increase.

B. decrease.

C. stay the same.

The net force 2.1.7.2

The net force is the sum of all of the contact and non contact forces acting on an object. Ultimately it is the net force that will determine the acceleration and movement of an object over time.

Theory and applications

The net force gives an understanding of the motion and stability of structures. A non-zero net force is an unbalanced force. According to Newton's first law, an object acted upon by an unbalanced force will undergo a change in motion. For structures such as buildings and bridges, the net force should always be equal to zero as we do not want them to move.

How is the net force acting on an object calculated?

The net force is found by adding all the forces acting upon an object.

$$F_{net} = F_1 + F_2 + F_3 + \ldots$$

In Figure 9 we calculate the net force acting on object A by taking the right as positive. This gives us $F_{net} = 40 - 20 = 20$ N to the right.

To calculate the net force in one dimension, simply add each force, making sure to include the positive or negative sign to indicate direction.

- Which direction we decide to make positive should be explicitly stated.
- The positive direction is often defined as upwards or to the right, however this can change depending on what is convenient for the question.
- When we write force equations for one dimension, a force's direction can either be positive or negative.

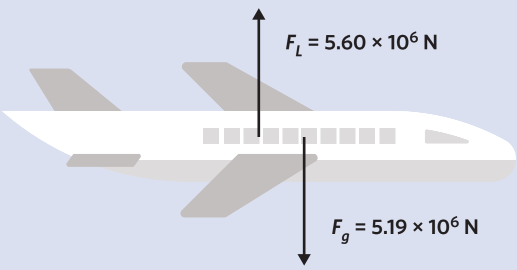
USEFUL TIP

Note that the net force can also be written as $F_{net} = \sum F$ which is equivalent to the sum of all forces: $F_{net} = F_1 + F_2 + F_3 + \ldots$

Figure 9 Net force on object A

WORKED EXAMPLE 3

A plane has two forces acting on it, a lift force and a force due to gravity. Calculate the magnitude and direction of the net force acting on the plane.



Step 1

Define up as positive. Identify the formula to calculate the net force.

$F_L = 5.60 \times 10^6$ N, $F_g = -5.19 \times 10^6$ N

$F_{net} = \sum F = F_L + F_g$

Step 2

Sum up all the forces together.

$F_{net} = 5.60 \times 10^6 + \left(-5.19 \times 10^6\right) = 0.410 \times 10^6$ N

Step 2

State the final answer, including both magnitude and direction.

$F_{net} = 4.10 \times 10^5$ N in the upwards direction

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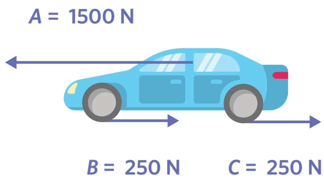
Progress questions

Use the following information to answer questions 15 and 16.

The forces acting on a car are modelled in the figure.



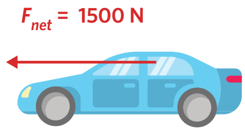
Question 15

Define a positive direction for forces in the following scenario and state whether forces A, B, and C act in a positive or negative direction.

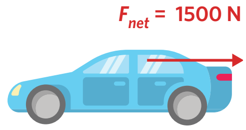
Question 16

Which of the images is a correct drawing of the net force acting on the car?

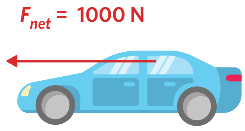
A.



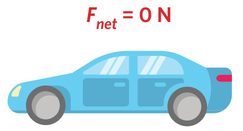
B.



C.



D.



Theory summary

- A force is a push or pull applied by one object on another.
  - Forces are vectors with a magnitude measured in newtons (N) and a direction.
- Force diagrams show all of the forces acting on an object.
  - We draw forces as arrows pointing in the direction they act, with a length proportional to their magnitude, beginning at the point of application.
- The force due to gravity attracts all masses.
  - $F_g = mg$, where g is the acceleration due to gravity.
  - The force due to gravity acts from the centre of mass of the object and points towards the centre of the object exerting the force.
- The normal force, F_N, is the contact force that pushes objects away from each other in a direction that is perpendicular to the contact surfaces.
- The sum of all forces acting on an object is called the net force.

Table 2 Newton's laws of motion

Newton's first law	Newton's second law	Newton's third law
An object will not accelerate unless a non-zero net force is applied.	The net force on an object is proportional to its acceleration and mass. $F_{net} = ma$	Every action force has an equal and opposite reaction force. $F_{on\ A\ by\ B} = -F_{on\ B\ by\ A}$

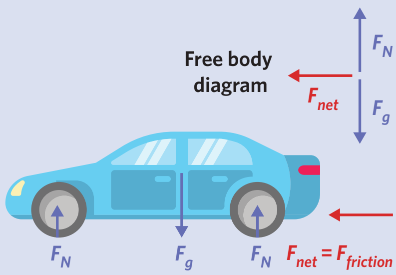
The content in this lesson is considered fundamental prior knowledge to Newton's laws of motion (Unit 3 AOS 1).

CONCEPT DISCUSSION

A key conclusion of Newton's first law is that an object can be moving without any net force acting on it. With reference to this conclusion, discuss the magnitudes and directions of the horizontal forces that a car must exert on the road when the car is accelerating and when the car has a constant velocity.

Prompts:

- What causes an object to accelerate?
- What is needed for a car to maintain a constant velocity?
- How do the forces that the car exerts on the road relate to the motion of the car?



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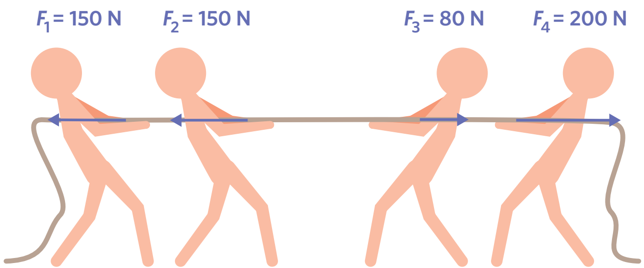
9A Questions

Mild Medium Spicy

Deconstructed exam-style

Use the following information to answer questions 17–19.

Four friends are exerting forces on a 5.0 kg rope in a 'tug-of-war'. The magnitude and direction of the four forces are shown. Take the positive direction as to the right.



Question 17 (1 MARK)

Which row correctly gives the sign that should be assigned to each force for calculations?

	F_1	F_2	F_3	F_4
A.	negative	positive	positive	positive
B.	positive	positive	positive	negative
C.	negative	negative	positive	positive
D.	positive	positive	negative	negative

Question 18 (1 MARK)

Which of the following is a correct equation for the net force acting on the rope? Remember to take the positive direction as to the right.

A. $F_{net} = F_1 + F_2 - F_3 - F_4$

B. $F_{net} = F_1 + F_3 - F_2 - F_4$

C. $F_{net} = F_1 + F_2 + F_3 - F_4$

D. $F_{net} = F_3 + F_4 - F_1 - F_2$

Question 19 (4 MARKS)

Determine the acceleration of the rope.

Exam-style

Question 20 (1 MARK)

An ultralight aeroplane of mass 500 kg flies in a horizontal straight line at a constant speed of 100 m s^{-1}. The horizontal resistance force acting on the aeroplane is 1500 N. Which one of the following best describes the magnitude of the forward horizontal thrust on the aeroplane?

A. 1500 N

B. Slightly less than 1500 N

C. Slightly more than 1500 N

D. 5000 N

VCAA 2019 exam Multiple choice Q11

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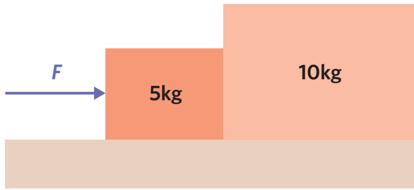
Question 21 (1 MARK)

Two blocks of mass 5 kg and 10 kg are placed in contact on a frictionless horizontal surface, as shown in the diagram. A constant horizontal force, F, is applied to the 5 kg block. Which of the following statements is correct?



A. The net force on each block is the same.

B. The acceleration experienced by the 5 kg block is twice the acceleration experienced by the 10 kg block.

C. The magnitude of the net force on the 5 kg block is half the magnitude of the net force on the 10 kg block.

D. The magnitude of the net force on the 5 kg block is twice the magnitude of the net force on the 10 kg block.

VCAA 2020 exam Multiple choice Q9

Question 22 (1 MARK)

Determine the magnitude of the acceleration of a 20 kg toy car if its wheels exert a 120 N net force on the car.

Question 23 (1 MARK)

Determine the magnitude of the net force acting on a 60.0 kg skydiver if they are accelerating towards the Earth's surface at 7.60 m s^{-2}.

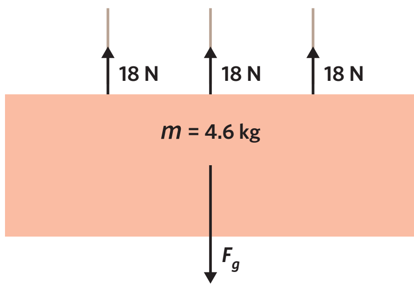
Question 24 (2 MARKS)

Liesel, a student of yoga, sits on the floor in the lotus pose, as shown. The action force, F_g, on Liesel due to gravity is 500 N down. Identify and explain what the reaction force is to the action force, F_g.

VCAA 2021 exam Short answer Q4

Question 25 (5 MARKS)

A mass of 4.6 kg is hanging by three strings, with the forces acting on the mass shown in the diagram.



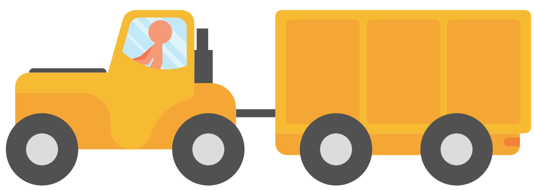
a. Calculate the magnitude of the acceleration of the mass. Assume that the mass is near the surface of the Earth. (3 MARKS)

b. Draw the net force acting on the mass. (2 MARKS)

Question 26 (2 MARKS)

A tractor, including the driver, has a mass of 500.0 kg and is towing a trailer of mass 2000 kg as shown in the diagram. The tractor and trailer are accelerating at 0.5000 m s^{-2}. Ignore any retarding friction forces. Ignore the mass of the towing rope. The tractor and trailer start from rest. What is the magnitude of the net force on the system of the tractor and trailer?

Adapted from VCAA 2011 Exam 1 Q1



Question 27 (6 MARKS)

A 30 kg box is sitting on a table near the Earth's surface.

a. Calculate the magnitude of the normal force acting on the box if it is at rest. (2 MARKS)

b. Calculate the magnitude of the normal force acting on the box if it and the table are accelerating towards the Earth at 9.8 m s^{-2}. (2 MARKS)

c. Calculate the magnitude of the normal force acting on the box if it and the table are accelerating upwards at 2.0 m s^{-2}. (2 MARKS)

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Question 28 (3 MARKS)

Explain, with reference to Newton's third law, why the normal force acting on a ball that is at rest on the ground and the force due to gravity acting on the ball are not an action-reaction pair.

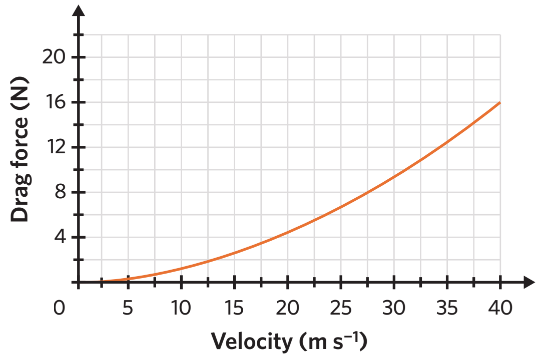
Question 29 (2 MARKS)

A spacesuit ejects small streams of air to move around. Explain how ejecting a stream of air can accelerate a spacesuit.

Question 30 (3 MARKS)

When a 1.5 kg object falls downwards towards the Earth, it experiences an aerodynamic drag force upwards. The magnitude of the drag force is dependent on velocity, as shown in the force vs velocity graph.

Estimate the maximum speed (the speed reached when acceleration is zero, called terminal velocity) that the object will reach as it falls towards the Earth. Assume that $g = 9.8 \text{ m s}^{-2}$ and that the object falls from a high altitude. Justify your answer with reference to Newton's first and second law.



Key science skills

Question 31 (7 MARKS)

Nu Tan collects data from an experiment on the bite force of different animals. The mass of each animal is recorded very precisely, but the bite force data has a measurement uncertainty of ±10 N.

Animal mass (kg)	Bite force (N)
4.0	30
6.0	50
22.0	180
45.0	355
85.0	680

a. Plot the data on an appropriate graph. Include a line of best fit and uncertainty bars. (5 MARKS)

b. Describe the relationship between animal mass and bite force. (2 MARKS)

FROM LESSON 11D

Previous lessons

Question 32 (3 MARKS)

Identify the kind of decay that would be most likely to occur in the following nuclides.

a. A heavy, unstable isotope with too many protons. (1 MARK)

b. A light unstable isotope with too many protons. (1 MARK)

c. An unstable isotope with too many neutrons. (1 MARK)

FROM LESSON 4C

Question 33 (3 MARKS)

A cyclist completes three complete loops of a velodrome in 2 minutes. The circumference of the velodrome is 350.0 m.

a. What is the distance travelled by the cyclist? (1 MARK)

b. What is the displacement of the cyclist? (1 MARK)

c. What is the average velocity of the cyclist? (1 MARK)

FROM LESSON 8A

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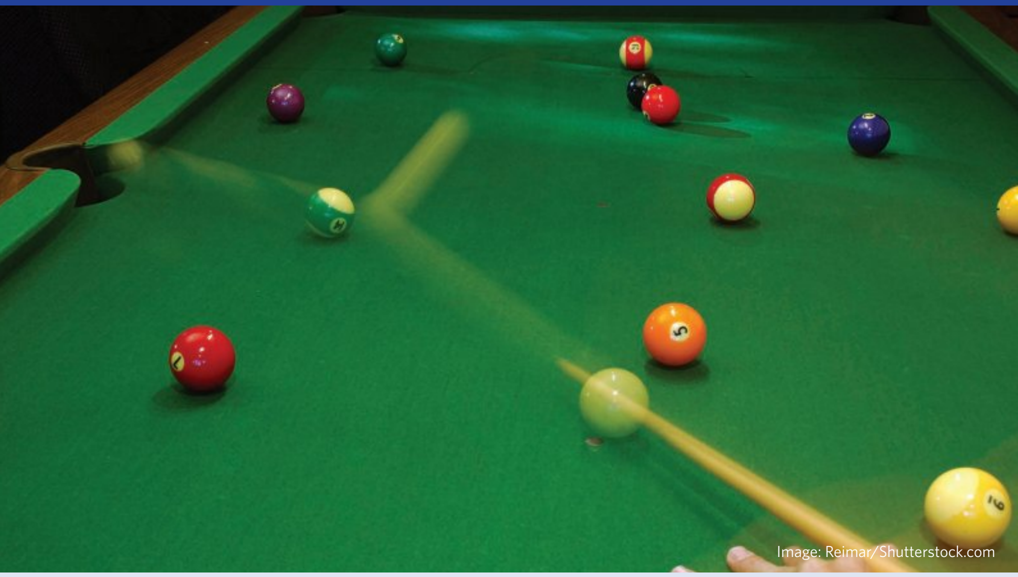
9B Momentum and impulse



How can conservation of momentum be used to predict the motion of pool balls?

This lesson will look at the concepts of momentum and impulse in one dimension, and investigate how we can use them in physics to describe motion and collisions in a straight line - just like the collisions between pool balls.

STUDY DESIGN DOT POINTS

- apply concepts of momentum to linear motion: $p = mv$
- explain changes in momentum as being caused by a net force: $\Delta p = F_{net}\Delta t$
- analyse impulse in an isolated system (for collisions between objects moving in a straight line): $F\Delta t = m\Delta v$
- investigate and analyse theoretically and practically momentum conservation in one dimension

9A 9B 9C 9D 9E 9F

2.1.4.1 & 2.1.16.1 Momentum

2.1.5.1 & 2.1.15.1 Impulse

ESSENTIAL PRIOR KNOWLEDGE

8A Velocity as a vector quantity

9A Newton's second law

9A Newton's third law

See questions 70–72.

ACTIVITIES

Log into your Edrolo account for activities that support this lesson.

KEY TERMS AND DEFINITIONS

collision the coming together of two or more objects where each object exerts a force on the other

impulse the change in momentum of a body as the result of a force acting over a time (vector)

isolated system a collection of interacting objects for which there is no external exchange of mass and energy

momentum a property of a body in motion which is equal to the mass of the body multiplied by its velocity (vector)

FORMULAS

- **momentum**
  $p = mv$
- **conservation of momentum**
  $\sum p_i = \sum p_f$
- **impulse**
  $\Delta p = m\Delta v$
- **impulse**
  $\Delta p = F\Delta t$

Momentum 2.1.4.1 & 2.1.16.1

Momentum is a vector quantity that describes how hard it is to stop a moving object. It's a quantity that is always conserved, allowing us to analyse the motion of two or more objects before and after a collision.

Theory and applications

Momentum and its conservation is a fundamental principle in physics which allows us to analyse and predict the motion of objects.

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How can momentum describe linear motion?

The difficulty of changing the motion of an object depends on its momentum. An object with a greater momentum will require a greater force and/or a greater time to stop.

Consider a heavy truck moving at the same speed as a lighter car in Figure 1. Due to its larger mass, the truck has a much greater momentum and, as a result, will take a greater distance and time to stop when compared to the car if they apply the same braking force.

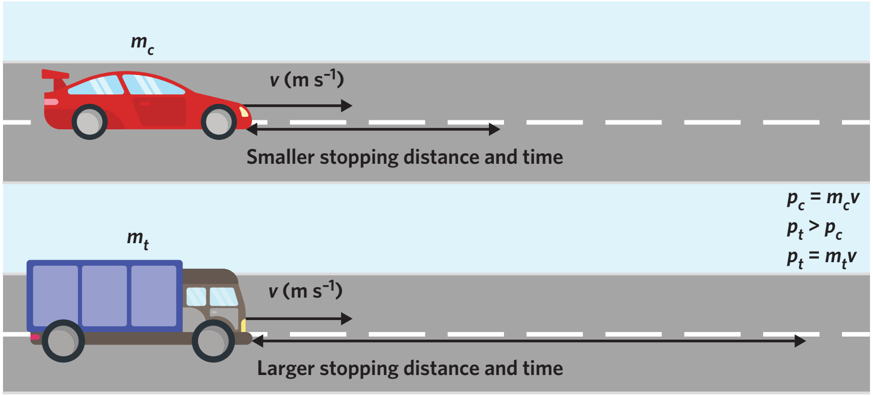

Figure 1 Momentum of different objects travelling at the same speed

Momentum is a vector quantity that is proportional to the mass and velocity of an object. The direction of an object's momentum is the same as the direction of its velocity. Figure 2 shows the equation in a formula triangle.

MISCONCEPTION

'Heavier objects always have a greater momentum.'

Momentum is dependent on both velocity and mass, so if a lighter object is going significantly faster than a heavier object, it may still have a greater momentum, even though it is lighter.

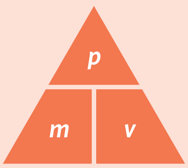

Figure 2 Formula triangle for momentum

FORMULA

$$p = mv$$

p = momentum (N s or kg m s^{-1})
m = mass (kg)
v = velocity (m s^{-1})

WORKED EXAMPLE 1

A car with a mass of 2000 kg is travelling east at 25 m s^{-1}.

Determine the momentum of the car.

Step 1

Identify the mass (m) and velocity (v) of the car and the equation that relates these variables.

$m = 2000$ kg, $v = 25$ m s^{-1}, $p = ?$

$p = mv$

Step 2

Substitute values into the momentum equation and solve. Ensure the units are in N s or kg m s^{-1}. Since momentum is a vector quantity, the direction also needs to be addressed in the answer.

$p = 2000 \times 25 = 5.0 \times 10^4$ N s or kg m s^{-1} to the east

Progress questions

Question 1

A bowling ball of 5.0 kg is travelling at 6.0 m s^{-1} to the north. What is the momentum of the bowling ball?

A. 6.0 N s to the north

B. 6.0 kg m s^{-1} to the south

C. 30 N s to the north

Continues →

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Question 2

A 5000 kg truck and a 500 kg car are compared. Which one has a greater momentum?

A. truck

B. car

C. There is not enough information to tell.

How is the conservation of momentum used to describe motion?

The law of conservation of momentum states that the total momentum of an isolated system will not change during any interaction or collision, such that the total momentum before a collision, $\sum p_i$, will be equal to the total momentum after a collision, $\sum p_f$. In this context, $\sum$ means 'the sum of' to indicate that we add up the momentum of every individual object in the system that we are analysing.

FORMULA

$$\sum p_i = \sum p_f$$

$\sum p_i$ = total initial momentum (N s or kg m s^{-1})
$\sum p_f$ = total final momentum (N s or kg m s^{-1})

USEFUL TIP

For conservation of momentum questions, it is important to treat momentum as a vector quantity with both magnitude and direction. At the beginning of a question, define which direction is considered positive. Any velocities or momenta in the opposite direction should be considered negative.

WORKED EXAMPLE 2

During a golf tournament, Wiger Toods uses his golf club to strike a stationary golf ball, with a mass of 0.0200 kg. The mass of his golf club is 0.250 kg and it travels at 40.0 m s^{-1} to the right immediately before the collision. During the collision it slows so that it travels at 30.0 m s^{-1} to the right immediately after the collision. Assume the golf club and the ball are an isolated system during the collision.

a. Determine the total momentum of the system before the golf club contacts the ball.

Step 1

Define the right as positive. Identify the initial velocity (u) and mass (m) of the club as well as the ball. We sum the initial momentum of the club and the ball together to get the total initial momentum of the system.

Direction to the right is positive

$m_{club} = 0.250$ kg, $u_{club} = 40.0$ m s^{-1}, $m_{ball} = 0.0200$ kg, $u_{ball} = 0$ m s^{-1}, $\sum p_i = ?$

$\sum p_i = m_{club} u_{club} + m_{ball} u_{ball}$

Step 2

Substitute values into the momentum equation and solve. Since momentum is a vector quantity, the direction also needs to be addressed in the answer.

$\sum p_i = 0.250 \times 40.0 + 0.0200 \times 0 = 10.0$ kg m s^{-1} or N s to the right

b. What is the momentum of the club-ball system after the ball has been struck?

Recognise that the final momentum of the system is equal to the initial momentum of the system.

$\sum p_i = \sum p_f = 10.0$ N s to the right

Continues →

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c. Calculate the speed of the golf ball immediately after it has made contact with the club.

Step 1

Define the right as positive. Identify the velocity the club travels at after the collision. We can use this information to calculate the speed of the golf ball after the collision using the conservation of momentum.

Direction to the right is positive.

$\sum p_f = 10.0$ N s, $m_{club} = 0.250$ kg, $v_{club} = 30.0$ m s^{-1}, $m_{ball} = 0.0200$ kg, $v_{ball} = ?$

$\sum p_f = m_{club} \times v_{club} + m_{ball} \times v_{ball}$

Step 2

Substitute values into the momentum equation, and solve. Since speed is a scalar quantity, we can ignore the direction in our final answer.

$10.0 = 0.250 \times 30.0 + 0.0200 \times v_{ball}$

$$v_{ball} = \frac{10.0 - 0.250 \times 30.0}{0.0200} = 125 \text{ m s}^{-1}$$

KEEN TO INVESTIGATE?

1 **How do different masses and velocities affect collisions?**
Search: Collision lab simulation

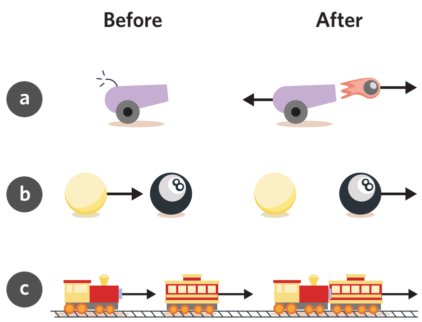


Figure 3 Conservation of momentum

Table 1 Three situations of momentum conservation in collisions[1]

	Before collision	After collision
Figure 3(a)	Stationary cannon and cannon ball. Total momentum is zero. $\sum p_i = 0$	Cannon ball and cannon have equal magnitude of momentum but in opposite directions. Total momentum is still zero. $\sum p_f = p_{ball} + p_{cannon} = 0$
Figure 3(b)	Yellow ball moves to the right and the black is stationary. Momentum of the whole system is the same as the yellow ball. $\sum p_i = p_{yellow\ ball}$	Yellow ball isn't moving and the black ball is moving with the momentum that the yellow ball initially had. $\sum p_f = p_{black\ ball}$
Figure 3(c)	Train and carriage are both moving to the right. $\sum p_i = p_{train} + p_{carriage}$	The train and the carriage are stuck together and so are moving to the right with the exact same velocity. $\sum p_f = (m_{train} + m_{carriage}) \times v_f$

Progress questions

Question 3

A 0.020 kg balloon is floating in the air, not moving, when it is popped. A 0.0050 kg piece of the balloon goes flying off to the right at 5.0 m s^{-1} after the balloon is popped. What is the total momentum of all the pieces of the balloon after it's popped?

A. 0 kg m s^{-1}

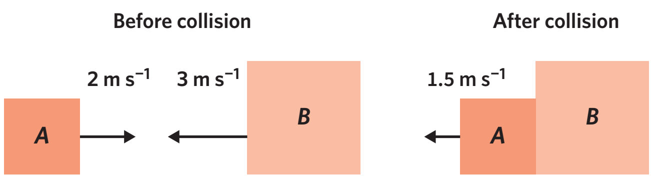
B. 1.0×10^{-4} kg m s^{-1} to the right

C. 1.0×10^{-4} kg m s^{-1} to the left

D. Not enough information

Question 4

Block A, of mass m_A, is travelling to the right at a speed of 2 m s^{-1} and collides with block B, of mass m_B, which is travelling to the left at 3 m s^{-1}. After the collision blocks A and B are moving to the left at a speed of 1.5 m s^{-1}.



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Which of the following options correctly indicates an equation for the momentum of the two blocks before the collision, and the momentum of the combined blocks after the collision? Take the right as the positive direction.

	Momentum of block A before the collision	Momentum of block B before the collision	Momentum of block A and B after the collision
A.	$p_A = m_A \times 2$	$p_B = m_B \times (-3)$	$\sum p_{after} = (m_A + m_B) \times 1.5$
B.	$p_A = m_A \times 2$	$p_B = m_B \times (-3)$	$\sum p_{after} = (m_A + m_B) \times (-1.5)$
C.	$p_A = m_A \times (-2)$	$p_B = m_B \times 3$	$\sum p_{after} = (m_A + m_B) \times (-1.5)$
D.	$p_A = m_A \times 2$	$p_B = m_B \times 3$	$\sum p_{after} = (m_A + m_B) \times 1.5$

Impulse 2.1.5.1 & 2.1.15.1

A force acting on an object over a period of time causes a change in momentum of that object. A change in momentum is how we define impulse. The concept of impulse is useful in investigating the severity of impacts.

Theory and applications

Safety is an important aspect of all product design. When engineers create smartphone cases, cars, and airbags, they must consider the consequences of impulse to maximise safety.

How does impulse describe changes in momentum?

The change in momentum of an object is known as impulse:

$$I = \Delta p$$

Hence impulse has the same units as momentum and is also a vector quantity. The direction of the impulse (change in momentum) is always in the same direction as the change in velocity.

The mass of an object does not change during a collision, so for momentum to change, the object's velocity must change.

FORMULA

$$\Delta p = m\Delta v$$

Δp = change in momentum/impulse (N s or kg m s^{-1})
m = mass (kg)
v = velocity (m s^{-1})

When an object changes its momentum (speed or direction), which happens whenever two bodies collide, there are forces that act to accelerate and change the velocity of those bodies.

We can use the equation for momentum, $p = mv$, to relate how the net force, F_{net}, acting to change the velocity of a body causes a change in the momentum, Δp.

1. From $F_{net} = ma$ and $a = \frac{\Delta v}{\Delta t}$, we can derive an alternative equation for the net force acting on a body.
2. $F_{net} = m \times \frac{\Delta v}{\Delta t}$
3. As $\Delta p = m \times \Delta v$, we conclude $F_{net} = \frac{\Delta p}{\Delta t}$.

We then rearrange $F_{net} = \frac{\Delta p}{\Delta t}$ to make the change in momentum (impulse) the subject, to show how the net force experienced by a body, and the time over which the force acts, affects the change in momentum.

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FORMULA

$$\Delta p = F\Delta t$$

Δp = change in momentum/ impulse (N s or kg m s^{-1})
F = average force (N)
Δt = change in time (s)

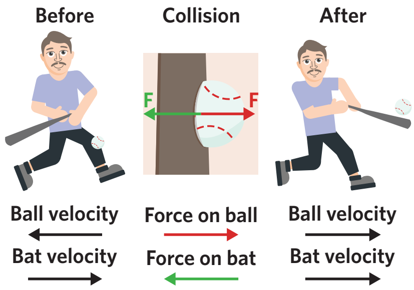


Figure 4 A ball undergoes an impulse as the batter hits it.

The direction of the impulse (change in momentum) is always in the same direction as the force applied. In Figure 4, a force on the ball by the bat acts to the right, which causes an impulse to the right. If the force varies during the collision, then F represents the average force, F_{avg}.

The variables of velocity, mass, force and time can all be related by the physics statement:

$$F\Delta t = m\Delta v$$

Newton's third law also applies to the force that causes an impulse. Hence, as both objects experience the same collision time, for an impulse on object A by object B, there will be an equal and opposite impulse on object B by object A.

$$I_{on\ A\ by\ B} = -I_{on\ B\ by\ A}$$

Consider two cars of the same mass which are having a drag race.[2]

- If one car accelerates to 100 km h^{-1} in the same time that the other car accelerates to 50 km h^{-1}, it has experienced a greater change in momentum and hence a greater net force.
- Similarly, if both cars accelerate to 100 km h^{-1} at different rates, the change in momentum will be the same but the car that took a greater time must have experienced a smaller net force.

KEEN TO INVESTIGATE?

[2] **How does the build of a car keep us safe in a collision?**
Search: Crumple zones and impulse

WORKED EXAMPLE 3

During the 2020 NFL Superb Cup, a punter strikes a stationary football of mass 0.425 kg. The football leaves the punter's foot with a speed of 30.0 m s^{-1} to the north, and is in contact with their foot for 15.0 × 10^{-3} s.

a. Determine the change in momentum of the football.

Step 1

Identify the mass, initial and final velocity of the ball, and the equation relating these variables.

$m_{ball} = 0.425$ kg, $v_{ball} = 30.0$ m s^{-1} north, $u_{ball} = 0$ m s^{-1}, $\Delta p_{ball} = ?$

$\Delta p_{ball} = m_{ball}\Delta v_{ball} = m \times (v - u)$

Step 2

Substitute the values into the equation and solve for momentum. Remember that momentum is a vector quantity and requires a magnitude and a direction.

$\Delta p_{ball} = 0.425 \times (30.0 - 0) = 12.75 = 12.8$ kg m s^{-1} or N s to the north

b. Calculate the impulse given to the football.

Step 1

Impulse is equal to change in momentum and is a vector so it must include a direction.

$I_{ball} = \Delta p_{ball} = 12.8$ kg m s^{-1} or N s to the north

Continues →

c. Calculate the impulse given to the punter's foot.

Step 1

The impulse given to the punter's foot will be equal in magnitude and opposite in direction to the impulse given to the football. The opposite direction to the north is south.

$I_{foot} = -I_{ball} = 12.8$ kg m s^{-1} or N s to the south

d. Determine the average force experienced by the football during its contact with the punter's foot.

Step 1

Identify the impulse, change in time and the equation relating these variables.

$I_{foot} = 12.8$ kg m s^{-1} north, $\Delta t = 15.0 \times 10^{-3}$ s, $F_{avg} = ?$

$I_{foot} = F_{avg}\Delta t$

Step 2

Substitute in the values, rearrange and solve for average force. Remember to include the direction of the average force in the final answer.

$12.75 = F_{avg} \times 15.0 \times 10^{-3}$

$F_{avg} = 850$ N to the north

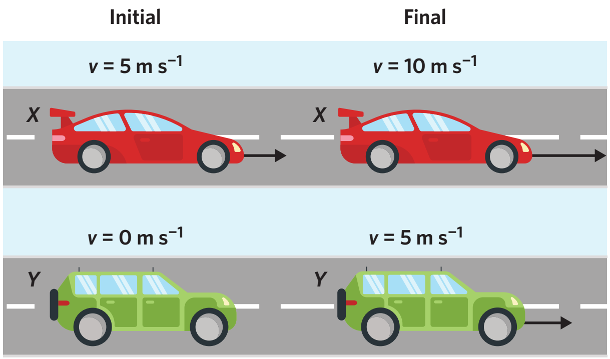
Progress questions

Question 5

Momentum is a __________ (vector/scalar) quantity equal to the multiplication of mass and __________ (acceleration/velocity). The direction of impulse is the __________(opposite/same) as the direction of the change in momentum and is caused by __________ (a net force acting on/a change in displacement of) the mass over time.

Question 6

Two cars, *X* and *Y*, of the same mass are on a road. Car *X* has an initial velocity of 5 m s^{-1} to the right and car *Y* is initially stationary. After a given amount of time, car *X* and *Y* have velocities of 10 m s^{-1} and 5 m s^{-1} respectively to the right.



Which of the following options best compares the initial momentum and final momentum of car *X* and *Y*, as well as the impulse they experience?

	Initial momentum	Impulse	Final momentum
A.	$p_x > p_y$	$I_x > I_y$	$p_x = p_y$
B.	$p_x = p_y$	$I_y > I_x$	$p_y > p_x$
C.	$p_x > p_y$	$I_y = I_x$	$p_x > p_y$

Use the following information to answer questions 7 and 8.

A bowling ball and a soccer ball are rolling towards each other and collide. The bowling ball has a greater mass than the soccer ball. The impulse given to the soccer ball is known to be equal to 10 N s to the right.

Question 7

The impulse given to the bowling ball is __________ (lesser/greater/equal) in magnitude compared to the impulse given to the soccer ball, and acts towards the __________ (right/left).

Question 8

What is the change in momentum of the bowling ball?

A. 10 kg m s^{-1}

B. 10 kg m s^{-1} to the right

C. 10 kg m s^{-1} to the left

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The content in this lesson is considered fundamental prior knowledge to Newton's laws of motion (Unit 3 AOS 1).

Theory summary

- Momentum is a vector quantity that is the product of the velocity and mass of an object measured in kg m s^{-1} or N s.
  - $p = mv$
- The law of conservation of momentum states that the total momentum before a collision will be equal to the total momentum after the collision within an isolated system.
  - $\Sigma p_i = \Sigma p_f$
- When an object experiences a change in momentum, it is due to a net force acting on the object.
  - $F_{net} = \frac{\Delta p}{\Delta t}$
- The change in momentum of an object is called impulse.
  - $\Delta p = F\Delta t$
  - $\Delta p = m\Delta v$
  - Impulse has the same direction as Δp and F_{net}.
  - Impulse is measured in kg m s^{-1} or N s.
- The impulse (change in momentum) experienced by two objects in a collision will always be equal in magnitude and opposite in direction.

CONCEPT DISCUSSION

Image: Phonlamai Photo/Shutterstock.com

Car accidents tragically occur nearly every day in Victoria. Due to new safety devices in cars the fatality rate of a car crash has decreased significantly. One of these safety devices is the airbag. Discuss how the force, time, impulse, and change in momentum on someone's head would vary during a collision when an airbag is installed vs. when one isn't present.

Prompts:

- How do the initial and final velocities of the head vary with and without airbags?
- How does change in momentum relate to impulse?
- What is the relationship between impulse, force, and time?
- How does the time of a collision affect the force experienced by the head?

9B Questions

Mild 🌶 Medium 🌶🌶 Spicy 🌶🌶🌶

Deconstructed exam-style

Use the following information to answer questions 9-14.

Block *A* of mass 2.0 kg is moving to the right at a speed of 10 m s^{-1}. It then collides and sticks to block *B*, which is stationary of mass 5.0 kg. The force during the collision acts over 4.0×10^{-2} s.

Question 9 (1 MARK) 🌶

Which of the following represents the momentum of block *A* before the collision.

A. 0 kg m s^{-1}

B. 5.0 kg m s^{-1} to the right

C. 10 kg m s^{-1} to the right

D. 20 kg m s^{-1} to the right

Question 10 (1 MARK)

Which of the following represents the momentum of block *B* before the collision?

A. 0 kg m s^{-1}

B. 5.0 kg m s^{-1} to the right

C. 10 kg m s^{-1} to the right

D. 20 kg m s^{-1} to the right

Question 11 (1 MARK)

Which of the following represents the total momentum after the collision?

A. 0 kg m s^{-1}

B. 5.0 kg m s^{-1} to the right

C. 10 kg m s^{-1} to the right

D. 20 kg m s^{-1} to the right

Question 12 (1 MARK)

Which of the following options represents the velocity of the two blocks after the collision?

A. 10 m s^{-1} to the right

B. 4.0 m s^{-1} to the right

C. 2.9 m s^{-1} to the right

D. 1.4 m s^{-1} to the right

Question 13 (1 MARK)

Which of the following options represents the change in momentum of block *B*?

A. 50 kg m s^{-1} to the left

B. 14 kg m s^{-1} to the right

C. 20 kg m s^{-1} to the left

D. 8.0 kg m s^{-1} to the right

Question 14 (6 MARKS)

Determine the magnitude of the average force experienced by block *B* when it collides with block *A*.

Exam-style

Question 15 (2 MARKS)

A bird of mass 3.5 kg is migrating south at a speed of 10 m s^{-1}. What is the momentum of the bird?

Question 16 (1 MARK)

A golf club strikes a stationary golf ball of mass 0.040 kg. The golf club is in contact with the ball for one millisecond. The ball moves off at 50 m s^{-1}. The average force exerted by the club on the ball is closest to

A. 2.0 N.

B. 1.0×10^3 N.

C. 2.0×10^3 N.

D. 1.0×10^6 N.

VCAA 2018 (NHT) exam Multiple choice Q12

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Question 17 (1 MARK)

A 45 g golf ball, initially at rest, is hit by a golf club. The contact time between the club and the ball is 0.50 ms. The magnitude of the final velocity of the ball is 41 m s^{-1}. Which one of the following is closest to the magnitude of the average force experienced by the golf ball?

A. 0.18 kN

B. 0.37 kN

C. 1.8 kN

D. 3.7 kN

VCAA 2021 (NHT) exam Multiple choice Q3

Question 18 (5 MARKS)

A small rubber ball of mass 50 g falls vertically from a given height and rebounds from a hard floor. The ball's speed immediately before impact is 3.6 m s^{-1}. The ball rebounds upward at a speed of 3.3 m s^{-1} immediately after it leaves the floor. The ball is in contact with the floor for 40 ms.

a. Calculate the magnitude and direction of the net average force acting on the 50 g ball while it is in contact with the floor. Show your working. (4 MARKS)

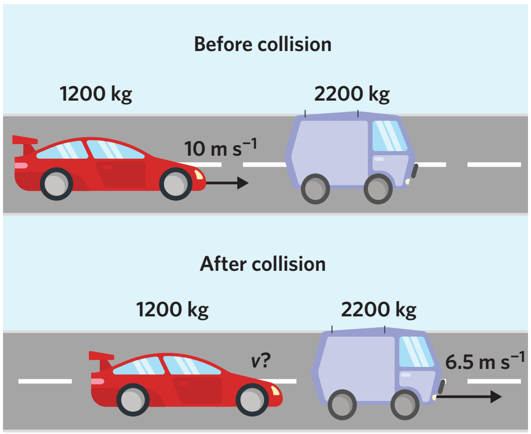
b. Just before the ball hits the floor, it has a certain amount of vertical momentum, *p*. At one instant when the ball is in contact with the floor, it is stationary before it rebounds.

What has happened to the vertical momentum, *p*, of the ball when it is stationary? (1 MARK)

VCAA 2021 (NHT) exam Short answer Q18a,c

Question 19 (9 MARKS)

Jacinda designs a computer simulation program as part of her practical investigation in the physics of vehicle collisions. She simulates colliding a car of mass 1200 kg, moving at 10 m s^{-1}, into a stationary van of mass 2200 kg. After the collision, the van moves to the right at 6.5 m s^{-1}.



a. Calculate the speed of the car after the collision and indicate the direction it would be travelling in. Show your working. (4 MARKS)

b. The collision between the car and the van takes 40 ms.

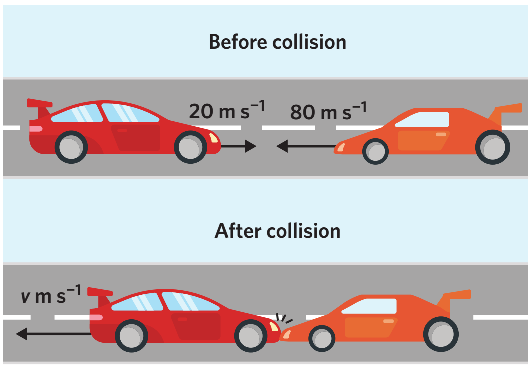
Calculate and indicate the direction of the average force on the van by the car. (3 MARKS)

c. Calculate the magnitude and indicate the direction of the average force on the car by the van. (2 MARKS)

2020 VCAA exam Short answer Q10a,c(i),c(ii)

Question 20 (6 MARKS)

During the Melbourne grand prix, a car accidentally enters the track and has a head-on collision with an F1 car. The car of mass 1900 kg was travelling at 20 m s^{-1} to the right and the F1 car of mass 750 kg was travelling at 80 m s^{-1} to the left. After the collision, the two cars stick together. Assume the two cars are an isolated system.



a. Calculate the total momentum of the system. (3 MARKS)

b. Calculate the final velocity, *v* m s^{-1}, of the two cars immediately after the collision. (3 MARKS)

Question 21 (7 MARKS)

A truck of mass 10 000 kg is travelling along an outback highway at a speed of 25 m s^{-1}. A camel walks onto the road and the truck is forced to stop with an average breaking force of 12 500 N.

a. Show that the magnitude of the impulse experienced by the truck is 2.5×10^5 kg m s^{-1}. (1 MARK)

b. Calculate how long the truck took to come to rest. (2 MARKS)

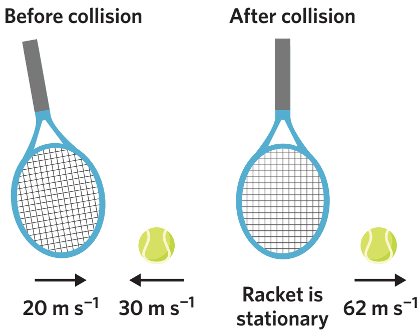
c. Calculate the magnitudes of both the initial and final momentum of the truck. (2 MARKS)

d. Is momentum conserved in this situation? Explain your answer. (2 MARKS)

Question 22 (8 MARKS)

A young tennis player is frustrated as to why he is unable to hit the ball as hard as his opponents. Instead of trying to improve his game, he intends to use his physics knowledge to analyse his shots. He compiles the following data.

Mass of tennis ball	0.050 kg
Mass of tennis racket	0.230 kg
Speed of tennis ball before being struck	30 m s^{-1} (towards the racket)
Speed of tennis ball after being struck	62 m s^{-1} (away from the racket)
Speed of tennis racket before striking the ball	20 m s^{-1}
Average force on the tennis ball by the racket	230 N



a. Calculate the magnitude of the impulse given to the tennis ball by the racket. Include an appropriate unit in your answer. (2 MARKS)

b. What is the magnitude and direction (according to the diagram) of the impulse given to the racket by the tennis ball? (2 MARKS)

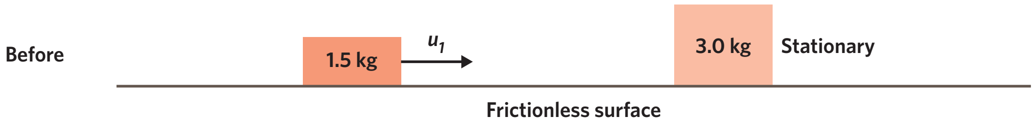
c. Calculate the time that the tennis ball is in contact with the racket. (2 MARKS)

d. What is the magnitude and direction (according to the diagram) of the force acting on the tennis racket? (2 MARKS)

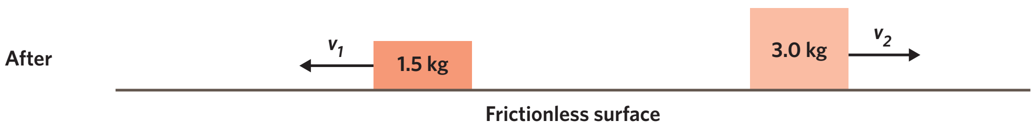
Adapted from VCAA 2019 (NHT) exam Short answer Q7a,b

Question 23 (3 MARKS)

A 1.5 kg block is initially moving towards the right at a speed of u_1 on a frictionless surface towards a stationary block of mass 3.0 kg.



After the collision, the 1.5 kg block is moving to the left at a speed of v_1 and the 3.0 kg block is moving towards the right at a speed of v_2.



The 3.0 kg block has a greater momentum after the collision than the 1.5 kg block did before the collision.

Explain why the greater momentum of the 3.0 kg block after the collision is consistent with the law of conservation of momentum. Use calculations to support your answer.

Adapted from VCAA 2012 Exam 1 Short answer Q2

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9B QUESTIONS

Key science skills

Question 24 (8 MARKS)

A physics teacher decides that her students are not well enough prepared for the key science skills section of their exam and sets them a surprise quiz on a Friday afternoon. One question presents the students with a toy car of mass 1 kg, that collides and sticks to a second stationary toy car. Information about the initial velocity of the first toy car and the velocity of the combined toy cars after the collision is given. It is known that there is an uncertainty in the combined velocity after the collision of ± 0.25 m s^{-1}.

Initial velocity of first toy car before collision, u (m s^{-1}) to the right	Velocity of combined toy cars after collision, v (m s^{-1}) to the right
2.0	0.66
4.0	1.45
6.0	1.80
8.0	2.70
10.0	3.30

a. On a set of axes, plot the data for the magnitude of the velocity of the combined cars on the vertical axis and the magnitude of the initial velocity on the horizontal axis. Include the following:

- An appropriate scale
- Axis labels with units
- Uncertainty bars
- A line of best fit (5 MARKS)

b. Knowing that the conservation of momentum leads to $m_1 \times u = (m_1 + m_2) \times v$, use the gradient of the line of best fit to determine the mass of the second toy car. (3 MARKS)

FROM LESSON 11D & 11E

Previous lessons

Question 25 (1 MARK)

Which of the following doses is likely to lead to severe short term effects?

A. 0.5 Gy

B. 5.0 Gy

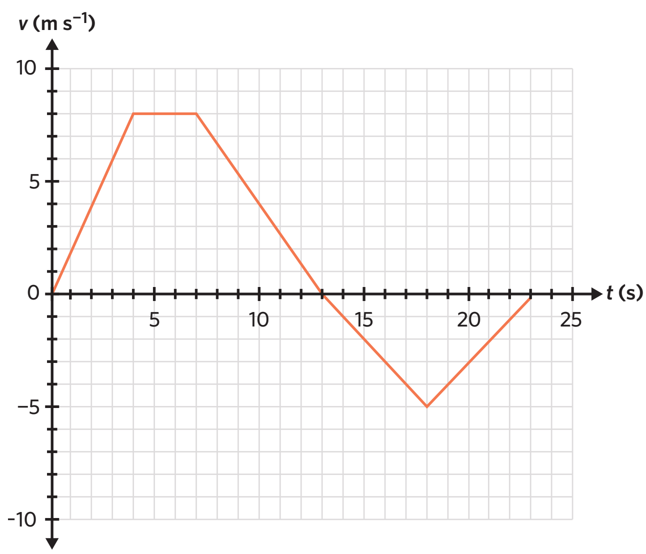
C. 0.5 Sv

D. 5.0 Sv

FROM LESSON 4D

Question 26 (4 MARKS)

Upon entering Worthwools, Ken Ematics sees that there is only one toilet paper roll left. The included velocity vs time graph represents his motion as he sprints in a straight line to the toilet paper and then walks to the checkout to pay.



a. What is Ken's acceleration over the first 4.0 seconds? (1 MARK)

b. By calculating Ken's displacement, determine how far he is from where he started. (3 MARKS)

FROM LESSON 8B

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9C Force vectors in two dimensions

STUDY DESIGN DOT POINT

- apply the vector model of forces, including vector addition and components of forces, to readily observable forces including the force due to gravity, friction and normal forces

9A 9B 9C 9D 9E 9F

2.1.9.1 Force vector components

2.1.9.2 Addition and subtraction of forces in two dimensions

ESSENTIAL PRIOR KNOWLEDGE

8A Vectors
9A Newton's second law
- Finding angles with trigonometry
- Pythagorean theorem

See questions 73–76.

ACTIVITIES

Log into your Edrolo account for activities that support this lesson.

How do we analyse the forces acting on a crane?

Having learned about some types of forces and Newton's laws in Lesson 9A, this lesson will expand our understanding to include force vectors in two dimensions and how to add and subtract these vectors. This knowledge will later be used to analyse more complex force systems.

KEY TERMS AND DEFINITIONS

vector resolution breaking down a vector into two perpendicular components

Force vector components 2.1.9.1

A vector can be resolved into two perpendicular components using trigonometry, usually in the horizontal (x) and vertical (y) directions.

Theory and applications

We often need to deal with forces that act at an angle in a two-dimensional plane. In these situations, the vectors can be resolved (broken down) into two perpendicular components, which sum to the original vector, in order to apply Newton's second law to the situation.

How can we resolve a vector in two dimensions?

A force that acts to the right and up, as in Figure 1, can be represented by a component to the right and another component upwards.

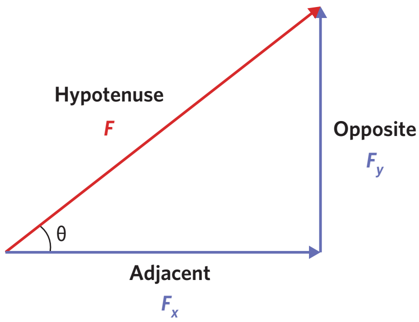

Figure 1 A force vector in two dimensions

Trigonometry is used to determine the magnitude of the two perpendicular components.

$$F_x = F\cos(\theta)$$
$$F_y = F\sin(\theta)$$

Pythagoras' theorem and trigonometry are used to determine the magnitude and direction of a force from its perpendicular components or the value of the angle θ (see Figure 2).

$$F_{net} = \sqrt{F_x^{\,2} + F_y^{\,2}}$$
$$\theta = \tan^{-1}\left(\frac{F_y}{F_x}\right)$$

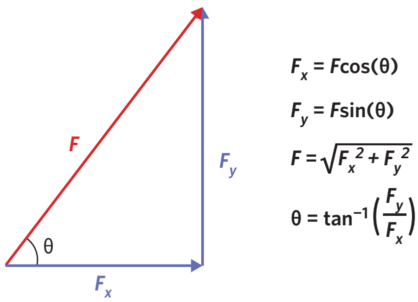

Figure 2 A force vector with its components in the x-y plane

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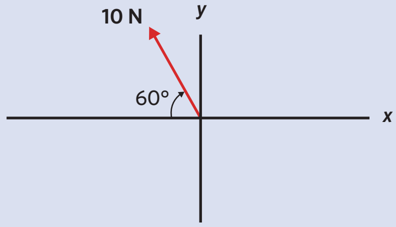
WORKED EXAMPLE 1

A force of 10 N acts at 60° above the negative direction of the x-axis. Determine the components of this force in the x- and y-directions. Take the positive directions as to the right and upwards.



Step 1

Determine the angle from the horizontal, magnitude of force and formulas relating these variables.

$\theta = 60°, F = 10\text{ N}, F_x = ?, F_y = ?$

$F_x = F\cos(\theta)$

$F_y = F\sin(\theta)$

Step 2

Substitute values into the relevant formula for the horizontal force component. Indicate direction from x-y plane.

$F_x = 10 \times \cos(60°) = 5\text{ N}$

$F_x = 5$ N, acting towards the left

Step 3

Substitute values into the relevant formula for the vertical force component. Indicate direction from x-y plane.

$F_y = 10 \times \sin(60°) = 8.66 = 8.7\text{ N}$

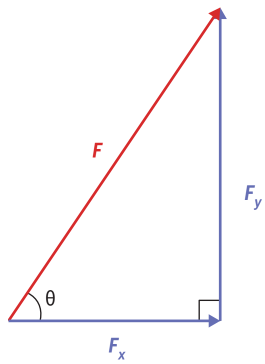
$F_y = 8.7$ N, acting upwards

USEFUL TIP

It is important to define the positive direction in both dimensions, with the positive directions usually taken as to the right and upwards.

Progress questions

Use the following force vector diagram to answer questions 1 and 2.



Question 1

Which of the following options correctly identifies the value of F_x and F_y?

A. $F_x = F\sin(\theta), F_y = F\cos(\theta)$

B. $F_x = F\cos(\theta), F_y = F\sin(\theta)$

Question 2

Which of the following equations represents the magnitude of the vector F?

A. $\sqrt{F_x^{\,2} + F_y^{\,2}}$

B. $F_x^{\,2} + F_y^{\,2}$

C. $F_x + F_y$

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Addition and subtraction of forces in two dimensions 2.1.9.2

Forces can be added or subtracted graphically using the tip-to-tail or parallelogram method, and algebraically by considering the components of forces.

Theory and applications

When multiple forces act on an object, the net force is the vector sum of all of the forces. There are two approaches we can use to add or subtract vectors:

- Approach 1: graphically adding and subtracting vectors
- Approach 2: algebraically adding and subtracting vectors

How can we add and subtract vectors graphically?

To graphically add two vectors, we will discuss two methods: the tip-to-tail method and the parallelogram method. For the tip-to-tail method, the tip of the first vector is connected to the tail of the second vector (see Figure 3). The resultant force is drawn from the tail of the first vector to the tip of the second.[1]

Figure 3 The tip and tail of a vector

KEEN TO INVESTIGATE?

1 **How can we visualise vectors on an *x*-*y* plane?**
Search: Vector addition simulation

Consider the vectors A and B shown in Figure 4. The tip of the first vector, A, is connected to the tail of the second vector, B, and the resultant vector, C, is drawn from the tail of A to the tip of B. This principle applies to the addition of any number of vectors.

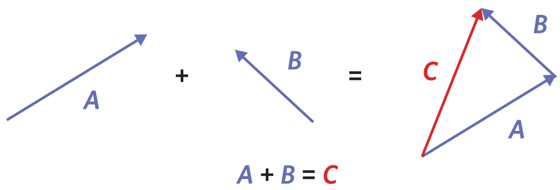


Figure 4 The graphical addition of vectors A and B, using the tip-to-tail method

The negative of a vector has the same magnitude but acts in the opposite direction compared to the positive, meaning graphically the tip and tail will flip. To graphically subtract vectors, such as $A - B$, we take vector A and add it to the negative of vector B, so $A - B$ becomes $A + (-B)$ (see Figure 5).

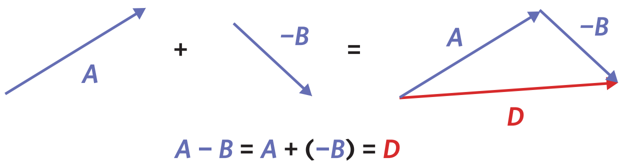


Figure 5 The graphical subtraction of vector B and vector A, using the tip-to-tail method

The parallelogram method will not be used explicitly in the following worked examples, but is another useful method of finding the addition or subtraction of two vectors. For the addition of two vectors, they are drawn tail-to-tail, and the resultant vector is drawn from the point the tails meet to the opposite corner of the parallelogram they create (see Figure 6).

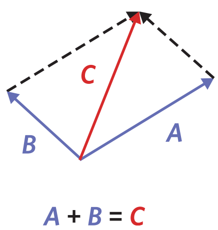
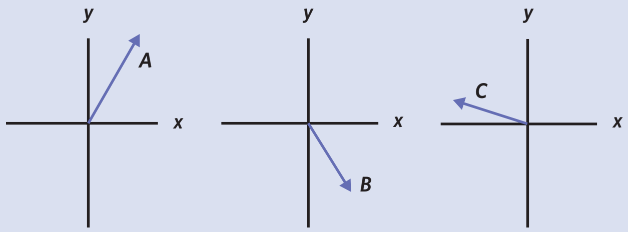


Figure 6 The graphical addition of vector B from vector A, using the parallelogram method

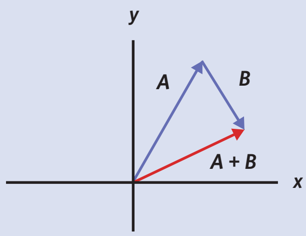
WORKED EXAMPLE 2

Graphically represent the following vector additions and subtractions. Label each force, including the resultant force.



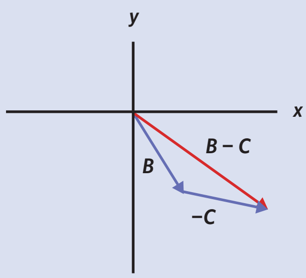
a. $A + B$

Using the tip-to-tail method, draw vector A and then draw vector B starting from vector A's tip.



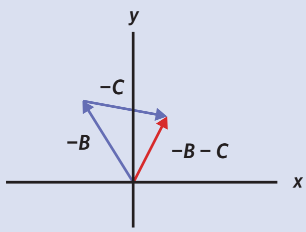
b. $B - C$

Using the tip-to-tail method, draw vector B and then draw vector $-C$ starting from vector B's tip.



c. $-B - C$

Using the tip-to-tail method, draw vector $-B$ and then draw vector $-C$ starting from vector $-B$'s tip.



How can we add and subtract vectors algebraically?

To add or subtract forces algebraically, we must resolve each vector into its perpendicular components, making sure to state which direction is positive for each dimension. We can then add or subtract the vector components in each dimension, and the signs will indicate their directions. The results of these additions or subtractions are the perpendicular components of the resultant vector (see Figure 7).

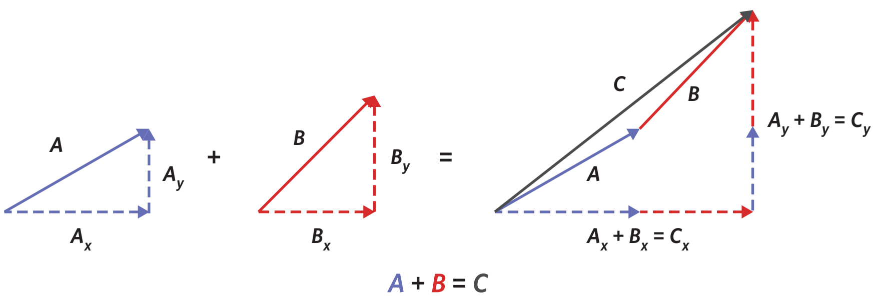


Figure 7 Addition of perpendicular components of two vectors

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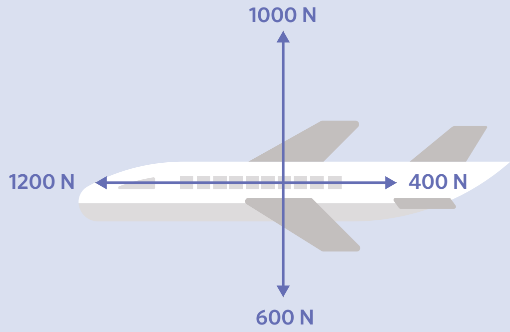
WORKED EXAMPLE 3

Determine the net force acting on the plane. Represent this on a diagram. Take the positive directions as to the right and upwards.



Step 1

Identify the force directions and formula that relates the sum of the horizontal and vertical forces.

$F_{right} = 400$ N, $F_{left} = -1200$ N, $F_{up} = 1000$ N, $F_{down} = -600$ N, $F_x = ?$, $F_y = ?$

$F_x = F_{right} + F_{left}$,

$F_y = F_{up} + F_{down}$

Step 2

Substitute forces into relevant formulas and solve for the sum of horizontal and vertical forces.

$F_x = 400 - 1200 = -800$ N

$F_y = 1000 - 600 = 400$ N

Step 3

Identify net forces in both directions, and formula that relates these variables.

$F_x = -800$ N, $F_y = 400$ N, $F_{net} = ?$, $\theta = ?$

$F_{net} = \sqrt{F_x^{\,2} + F_y^{\,2}}$

$\theta = \tan^{-1}\left(\frac{F_y}{F_x}\right)$

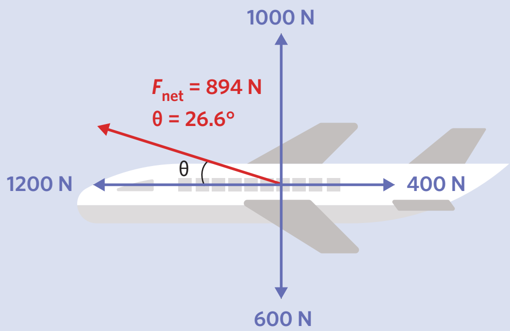
Step 4

Substitute values for F_x and F_y into both formulas, and solve for net force. Draw this on the force diagram.

$F_{net} = \sqrt{(-800)^2 + 400^2} = 894.4 = 894$ N

$\theta = \tan^{-1}\left(\frac{400}{-800}\right) = -26.56 = -26.6°$

Net force has a magnitude of 894 N, and acts at an angle of 26.6° from the negative x-axis.



Algebraically adding and subtracting forces that act in different directions in a two dimensional space relies on resolving the vectors into their components. We can then work in the two perpendicular directions independently (usually the x-y directions), as in Worked Example 4, to find the resultant vector.[2]

KEEN TO INVESTIGATE?

[2] **How can we apply Newton's second law in two dimensions?**
Search YouTube: Three forces Newton's second law

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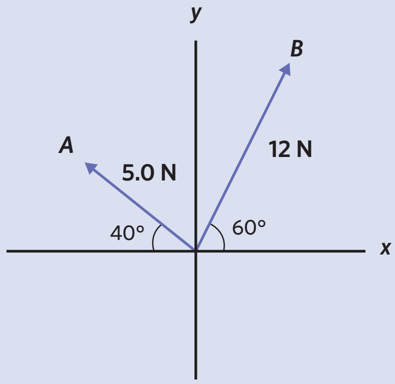
WORKED EXAMPLE 4

Consider the diagram which shows two forces, A and B, acting within a two-dimensional plane. Take the positive directions as to the right and upwards.



a. Add forces A and B. Provide the magnitude and direction (measured from the positive x-direction) of the result.

Step 1

Identify the forces and their angles, and the relevant formula to resolve these vectors.

$A = 5.0$ N, $B = 12$ N, $\alpha = 40°$, $\beta = 60°$, $F_x = ?$, $F_y = ?$

$F_x = A_x + B_x = A\cos(\alpha) + B\cos(\beta)$

$F_y = A_y + B_y = A\sin(\alpha) + B\sin(\beta)$

Step 2

Substitute the values into the relevant formulas and solve for net x and y components.

$F_x = -5.0\cos(40°) + 12\cos(60°) = 2.17 = 2.2$ N

$F_y = 5.0\sin(40°) + 12\sin(60°) = 13.6 = 14$ N

Step 3

Identify net forces in both directions, and formula that relates these variables.

$F_x = 2.17$ N, $F_y = 13.6$ N, $F_{net} = ?$, $\theta = ?$

$F_{net} = \sqrt{F_x{}^2 + F_y{}^2}$

$\theta = \tan^{-1}\left(\frac{F_y}{F_x}\right)$

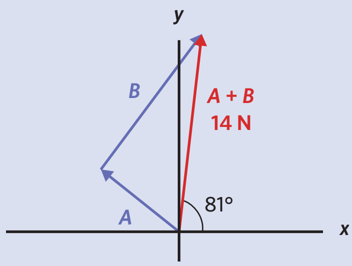
Step 4

Substitute values for F_x and F_y into both formulas, and solve for net force.

$F_{net} = \sqrt{2.17^2 + 13.6^2} = 13.8 = 14$ N

$\theta = \tan^{-1}\left(\frac{13.6}{2.17}\right) = 80.9 = 81°$

Net force has a magnitude of 14 N, and acts at an angle of 81° from the positive direction of the x axis.



b. Subtract force A from force B. Provide the magnitude and direction (measured from the positive x-direction) of the result.

Step 1

Identify the forces and their angles, and the relevant formula to resolve these vectors.

$A = 5.0$ N, $B = 12$ N, $\alpha = 40°$, $\beta = 60°$, $F_x = ?$, $F_y = ?$

$F_x = -A_x + B_x = -(-A\cos(\alpha)) + B\cos(\beta)$

$F_y = -A_y + B_y = -A\sin(\alpha) + B\sin(\beta)$

Continues →

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Step 2

Substitute the values into the relevant formulas and solve for net x and y components.

$F_x = 5.0\cos(40°) + 12\cos(60°) = 9.83 = 9.8 \text{ N}$

$F_y = -5.0\sin(40°) + 12\sin(60°) = 7.18 = 7.2 \text{ N}$

Step 3

Identify net forces in both directions, and formula that relates these variables.

$F_x = 9.83 \text{ N}, F_y = 7.18 \text{ N}, F_{net} = ?, \theta = ?$

$$F_{net} = \sqrt{F_x^{\ 2} + F_y^{\ 2}}$$

$$\theta = \tan^{-1}\left(\frac{F_y}{F_x}\right)$$

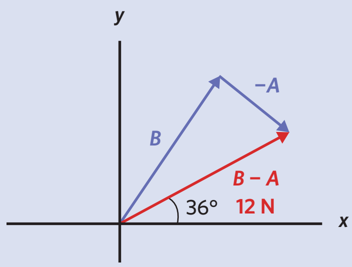
Step 4

Substitute values for F_x and F_y into both formulas, and solve for net force.

$$F_{net} = \sqrt{9.83^2 + 7.18^2} = 12.2 = 12 \text{ N}$$

$$\theta = \tan^{-1}\left(\frac{7.18}{9.83}\right) = 36.1 = 36°$$

Net force has a magnitude of 12 N, and acts at an angle of 36° from the positive direction of the x-axis.



Progress questions

Use the following force vector diagram to answer questions 3 and 4.

Question 3

Which force (A–D) best represents the sum of forces P and Q?

Question 4

If vector P has a magnitude of 3 N and vector Q has a magnitude of 5 N, which of the following equations best represents $P - Q$? Take the positive directions as to the right and upwards.

A. $-3 - 5$

B. $3 + (-5)$

C. $(-3) + 5$

D. $3 - (-5)$

Continues →

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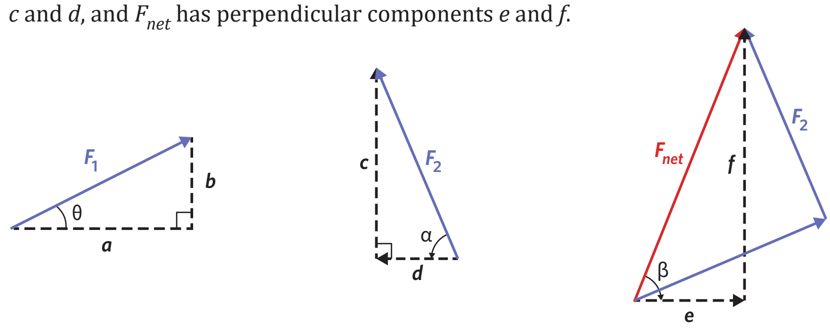
Use the following information to answer questions 5-7.

Two force vectors, F_1 and F_2, are added together to form the force vector F_{net}. F_1 has perpendicular components a and b, F_2 has perpendicular components c and d, and F_{net} has perpendicular components e and f.



Question 5

Which of the following equations correctly represents the horizontal component e?

A. $e = a + d$

B. $e = a - d$

C. $e = b + c$

D. $e = a + b + c + d$

Question 6

Which of the following equations correctly represents the vertical component f?

A. $f = a + d$

B. $f = a - d$

C. $f = b + c$

D. $f = a + b + c + d$

Question 7

Which of the following equations correctly represents the angle α?

A. $\alpha = \cos^{-1}\left(\frac{f}{F_{net}}\right)$

B. $\alpha = \tan^{-1}\left(\frac{c}{d}\right)$

C. $\alpha = \theta + \beta$

D. $\alpha = \theta$

Theory summary

- Forces can be resolved into two perpendicular components using trigonometry.
  - $F_x = F\cos(\theta)$ and $F_y = F\sin(\theta)$, where θ is measured from the positive x-direction.
- The magnitude and direction of a force can be found from its perpendicular components using the Pythagorean theorem and trigonometry.
- Graphically, vectors can be added by joining them tip-to-tail, or by the parallelogram method.
  - When subtracting, add the negative of the vector being subtracted.
- To algebraically add (or subtract) forces that act in different directions within a 2D plane, add (or subtract) the components of each vector then use the new components to find the resultant vector.

The content in this lesson is considered fundamental prior knowledge to Newton's laws of motion (Unit 3 AOS 1).

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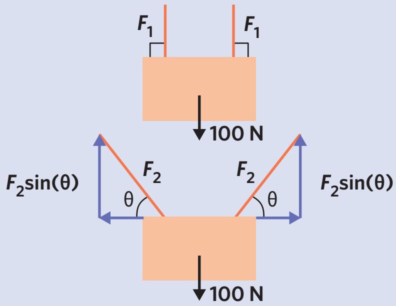
CONCEPT DISCUSSION

A builder is deciding how to use two pieces of weak string to support a weight of 100 N. Two possibilities are shown in the included diagram, where the strings are positioned vertically or at angles of 45° to the horizontal. Discuss which configuration is more likely to cause the strings to break.



Prompts:

- What is the net force acting on the mass?
- How is the 100 N force shared between the two vertical pieces of string?
- What component of the 45° forces along the strings act to oppose the 100 N force?
- What is the value of the total force along the 45° strings?

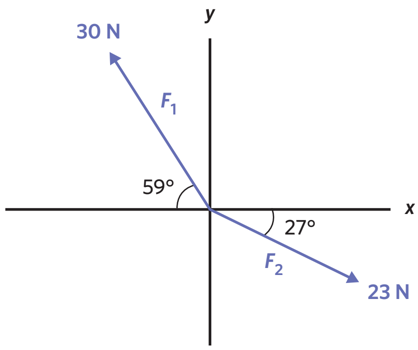
9C Questions

Mild 🌶 Medium 🌶🌶 Spicy 🌶🌶🌶

Deconstructed exam-style

Use the following information to answer questions 8–12.

An object is acted on by three forces; F_1, F_2 and F_3. The net force acting on the object is zero. Two of these forces, F_1 and F_2, are shown in the included diagram. Take the positive directions as to the right and upwards.



Question 8 (1 MARK) 🌶

As the net force acting on the object is zero, which of the following equations correctly represents F_3 in terms of the other forces?

A. $F_3 = F_1 + F_2$

B. $F_3 = -(F_1 + F_2)$

C. $F_3 = F_1 - F_2$

D. $F_3 = F_2 - F_1$

Question 9 (1 MARK) 🌶

Which of the following equations correctly represents the x-component of $F_1 + F_2$, F_x?

A. $F_x = (-30 \times \cos(59°)) + 23 \times \cos(27°)$

B. $F_x = 30 \times \cos(59°) + 23 \times \cos(27°)$

C. $F_x = 30 \times \cos(59°) + (-23 \times \cos(27°))$

D. $F_x = (-30 \times \sin(59°)) + 23 \times \sin(27°)$

Question 10 (1 MARK) 🌶

Which of the following equations correctly represents the y-component of $F_1 + F_2$, F_y?

A. $F_y = 30 \times \sin(59°) + 23 \times \sin(27°)$

B. $F_y = 30 \times \sin(59°) + (-23 \times \sin(27°))$

C. $F_y = 30 \times \cos(59°) + (-23 \times \sin(27°))$

D. $F_y = (59°) + 23 \times \sin(27°)$

Question 11 (1 MARK)

Which of the following options correctly identifies the magnitude of $F_1 + F_2$?

A. $F_x + F_y$

B. $\sqrt{F_x^{\,2} - F_y^{\,2}}$

C. $\sqrt{F_x^{\,2} + F_y^{\,2}}$

D. $F_x^{\,2} + F_y^{\,2}$

Question 12 (7 MARKS)

What is the magnitude and direction of the third force, such that the object experiences no net force?

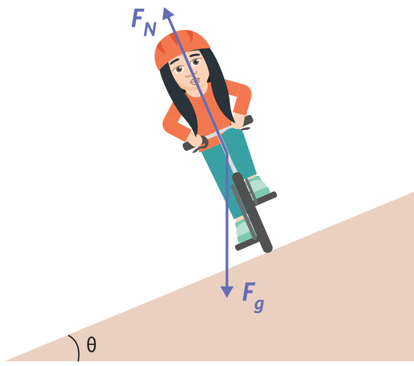
Exam-style

Question 13 (2 MARKS)

When a cyclist is moving around a banked track as in the included image, two forces act on them. The force due to gravity, F_g, acts vertically downwards and the normal force, F_N, acts perpendicular to the slope.

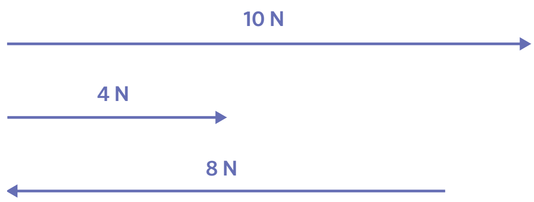
On a copy of this diagram, show the vector addition of F_N and F_g with a dashed line.

Adapted from 2017 VCAA Exam Section B Q7a



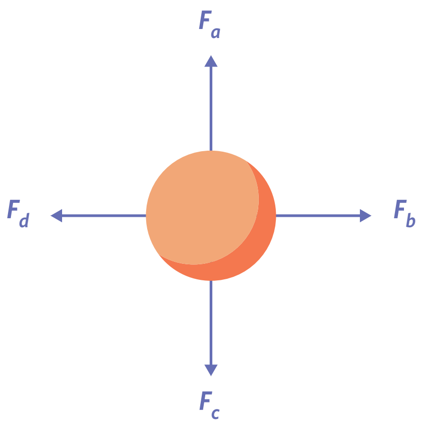
Question 14 (2 MARKS)

Draw and label the resultant force when the three force vectors shown are added together. Your label should include the force magnitude.



Question 15 (4 MARKS)

Four students are each pulling on ropes during a four-person tug of war. The magnitude of the forces exerted by the four students are F_a = 190 N, F_b = 230 N, F_c = 150 N and F_d = 145 N. The direction of the four forces are shown on the included diagram.



a. Calculate the magnitude of the net force acting at the centre of the tug of war. (3 MARKS)

b. What angle does the net force make with the positive x-axis? (1 MARK)

Adapted from 2018 VCAA Exam Section A Q5

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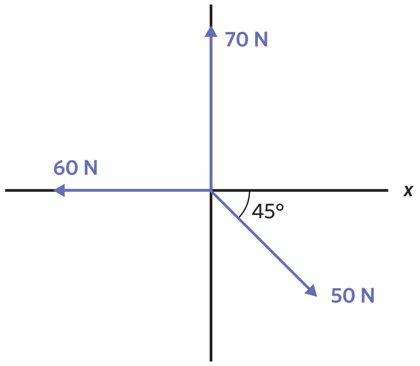
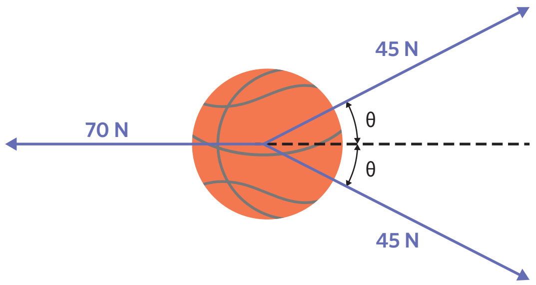
Question 16 (6 MARKS)

Three forces act on an object as shown in the included diagram. Calculate the magnitude of the net force acting on the object and its angle from the negative x-direction.



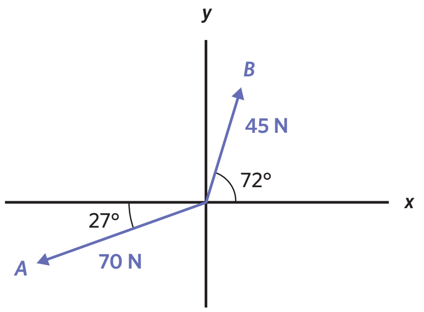
Question 17 (3 MARKS)

In a game of basketball, three different players are pulling on the ball. One player pulls to the left with a force of 70 N, and the other two players pull with a force of 45 N at an angle θ from the horizontal. The net force on the ball is zero. Determine the value of θ.



Question 18 (11 MARKS)

Two forces, A and B, act on an object of mass 5.0 kg.



a. Determine the magnitude of the net force on the object. (5 MARKS)

b. Determine the magnitude of the acceleration of the object. (2 MARKS)

c. Calculate the angle that the net force makes with the positive x-axis. (2 MARKS)

d. Draw a vector representing the net force. Include a magnitude and direction. (2 MARKS)

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Key science skills

Question 19 (3 MARKS)

Two school children, Forcia and Victor, are using a piece of string to exert a force on an object at various angles to explore the idea of force vectors. They each use a force transducer to measure the force with which the object is being pulled. They record the force displayed on the force transducer for one experimental setup that is repeated five times and calculate an average. The true value of the force is 5.50 N.

	Meas. 1 (N)	Meas. 2 (N)	Meas. 3 (N)	Meas. 4 (N)	Meas. 5 (N)	Avg. (N)
Forcia	5.43	5.41	5.57	5.50	5.63	5.51
Victor	5.43	5.45	5.42	5.41	5.42	5.43

Identify and explain which set of results is more accurate and which set is more precise.

FROM LESSON 11C

Previous lessons

Question 20 (1 MARK)

A person is exposed to 4.5 Gy of alpha radiation, with a radiation weighting factor of 20. Which of the following is the equivalent dose of radiation received?

A. 4.5 Gy

B. 4.5 Sv

C. 90 Gy

D. 90 Sv

FROM LESSON 4D

Question 21 (5 MARKS)

The driver of a BMW accelerates from rest at a rate of 7.0 m s^{-2} away from a set of traffic lights. Ignoring his speedometer, the driver uses a calculator in order to determine his speed after accelerating for 5.0 seconds.

a. Determine the speed of the BMW after 5.0 seconds. (2 MARKS)

b. Looking up from his calculator, the driver sees an elephant on the road 75 m ahead. Knowing that his car is able to decelerate at 10.0 m s^{-2}, he then calculates if he will be able to stop in time before hitting the elephant.

Will the BMW stop before it makes contact with the elephant? Use calculations to support your answer. (3 MARKS)

FROM LESSON 8C

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9D Inclined planes and connected bodies

Image: Nightman1965/Shutterstock.com

STUDY DESIGN DOT POINT

- apply the vector model of forces, including vector addition and components of forces, to readily observable forces including the force due to gravity, friction and normal forces

9A 9B 9C 9D 9E 9F

2.1.9.3 Inclined planes

2.1.9.4 Connected bodies

ESSENTIAL PRIOR KNOWLEDGE

9A Force due to gravity

9A Newton's second law

9C Resolving forces in two dimensions

See questions 77–79.

ACTIVITIES

Log into your Edrolo account for activities that support this lesson.

How does the force produced by a tugboat pull an entire oil tanker?

When objects are connected to one another, due to either tension or contact, they will accelerate together at the same rate. This lesson will build on the ideas of Newton's laws and force vectors in two dimensions to analyse complex situations, such as objects on inclined planes and connected bodies.

KEY TERMS AND DEFINITIONS

connected bodies two or more objects either in direct contact or attached by a string or similar connection

friction a contact force that resists the relative motion of two surfaces in contact

inclined plane a flat surface at an angle to the horizontal plane

tension a pulling or stretching force that acts through an object connecting two bodies

FORMULAS

- **force due to gravity**
  $F = mg$
- **Newton's second law**
  $F_{net} = ma$

Inclined planes 2.1.9.3

When an object is on an inclined plane, the normal force (F_N) will act perpendicular to the plane, the force due to gravity (F_g) will act vertically down, and the net force (F_{net}) will act parallel to the slope.

Theory and applications

When an object is placed on a hill without sufficient friction, it will accelerate down the hill. Using Newton's second law we can conclude that the net force must be acting down the slope. The hill is an example of an inclined plane: a surface that is at an angle from the horizontal.

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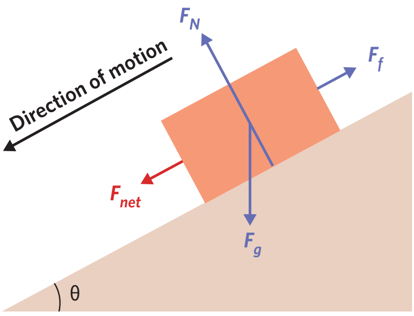

Figure 1 The basic forces that may act on a body on an inclined plane

KEEN TO INVESTIGATE?

1 **How does friction change on an inclined plane?**
Search: Static and kinetic friction on an inclined plane simulation

USEFUL TIP

A surface is referred to as rough if there are frictional forces present when an object is in contact with that surface.

How do we analyse objects on an inclined plane?

When a body is on an inclined plane (Figure 1), the forces always present are:

- the force due to gravity (F_g) which acts vertically down, and
- the normal force (F_N) which acts perpendicular to the inclined plane.

Furthermore, there may be a friction force (F_f) due to the contact between the body and the inclined plane. This friction force will act in the opposite direction to the motion.[1]

Consider the force due to gravity and the normal force. We can use tip-to-tail vector addition to confirm that the net force will act parallel to and down the plane as shown in Figure 2.

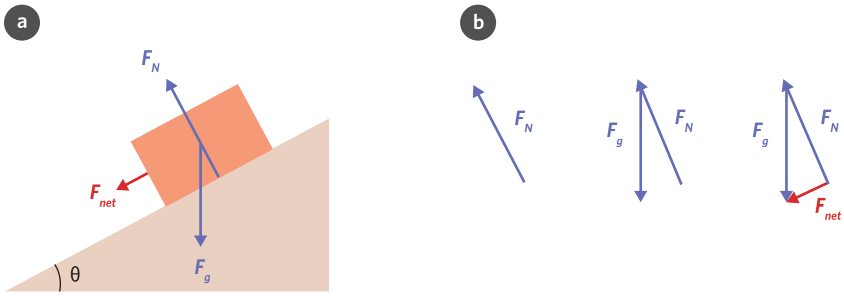

Figure 2 **(a)** Forces acting on a body on a frictionless inclined plane and **(b)** adding F_g and F_N by the tip-to-tail method

We can quantify the net force by resolving our force vectors such that all forces act parallel or perpendicular to the plane. This will allow us to use addition of vectors in one direction to find the net force. We use trigonometry to resolve F_g into two components (see Figure 3):

- The component of F_g acting parallel to the plane, $F_{g\parallel}$, is given by $mg\sin(\theta)$.
- The component of F_g acting perpendicular to the plane, $F_{g\perp}$, is given by $mg\cos(\theta)$.

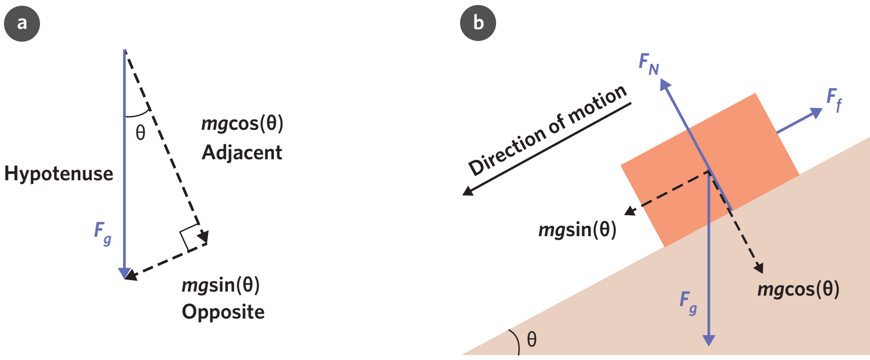

Figure 3 **(a)** Resolving F_g and **(b)** replacing F_g with its components on an inclined plane

Given that the object does not accelerate off the plane or into the plane, the normal force must balance the component of gravity that is perpendicular to the plane (if no other forces in that direction are present). That is, the magnitude of the normal force is given by:

$$F_N = F_{g\perp} = mg\cos(\theta).$$

Using Newton's second law, our equation for the net force acting on the body accelerating down the plane, if a frictional force is present, will be:

$$F_{net} = F_{g\parallel} - F_f = mg\sin(\theta) - F_f$$

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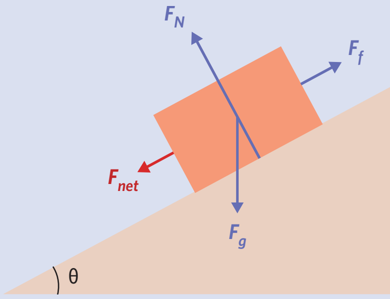
WORKED EXAMPLE 1

A block of mass 1.0 kg is placed on an inclined plane angled at 45° to the horizontal. There is a constant frictional force of 2.0 N exerted on the block by the inclined plane.



a. Calculate the magnitude of the normal force acting on the 1.0 kg block.

Step 1

Identify the forces on the object and acceleration perpendicular to the inclined plane. Take direction of F_N as positive.

$F_{g\perp} = mg\cos(\theta)$ N, $a = 0$ m s^{-2}, $F_N = ?$

$F_{net} = F_N - F_{g\perp} = ma$

Step 2

Solve for the normal force.

$F_N - mg\cos(\theta) = 0 \Rightarrow F_N = mg\cos(\theta)$

$F_N = 1.0 \times 9.8 \times \cos(45°) = 6.93 = 6.9$ N

b. Calculate the acceleration of the 1.0 kg block.

Step 1

Identify the forces on the object and acceleration parallel to the inclined plane. Take down the plane as the positive direction.

$F_{g\parallel} = mg\sin(\theta)$ N, $F_f = 2.0$ N, $F_{net} = ?$

$F_{net} = F_{g\parallel} - F_f$

Step 2

Solve for the net force acting on the object down the plane.

$F_{net} = 1.0 \times 9.8 \times \sin(45°) - 2 = 4.93$ N

Step 3

Solve for acceleration of the block.

$F_{net} = ma \Rightarrow 4.93 = 1.0 \times a$

$a = \frac{4.93}{1.0} = 4.93 = 4.9$ m s^{-2}

Progress questions

Use the following information to answer questions 1–3.

A block of mass m is at rest on a rough inclined plane angled at θ° to the horizontal.

Question 1

Which of the following correctly describes the frictional force acting on the mass?

A. No frictional force is present.

B. A frictional force is present, and acts up the plane.

Continues →

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Question 2

Which of the following correctly calculates the component of the gravitational force acting down the plane?

A. $mg\cos(\theta)$

B. $mg\sin(\theta)$

C. $mg\sin(\theta) - F_f$

Question 3

Which of the following correctly describes the relationship between the normal and gravitational force?

A. $F_N = F_g = mg$

B. $F_N = F_{g\perp} = mg\cos(\theta)$

C. $F_N = F_{g\perp} = mg\sin(\theta)$

Connected bodies 2.1.9.4

When two or more bodies are connected or are in direct contact, there is a tension force (T) or a contact force that acts on each object with equal magnitude but in opposite directions.

Theory and applications

When bodies are connected they will always travel with the same acceleration. Newton's second law can be applied to either individual bodies in the system or the system as a whole to find the acceleration or forces acting in the system.

What is tension and how do we analyse bodies connected in tension?

USEFUL TIP

In VCE physics, the string or otherwise in which the tension force exists will be considered massless, and hence not need to be included in any mass calculations.

When two or more bodies are connected by a string or similar material, the force that acts between the bodies is tension (F_T). This force has the same magnitude for both bodies, and pulls the bodies towards one another.

We experience the tension force in a game of tug of war. The tension force has the same magnitude but acts in the opposite direction on each team, meaning that both teams will be pulled by the rope towards the centre with the same force. The system will move in the direction of the team that applies a greater force on the ground than the tension in the rope, see Figure 4.

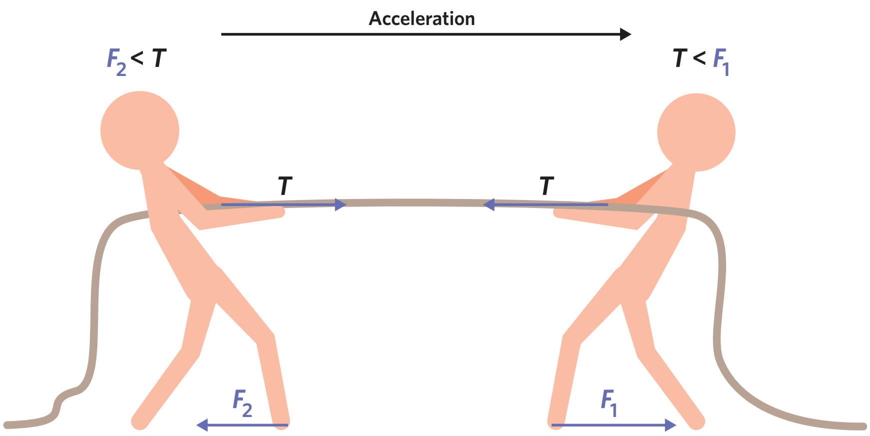

Figure 4 A tension force of equal magnitude acts in the opposite direction.

Figure 5 shows a cart, A, which is experiencing a pulling force, F_x, to the right and is towing a block, B. Both the cart and the block experience the tension force, T, which acts with equal magnitude on both objects but in the opposite direction.

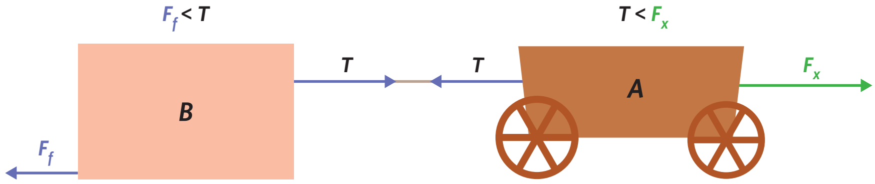

Figure 5 The horizontal forces involved when a cart is towing a block

To analyse the motion of bodies which are connected, we are able to apply Newton's second law, $F_{net} = ma$, to the entire system or to each part of the system. Figure 5 is made up of multiple systems:

- The cart and the block as a single combined system.
- The individual cart as a system.
- The individual block as a system.

When analysing the combined system, we treat the block and the cart as a single object (see Figure 6):

- The tension forces may be ignored, because they have the same magnitude in opposite directions, cancelling each other out.
- The mass of the combined system will be the sum of all bodies.

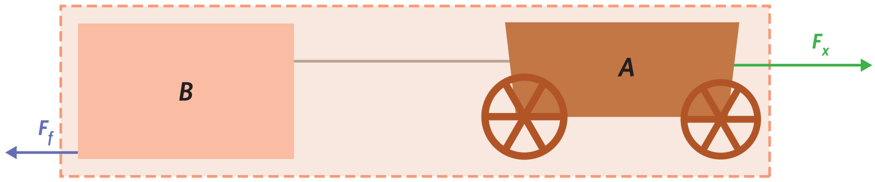

Figure 6 The horizontal forces acting on the combined cart and block system

When analysing the combined system with Newton's second law, taking the right as positive, we generate the equations:

- $F_{net} = F_x - F_f$
- $F_{net} = m_{total} a = (m_A + m_B) \times a$

When analysing an individual object within the connected body system (see Figure 7):

- We consider only the forces acting directly on that object, including the tension force.
- Use only the mass of that object.

When analysing the individual cart system with Newton's second law, taking the right as positive, we generate the equations:

- $F_{net} = F_x - T$
- $F_{net} = m_A \times a$

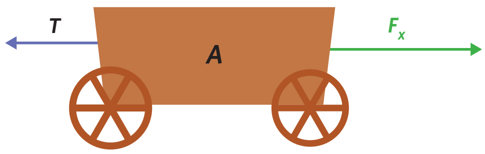

Figure 7 The horizontal forces acting on the individual cart system

STRATEGY

In order to calculate acceleration of a system, consider the combined system.
In order to calculate internal forces of a system, consider the individual bodies.

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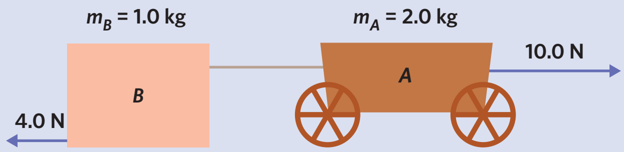
WORKED EXAMPLE 2

A cart of mass 2.0 kg pulls a block of mass 1.0 kg. The cart is pulled by a force of 10.0 N and there is a constant friction force of 4.0 N that acts on the block. Take to the right as the positive direction.



a. Calculate the magnitude of the acceleration of the block.

Step 1

Consider the combined system. Identify the mass and forces acting on the combined system, and formula that relates these variables.

$F_p = 10.0$ N, $F_f = 4.0$ N, $m_{total} = 2.0 + 1.0 = 3.0$ kg, $a = ?$

$F_{net} = ma = F_p - F_f$

Step 2

Substitute forces and mass into Newton's second law and solve for the acceleration.

$10.0 - 4.0 = 3.0 \times a$

$a = \frac{6.0}{3.0} = 2.0 \text{ m s}^{-2}$

b. Calculate the tension force in the string that connects the cart to the block.

Step 1

Consider an individual body (in this case the cart). Identify the forces acting on the body, mass, acceleration and formula that relates these variables.

$F_p = 10.0$ N, $m = 2.0$ kg, $a = 2.0 \text{ m s}^{-2}$, $F_T = ?$

$F_{net} = F_p + F_T = ma$

Step 2

Substitute the values into the formula and solve for the magnitude of tension force.

$10.0 + F_T = 2.0 \times 2.0$

$F_T = 2.0 \times 2.0 - 10.0 = -6.0$ N

KEEN TO INVESTIGATE?

[2] **How can we analyse a pulley system?**
Search YouTube: Connected bodies pulley system

We use a similar approach to answer questions when one or two of the connected masses are hanging via a pulley (see Figure 8). We can model the system as if it were on a horizontal plane, as the pulley simply changes the direction of motion. The same principle of applying individual or combined systems to find the desired force or acceleration is still suitable.[2]

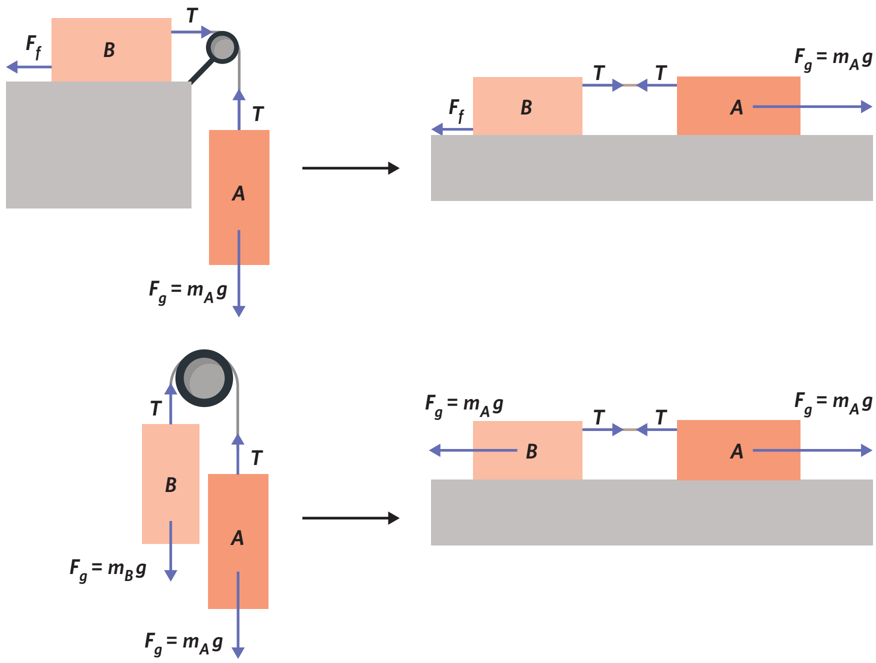


Figure 8 Representing a pulley system on a horizontal surface

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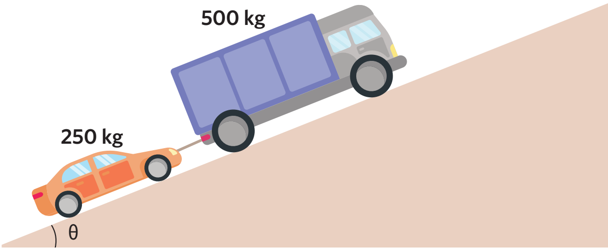
Progress questions

Use the following information to answer questions 4–6.

A truck of mass 500 kg is towing a car of mass 250 kg up a slope.



Question 4

If the tension force pulling the car up the slope is 150 N, what is the tension force pulling the truck down the slope?

A. 150 N

B. 300 N

C. More information is required.

Question 5

Which of the following best describes the magnitude of the net force acting on the car?

A. half the net force acting on the truck

B. same as the net force acting on the truck

C. double the net force acting on the truck

Question 6

Which of the following correctly calculates the net force acting on the car?

A. $F_{net} = F_T$

B. $F_{net} = F_T - 250 \times 9.8 \times \cos(\theta)$

C. $F_{net} = F_T - 250 \times 9.8 \times \sin(\theta)$

How do we analyse bodies connected in contact?

We can apply Newton's third law to analyse bodies connected in contact. In Figure 9(a), a force acts on block B due to its contact with block A, $F_{on\ B\ by\ A}$, and in Figure 9(b), a force acts on block B due to its contact with the person, A. By Newton's third law there will also be a contact force on block A by block B that is equal in magnitude and opposite in direction, $F_{on\ A\ by\ B}$.

Similar to connected bodies in tension, the way we analyse situations involving connected bodies in contact is to consider the combined system or each individual element. The only difference is that tension is being replaced by the contact force.

We can consider:

- Both blocks as a combined system.
- An individual block as a system.

When analysing the combined system, we can treat all bodies as a single object:

- Ignore the contact forces, which cancel each other out.
- The mass of the combined system will be the sum of all bodies

When analysing the combined system (see Figure 10) with Newton's second law, taking the right as positive, we generate the equations:

- $F_{net} = F_x$
- $F_{net} = m_{total} a = (m_A + m_B) \times a$

When analysing an individual object within the connected body system:

- Consider only the forces acting directly on that object, including the contact force.
- Use only the mass of that object.

When analysing the individual block A (see Figure 11) with Newton's second law (taking the right as positive) we generate the equations:

- $F_{net} = F_x - F_{on\ A\ by\ B}$
- $F_{net} = m_A \times a$

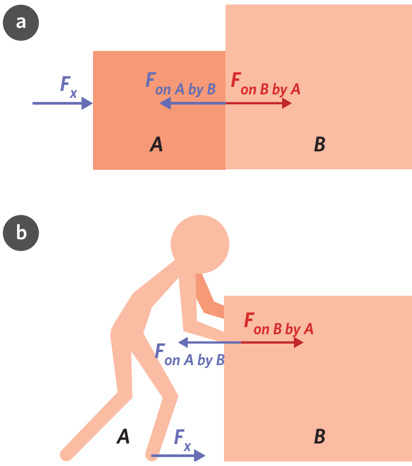


Figure 9 **(a)** The horizontal forces acting on two connected blocks with an applied force and **(b)** a block being pushed in contact with a person

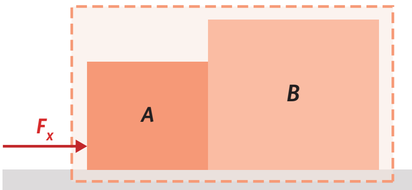


Figure 10 The horizontal forces acting on the whole system

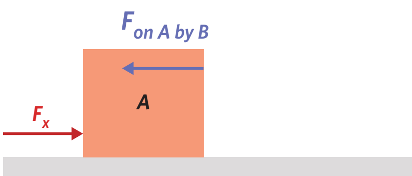


Figure 11 The horizontal forces acting on block A

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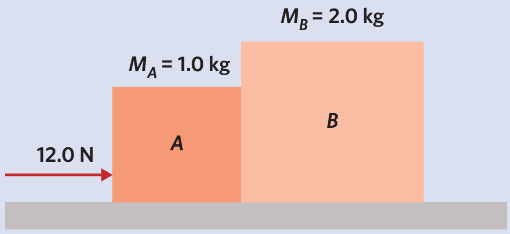
WORKED EXAMPLE 3

Two blocks, A and B, are in contact and being pushed by a force of 12.0 N on a frictionless surface. Block A has a mass of 1.0 kg and block B has a mass of 2.0 kg. Take to the right as the positive direction.



a. Calculate the acceleration of the blocks

Step 1

Consider the combined system. Identify the forces, mass and formula that relates these variables.

$F_P = 12.0$ N, $m_{total} = 1.0 + 2.0 = 3.0$ kg, $a = ?$

$F_{net} = F_P = ma$

Step 2

Substitute the values into Newton's second law and solve for the acceleration of the system.

$12.0 = 3.0 \times a$

$a = \frac{12.0}{3.0} = 4.0 \text{ m s}^{-2}$

b. Calculate the force on block A by block B

Step 1

Consider the forces acting on block A. Identify the forces, mass, acceleration and formula that relates these variables.

$F_P = 12.0$ N, $m_a = 1.0$ kg, $a = 4.0 \text{ m s}^{-2}$, $F_{on\,A\,by\,B} = ?$

$F_{net} = F_P + F_{on\,A\,by\,B} = ma$

Step 2

Substitute the values into Newton's second law and solve for force on block A by block B.

$12.0 + F_{on\,A\,by\,B} = 1.0 \times 4.0$

$F_{on\,A\,by\,B} = 4.0 - 12.0 = -8.0$ N

$F_{on\,A\,by\,B} = 8.0$ N to the left

c. Calculate the force on block B by block A

Step 1

Identify force on block B by block A as the reaction force to force on block A by block B.

$F_{on\,A\,by\,B} = 8.0$ N, $F_{on\,B\,by\,A} = ?$

$F_{on\,B\,by\,A} = -F_{on\,A\,by\,B}$

Step 2

Substitute the values into Newton's third law.

$F_{on\,B\,by\,A} = -(-8.0) = 8.0$ N

$F_{on\,B\,by\,A} = 8.0$ N to the right

Progress questions

Question 7

Which of the following is always true about two bodies in contact with one another?

A. the two bodies will experience the same net force

B. the two bodies will experience the same acceleration

Question 8

Two blocks, of different masses, are in contact and accelerated along a rough surface. Which of the following is true about the contact force on each object?

A. Both blocks experience the same internal force, according to Newton's third law.

B. The heavier block will exert a greater force on the light block than the reverse.

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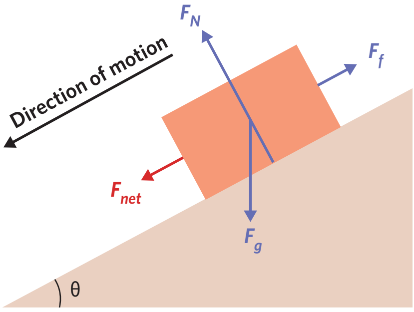
Theory summary

- The forces acting on a body on an inclined plane:



- The net force, F_{net}, acting on a body on an inclined plane acts down the slope.
  - When friction is absent: $F_{net} = F_{g\parallel} = mg\sin(\theta)$
  - When friction is present: $F_{net} = F_{g\parallel} - F_f = mg\sin(\theta) - F_f$
- For connected bodies, we can apply Newton's second law to the combined system or to individual elements to calculate acceleration or internal forces.
- When considering the combined system:
  - Use the sum of the individual masses.
  - The tension and contact forces should not appear in calculations.
- When considering the individual components:
  - Use only the mass of the individual component.
  - Make sure to consider the tension and contact forces present.

KEEN TO INVESTIGATE?

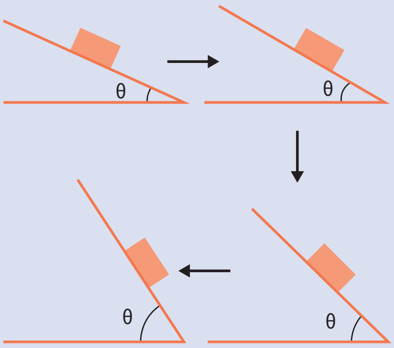
How can we analyse motion on a ramp?
Search: Ramp: Forces and motion simulation

The content in this lesson is considered fundamental prior knowledge to Newton's laws of motion (Unit 3 AOS 1).

CONCEPT DISCUSSION

For each of the following forces acting on the block, discuss how both the magnitude and the direction (relative to the horizontal) changes or remains constant as the angle of an inclined plane to the horizontal increases as shown in the diagram.

a. Force due to gravity
b. Normal force
c. Component of the force due to gravity acting down the slope



Prompts:

- Does the magnitude of the force depend on the angle of the inclined plane?
- What is the direction of the force relative to the inclined plane?
- How does the direction of the force change as θ increases?

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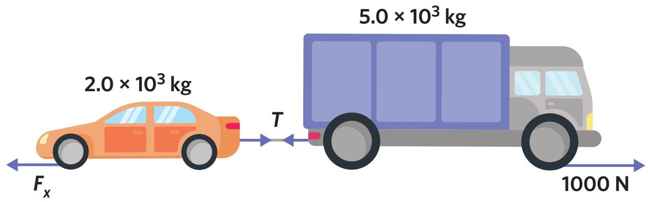
9D Questions

Mild 🌶 Medium 🌶🌶 Spicy 🌶🌶🌶

Deconstructed exam-style

Use the following information to answer questions 9–13.

An angry man is using his truck, of mass 5.0×10^3 kg, to pull his neighbours' car, of mass 2.0×10^3 kg, to the right across the road. The truck exerts a driving force of 1000 N and the car exerts a driving force in the opposite direction of F_x N, as shown on the included diagram. The truck and the car accelerate to the right at a rate of 5.0×10^{-2} m s^{-2}.



Question 9 (1 MARK) 🌶

What is the magnitude of the net force acting on the truck?

A. 2.5×10^2 N

B. 1.0×10^2 N

C. 3.5×10^2 N

D. 2.0×10^2 N

Question 10 (1 MARK) 🌶

Which of the following shows an equation representing the net force acting on the truck?

A. $F_{net\ truck} = 5.0 \times 10^3 + T$

B. $F_{net\ truck} = 1000 - T$

C. $F_{net\ truck} = 1000 - T - F_x$

D. $F_{net\ truck} = 1000 + T + F_x$

Question 11 (1 MARK) 🌶

What is the magnitude of the net force acting on the whole system?

A. 2.5×10^2 N

B. 3.5×10^2 N

C. 1.0×10^2 N

D. 1.5×10^2 N

Question 12 (1 MARK) 🌶

Which of the following shows an equation representing the net force acting on the whole system?

A. $F_{net} = 1000 - T$

B. $F_{net} = 1000 - T - F_x$

C. $F_{net} = 1000 + T - F_x$

D. $F_{net} = 1000 - F_x$

Question 13 (5 MARKS) 🌶🌶

Determine the magnitude of the tension force, T, and the magnitude of the driving force of the car, F_x.

Exam-style

Question 14 (6 MARKS) 🌶

A block of mass 20 kg is placed on a frictionless inclined plane at 30°. Take acceleration due to gravity, g, as 9.8 m s^{-2}.

a. List all the forces acting on the mass. (2 MARKS)

b. Determine the magnitude of the component of the force due to gravity acting down the slope, $F_{g\parallel}$. (2 MARKS)

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c. Calculate the magnitude of the normal force, F_N. (2 MARKS)

Question 15 (4 MARKS)

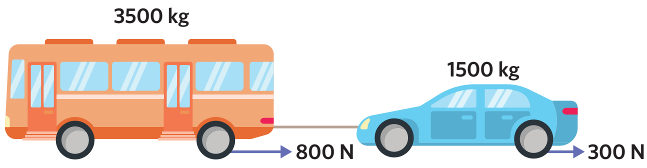
A car of mass 2500 kg is being used to tow a 1000 kg boat connected by a metal coupling. The car accelerates at a rate of 2.0 m s^{-2}. Ignore the effects of friction.

a. Determine the driving force of the car which causes it to accelerate, F_d. (2 MARKS)

b. Calculate the tension in the metal coupling, T. (2 MARKS)

Question 16 (7 MARKS)

A bus of mass 3500 kg is being used to tow a car of mass 1500 kg at a constant speed. There is a constant friction force of 800 N on the bus and 300 N on the car.



a. What is the driving force produced by the bus? (2 MARKS)

b. Determine the value of the tension force acting on the car. (1 MARK)

c. The bus now increases its driving force so it accelerates at 2.0 m s^{-2}. Calculate the magnitude of the tension force acting on the car. (2 MARKS)

d. What is the magnitude and direction of the tension force acting on the bus? (2 MARKS)

Adapted from VCAA 2006 Exam 1 Section Q1–2

Question 17 (7 MARKS)

After playing a game of truth or dare, Victoria Smith finds herself skiing down a volcano. The volcano can be modelled as an inclined plane at 15° to the horizontal with a constant friction force of 75 N. Victoria and her skis have a combined mass of 80 kg. Take the acceleration due to gravity, g, to be 9.8 m s^{-2}.

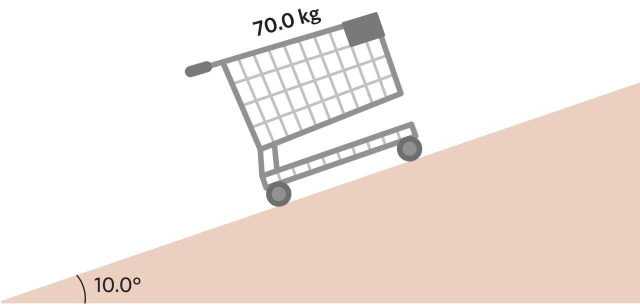
a. Draw and label all of the forces acting on Victoria. Include the net force as a dotted arrow. Values are not required. (4 MARKS)

b. Calculate the magnitude of the net force acting on Victoria and the skis. (2 MARKS)

c. Determine the acceleration of Victoria and her skis down the volcano. (1 MARK)

Question 18 (8 MARKS)

After being forced to go shopping with their mum, a young child decides to get revenge and pushes the shopping cart of mass 70.0 kg down a rough hill inclined at 10.0°. Whilst chasing the shopping cart, the mother notices that it is moving down the hill with a constant velocity. Take acceleration due to gravity, g, as 9.8 m s^{-2}.



a. What is the net force acting on the cart? (1 MARK)

b. Determine the magnitude and direction of the normal force acting on the car. (3 MARKS)

c. Calculate the component of the force due to gravity that acts down the slope. (2 MARKS)

d. Determine the magnitude of the friction force acting on the shopping cart. (2 MARKS)

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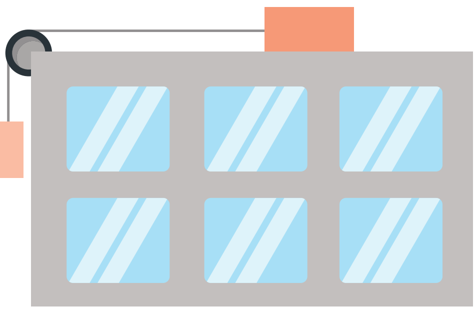
Question 19 (10 MARKS)

Whilst moving houses, a couple must lower a box M_2 (60.0 kg) off the roof of their apartment building. To stop the box accelerating too fast, they use a string and a pulley to connect it to another box M_1 (85.0 kg). The roof is initially a frictionless surface. Take acceleration due to gravity, g, as 9.80 m s^{-2}.



a. On the diagram, draw and label all forces that act on each box. Values are not required. (3 MARKS)

b. Calculate the magnitude of the acceleration of M_2. (3 MARKS)

c. Determine the tension in the string. (1 MARK)

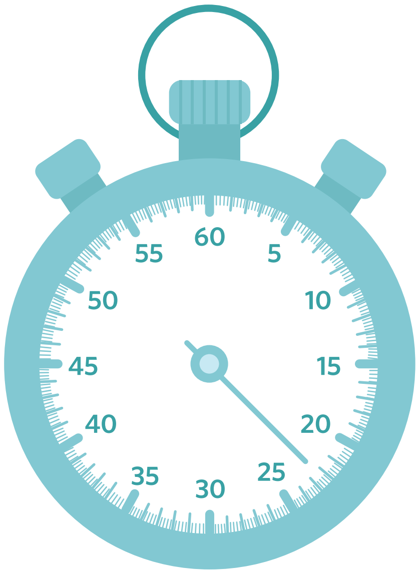
d. The couple realises that the block will fall too fast, so they add sand to the building roof so that there is a friction force acting on M_1.

What is the value of the friction force, F_f, such that M_2 accelerates at 1.0 m s^{-2}? (3 MARKS)

Key science skills

Question 20 (3 MARKS)

Whilst playing with a toy car and a long ramp, a toddler decides that she will measure the time it takes for the car to reach the bottom of the ramp. The stopwatch, as in the included diagram, has gradation marks every 0.2 seconds. The mechanical nature of the stopwatch consistently measures the times to be 0.6 seconds longer than in reality.



a. What is the uncertainty in the measurements from the stopwatch? (1 MARK)

b. Determine the type of error that the 0.6 second delay in the stopwatch is. Suggest one method that could be used to reduce this error. (2 MARKS)

FROM LESSON 11C

Previous lessons

Question 21 (2 MARKS)

What is the difference between mass defect and binding energy?

FROM LESSON 5A

Question 22 (3 MARKS)

Determine the force F needed to accelerate an 18 kg wheelie bin at 2.0 m s^{-2} to the right given that there is a force of 12 N resisting its motion.

FROM LESSON 9A

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9E Torque

STUDY DESIGN DOT POINT

- calculate torque: $\tau = r_{\perp}F$

9A 9B 9C 9D 9E 9F

2.1.17.1 Introduction to torque

2.1.17.2 Torque due to multiple forces

ESSENTIAL PRIOR KNOWLEDGE

9A The net force

9C Force vectors in two dimensions

9C Resolving forces in two dimensions

See questions 80–81.

ACTIVITIES

Log into your Edrolo account for activities that support this lesson.

How is a nut tightened by a wheel gun?

What do applying a force to a wrench, opening a door, and flexing your biceps have in common? They are all forms of rotation. This lesson will introduce the concept of torque and demonstrate how it applies to various common situations. This knowledge will later be used to describe the rotational equilibrium of systems such as seesaws, cranes and bridges.

KEY TERMS AND DEFINITIONS

torque the turning effect caused by a force at a distance from a pivot point (vector)

FORMULAS

- **torque** $\tau = r_{\perp}F$

Introduction to torque 2.1.17.1

Torque is a quantity that describes the ability of a force to turn an object.

Theory and applications

We have explored in previous lessons how forces can cause objects to move in straight lines. When considering movement such as rolling a wheel or opening of a door on a hinge, torque is used to describe how forces can cause the objects to rotate, rather than move linearly.

What is torque?

Torque (τ) is a vector quantity that represents the turning effect created by a force (F) that acts at a perpendicular distance ($r_{\perp}$) from an axis of rotation or pivot point. Torque is measured in Newton-metres (N m). For example, the axis of rotation of a bike wheel is the central axle, shown in Figure 1. The directional component of torque can be found by considering whether the applied force will cause the object to rotate clockwise or anticlockwise about the axis of rotation.

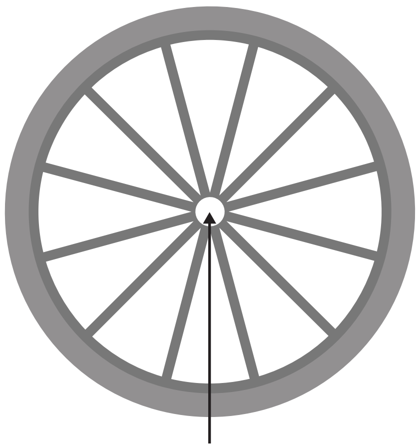

Figure 1 The axis of rotation of a bicycle wheel is its centre.

USEFUL TIP

⊥ is a symbol used to represent a perpendicular component, that is at right angles to a surface or object in question.

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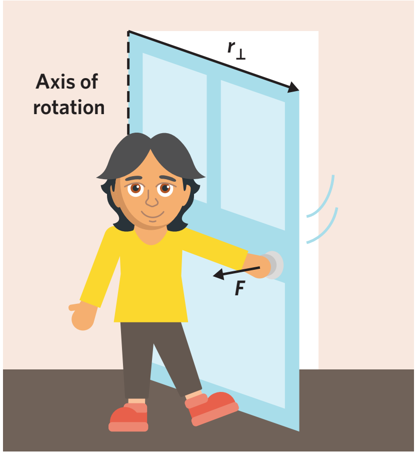


Figure 2 Applying a torque to a door

Picture opening a door, such as in Figure 2. When we pull on the door we apply a force (F) which acts perpendicular to the door at a distance ($r_\perp$) from the hinges (axis of rotation), so the door experiences a torque.

An object will experience maximum torque when the force acts perpendicular to the axis of rotation. Imagine trying to tighten a nut using the wrench shown in Figure 3(a). We can apply the maximum torque to the bolt by applying a force perpendicular to the wrench. In Figure 3(b), where the force is directed parallel to the axis of rotation, the torque will be zero and no rotation will occur.

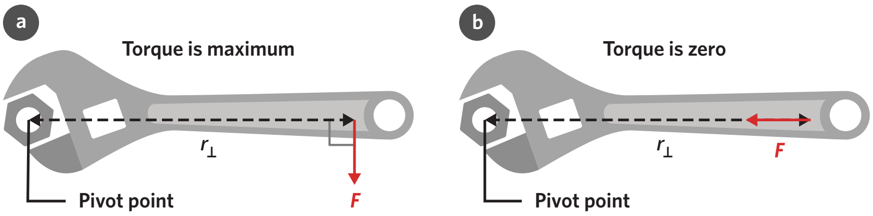


Figure 3 Force acting **(a)** perpendicular and **(b)** parallel to the axis of rotation

MISCONCEPTION

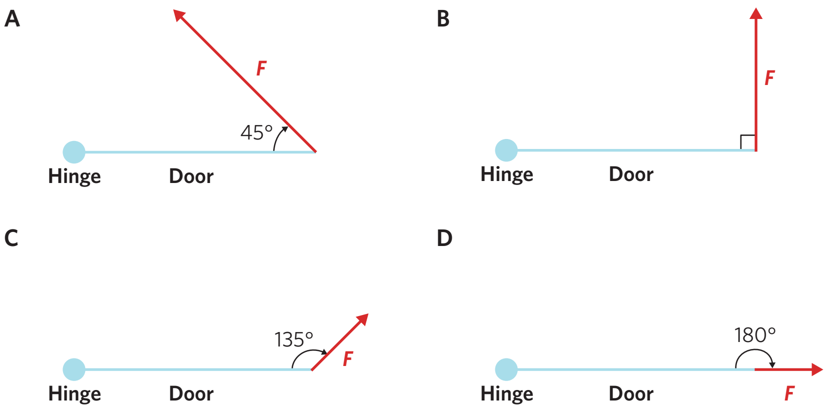
'Applying a force to an object is the same as applying a torque.'

Force is applying a linear push or pull to an object, whereas torque is applying a rotational push or pull.

Progress questions

Use the following information to answer questions 1 and 2.

A door is pulled with a constant magnitude force but in different directions. The six different situations (A-D) are shown in the included diagram.



Question 1

Which of the situations (A-D) results in the minimum magnitude of torque acting on the door?

Question 2

Which of the situations (A-D) results in the maximum magnitude of torque acting on the door?

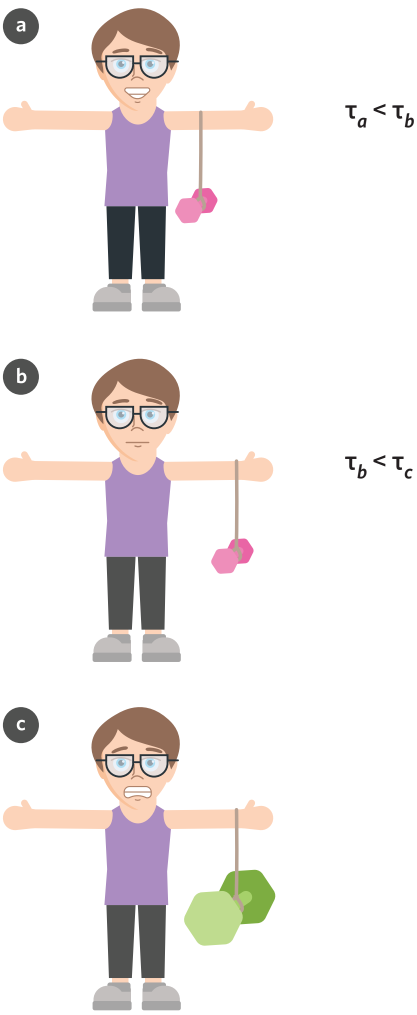


Figure 4 The impact of increasing magnitude and distance of a force on torque

How can torque be calculated?

For a perpendicular force, torque is directly proportional to the magnitude of the force and the perpendicular distance to the pivot point.[1] So, to increase the torque acting on an object, we could:

- increase the magnitude of the force, or;
- increase the distance from the axis of rotation that the force acts (see Figure 4).

KEEN TO INVESTIGATE?

[1] **What's the difference between horsepower and torque?**
Search YouTube: Horsepower vs torque – a simple explanation

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The formula for torque (see formula triangle in Figure 5) is:

FORMULA

$$\tau = r_{\perp}F$$

τ = torque (N m)
$r_{\perp}$ = perpendicular distance (m)
F = force (N)

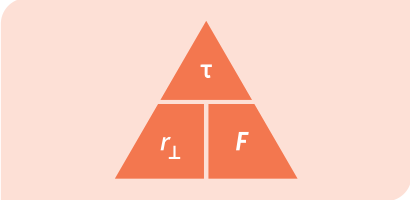
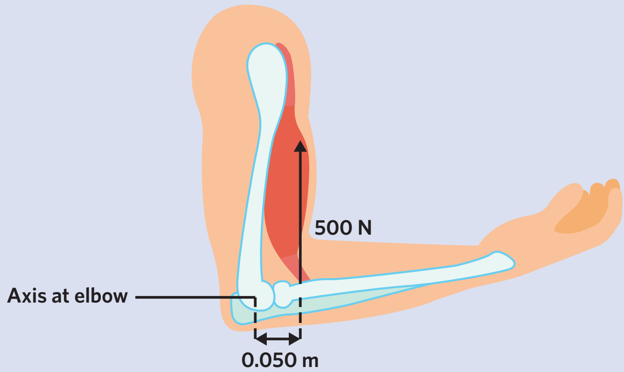


Figure 5 Formula triangle for torque

WORKED EXAMPLE 1

An athlete's right biceps is able to generate 500 N of force which acts perpendicular to the forearm, and left biceps can produce 40 N m of torque clockwise on their forearm, both at a distance of 0.050 m from the elbow joint.



a. Determine the torque acting on the athlete's right forearm by the biceps.

Step 1

Identify the relevant variables and the equation relating these variables.

$F = 500$ N, $r_{\perp} = 0.050$ m, $\tau = ?$

$\tau = r_{\perp}F$

Step 2

Substitute values into the equation and solve for torque τ. Identify the direction of torque, from the diagram.

$\tau = r_{\perp}F = 0.050 \times 500 = 25$ N m

$\tau = 25$ N m anticlockwise.

b. Determine the magnitude of the force generated by the athlete's left biceps.

Step 1

Identify the relevant variables and the equation relating these variables.

$r_{\perp} = 0.050$ m, $\tau = 40$ N m, $F = ?$

$\tau = r_{\perp}F$

Step 2

Substitute values into the equation and solve for the magnitude of the force.

$40 = 0.050 \times F$

$F = \frac{40}{0.050} = 8.0 \times 10^2$ N

It is common for the force acting on an object to not act perpendicular to the line between the pivot point and the point of action of the force. In this case, the force does not induce the maximum torque. There are two ways we can calculate the magnitude of the torque in this situation:

- Approach 1: calculate the perpendicular component of the force
- Approach 2: calculate the lever arm

USEFUL TIP

Forces can be resolved into perpendicular components to visualise the direction of rotation each force will create.

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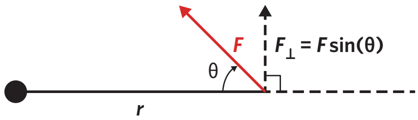


Figure 6 The perpendicular component of a force

STRATEGY

Implementing approach 1, the component of the force which acts perpendicular to the object can be found using trigonometry, shown in Figure 6.

$$\sin(\theta) = \frac{opposite}{hypotenuse} = \frac{F_\perp}{F}$$

$$F_\perp = F\sin(\theta)$$

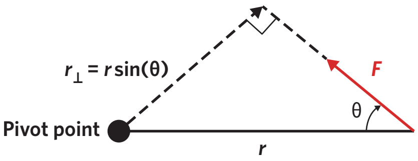


Figure 7 The lever arm of a force

STRATEGY

Implementing approach 2, length of a force from the axis of rotation if it were to act in perpendicular direction is referred to as the lever arm, shown in Figure 7, can be found using trigonometry.

$$\sin(\theta) = \frac{opposite}{hypotenuse} = \frac{r_\perp}{r}$$

$$r_\perp = r\sin(\theta)$$

KEEN TO INVESTIGATE?

[2] **How can torque be calculated?**
Search YouTube: Torque at an angle

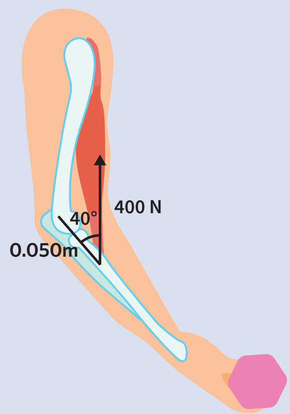
Both of these methods are valid and yield the same final equation for the magnitude of the torque for a non-perpendicular force:[2]

$$\tau = rF\sin(\theta)$$

WORKED EXAMPLE 2

Whilst lifting a weight in the gym, an athlete's biceps applies a force of 400 N to their forearm at an angle of 40°. The force acts at a distance of 0.050 m from the elbow joint.

Determine the torque applied to the athlete's forearm by the biceps.



Step 1

Identify the formula for torque due to a non-perpendicular force.

$F = 400$ N, $r = 0.050$ m, $\theta = 40°$, $\tau = ?$

$\tau = rF\sin(\theta)$

Step 2

Substitute values into the equation and solve for torque τ.

$\tau = 0.050 \times 400 \times \sin(40°) = 12.9$ N m

Step 3

Give the answer as a vector value. Identify the direction of torque, from the diagram.

$\tau = 13$ N m anticlockwise.

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Progress questions

Question 3

A wrench applies a 15 N force, at a perpendicular distance of 2.0 m to a nut. What is the magnitude of the torque on the nut?

A. 0.0 N m

B. 7.5 N m

C. 30 N m

Question 4

A person applies a 10 N force perpendicular to the end of the 20 cm long wrench. Which of the following alternatives would provide the same torque?

A. 20 N acting on a 40 cm wrench

B. 20 N acting on a 10 cm wrench

C. 10 N acting on a 40 cm wrench

Question 5

A car has a peak engine torque twice as great as another. Which of the following statements is true?

A. The force of the engine in the car with the greater torque must be greater.

B. The force of the engine in the car with the greater torque must act at a greater perpendicular distance from the pivot point.

C. The product of the turning force of the engine and the perpendicular distance from the pivot point of the car with the greater torque must be greater.

Torque due to multiple forces 2.1.17.2

In situations where multiple forces are acting on the same object, we can find the resultant or net torque by considering the direction in which each torque acts – clockwise or anticlockwise. The net torque acting on an object is the sum of all of the torques acting on it.

Theory and applications

Finding the net torque on an object will determine whether an object will undergo rotation, and if so, in which direction. Just as a net force causes acceleration in the direction of the net force, a net torque will cause rotational acceleration in the direction of the net torque.

How do we calculate the net torque?

It is common to consider the anticlockwise direction as the positive direction. We will follow this convention in our working. However, as long as the positive direction is consistent, it will not matter which direction you choose.

USEFUL TIP

Draw a circular arrow, like in Figure 8, of the rotation each force creates, to avoid confusion between the direction of the force and the direction of rotation it causes.

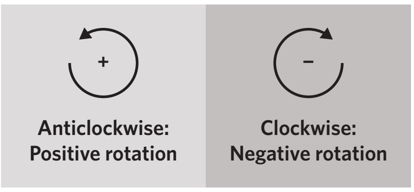


Figure 8 Positive and negative conventions for anticlockwise and clockwise rotation

MISCONCEPTION

'If two forces act in the same direction, they will always cause rotation in the same direction.'

The direction of rotation depends upon the direction of the force in relation to the pivot point. For example two people either side of a seesaw will cause rotation in different directions about the pivot point.

If we consider Figure 9, the force F_2 will result in an anticlockwise torque acting on the object, whereas the force F_1 will result in a clockwise torque acting on the object. Taking the anticlockwise direction as positive, we can state that $\tau_{net} = r_2F_2 - r_1F_1$.

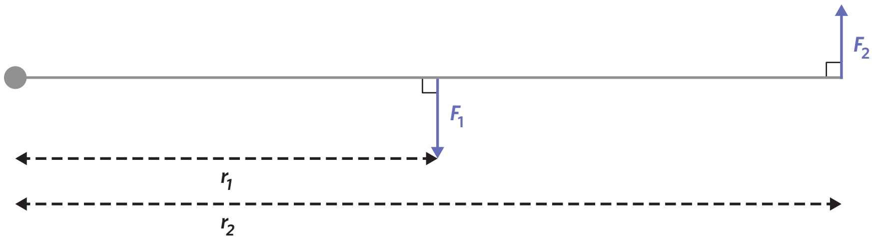
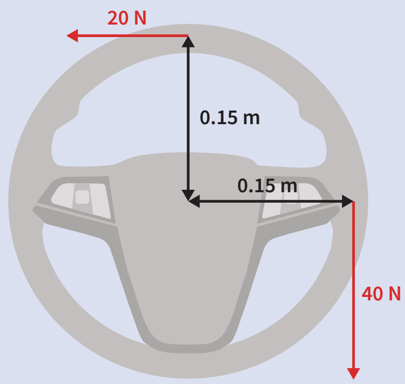


Figure 9 Two forces acting on an object at different distances

WORKED EXAMPLE 3

While on her learner permit, a young driver applies a force of 40 N vertically downwards on the right-hand side of the steering wheel of her car. Her instructor, anticipating a crash, applies a force of 20 N directly to the left on the top of the steering wheel.

Both forces are perpendicular and at a distance of 0.15 m from the axis of rotation of the steering wheel. Find the net torque acting on the steering wheel.



Step 1

Identify the direction of rotation each force creates.

F_1 creates clockwise torque

F_2 creates anticlockwise torque

Step 2

Identify the equation for net torque, and positive direction.

We will take anticlockwise direction to be positive

$\tau_{\text{net}} = \tau_2 - \tau_1 = r_{\perp}F_2 - r_{\perp}F_1$

Step 3

Substitute values into the equation and solve for torque τ. Give the answer as a vector quantity. Identify the direction of torque from the sign.

$F_1 = 40$ N, $F_2 = 20$ N, $r_{\perp} = 0.15$ m, $\tau_{net} = ?$

$\tau_{net} = 0.15 \times 20 - 0.15 \times 40 = -3.0$ N m

$\tau_{net} = 3.0$ N clockwise

Progress questions

Question 6

In which of the following situations is there a non-zero net torque?

A. a stationary diving board with a diver on the edge waiting to jump

B. a stationary seesaw, with people on either side

C. a seesaw oscillating about the centre

Question 7

Which of the following provides the greatest net torque on a seesaw?

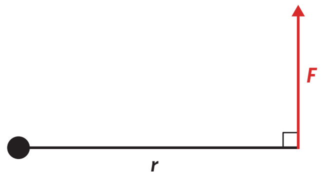
A. two people sitting 5 m either side of the centre, of mass 40 kg and 60 kg respectively

B. one person sitting 4 m to the right of a seesaw, of mass 55 kg

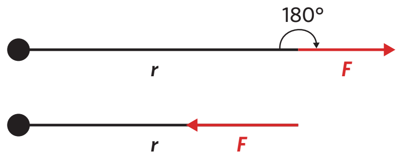
C. one person sitting on the middle of a seesaw, of mass 50 kg

Theory summary

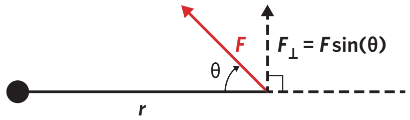
- Torque is a turning effect about an object's axis of rotation or pivot point.
  - $\tau = r_{\perp}F$
  - Measured in Newton-metres (N m)
  - Torque is a vector with a direction of rotation.
- The torque on an object will be at a maximum when the force acts perpendicular to the line between the pivot point and the location of the applied force.



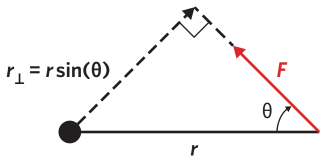
- The torque will be zero when the force acts parallel to the line between the pivot point and the location of the applied force.



- When torque acts at a non-perpendicular angle to the object, there are two approaches that can be used to calculate the torque.
  - Approach 1: Find the component of the force which acts perpendicular to the object. $\tau = rF_{\perp}$



  - Approach 2: Find the lever arm as the perpendicular line between the line of action of the force and the pivot point. $\tau = r_{\perp}F$



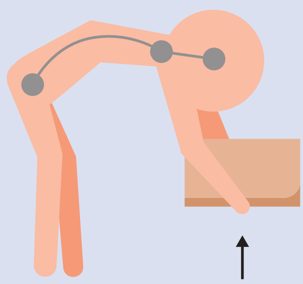
    - Both of these approaches result in the equation $\tau = rF\sin(\theta)$
- When multiple forces are acting on the same object, the net torque can be found by the addition of the individual torques and considering the direction in which they act.

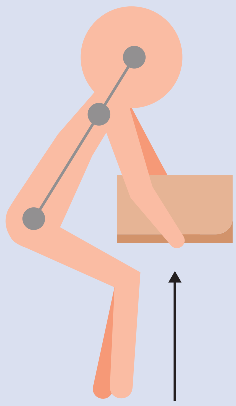
CONCEPT DISCUSSION

When lifting heavy objects, we are often told to lift with the knees, rather than the back to avoid back pain. Discuss how lifting with our knees is safer than lifting with our back. Within your answer, reference the force, angle and distance to the pivot point with the torque experienced by the lower back.

Prompts:

- What force is acting to create a torque on the person lifting?
- Where does this force act and where is the pivot point?
- Is the distance between the pivot point and the point where the force is applied the same in the two scenarios?
- How does the angle between the back and the force differ in the two scenarios?
- How does the angle of application of a force relate to the torque produced?





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9E Questions

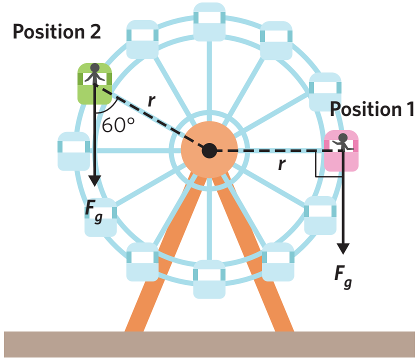
Mild Medium Spicy

Deconstructed exam-style

Use the following information to answer questions 8–12.

Two friends are on a Ferris wheel and are positioned in different passenger cars. Each person has a mass of 77 kg. The force due to gravity from the person in the first position acts at an angle of 90°, whereas the force from the person in the second position acts at an angle of 60°. The distance from the axis of rotation and the point of action of both forces is r metres.

The resultant torque acting on the Ferris wheel is 805 N m in the clockwise direction. Take the anticlockwise direction as positive, and the value of $g = 9.8 \text{ m s}^{-2}$. Ignore the mass of the Ferris wheel.



Question 8 (1 MARK)

Which of the following equations correctly calculates the force due to gravity acting on a single person?

A. $F_g = 77 \times 9.8$

B. $F_g = (77 + 77) \times 9.8$

C. $F_g = 77 \times 9.8 \times h$

D. $F_g = 77$

Question 9 (1 MARK)

Which of the following represents the torque acting on the Ferris wheel from the force at position 1?

A. $\tau_1 = r \times F_g \times \cos(90°)$ clockwise

B. $\tau_1 = r \times F_g \times \cos(90°)$ anticlockwise

C. $\tau_1 = r \times F_g$ clockwise

D. $\tau_1 = r \times F_g$ anticlockwise

Question 10 (1 MARK)

Which of the following represents the torque acting on the Ferris wheel from the force at position 2?

A. $\tau_2 = r \times F_g \times \sin(60°)$ clockwise

B. $\tau_2 = r \times F_g \times \sin(60°)$ anticlockwise

C. $\tau_2 = r \times F_g$ clockwise

D. $\tau_2 = r \times F_g$ anticlockwise

Question 11 (1 MARK)

Which of the following shows an equation for the net torque acting on the Ferris wheel as a result of the two forces? Note that the anticlockwise direction is positive.

A. $\tau_{net} = r \times F_g - r \times F_g \times \cos(60°)$

B. $\tau_{net} = r \times F_g \times \sin(60°) - r \times F_g$

C. $\tau_{net} = r \times F_g \times \sin(60°)$

D. $\tau_{net} = r \times F_g - r \times F_g \times \sin(60°)$

Question 12 (5 MARKS)

What is the radius, r, of the Ferris wheel?

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Exam-style

Question 13 (4 MARKS)

A builder applies a force of 125 N by a wrench at a perpendicular distance of 25.0 cm from the axis of rotation of the bolt.

a. Determine the magnitude of the torque applied, giving your answer in N m. (2 MARKS)

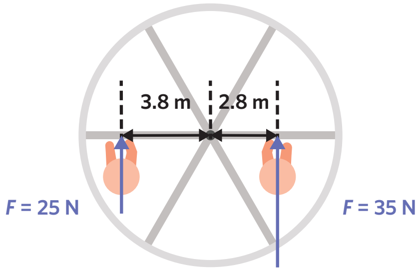
b. If a 35.0 cm long wrench is used instead, calculate the magnitude of the force applied such that the same torque is applied. (2 MARKS)

Question 14 (2 MARKS)

Whilst getting home after a hardcore gym session, a bodybuilder must open his door without exceeding a torque of 1200 N m, or the door will break. The bodybuilder knows he will push perpendicular to the door with a force of 900 N. What is the maximum distance from the hinges of the door the bodybuilder can push so that the door will not break?

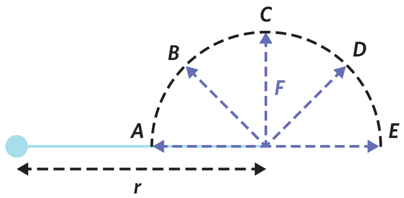
Question 15 (3 MARKS)

Fabio and Harvey are trying to walk through a revolving door in opposite directions. Fabio applies a force of 25 N, 3.8 m from the pivot point of the door, whereas Harvey applies a force of 35 N, 2.8 m from the pivot point. What is the magnitude and direction of the net torque acting on the door?



Question 16 (3 MARKS)

Describe how the magnitude of the torque on an object changes as the direction of the force changes from *A* to *E* as shown in the included diagram.



Question 17 (3 MARKS)

On a construction site, an excavator is used to lift a 500 kg rock. The rock in the bucket of the excavator is positioned 5.0 m from the axis of rotation, corresponding to a 4.0 m horizontal distance. Take the acceleration due to gravity to be 9.8 m s^{-2}. Calculate the magnitude and the direction of the torque acting on the excavator.

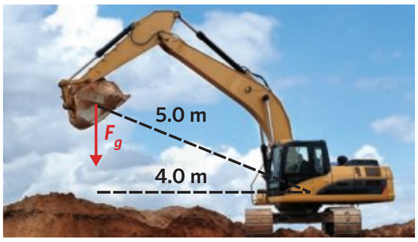


Image: Dmitry Kalinovsky/Shutterstock.com

Question 18 (6 MARKS)

In the process of starting some planes' engines, the propeller must be manually rotated. In the scenario shown in the photo, a force of 150 N is applied downwards at 70° to the propeller and at a distance of 0.90 m from the axis of rotation. However, due to a constant resistance within the engine, a torque opposing this can be modelled as the result of a 50 N force acting upwards and perpendicular to the propeller at a distance of 0.60 m from the axis of rotation.

a. Determine the magnitude and direction of the net torque acting on the propeller. (3 MARKS)

b. The engine properly starts when the net torque acting on the propeller is 100 N m. If the same force were to be applied to the propeller, calculate the angle it must be applied at so that the propeller properly starts. (3 MARKS)

Image: SDASM Archives/Shutterstock.com

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Question 19 (7 MARKS)

Sarah is walking home after a long day of work when she gets caught out by the rain. Suddenly a gust of wind causes a force of 25 N to act at an angle of 120° to her umbrella. Take the pivot point to be where Sarah is holding the umbrella, 85 cm from where the force is acting.

a. Find the magnitude and direction of the torque acting on Sarah's umbrella when viewed from in front of her. (2 MARKS)

b. If the force acting on the umbrella was increased by a factor of 2, by what factor would the torque increase? Calculations are not required. Explain your answer. (2 MARKS)

c. For the maximum torque to act on the umbrella, what direction would the force need to act on the umbrella? Explain your answer. (3 MARKS)

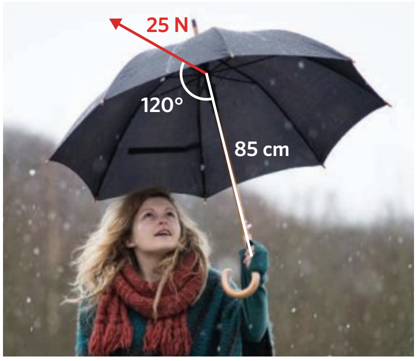


Image: GertjanVH/Shutterstock.com

Key science skills

Question 20 (5 MARKS)

Radha is attempting to better understand the idea of torque so she can easily open beverage cans, and decides that she will conduct an experiment. Whilst changing the magnitude of the force she is applying perpendicular to a bottle opener, she records the torque acting on the bottle cap with an imprecise torque sensor.

a. For this experiment, determine the independent variable, the dependent variable and a controlled variable. (3 MARKS)

b. Radha wants to reduce the random error associated in each of her measurements. What is one change she could make to her experiment to achieve this? (1 MARK)

c. What is one way Radha could reduce the effect of random errors on her results? (1 MARK)

FROM LESSONS 11A & 11C

Previous lessons

Question 21 (1 MARK)

Which of the following is the best definition of nuclear fission?

A. the combination of two light nuclei, with no net change in energy

B. the combination of two light nuclei, leading to the release of energy

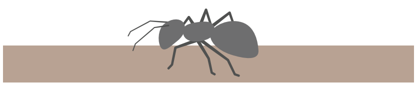
C. the splitting of one heavy nucleus, with no net change in energy

D. the splitting of one heavy nucleus, leading to the release of energy

FROM LESSON 5A

Question 22 (8 MARKS)

An ant of mass 2.0×10^{-6} kg is attempting to cross a tightrope in order to reach some food. Whilst crossing the tightrope, a gust of wind causes a force, F_w, to act vertically upwards on the ant with a force of 2.5×10^{-5} N. Take the acceleration due to gravity to be 9.8 m s^{-2}.



a. What is the magnitude and direction of the force due to gravity acting on the ant? (2 MARKS)

b. Copy the included diagram, and draw and label the force vectors representing the force due to gravity, F_g, and the force due to the wind, F_w. (3 MARKS)

c. Calculate the magnitude of the acceleration of the ant. (3 MARKS)

FROM LESSON 9A

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9F Equilibrium


Image: Daria Andraczko

How does the Leaning Tower of Pisa remain standing?

Structures that remain stable are in a state of equilibrium. When designing a structure like a bridge or a building, it is critical that the structure neither accelerates nor rotates. This lesson uses what we have learned about force and torque to solve for unknown forces that act on simple structures in equilibrium.

STUDY DESIGN DOT POINT

- analyse translational and rotational forces (torques) in simple structures in translational and rotational equilibrium

9A 9B 9C 9D 9E 9F

2.1.18.1 & 2.1.18.2 Systems in equilibrium

ESSENTIAL PRIOR KNOWLEDGE

9C Forces vectors in two dimensions

9E Calculating torque

See questions 82–83.

ACTIVITIES

Log into your Edrolo account for activities that support this lesson.

KEY TERMS AND DEFINITIONS

equilibrium the state of a system when it is in both translational and rotational equilibrium

rotational equilibrium the state of a system when the torques on the system sum to zero

translational equilibrium the state of a system when the forces on the system sum to zero

FORMULAS

- **force due to gravity**
  $F_g = mg$
- **Newton's second law**
  $F_{net} = ma$
- **torque**
  $\tau = r_{\perp}F$

Systems in equilibrium 2.1.18.1 & 2.1.18.2

Equilibrium is the state a system achieves when it is in both translational and rotational equilibrium.

Theory and applications

To be in a state of equilibrium requires both the net force on a structure and net torque on the structure to be zero. If either of these conditions are not met, the structure will experience some form of acceleration, either linearly or rotationally. If a system experiences acceleration this would cause the building to collapse or be unfit for purpose.

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How is a system in translational equilibrium?

Translational equilibrium describes the state of a system with zero net force acting on it, meaning the linear acceleration is zero.

Condition for translational equilibrium:

$$F_{net} = 0$$

MISCONCEPTION

'An object in translational equilibrium is at rest.'

An object in translational equilibrium has no linear acceleration. It may be at rest, but could also be moving at constant velocity.

USEFUL TIP

Note that the $\sum F$ is equivalent to the net force acting on an object, $\sum F = F_1 + F_2 + F_3 \dots + F_N$

In Lesson 9C, we learned we can resolve forces into horizontal (x-direction) and vertical (y-direction) components. If we resolve F_{net} into its horizontal and vertical components, we arrive at two separate translational equilibrium equations that both must hold true for the structure to not accelerate vertically or horizontally. Figure 1(a) shows a car in translational equilibrium, as the forces in both the vertical and horizontal direction are balanced. See Figure 1(b).

Condition for translational equilibrium:

$$\sum F_x = 0 \text{ and } \sum F_y = 0$$

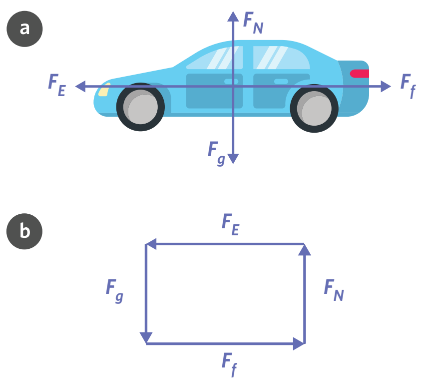


Figure 1 **(a)** Car in translational equilibrium and **(b)** tip-to-tail addition of its forces in translational equilibrium

USEFUL TIP

If a system is in translational equilibrium, all its forces added tip-to-tail must return to the tail of the first vector.

Note that the words system and structure may be used interchangeably throughout this lesson.

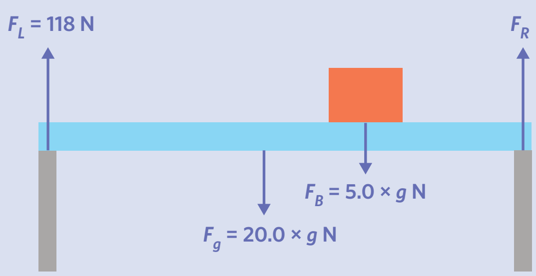
WORKED EXAMPLE 1

A uniform beam with a length of 10.0 metres and a mass of 20.0 kg is supported by a column at each end. There is a block of mass 5.0 kg resting on the beam. The force on the beam by the left-hand column is known to be 118 N.

Calculate the magnitude of the force on the beam by the right-hand column.

Step 1

Identify all the forces acting on the beam. Treat the force on the beam due to gravity as acting at the centre (C).



Step 2

Write the translational equilibrium equation. In this case we have forces in the vertical direction only.

Take upwards as the positive direction.

$F_{net} = 0$

$F_L - F_g - F_B + F_R = 0$

Continues →

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Step 3

Substitute known values into the equation and solve for the unknown force.

$118 - 20.0 \times 9.8 - 5.0 \times 9.8 + F_R = 0$

$118 - 196 - 49 + F_R = 0$

$F_R = 127 = 1.3 \times 10^2$ N

Progress questions

Question 1

If an object is in translational equilibrium, what is true about its motion?

A. It is not moving at all.

B. It is not accelerating linearly.

Question 2

In which of the following situations is the car not in translational equilibrium?

A. a car driving at a constant velocity

B. a car braking for a red light

C. a car stationary at a red light

When is a structure in rotational equilibrium?

Rotational equilibrium describes the state of a system with zero net torque acting on it. This means that the rotational acceleration of the system is zero.

Condition for rotational equilibrium:

$$\sum \tau = 0$$

If the net torque is zero, the sum of clockwise torques acting on the system is equal to the sum of anticlockwise torques acting on the system.[1] The ferris wheel in Figure 2 shows the clockwise torque due to the person in position 1 is balanced by the anticlockwise force due to the person in position 2.

Condition for rotational equilibrium:

$$\sum \tau_{clockwise} = \sum \tau_{anticlockwise}$$

For an object in rotational equilibrium, the torque is balanced when measured around any point. This means that any point can be treated as the pivot point for the purpose of calculating torques. When two unknown forces are present, selecting the point at which one force acts as the pivot point will eliminate it from the rotational equilibrium equation, as the torque due to that force will be zero.

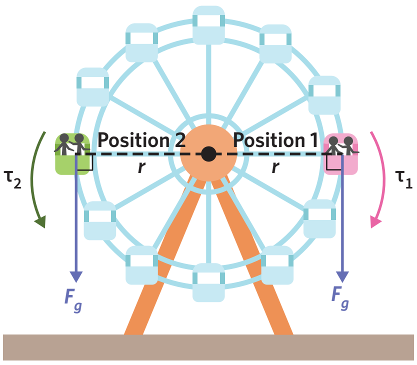


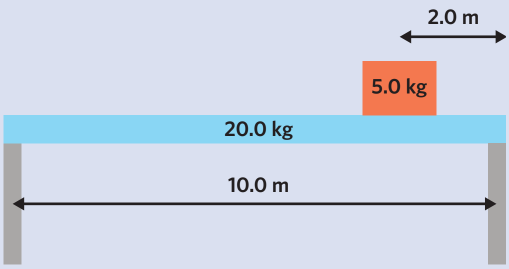
Figure 2 Ferris wheel in rotational equilibrium

KEEN TO INVESTIGATE?

[1] **How does a seesaw remain in rotational equilibrium?**
Search: Balancing act simulation

WORKED EXAMPLE 2

A uniform beam with a length of 10.0 metres and a mass of 20.0 kg is supported by a column at each end. There is a block of mass 5.0 kg resting 2.0 metres from the right-hand column. Calculate the magnitude of the force on the beam by the left-hand column.



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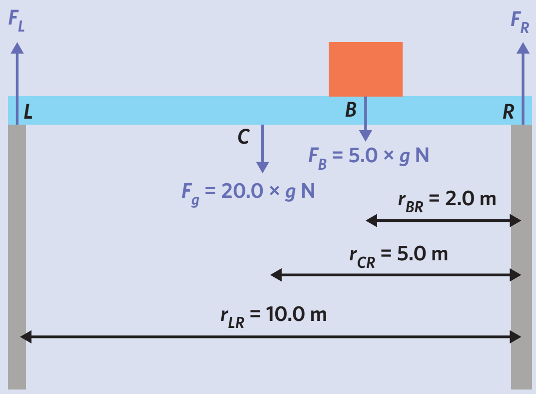
Step 1

Identify all the forces acting on the beam. Treat the force on the beam due to gravity as acting at the centre (C).



Step 2

Write the rotational equilibrium equation. In this case we have forces in the vertical direction only.

$$\sum\tau_{anticlockwise} = \sum\tau_{clockwise}$$

Step 3

Choose the point of application of the unknown force that we are not solving for (in this case, R) as the pivot point.

Consider the torques measured around point R:

$$r_{CR} \times F_g + r_{BR} \times F_B = r_{LR} \times F_L$$

Step 4

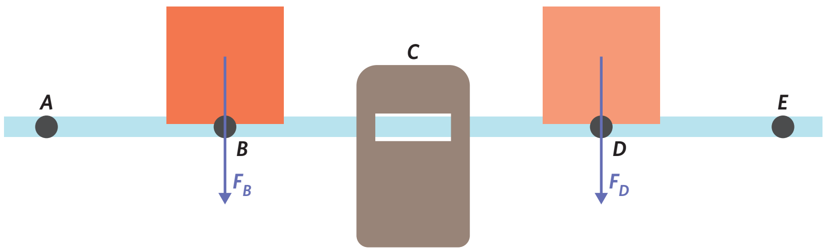
Substitute known values into the equation and solve for the unknown force.

$$5.0 \times 20.0 \times 9.8 + 2.0 \times 5.0 \times 9.8 = 10.0 \times F_L$$

$$F_L = 108 = 1.1 \times 10^2 \text{ N}$$

Progress questions

Use the following information to answer questions 3-5.



Question 3

When considering the torques around the centre (C), what are the directions of the torques due to the blocks at B and D?

A. both are clockwise

B. both are anticlockwise

C. B is anticlockwise, D is clockwise

D. B is clockwise, D is anticlockwise

Question 4

When considering the torques around the right hand side (E), what are the directions of the torques due to the blocks at B and D?

A. both are clockwise

B. B is clockwise, D is anticlockwise

C. B is anticlockwise, D is clockwise

D. both are anticlockwise

Continues →

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Question 5

Blocks B and D provide a total magnitude of 10 N m of torque around point E. If point C is 5.0 m from point E and the beam is in rotational equilibrium, calculate the force of column C on the beam.

A. 2.0 N

B. 2.0 N up

C. 2.0 N down

How do we analyse a structure in equilibrium?

Equilibrium occurs when an object is in both rotational and translational equilibrium. Mathematically, this is the case when:

$$\sum F = 0 \text{ and } \sum \tau = 0$$

For structures like bridges and buildings to remain at rest, they must satisfy the conditions of equilibrium.[2] We can use these mathematical equations to solve for unknown forces that act on an object or structure.

STRATEGY

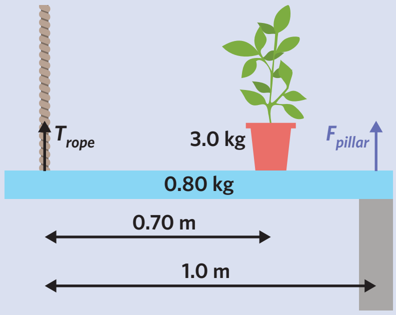
When there is only one unknown force, it is simplest to use the translational equilibrium equation to solve for that force. When there are two unknown forces, both the rotational and the translational equilibrium equations need to be used.

KEEN TO INVESTIGATE?

[2] **How can cables help structures remain in equilibrium?**
Search: Bar supported by cable simulation

WORKED EXAMPLE 3

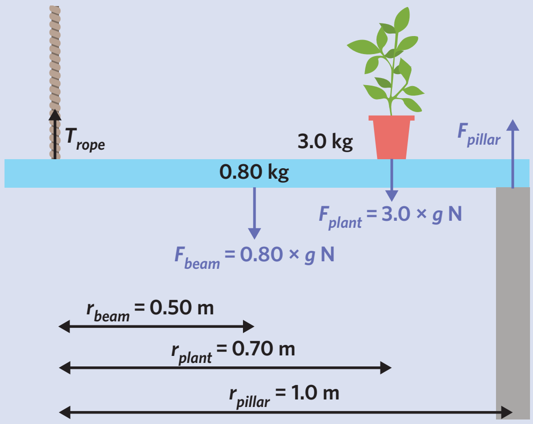
A uniform beam, with mass 0.80 kg, sitting on a column is held in equilibrium by a rope. The rope is attached 1.0 m from the centre of the column, and a 3.0 kg plant sits 0.70 m from the rope.



a. Calculate the force of the pillar on the beam

Step 1

Identify all the forces acting on the beam. Treat the force on the beam due to gravity as acting at the centre (C).



Step 2

Write the rotational equilibrium equation. In this case we have forces in the vertical direction only.

$$\sum \tau_{anticlockwise} = \sum \tau_{clockwise}$$

Continues →

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Step 3

Choose the point of application of the unknown force that we are not solving for (in this case, T_{rope}) as the pivot point.

Consider the torques measured around the rope:

$r_{pillar} \times F_{pillar} = r_{beam} \times F_{beam} + r_{plant} \times F_{plant}$

Step 4

Substitute known values into the equation and solve for the unknown force.

$1.0 \times F_{pillar} = 0.50 \times 9.8 \times 0.80 + 0.7 \times 9.8 \times 3.0$

$F_{pillar} = 25$ N

b. Calculate the tension in the rope

Step 1

Write the translational equilibrium equation. In this case we have forces in the vertical direction only.

Take upwards as the positive direction.

$F_{net} = 0 \Rightarrow T_{rope} - F_g - F_{plant} + F_{pillar} = 0$

Step 2

Substitute known values into the equation and solve for the unknown force.

$T_{rope} - 0.80 \times 9.8 - 3.0 \times 9.8 + 24.5 = 0$

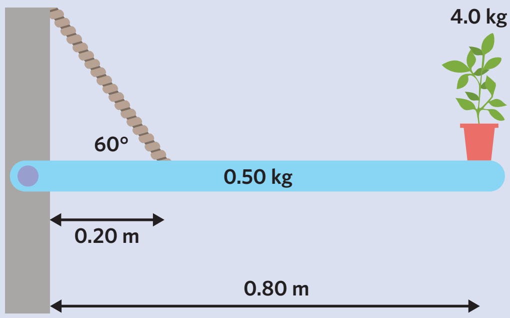
$T_{rope} = 0.80 \times 9.8 + 3.0 \times 9.8 - 24.5$

$T_{rope} = 13$ N

WORKED EXAMPLE 4

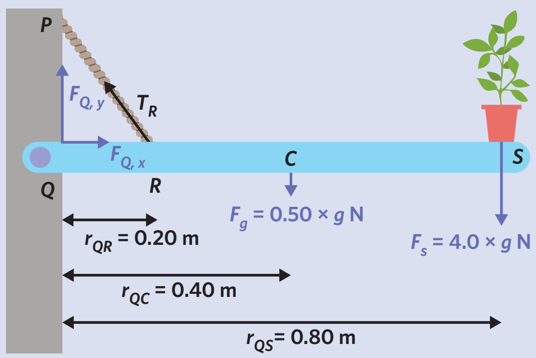
A pot plant with a mass of 4.0 kg is resting at the end of a uniform plank with a length of 0.80 m. The plank has a mass of 0.50 kg and it is supported by a frictionless pivot connection at the wall and a rope from the wall. The rope connects to the plank 0.20 m from the wall and it makes an angle of 60° with the horizontal.

Calculate the magnitude of the tension force in the rope.



Step 1

Identify all the forces acting on the beam. Treat the force on the beam due to gravity as acting at the centre (C).



Step 2

Write the rotational equilibrium equation.

$\sum \tau_{anticlockwise} = \sum \tau_{clockwise}$

Step 3

Choose the point of application of the unknown force that we are not solving for (in this case, Q) as the pivot point.

Consider the torques measured around point Q:

$r_{QR} T_{R,y} = r_{QC} F_g + r_{QS} F_S$

Continues →

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Step 4

Substitute known values into the equation and solve for the vertical component of the tension force.

$0.20 \times T_{R,y} = 0.40 \times 0.50 \times 9.8 + 0.80 \times 4.0 \times 9.8$

$T_{R,y} = 166.6\ \text{N}$

Step 5

Use trigonometry to solve for the magnitude of the tension force.

$T_{R,y} = T_R \times \sin(60°) \Rightarrow 166.6 = T_R \times \sin(60°)$

$T_R = 192 = 1.9 \times 10^2\ \text{N}$

Progress questions

Question 6

Which of the following is generally necessary for a structure to remain stable?

A. zero net force acting on the structure

B. zero net torque acting on the structure

C. zero net force and zero net torque acting on the structure

Question 7

Two people of the same mass sit the same distance either side of the centre of a seesaw. What is necessary for the structure to remain in equilibrium?

A. A downwards force is required on the centre of the seesaw.

B. An upwards force is required on the centre of the seesaw.

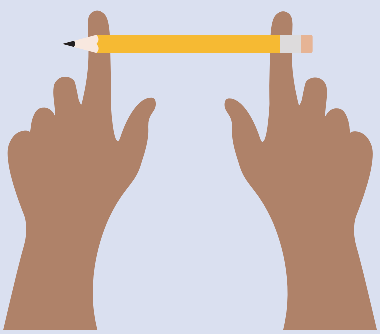
C. No additional force is required for the object to remain in equilibrium.

Theory summary

- Equilibrium is achieved when an object is in translational equilibrium and rotational equilibrium.
- Translational equilibrium occurs when $F_{net} = 0$. This means that
  - the sum of forces in the x-direction is zero and the sum of forces in the y-direction is zero.
  - the linear acceleration is zero.
- Rotational equilibrium occurs when $\tau_{net} = 0$ at all points. This means that
  - the sum of clockwise torques equals the sum of anticlockwise torques.
  - the rotational acceleration is zero.

CONCEPT DISCUSSION

Place a pencil on your two forefingers like so and try to move one hand independently towards the other until they touch. Experiment with different starting positions, pencils, pens, and rulers. In all cases, your fingers should end up touching with the object balanced in the middle. Using the concept of equilibrium, discuss why this occurs and what might happen if you added an imbalance to the object by tying an eraser or similar weight to one end.



Prompts:

- What forces and torques act in this system?
- Where are they being measured from?
- Have you considered the centre of mass and how it might change?

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9F QUESTIONS

9F Questions

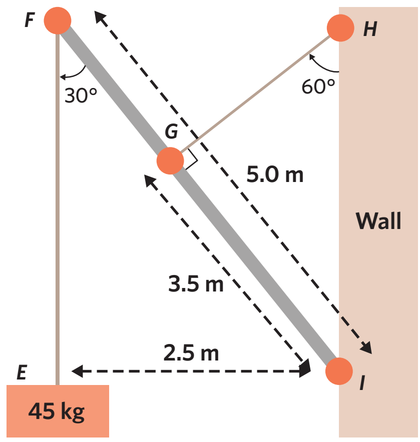
Mild Medium Spicy

Deconstructed exam-style

Use the following information to answer questions 8–11.

A uniform beam *FI* of mass 10 kg and length 5.0 m is attached to the wall with a frictionless pivot at point *I* and is held up by a massless section of rope *GH*. This beam suspends a mass of 45 kg from point *F*. Take the acceleration due to gravity g to be 9.8 m s^{-2}.

Adapted from VCAA 2015 exam Detailed Study 2 Q10



Question 8 (1 MARK)

Which of the following expressions represents the magnitude of the torque (in N m) on the beam *FI* around the point *I* due to the 45 kg mass that is suspended?

A. $5.0 \times \sin(30°) \times 45 \times g$

B. $2.5 \times \sin(30°) \times 45 \times g$

C. $5.0 \times 45 \times g$

D. $5.0 \times 45 \times g \times \cos(30°)$

Question 9 (1 MARK)

Which of the following expressions represents the magnitude of the torque (in N m) on the beam *FI* around the point *I* due to the tension, T_{GH}, in section *GH*?

A. $3.5 \times T_{GH}$

B. $3.5 \times T_{GH} \times \cos(30°)$

C. $3.5 \times \sin(30°) \times T_{GH}$

D. $1.75 \times T_{GH} \times \sin(30°)$

Question 10 (1 MARK)

Which of the following expressions represents the magnitude of the torque (in N m) on the beam *FI* around the point *I* due to the mass of the beam *FI*?

A. $\frac{2.5}{2} \times 10 \times g$

B. $2.5 \times 10 \times g$

C. $2.5 \times 10 \times g \times \cos(30°)$

D. $5.0 \times \sin(30°) \times 10 \times g$

Question 11 (3 MARKS)

Calculate the magnitude of the tension force in the section *GH*. (3 MARKS)

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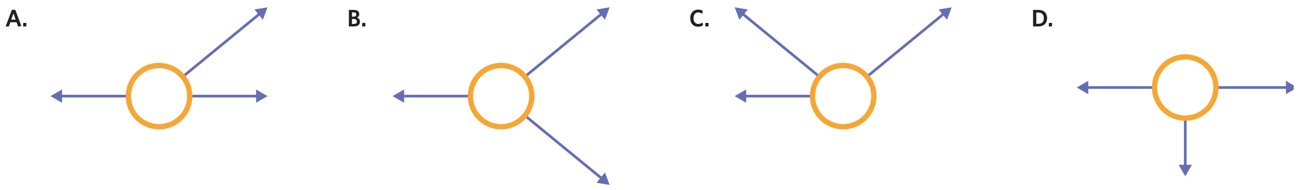
Exam-style

Question 12 (1 MARK)

A metal ring is held in equilibrium by three non-zero forces acting on it. Identify which of the following arrangements could hold the ring stationary.



Adapted from VCAA 2012 Exam 1 Q3

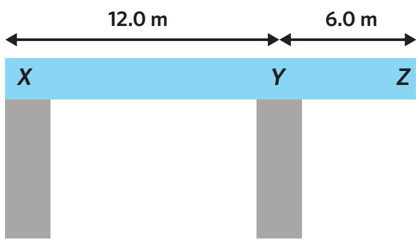
Question 13 (2 MARKS)

A clown is balancing on a beam on top of a ball. How must the clown's feet be positioned so that the beam does not rotate? Assume the force on the beam from each foot has the same magnitude.

Question 14 (2 MARKS)

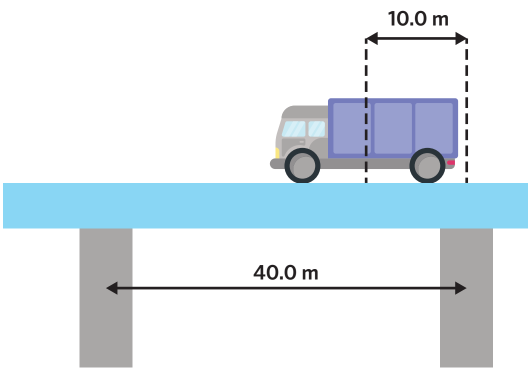
A uniform concrete slab is placed onto two pillars and a structural engineer is attempting to determine the stability of the structure. The slab has a mass of 2000 kg and a length of 18.0 m.

Calculate the magnitude of the force on the pillar at point *X*.



Question 15 (6 MARKS)

A truck with a mass of 6.0 tonnes is sitting upon a concrete slab which has a uniformly distributed mass of 40.0 tonnes. The slab rests evenly on two pillars a distance of 40 m apart. The truck's centre of mass is 10.0 m from one of the pillars.



a. Calculate the magnitude of the force on each pillar when the truck is not on the slab. (2 MARKS)

b. Calculate the magnitude of the force on each pillar when the truck is on the slab. (4 MARKS)

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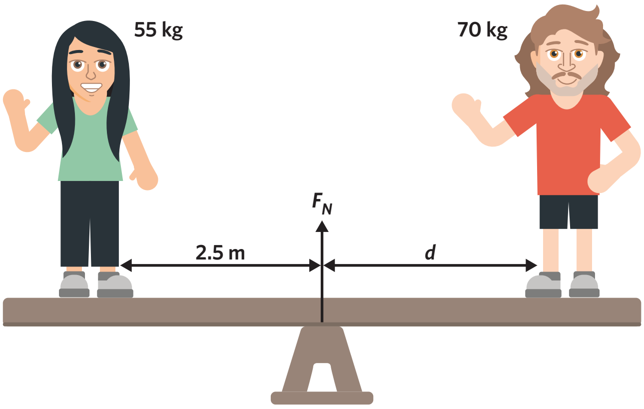
Question 16 (5 MARKS)

Two people, one with a mass of 55 kg and the other with a mass of 70 kg are standing on a see-saw. The 55 kg person is 2.5 m from the fulcrum (pivot point). Take the acceleration due to gravity g to be 9.8 m s^{-2}.



a. At what distance, d, from the centre of the see-saw should the 70 kg person stand such that the see-saw is balanced? (3 MARKS)

b. Determine the magnitude of the force on the see-saw by the fulcrum, F_N, now that it is balanced. Ignore the mass of the see-saw. (2 MARKS)

Question 17 (3 MARKS)

Angus and Dom are discussing the concept of torque with relation to equilibrium. Angus states that an object with no net force acting on it has no net torque acting on it, whereas Dom states that an object with a net force acting on must have a net torque acting on it.

Evaluate who is correct and give an example to support your answer.

Question 18 (3 MARKS)

Before digital scales, a traditional scale was made up of two platforms each equidistant from a fulcrum in the centre. Explain how this system can use objects of known mass, and rotational equilibrium to find an unknown mass of an object.

Image: corgarashu/Shutterstock.com

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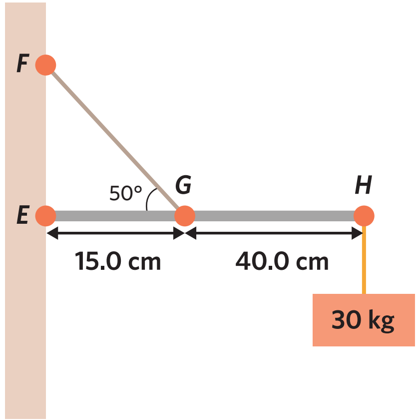
Use the following information to answer questions 19 and 20.

A 30 kg mass is hanging from a 55.0 cm beam of uniform mass supported by a cable *FG* such that the system is in equilibrium. Point *E* is a frictionless pivot. The cable makes an angle of 50° with the horizontal. Ignore the mass of the beam.



Question 19 (1 MARK)

What is the magnitude of the net torque acting on the beam about the point *E*?

A. 2.9×10^2 N

B. 1.6×10^2 N m

C. 1.2×10^2 N m

D. 0.0 N m

Question 20 (3 MARKS)

Calculate the magnitude of the horizontal force acting on the beam *EH* at point *E*.

Key science skills

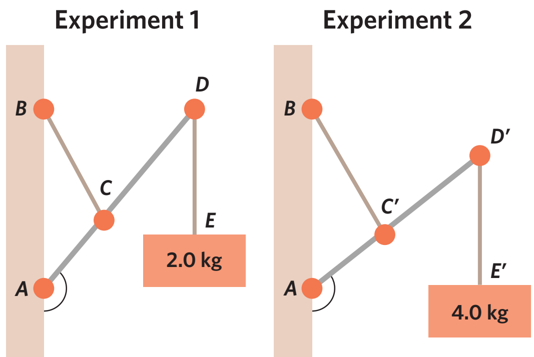
Question 21 (2 MARKS)

Tèa is attempting to calculate the strength of the cord *BC*. She takes increasingly heavy weights and then remeasures how long the section of the rope *BC* is.

She conducts a large range of experiments using multiple weights and many repetitions, however she notices an abnormality in her data. When Tèa calculates the mass of the block from the data, in every experiment it was 0.5 kg greater than the mass used in the experiment.

Explain which type of error might be causing this difference between the theoretical and experimental mass of the block.

FROM LESSON 11C



Previous lessons

Question 22 (2 MARKS)

Give two examples of ways that the neutron multiplication factor of a fissile mass could be increased.

FROM LESSON 5B

Question 23 (4 MARKS)

A train travelling at 20 m s^{-1} to the right, of mass 1.5 tonnes, collides with a stationary car of mass 500 kg and couples together. What is the velocity of the combined system after collision?

FROM LESSON 9B

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Chapter 9 review

Mild / Medium // Spicy ///

These questions are typical of 40 minutes worth of questions on the VCE Physics Exam.

Total marks: 30

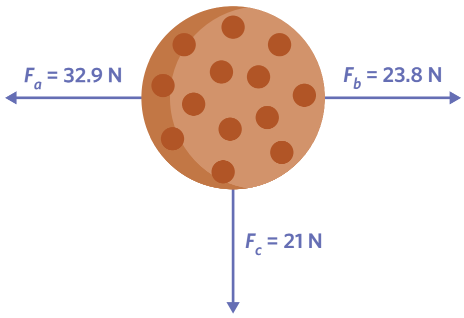
Section A

All questions in this section are worth one mark.

Unless otherwise indicated, the diagrams in this book are not drawn to scale.

Question 1 (Mild)

Emma is pulling apart a cookie with three forces, $F_a = 32.9$ N, $F_b = 23.8$ N and $F_c = 21$ N.
Calculate the magnitude of the resultant force on the cookie.
Forces are not drawn to scale.



A. 77 N

B. 30 N

C. 23 N

D. 21 N

Adapted from VCAA 2018 exam Multiple choice Q5

Question 2 (Mild)

A rally driver decelerates a 1.20 tonne car to a stop by providing a braking force of 2.54×10^4 N. Calculate the magnitude of the car's acceleration.

A. 21.2 m s^{-2}

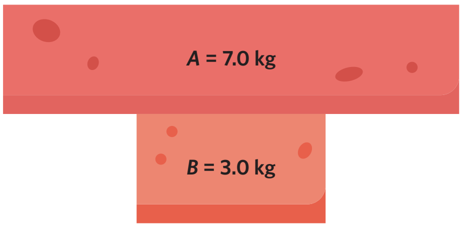
B. 25.6 m s^{-2}

C. 212 m s^{-2}

D. 256 m s^{-2}

Question 3 (Mild)

A person places brick *A* of 7.0 kg on top of brick *B* of 3.0 kg as per the diagram. What is the magnitude and direction of $F_{on\ A\ by\ B}$?
Take acceleration due to gravity, g, to be 9.8 m s^{-2}.



A. 69 N downwards

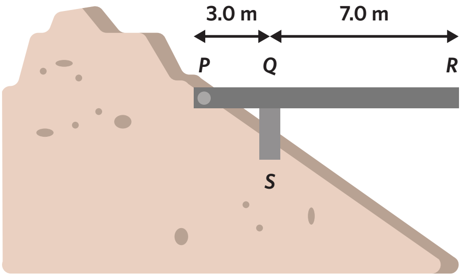
B. 49 N downwards

C. 69 N upwards

D. 49 N upwards

Question 4 (Medium)

A 3000 kg, uniform concrete beam *PR* of length 10.0 m is supported by column *QS*. It is attached at *P* with a frictionless pivot to a stable rock slab.



The magnitude of the force on *QS* by *PR* is

A. 1.8×10^4 N.

B. 2.0×10^4 N.

C. 3.0×10^4 N.

D. 5.0×10^4 N.

Adapted from VCAA 2013 exam 2013 Detailed Study 2 Q8

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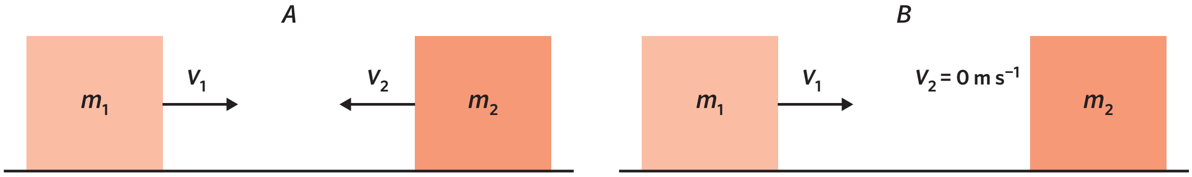
Question 5

Consider the following two collisions: (*A*) two blocks moving in opposite directions collide and (*B*) a moving block collides with a stationary block. After both collisions, the blocks join together and move off as one body. In both cases, $m_1 > m_2$. Which of the following statements must be true?



A. After the collision, the joined blocks in both *A* and *B* must move off to the right by the conservation of momentum, regardless of whether v_1 or v_2 is greater.

B. In *B*, the magnitude of the impulse experienced by m_2 will be greater than the magnitude of the impulse experienced by m_1.

C. In *B*, the magnitude of the velocity of m_1 after the collision will be less than the magnitude of its velocity before the collision.

D. In *A*, the force applied on m_2 by m_1 is greater than the force applied on m_1 by m_2.

Section B

In questions where more than one mark is available, appropriate working must be shown.

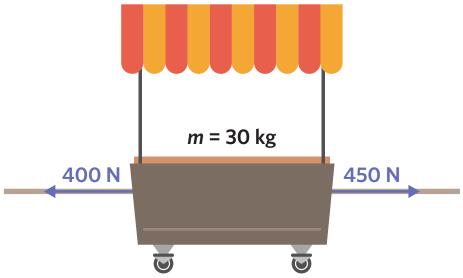
Unless otherwise indicated, the diagrams in this book are not drawn to scale.

Question 6 (3 MARKS)

A 30 kg cart is being pulled in opposite directions as it moves along a horizontal surface as shown in the diagram. A rope pulls the cart to the right with a force 450 N, while a second rope pulls the cart with a force of 400 N in the opposite direction.

a. Calculate the magnitude of the normal force acting on the cart. (1 MARK)

b. Determine the magnitude and direction of the cart's acceleration. (2 MARKS)

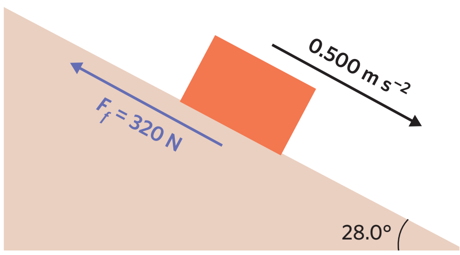


Question 7 (2 MARKS)

Egan is riding a bike along a flat stretch of road but finds that unless he keeps pedalling he will eventually stop moving. Use Newton's first law to explain why there must be a force acting on Egan even when he stops pedaling.

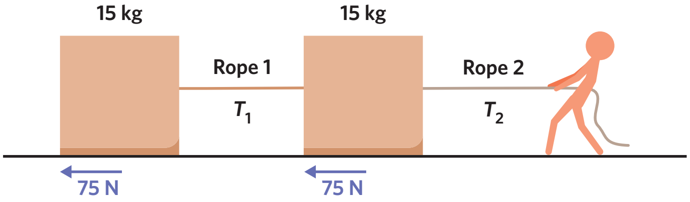
Question 8 (2 MARKS)

A block is sliding down a 28.0° slope whilst accelerating at a rate of 0.500 m s^{-2}. It experiences a frictional force of 320 N resisting its motion. Calculate the mass of the block.



Question 9 (4 MARKS)

Kaisha is pulling two identical storage units to the right. Each has a mass of 15 kg. A friction force is resisting the motion of each storage unit with a magnitude of 75 N.

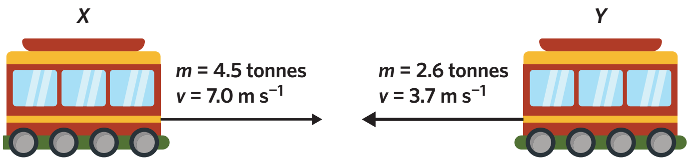


a. What force would Kaisha have to provide (T_2) in order to maintain a constant speed when she is pulling the storage units around the house? (1 MARK)

b. Calculate the magnitude of the tension acting on the left hand storage unit to maintain an acceleration of 0.30 m s^{-2}. (3 MARKS)

Question 10 (8 MARKS)

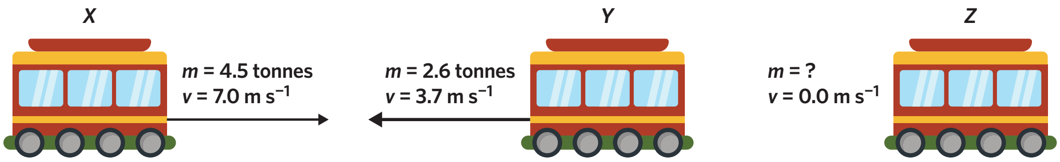
There has been an accident on the railway crossing and two trolley carts *X* and *Y* are on a collision course as shown in the included diagram. Trolley cart *X* has a mass of 4.5 tonnes and is moving to the right at 7.0 m s^{-1}. Trolley cart *Y* has a mass of 2.6 tonnes and is moving to the left at 3.7 m s^{-1}. After the collision, the trolley carts join together and move off as one.



a. What is the velocity *v* of the trolley carts immediately after the collision? (3 MARKS)

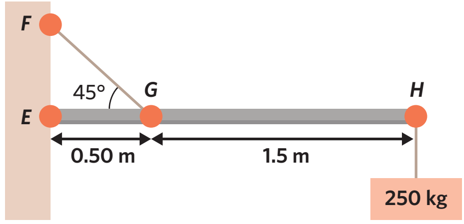
b. If trolley cart *X* collides with trolley cart *Y* with an average force of 25 000 N, calculate the duration of the collision, *t*. (2 MARKS)

c. The combined system is now set to collide with a third trolley cart *Z*. Explain why, regardless of the mass of *Z* is, it is impossible for it to remain stationary after the collision. (3 MARKS)



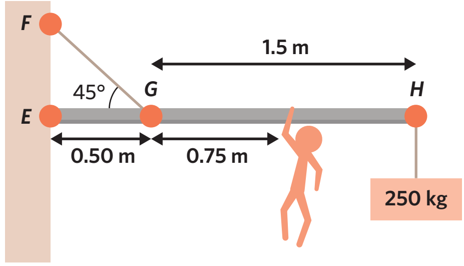
Question 11 (6 MARKS)

A 250 kg mass is hanging from a 2.0 m beam supported by a cable *FG* and attached to a frictionless pivot at *E* such that the system is in static equilibrium. The beam has a mass of 20 kg. The cable makes an angle of 45° to the horizontal.



a. Calculate the tension in the cable *FG*. (3 MARKS)

b. Agent 007, Jimmy Oath, climbs up the building and grabs on to the beam 0.75 m to the right of point *G*. The cable *FG* has a maximum tensile capacity of 2.0×10^4 N. Determine the maximum mass Jimmy Oath could have such that the cable does not snap. (3 MARKS)



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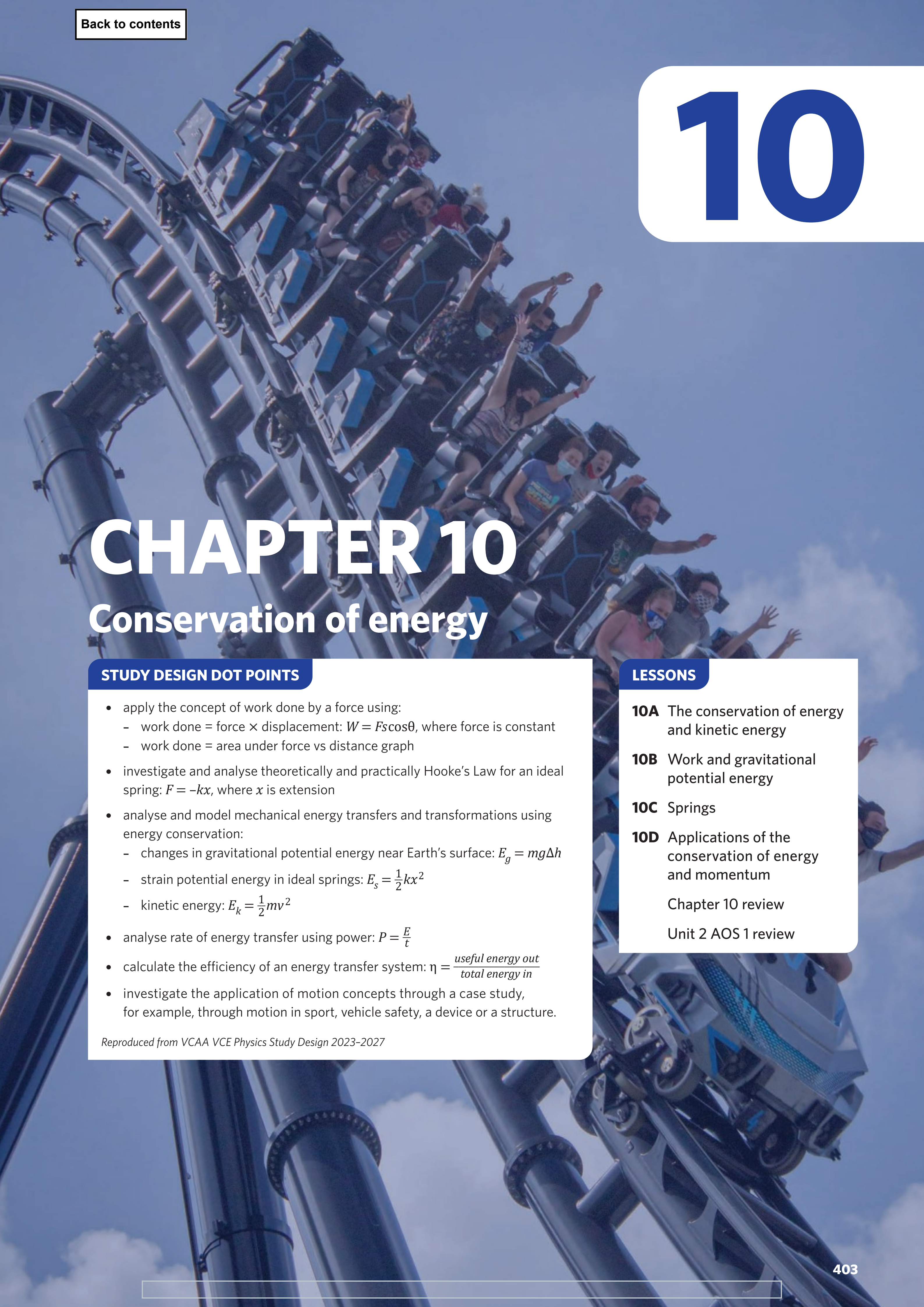

10

CHAPTER 10

Conservation of energy

STUDY DESIGN DOT POINTS

- apply the concept of work done by a force using:
  - work done = force × displacement: $W = Fs\cos\theta$, where force is constant
  - work done = area under force vs distance graph
- investigate and analyse theoretically and practically Hooke's Law for an ideal spring: $F = -kx$, where x is extension
- analyse and model mechanical energy transfers and transformations using energy conservation:
  - changes in gravitational potential energy near Earth's surface: $E_g = mg\Delta h$
  - strain potential energy in ideal springs: $E_s = \frac{1}{2}kx^2$
  - kinetic energy: $E_k = \frac{1}{2}mv^2$
- analyse rate of energy transfer using power: $P = \frac{E}{t}$
- calculate the efficiency of an energy transfer system: $\eta = \frac{useful\ energy\ out}{total\ energy\ in}$
- investigate the application of motion concepts through a case study, for example, through motion in sport, vehicle safety, a device or a structure.

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LESSONS

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10A The conservation of energy and kinetic energy

STUDY DESIGN DOT POINT

- analyse and model mechanical energy transfers and transformations using energy conservation:
  - changes in gravitational potential energy near Earth's surface: $E_g = mg\Delta h$
  - strain potential energy in ideal springs: $E_s = \frac{1}{2}kx^2$
  - kinetic energy: $E_k = \frac{1}{2}mv^2$

ACTIVITIES

Log into your Edrolo account for activities that support this lesson.

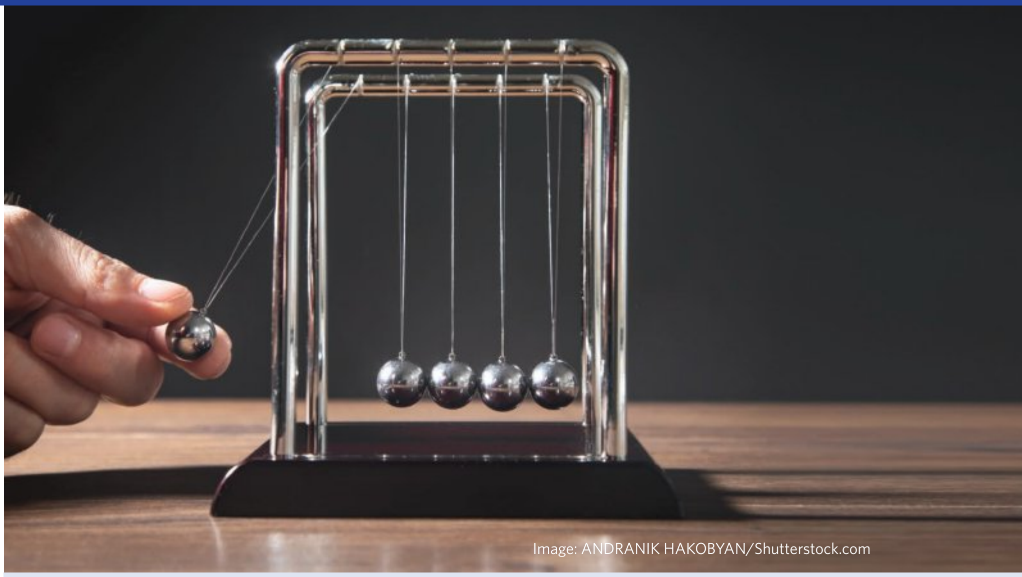

Image: ANDRANIK HAKOBYAN/Shutterstock.com

Why does Newton's cradle transfer motion back and forth?

In an isolated system, energy can be neither created or destroyed. As a result, energy cannot simply be lost in a process, but instead must be transformed from one form to another. We can use the conservation of mechanical energy to predict the outcomes of a range of situations, with a focus on kinetic energy (the energy of motion) in this lesson.

KEY TERMS AND DEFINITIONS

energy a quantity describing the ability to cause a physical change (scalar)

gravitational potential energy the stored energy associated with the position of an object in a gravitational field

kinetic energy the energy associated with the motion of an object

mechanical energy the energy associated with the motion or position of an object

strain potential energy the energy stored by the deformation of an object

FORMULAS

- **kinetic energy**
  $KE = \frac{1}{2}mv^2$
- **conservation of energy**
  $KE_i + GPE_i + SPE_i = KE_f + GPE_f + SPE_f$
- **change in kinetic energy**
  $\Delta KE = \frac{1}{2}m(v^2 - u^2)$

Conservation of energy 2.1.12.1

A fundamental law of the universe is that energy is always conserved in a closed system.

Theory and applications

Energy conservation can be seen everywhere throughout our lives. Consider bouncing a tennis ball, driving a car, or getting energy from eating food. All these processes involve the conversion of one form of energy to another, without energy being created nor destroyed.

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What is energy and how is it conserved?

Energy is hard to describe as a single thing. Instead, it is a concept and quantity used to describe and explain change. This is why it is useful to discuss energy in different forms depending on the context. These categories can range from thermal energy (explored in Chapter 2) to nuclear energy (explored in Chapter 5), or mechanical energy (explored in this chapter).

There are two main categories of mechanical energy: kinetic energy and potential energy. Kinetic energy refers to the energy associated with an object's motion, whereas potential energy refers to a stored energy due to an object's position.

Table 1 Some forms of mechanical energy

Energy Form	Symbol	Definition	Formula	Lesson discussed
Kinetic energy	*KE*	Energy associated with an object's motion	$KE = \frac{1}{2}mv^2$	10A
Gravitational potential energy	*GPE*	Energy associated with an object's position in a gravitational field	$GPE = mg\Delta h$	10B
Strain potential energy	*SPE*	Energy associated with the deformation (compression or extension) of a spring	$SPE = \frac{1}{2}k(\Delta x)^2$	10C

USEFUL TIP

In VCE Physics, it is common to see kinetic energy written as E_k, however in order to clearly differentiate between different types of energy, in this book it will be presented as *KE*.

In order to answer questions relating to energy, we need to identify the forms of energy present. A bus driving will have kinetic energy, a drone in the sky will have gravitational potential energy and a compressed string will have strain potential energy (see Figure 1). When a form of energy is present in a particular scenario, it may be referred to as a non-zero energy.

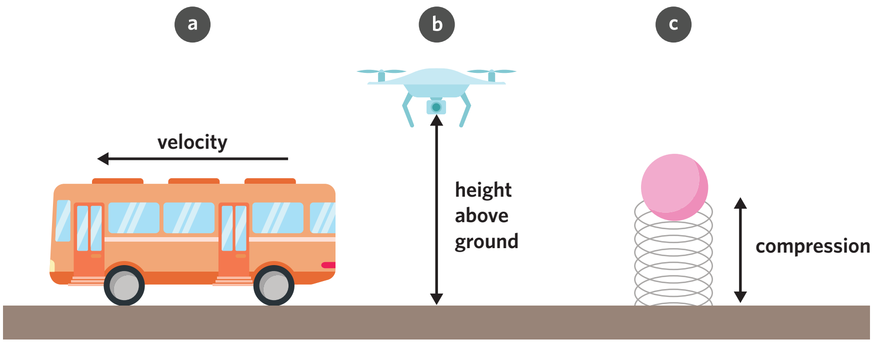

Figure 1 **(a)** Bus with *KE*, **(b)** drone with *GPE*, and **(c)** spring with *SPE*.

Consider bowling a cricket ball. The path of the ball and energy forms present along the flight are shown in Figure 2 and Table 2 respectively.

Table 2 Main energy forms present during the motion of the cricket ball

Diagram	Stage	Energy form present
A	When the ball is being bowled	Kinetic energy + gravitational potential energy of the arm and ball
B	When the ball is released and in motion	Kinetic energy + gravitational potential energy of the ball
C	Just before the ball bounces on the ground	Kinetic energy of the ball
D	When the ball hits stumps and comes to rest	Energy dissipated by the stumps

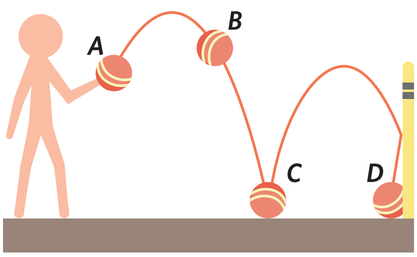

Figure 2 Flight of a cricket ball

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Image: VanHart/Shutterstock.com

Figure 3 Sound energy is present when billiard balls collide

USEFUL TIP

In VCE Physics, it is assumed that mechanical energy is always conserved, and no energy is lost to other forms unless otherwise stated.

In some situations energy may appear to be lost or destroyed, such as when a cricket ball hits the stumps or in a high speed car collision. Instead, mechanical energy is converted into other forms of energy such as light, heat and sound energy. In Figure 3, when two billiard balls collide a loud sound is often emitted, from the transformation of kinetic energy to sound energy.

STRATEGY

How to solve a problem using conservation of energy:

1. Write out the conservation of energy statement:

   $KE_i + GPE_i + SPE_i = KE_f + GPE_f + SPE_f$
2. Find the terms that are equal to zero.
   - When $v = 0$, then $KE = 0$
   - When $h = 0$, then $GPE = 0$
   - When $\Delta x = 0$, then $SPE = 0$
3. Rewrite the equation but ignore the terms that are equal to zero.

   For example: $SPE_i = KE_f + GPE_f$
4. Substitute the formulas for the unknown energies.
5. Substitute the known values into the equation and solve.

This method of solving will be implemented throughout Chapter 10.

Progress questions

Question 1

Determine the non-zero mechanical energy form present when a car is driving along a flat road.

A. kinetic energy
B. strain potential energy
C. nuclear energy
D. chemical energy

Question 2

Determine the non-zero mechanical energy form when a person is at the peak of their jump on a trampoline.

A. kinetic energy
B. gravitational potential energy
C. strain potential energy
D. radiation energy

Question 3

Identify the energy transformation taking place as a ball falls to the floor.

A. strain potential energy to gravitational potential energy
B. gravitational potential energy to strain potential energy
C. kinetic energy to gravitational potential energy
D. gravitational potential energy to kinetic energy

Continues →

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Question 4

In which of the following scenarios is energy created?

A. A car crashes into a tree.

B. A crane lifts a structure off the ground.

C. A person jumps off a diving board.

D. none of the above

Question 5

In which of the following scenarios is energy destroyed?

A. A car crashes in a tree.

B. A crane lifts a structure off the ground.

C. A person jumps off a diving board.

D. none of the above

Kinetic energy 2.1.12.2

Kinetic energy is the energy an object has due to its motion. The kinetic energy of an object can be calculated by $KE = \frac{1}{2}mv^2$.

Theory and applications

Lesson 2A looked at the relationship between kinetic energy and the temperature of a system on the scale of individual particles. We can also apply the concept of kinetic energy to the motion of large scale objects and systems.

How is kinetic energy calculated?

The amount of kinetic energy that an object has at a given moment depends on its mass and its velocity. Using this form of energy, we are able to model objects in motion.

FORMULA

$$KE = \frac{1}{2}mv^2$$

KE = kinetic energy (J)
m = mass (kg)
v = velocity (m s^{-1})

USEFUL TIP

When an object is mentioned as being at rest, its velocity is zero, and hence has no kinetic energy.

- For two objects that are travelling at the same velocity, the object with a larger mass will have more kinetic energy.
- For two objects with the same mass, the object with a larger velocity will have more kinetic energy.

MISCONCEPTION

'Kinetic energy is a vector quantity'

Kinetic energy, although being related to velocity, is a scalar quantity. All forms of energy are scalar quantities.

For an object of mass, m, with an initial velocity, u, and a final velocity, v, the change in kinetic energy, ΔKE, is given by:

$$\Delta KE = KE_f - KE_i = \frac{1}{2}mv^2 - \frac{1}{2}mu^2 = \frac{1}{2}m(v^2 - u^2)$$

Whilst the amount of kinetic energy at a particular point in time cannot be negative, the change in kinetic energy can be. This is the case when the magnitude of the final velocity, v, is smaller than the magnitude of the initial velocity, u, for example when the object is slowing down.

WORKED EXAMPLE 1

Maria is riding her tricycle after school. The total mass of Maria and the tricycle is 60 kg.

a. What is the kinetic energy of Maria and the tricycle when riding at 10 m s^{-1}?

Step 1

Identify velocity and mass, and the equation that relates these variables.

$v = 10 \text{ m s}^{-1}$, $m = 60$ kg, $KE = ?$

$KE = \frac{1}{2}mv^2$

Step 2

Substitute in the values and calculate kinetic energy.

$KE = \frac{1}{2} \times 60 \times 10^2 = 3000 = 3.0 \times 10^3$ J

b. Maria accelerates to 15 m s^{-1}. What is the change in kinetic energy of Maria and the tricycle over this period of acceleration?

Step 1

Identify final and initial velocity, mass, and the change in kinetic energy equation.

$u = 10 \text{ m s}^{-1}$, $v = 15 \text{ m s}^{-1}$, $m = 60$ kg, $\Delta KE = ?$

$\Delta KE = \frac{1}{2}m(v^2 - u^2)$

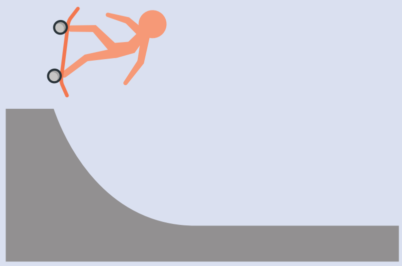
Step 2

Substitute the values and calculate the change in kinetic energy.

$\Delta KE = \frac{1}{2} \times 60 \times (15^2 - 10^2) = 3750 = 3.8 \times 10^3$ J

WORKED EXAMPLE 2

A skateboarder, of mass 70 kg, drops into a ramp with a gravitational potential energy of 8.0×10^3 J, compared to the bottom of the ramp. Determine the speed of the skateboarder at the bottom of the ramp.



Step 1

Create a conservation of energy equation and determine the zero energy values of the initial and final states.

$KE_i + GPE_i + SPE_i = KE_f + GPE_f + SPE_f$

$KE_i = 0, SPE_i = 0, GPE_f = 0, SPE_f = 0$

$GPE_i = KE_f$

Step 2

Identify gravitational potential energy given in question and its relation to the speed of the skateboarder at the bottom of the ramp.

$GPE_i = 8000$ J, $m = 70$ kg, $v = ?$

$8000 = \frac{1}{2}mv^2$

Step 3

Substitute the values into the conservation of energy equation and solve for the final velocity of the skateboarder.

$8000 = \frac{1}{2} \times 70 \times v^2$

$v = 15 \text{ m s}^{-1}$

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Progress questions

Question 6

A car of mass 500 kg is travelling at 10 m s^{-1}. What is its kinetic energy?

A. 25 J
B. 25 kJ
C. 50 J
D. 50 kJ

Question 7

A ball is hit horizontally by a baseball bat. Which of the following is true about the energy transformations that take place?

A. No energy is transformed.
B. The kinetic energy of the bat is transferred to the ball.
C. The kinetic energy of the bat is transformed to the gravitational potential energy of the ball.
D. The strain potential energy of the bat is transformed to the kinetic energy of the ball.

Question 8

If a stationary ball of mass 50 g is dropped from a height with 15 J of gravitational potential energy relative to the ground, how much kinetic energy does it have just before it hits the ground?

A. 0.0 J
B. 10 J
C. 15 J
D. 50 J

Theory summary

- Energy can neither be created nor destroyed but can be transformed from one type of energy to another.
  - The initial energy equals the final energy of the system.
- Conservation of energy:
  - Energy can be transformed between kinetic, gravitational and strain potential energy.
  - The total energy in a system must remain constant.
  - In a closed system:
    - $KE_i + GPE_i + SPE_i = KE_f + GPE_f + SPE_f$
- Kinetic energy is the energy associated with motion:
  - $KE = \frac{1}{2}mv^2$
  - $\Delta KE = \frac{1}{2}m(v^2 - u^2)$

The content in this lesson is considered fundamental prior knowledge to relationships between force, energy and mass (Unit 3 AOS 1).

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CONCEPT DISCUSSION

Image: Sashkin/Shutterstock.com

Newton's cradle is a succession of metal balls hanging from strings next to one another. When one ball is raised and released from rest, it will swing down and collide with a chain of balls. At this point the final ball will then swing out, much like the first, and then return to collide with the rest of the balls. This motion will continue to oscillate and repeat. With reference to the conservation of energy, discuss why this motion continues for an extended period of time, before eventually coming to rest.

Prompts:

- What are the initial forms of energy present?
- How is this transformed throughout the oscillation?
- What other forms of energy may the mechanical energy of the system be transferred to throughout the motion?

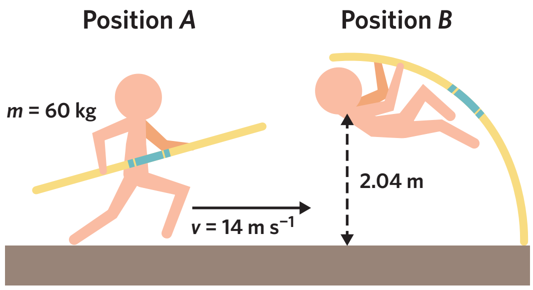
10A Questions

Mild Medium Spicy

Deconstructed exam-style

Use the following information to answer questions 9–13.

Pole vaulters utilise strain potential energy in their pole to launch themselves over a beam. One athlete, of mass 60 kg, runs in at a speed of 14 m s^{-1}, attempting to make it over the beam. Assume the mass of the pole vault and the velocity of the athlete at point *B* is negligible.



Question 9 (1 MARK)

What is the initial kinetic energy of the athlete?

A. 1.4×10^3 J

B. 5.9×10^3 J

C. 7.6×10^3 J

D. 1.2×10^4 J

Question 10 (1 MARK)

Which of the following correctly describes the energy transformation as the athlete goes from position *A* to position *B*?

A. gravitational potential energy to kinetic energy

B. kinetic energy to strain potential energy

C. kinetic energy to gravitational potential energy

D. kinetic energy to strain potential energy and gravitational potential energy

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Question 11 (1 MARK)

Which of the following correctly lists the non-zero energies when the pole vaulter is at position *B*, as shown in the diagram?

A. *GPE*

B. *SPE*, *GPE*

C. *SPE*, *GPE*, *KE*

D. None of the above

Question 12 (1 MARK)

Which of the following shows the conservation of energy equation for this situation?

A. $KE_i = GPE_f$

B. $KE_i = SPE_f + GPE_f$

C. $SPE_i + KE_i = GPE_f$

D. $KE_i + GPE_i + KE_i = KE_f + GPE_f$

Question 13 (4 MARKS)

If the athlete has 1200 J of *GPE* at position B, determine the amount of energy stored in the pole at that point.

Exam-style

Question 14 (4 MARKS)

In order to serve a ball, a player needs to throw it in the air before hitting it with their racquet. A ball, of mass 2.0 kg, is thrown up at a speed of 15 m s^{-1}, and travels at 50 m s^{-1} after it is served.

a. What is the kinetic energy of the ball immediately after it is thrown? (2 MARKS)

b. What is the kinetic energy of the ball after it is hit? (2 MARKS)

Question 15 (3 MARKS)

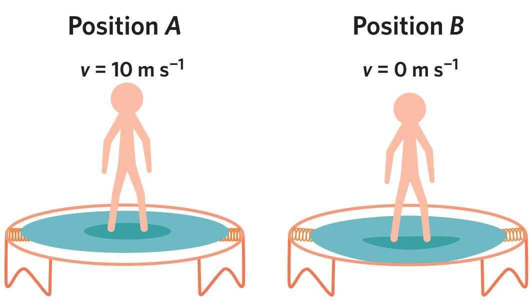
A car, of mass 0.50 tonnes, exits a freeway and decelerates from 100 km h^{-1} to 60 km h^{-1}. Determine the change in kinetic energy of the car and provide a brief explanation for the sign of your answer.

Question 16 (3 MARKS)

A person riding a bicycle at 17 m s^{-1}, with a combined mass of 160 kg, overtakes someone on a motorbike travelling at just 10 m s^{-1}, with a combined mass of 400 kg. Determine which has a greater kinetic energy.

Question 17 (3 MARKS)

A gymnast of mass 75 kg is travelling at 10 m s^{-1} just before they hit the trampoline (position *A*). Just before the trampoline propels them back up again, they briefly come to rest (position *B*). How much strain potential energy does the trampoline hold as the gymnast comes to rest? Assume the change in height during the contact is negligible.



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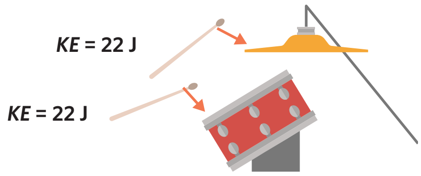
Question 18 (9 MARKS)

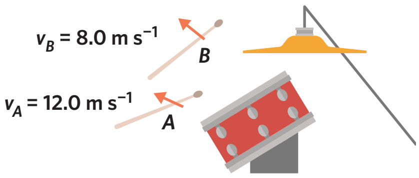
A drummer swings their drumsticks with a kinetic energy of 22 J each. Assume the changes in gravitational potential energy are negligible.



a. Calculate the mass of a single drumstick if it is travelling at 20 m s^{-1}. (2 MARKS)

b. Drumstick *A* hits the snare drum, and it rebounds back with a velocity of 12 m s^{-1}. Drumstick *B* hits the cymbal, and it rebounds back with a velocity of 8.0 m s^{-1}. Assume no other energy transformations took place.

Explain, with reference to the conservation of energy, whether the sound from the snare or cymbal will be louder. Assume that the properties of the cymbal or snare drum does not make a difference to how loud the sound is. (4 MARKS)



c. Calculate the total amount of kinetic energy transformed to sound energy. (3 MARKS)

Key science skills

Question 19 (3 MARKS)

Ted is conducting an experiment with the aim of measuring the relationship between the final velocity of a model car and its mass. Every time they increase the mass, they also increase the height of the ramp it is dropped from. Comment on the validity of Ted's experimental procedure.

FROM LESSON 11C

Previous lessons

Question 20 (2 MARKS)

Using the table, match the terms on the left to their definitions on the right (shown in an incorrect order).

Term	Definition/Process
Supercritical mass	decreases the neutron multiplication factor of a fissile mass.
Neutron multiplication factor	reduce the energy of neutrons through collisions with them.
Neutron moderators	has a fission chain reaction which is growing in number of reactions per unit time.
Increasing surface area	is a measure of how a fission chain reaction is growing, shrinking, or being sustained.

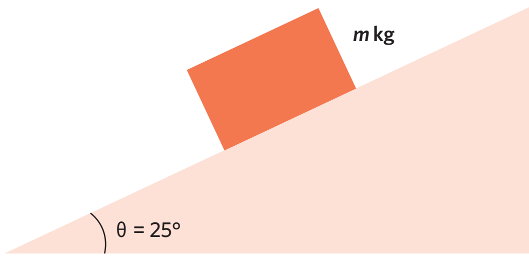
FROM LESSON 5B

Question 21 (3 MARKS)

Consider the system shown below.

There is a frictional force $F_f = 18$ N between m and the inclined plane. Calculate the largest mass the block could have before it begins to slide down the plane.

FROM LESSON 9C



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10B Work and gravitational potential energy

Image: PM Simmons/Shutterstock.com

Why does a roller coaster speed up as it falls?

When an object experiences a change in height, its gravitational potential energy is transformed to other forms of energy, according to the conservation of energy, including kinetic energy. This lesson introduces the concept of work in relation to energy, and its application to gravitational potential energy.

STUDY DESIGN DOT POINTS

- apply the concept of work done by a force using:
  - work done = force × displacement: $W = Fs\cos\theta$, where force is constant
  - work done = area under force vs distance graph
- analyse and model mechanical energy transfers and transformations using energy conservation:
  - changes in gravitational potential energy near Earth's surface: $Eg = mg\Delta h$
  - strain potential energy in ideal springs: $E_s = \frac{1}{2}kx^2$
  - kinetic energy: $E_k = \frac{1}{2}mv^2$
- analyse rate of energy transfer using power: $P = \frac{E}{t}$
- calculate the efficiency of an energy transfer system: $n = \frac{useful\ energy\ out}{total\ energy\ in}$

10A 10B 10C 10D

- 2.1.10.1 Work
- 2.1.10.2 & 2.1.12.4 Gravitational potential energy
- 2.1.13.1 & 2.1.14.1 Energy transfers

KEY TERMS AND DEFINITIONS

energy efficiency the ratio of useful output energy to input energy in an energy transfer

power the rate at which an energy transfer takes place with respect to time

work the change in energy caused by a force displacing an object

FORMULAS

- gravitational potential energy
  $\Delta GPE = mg\Delta h$
- conservation of energy
  $KE_i + GPE_i + SPE_i = KE_f + GPE_f + SPE_f$
- work
  $W = Fs$

ESSENTIAL PRIOR KNOWLEDGE

- **9A** Force due to gravity
- **9C** Resolving in two dimensions
- **10A** Kinetic energy
- **10A** Conservation of energy

See questions 84–87.

Work 2.1.10.1

The energy of an object describes its ability to cause change. Work is done when an applied force causes a change in energy.

Theory and applications

Work is defined as the change in energy of an object caused by an applied force. In order for work to be done by or on an object, there must be a change in energy that takes place.[1] We will look at work in the context of the three mechanical energy forms introduced in Lesson 10A.

KEEN TO INVESTIGATE?

[1] **What is work, in the context of physics?**
Search YouTube: What is work?

ACTIVITIES

Log into your Edrolo account for activities that support this lesson.

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What does it mean to do work, and how do we calculate it?

- Work is said to be done on an object when the energy of that object increases due to an applied force.
- Work is said to be done by an object when the energy of that object decreases due to an applied force.
- Work is proportional to the force applied, and the displacement of the object:

USEFUL TIP

The formula $W = Fs$ can only be used when the magnitude of the applied force is constant and the force is applied in the same direction as the displacement.

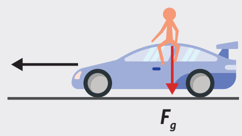
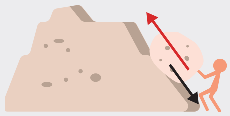
FORMULA

$$W = Fs$$

W = work done on an object (J)
F = magnitude of the force parallel to motion (N)
s = displacement (m)

When a force is applied to an object, there are three different outcomes for the type of work that has occurred, summarised in Table 1.

Table 1 Work applied in different situations

Situation	Force applied	Diagram	Mechanical energy change	Work done?
Person sitting on top of a moving car	Perpendicular to the direction of motion		×	×
Person pulling a car towards themselves	In the direction of motion		Increased	On the object
Person stopping a boulder falling down a cliff	Opposite to the direction of motion		Decreased	By the object

USEFUL TIP

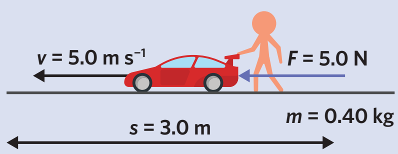
Work can be done both on and by the object at the same time, such as when pushing a block along the ground that is experiencing a frictional force. When this is the case, the net work done can be calculated by multiplying the net force by the displacement.

Recall Newton's laws of motion: when a net force is applied to an object, the object will experience an acceleration in the direction of the force. From what we learned in Lesson 10A, we know that a change in the velocity (an acceleration) of an object leads to a change in its kinetic energy. If no other changes of energy occur, then we can relate work to kinetic energy as follows:

$$W = \Delta KE$$
$$\Rightarrow Fs = \frac{1}{2}m(v^2 - u^2)$$

WORKED EXAMPLE 1

Goldie's toy car has a mass of 0.40 kg and is rolling along a frictionless floor at 5.0 m s^{-1}. She then applies a force of 5.0 N on the car over a distance of 3.0 m.



a. How much work did Goldie do on the car?

Step 1

Identify force and displacement of the object, and the formula that relates these variables.

$F = 5.0$ N, $s = 3.0$ m, $W = ?$

$W = Fs$

Step 2

Substitute the values and calculate the work done.

$W = 5.0 \times 3.0 = 15$ J

Continues →

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b. Calculate the final kinetic energy of the car.

Step 1

Identify work done as the change in kinetic energy.

$W = \Delta KE$

$\Delta KE = 15 \text{ J}$

Step 2

Identify the initial velocity and mass of the car, and the formula that relates these variables.

$u = 5.0 \text{ m s}^{-1}, m = 0.40 \text{ kg}, KE_i = ?$

$KE_i = \frac{1}{2}mu^2$

Step 3

Substitute the values and calculate the initial kinetic energy.

$KE_i = \frac{1}{2} \times 0.40 \times 5.0^2$

$KE_i = 5.0 \text{ J}$

Step 4

Equate the change in energy to the final and initial kinetic energy, and solve for final kinetic energy.

$\Delta KE = KE_f - KE_i$

$KE_f = \Delta KE + KE_i = 15 + 5.0 = 20 \text{ J}$

When force is applied at an angle to the displacement of the object, the component of the force in the direction of the displacement contributes to the work done. Recall from Lesson 9C, this is related to the net force with cos(θ), shown in Figure 1.

$$W = F\cos(\theta)$$

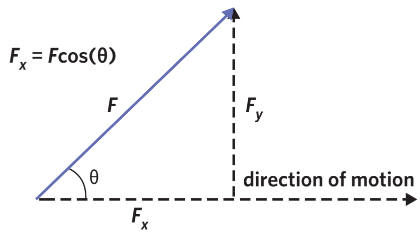
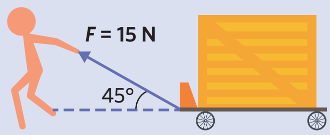


Figure 1 Resolving a force into its perpendicular components

WORKED EXAMPLE 2

A worker pulls a box with a force of 15 N, at an angle of 45°, for 6.0 m. Calculate the work done on the box.



Step 1

Identify the force, the angle at which it acts, the displacement of the object, and the formula relating these variables.

$F = 15 \text{ N}, s = 6.0 \text{ m}, \theta = 45°, W = ?$

$W = F\cos(\theta)$

Step 2

Calculate the work done on the box.

$W = 15 \times 6 \times \cos(45°) = 63.6 = 64 \text{ J}$

Progress questions

Question 1

In which of the following situations is work done on the object?

A. pushing a car that begins to move

B. pushing a car that refuses to budge

C. holding a weight still above your head

D. failing to lift a heavy object

Continues →

Question 2

In which of the following situations is work done by the object?

A. a person keeping a car stationary on a hill

B. a bike slowing down due to friction

C. coffee cup sitting on a table

Question 3

A man pushes a trolley with a force of 12 N, at an angle of 35° to the horizontal, over 4.0 m. Calculate the work done on the trolley.

A. 39 J

B. 39 N

C. 48 J

D. 48 N

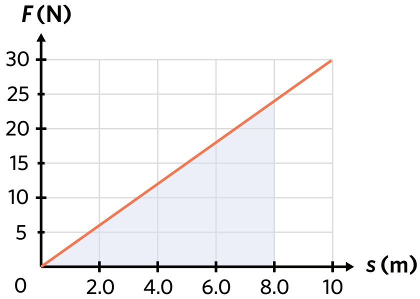


Figure 2 Graph of force varying with displacement

How can we analyse work from a graph?

When the force applied on an object changes with its displacement, we can produce a force-displacement graph to analyse the work done (see Figure 2).

The total area under the graph between two points is equal to the work done (in J) over that interval. The geometric methods of calculating areas under the graph, see Figure 3, were discussed in Lesson 8B. Other methods, such as counting the squares under the graph, may be used but will not be covered explicitly in this lesson.

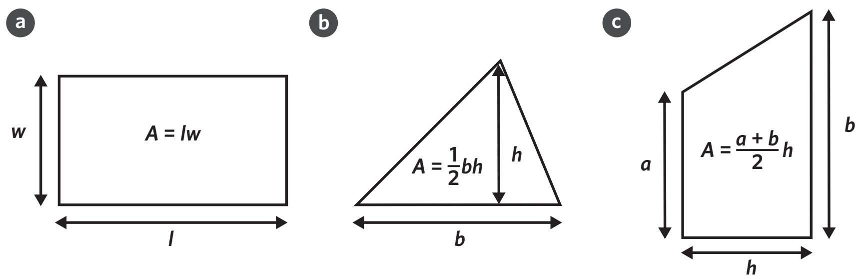


Figure 3 Calculating the area of **(a)** a rectangle, **(b)** a triangle and **(c)** a trapezium.

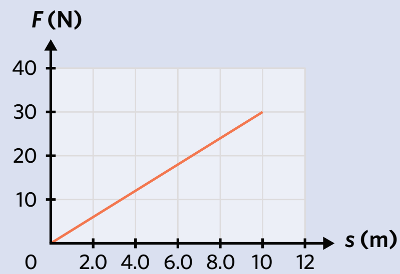
$$W = \text{area under force vs displacement graph}$$

USEFUL TIP

The VCE Study Design references a force-distance graph instead of a force-displacement graph. Force-distance graphs are not accurate for calculating work done when the direction of the force changes, but are otherwise interchangeable for calculation purposes.

WORKED EXAMPLE 3

Kaitlyn is pushing a 20 kg crate across a smooth floor from one side of the room to the other. This produces the force-displacement graph shown.



a. How much work is done on the crate between $s = 0.0$ m and $s = 10$ m?

Step 1

Identify the shape of the area under the graph, and its relationship to work.

$b = 10$ m, $h = 30$ N

$W = \textit{area under graph} = \frac{1}{2}bh$

Step 2

Substitute values into the formula and solve for the work done.

$W = \frac{1}{2} \times 10 \times 30 = 150 = 1.5 \times 10^2$ J

Continues →

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b. Calculate the final velocity of the crate.

Step 1

Identify work done as the change in kinetic energy.

$W = \Delta KE$

$\Delta KE = 1.5 \times 10^2$ J

Step 2

Identify the initial kinetic energy and the mass of the car, and hence the initial kinetic energy.

$u = 0.0$ m s^{-1}, $m = 20$ kg, $KE_i = ?$

$KE_i = \frac{1}{2}mu^2 = 0.0$ J

Step 3

Relate the change in energy to the final and initial kinetic energy, and solve for final kinetic energy.

$\Delta KE = KE_f - KE_i$

$KE_f = \Delta KE + KE_i = 1.5 \times 10^2 + 0.0 = 1.5 \times 10^2$ J

Step 4

Substitute values into the formula and solve for the velocity.

$KE_f = \frac{1}{2}mv^2$

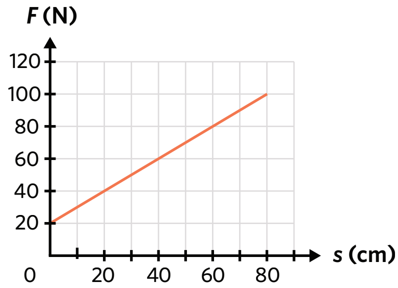
$1.5 \times 10^2 = \frac{1}{2} \times 20 \times v^2$

$v = 3.9$ m s^{-1}

Progress questions

Use the following information to answer questions 4 and 5.

A variable force is applied to a trolley. The following force vs displacement graph represents this force.



Question 4

What is the work done on the trolley over the first 40 cm?

A. 12 J

B. 1.2 kJ

C. 16 J

D. 1.6 kJ

Question 5

What is the change in kinetic energy of the trolley over the first 40 cm?

A. 12 J

B. 1.2 kJ

C. 16 J

D. 1.6 kJ

Gravitational potential energy 2.1.10.2 & 2.1.12.4

Gravitational potential energy is the energy stored by an object as a result of its position in a gravitational field. We will look at changes in gravitational potential energy due to an object's position above some reference height.

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Theory and applications

The change in gravitational potential energy of an object is equal to the amount of energy required to move the object through a gravitational field. In this lesson, ΔGPE refers to the energy lost or gained by an object moving closer or further away from the Earth. We will use the defined formula for work earlier in the lesson to arrive at the gravitational potential energy formula, $\Delta GPE = mg\Delta h$.

How can we use work to analyse changes in gravitational potential energy?

We saw earlier in the lesson that work can be defined as the change in energy of an object, due to its displacement ($W = Fs$).

- When work is done to move an object in a gravitational field, it is due to the gravitational force, $F = mg$.
- The displacement of an object, s, is the same as its change in height, Δh.

This leads to our change in gravitational potential energy formula:

$$W = \Delta E = Fs$$
$$\Rightarrow \Delta GPE = mg\Delta h$$

FORMULA

$$\Delta GPE = mg\Delta h$$

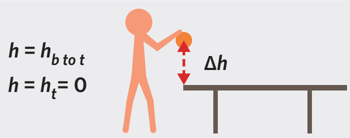
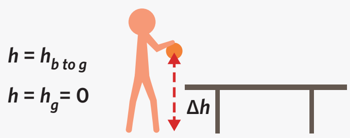
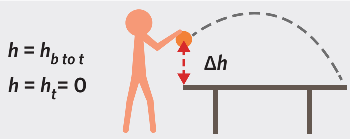
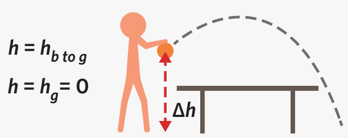
ΔGPE = change in gravitational potential energy (J)
m = mass of object (kg)
g = gravitational field strength (N kg^{-1})
Δh = change in height (m)

USEFUL TIP

Note that the VCE Physics Study Design uses the abbreviation E_g for gravitational potential energy. For the purposes of making an obvious distinction between different forms of energy, this book will usually use ΔGPE.

It is important to set the reference height of a particular situation as the lowest point relevant in that scenario. This will simplify problems, as the change in height of the object will simply be its height above the reference point, $\Delta h = (h - 0) = h$. Choices for reference height in some scenarios involving table tennis are shown in Table 2.

Table 2 Choice of reference height in table tennis

Scenario	Reference height	Change in height of the ball	*GPE*	Diagram
Dropping a ball (b) onto the table (t)	h_t	$\Delta h = (h_{b\ to\ t} - h_t)$ $= (h_{b\ to\ t} - 0)$ $= h_{b\ to\ t}$	When dropped: $mg\Delta h = mgh_{b\ to\ t}$ At the table: $mg\Delta h = 0$	
Dropping a ball onto the ground (g)	h_g	$\Delta h = (h_{b\ to\ g} - h_g)$ $= (h_{b\ to\ g} - 0)$ $= h_{b\ to\ g}$	When dropped: $mg\Delta h = mgh_{b\ to\ g}$ At the ground: $mg\Delta h = 0$	
Hitting a ball from above the table to the other side	h_t	$\Delta h = (h_{b\ to\ t} - h_t)$ $= (h_{b\ to\ t} - 0)$ $= h_{b\ to\ t}$	When hit: $mg\Delta h = mgh_{b\ to\ t}$ At the table: $mg\Delta h = 0$	
Hitting a ball beyond the table onto the ground	h_g	$\Delta h = (h_{b\ to\ g} - h_g)$ $= (h_{b\ to\ g} - 0)$ $= h_{b\ to\ g}$	When hit: $mg\Delta h = mgh_{b\ to\ g}$ At the ground: $mg\Delta h = 0$	

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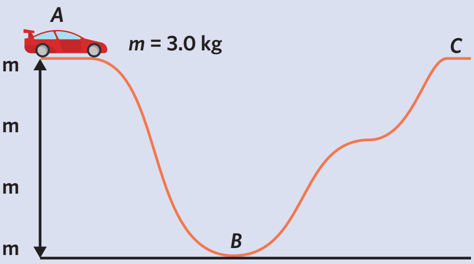
WORKED EXAMPLE 4

A 3.0 kilogram toy car is released from the top of a track with an initial height of 6.0 m, as shown in the diagram. Take the acceleration due to gravity to be 9.8 m s^{-2}. Assume friction is negligible.



a. What is the change in gravitational potential energy of the car from point *A* to point *B*?

Step 1

Set the reference height at the lowest point, the height of point *B*. Identify the initial and final height, mass and equation relating these variables.

$h_i = 6.0$ m, $h_f = 0.0$ m, $m = 3.0$ kg, $g = 9.8$ m s^{-2}, $\Delta GPE = ?$

$\Delta GPE = mg\Delta h$

Step 2

Calculate the change in gravitational potential energy between the two points.

$\Delta GPE = 3.0 \times 9.8 \times (0.0 - 6.0) = -1.76 \times 10^2$
$= -1.8 \times 10^2$ J

b. What is the change in gravitational potential energy of the toy car from point *A* to point *C*?

Step 1

Set the reference height at the lowest point, the height of point *A*/*C*. Identify the initial and final height, mass and equation relating these variables.

$h_i = 0.0$ m, $h_f = 0.0$ m, $m = 3.0$ kg, $g = 9.8$ m s^{-2}, $\Delta GPE = ?$

$\Delta GPE = mg\Delta h$

Step 2

Calculate the change in gravitational potential energy between the two points.

$\Delta GPE = 3.0 \times 9.8 \times (0.0 - 0.0) = 0.0$ J

The area under a gravitational force-height graph for an object close to Earth's surface represents its change in gravitational potential energy (see Figure 4). The gravitational potential energy of objects far from the Earth's surface are not considered in this lesson.[2]

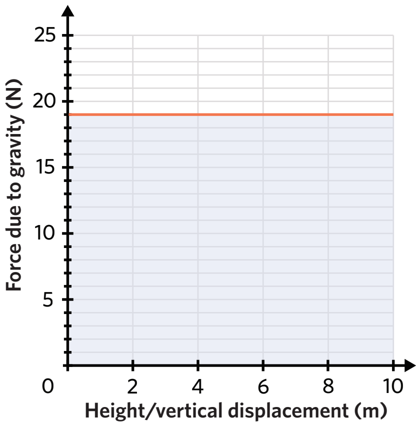


Figure 4 A gravitational force-height/vertical displacement graph for a 2 kg object.

How can gravitational potential energy be used in a system to model the conservation of energy?

- If kinetic energy and gravitational potential energy are the only relevant types of energy in a system, the total energy can be represented by: $E_{total} = KE + GPE$.
- Since energy is conserved (the total energy must be constant), we can equate the initial and final state, giving us:

  $KE_i + GPE_i = KE_f + GPE_f$

  $\Rightarrow \frac{1}{2}mu^2 + mgh_i = \frac{1}{2}mv^2 + mgh_f$
- By rearranging this equation (using $\Delta h = h_f - h_i$), we can find a formula for the final speed of an object moving through a gravitational field:

FORMULA

$$v = \sqrt{-2g\Delta h + u^2}$$

v = final speed (m s^{-1})
g = acceleration due to gravity (m s^{-2})
Δh = change in height (m)
u = initial speed (m s^{-1})

KEEN TO INVESTIGATE?

[2] **How do we model *GPE* at large distances?**
Search YouTube: Gravitational potential energy

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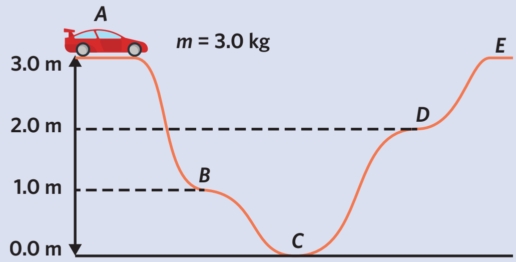
WORKED EXAMPLE 5

A 3.0 kilogram toy car is released from the top of a track with an initial height of 3.0 m. Its path is represented in the included diagram. Its speed is initially zero. Take the gravitational potential energy at point *C* to be zero.



a. Calculate the kinetic energy of the car at point *B*.

Step 1

Set the reference height at the height of point *B*. Identify the relevant variables and equation of conservation of energy.

$u = 0.0 \text{ m s}^{-1}$, $h_i = 2.0$ m, $h_f = 0.0$ m, $m = 3.0$ kg, $g = 9.8 \text{ m s}^{-2}$, $KE_f = ?$

$KE_i + GPE_i = KE_f + GPE_f \Rightarrow \frac{1}{2}mu^2 + mgh_i = \frac{1}{2}mv^2 + mgh_f$

Step 2

Calculate the final kinetic energy.

$\frac{1}{2} \times 3.0 \times 0^2 + 3.0 \times 9.8 \times 2 = KE_f + 3.0 \times 9.8 \times 0$

$KE_f = 58.8 = 59$ J

b. Calculate the speed of the car at point *C*.

Step 1

Identify the relevant variables and the equation for speed due to change in height.

$u = 0.0 \text{ m s}^{-1}$, $h_i = 3.0$ m, $h_f = 0.0$ m, $m = 3.0$ kg, $g = 9.8 \text{ m s}^{-2}$, $v = ?$

$v = \sqrt{-2g\Delta h + u^2}$

Step 2

Calculate the speed at point *C*.

$v = \sqrt{-2 \times 9.8 \times (0.0 - 3.0) + 0.0^2} = 7.7 \text{ m s}^{-1}$

Progress questions

Question 6

A plane of mass 750 kg is 400 m above the ground. What is the gravitational potential energy of the plane, with reference to the ground?

A. 2.4 MJ

B. 2.9 MJ

C. 3.0 MJ

D. 3.5 MJ

Use the following information to answer questions 7 and 8.

A ball of mass 1.0 kg is dropped from a height of 7.0 m, onto a table 4.0 m above the ground.

Question 7

When calculating the speed of the ball as it hits the table, which height should be taken as the reference height?

A. the centre of the earth

B. ground level

C. the height of the table

D. the initial height of the ball

Continues →

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Question 8

What is the speed of the ball as it hits the table?

A. $2.2\ \text{m s}^{-1}$

B. $5.5\ \text{m s}^{-1}$

C. $7.7\ \text{m s}^{-1}$

Energy transfers 2.1.13.1 & 2.1.14.1

We will look at two ways of measuring energy transfer: the rate at which energy is transferred (power), and the effectiveness of the energy transfer (energy efficiency).

Theory and applications

Power is the change in energy (work done) per unit of time, which measures the rate at which energy is being transferred or transformed. Efficiency is a measure of how much energy is lost due to resistive forces like friction and air resistance.

How can we analyse energy transfers?

Power is related to energy and time through the following formula:

FORMULA

$$P = \frac{E}{t}$$

P = power (W)
E = energy transferred/transformed (J)
t = time (s)

- The SI unit for power is Watts (W), where 1 W is equal to one joule per second ($1\ \text{J s}^{-1}$).
- Power is a scalar quantity.
- Power is a measure of the rate of change of energy, not the amount of energy that has been transferred/transformed.
- Power can also be expressed as $P = \frac{W}{t}$, where W = work done, however this is only applicable when the change in energy is caused by an applied force.

USEFUL TIP

Power can be thought of as the "speed" of an energy transfer, which increases as an energy transfer quickens.

WORKED EXAMPLE 6

A tow car does 75 kJ of work on a broken vehicle over the course of 24 seconds. Calculate the power output of this energy transfer.

Step 1

Identify the work done, duration and formula that relates these variables.

$E = W = 75 \times 10^3\ \text{J}, t = 24\ \text{s}, P = ?$

$P = \frac{E}{t}$

Step 2

Substitute values into the formula and solve for the power output.

$P = \frac{75 \times 10^3}{24} = 3125 = 3.1 \times 10^3\ \text{W}$

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10B THEORY

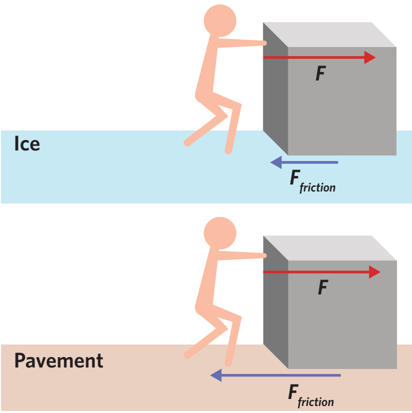

Figure 5 Pushing a block across ice versus pavement.

KEEN TO INVESTIGATE?

[3] **What is the efficiency of everyday devices?**
Search YouTube: Efficiency #8

An efficient transfer of energy is where minimal energy is lost to the environment due to resistive forces. We can calculate the efficiency of a system by dividing the final amount of useful energy by the total amount of energy supplied. The efficiency of pushing a block over ice will be greater than pushing it over the pavement (see Figure 5), as there is less energy lost to friction when the block is moving over ice.

'Useful' energy is considered to be forms of energy like kinetic energy or potential energy that can be used to do additional work. When energy is converted into non-useful energy, it is irrecoverable.

- The efficiency is generally expressed as a decimal between 0 (perfectly inefficient) and 1 (perfectly efficient).
- We can assume that a system is perfectly efficient unless otherwise specified. In reality, however, this is impossible to achieve.[3]

FORMULA

$$\eta = \frac{useful\ energy\ out}{total\ energy\ in}$$

η = efficiency (no units)
useful energy out (J)
total energy in (J)

WORKED EXAMPLE 7

Shanesia is investigating the efficiency of pushing a box across her wooden floor. She does 150 J of work on a 2.5 kg box and then measures its velocity as 5.0 m s^{-1} at the point of release. What was the efficiency of the energy transfer?

Step 1

Identify the mass and velocity of the box after the energy transfer, and the formula that relates these variables.

$m = 2.5$ kg, $v = 5.0$ m s^{-1}, $KE_f = ?$

$KE_f = \frac{1}{2}mv^2$

Step 2

Substitute values into the formula and solve for final kinetic energy.

$KE_f = \frac{1}{2} \times 2.5 \times 5.0^2 = 31.25 = 31$ J

Step 3

Identify useful energy out and useful energy in, and the formula that relates these variables.

useful energy out $= KE_f = 31$ J

total energy in $= W = 150$ J

$\eta = \frac{useful\ energy\ out}{total\ energy\ in}$

Step 4

Substitute values into the formula and solve for the efficiency of the transfer.

$\eta = \frac{31}{150} = 0.208 = 0.21$

USEFUL TIP

The efficiency of an object can never be more than 1, as energy cannot be created during a process.

Progress questions

Question 9

Which of the following is a measure of the rate at which the work is being done?

A. work
B. power
C. energy efficiency

Continues →

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Question 10

If work is done over a short period of time, how would the power output compare to if the same amount of work was done over a longer period of time?

A. smaller

B. larger

C. the same as

Question 11

How would the energy efficiency of pushing an object over a rough wood surface compare to pushing an object across ice?

A. less efficient

B. more efficient

C. the same efficiency

Theory summary

- A force is said to have done work on an object if it displaces it in the direction in which the force is acting.
  - Work is equal to the product of force and displacement ($W = Fs$) or the area under a force-displacement graph.
  - When the applied force is in the same direction as motion, the work done is positive.
  - When the applied force is in the opposite direction of motion, the work done is negative.
- A change in gravitational potential energy can be calculated from
  - the equation $\Delta GPE = mg\Delta h$.
  - the area under a gravitational force-height graph.
- For a system involving only kinetic energy and gravitational potential energy, this gives us:
  - $KE_i + GPE_i = KE_f + GPE_f$
  - $v = \sqrt{-2g\Delta h + u^2}$
- Power, P, is a measure of the change in energy per unit time.
  - $P = \frac{E}{t}$
- Energy efficiency is a measure of how much of the total energy supplied ends up as useful energy.
  - $\eta = \frac{useful\ energy\ out}{total\ energy\ in}$

The content in this lesson is considered fundamental prior knowledge to relationships between force, energy and mass (Unit 3 AOS 1).

CONCEPT DISCUSSION

The Moon's orbit is within the Earth's gravitational field. It maintains a relatively constant distance from Earth's centre (Δh), has a constant mass, and a relatively constant speed. Discuss how the Moon's velocity would change if it were to be moved further away from or closer to the Earth.

Prompts:

- As the Moon gets closer to or further away from the Earth, what forms of energy are interchanged between?
- How would this change the Moon's speed?

Image: Whitelion61/Shutterstock.com

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10B QUESTIONS

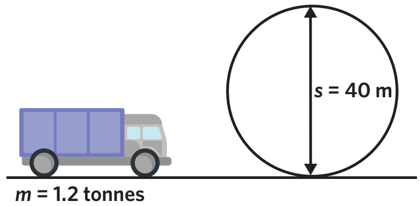
10B Questions

Mild Medium Spicy

Deconstructed exam-style

Use the following information to answer questions 12–15.

A 1.2 tonne cart is rolling along a roller coaster track towards a loop-the-loop. The loop-the-loop has a diameter of 40 m and the cart has a kinetic energy of 2.4×10^5 J at the top of the loop. Take the acceleration of gravity, g, to be 9.8 m s^{-2} and assume that the cart has no motors or brakes with which it could accelerate or decelerate.



Question 12 (1 MARK)

Which is the most appropriate equation to calculate the change in velocity for a body moving through a gravitational field?

A. $v = \sqrt{-2g\Delta h + u^2}$

B. $KE = \frac{1}{2}mv^2$

C. $\Delta GPE = mg\Delta h$

D. $KE_i + GPE_i = KE_f + GPE_f$

Question 13 (1 MARK)

As it travels to the top of the loop-the-loop, the cart can be said to have

A. lost energy.

B. converted gravitational potential energy into kinetic energy.

C. converted kinetic energy into gravitational potential energy.

D. gained energy.

Question 14 (1 MARK)

Compared to when the cart is at the bottom of the loop-the-loop, at the top of the loop-the-loop the cart will have

A. the same speed.

B. a lower speed.

C. a greater speed

Question 15 (4 MARKS)

Calculate the magnitude of the initial velocity of the cart before it enters the loop-the-loop.

Exam-style

Question 16 (3 MARKS)

Determine whether work is being done by the object, on the object, or no work is being done in the following scenarios.

a. Rachel picks up a pile of books from the floor. (1 MARK)

b. Maria gets tired from carrying her backpack as she stands in line. (1 MARK)

c. A ball rolls 10 m along a rough surface and comes to rest. (1 MARK)

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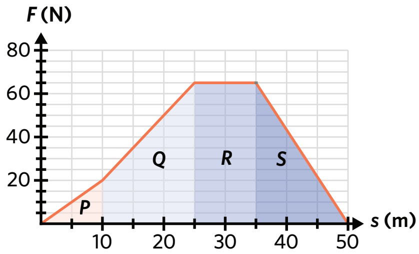
Question 17 (3 MARKS)

For the force-displacement graph below, decide which combination of letters provides the work done over the specified range. There is no need to calculate the areas.

a. From $s = 0$ m to $s = 10$ m. (1 MARK)

b. From $s = 0$ m to $s = 35$ m. (1 MARK)

c. From $s = 0$ m to $s = 50$ m. (1 MARK)



Question 18 (4 MARKS)

A skier is at a height of 750 m and wants to ride the chair lift to a height of 1000 m.

a. If the difference in gravitational potential energy of the skier between these two altitudes is 1.764×10^5 J, calculate the skier's mass. (2 MARKS)

b. The skier decides to ski back down the distance travelled in the chair lift. Calculate the velocity of the skier at the bottom of the hill. Assume no energy has been lost during this journey. (2 MARKS)

Question 19 (3 MARKS)

Sandra is moving some boxes around her office.

a. Calculate how much work she does when she pushes a box from rest across the floor for 4.5 m with a force of 40 N. (1 MARK)

b. What is the kinetic energy of the box after Sandra has pushed it 4.5 m? Ignore the effects of resistance forces. (2 MARKS)

Question 20 (5 MARKS)

A formula one car is able to produce useful power close to 7.8×10^5 W.

a. Calculate how much useful energy the engine produces over 13 seconds down the straight. Give your answer in MJ. (3 MARKS)

b. If the energy efficiency of the car is 0.68, calculate the total energy produced. (2 MARKS)

Question 21 (3 MARKS)

When someone is holding an object off the ground, explain why no work is being done, even though the person is applying a force on the object.

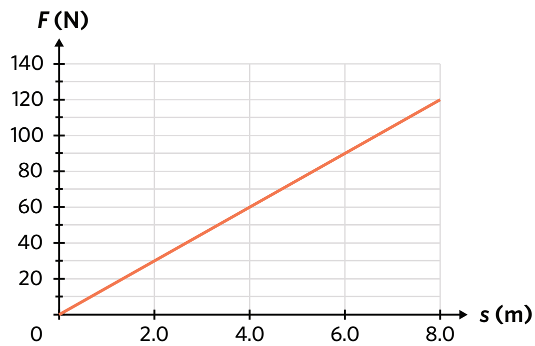
Question 22 (5 MARKS)

Jock is showing off his strength by pushing an 80 kg sofa along the floor. The corresponding force-displacement graph is shown.

a. How much work does Jock do over the first 8.0 m? (1 MARK)

b. If the velocity of the sofa was 0.75 m s^{-1} after Jock had pushed it for 8.0 m, calculate the force due to friction between the sofa and the floor. Assume that the force due to friction remained constant and that the sofa started from rest. (3 MARKS)

c. Calculate the energy efficiency of the work done by Jock. (1 MARK)

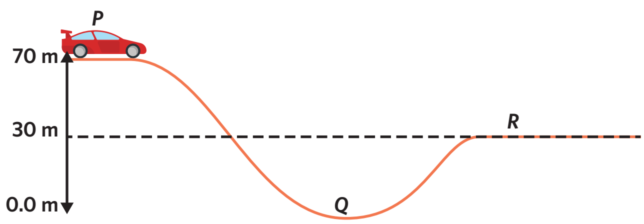


Question 23 (4 MARKS)

A 950 kg car is moving at 12.0 m s^{-1} towards a dip in the road. Ignore any frictional forces.

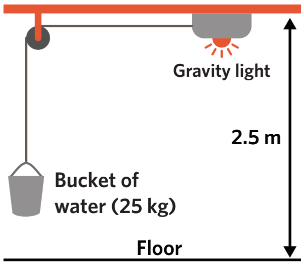
a. Calculate the car's total energy at Q. (2 MARKS)

b. Calculate the car's kinetic energy at R. (2 MARKS)



Question 24 (4 MARKS)

Students are testing a gravity-powered light. A 25 kg bucket of water falls from a height of 2.5 m. The energy that it generates is converted into electrical energy to power a 2.0 W light. Assume that the generator is ideal, meaning that it converts all of the input energy to light energy.

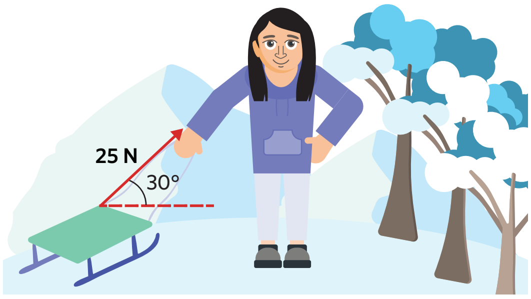


a. Calculate the maximum amount of energy that the bucket of water could generate. Ignore any resistance forces and any energy conversions as a result of the bucket of water moving and colliding with the ground. (2 MARKS)

b. For how long will the light stay on as a result of the bucket of water falling from its maximum height to the ground? (2 MARKS)

Question 25 (5 MARKS)

A keen sledder is enjoying a weekend at the snow. At one point on a flat stretch of snow, they pull their sled behind them such that there is a constant force of 25 N in the rope and it makes an angle of 30 degrees with the horizontal. Assume that there is no friction between the sled and the snow.



a. Explain why, as the sled is being pulled along, the magnitude of the force doing work on the sled is given by 25cos(30°) N and not 25 N. (3 MARKS)

b. Calculate how far the sled would have to be pulled before it has 150 J of kinetic energy, assuming that it started from rest. (2 MARKS)

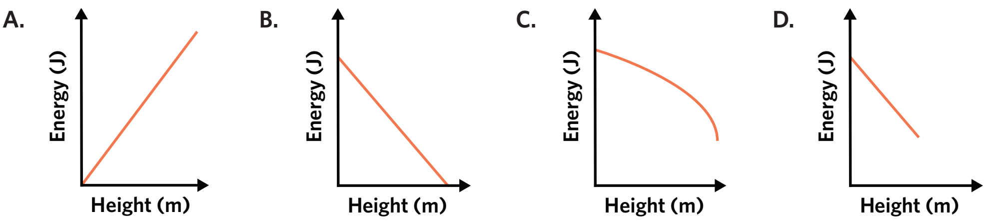
Question 26 (3 MARKS)

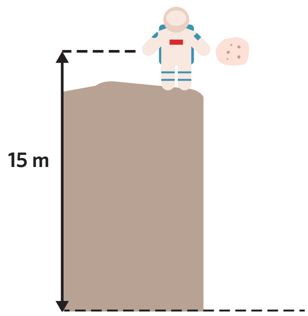
The Fosbury Flop is a common high jump technique that lowers the centre of mass of the jumper below the bar to be cleared. Explain how the Fosbury flop allows jumpers to clear higher bars, with reference to gravitational potential energy.

Image: sportpoint/Shutterstock.com

Question 27 (10 MARKS)

An astronaut on the moon drops a 1.0 kg moon rock from rest from a height of 15 m off a cliff. Take the gravitational potential energy at the bottom of the cliff to be zero. The moon has an acceleration due to gravity of 1.62 m s^{-2}.





a. Which graph (A–D) best shows the gravitational potential energy of the rock as a function of its height above the ground? Explain your answer. (3 MARKS)

b. Which graph (A–D) best shows the kinetic energy of the rock as a function of its height above the ground? Explain your answer. (3 MARKS)

c. Calculate the kinetic energy of the rock right before it lands at the bottom of the cliff. (2 MARKS)

d. Calculate the magnitude of the velocity of the rock when it has fallen 12 m. (2 MARKS)

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Key science skills

Question 28 (3 MARKS)

Bella is trying to determine if the mass of a ball influences the time it takes for it to roll down a ramp. The first ball is 2.0 kg and Bella increases the mass of the ball by 1.0 kg each time. Bella discovers that she does not have a ball weighing 4.0 kg with the same radius as the others used, so uses a larger ball for this reading before continuing with balls of the original size. Determine whether the experiment is valid and provide a reason why or why not.

FROM LESSON 11C

Previous lessons

Question 29 (3 MARKS)

Determine the amount of charge transferred by a 500 W jigsaw in 10 minutes, if it is connected to a 120 V power supply.

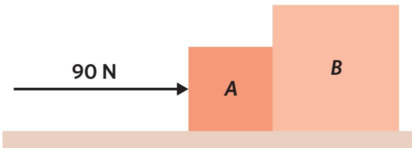
FROM LESSON 6A

Question 30 (2 MARKS)

Two blocks *A* (3.5 kg) and *B* (4.0 kg) are in contact and pushed across a frictionless surface by a force of 90N. Calculate the acceleration of the two blocks.

Adapted from VCAA 2018 exam Short answer Q8

FROM LESSON 9D



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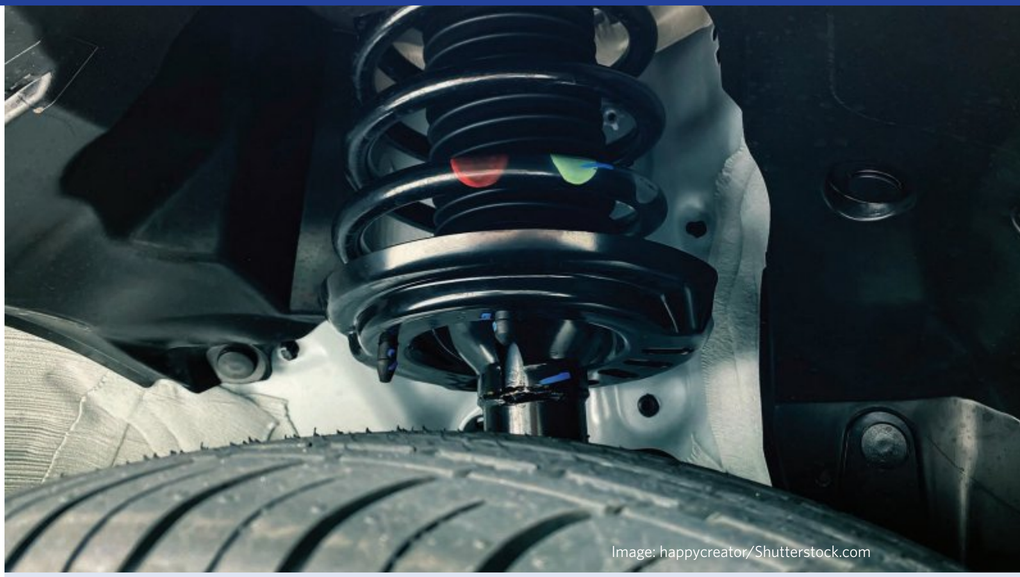
10C Springs



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STUDY DESIGN DOT POINTS

- investigate and analyse theoretically and practically Hooke's Law for an ideal spring: $F = -kx$, where x is extension
- analyse and model mechanical energy transfers and transformations using energy conservation:
  - changes in gravitational potential energy near Earth's surface: $E_g = mg\Delta h$
  - strain potential energy in ideal springs: $E_s = \frac{1}{2}kx^2$
  - kinetic energy: $E_k = \frac{1}{2}mv^2$

10A 10B 10C 10D

2.1.11.1 Hooke's Law for springs

2.1.12.3 Strain potential energy

ESSENTIAL PRIOR KNOWLEDGE

9A Force due to gravity
10A Conservation of energy
10A Kinetic energy
10B Gravitational potential energy
10B Work

See questions 88-92.

ACTIVITIES

Log into your Edrolo account for activities that support this lesson.

How do the suspension springs in a car act to give us a smooth ride down a bumpy road?

This lesson will introduce the force and potential energy associated with ideal springs and apply them in the wider context of energy conservation and transformation.

KEY TERMS AND DEFINITIONS

compression (spring) a decrease in the spring's length from the natural length

equilibrium position the position a spring is in when the external forces on it are equal to the restoring force of the spring

extension (spring) an increase in the spring's length from the natural length

natural length the length of a spring when no external forces are acting on it

spring any object that can deform and return to its original shape after external forces have been removed

spring constant a value that describes the stiffness of a spring

FORMULAS

- **Hooke's Law**
  $F_s = -k\Delta x$
- **strain potential energy**
  $SPE = \frac{1}{2}k(\Delta x)^2$
- **force due to gravity**
  $F_g = mg$
- **kinetic energy**
  $KE = \frac{1}{2}mv^2$
- **gravitational potential energy**
  $GPE = mg\Delta h$
- **conservation of energy**
  $KE_i + GPE_i + SPE_i$
  $= KE_f + GPE_f + SPE_f$

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Hooke's Law for springs 2.1.11.1

Hooke's Law describes the linear relationship between the force and displacement of an ideal spring.

Theory and applications

When springs are deformed from their natural length through stretching or compression, they will produce a force which acts to restore their natural length. Imagine stretching a rubber band, as the length of the rubber band increases, so too does the resistance force.

How is the force that a spring produces calculated?

Hooke's Law is used to calculate the restoring force exerted by an ideal spring to return to its natural length (see Figure 1).[1]

KEEN TO INVESTIGATE?

[1] **What is Hooke's Law?**
Search YouTube: Hooke's Law Introduction – Force of a Spring

FORMULA

$$F_s = -k\Delta x$$

F_s = spring restoring force (N)
k = spring constant (N m^{-1})
Δx = displacement from natural position (m)

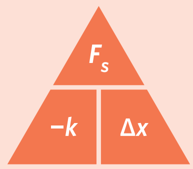

Figure 1 Formula triangle for Hooke's Law

The spring constant, k, represents the stiffness of a spring and determines how quickly the restoring force will increase as the spring is compressed or extended.

- It is a property of the material the spring is made of, and the geometry of the spring. For example, a metal spring will generally have a greater spring constant than a plastic spring.
- It is a scalar quantity and therefore is always a positive value.

A spring will always produce a force in the opposite direction to the spring's displacement from the natural position, Δx. This is represented by the negative sign in Hooke's Law.

- The negative sign is often excluded as it is common to deal with just the magnitudes of forces, therefore we would use $F_s = k\Delta x$ in our calculations.
- When a spring is in its natural position (neither compressed nor stretched, $\Delta x = 0$), it will not exert a force ($F_s = -k\Delta x = 0$).

USEFUL TIP

An ideal spring is one which obeys Hooke's Law, where force increases linearly with distance. Unless otherwise stated, all springs in this course should be considered ideal.

For an object attached to a vertical spring, when the force due to gravity acting on the object has the same magnitude as the restoring force of the spring, the net force on the object is zero.

$$mg = k\Delta x$$

This is often called the equilibrium position, as it is the position where an object attached to a spring will come to rest over a period of time when friction is present. In a vertical spring, this is also the position at which the speed of the attached object will be a maximum, as the object is no longer accelerating.

USEFUL TIP

Many elastic objects obey Hooke's Law, such as elastic bands. All such objects are technically known as springs, even though we associate this term most with coil springs. Coil springs are the most commonly used in VCE Physics.

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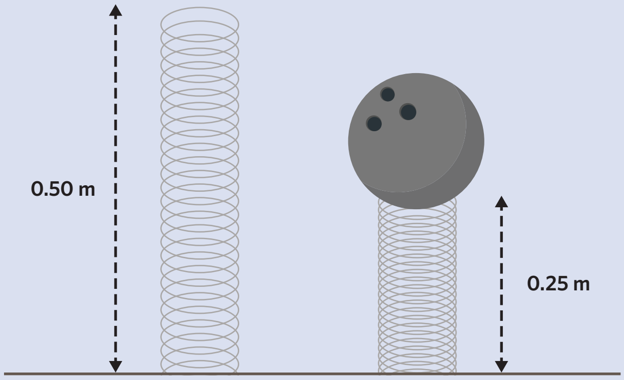
MISCONCEPTION

'Equilibrium and natural position are the same thing.'

The equilibrium position will be different to the natural position on a vertical spring. The natural position is always when $-k\Delta x = 0$ whereas the equilibrium position is when $k\Delta x = mg$.

WORKED EXAMPLE 1

An ideal spring has a spring constant of 200 N m^{-1} and a natural length of 0.50 m. When a bowling ball is at rest on the spring such that it is in the equilibrium position, the spring is compressed to a length of 0.25 m.



a. What is the magnitude of the displacement, Δx, of the spring from its natural length?

Identify that Δx is the difference between the spring's natural length, 0.50 m, and compressed length, 0.25 m.

$\Delta x = 0.50 - 0.25 = 0.25$ m

b. Determine the force produced by the spring.

Step 1

Identify the spring constant, compression of the string, and Hooke's Law relating these variables.

$k = 200$ N m^{-1}, $\Delta x = 0.25$ m, $F_s = ?$

$F_s = k\Delta x$

Step 2

Substitute in the values and identify the direction to find the force that the spring produces. The direction of the force is in the opposite direction to its downwards displacement, so upwards.

$F_s = 200 \times 0.25 = 50$ N upwards.

c. Calculate the mass of the bowling ball. Take the acceleration due to gravity, g, to be 9.8 m s^{-2}.

Step 1

Identify that as the spring is in the equilibrium position, the magnitude of the spring force will be equal to the force due to gravity of the bowling ball: $mg = k\Delta x$.

$k = 200$ N m^{-1}, $\Delta x = 0.25$ m, $g = 9.8$ m s^{-2}, $m = ?$

$mg = k\Delta x$

Step 2

Substitute in the values and solve for the bowling ball's mass.

$m \times 9.8 = 200 \times 0.25$

$m = \frac{200 \times 0.25}{9.8} = 5.1$ kg

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Progress questions

Question 1

If a spring has a spring constant of 100 N m^{-1} and is compressed by 1 m, what is the applied force on the spring?

A. 0 N

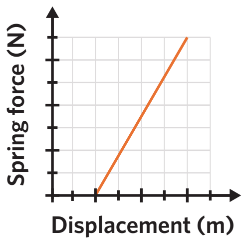
B. 100 N

C. 200 N

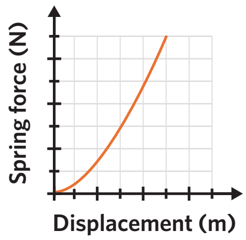
Question 2

Which of the following spring force-displacement graphs correctly represents an ideal spring?

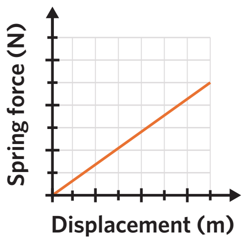
A.



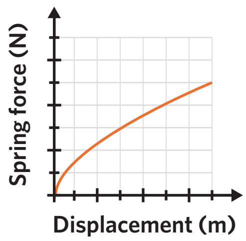
B.



C.

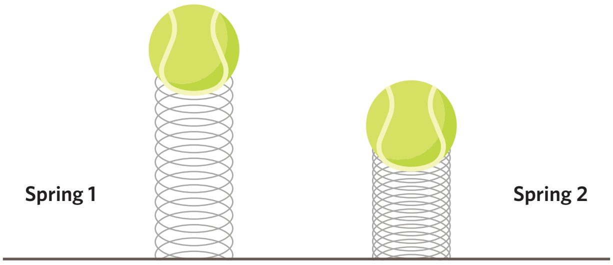


D.



Use the following information to answer questions 3 and 4.

Two balls of identical mass are at rest on two springs of the same length but with different spring constants. Spring 2 is compressed more than Spring 1.



Question 3

Which of the following options identifies the spring with the greater spring constant, k?

A. Spring 1

B. Spring 2

C. They have the same spring constant.

D. Not enough information is given.

Question 4

Which of the following options identifies the spring producing the greatest upwards force, F_s?

A. Spring 1

B. Spring 2

C. They are producing the same upwards force.

D. Not enough information is given.

Strain potential energy 2.1.12.3

Strain potential energy represents the energy that is stored in a spring when it is compressed or extended. It can be transformed into gravitational potential energy or kinetic energy in line with the law of conservation of energy.

USEFUL TIP

Strain potential energy is also sometimes referred to as spring potential energy or elastic potential energy. They are all exactly the same.

Theory and applications

Strain potential energy will be the last form of mechanical energy that we will learn in VCE physics. With this form of energy we are able to model the complex motion of objects.

How is strain potential energy calculated?

Strain potential energy represents a spring's potential to do work as it returns to its natural length. When the spring returns to its natural length, this potential energy will be converted to other forms, usually kinetic energy and/or gravitational potential energy.

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10C THEORY

USEFUL TIP

Note that the VCE Physics Study Design uses the abbreviation E_s for strain potential energy. For the purposes of making an obvious distinction between different forms of energy, this book will use *SPE*.

FORMULA

$$SPE = \frac{1}{2}k(\Delta x)^2$$

SPE = strain potential energy (J)
k = spring constant (N m^{-1})
Δx = displacement from natural position (m)

Progress questions

Question 5

What is the magnitude of the displacement, Δx, required to have $SPE = 40$ J when the spring constant $k = 500$ N m^{-1}.

A. 0 m

B. 0.16 m

C. 0.40 m

D. 1.0 m

Question 6

What is the value of the spring constant of an ideal spring that gives an object 20 J of kinetic energy after the object extends the spring by 2.0 m?

A. 0 N m^{-1}

B. 5.0 N m^{-1}

C. 10 N m^{-1}

D. 20 N m^{-1}

How can strain potential energy be used to model the conservation of energy?

As learnt in Lesson 10A, the total energy of a system is always conserved.[2] This means we can equate the total energy of the initial state of a spring-mass system with the total energy of the final state of the system to determine unknown quantities.

In practice, energy will be dissipated to the environment commonly in the form of thermal energy, sound energy, and the permanent deformation of the spring material. This will not be considered in Unit 1&2 VCE Physics.

KEEN TO INVESTIGATE?

[2] **How do energies change for a mass oscillating on a spring?**
Search: Masses and springs simulation

STRATEGY

How to solve a problem using conservation of energy:

1. Write out the conservation of energy statement:

   $KE_i + GPE_i + SPE_i = KE_f + GPE_f + SPE_f$

2. Find the terms that are equal to zero.
   - When $v = 0$, then $KE = 0$
   - When $h = 0$, then $GPE = 0$
   - When $\Delta x = 0$, then $SPE = 0$

3. Rewrite the equation but ignore the terms that are equal to zero.

   For example: $SPE_i = KE_f + GPE_f$

4. Substitute the formulas for the unknown energies.

   For example: $\frac{1}{2}k(\Delta x)_i^2 = \frac{1}{2}mv^2 + mgh_f$

5. Substitute the known values into the equation and solve.

This method of solving will be implemented throughout Chapter 10.

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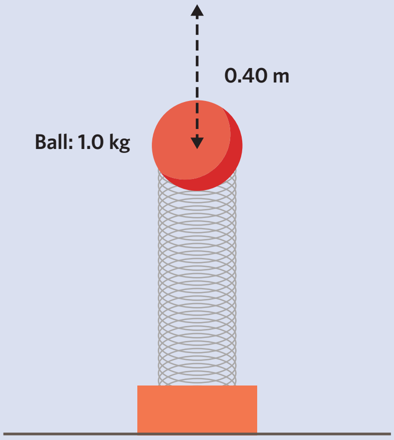
WORKED EXAMPLE 2

An ideal spring is being used to launch a 1.0 kg ball vertically upwards. The spring is initially compressed by 0.40 m and has a spring constant of 80 N m^{-1}.



a. Calculate the strain potential energy initially stored in the spring.

Step 1

Identify displacement and spring constant, and the strain potential energy formula that relates these variables.

$k = 80 \text{ N m}^{-1}, \Delta x = 0.40 \text{ m}, SPE = ?$

$SPE = \frac{1}{2}k(\Delta x)^2$

Step 2

Substitute in the values and calculate strain potential energy.

$SPE = \frac{1}{2} \times 80 \times 0.40^2 = 6.4 \text{ J}$

b. Determine the maximum speed of the ball.

Step 1

Identify mass, spring constant, and the equation that relates these variables to spring displacement. Note we are calculating the displacement at the equilibrium point, as this is where the ball will have maximum speed.

$m = 1.0 \text{ kg}, g = 9.8 \text{ m s}^{-2}, k = 80 \text{ N m}^{-1}, \Delta x = ?$

$mg = k\Delta x$

Step 2

Substitute in the values and solve for the compression of the spring when the ball has maximum speed.

$1.0 \times 9.8 = 80 \times \Delta x$

$\Delta x = \frac{1.0 \times 9.8}{80} = 0.12 \text{ m}$

Step 3

Create a conservation of energy equation and determine the zero energy values of the initial and final states.

$GPE_i = 0$ as we define the initial height as the reference height.

$KE_i + GPE_i + SPE_i = KE_f + GPE_f + SPE_f$

$GPE_i = 0, KE_i = 0$

$SPE_i = KE_f + GPE_f + SPE_f$

Step 4

Expand out the conservation of energy equation and determine the important values in this equation (using the spring displacement at equilibrium position).

$m = 1.0 \text{ kg}, g = 9.8 \text{ m s}^{-2}, k = 80 \text{ N m}^{-1}, \Delta x_i = 0.40 \text{ m},$
$h_f = (0.40 - 0.12) \text{ m}, \Delta x_f = 0.12 \text{ m}, v = ?$

$\frac{1}{2}k(\Delta x_i)^2 = \frac{1}{2}mv^2 + mgh + \frac{1}{2}k(\Delta x_f)^2$

Step 5

Substitute the values into the conservation of energy equation and solve for the final velocity of the ball. Note that since energy is a scalar quantity only positive values should be placed into the equation.

$\frac{1}{2} \times 80 \times 0.40^2$
$= \frac{1}{2} \times 1.0 \times v^2 + 1.0 \times 9.8 \times (0.40 - 0.12) + \frac{1}{2} \times 80 \times (0.12)^2$

$v = 2.5 \text{ m s}^{-1}$

Continues →

c. Calculate the maximum height, h, that the ball reaches above its starting position.

Step 1

Identify energy conservation and determine the zero energy values of the initial and final state. Note that $KE_f = 0$ as the ball is instantaneously at rest when it reaches its maximum height.

$KE_i + GPE_i + SPE_i = KE_f + GPE_f + SPE_f$

$GPE_i = 0,\ KE_i = 0,\ KE_f = 0,\ SPE_f = 0$

$SPE_i = GPE_f$

Step 2

Expand out the conservation of energy equation and determine the important values to find the initial and final energies.

$m = 1.0$ kg, $g = 9.8$ m s^{-2}, $k = 80$ N m^{-1}, $\Delta x_i = 0.40$ m, $h = ?$

$\frac{1}{2}k(\Delta x)^2 = mgh$

Step 3

Substitute in the values and solve for the final height.

$\frac{1}{2} \times 80 \times 0.40^2 = 1.0 \times 9.8 \times h$

$h = 0.65$ m

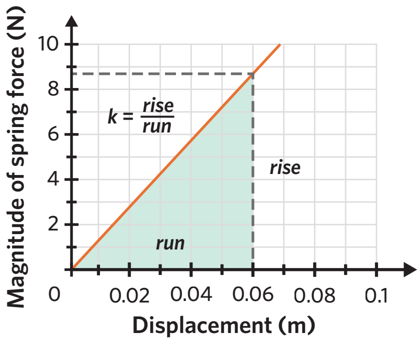


Figure 2 Spring force-displacement graph

USEFUL TIP

The area of a triangle can be found using $A_{triangle} = \frac{1}{2}bh$. Other methods of finding the area under a graph are shown in Lesson 10B.

A spring force-displacement graph (see Figure 2) is a useful way of displaying the properties of a spring, and shows the magnitude of the spring force for a continuous range of displacements of the spring. For ideal springs, their spring force-displacement graph will be linear (a constant gradient) modelled by Hooke's Law, and its features will represent physical quantities as given in Table 1.

Table 1 Key features of spring force-displacement graphs

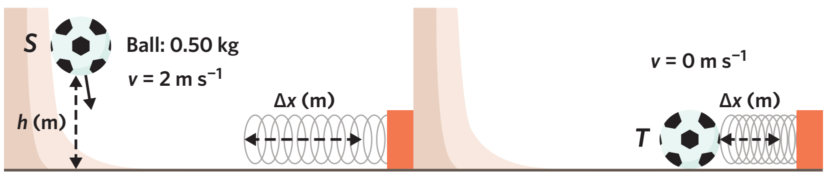
Spring force-displacement graph feature	What the feature represents
Gradient	Spring constant (k)
Area under the graph (work)	Change in strain potential energy (ΔSPE)
Vertical axis value	Spring force (F_s)

The gradient of the spring force-displacement graph shown in Figure 2 is the spring constant, $k = \frac{8.8 - 0}{0.060 - 0} = 1.5 \times 10^2$ N m^{-1}. The shaded area shows the change in strain potential energy, $\frac{1}{2}bh = \frac{1}{2} \times 0.060 \times 8.8 = 0.26$ J, and the specific vertical axis value shows the magnitude of the spring force, 8.8 N, when the spring is displaced 0.06 m from its natural length.

Progress questions

Question 7

A ball is pushed down a ramp such that it has an initial speed of 2 m s^{-1} at position S, before compressing a spring and momentarily coming to rest at position T. Assume $h = 0$ at the ground. Which of the following lists the non-zero energies at position S and position T?



	Non-zero energies at position S	Non-zero energies at position T
A.	GPE	SPE and KE
B.	GPE and KE	SPE
C.	GPE, KE and SPE	None
D.	KE and SPE	GPE

Continues →

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Question 8

A toy car is moving to the right and has a kinetic energy of 2.5 J. It hits a horizontal spring where all of its energy is converted into *SPE*, before being launched back in the direction that it originally came from. What is the kinetic energy of the car after the collision?

A. 2.5 J to the left

B. 2.5 J to the right

C. 2.5 J

D. Not enough information to answer the question

Question 9

On a spring force-displacement graph, the spring constant is equivalent to the __________ (gradient/area under the graph) and the strain potential energy is equivalent to the __________ (gradient/area under the graph).

Theory summary

- Hooke's Law relates the spring force to the displacement of an ideal spring:
  - $F_s = -k\Delta x$
- Strain potential energy can be calculated by $SPE = \frac{1}{2}k(\Delta x)^2$
- Conservation of energy:
  - Energy can be transformed between kinetic, gravitational and strain potential energy.
  - The total energy in a system must remain constant.
  - In a closed system:
    - $KE_i + GPE_i + SPE_i = KE_f + GPE_f + SPE_f$
- On a spring force-displacement graph for an ideal spring:
  - the graph is linear, with the gradient equal to the spring constant, k,
  - the area under the graph is equal to the change in strain potential energy, *SPE*, and
  - the vertical axis value is the spring force, F_s.

The content in this lesson is considered fundamental prior knowledge to relationships between force, energy and mass (Unit 3 AOS 1).

CONCEPT DISCUSSION

Rubber bands can be thought of as similar to ideal springs since they can store strain potential energy and obey Hooke's Law for small displacements. They can be shot from someone's hand by stretching it and then releasing it, as shown in the included diagram. If the objective is for a rubber band to be shot at a maximum speed, discuss whether a small, stiff rubber band or a larger, stretchier rubber band would be preferred, assuming they have equal restoring force before release.

Prompts:

- How do the properties of the two rubber bands compare?
- How do these properties affect the strain potential energy stored in a stretched rubber band?
- How will these factors relate to the maximum speed of the rubber band?

Image: Sharomka/Shutterstock.com

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10C Questions

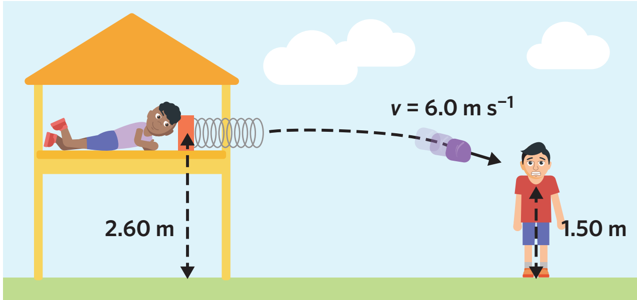
Mild Medium Spicy

Deconstructed exam-style

Use the following information to answer questions 10-14.

In a school playground, a teenager named Ex Tension uses an ideal spring to launch a bean bag towards one of his friends, Hook Slaw.

- It is launched from a height of 2.60 m and strikes Hook Slaw at a height of 1.50 m and speed of 6.0 m s^{-1} before falling to the ground.
- The bean bag has a mass of 0.15 kg.
- Ex Tension knows that when the spring is compressed by 0.35 m, there is a restoring force of 60 N.



Question 10 (1 MARK)

Which of the following values represents the spring constant, *k*, of the ideal spring?

A. 11 N m^{-1}

B. 87 N m^{-1}

C. 171 N m^{-1}

D. 400 N m^{-1}

Question 11 (1 MARK)

Which of the following correctly lists the non-zero energies when the bean bag is at rest and compressing the spring?

A. *SPE*

B. *SPE, GPE*

C. *SPE, GPE, KE*

D. None of the above

Question 12 (1 MARK)

Which of the following correctly lists the non-zero energies just before the bean bag strikes Hook Slaw?

A. *KE*

B. *KE, GPE*

C. *KE, GPE, SPE*

D. None of the above

Question 13 (1 MARK)

Which of the following shows the conservation of energy equation for this situation?

A. $SPE_i = KE_f$

B. $SPE_i = KE_f + GPE_f$

C. $SPE_i + GPE_i = KE_f + GPE_f$

D. $SPE_i + GPE_i + KE_i = KE_f + GPE_f$

Question 14 (4 MARKS)

Determine the compression of the spring used to launch the bean bag.

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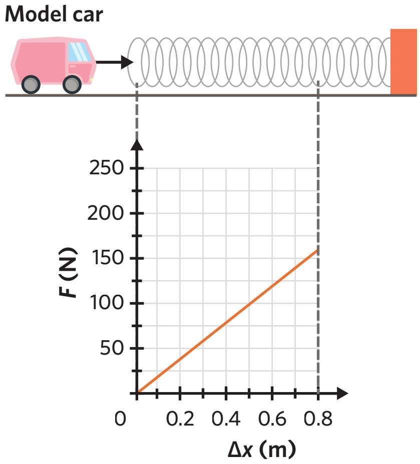
Exam-style

Use the following information to answer questions 15–17.

As shown in the included diagram, a model car is moving towards an ideal spring which it collides with and then compresses. The model car compresses the ideal spring by 0.80 m from its natural position before coming to rest. The spring force-displacement graph is included. Ignore the effects of friction.



Question 15 (1 MARK)

From the included spring force-displacement graph, which of the following values best represents the spring constant, *k*?

A. 100 N m^{-1}

B. 150 N m^{-1}

C. 200 N m^{-1}

D. 250 N m^{-1}

Adapted from VCAA 2017 exam Short answer Q12

Question 16 (1 MARK)

Before colliding with the spring, what is the kinetic energy of the car?

A. 64 J

B. 80 J

C. 100 J

D. 128 J

Adapted from VCAA 2017 exam Short answer Q13

Question 17 (1 MARK)

What is the magnitude of the force that the spring exerts on the car when compressed 0.40 m?

A. 60 N

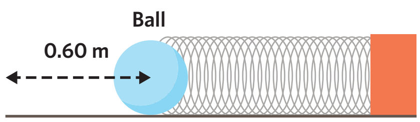
B. 80 N

C. 100 N

D. 120 N

Question 18 (10 MARKS)

A ball of mass 0.35 kg is held against an ideal spring with a spring constant of 200 N m^{-1}. The spring is compressed from its unstretched position by 0.60 m. The ball is then released and fired across a frictionless surface.



a. At the moment the ball is released, determine the magnitude of the spring force which acts on it. (1 MARK)

b. What is the strain potential energy stored in the compressed spring? (2 MARKS)

c. Calculate the maximum speed of the ball after being released. (3 MARKS)

d. Explain how strain potential energy, kinetic energy and total energy of the system changes after the ball is released. (4 MARKS)

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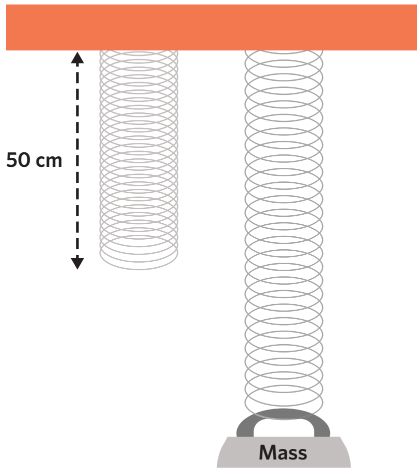
Question 19 (4 MARKS)

Students in a physics class are attempting to find the spring constant, k, of an ideal spring (of natural length 50 cm) by hanging a number of 30 g masses from it and measuring the extension, Δx. Their data is shown in the included table.



Number of 30 g masses	Extension of spring, Δx
0	0
1	10 cm
2	20 cm
3	30 cm

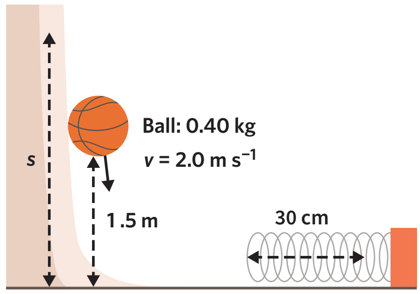
a. Determine the value of the spring constant, k. (2 MARKS)

b. When the spring has a total length of 80 cm, calculate the amount of strain potential energy in the spring. (2 MARKS)

Adapted from VCAA 2016 exam Short Answer 1 Q3

Question 20 (9 MARKS)

A ball of mass 0.40 kg is positioned on a ramp at a height of 1.5 m. It is then pushed down the ramp such that it has an initial speed of 2.0 m s^{-1}. At the bottom of the ramp it collides with an ideal spring and compresses it by 30 cm from its unstretched position.



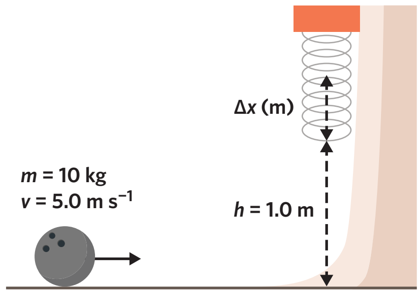
a. Calculate the spring constant, k, of the spring. (3 MARKS)

b. Determine the maximum speed of the ball. (3 MARKS)

c. If the ball is then launched from the compressed spring back towards its initial position, calculate the maximum height, s, it will reach. (3 MARKS)

Question 21 (8 MARKS)

A ball of mass 10 kg has a speed of 5.0 m s^{-1} on a frictionless surface. The ball travels up a ramp where it compresses an ideal spring by 0.20 m before momentarily coming to rest. The spring is positioned such that it contacts the ball at a height of 1.0 m.



a. Show that the spring constant, k, of the spring is 3.7×10^2 N m^{-1}. (2 MARKS)

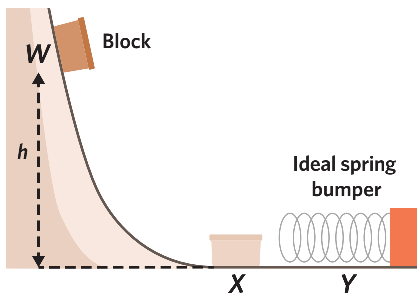
b. What is the magnitude and direction of the acceleration of the ball when the spring is compressed 0.20 m? (2 MARKS)

c. Calculate the speed of the ball when the spring is compressed by 0.05 m. (3 MARKS)

d. What is the velocity of the ball after travelling down the ramp and returning to its starting position? (1 MARK)

Question 22 (6 MARKS)

In a model of a proposed ride at a theme park, a 5.0 kg smooth block slides down a ramp from point W and into an ideal spring bumper without any friction or air resistance, as shown in the image. The final section of the ramp, between points X and Y, is horizontal. The block comes to an instantaneous stop at point Y.



a. Describe the magnitude and direction of the acceleration of the block at points W, X and Y. (3 MARKS)

b. The maximum compression of the spring is measured as 3.0 m and its spring constant, k, is 100 N m^{-1}.

Calculate the release height, h. Show your working. (3 MARKS)

VCAA 2021 NHT exam Short answer Q9a, b

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Key science skills

Question 23 (7 MARKS)

As part of a practical investigation, students are investigating a vertical spring system made of a single ideal spring and a platform. In the investigation, students place various masses on the platform and measure the compression of the spring. Their results are shown in the included table. The ruler used to measure the compression has an uncertainty of ±3 mm. Take acceleration due to gravity, g, to be 10 m s^{-2}.

Mass (g)	Compression, Δx (mm)
0	0
150	16
300	33
450	43
600	61

a. On a set of axes: (5 MARKS)

- Plot the students' data showing force (N) against compression (m).
- Include appropriate uncertainty bars for the compression of the spring.
- Include appropriate scales, units and axis labels.
- Include a line of best fit.

b. Determine the spring constant, k. (2 MARKS)

FROM LESSONS 11D & 11E

Previous lessons

Question 24 (4 MARKS)

A light bulb runs for 10 hours and uses 432 kJ of energy over this period.

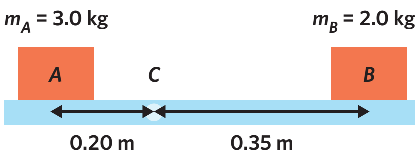
a. Calculate the power consumption of the light bulb in watts. (2 MARKS)

b. If the light bulb draws 2.0 A of current, calculate the voltage supplied to the light bulb. (2 MARKS)

FROM LESSON 6A

Question 25 (3 MARKS)

Blocks A and B, of mass 3.0 kg and 2.0 kg respectively, are on a plank which can pivot around point C. Block A is 0.20 m to the left of C, Block B is 0.35 m to the right. Calculate the magnitude and direction of the net torque on the plank. Take acceleration due to gravity, g, to be 9.8 m s^{-2}.



FROM LESSON 9E

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10D Applications of motion: case study

STUDY DESIGN DOT POINT

- investigate the application of motion concepts through a case study, for example, through motion in sport, vehicle safety, a device or a structure.

10A 10B 10C 10D

2.1.19.1 Vehicle safety

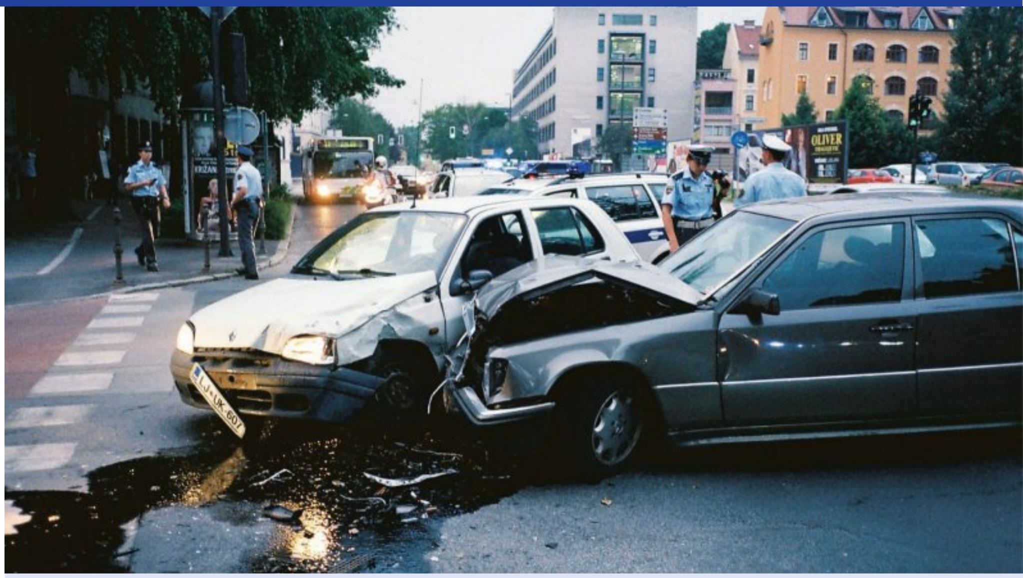
ESSENTIAL PRIOR KNOWLEDGE

- Describing motion (Chapter 8)
- Forces and momentum (Chapter 9)
- Energy (Chapter 10)

See questions 93–95.

ACTIVITIES

Log into your Edrolo account for activities that support this lesson.



Why are cars built to deform in the case of a collision?

A detailed case study investigating the physics behind vehicle safety, and the structure of cars, will be used to develop a deeper understanding of how physics shapes the world around us. This lesson requires us to apply the knowledge we have learned in Chapters 8, 9, and 10.

KEY TERMS AND DEFINITIONS

braking distance the distance a car travels when the brakes are fully applied

crumple zone the front section of a car (the bonnet) that is intentionally designed to deform on impact

reaction distance the distance a car travels in the time it takes a driver to react to a hazard

reaction time the time it takes for a driver to react to a hazard

safety the ability to minimise the impact force acting on a human body

stopping distance the distance travelled from when a driver first sees a hazard to when they come to a complete stop

FORMULAS

- **constant velocity equation**
  $s = vt$
- **constant acceleration equation**
  $v^2 = u^2 + 2as$
- **momentum**
  $p = mv$
- **conservation of momentum**
  $\Sigma p_i = \Sigma p_f$
- **impulse**
  $\Delta p = F\Delta t$
- **kinetic energy**
  $KE = \frac{1}{2}mv^2$

Vehicle safety 2.1.19.1

The following is a case study on vehicle safety in Australia. Within this case study, we will apply the physics that we have learned in Chapters 8, 9, and 10 to real world situations.

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Theory and applications

CASE STUDY

- In the last 5 years, an average of 236 Victorians have lost their lives on the road.
  - On average, 35 of those killed are pedestrians.
- Speeding is a major factor contributing to road accidents in Victoria. Since 2008, 29% of total fatalities involved speeding.
  - Risk of injury doubles for every 5 km h^{-1} increase when travelling at speeds above 60 km h^{-1}.
  - Every 1% increase in speed corresponds to a 4% increase in the likelihood of crashing.
- Mobile safety cameras caught 52 590 speeding infringements on average per month in 2021.
  - On average, 565 of these were 'excessive speed infringements'.
- Low-level speeding (<10 km h^{-1} above the limit) contributes the most to speeding-related crashes that cause injury or death in Victoria.

Why is speeding so dangerous?

The ability of a car to stop before hitting an object is determined by the sum of reaction distance and braking distance, both of which increase significantly with relatively minor increases in speed.[1]

Consider the following scenario:

- Two cars are travelling along the same road in a 40 km h^{-1} school zone.
- A red car travels at 45 km h^{-1} (or 12.5 m s^{-1}).
- A blue car travels at 40 km h^{-1} (or 11.1 m s^{-1}).
- A child on a bicycle, Tom, rides onto the road 20.0 m in front of the cars.
- Both drivers see the child at the same time and take 1.5 s to react by applying the brakes.
- The cars both decelerate at a rate of 10 m s^{-2}.

KEEN TO INVESTIGATE?

[1] **Why is speeding so dangerous?**
Search: The physics of speeding cars

Table 1 Effect of speeding on the reaction distance

Reaction distance (see Figure 1) can be calculated using the constant velocity equation: $s = vt$.	
$v = 12.5 \text{ m s}^{-1}$, $t = 1.5$ s, $s_{react} = ?$ $s_{react} = 12.5 \times 1.5 = 18.8$ m	$v = 11.1 \text{ m s}^{-1}$, $t = 1.5$ s, $s_{react} = ?$ $s_{react} = 11.1 \times 1.5 = 17.3$ m
A difference of only 1.5 m seems small, but along with other factors it could be the difference between life and death. Note, 1.5 s is the average reaction time of a driver. Someone distracted, for example by listening to loud music, having drunk alcohol, or by using a mobile phone, can take as long as 3.0 s to react.	

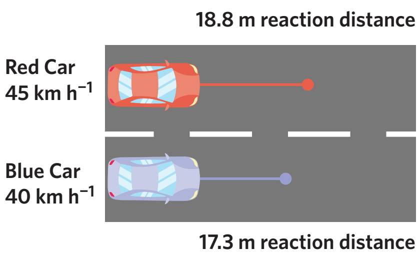

Figure 1 Effect of speed on the reaction distance

Table 2 Effect of speeding on the braking distance

Braking distance (see Figure 2) can be calculated using the constant acceleration equation: $v^2 = u^2 + 2as$. We know the final speed when the car stops will be zero, and the cars decelerate at a constant rate of $a = 10 \text{ m s}^{-2}$.	
$v = 0 \text{ m s}^{-1}$, $u = 12.5 \text{ m s}^{-1}$, $a = -10 \text{ m s}^{-2}$, $s_{brake} = ?$ $0^2 = 12.5^2 + 2 \times (-10) \times s_{brake}$ $s_{brake} = \frac{12.5^2}{2 \times 10} = 7.8$ m	$v = 0 \text{ m s}^{-1}$, $u = 11.1 \text{ m s}^{-1}$, $a = -10 \text{ m s}^{-2}$, $s_{brake} = ?$ $0^2 = 11.1^2 + 2 \times (-10) \times s$ $s_{brake} = \frac{11.1^2}{2 \times 10} = 6.2$ m
The most important factor influencing braking distance is the initial speed, as it's proportional to the square of the initial velocity u.	

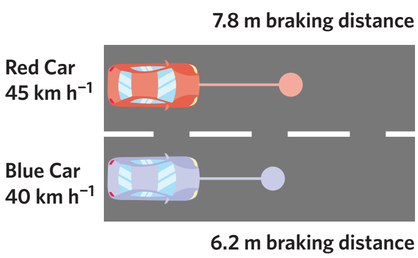

Figure 2 Effect of speed on braking distance

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USEFUL TIP

The braking distance depends on a number of variables besides initial speed, including vehicle mass, brake pads, and the slope of the road. A car will stop more quickly if it is going uphill, as the force of gravity will contribute to the deceleration.

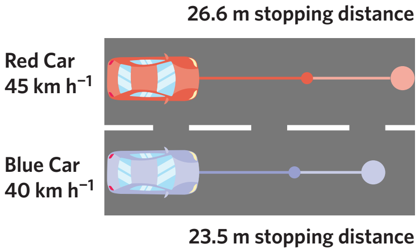

Figure 3 Effect of speed on stopping distance

Table 3 Effect of speeding on the stopping distance

We add the reaction distance to braking distance to get the total stopping distance (see Figure 3).	
$s_{react} = 18.8$ m, $s_{brake} = 7.8$ m, $s_{stop} = ?$ $s_{stop} = 18.8 + 7.8 = 26.6$ m	$s_{react} = 17.3$ m, $s_{brake} = 6.2$ m, $s_{stop} = ?$ $s_{stop} = 17.3 + 6.2 = 23.5$ m
The red car stops 3.1 m after the blue car, a difference of 13%. If Tom is 25.0 m away instead of 20.0 m, when the drivers see him, the blue car will stop just in time, but the red car will hit him.	

Table 4 Effect of speeding on impact velocity

The impact velocity can be calculated by rearranging the constant acceleration equation $v^2 = u^2 + 2as$. Taking the square root of both sides gives the equation in form $v = \sqrt{u^2 + 2as}$, and allows us to calculate how fast the car is travelling when it impacts Tom. In order to use this equation, we need to calculate how far away from Tom the cars are when they begin braking. The distance, s, of the cars from Tom when they begin braking is: • $s = 20.0 - 18.8 = 1.2$ m and, • $s = 20.0 - 17.3 = 2.7$ m	
$u = 12.5$ m s^{-1}, $a = -10$ m s^{-2}, $s = 1.2$ m, $v = ?$ $v = \sqrt{12.5^2 + 2 \times (-10) \times 1.2}$ $= 11.5$ m s^{-1} $= 41.4$ km h^{-1}	$u = 11.1$ m s^{-1}, $a = -10$ m s^{-2}, $s = 2.7$ m, $v = ?$ $v = \sqrt{11.1^2 + 2 \times (-10) \times 2.7}$ $= 8.32$ m s^{-1} $= 29.9$ km h^{-1}
The impact occurs around 11.5 km h^{-1} faster for the Red Car compared to the Blue Car, even though the Red Car was just 5 km h^{-1} over the speed limit (see Figure 4). This slight increase could be the difference between life and death.	

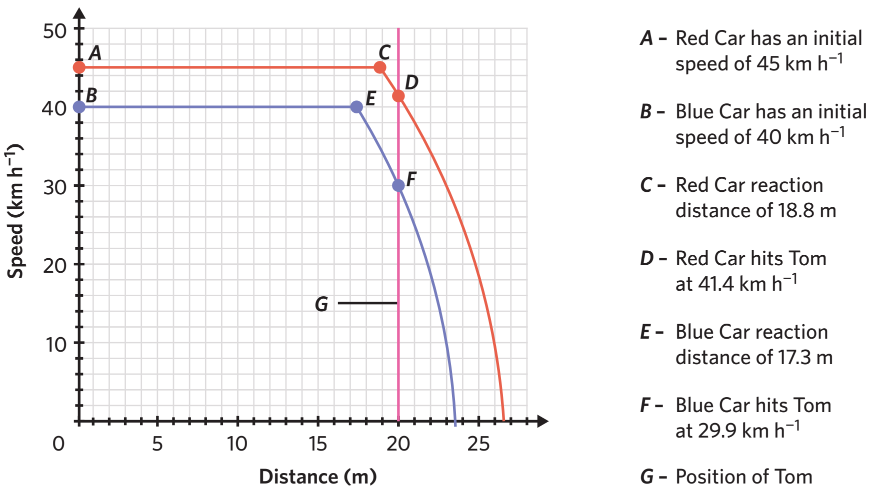

Figure 4 Graph of the cars distance and speed away from Tom

Progress questions

Question 1

The government decided to reduce the speed limit in school zones by 25%. What effect would this have on braking distance?

A. reduce braking distance by about 25%

B. increase braking distance by about 25%

C. reduce braking distance by more than 25%

Continues →

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Question 2

The government decided to increase the speed limit on a major arterial road from 50 km h^{-1} to 60 km h^{-1}. What effect would this have on the stopping distance and braking distance of cars on that road?

A. stopping distance and braking distance increase

B. stopping distance increases but braking distance decreases

C. stopping distance decreases but braking distance increases

D. stopping distance and braking distance decrease

Why is it unsafe to be a pedestrian around heavy vehicles?

The following scenario shows how cars, even at very low speeds, are extremely dangerous to be around. We will imagine a test dummy, named Lily, who is struck by a car (see Figure 5).

- Lily is standing still and so has no initial velocity before the collision.
- Assume that a car impacts Lily at a speed of $v = 25.0$ km h^{-1} ($v = \frac{25.0}{3.6} = 6.9$ m s^{-1}).
- Assume Lily has a mass of 50 kg and the car has a mass of 700 kg.
- Lily's change in velocity occurs over the time it takes for the car to travel a distance equal to Lily's width, about 20 cm.
- Assume that the car and Lily are travelling at the same velocity after the collision.

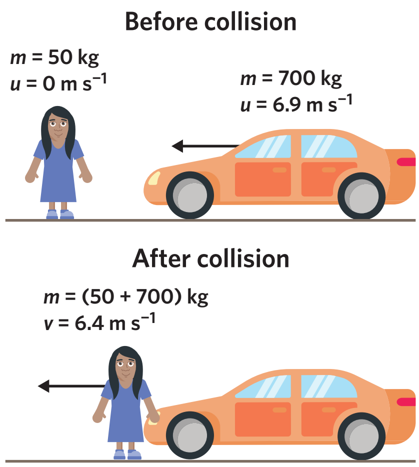

Figure 5 Conservation of momentum in a collision with a pedestrian

Table 5 Calculating the force of an impact on a pedestrian

Process	Working	Discussion
Change in velocity through the conservation of momentum $\Sigma p_i = \Sigma p_f$	$p_{i\,car} + p_{i\,Lily} = p_{f\,car} + p_{f\,Lily}$ $700 \times 6.9 + 0 = v_f(700 + 50)$ $v_f = \frac{700 \times 6.9}{700 + 50} = 6.4$ m s^{-1}	In the same period of time, Lily's velocity changes by 6.4 m s^{-1}, while the car's velocity changes by only 0.50 m s^{-1}.
The time over which the impact occurred through the constant velocity equation: $v = \frac{s}{t}$	$t = \frac{0.20}{6.9} = 0.029$ s	The impact lasts for a very short 0.029 s. The shorter the impact the greater the impact forces will be on Lily.
The force of impact through the equation for impulse: $m\Delta v = F\Delta t$	$50 \times (6.4 - 0) = F \times 0.024$ $F = \frac{50 \times (6.4 - 0)}{0.024} = 13\,333$ N	The impact force on Lily is about 13 000 N (equivalent to an acceleration of 27.2 times that of gravity). This amount of force is likely to cause serious injuries but not death.

Lily is much lighter than a car. Due to the conservation of momentum, the car will increase Lily's velocity significantly while Lily will barely have an impact on the car's velocity.

The probability of serious injury or death for a pedestrian involved in a car crash is heavily dependent on the impact speed. Reducing the speed to 40 km h^{-1}, from 60 km h^{-1}, as in school zones, reduces the likelihood of death by four times, but the likelihood of injury still remains close to 100%.

The kinetic energy of the car is represented by: $E_K = \frac{1}{2}mv^2$. Kinetic energy is proportional to the velocity squared, so with only a small increase in velocity there is a significant increase in kinetic energy. At higher energies, the severity of collisions increases.

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Progress questions

Use the following information to answer questions 3 and 4.

The city council are investigating changes to Melbourne's road rules within the central business district.

Image: TK Kurikawa/Shutterstock.com

Question 3

If the city council limited the mass of vehicles in the city to one tonne, would this improve pedestrian safety, in the event of a collision?

A. Yes, as a pedestrian would have a lower change in velocity, and therefore a lower impact force, when colliding with a lighter car.

B. No, as only the vehicle's initial speed affects the impact force on a pedestrian.

C. No, as heavy cars produce a lower impact force.

Question 4

The city is also investigating decreasing the travel time of trams, which have a mass of 16.8 tonnes, by increasing their speed limit from 30 km h^{-1} to 40 km h^{-1}. How would this affect pedestrian safety in the event of a collision?

A. Improve pedestrian safety, as trams run on rails.

B. Improve pedestrian safety, as the tram has a greater momentum.

C. Decrease pedestrian safety, as the impact speed will be greater.

Image: MM.f/Shutterstock.com

Figure 6 Comparison of old and new car design

How have car designs evolved to improve safety?

Modern cars with low streamlined bonnets are safer for pedestrians than upright designs, such as 4-wheel drive vehicles, since the pedestrian is pushed upwards over the bonnet, increasing the time of impact (see Figure 6). Bull-bars on cars are particularly unsafe to pedestrians and other vehicles as they're designed only to protect their occupants with little regard for others, especially in the case of animal collisions.

Figure 7 shows common safety technologies within modern cars such as airbags, crumple zones, and seat belts.

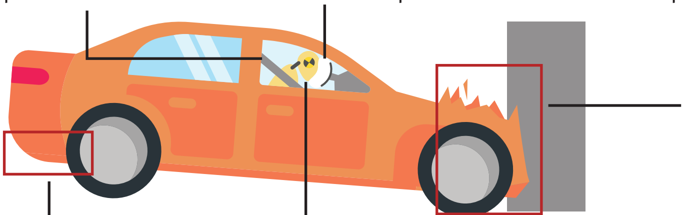

Figure 7 Technologies that cars use to protect passengers

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Increasing the time over which momentum changes, and therefore decreasing the impact force, is the principle behind modern car design. Knowing that: $I = F\Delta t$, as we increase the Δt the force, F, must decrease in order for the impulse to remain the same.[2]

KEEN TO INVESTIGATE?

[2] **How do crumple zones work?**
Search YouTube: Cars are designed to crumple

The effectiveness of a crumple zone (see Figure 8) can also be explained with reference to energy transformation. In a crash, the reduction in kinetic energy of the car must be transformed into various forms. Adding the crumple zone ensures that a large amount of the initial kinetic energy of the car will be transformed into deforming the front of the car, instead of being absorbed by the passengers.

Image: SKT Studio/Shutterstock.com

Figure 8 Car crumple zone

WORKED EXAMPLE 1

A Toyogo Tarato is travelling at 80 km h^{-1} down the Nepean Highway in Melbourne. Tragically it swerves off and hits a light post. Luckily due to developments in crumple zone technology, all occupants are able to walk away with minimal injuries. Explain how the design of crumple zones improves car safety.

[Crumple zones are designed to improve safety by lowering the impact force on passengers in the case of an impact.[1]] [When the crumple zone deforms, it brings the passenger's body to a rest over a longer period of time.[2]] [Hence the impact force on the passenger is decreased[3]] [noting that $I = F\Delta t$.[4]]

- I have explicitly addressed the question.[1]
- I have referenced that time of impact is increased.[2]
- I have referenced that impact force is decreased.[3]
- I have used the relevant theory: impulse.[4]

Progress questions

Use the following information to answer questions 5 and 6.

The Australian government regulates the design requirements of vehicles that can be imported into the country to meet minimum safety standards. As a scientist who understands the physics of vehicle safety, we must provide advice on how car designs would affect passenger safety.

Question 5

The Smart electric car has the motor under the passenger seat and a very small crumple zone at the front of the car. Why does the design of a smart car decrease passenger safety, in the event of a collision?

Image: Art Konovalov/Shutterstock.com

A. The crumple zone is very small, so would not absorb much of the energy in the collision.

B. The larger windows are more likely to break.

C. The car doesn't hold any rear passengers.

D. The car is stiffer so will not crumple up in the case of a collision.

Continues →

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Question 6

A Tesla has a large crumple zone and no motor in the front. Why does this design improve the safety for passengers?

A. decreases the impulse in the case of a collision

B. reduces the time over which a force will be applied to the passengers

C. More of the car's kinetic energy can go into deforming the larger crumple zone.

Theory summary

- Speeding increaes the likelihood and severity of collisions due to:
  - increased reaction distance and braking distance, i.e stopping distance, and
  - increased impact velocity.
- Car manufacturers utilise the principles of impulse and the law of conservation of energy to create cars that are safer for occupants by designing:
  - crumple zones,
  - airbags, and
  - seatbelts.

The content in this lesson is considered fundamental prior knowledge to relationships between force, energy and mass (Unit 3 AOS 1).

CONCEPT DISCUSSION

Image: Tricky_Shark/Shutterstock.com

Consider a front-on collision between a 5 tonne bus and a 500 kg car. According to Newton's third law, both vehicles will experience the same magnitude of impulse over the same period of time. For such a collision, discuss which vehicle a passenger would be less safe in.

Prompts:

- How would the change in the velocity of the bus differ from that of the car?
- What portion of the total mass would a person on the bus be compared to someone in a car?

10D Questions

Mild Medium Spicy

Deconstructed exam-style

Use the following information to answer questions 7–10.

A P-plater is speeding down the Hume highway at 130 km h^{-1}. The speed limit on this road is 110 km h^{-1}. Just 100 m away, a kangaroo jumps out onto the road. The P-plater takes 1.4 s to react and apply full braking force to avoid hitting the animal. Assume the car has constant deceleration of 7.71 m s^{-2}. The P-plater will be safe if they hit the kangaroo at a speed of less than 20 km h^{-1}.

Question 7 (1 MARK)

What speed is the P-plater travelling at, in m s^{-1}?

A. 36.1 m s^{-1}

B. 43.3 m s^{-1}

C. 130 m s^{-1}

D. 468 m s^{-1}

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Question 8 (1 MARK)

How far does the car travel before the brakes are applied?

A. 36.1 m

B. 50.5 m

C. 54.2 m

D. 182 m

Question 9 (1 MARK)

At the point when the P-plater reacts to the kangaroo and applies the brakes, how far away is the kangaroo?

A. 0 m

B. 50 m

C. 85 m

D. 100 m

Question 10 (3 MARKS)

Determine whether the P-plater will be safe.

Exam-style

Use the following information to answer questions 11 and 12.

Two identical cars, *S* and *T*, are travelling down a road. Car *S* is travelling 5% faster than car *T*.

Question 11 (1 MARK)

The kinetic energy of car *S* is

A. the same as car *T*.

B. less than 5% greater than car *T*.

C. exactly 5% greater than car *T*.

D. more than 5% greater than car *T*.

Question 12 (1 MARK)

Which of the two cars is more likely to be involved in a collision and what is the best explanation why?

A. Car *S* is more likely to get into an accident because as it is travelling at a faster speed, the ability for the driver to stop with enough space to prevent a collision is more difficult.

B. Car *S* is more likely to be involved in a collision because drivers who travel faster tend to be more reckless and pay less attention on the road leading to a greater reaction distance.

C. Car *T* is more likely to be involved in a collision because when drivers are slower, they have less opportunity to swerve to avoid an accident.

D. Car *T* is more likely to be involved in a collision because slower drivers can fall asleep at the wheel leading to inattention and a greater risk of a collision.

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Question 13 (4 MARKS)

A Jazda 3 is travelling at 60 km h^{-1} down a road in Ballarat when all of a sudden it hits another car in a head-on collision. The airbags were deployed, saving the drivers life by stopping their head from smashing into the steering wheel. The images compare a crash with (a) and without (b) an airbag.

Explain how the design of airbags improve the safety of passengers in the event of a car crash.

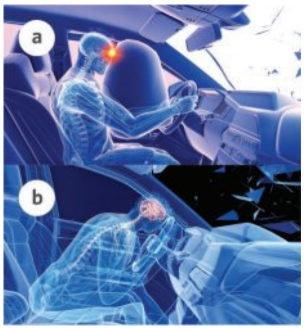


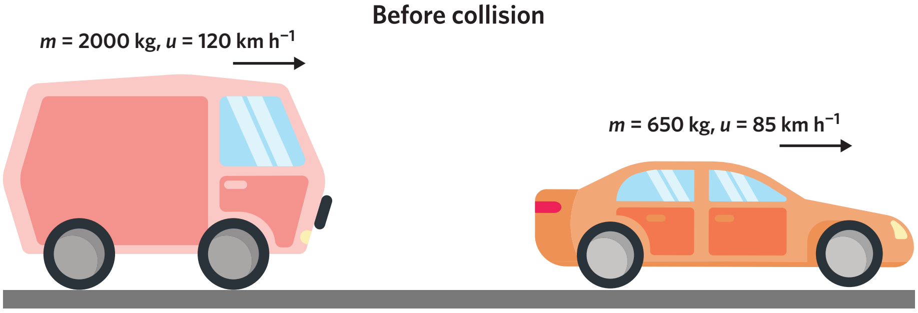
Image: SciePro/Shutterstock.com

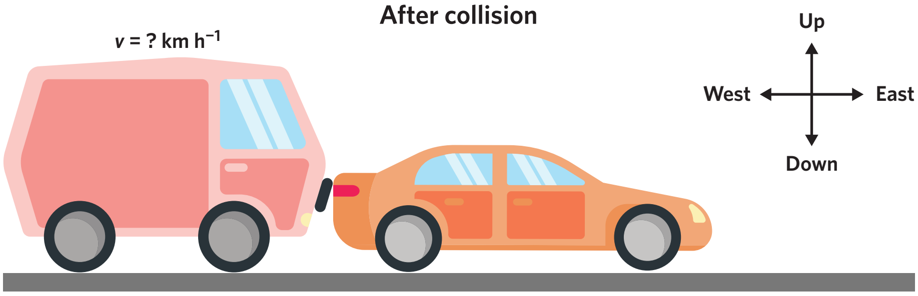
Question 14 (3 MARKS)

The law of conservation of energy states that energy cannot be created or destroyed, and is instead transformed from one form to another. Car crashes can involve huge amounts of energy. How does the car's design affect the transformation of the energy and, ultimately, protect the occupants?

Question 15 (9 MARKS)

Two vehicles are travelling eastwards down the Princess Highway to Bairnsdale which has a speed limit of 100 km h^{-1}. A van of mass 2000 kg is travelling at 120 km h^{-1}, attempting to overtake a slow car of 650 kg travelling at 85 km h^{-1}. The driver of the van misjudges the distance between them and the car, and so collides with the back of it.





a. Calculate the final velocity of the vehicles, assuming they stick together after the collision. Give your answer in km h^{-1}. (3 MARKS)

b. Determine which car has a greater change in speed, and explain which car it would be safer to be in. (4 MARKS)

c. Why are collisions of cars travelling in the same direction far safer than cars travelling in different directions? (2 MARKS)

Question 16 (3 MARKS)

Two cars of equal mass and speed travelling towards each other, car *A* and car *B*, are involved in a head on collision. Car *A* is a modern car, with a crumple zone that is significantly damaged after the collision, whereas Car *B* is an older car that escapes with minor dents. With reference to the energy absorption, discuss which occupants are more likely to be injured as a result of the collision.

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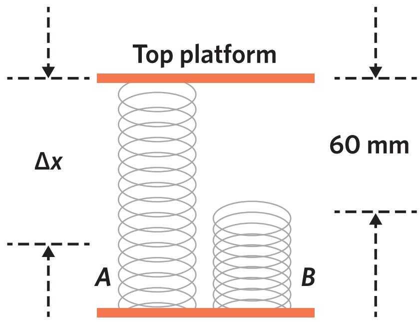
Key science skills

Question 17 (10 MARKS)

As part of their practical investigation, some students investigate a spring system consisting of two springs, A and B, and a top platform. The students place various masses on the top platform. Assume that the top platform has negligible mass.



With no masses on the top platform of the spring system, the distance between the uncompressed Spring A and the top of Spring B is 60 mm.

The students place various masses on the top platform of the spring system and note the vertical compression, Δx, of the spring system.

They use a ruler with millimetre gradations to take readings of the compression of the spring (s), Δx, with an uncertainty of ± 2 mm.

The results of their investigation are shown in the table.

Mass (g)	Compression, Δx (mm)
0	0
300	21
600	40
900	60
1300	68
1700	75
1900	80

The students plot a force (F) versus compression (Δx) graph for the spring system and use $g = 10$ N kg^{-1} for the value of the magnitude of the gravitational field strength.

a. On the axes provided below:

- Plot a graph of force (F) versus compression (Δx) for the spring system
- Include scales and units on each axis
- Insert appropriate uncertainty bars for the compression values on the graph
- Draw lines that best fit the data for:
  - the effect of Spring A alone
  - the effect of Spring A, and Spring B.

(6 MARKS)

b. Using the area under the force (F) versus compression (Δx) graph, or otherwise, determine the potential energy (PE_{A+B}) stored in the spring system when the spring system is compressed by 80 mm. Show your working. (2 MARKS)

c. Explain how this type of spring system could be used in car spring suspension systems to enable the car to negotiate small bumps and more severe bumps in the road. (2 MARKS)

Adapted from VCAA 2019 exam Short answer Q19

FROM LESSONS 11D & 11E

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10D QUESTIONS

Previous lessons

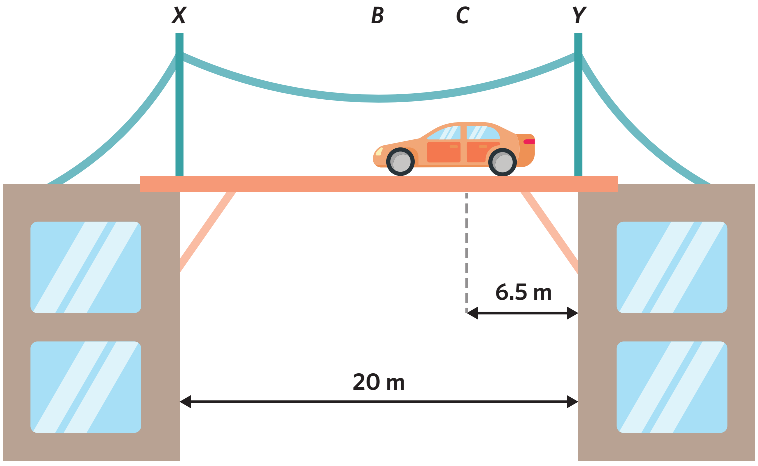
Question 18 (2 MARKS)

A 40 V battery operates on a series circuit with two resistors. The resistors have a resistance of 12 Ω and 50 Ω respectively. Calculate the current in the circuit when it is switched on.

FROM LESSON 6B

Question 19 (4 MARKS)

Engineers have designed a bridge to transport cars between two multilevel car parks. The uniform bridge with a length of 20 m has a centre at *B*, a mass of 5.0×10^4 kg and is supported by the buildings on each end, at points *X* and *Y*. A car of mass 2.2×10^3 kg is 6.5 m from the right building, at position *C*.



a. Calculate the magnitude of the force acting up on the bridge by the left building, F_X. (2 MARKS)

b. Calculate the magnitude of the force acting up on the bridge by the right building, F_Y. (2 MARKS)

FROM LESSON 9F

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Chapter 10 review

Mild Medium Spicy

These questions are typical of 40 minutes worth of questions on the VCE Physics Exam.

Total marks: 30

Section A

All questions in this section are worth one mark.

Unless otherwise indicated, the diagrams in this book are not drawn to scale.

Question 1

Mercury Williams serves a 56 g tennis ball with an average contact force of 140 N. If the ball leaves the racket with a speed of 50 m s^{-1}, and assuming the ball is initially at rest, for how long was the ball in contact with the racket strings?

A. 0.020 s

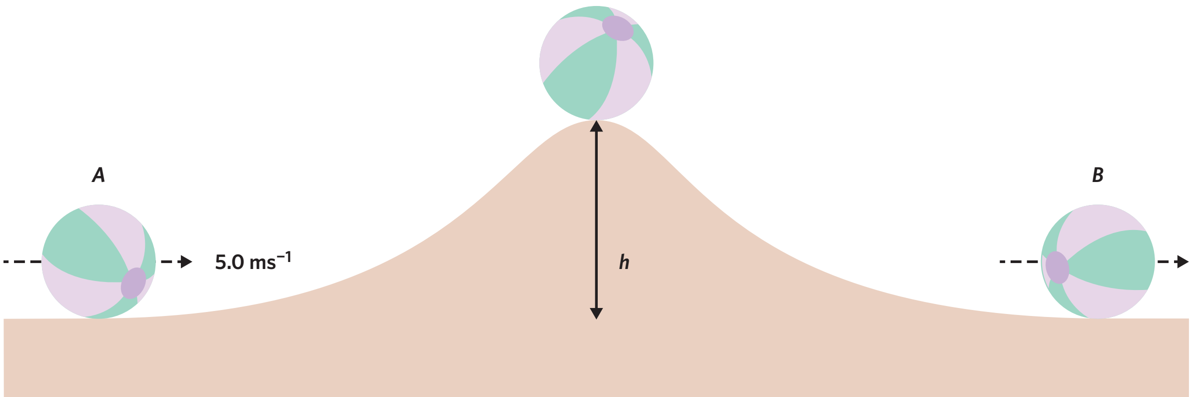
B. 0.16 s

C. 0.050 s

D. 0.020 m s

Use the following information to answer questions 2 and 3.

Consider the following scenario where a 300 g ball rolls up and over a narrow hill of height h m. The ball has a velocity of 5.0 m s^{-1} at point A and stops briefly at the top of the hill, before continuing down the other side. Assume that there is negligible friction acting on the ball and take the acceleration due to gravity, g, to be 9.8 m s^{-2}.



Question 2

What is the value of h?

A. 0.26 m

B. 1.3 m

C. 0.38 m

D. 2.6 m

Question 3

What is the speed of the ball when it reaches point B?

A. 0 m s^{-1}

B. It depends on how far B is from the top of the hill.

C. It depends on how long it takes for the ball to roll down the hill.

D. 5.0 m s^{-1}

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Question 4

A force is applied to extend an ideal spring by x m. This gives it 50 J of strain potential energy. How much strain potential energy would the spring have if the extension were increased to $4x$ m? Assume the new extension is within the elastic limit of the spring.

A. 200 J

B. 800 J

C. 12.5 J

D. It would depend on the spring constant, k.

Question 5

A driver travelling at 13.0 m s^{-1} sees a ball roll across the road, 40.0 m ahead. How far will the driver stop from the ball, assuming it takes 1.50 s to react and the car decelerates at 5.00 m s^{-2}?

A. the driver will hit the ball

B. 3.60 m before the ball

C. 36.4 m before the ball

D. not enough information is given

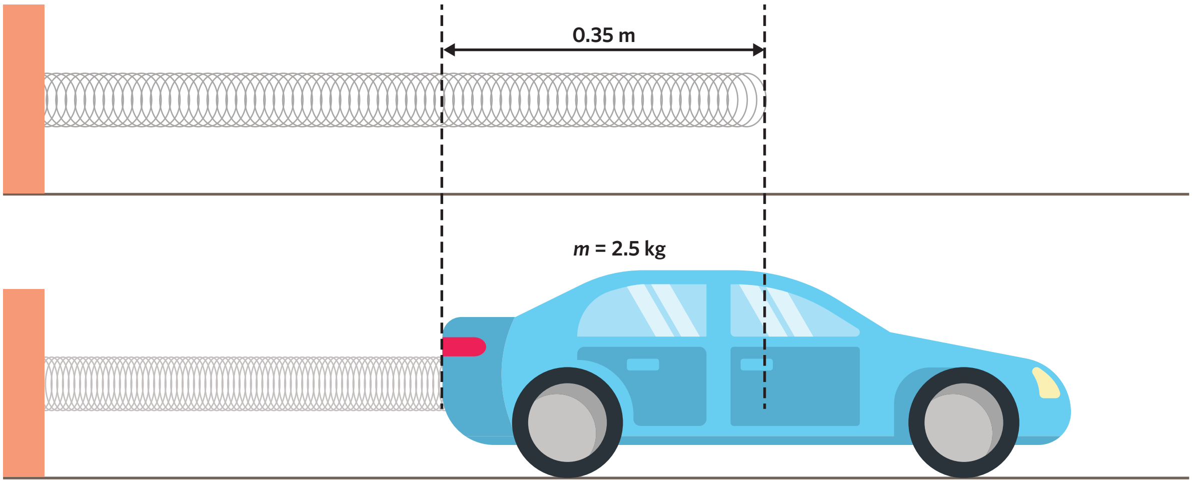
Section B

In questions where more than one mark is available, appropriate working must be shown.

Unless otherwise indicated, the diagrams in this book are not drawn to scale.

Question 6 (4 MARKS)

Aubrey is using a model car and a spring to investigate work and momentum. The car of mass 2.5 kg is held against a spring, compressing it by 0.35 m from its natural length, and then released, as shown in the included diagram.



a. A force of 70 N is required to hold the car in place. Show that the spring constant, k, is 2.0×10^2 N m^{-1}. (1 MARK)

b. If the car is subject to a constant frictional resistance of 3.10 N when it has left contact with the spring, determine how far the car will travel past the natural length of the spring before coming to rest. Assume there is negligible friction acting on the car when the spring is extending. (3 MARKS)

Adapted from VCAA 2016 exam Short answer Q4

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Question 7 (8 MARKS)

An AFL umpire bounces the ball after a goal by throwing it into the ground. The ball has a mass of 450 g and is thrown vertically downwards so that it impacts the ground at 12.0 m s^{-1} and rebounds off at 9.0 m s^{-1} vertically upwards.

a. Calculate the change in kinetic energy of the ball during the bounce. Does bouncing the ball violate the law of conservation of energy? Explain your answer. (3 MARKS)

b. What is the maximum height the ball reaches after leaving the ground? (2 MARKS)

c. Over small ranges of compression, the ball can be modelled as an ideal spring. If the ball is compressed by 5.8 cm on impact with the ground before rebounding up, calculate the spring constant, k. (3 MARKS)

Question 8 (6 MARKS)

Friederick, a 75.0 kg person, is going bungee jumping for the first time. The bungee cord can be modelled as an ideal spring with a spring constant, k, of 300 N m^{-1}.

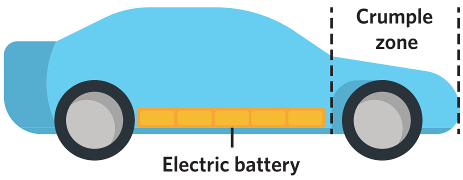
a. After the jump, Friederick bounces up and down before eventually coming to rest. Find the extension of the bungee cord at this point. (1 MARK)

b. During the jump, Friederick reaches the lowest point after he has fallen 65.0 m. Use this information to find the natural length of the bungee cord. (3 MARKS)

c. What is Friederick's speed when he has fallen 25 m? (2 MARKS)

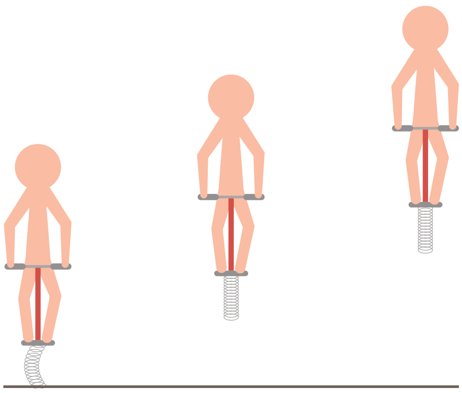
Question 9 (3 MARKS)

Electric cars place their battery below the car, in order to lower the centre of mass and increase the crumple zone in the bonnet, without the need for an engine. Explain the safety benefits of this design in the event of a front-on car crash.



Question 10 (4 MARKS)

A pogo stick uses a simple spring to store and release energy, as a person jumps on it. Determine the non-zero energy forms at the bottom, middle and top of the jump, and how the total mechanical energy changes in the process. Assume the person is at rest at the bottom and at the peak of their flight.



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Unit 2 AOS 1 review

Mild Medium Spicy

These questions are typical of one hour's worth of questions on the VCE Physics Exam.

Total Marks: 50

Section A

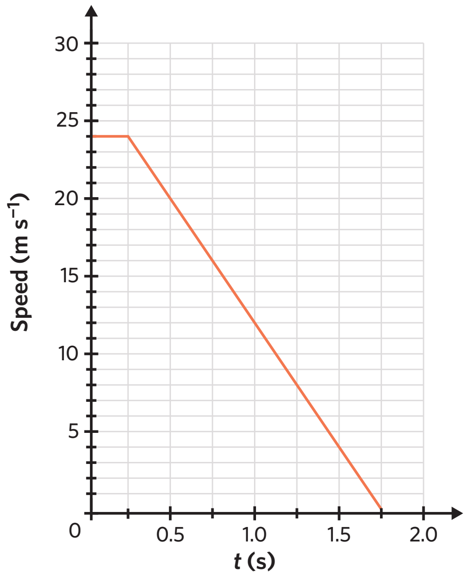
All questions in this section are worth one mark.

Unless otherwise indicated, the diagrams in this book are not drawn to scale.

Take the value of g to be 9.8 m s^{-2} and ignore the effects of air resistance.

Use the following information to answer questions 1 and 2.

Arcadio is riding his motorcycle of mass 280 kg when he is forced to brake suddenly to avoid an oncoming collision. He takes 0.25 s to react and then brakes with a constant braking force until he is stationary. His speed-time graph is shown to the right.



Question 1

Which one of the following is the best estimate of how far Arcadio travels before coming to rest, including the time he takes to react?

A. 21 m

B. 24 m

C. 36 m

D. 42 m

Question 2

Which one of the following is closest to the magnitude of the braking force acting on Arcadio's motorcycle during the braking period?

A. 3.8 kN

B. 4.5 kN

C. 6.7 kN

D. 27 kN

Adapted from VCAA 2018 Physics Exam Section A Q6

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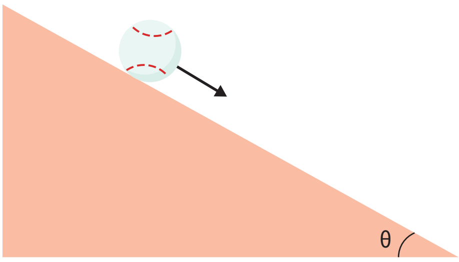
Question 3

A ball is on an inclined frictionless plane as shown in the provided diagram.



Which one of the following statements about the motion of the ball as it rolls down the plane is correct?

A. The ball travels at a constant speed.

B. The momentum of the ball is conserved.

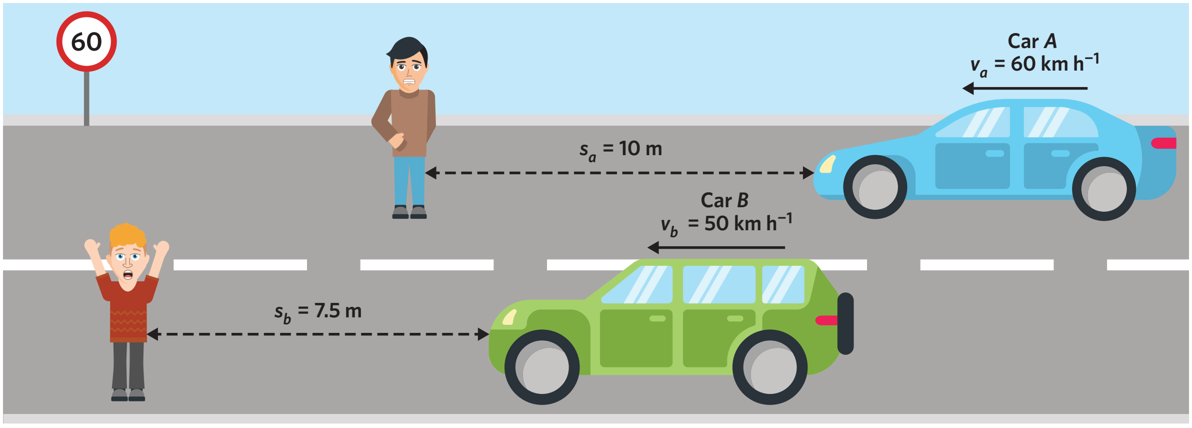
C. The magnitude of the normal force is less than the force due to gravity.

D. The ball is accelerating perpendicular to the plane.

Adapted from VCAA 2019 Physics Exam Section A Q12

Question 4

Two pedestrians are standing on a road with a speed limit of 60 km hr^{-1} in separate lanes. Car *A*, travelling the speed limit, begins to break when they are 10 m away from the person in their lane. Car *B*, travelling 10 km hr^{-1} under the speed limit, begins to break when they are 7.5 m away from the person in their lane. Which car will have a greater impact speed with the pedestrian? Assume both cars decelerate at a constant rate of 12 m s^{-2}.



A. Car *A* will have a greater impact speed than Car *B*.

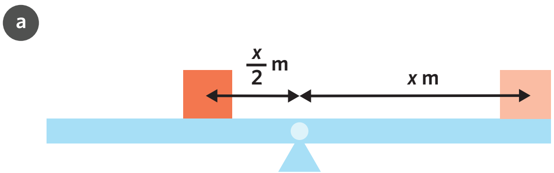
B. Car *B* will have a greater impact speed than Car *A*.

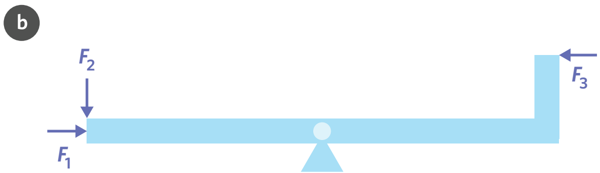
C. Both cars will collide with the pedestrians at the same speed.

D. Both cars will come to a complete stop before colliding with the pedestrians.

Question 5

The provided diagrams show (a) two blocks of different masses resting on a seesaw and (b) three non-zero forces acting on an identical seesaw. Which one of the following statements must be true, assuming all parts of the see-saw are weightless?





A. (a) cannot be in equilibrium because the masses are different distances from the pivot point.

B. (b) cannot be in equilibrium because it cannot be in rotational equilibrium.

C. Both (a) and (b) can be in equilibrium for certain values of the unknowns.

D. (b) will always be in equilibrium because F_1 and F_3 are acting in opposite directions.

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Section B

In questions where more than one mark is available, appropriate working must be shown.

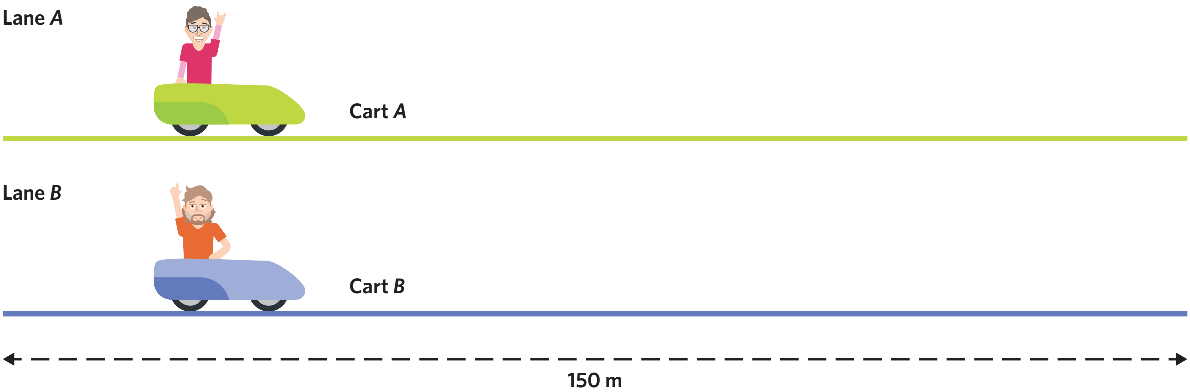
Unless otherwise indicated, the diagrams in this book are not drawn to scale.

Take the value of g to be 9.8 m s^{-2} and ignore the effects of air resistance and friction unless otherwise indicated.

Question 6 (8 MARKS)

A theme park is opening a new roller coaster ride. It features two tracks for two carts which travel at different speeds. Part of the ride consists of a flat section of length 150 m as shown in the provided diagram.

The cart in Lane A accelerates through the flat section at a constant rate for 5.50 s and has a velocity of 39.0 m s^{-1} when it reaches the end of the section.



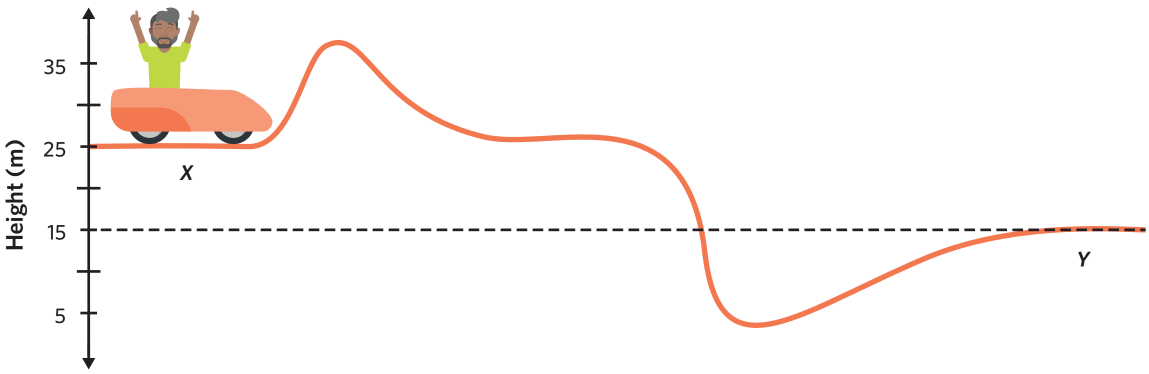
a. Calculate cart A's speed at the beginning of the flat section. (2 MARKS)

b. The designers of the ride want to make this straight portion of track longer so that cart A and cart B will reach the end of it at the same time. They plan for cart A to travel through the section at a constant velocity of 24 m s^{-1}. Cart B will start, from rest, 1.0 s after cart A leaves and will accelerate at 8.5 m s^{-2} for 4.0 s before maintaining a constant velocity.

Calculate how long the track would have to be for cart B to catch up to cart A at the end of the track. (4 MARKS)

c. Another cart enters the portion of track at point X shown in the diagram below with an initial velocity of 15 m s^{-1}. The cart's motors provide no acceleration at any point along this part of the ride.

Calculate the final speed of the cart at point Y. Assume that the cart has enough kinetic energy to roll over the uphill sections shown. (2 MARKS)



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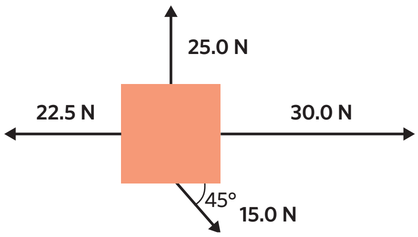
Question 7 (5 MARKS)

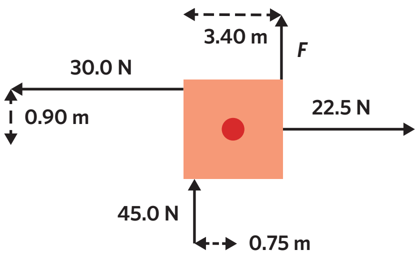
A block is being pulled on four sides by forces of different magnitudes and directions.

a. The provided diagram shows the first series of forces acting on a block. Calculate the magnitude of the net force acting on the block and the angle it makes to the horizontal, in the positive direction. Take to the right and upwards as the positive direction. (3 MARKS)



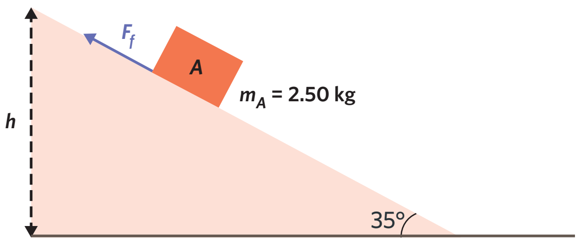
b. As shown in the diagram, the forces acting on the block have now changed.

Considering that the block is in rotational equilibrium, find the magnitude of the force labelled F in the provided diagram. Assume that the block rotates about its centre (shown in red). (2 MARKS)



Question 8 (13 MARKS)

A distribution company is trialling a new conveyor system for their boxes as shown in the provided diagram. The boxes first slide down a rough inclined plane and then onto a smooth frictionless surface. A particular box A is currently sliding down the inclined plane, and has a mass of 2.50 kg.



a. Calculate the magnitude of the normal force acting on box A. (2 MARKS)

b. Starting from rest, box A accelerates down the plane at a constant rate of 0.25 m s^{-2}.

Calculate the magnitude of the friction force acting on the box. (2 MARKS)

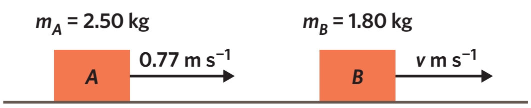
c. The friction force does 16 J of work over the distance it slides down the entire distance of the ramp.

Calculate the height of the ramp. (4 MARKS)

d. Show that the magnitude of box A's velocity when it reaches the bottom of the ramp is 0.77 m s^{-1}. (2 MARKS)

e. Continuing to move at the velocity found in part d, box A collides with another box B, which has a mass of 1.80 kg.

Calculate the required magnitude of v so that after the collision the two boxes have a speed of 0.50 m s^{-1}. Assume that the two blocks remain in contact after the collision. (3 MARKS)



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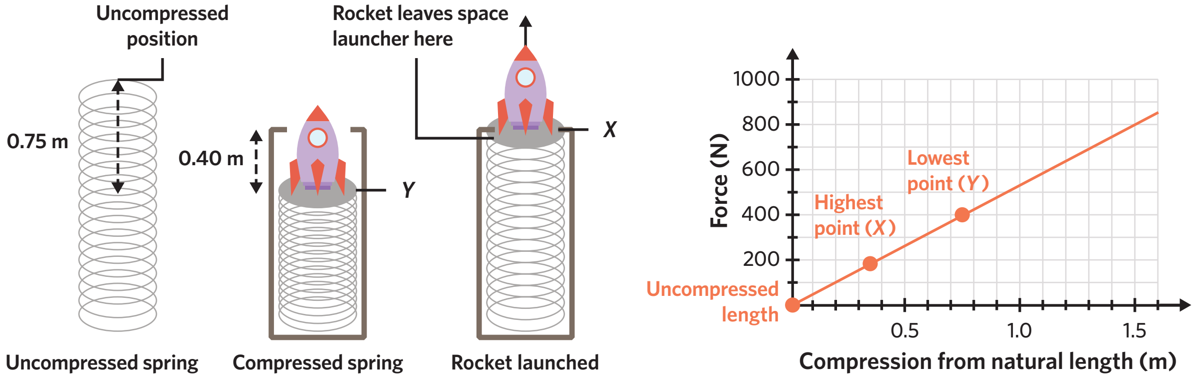
Question 9 (4 MARKS)

A car comes to a stop due to a hazard ahead. Explain the two stages involved in the car stopping and how the distances travelled during these stages may be calculated, if we know the initial velocity of the car and its acceleration under braking. Assume the car's brakes apply a constant force under breaking. (4 MARKS)

Question 10 (6 MARKS)

Elon Tusk is currently trialling different methods of launch for his SpaceZ program. One suggestion is to use springs instead of thrusters, so he is conducting a trial version with an 800 g model spacecraft. The spring launcher is shown in the included diagram. When the spring is released from *Y* and reaches *X*, it is held stationary, but is still partly compressed. Ignore the mass of the spring.



a. Show that the spring constant, k, is equal to 5.33×10^2 N m^{-1}. (1 MARK)

b. Show that the speed of the rocket when it leaves the launcher (at point X) is 17 m s^{-1}. (2 MARKS)

c. Due to air resistance, the rocket only reaches a maximum height of 12.5 m. Calculate the percentage of energy given to the rocket by the spring launcher that the rocket loses to air resistance. (3 MARKS)

Adapted from 2018 VCAA NHT Exam Section B Q9

Question 11 (9 MARKS)

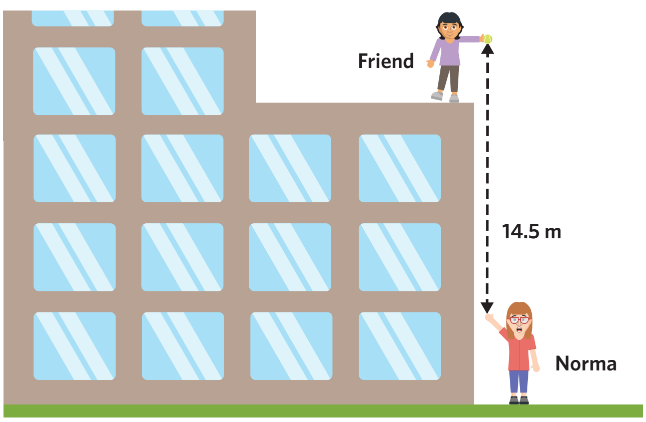
Norma is trying to catch a tennis ball at the highest speed she can. To do this she stands on flat ground and throws the ball up vertically as hard as she can. Her goal is to catch the ball (at the height she threw it from) when it has a speed of 18.0 m s^{-1}.

a. What will be the maximum height the ball reaches with this final velocity? (2 MARKS)

b. Norma's hardest throw only gives the ball an initial velocity of 15.0 m s^{-1} upwards. Explain why it is impossible for Norma to catch the ball at 18.0 m s^{-1}. (3 MARKS)

c. Norma changes her plan and asks her friend to throw the ball vertically down to her from a building. Norma catches the ball at 18.0 m s^{-1} after it has fallen 14.5 m.

Calculate the amount of time for which the ball was in the air. (4 MARKS)



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UNIT 2 AOS 2

How does physics help us to understand the world?

In this Area of Study, students choose one of eighteen options related to climate science, nuclear energy, flight, structural engineering, biomechanics, medical physics, bioelectricity, optics, photography, music, sports science, electronics, astrophysics, astrobiology, Australian traditional artefacts and techniques, particle physics, cosmology and local physics research. The selection of an option enables students to pursue an area of interest through an investigation and using physics to justify a stance, response or solution to a contemporary societal issue or application related to the option.

A student-adapted or student-designed scientific investigation is undertaken in Area of Study 3. The investigation involves the generation of primary data and draws on the key science skills and key knowledge from Area of Study 1 and/or Area of Study 2.

This book covers content from the entirety of Unit 1, Unit 2 Area of Study 1, and Unit 2 Area of Study 3 but does not include content from Unit 2 Area of Study 2. Instead, this will appear online. Unit 2 Area of Study 2 contains eighteen options for topics and we have chosen three of them to appear as chapters online, specifically:

- **Chapter 12 (Option 16)**
  'How do particle accelerators work?',
- **Chapter 13 (Option 10)**
  'How do instruments make music?',
- **Chapter 14 (Option 11)**
  'How can performance in ball sports be improved?'.

Much like in the physical textbook, these chapters will be broken down into lessons which are almost identical in structure to those in the print text, with theory and questions. They will be accessible from your Edrolo account along with corresponding video theory from our Theory Master presenters.

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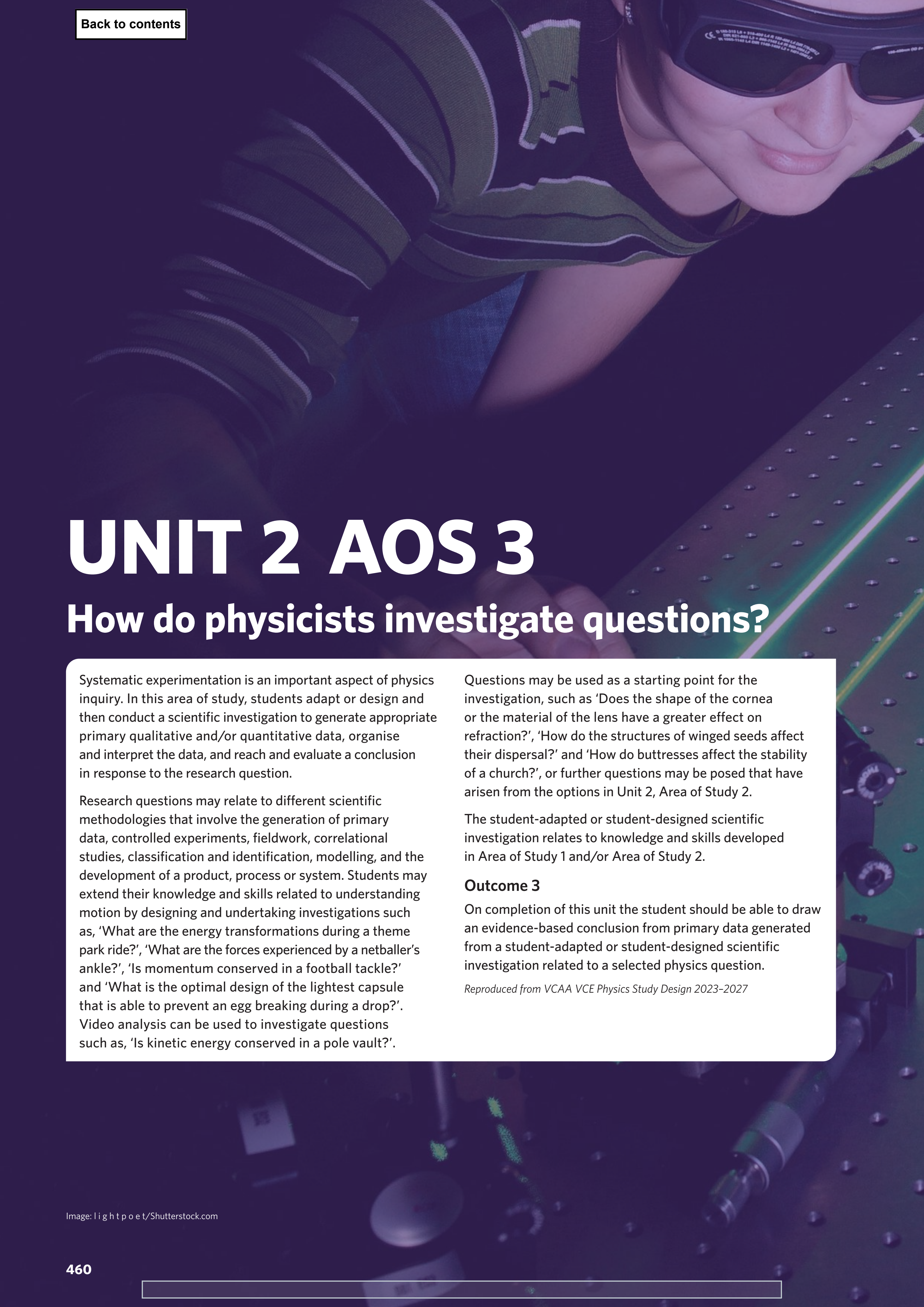

UNIT 2 AOS 3

How do physicists investigate questions?

Systematic experimentation is an important aspect of physics inquiry. In this area of study, students adapt or design and then conduct a scientific investigation to generate appropriate primary qualitative and/or quantitative data, organise and interpret the data, and reach and evaluate a conclusion in response to the research question.

Research questions may relate to different scientific methodologies that involve the generation of primary data, controlled experiments, fieldwork, correlational studies, classification and identification, modelling, and the development of a product, process or system. Students may extend their knowledge and skills related to understanding motion by designing and undertaking investigations such as, 'What are the energy transformations during a theme park ride?', 'What are the forces experienced by a netballer's ankle?', 'Is momentum conserved in a football tackle?' and 'What is the optimal design of the lightest capsule that is able to prevent an egg breaking during a drop?'. Video analysis can be used to investigate questions such as, 'Is kinetic energy conserved in a pole vault?'.

Questions may be used as a starting point for the investigation, such as 'Does the shape of the cornea or the material of the lens have a greater effect on refraction?', 'How do the structures of winged seeds affect their dispersal?' and 'How do buttresses affect the stability of a church?', or further questions may be posed that have arisen from the options in Unit 2, Area of Study 2.

The student-adapted or student-designed scientific investigation relates to knowledge and skills developed in Area of Study 1 and/or Area of Study 2.

Outcome 3

On completion of this unit the student should be able to draw an evidence-based conclusion from primary data generated from a student-adapted or student-designed scientific investigation related to a selected physics question.

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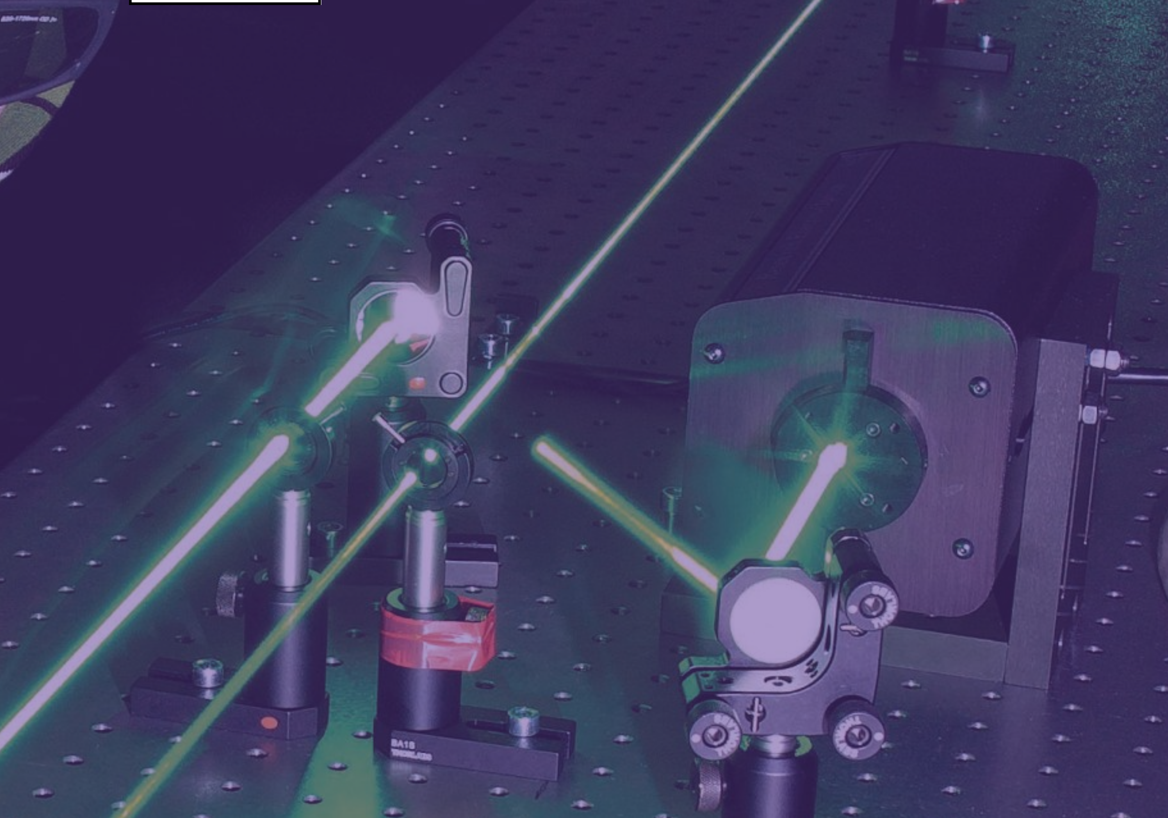

11

CHAPTER 11

Scientific investigations

STUDY DESIGN DOT POINTS

- apply the physics concepts specific to the selected investigation and explain their significance, including definitions of key terms, and physics representations
- evaluate the characteristics of the scientific methodology relevant to the investigation, selected from: experiment; fieldwork, classification and identification, modelling, simulation, and the development of a product, process or system
- apply techniques of primary qualitative and quantitative data generation relevant to the investigation
- identify and apply concepts of accuracy, precision, repeatability, reproducibility, resolution, and validity of data in relation to the investigation
- identify and apply health, safety and ethical guidelines relevant to the selected scientific investigation
- distinguish between an aim, a hypothesis, a model, a theory and a law
- identify and explain observations and experiments that are consistent with, or challenge, current models or theories
- describe the characteristics of primary data
- evaluate methods of organising, analysing and evaluating primary data to identify patterns and relationships including scientific error, causes of uncertainty, and limitations of data, methodologies and methods
- model the scientific practice of using a logbook to authenticate generated primary data
- apply the conventions of scientific report writing including scientific terminology and representations, standard abbreviations, units of measurement, significant figures and acknowledgement of references
- apply the key findings of the selected investigation and their relationship to key physics concepts.

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LESSONS

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11A Asking questions, identifying variables, and making predictions

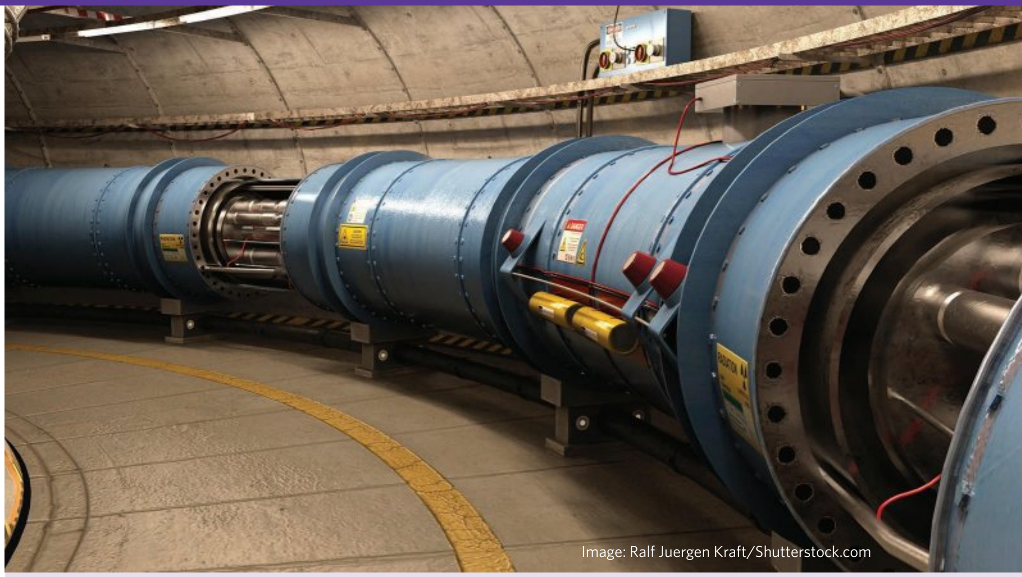
Image: Ralf Juergen Kraft/Shutterstock.com

STUDY DESIGN DOT POINTS

- distinguish between an aim, a hypothesis, a model, a theory and a law
- identify and explain observations and experiments that are consistent with, or challenge, current models or theories
- describe the characteristics of primary *(and secondary)* data
- evaluate the characteristics of the scientific methodology relevant to the investigation, selected from: experiment; fieldwork, classification and identification, modelling, simulation, and the development of a product, process or system
- apply techniques of primary qualitative and quantitative data generation relevant to the investigation

How do observations become scientific theories?

'Why' is a great question to ask. Why is the sky blue? Why do things fall? Science is the process of asking questions and seeking explanations for how the universe behaves so that we can make informed and accurate predictions. Physics is the part of science that focuses on the most fundamental features of the universe: matter and energy. This lesson will explain the scientific method as a process of seeking answers to questions by testing predictions involving different variables.

KEY TERMS AND DEFINITIONS

aim the purpose of an experiment

controlled variable a variable that has been held constant in an experiment

dependent variable a variable that is measured by the experimenter, expected to be impacted by the independent variable

hypothesis a proposed explanation that predicts a relationship between variables and can be tested through experimentation

independent variable a variable that is deliberately manipulated by the experimenter

law (scientific) a statement, based on repeated experiments or observations, that describes or predicts a phenomenon.

model (scientific) a representation of a physical process that cannot be directly experienced

observation the acquisition of data using senses such as seeing and hearing or with scientific instruments

primary data original data collected firsthand by researchers

qualitative data data that cannot be described by numerical values

quantitative data data that can be described by numerical values

secondary data data that has been previously collected that is accessible to different researchers

theory (scientific) an explanation of a physical phenomenon that has been repeatedly confirmed by experimental evidence and observation

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Variables, types of data, and characteristics of data 2.3.3.1 & 2.3.8.1

There are different types of variables that can be measured when gathering data in an experiment. It is important to have an understanding of data types and their characteristics to communicate our results effectively.

Theory and applications

We use the scientific method to obtain results which can be used to support a scientific theory. When conducting an experiment, we investigate the relationship between variables: what happens to variable Y when we change variable X?

Why do we have different types of variables?

To try to find a relation between variables X and Y, we make one the independent variable and the other the dependent variable.

- An independent variable is a variable that the experimenter directly and intentionally changes in order to determine what effect it has on the dependent variable.
- A dependent variable is a variable that the experimenter measures in order to determine whether it is affected by (dependent on) the independent variable.
- A controlled variable is a variable which is kept constant to avoid affecting the results for the dependent variable.

If we were conducting an experiment to see if surface area has an effect on the time it takes for water to freeze, our variables would be as shown in Table 1.

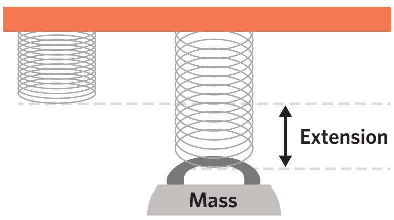
Table 1 Classification of the variables in water freezing experiment

Variable classification	Example(s)
Independent variable	Surface area of water/ice
Dependent variable	Time taken to freeze
Possible controlled variables	Volume of water Initial temperature of water Temperature of freezer Properties of container material

Progress questions

Question 1

Elodie conducts an experiment in which she attaches different masses to a hanging spring and measures the extension of the spring for each mass. She uses the same spring for all measurements. Which variable in this experiment is the dependent variable?



A. extension of spring

B. spring used

C. mass attached

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How can we classify different types of data?

To continue to develop scientific theory, we conduct experiments and obtain data which is used to develop conclusions about our area of study. There are two types of data that can be collected and analysed:

- Primary data:
  - This is gathered by a researcher directly from an experiment.
  - Typically this means we have done the experiment ourselves.
- Secondary data:
  - This is collected indirectly from other experiments.
  - Typically this means doing research on the topic we are investigating.

USEFUL TIP

Primary data = 'first hand' data

Secondary data = 'second hand' data

Data doesn't just have to be numerical (quantitative). Qualitative data describes any data which cannot be (easily) described with numerical values, and instead we can describe it with words.

- The material from which a container is made may be more easily described by non-numerical data (such as silicone).
- The dimensions and density of the container are better described by quantitative data values (such as 10 cm^3).

USEFUL TIP

Not all numbers are treated as quantitative data. For example, assigning numbers to tennis ball brands is qualitative data.

Progress questions

Question 2

Which of the following is best classified as qualitative data? **(Select all that apply)**

I. the length of a ramp down which a ball rolls
II. the type of ball (basketball, soccer ball etc.)
III. the material from which the ball is made
IV. the angle of the ramp
V. the diameter of the ball

Question 3

Secondary data can be

A. qualitative only.
B. both quantitative and qualitative.

The scientific method 2.3.2.1 & 2.3.6.1

The scientific method is a way of reasoning. It is a process of collecting and analysing information to disprove incorrect explanations about the world.

Theory and applications

The scientific method is a process which begins with the idea that all possible explanations for an observation could be true unless (and until) they are disproved. This process uses variables and data to provide great confidence in explanations about the world which have not yet been disproved.

How do we use the scientific method?

We use the scientific method to follow a sequence of logical steps to gather information in order to test an explanation, known as the hypothesis. That is, we try to disprove the hypothesis.

- If, after multiple attempts to do this, the hypothesis has not been disproved, then we have greater confidence that it is a correct explanation for our observations.

We will use the scientific method to find a relationship between surface area and time it takes for water to freeze. The left hand side of Table 2 outlines the general process, and the right hand side describes the application to our example experiment.

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Table 2 The scientific process

	Method	Example
Step 1: Observe and question	We observe a physical phenomenon and ask 'why does this happen?' Sometimes we need to break the question into more specific parts such as 'what are the factors that affect…?' When we have answered this question, we could move to the question of why the identified factors have the effect that they do.	For example, we put a large jug of water and a small jug of water into the same freezer, and we observe that the water in the larger jug takes longer to freeze than the water in the smaller jug. We ask 'what are the factors that affect how long it takes to freeze water?'
Step 2: Formulate an aim and hypothesis	The aim of an experiment is a statement about the purpose of the research; why are we conducting the experiment. A hypothesis should make a testable prediction by describing the effect of changing one variable on another variable. To ensure the hypothesis meets this requirement, it can help to follow a structure such as: • If [describe predicted physics principles] then [describe the predicted change to the dependent variable] when [the independent variable] is [increased/ decreased]. • It is predicted that [increasing/decreasing] [independent variable] will [increase/decrease] [dependent variable] because [describe predicted relationship between independent variable and dependent variable].	We consider which conditions were (or could have been) different between the two jugs. • The larger jug had a greater total surface area of water. • The larger jug had a greater volume of water. • The jugs might have had different initial temperatures. • The jugs might have been made from different materials. We decide that the different surface area might be the best explanation for the different freezing times. We formulate an aim: 'To investigate the relationship between surface area of a jug and the freezing time of water.' We formulate a hypothesis: 'If the time taken for water to freeze is directly related to its total surface area, then the time taken for a fixed volume of water to freeze will increase when its surface area increases.'
Step 3: Experiment (test the hypothesis)	In performing an experiment, only an independent variable should be deliberately changed. The dependent variable should then be measured. All other variables (controlled variables) should be kept constant. We should take several measurements of our dependent variable. It is best to do this at regular and frequent intervals of change in our independent variable. We record any relevant results, whether that is quantitative or qualitative. We record our method in detail so that another experimenter could attempt to replicate it in order to verify our results. Lesson 11C will further explain this section of the scientific method.	We measure the time it takes to freeze water in a variety of different shapes that have different surface areas but we try to keep all of the following conditions constant: water volume (250 cm^3), initial water temperature (20°C), freezer temperature (–18°C), and container material (silicone). We use nine different values of surface area. Using a greater number of different values of the surface area will give us greater confidence in any trends we observe. We take five measurements of the freezing time for each value of the surface area and then calculate the average time for each. The example results are shown in Table 3.
Step 4: Analyse and conclude	We should present information in a way that makes it clear what (if any) relationship exists between the variables in our experiment. Plotting graphs of the dependent variable versus the independent variable is a useful visual way of identifying relationships. We try to make conclusions based on the analysis as to whether the data supports the hypothesis. We acknowledge any factors that may have affected our results which we could not control or any uncertainty in our results. We can never have complete certainty that the conclusion is true because there may be variables which we did not correctly control or even recognise. Lessons 11D and 11E will further explain this section of the scientific method.	We choose to represent the data on a graph (see Figure 1), with the surface area on the horizontal axis and the average time to freeze on the vertical axis. We notice that the time for the water to freeze seems to decrease as surface area increases. We conclude that our results do not support our hypothesis that 'increasing the surface area of water will increase the time it takes to freeze'. Even though we kept the volume constant, there may have been other differences in the geometry for each value of the surface area such as the existence/angles of corners.
Step 5: Share the results	We make our results (and the method we used) public for other experimenters to view.	If other experimenters conduct their own experiments freezing water and find similar results, then we become increasingly confident that increasing surface area decreases the time taken for water to freeze.

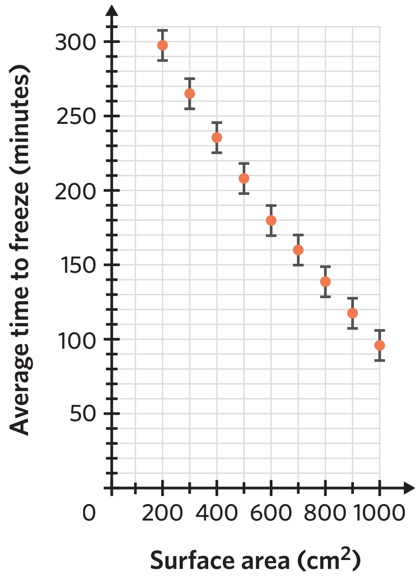

Figure 1 A graphical representation of the data from Table 2

Table 3 Example results for the time taken for water to freeze with different surface areas

Surface area (cm^2)	Time to freeze (minutes)					
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average
200	299	287	295	297	307	297
300	254	268	260	274	264	264
400	230	244	224	240	232	234
500	197	207	213	201	217	207
600	170	188	190	170	182	180
700	169	157	161	159	149	159
800	148	128	136	140	138	138
900	113	115	127	123	107	117
1000	87	103	91	97	107	97

Progress questions

Question 4

A hypothesis should always

A. predict the relationship between variables in an experiment.

B. predict the specific values that will be measured in an experiment.

Question 5

Which of the following statements about the scientific method are true?
(Select all that apply)

I. The scientific method guarantees that correct conclusions will be obtained.

II. The scientific method attempts to systematically eliminate incorrect explanations about the world.

III. The more data collected and the more independent experiments conducted, the greater the confidence we can have in the conclusions of experiments that follow the scientific method.

IV. We have confidence in a hypothesis that is supported by the scientific method because the experimenter has tried without success to disprove the hypothesis.

Theories, models, and laws 2.3.6.2 & 2.3.7.1

Theories, models, and laws help us communicate our understanding of the world around us. They may change as we develop better technology, but are accepted as true until disproved.

Theory and applications

When the predictions made by a hypothesis have been tested many times, and the results consistently support the hypothesis, then the scientific community will consider the hypothesis to be true with a high degree of confidence. At this point, the explanation is now considered a scientific theory.

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How do theories, models, and laws help our understanding of the physical world?

Scientific theory explains a phenomenon and a law is a summary of that observation. When looking at the law on its own, we don't gain an understanding of why it happens, only what happens.

- Newton's first law of motion tells us that an object will stay in motion unless acted upon by an external force.

We can never say something is correct with complete certainty and any explanation must be considered possible until it has been disproved.

- Scientists will favour explanations with the least assumptions.
  - Issac Newton's law of gravitation made predictions that did not align with observations.
  - Albert Einstein developed an alternative explanation which has been shown to make correct predictions. His explanation is the theory of general relativity.

We can use models to simplify concepts and phenomena that cannot be easily experienced or observed. Models have limitations but can depict things we otherwise would not see, such as atoms.

- We model matter as being continuous, rather than as discrete with several atoms. Figure 2(a) shows the solid model of a cube, and Figure 2(b) shows where matter is concentrated in the nuclei of atoms, and the cube is mostly empty space.
- Examples of models we use in VCE Physics are the particle model of atomic nuclei, the electromagnetic wave model for light, and a vector model for forces.

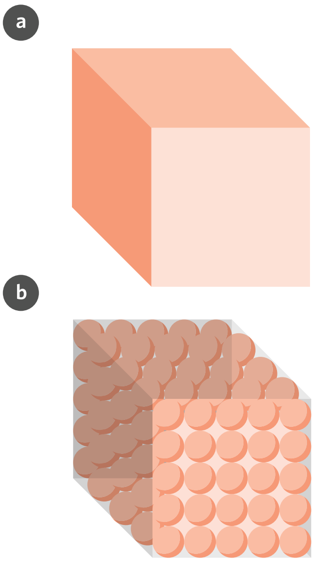

Figure 2 **(a)** Matter modelled as a solid, continuous entity and **(b)** attempting to model matter as a discrete entity made of atoms. Note that this diagram is not to scale.

Progress questions

Question 6

A conclusion that is formed with high confidence due to withstanding rigorous testing and which can explain observations and predict the results of future experiments is best described as

A. a hypothesis.

B. a scientific model.

C. a scientific theory.

D. an observation or measurement.

Question 7

A simple representation that helps to describe and predict scientific results but which is known to be incomplete or partly incorrect is best described as

A. a hypothesis.

B. a scientific model.

C. a scientific theory.

D. an observation or measurement.

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Theory summary

- An independent variable is directly changed by the experimenter.
- A dependent variable is observed or measured by the experimenter, and is expected to be impacted by the independent variable.
- A controlled variable is kept constant to avoid affecting the observations or measurements of the dependent variable.
- Primary data is collected first-hand and secondary data is obtained from someone else, usually through research.
- Information collected in an experiment can be classified as quantitative (numerical) or qualitative (non-numerical) data.
- The scientific method is a way of reasoning in order to create correct theories about how the world works, by testing whether or not a hypothesis is supported by observations.
- A hypothesis is a proposed explanation which makes testable predictions about the relationship between variables.
- A scientific law is a statement of what happens in a physics phenomenon. A scientific theory is the how or why such an event occurs.
- Scientific models are representations which help explain physical theories.

11A Questions

Mild 🌶 Medium 🌶🌶 Spicy 🌶🌶🌶

Exam-style

Question 8 (2 MARKS) 🌶

Nathan wants to conduct an experiment on centripetal force, but does not have the equipment he needs at home. Instead he researches online for data to use.

a. What type of data has Nathan collected? (1 MARK)

b. If Nathan is then able to complete the experiment himself with school equipment, what type of data does he collect? (1 MARK)

Question 9 (2 MARKS) 🌶🌶

Explain the difference between a scientific law and a theory.

Question 10 (3 MARKS) 🌶🌶

For each statement, choose the type of explanation/representation that it is best described by.

Explanation/representation

- Scientific law
- Scientific model
- Scientific hypothesis

Statement

a. The shape of the Earth is treated as a perfect sphere for the purpose of calculations. (1 MARK)

b. Ice melts into water when provided with sufficient heat. (1 MARK)

c. If larger mass objects roll downhill at a greater rate than smaller mass objects, then the time taken for the cart to reach the bottom should decrease when the mass on the cart is increased. (1 MARK)

Question 11 (5 MARKS)

Meg conducts an experiment in which she measures the maximum distance from her phone that she can hear the message alert tone for various volume settings (identified as 'quiet', 'medium', 'loud', and 'very loud') on the phone. She uses the same message alert tone for each trial and conducts the experiment in a large quiet outdoor space.

a. Identify the independent variable and whether it is measured with quantitative data or qualitative data. (2 MARKS)

b. Identify the dependent variable and whether it is measured with quantitative data or qualitative data. (2 MARKS)

c. Identify a controlled variable in this experiment. (1 MARK)

Adapted from 2017 VCAA Exam Short answer Q9b

Question 12 (3 MARKS)

Ava and Julian notice that when they drop a rubber ball from a low height onto concrete, the ball doesn't bounce back as high as when it is dropped from a greater height. They want to conduct an experiment to find the relationship between the height a ball is dropped and the peak of its initial bounce. Write a hypothesis for this experiment.

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11B Scientific conventions

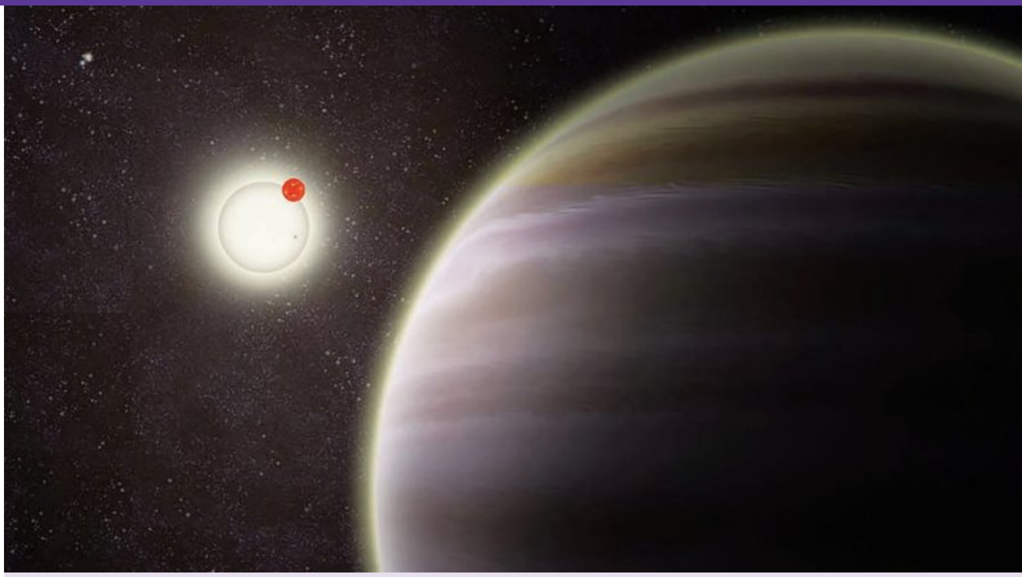
STUDY DESIGN DOT POINT

- apply the conventions of scientific report writing including scientific terminology and representations, standard abbreviations, units of measurement, significant figures and acknowledgement of references

11A 11B 11C 11D 11E

2.3.11.1 Units of measurement

2.3.11.2 Significant figures



How far away are the stars?

When recording data, the magnitude of a value can only communicate limited information without a corresponding unit of measurement. Scientists have conventions for different units and the number of figures that should be displayed with numerical values. This way, everyone can understand the size and confidence of that value.

KEY TERMS AND DEFINITIONS

magnitude the size or numerical value of a quantity without sign (positive or negative) or direction

SI unit an accepted standard unit used for measuring a quantity

significant figures all digits quoted, starting with the first non-zero digit, giving an indication of the confidence in a measurement

Units of measurement 2.3.11.1

We use units of measurement as a standard reference for the magnitude of different quantities, so that different physical objects and processes can be compared. There are many different systems of measurement used in different countries and contexts.

Theory and applications

The SI system of measurement is used globally as the preferred system of measurement in scientific contexts. Physical quantities are expressed in SI units, using the seven 'base' units.

How can we describe quantities using SI units?

The seven base units are defined in terms of physical constants or processes.

For example:

- the metre is defined with reference to the speed of light
- the second is defined by the frequency of energy transitions in caesium-133

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Table 1 The base SI units and their symbols

Quantity	Unit name	Symbol
Time	second	s
Length	metre	m
Mass	kilogram	kg
Electric current	ampere	A
Temperature	kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd

USEFUL TIP

The astronomical unit is a unit of length used in astronomy. It is the mean distance from the Earth to the Sun, approximately 150 million kilometres.

All other SI units are derived from the base SI units. That is, they are formed by multiplying or dividing the SI units. They are appropriately called 'derived SI units'. A few examples of derived SI units can be found in Table 2, but are not required knowledge for VCE Physics.

Table 2 Some derived SI units and their symbols

Quantity	Unit name	Symbol	Equivalent base SI units
Frequency	hertz	Hz	s^{-1}
Force	newton	N	$kg\ m\ s^{-2}$
Energy	joule	J	$kg\ m^2\ s^{-2}$
Resistance	ohm	Ω	$kg\ m^2\ s^{-3}\ A^{-2}$

Certain quantities like velocity and acceleration, shown in Table 3, do not have their own dedicated SI units. Instead they each use equivalent base (and/or derived) SI units. These units are required knowledge for VCE Physics.

Table 3 The equivalent base/derived SI units for other select quantities

Quantity	Equivalent base/derived SI units
Velocity	$m\ s^{-1}$
Acceleration	$m\ s^{-2}$
Area	m^2
Volume	m^3
Specific heat capacity	$J\ kg^{-1}\ K^{-1}$
Latent heat	$J\ kg^{-1}$

USEFUL TIP

We can gain a lot of clues about physics problems from unit analysis. For example, if we see the unit for velocity is $m\ s^{-1}$ (metres divided by seconds), that indicates that the formula for velocity will contain some length variable divided by some time variable.

When an answer is asked for in SI units, this includes both base units and derived units.

Prefixes, shown in Table 4, are used to change the magnitude and indicate the factor by which the value should be multiplied. For example, nine picometers = 9.0 pm = 9.0×10^{-12} m.

Table 4 Some SI prefixes

Symbol	p	n	μ	m	k	M	G
Prefix	pico	nano	micro	milli	kilo	mega	giga
Order of magnitude	10^{-12}	10^{-9}	10^{-6}	10^{-3}	10^{3}	10^{6}	10^{9}

The SI unit for mass (the kilogram) is a special case since it has a prefix already within its name ('kilo'). Prefixes are put in front of 'grams' instead. For example, one milligram expressed in SI units would be 10^{-6} kilograms.

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Progress questions

Question 1

Which of the following are base or derived SI units?
(Select all that apply)

I. seconds
II. fahrenheit
III. ohms
IV. metres cubed (m^3)
V. grams
VI. light-years
VII. hours
VIII. volts

Question 2

Express 6.4 kJ in SI units.

A. 6.4×10^{-3} J
B. 6.4×10^{3} kJ
C. 6.4×10^{3} J

Significant figures 2.3.11.2

When representing numerical information, it is important to communicate how confident we are in the measurement.

Theory and applications

Significant figures indicate to what degree we are confident in a value. For example, if we have a number with two significant figures, that indicates to the reader that we are not confident in the value of that number past those first two digits. This ties heavily into the concept of uncertainty which will be explored in Lesson 11C.

How do we use significant figures?

There are certain conventions used when representing numbers in VCE Physics, so that the reader can understand how confident we are in our values.

Table 5 Significant figure conventions

Convention	Example	Number of significant figures
Leading zeros are never significant	0.32	Two
All non-zero digits are always significant	53.2	Three
Trailing zeros are always significant.	53.00 or 5300	Four
Zeros between digits are always significant.	302	Three

There are rules that we follow so the results of our calculations are expressed to the correct level of confidence given the level of certainty in the numbers with which we started:

Table 6 Conventions for calculations

Operation	Convention for answer	Example
Addition and subtraction	Least number of decimal places	$34.477 + 2.31 = 36.79$ Final answer has 2 decimal places as 2.31 has 2 decimal places
Multiplication and division	Least number of significant figures	$34.477 \times 2.31 = 79.6$ Final answer has 3 significant figures as 2.31 has 3 significant figure

USEFUL TIP

The significant figures given for constants in a formula sheet limits the amount of significant figures in exam-style questions.

For example, any question involving $c = 3.0 \times 10^{8}$ m s^{-1} will be limited to 2 significant figures.

USEFUL TIP

In worked solutions in this book, we will provide additional significant figures in each line of working as it is good practice to do so to ensure the correct confidence is communicated in the final answer.

STRATEGY

Calculations should be rounded to the correct amount of significant figures only in the last step of working. Otherwise, rounding during working can result in an incorrect answer.

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Progress questions

Question 3

The number 180 030.0 contains

A. seven significant figures.

B. five significant figures.

Question 4

Consider the following calculation: 7.113 + 0.64. Which of the following statements is true?

A. The answer would be expressed to two decimal places.

B. The answer would be expressed to two significant figures.

Question 5

Consider the following calculation: 0.51×1.996. Which of the following statements is true?

A. The answer would be expressed to four significant figures.

B. The answer would be expressed to two significant figures.

Why do we use scientific notation?

We can use scientific notation to express the value to the correct number of significant figures. We write numbers in scientific notation in the following form:

$$m \times 10^n$$

where m is a positive number greater than or equal to 1 and less than 10 (such as 5 or 4.56) and n is a whole number. All the digits in m are significant.

We use scientific notation for two reasons:

- to write large and small numbers with only a few digits,
  - For example, 6.67×10^{-11} without using scientific notation is written as 0.0000000000667.
- to correctly represent the degree of confidence we have in numerical values.
  - For example, 2000 m implies four significant figures, but 2.0×10^3 m has two significant figures.

Table 7 Examples of how to write numbers using scientific notation

Number	Scientific notation	Significant figures
230	2.30×10^2	3
0.00067	6.7×10^{-4}	2
0450.2	4.502×10^2	4
0.3700	3.700×10^{-1}	4

USEFUL TIP

When converting from standard notation to scientific notation, the magnitude of n is the number of digits between the first significant digit and the decimal place.

- If the first significant digit is before the decimal place, move the decimal place n digits to the left, Figure 1(a).
- If the first significant digit is after the decimal place, move the decimal place n digits to the right (the n value is negative), Figure 1(b).

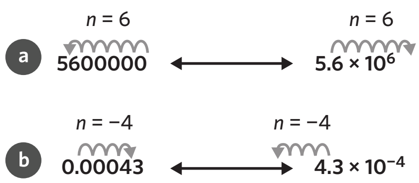

Figure 1 Converting between standard and scientific notation when n is **(a)** positive and **(b)** negative

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WORKED EXAMPLE 1

Convert 467.1 km to the SI unit for length, with two significant figures.

Step 1

Identify the SI unit for length, the prefix and the order of magnitude that relates them.

The SI unit for length is metres.

Our current value is in kilometres.

The order of magnitude for kilo is 10^3.

Step 2

Substitute the prefix for the order of magnitude.

$467.1 \text{ km} = 467.1 \times 10^3 \text{ m}$

Step 3

Identify the number of significant figures required and how to manipulate the current value.

467.1×10^3 has four significant figures.

Use scientific notation to get the final answer to two significant figures.

Step 4

Convert the answer to the correct number of significant figures, remembering to round where necessary.

$4.67 \times 10^2 \times 10^3 = 4.67 \times 10^5$

$4.67 \times 10^5 = 4.7 \times 10^5 \text{ m}$

Progress questions

Question 6

How do we express 0.000000030 in scientific notation?

A. 3.0×10^{-8}

B. 3.0×10^{8}

Question 7

How do we express 8.7×10^{-3} in standard notation?

A. 8700

B. 0.0087

Theory summary

- SI units are used in scientific contexts, and most physical formulas require SI units to be used to attain correct values.
  - Prefixes can be added to SI units to indicate different orders of magnitude.
- The following rules apply to significant figures:
  - All digits are significant except leading zeros in VCE Physics.
  - When adding or subtracting, the final answer should have the same number of decimal places as the lowest provided quantity.
  - When multiplying or dividing, the final answer should have the same number of significant figures as the lowest provided quantity.
- Numbers can be written in scientific notation by writing them in the form $m \times 10^n$.

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11B Questions

Mild Medium Spicy

Exam-style

Question 8 (3 MARKS)

Write the following numbers in scientific notation, to two significant figures.

a. 6000

b. 8 900 000

c. 63 700

Question 9 (5 MARKS)

Express the following quantities in terms of SI units and in scientific notation.

a. 600 ms

b. 0.400 µg

c. 23 MΩ

d. 360 nm

e. 7.0 pA

Question 10 (2 MARKS)

Yusif and Nina are adding together a set of numerical data as listed below.

12.1 14.25 8.0 10.984 15.0982

Nina claims that the final answer should have two significant figures as the final answer should only have as many significant figures as the least in the addition. Yusif disagrees, and claims that the final answer should have only one number after the decimal place.

Evaluate whether Nina or Yusif is correct and provide a reason why.

Question 11 (2 MARKS)

Oliver wants to know how many times 200 goes into 7.4. He wants his calculation to follow scientific conventions.

a. How many significant figures should Oliver's solution have? (1 MARK)

b. Solve Oliver's problem. Give the answer in scientific notation and to the correct amount of significant figures. (1 MARK)

Question 12 (2 MARKS)

Calculate the electric potential energy (E) of a 4.00 C charge (Q) after passing through a 6.00 V (V) laptop charger to the correct number of significant figures. The formula for electric potential energy is $E = VQ$. For this question we do not need to change the units, as multiplying charge by voltage gives the SI unit for energy, joule.

Question 13 (3 MARKS)

Calculate the average speed for the journey of a runner who takes 67.0 seconds to run 0.135 kilometres up a hill and a further 63 metres along a footpath to the correct number of significant figures. Average speed is calculated using $speed = \frac{total\ distance}{time}$.

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11C Collecting data

STUDY DESIGN DOT POINTS

- evaluate methods of organising, analysing and evaluating primary data to identify patterns and relationships including scientific error, causes of uncertainty, and limitations of data, methodologies and methods
- identify and apply concepts of accuracy, precision, repeatability, reproducibility, resolution, and validity of data in relation to the investigation

11A 11B 11C 11D 11E

2.3.4.1 & 2.3.4.4 Precision, accuracy, and resolution

2.3.9.1 & 2.3.9.2 Error and uncertainty

2.3.4.2 & 2.3.4.6 Validity, repeatability, and reproducibility

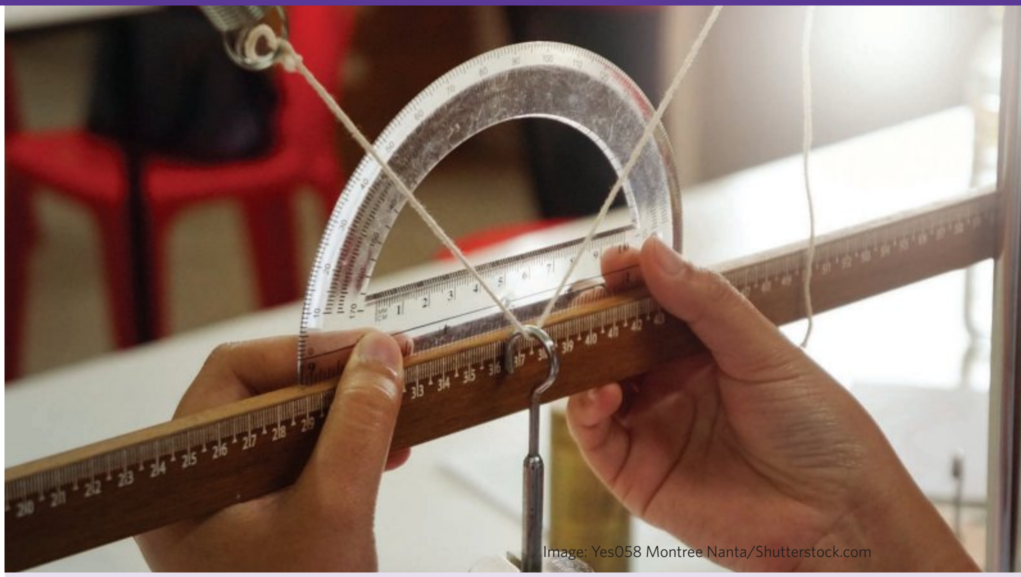


Image: Yes058 Montree Nanta/Shutterstock.com

How do we determine the calibre of our data?

The ability to properly conduct experiments and gather data is an essential part of science. When collecting data in an experiment, there are many things to keep in mind to ensure the conclusions drawn are valid. Errors can occur when care is not given to the scientific method. This can impact the precision and accuracy of our data, as well as create uncertainties.

KEY TERMS AND DEFINITIONS

accuracy a relative indicator of how well a measurement agrees with the 'true' value of a measurement

error the difference between a measured value and its 'true' value

personal error mistakes in the execution of an experiment or the analysis, caused by a lack of care that negatively impact or invalidate the conclusions of an experiment

precision a relative indicator of how closely different measurements of the same quantity agree with each other

random error the unpredictable variations in the measurement of quantities

repeatability the closeness of agreement of results when an experiment is repeated by the same experimenter under the same conditions (using the same equipment and in the same laboratory)

reproducibility the closeness of agreement of results when an experiment is replicated by a different experimenter under slightly different conditions (using their own equipment and laboratory)

resolution the smallest change in a quantity that is measurable

systematic error a consistent, repeatable deviation in the measured results from the true values, often due to a problem with the experimental design or calibration of equipment

uncertainty the qualitative or quantitative judgement of how well an experiment measures what it is intended to measure

validity the degree to which an experiment measures what it intends to measure

Precision, accuracy, and resolution 2.3.4.1 & 2.3.4.4

Precision and accuracy are both relative measures of the quality of data collected in an experiment.

Theory and applications

Precision is an indicator of how well a set of measurements agree with each other. It can be thought of as a measure of the spread or range of data – a bigger range is less precise. Accuracy is an indicator of how well a measurement agrees with the 'true' value of a measurement. This 'true' value is the value that would be measured if it were possible to take measurements with no errors.

How are precision and accuracy different?

Both precision and accuracy are relative indicators, and therefore, measurements cannot be objectively 'precise' or 'accurate'. Instead, they can only be more or less precise or accurate compared to another set of measurements.

We can use targets to help us visualise the difference between precision and accuracy, see Figure 1. The bullseye of the target is the desired, 'true' value.

- Figure 1(a) shows our marks consistently hitting a similar area of the target, but not the bullseye. This is demonstrating precise yet inaccurate data.
  - If we translate this to data, our data would have a small range, and hence be more precise.
- Figure 1(b) shows our marks hitting near the bullseye, but they are not closely spaced. This is demonstrating accurate yet imprecise data.
  - If we translate this to data, the average of our data would be close to the 'true' value, but may have a wide range of values.

Measurements that are precise aren't necessarily accurate; and measurements that differ from the true value can still be considered precise. We can therefore categorise data based on both accuracy and precision, Figure 2.

Resolution is the smallest change in the quantity being measured that causes a detectable change in the value indicated on the measuring instrument. The smaller the resolution, the more precise the recorded value will be. A digital stopwatch, see Figure 3(a), with resolution 0.01 s will be able to make a reading closer to the true measurement compared to an analogue stopwatch, see Figure 3(b), with a resolution 0.05 s.

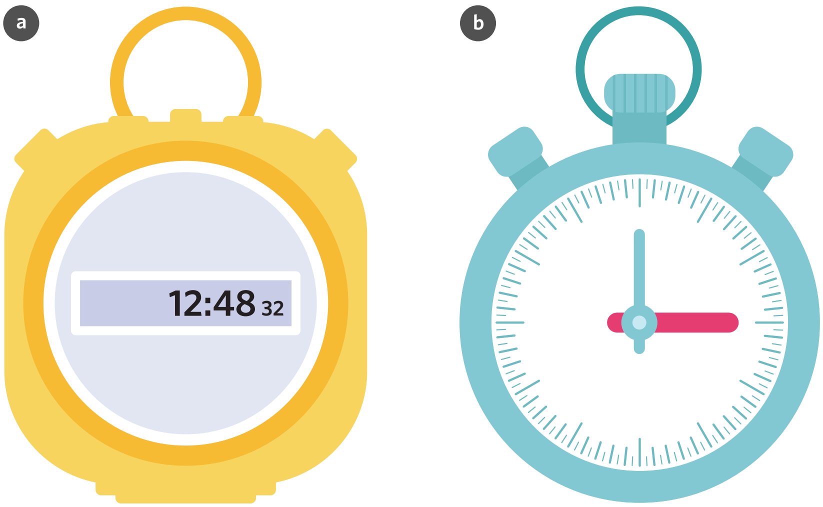


Figure 3 **(a)** Digital stopwatch and **(b)** analogue stopwatch

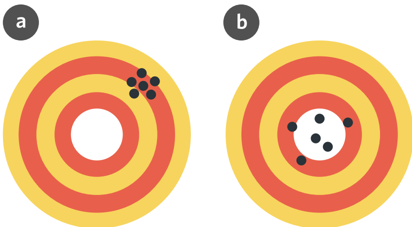


Figure 1 Targets depicting **(a)** high precision and **(b)** high accuracy

USEFUL TIP

When asked to identify the most precise set of measurements, identify the set with the smallest range (maximum value – minimum value). When asked to identify the most accurate set of measurements, identify the set with an average that is closest to the 'true' value.

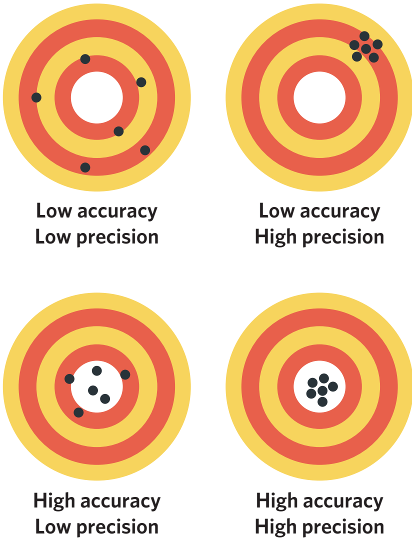
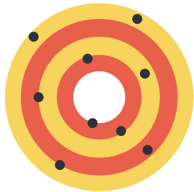


Figure 2 Targets Illustrating different levels of precision and accuracy

Progress questions

Use the following diagram for questions 1 and 2.



Question 1

The diagram shows data that is

A. not precise.

B. very precise.

Question 2

For the data shown to be accurate, the data points need to be

A. as close as possible to the centre of the target.

B. clustered together anywhere on the target.

Question 3

What is the resolution of a 10 cm ruler with millimetre marking?

A. 10 cm

B. 1 mm

C. 0.5 mm

Error and uncertainty 2.3.9.1 & 2.3.9.2

The data we obtain in an experiment will never be absolutely precise or accurate, as there are many types of error that can occur.

Theory and applications

Error refers to the difference between a measured value and its 'true' value. Errors lead to uncertainty in our data collected in the experiment.

How does error occur?

Systematic errors are errors that uniformly affect the accuracy of data in an experiment.

Examples include:

- An uncalibrated weighing scale. Each measurement would differ from the true value by a consistent amount.
- Parallax error, which occurs when an analogue scale is read at an angle to the display, Figure 4.

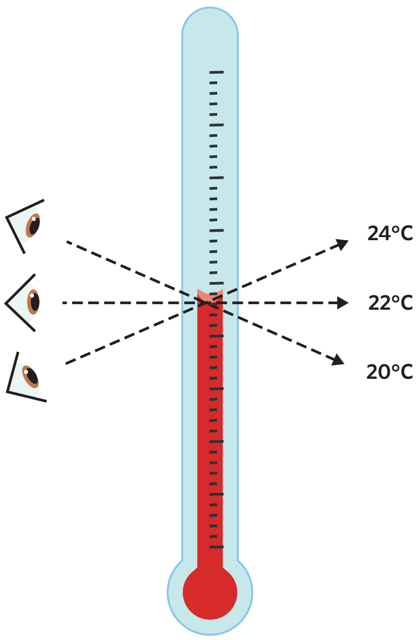


Figure 4 Examples of parallax error when reading a thermometer

To reduce the effect of systematic errors, we should calibrate all apparatuses before conducting the experiment, and analyse the method, to identify steps that could introduce errors.

- Since all measurements are impacted the same, averaging them out will not improve the accuracy of the data.

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Personal errors are mistakes in an experiment's execution or analysis caused by a lack of care that negatively impact or invalidate the conclusions of an experiment. An example of personal error could be misreading the scale on a thermometer.

- Data points with these types of errors should not be included in the report or analysis of data.

Random error is the unpredictable variation in the measurement of quantities. In general, random errors can be reduced but not entirely avoided. Examples of where random error is introduced include:

- Reading between the intervals of a measuring device,
- Taking values from a device where the value is fluctuating.

Any physical measurement will have an associated random error which is caused by uncontrolled variations in the conditions of an experiment between each trial. We can reduce random error by:

- choosing equipment that will result in less variation.
- averaging the results from repeated measurement, improving the precision and accuracy.

We can use our target analogy to help us understand the difference between systematic and random error.

- In Figure 5(a), the marks, our data, are all impacted by the same systematic error and become less accurate.
- In Figure 5(b), the marks, our data, are impacted by random errors and become less precise.

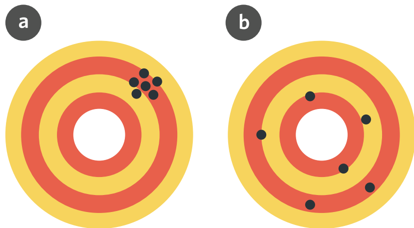

Figure 5 Targets depicting **(a)** systematic error and **(b)** random error

We can see systematic and random errors when we plot our data. Plotting data is discussed in more detail in Lesson 11D. In Figure 6, the 'true' data are the dots that lie on the orange line.

- The green line has a non-zero y-intercept when it is supposed to. This is usually an indicator of systematic error, since all points are impacted in a similar manner.
- The orange data points that do not sit on the trendline indicate that random error has occurred, since not all points are impacted the same.

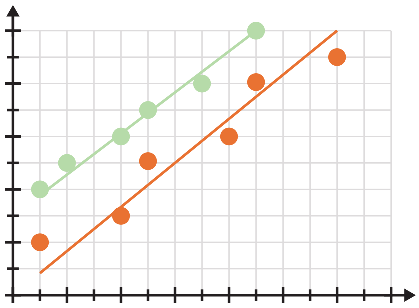

Figure 6 Plots of two experiments measuring a relationship between the same two variables

Any sources of error that cannot be removed, or were not identified during the experiment, should be discussed in the experimental report.

Uncertainty is an indicator of a range that the 'true' value of a measurement should lie within, as shown in Figure 7. Having uncertainty in measurements is unavoidable due to how measurements vary when repeated, or how they deviate due to systematic or random errors.

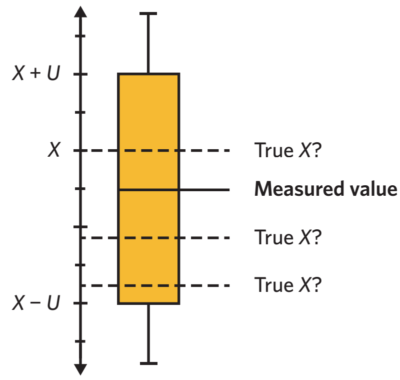

Figure 7 The 'true' value of X can be anywhere within the uncertainty bounds. U represents the uncertainty in this experiment.

USEFUL TIP

Uncertainty can be reduced by using measurements with smaller intervals, such as using a ruler with millimetre markings rather than centimetre markings.

This is because uncertainty of a measuring device is calculated as half of the smallest measuring increment.

In VCE we only need to look at uncertainty from a qualitative perspective.

Progress questions

Question 4

Error is best described as

A. a qualitative estimate of the range of values associated with a measurement.

B. how confident a scientist feels while performing data analysis.

C. the difference between a measured value and its 'true' value.

Continues →

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Question 5

When a measurement is taken from the average of multiple readings, taking more readings

A. increases the effect of random error.

B. does not change the effect of random error.

C. reduces the effect of systematic error.

D. does not change the effect of systematic error.

Question 6

Which of the following statements about error is correct?

A. Random errors cause the measured value to be uniformly different from the true value.

B. Personal errors are unavoidable.

C. Systematic errors do not affect all data points.

D. Random errors are unavoidable.

Validity, repeatability, and reproducibility 2.3.4.2 & 2.3.4.6

Any source of error, uncertainty, or bias may impact the validity of an experiment.

Theory and applications

An experiment is regarded as valid if it is able to successfully measure what it aims to measure. If there are any errors during any part of the experiment, it may impact the validity of the experiment.

How do we know an experiment is valid?

The validity of an experiment can be impacted before, during, and after performing an experiment.

Table 1 Some requirements for an experiment to be valid before, during, and after an experiment. This list is not exhaustive.

Time period	Elements necessary to be valid
Before the experiment	• The experiment is designed to have one independent and one dependent variable. • No variables, other than the independent variable, are changed. • The experiment is designed to minimise errors and uncertainties. • All necessary assumptions for analysis (such as simplifications) are addressed in the design of the experiment.
During the experiment	• No controlled variables are allowed to change. • All steps of the scientific method are followed. • The experiment measures the correct dependent variable. • Appropriate equipment is used in order to minimise errors and uncertainties. • Observer bias is minimised.
After the experiment (data analysis)	• All data is included and explained. Data cannot be arbitrarily selected to produce the desired trend. • Any outliers are addressed in discussion and are included in the initial data. • Results are examined. Correlation between two variables is not automatically assumed to mean causation.

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There are two main ideas that are affected by the presence of errors:

- Repeatability refers to the closeness of agreement of results (the precision) when an experiment is repeated by the same experimenter under the same conditions (using the same equipment and in the same laboratory).
- Reproducibility refers to the closeness of agreement of results (the precision) when an experiment is repeated by a different experimenter under slightly different conditions (using their own equipment and laboratory).

Progress questions

Question 7

Experiments with reproducible results

A. can be replicated by other experimenters under different conditions to yield similar results.

B. can be replicated by other experimenters under the same conditions to yield similar results.

Question 8

Experiments with repeatable results

A. can be replicated by other experimenters under the same conditions to yield similar results.

B. can be replicated by the same experimenter under the same conditions to yield similar results.

Theory summary

- Precision and accuracy are relative measures describing the spread of a set of measured values and how well the set of measurements relates to the 'true' value.
  - A more precise set of measurements will have a smaller range of data.
  - A more accurate set of measurements will have an average closer to the true value.
- Resolution is the smallest increment of change that can be detected by a measuring device.
- Experimental errors impact the data collected and results. Minimising these reduces uncertainty in our measurements.
  - Systematic error: a consistent, repeatable deviation in the measured results from the true values.
  - Random error: the unpredictable variations in the measurement of quantities.
- An experiment is valid if it is able to measure what it intends to measure.
- Repeatability and reproducibility refer to the ability of the results to be obtained by replicating the experiment under the same or different conditions.

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11C Questions

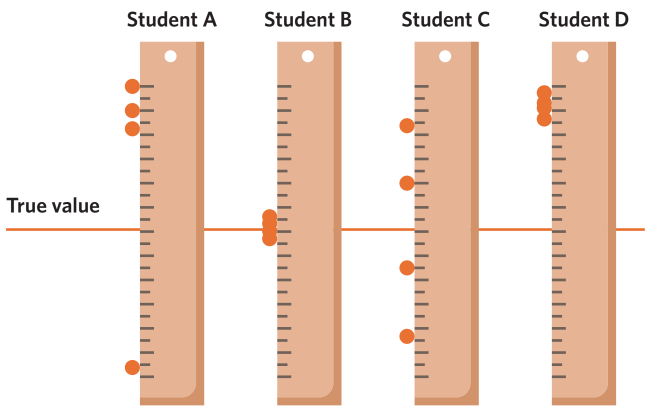
Mild Medium Spicy

Exam-style

Use the following information to answer questions 9 and 10.

Four students take a measurement of the length of a piece of wire. The measurements are then indicated as dots on a ruler (as shown on the diagram). The true value of the length of the wire is also indicated on the diagram.

Adapted from 2019 VCAA NHT Exam Multiple choice Q20



Question 9 (1 MARK)

Which student's results are the most precise and accurate?

A. student A

B. student B

C. student C

D. student D

Question 10 (1 MARK)

Which student's results are the least accurate?

A. student A

B. student B

C. student C

D. student D

Question 11 (1 MARK)

Which one of the following statements about systematic and random errors is correct?

A. Effect of random errors can be reduced by averaging readings.

B. Effect of both random and systematic errors can be reduced by repeated readings.

C. Effect of systematic errors can be reduced by averaging readings.

D. Effect of neither systematic nor random errors can be reduced by repeated readings.

Adapted from 2017 VCAA exam Multiple choice Q20

Question 12 (8 MARKS)

Gen and Jana perform an experiment and measure the voltage across a resistor. The true value of the voltage is 4.2 V.

	Trial 1	Trial 2	Trial 3	Trial 4
Gen	4.0 V	4.5 V	3.6 V	4.3 V
Jana	3.8 V	4.1 V	4.2 V	3.9 V

a. Calculate the average of Gen's and Jana's results. (2 MARKS)

b. Calculate the range of Gen's and Jana's results. (2 MARKS)

c. Comment on the relative accuracy of Gen and Jana's results. (2 MARKS)

d. Comment on the relative precision of Gen and Jana's results. (2 MARKS)

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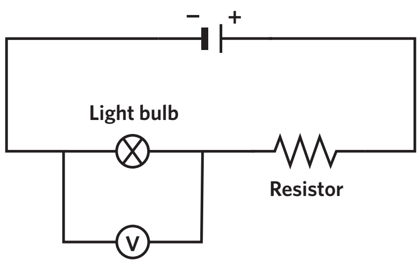
Question 13 (5 MARKS)

Gwen designs an experiment to determine how the voltage drop across a lightbulb in a series circuit varies with the resistance of the lightbulb. The circuit also contains a resistor.



Consider the options below and indicate which options (when added individually to this experimental design) would result in the experiment (including experimental method, analysis, and conclusions) being invalid. **(Select all that apply)**

Note that knowledge of electricity and circuits is not required to answer this question.

I. The resistance of the light bulb being tested is varied between 5 Ω and 20 Ω in 5 Ω intervals.

II. An 8 V battery is used for all trials.

III. The voltage of the battery is changed for the 20 Ω lightbulb test to a 6 V battery from an 8 V battery. This impacts the voltage drop across the light bulb.

IV. Measurements of the voltage are taken three times for each light bulb and then averaged.

V. The resistance of the resistor is changed during trials of the 10 Ω light bulb. This impacts the voltage drop across the light bulb.

VI. Gwen notices the display on the voltmeter flicks between a few values before settling down when she turns the circuit on, so she chooses the value that seems closest to her experimental prediction.

VII. The voltmeter used dies halfway through the experiment and is switched out for a different model of voltmeter.

VIII. Data is analysed to plot resistance on the horizontal axis and voltage drop on the vertical axis.

IX. An obvious outlier result is excluded from the data in Gwen's report and left unmentioned.

X. Another student is able to repeat Gwen's experiment and produce the same results.

Question 14 (3 MARKS)

Explain why ensuring measuring devices are properly calibrated can increase the accuracy of measurements.

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11D Representing and analysing data

STUDY DESIGN DOT POINTS

- evaluate methods of organising, analysing and evaluating primary data to identify patterns and relationships including scientific error, causes of uncertainty, and limitations of data, methodologies and methods
- apply the conventions of scientific report writing including scientific terminology and representations, standard abbreviations, units of measurement, significant figures and acknowledgement of references

11A 11B 11C 11D 11E

2.3.9.3 & 2.3.11.3 Plotting data

2.3.9.4 Drawing linear and non-linear lines of best fit

ESSENTIAL PRIOR KNOWLEDGE

11A Independent and dependent variables

See question 96.

How do we find the significance of our data?

The analysis stage of a scientific investigation is where conclusions can be made. It involves the identification of trends in data and making allowances for errors and uncertainties, in order to determine the nature of the relationship (if any exists) between the dependent and independent variables. This lesson explores the conventions of graphing data and drawing linear and non-linear lines of best fit. Understanding these conventions is critically important for clearly and correctly communicating the data from a scientific investigation.

KEY TERMS AND DEFINITIONS

linearise the process of transforming data so that, when graphed, a line of best fit can be drawn through the data

line of best fit see linear line of best fit or non-linear line of best fit

linear line of best fit a straight line that indicates the relationship between the independent and dependent variables on a graph

non-linear line of best fit a curved line that indicates the relationship between the independent and dependent variables on a graph

trendline see linear line of best fit or non-linear line of best fit

Plotting data 2.3.9.3 & 2.3.11.3

Graphs help provide a visualisation of data. There are conventions that should be followed for labelling the graph, choosing a scale for each axis, and plotting uncertainty bars. Data can also be linearised to help understand the relationship between variables.

Theory and applications

Representing data collected in an experiment in a clear way is important so it can be analysed and understood. This can be done with tables and graphs.

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How do we represent our data visually?

Data collected in an experiment can be represented in a table. We may include the uncertainties along with the average from our multiple trials, see Table 1. To help us understand the concepts and conventions of plotting graphs, we will use the example of an experiment that investigates the relationship between the time it takes for a block to slide down a one metre ramp and the angle of the ramp.

Table 1 Data collected and analysed in an experiment

Angle (±5°)	Time for block to slide down ramp (±0.1 s)			Average time for block to slide down ramp (s)
	Trial 1	Trial 2	Trial 3	
10	3.2	3.5	3.4	3.4 ± 0.2
20	2.4	2.5	2.4	2.4 ± 0.1
30	1.8	2.1	2.0	2.0 ± 0.2
40	1.8	1.8	1.7	1.8 ± 0.1
50	1.5	1.7	1.6	1.6 ± 0.1
60	1.4	1.5	1.5	1.5 ± 0.1

USEFUL TIP

Averages can be calculated by taking the sum of a group of variables and dividing by the number of variables.

For example the average of 3.2, 3.5 and 3.4 is $\frac{3.2 + 3.5 + 3.4}{3} = 3.367 = 3.4$

USEFUL TIP

In VCE Physics, when calculating the uncertainty in the average of multiple measurements, the uncertainty can be taken as the magnitude of the difference between the average value of the measurements and the most extreme measurement.

If each of our measurements has an uncertainty of 0.1, our average uncertainty is 0.2 since 3.4 is 0.2 units away from 3.2.

We use the table to create a list of points that should be graphed to analyse the relationship between the independent variable and dependent variable.

- The first listed coordinate in a point corresponds to the independent variable and the second corresponds to the dependent variable.
- In our example, the independent variable is the angle of the ramp and the dependent variable is the average time for the block to slide down the ramp.
  - As such, the points to be plotted are: (10, 3.4), (20, 2.4), (30, 2.0), (40, 1.8), (50, 1.6), (60, 1.5).

USEFUL TIP

In an exam, marked axes and a grid will be provided but sometimes an appropriate scale will need to be chosen. When answering graphing questions from this book, it is suggested to sketch answers on graph paper to practise choosing an appropriate scale to fit a given grid and data set.

There are several conventions that must be followed to correctly represent scientific data on a graph. We label the axes and title the graph to communicate what was recorded from the experiment.

- The independent variable should be plotted on the horizontal axis.
- The dependent variable should be plotted on the vertical axis.
- The variables should be labelled on the relevant axis with their respective units.
- The graph title should generally be of the form '[dependent variable] versus [independent variable]'.

Each axis should have a consistent scale so that the intervals between grid lines on an axis represents a constant value. Note, this is not the case for log graphs.

- The scale on each axis should be chosen so that the data points take up the majority of the available graph space (the spread of the data points should cover more than 50% of each axis).
- The axis can (but does not have to) indicate a power of ten on the scale by which all values on that axis should be multiplied.

If measurement uncertainties are stated, uncertainty bars should be plotted on the graph using lines with an end cap. The length of the lines indicate the magnitude of the uncertainty.

- Horizontal uncertainty bars are the uncertainty in the independent variable.
- Vertical uncertainty bars are the uncertainty in the dependent variable.
- The combination of the horizontal and vertical uncertainty bars indicates a rectangular area where the 'true' value may be, as indicated by the shaded box in Figure 1.

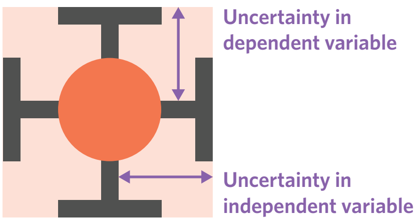

Figure 1 A point with horizontal and vertical uncertainty bars

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Using these principles, an appropriate graph for the data from Table 1 is shown in Figure 2.

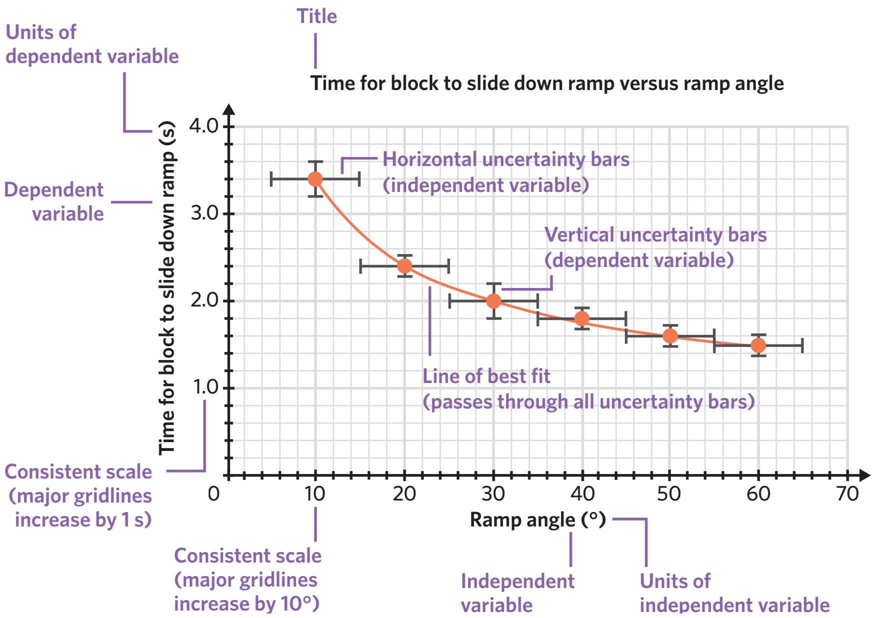

Figure 2 An annotated graph of the data from Table 1

Progress questions

Question 1

When creating a graph of data, which of the following is incorrect?

A. The independent variable should be plotted on the vertical axis.

B. The variables should be labelled on their respective axis with units.

C. The axes should have consistent scales.

D. The scale on the axes should be chosen such that the data points take up the majority of the available graph space.

Question 2

Which of the following statements is true regarding uncertainty bars?

A. Vertical uncertainty bars indicate the uncertainty in the independent variable.

B. The 'true' value should lie in the area indicated by the uncertainty bars.

C. The distance between the two end caps of an uncertainty bar is the magnitude of the uncertainty.

How can we make our data easier to analyse?

To help us determine a mathematical form for the relationship between two variables, we can linearise the data. Linearising data is the process of transforming one or both of the independent and dependent values, so that the graph demonstrates a linear (straight line) relationship.

- Linearised graphs do not need to trend towards the origin.
- If a variable is transformed appropriately and the result is a linear line that passes through the origin, this indicates a proportional relationship between the variables plotted. We can use k as a constant in the mathematical form to represent the gradient (slope) of the graph. Gradients are discussed in more detail in Lesson 11E.

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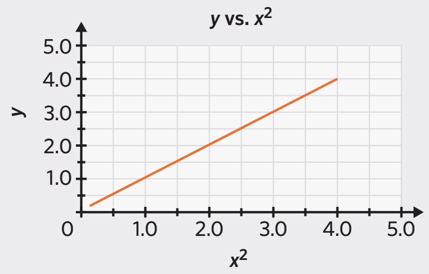
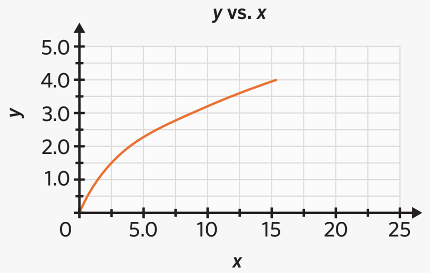
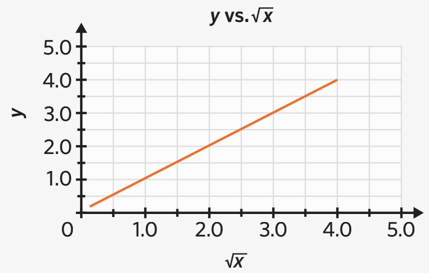
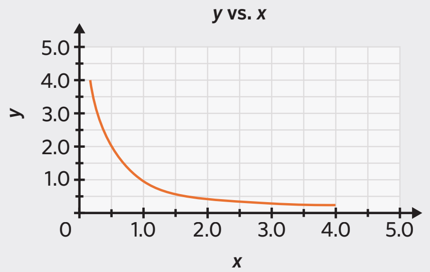
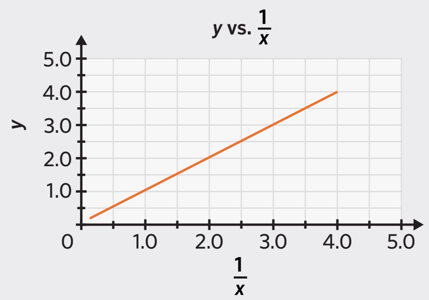
Table 3 Examples of how different graphs can be linearised by transforming the independent variable

Type of graph	Visual	Transformation	Linearised graph, with x transformation
Parabolic, $y \propto x^2$ or $y = kx^2$		x values: square **OR** y values: take the square root	
Square root, $y \propto \sqrt{x}$ or $y = k\sqrt{x}$		x values: take the square root **OR** y values: square	
Hyperbolic, $y \propto \frac{1}{x}$ or $y = \frac{k}{x}$		x values: take the reciprocal **OR** y values: take the reciprocal	

USEFUL TIP

Similar transformations can be made to the dependent variable in order to linearise data and establish a relationship such as $\sqrt{y} \propto x$.

STRATEGY

Proportional relationships can also be used in calculations. For example, suppose $A \propto B$ and $A_1 = x$ when $B_1 = y$. Then if $A_2 = \frac{x}{3}$, we have that $B_2 = \frac{y}{3}$.

WORKED EXAMPLE 1

A student collected data on the distance travelled (d) by a ball that starts from rest and rolls down a ramp for different amounts of time (t). The angle of the ramp is fixed.

Time, t (s)	Distance, d (m)
1.00	0.50
2.00	2.00
3.00	4.50
4.00	8.00
5.00	12.5

Continues →

a. Plot a graph of the data. Assume the uncertainty in distance and time are negligible.

Step 1

Identify the independent and dependent variable.

The variable we are changing is the time, therefore time is the independent variable.

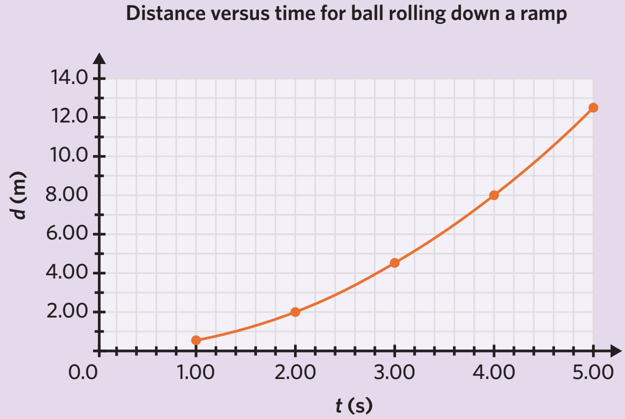
The variable we are measuring is the distance the ball rolls, therefore distance is the dependent variable

Step 2

Plot the data from the table with the independent variable on the horizontal axis and the dependent variable on the vertical axis.

Remember to label the axes and title the graph.

Note: a non-linear line of best fit has been added to see the relationship. This will be covered later in the lesson.



b. Linearise the data and plot a graph to show that $d \propto t^2$.

Step 1

Identify the transformation required to linearise the data.

As our original graph has a quadratic relationship, we can transform our time values by raising them to the power of two.

Step 2

Calculate the values of t^2.

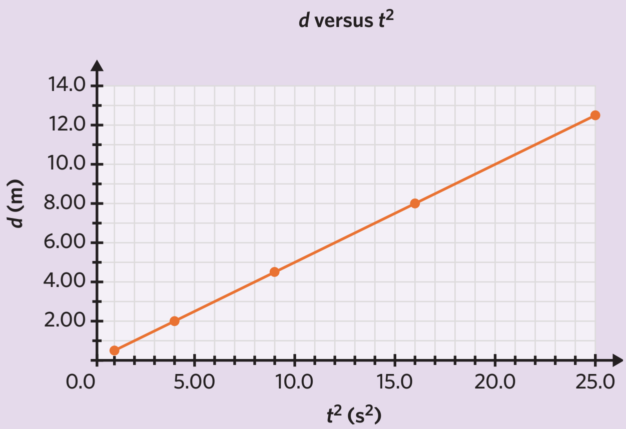
Note that the units undergo the same transformation.

Time, t^2 (s^2)	Distance, d (m)
1.00	0.50
4.00	2.00
9.00	4.50
16.0	8.00
25.0	12.5

Step 3

Plot the data from the table with the transformed independent variable on the horizontal axis and the dependent variable on the vertical.

Remember to label the axes and title the graph.



Since d vs t^2 has a linear relationship, $d \propto t^2$

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Progress questions

Question 3

Physicists have determined that the power (P) dissipated in a resistor of fixed resistance (R), as the voltage (V) across the resistor is varied, can be calculated using the formula $P = \frac{V^2}{R}$. A student is testing this theory and wants to linearise their data. Which of the following would describe the linear relationship?

A. P vs V

B. P^2 vs V^2

C. P vs V^2

D. $\sqrt{P}$ vs V^2

Drawing linear and non-linear lines of best fit 2.3.9.4

Linear lines of best fit and non-linear lines of best fit are straight and curved lines respectively that indicate the relationship between the independent and dependent variables on a graph.

Theory and applications

We can draw lines of best fit to visualise a correlation between our variables. Lines of best fit can later be used to solve for unknown variables in physics equations.

How do we draw linear and non-linear lines of best fit?

Lines of best fit must meet the following requirements:

- pass through the uncertainty bars of all points (though it does not need to pass through the specific data point),
- be smooth: not be forced to change direction in order to pass through all points,
- not be forced to pass through the origin,
- not be forced to pass through the first and/or last point (or any point on the graph), and
- not extend significantly beyond the region of the points.

This ensures that all data points are treated as equally important.

If a straight line cannot be drawn so that it passes through all the uncertainty bars, there cannot be a linear line of best fit, so the trend would be better represented by a non-linear line of best fit, see Figure 3. It is also possible that the uncertainty is too great or the spread of data is too small to establish the true relationship.

Progress questions

Question 4

If no points in a data set are outliers, lines of best fit don't have to pass through every uncertainty bar on the graph. Is this statement true or false?

A. True

B. False

Continues →

USEFUL TIP

If we expect our graph to pass through the origin and our trendline does not, this is an indication of systematic error.

USEFUL TIP

If a point or points in the data have experienced significant random error, they can become outliers and should be disregarded when plotting data and drawing trendlines.

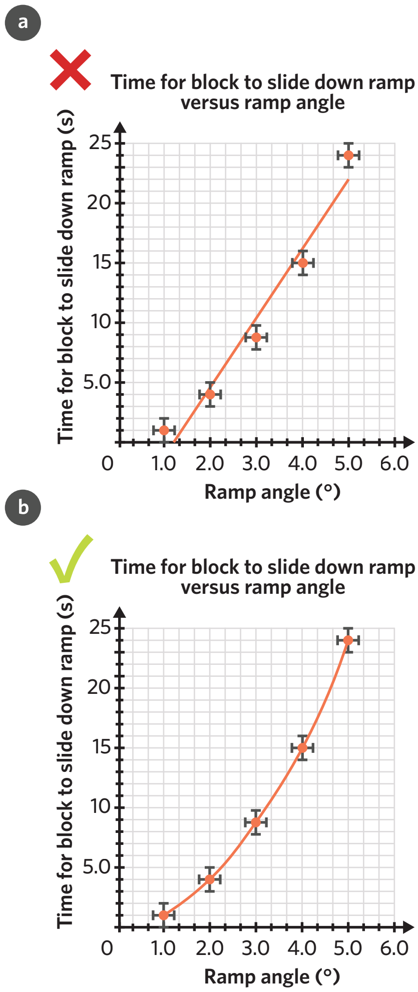

Figure 3 **(a)** An invalid linear line of best fit and **(b)** valid non-linear line of best fit

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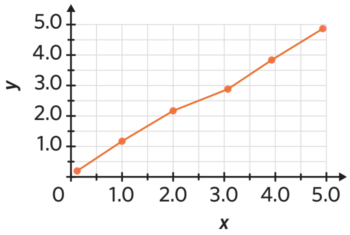
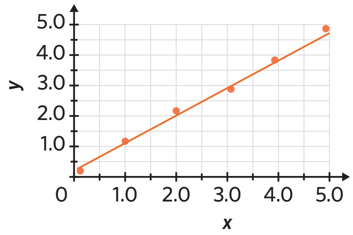
Question 5

Which graph has the correct line of best fit?

A.



B.



Theory summary

- Independent variables are plotted on the horizontal axis and dependent variables on the vertical axis.
- Graphs should have a title and labelled axes, with units.
- The scale of the graph should be consistent and chosen so that the data points take up the majority of the graph space.
- Linear and non-linear lines of best fit should be smooth and pass through the uncertainty bars of all points.
  - They should not be forced to go through any point, including the origin.

11D Questions

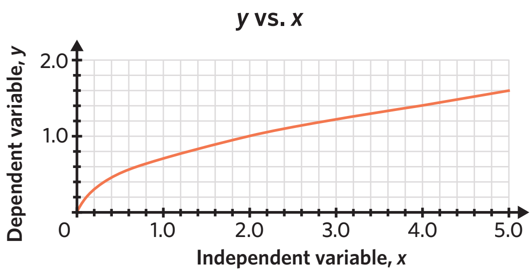
Mild Medium Spicy

Exam-style

Question 6 (1 MARK)

Nat collects data in an experiment. When she plots it, the data has a non-linear line of best fit that looks like the square root graph pictured.

If Nat wants to linearise her data, what transformation should she do to the independent variable?



Question 7 (5 MARKS)

Fatima is running on a track that has a marking every 10 m. Her friend records the time in seconds that it takes her to run 100 metres, noting roughly the time it takes for her to pass each 10 m mark on the track.

Draw a graph of this data with uncertainty bars and a linear or non-linear line of best fit as appropriate.

Distance, *d* (m)	Time, *t* (±1 s)
10	2
20	4
30	7
40	11
50	14
60	18
70	23
80	28
90	34
100	41

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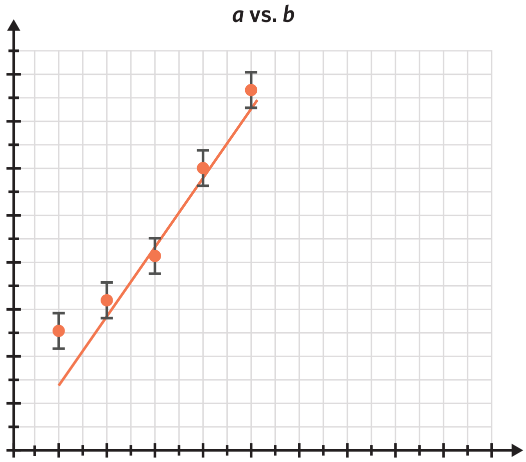
Question 8 (4 MARKS)

The following graph of variable *a* and variable *b* is plotted with a line of best fit. Identify the errors made and explain how they could be improved.

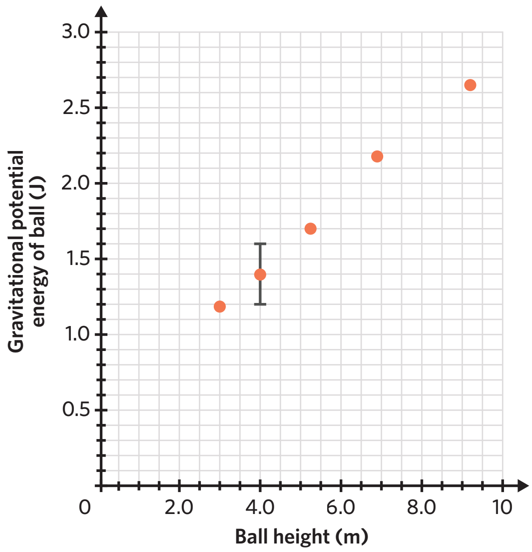


Question 9 (3 MARKS)

A student is plotting a graph of the gravitational potential energy of a ball versus the height it is lifted above the ground. The uncertainty in measuring the height is negligible and the constant uncertainty in measuring the gravitational potential energy is indicated on one graphed data point.

Can this graph have a line of best fit? Describe the steps that must be taken to determine if this graph can have a line of best fit.

Adapted from VCAA Sample 2017 Exam Short answer Q17f



Question 10 (5 MARKS)

Duncan and Arushi are studying the radioactive decay of phosphorus-32. They record the data shown in the table.

Time elapsed (days)	Uncertainty in time (days)	Phosphorus-32 mass (g)	Uncertainty in phosphorus-23 mass (g)
0	±1	100	±5
11	±1	60.0	±5
27	±1	28.0	±5
52	±1	8.00	±5

Using this data:

- Plot a graph of the phosphorus-32 mass versus the time elapsed.
- Include uncertainty bars for each data point.
- Draw a non-linear line of best fit.
- Include appropriate labels and scales for both axes.

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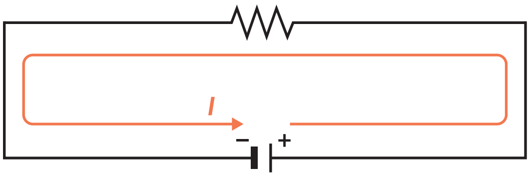
Question 11 (12 MARKS)

Maneesha studies the current, I, passing through a resistor of resistance, R, in a circuit connected to a 1.5 V AA battery. Maneesha believes that $I \propto \frac{1}{R}$.



Resistance, R (Ω)	Uncertainty in resistance, R (Ω)	Current, I (A)	Uncertainty in current, I (A)
0.50	±0.05	3.0	±0.1
1.00	±0.05	1.5	±0.1
1.50	±0.05	1.0	±0.1
2.00	±0.05	0.8	±0.1
2.50	±0.05	0.6	±0.1
3.00	±0.05	0.5	±0.1

a. Plot a graph of the data recorded in the table above. Include uncertainty bars and a non-linear line of best fit as appropriate. (5 MARKS)

b. Calculate the values of $\frac{1}{R}$ and hence plot the graph of I versus $\frac{1}{R}$. Include vertical uncertainty bars (horizontal uncertainty bars are not required), and include a line of best fit as appropriate. (6 MARKS)

c. Is Maneesha's hypothesis that $I \propto \frac{1}{R}$ supported by her experimental data? (1 MARK)

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11E Gradients

STUDY DESIGN DOT POINT

- evaluate methods of organising, analysing and evaluating primary data to identify patterns and relationships including scientific error, causes of uncertainty, and limitations of data, methodologies and methods

11A 11B 11C 11D 11E

2.3.9.5 & 2.3.9.6 Calculating the gradient

FORMULAS

- gradient of a straight line
  $gradient = \frac{y_2 - y_1}{x_2 - x_1} = \frac{\Delta y}{\Delta x}$

How can we derive the value of physics constants?

The gradient of data with a linear relationship is often a significant value which represents the constant rate of change between the two quantities being analysed. This lesson explains how to correctly calculate the gradient from experimental data, and how to interpret the physical meaning of a gradient.

KEY TERMS AND DEFINITIONS

gradient the graphical representation of the rate of change of one variable with respect to another

Calculating the gradient 2.3.9.5 & 2.3.9.6

On a graph, the gradient (or slope) is the ratio of the change in the variable on the vertical axis to the change in the variable on the horizontal axis.

Theory and applications

A gradient is a rate of change.

- A positive gradient means that, when the independent variable increases, the dependent variable also increases.
- A negative gradient means that, when the independent variable increases, the dependent variable decreases.
- The greater the magnitude of the gradient, the more the dependent variable will increase (or decrease) per unit increase in the independent variable.

How do we calculate gradients?

We can calculate the gradient of a straight line from two points on the line.

FORMULA

$$gradient = \frac{y_2 - y_1}{x_2 - x_1} = \frac{\Delta y}{\Delta x}$$

(x_1, y_1) = a point on the line of best fit

(x_2, y_2) = another point on the line of best fit

USEFUL TIP

If it is known that the line passes through the origin, then the gradient is equivalent to the vertical axis variable divided by the horizontal axis variable $\left(gradient = \frac{y}{x}\right)$. Not all lines will pass through the origin so it is important to check before taking this approach.

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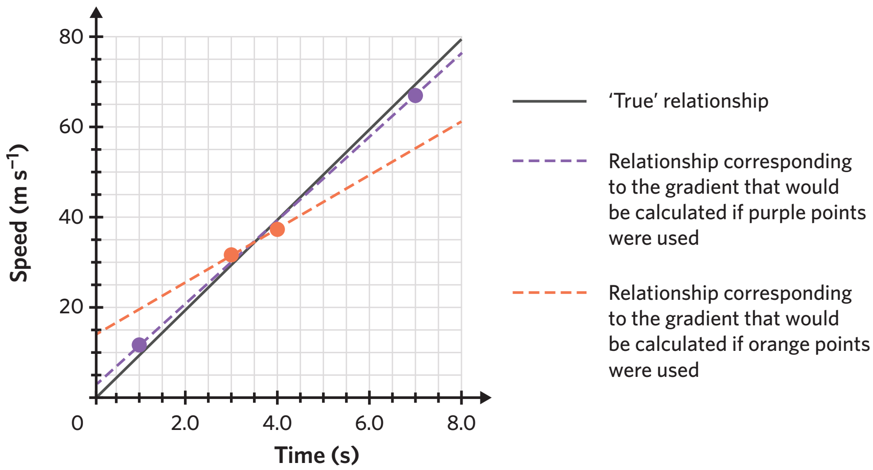


Figure 1 Using two points close together can lead to errors in calculation of gradient.

There are some important points to emphasise for calculating the gradient of a line of best fit:

- We should choose coordinates that are relatively far apart. This reduces the effect of any random errors that we make when reading the points from the graph, which improves the accuracy of the gradient calculation.
  - Consider Figure 1, the orange and purple data points have the same error when compared to the 'true' values, but the gradient that would be calculated using the purple data points is more accurate than the gradient that would be calculated using the orange data points.
- We should ignore the measured data points and use only points that are on the line of best fit.
- Check the scale on each axis and apply a scale factor if applicable.
- The units of the gradient are given by $\frac{\textit{units on vertical axis}}{\textit{units on horizontal axis}}$.

USEFUL TIP

The change in the vertical axis values $(y_2 - y_1)$ is often called the 'rise' and the change in the horizontal axis values $(x_2 - x_1)$ is often called the 'run'. We can remember that the gradient is equal to rise over run, $\frac{rise}{run}$.

Straight line graphs have a constant gradient, which means that the dependent variable (on the vertical axis) will increase or decrease by a fixed amount for every unit increase in the independent variable (on the horizontal axis).

- Consider Figure 2, which shows the speed of an object that has been released from rest. The object's speed increases by a fixed amount, 9.8 m s^{-1}, for each second that passes.
- This means the gradient is 9.8 m s^{-2} $\left(\frac{9.8 \text{ m s}^{-1}}{1 \text{ s}}\right)$. So when the time increases by 5.0 seconds, the speed increases by $5.0 \times 9.8 = 49$ m s^{-1}.

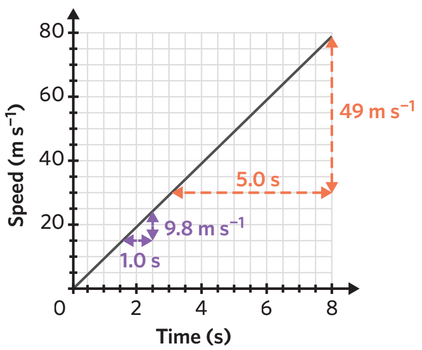
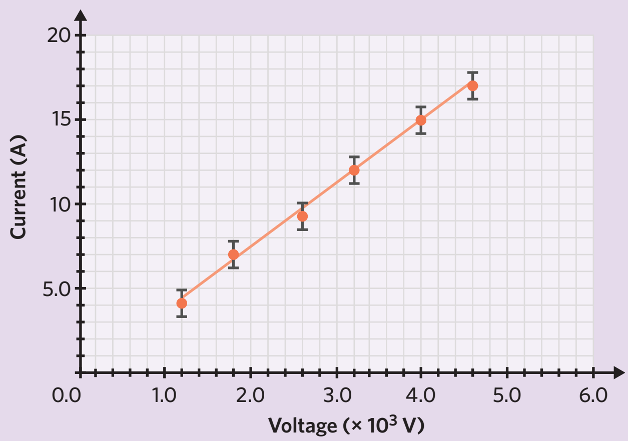


Figure 2 Speed vs time graph for an object in free fall without air resistance

WORKED EXAMPLE 1

Find the gradient of this current versus voltage graph.



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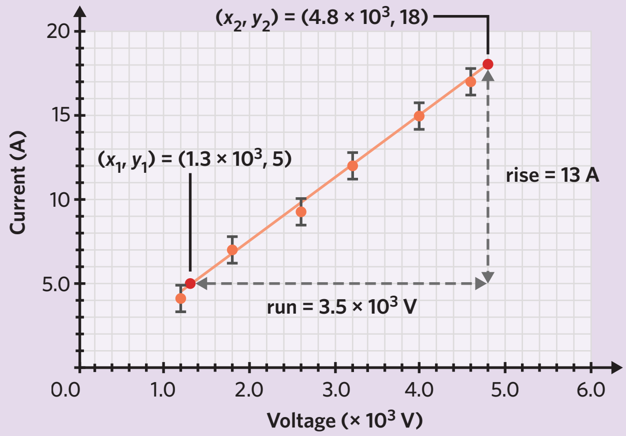
Step 1

Identify two points on the line of best fit that are relatively far apart and the equation that relates these points.



$$gradient = \frac{y_2 - y_1}{x_2 - x_1}$$

Step 2

Calculate the gradient and corresponding units, remembering to include the scale factor on the horizontal axis.

$$gradient = \frac{18 - 5.0}{(4.8 - 1.3) \times 10^3} = \frac{13\text{ A}}{3.5 \times 10^3\text{ V}}$$

$$gradient = 3.71 \times 10^{-3} = 3.7 \times 10^{-3}\text{ A V}^{-1}$$

Progress questions

Question 1

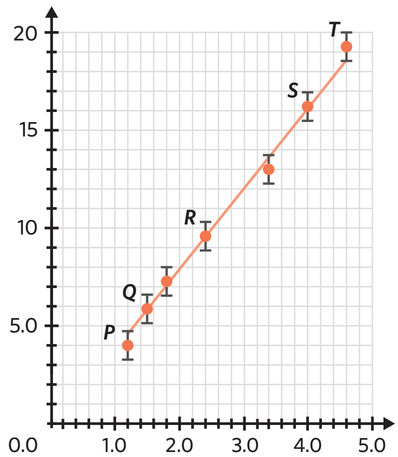
Which two data points from those identified on the graph (*P*, *Q*, *R*, *S*, and *T*) would be the best choice to calculate the gradient of the line of best fit?

A. *Q* and *S*

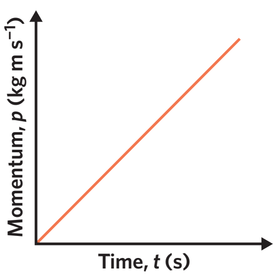
B. *P* and *T*

C. *R* and *S*

D. *Q* and *R*



Use the following graph to answer questions 2 and 3.



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Question 2

Which of the following expressions does the gradient of this graph represent?

A. $\Delta p \times \Delta t$

B. $p + t$

C. $\frac{t}{p}$

D. $\frac{\Delta p}{\Delta t}$

Question 3

Which of the following units should be used for the gradient of this graph?

A. kg m s^{-2}

B. kg

C. kg s

D. kg m

USEFUL TIP

It is common for an exam question to ask us to use the gradient from a line of best fit to determine the experimental value of a known constant. It is important that we do use the gradient of the line of best fit for the experimental data in these cases, rather than the known value.

How do we analyse the gradient of a graph?

We can determine the physical meaning of a gradient from an equation relating the dependent and independent variable and the context of the physical situation. Equations for linear lines of best fit follow the form $y = mx + c$, where m is the gradient and c is a constant.

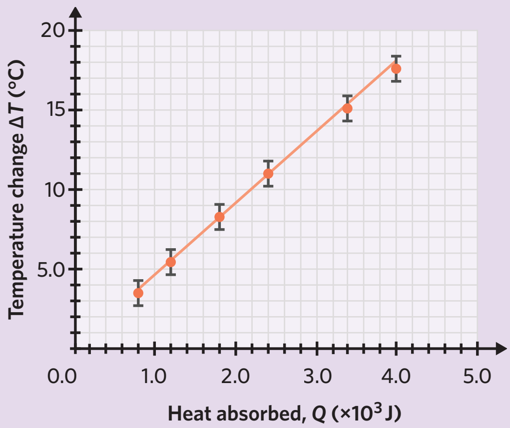
- From Figure 2, $gradient = \frac{change\ in\ speed}{change\ in\ time} = \frac{\Delta v}{\Delta t}$.
- In Lesson 8A, we see how the magnitude of acceleration is given by $a = \frac{\Delta v}{\Delta t}$.
- Therefore, we can conclude that the gradient in Figure 2 is equal to the magnitude of acceleration.

WORKED EXAMPLE 2

The change in temperature, ΔT (measured in degrees celsius, °C), of an object that absorbs some heat, Q (measured in joules, J), can be calculated from the equation $\Delta T = \frac{Q}{mc}$, where m is the mass of the object in kilograms and c is the specific heat capacity of the object, measured in J kg^{-1} °C^{-1}.

Scientists undertake an experiment where they measure the temperature change of an object with a mass of 2.0 kg as it is heated. They plot the data for ΔT against Q and draw a line of best fit as shown. The line of best fit has a gradient of 4.5×10^{-3} °C J^{-1}.

Use the gradient to calculate the value of the specific heat capacity, c.



Step 1

Identify the gradient of the given graph, its relationship to the variables on the axes and the equation that relates these variables.

$gradient = 4.5 \times 10^{-3}$ °C J^{-1}

$gradient = \frac{vertical\ axis\ variable}{horizontal\ axis\ variable} = \frac{\Delta T}{Q}$

$\Delta T = \frac{Q}{mc}$

Continues →

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Step 2

Rearrange the known equation for $\frac{\Delta T}{Q}$.

Rearranging $\Delta T = \frac{Q}{mc}$ gives $\frac{\Delta T}{Q} = \frac{1}{mc}$

Step 3

Identify the mass, specific heat capacity, gradient and the equation that relates them.

$m = 2.0$ kg, $\frac{\Delta T}{Q} = 4.5 \times 10^{-3}$ °C J^{-1}, $c = ?$

$\frac{\Delta T}{Q} = \frac{1}{mc}$

Step 4

Substitute known values and solve for the specific heat capacity.

(Note, due to the uncertainty bars of each point, there are a range of possible lines of best fit which could be used with a range of gradients. Hence, there are a range of possible values for *c*.)

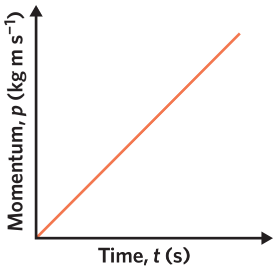
$4.5 \times 10^{-3} = \frac{1}{2.0 \times c}$

$c = \frac{1}{2.0 \times 4.5 \times 10^{-3}} = 111 = 1.1 \times 10^{2}$ J kg^{-1} °C^{-1}

Progress questions

Question 4

It is known that $\Delta p = F\Delta t$, where F is the force acting on the object being measured. Determine which of the following expressions the gradient of the graph also represents.



A. F

B. $\frac{1}{F}$

C. $\frac{F}{\Delta t}$

D. $\frac{F}{\Delta p}$

Question 5

It is known that $F = -k\Delta x$, where k is the spring constant. In an experiment, Leo extends a spring by different distances, x, and measures the force, F, the spring applies back. Force is the dependent variable and plotted on the vertical axis. What does the gradient of the line of best fit represent?

A. $-k$

B. $-\frac{1}{k}$

Theory summary

- A gradient is the rate of change between two variables.
- Gradients can be calculated by finding two points on the line of best fit and substituting them into the formula: $gradient = \frac{y_2 - y_1}{x_2 - x_1}$.
  – Points should be chosen that are far apart on the line.
- By dividing the variables of the vertical axis by those of the horizontal axis, we can determine what the gradient represents.

11E Questions

Mild Medium Spicy

Exam-style

Question 6 (2 MARKS)

A graph has the points (0.50, 8.3) and (4.6, 2.1). Calculate the gradient of a linear line between these two points.

Question 7 (2 MARK)

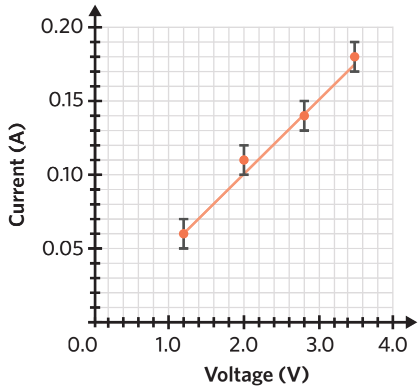
A linear line of best fit passes through the point (2.9, 7.6). If the line also passes through the origin, what is the gradient of the line?

Question 8 (4 MARKS)

Students measure the electric current passing through a particular device with a constant electrical resistance when different voltages are connected across the device. For a device with a constant electrical resistance, it is known that $I = \frac{V}{R}$ where I is the current measured in amps (A), V is the voltage measured in volts (V), and R is the resistance measured in ohms.

The data is plotted on a graph with voltage on the horizontal axis and current on the vertical axis. A line of best fit is drawn through the data as shown.

Use the gradient of the line of best fit to calculate the experimentally determined resistance of the device, R.



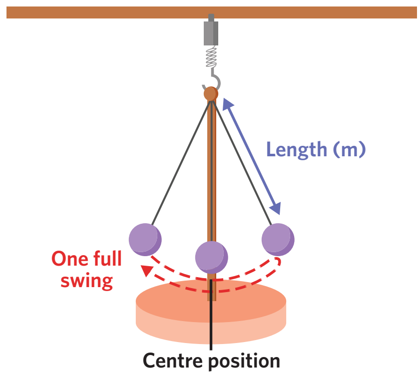
Question 9 (4 MARKS)

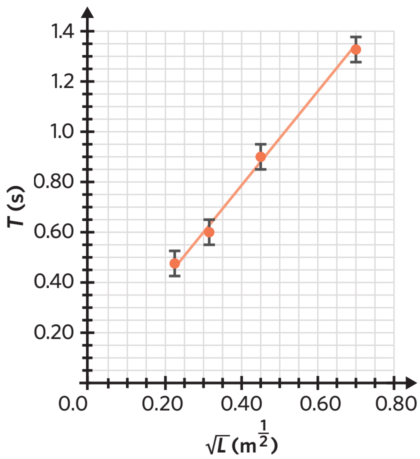
Students conduct an experiment in which they measure the period (the time taken to complete one full swing and return to the same position) of a pendulum of varying lengths.

It is known that the relationship between the length of a pendulum, L (measured in metres, m), and its period, T (measured in seconds, s), is approximated by $T = 2\pi\sqrt{\frac{L}{g}}$, where g is the magnitude of the acceleration due to gravity (m s^{-2}).

The students plot T against $\sqrt{L}$ to obtain a line of best fit. The uncertainty in the period measurements is ± 0.5 seconds. Note that the lengths are measured to a high level of confidence.

Use the line of best fit to calculate the magnitude of the acceleration due to gravity.

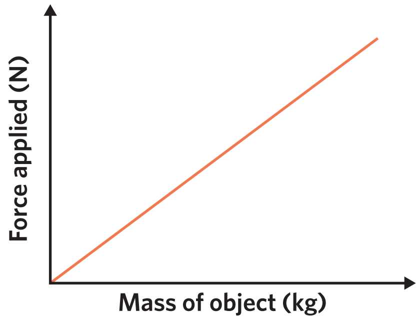




Question 10 (3 MARKS)

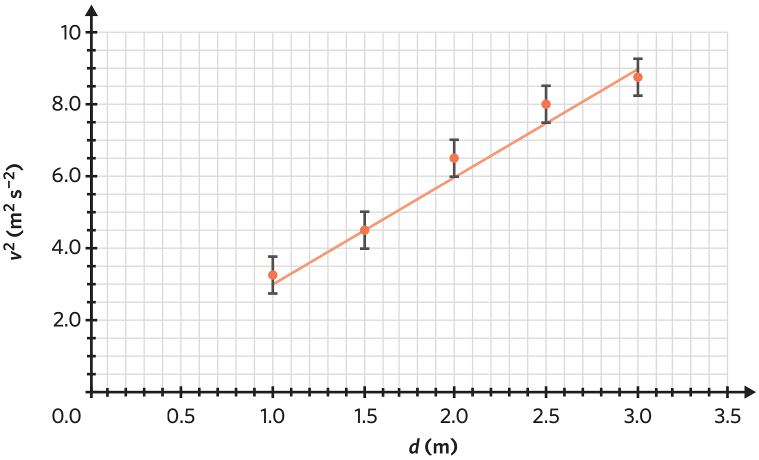
It is known that $F = mg$ where F is the force applied, m is the mass of an object, and g is the acceleration due to gravity. A student plots the following graph of the data they collected in an experiment.

The student says that the acceleration due to gravity is changing because the gradient of the graph is not a horizontal line. Is this student correct? Explain your answer.



Question 11 (4 MARKS)

A cart starts from rest and accelerates at a constant rate in a straight line. Its speed is measured at particular distances from its starting position. It is known that the speed, v (m s^{-1}), relates to the distance travelled, d (m), by the equation $v^2 = 2ad$, where a is the magnitude of the acceleration (m s^{-2}).



The data is plotted on a graph with d on the horizontal axis and v^2 on the vertical axis. A line of best fit is drawn through the data as shown.

a. Calculate the gradient of the line of best fit. (2 MARKS)

b. Use the gradient of the line of best fit to calculate the value of a determined in this experiment. (2 MARKS)

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Chapter 11 review

Mild Medium Spicy

These questions are typical of 40 minutes worth of questions on the VCE Physics Exam.

Total marks: 30

Section A

All questions in this section are worth one mark.

Unless otherwise indicated, the diagrams in this book are not drawn to scale.

Question 1

A model is best described as

A. a prediction that can be tested through experimentation.

B. only useful as a teaching tool.

C. a representation of a physical process that cannot be directly experienced.

D. an explanation of a physical phenomenon that has been repeatedly confirmed by experimental evidence and observation.

Question 2

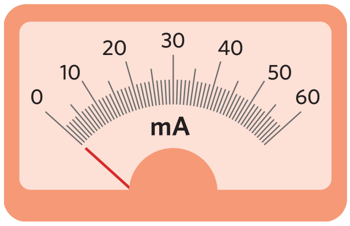
What is the resolution of this ammeter?

A. 0.5 mA

B. 1 mA

C. 5 mA

D. 10 mA



Question 3

According to the rules of significant figures and decimal places, determine which of the following is the correct value of the expression: $5.124 \times 10^{10} - 1.2 \times 10^{9}$.

A. 3.9×10^{10}

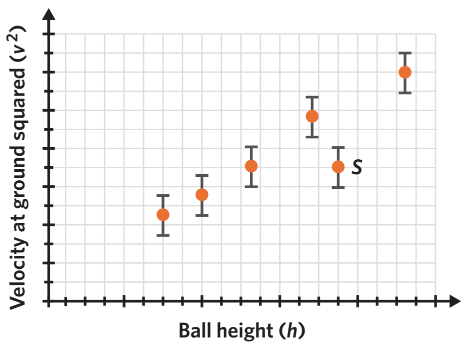
B. 5.00×10^{10}

C. 5.004×10^{10}

D. 3.92×10^{10}

Use the following information to answer questions 4 and 5.

Mike is conducting an experiment relating the height a ball is dropped from to its velocity when it reaches the ground. He collects his data using valid methods and plots the following graph.



Question 4

Mike's plot has one data point, *S*, that prevents him from drawing a line of best fit for his data. Mike remembers that when he was recording the time for that data point he got distracted by a classmate and made his measurement after the ball had bounced off of the ground. Select Mike's best choice in how to treat point *S* as he attempts to draw a line of best fit:

A. Draw a line of best fit for the other data but leave point *S* on the graph.

B. Draw a line from the centre of each point to the next, including point *S*.

C. Discard all of his data and repeat the experiment as the presence of irregular data, such as point *S*, proves that the rest of the data is unreliable.

D. Disregard point *S* and remove it from the graph, then draw a line of best fit through the remaining data.

Question 5

We can relate the height an object is released from, h, to its velocity squared at the ground, v^2, through the equation $gh = \frac{1}{2}v^2$ where g is the acceleration due to gravity. Assuming that a line of best fit is valid, determine what the gradient of this line would represent.

A. $2g$, twice the acceleration due to gravity

B. g, the acceleration due to gravity

C. t, the time the ball would take to fall

D. h, the original height the ball was dropped from

Section B

In questions where more than one mark is available, appropriate working must be shown.

Unless otherwise indicated, the diagrams in this book are not drawn to scale.

Question 6 (5 MARKS)

A team of scientists have been employed by Big Smoke Ltd., the world's largest fictional cigarette company, to determine the effects of smoking cigarettes on beard growth. After their first meeting the scientists return with a statement about the experiment they will perform, stating:

"We expect that increased smoking of cigarettes will have a negligible effect on the growth of a beard but may have consequences for the chemical makeup of the beard's hair follicles."

a. Is this statement an example of a scientific model, theory, or hypothesis? Justify your answer. (2 MARKS)

b. After the experiment was conducted the scientists concluded:

"Smoking cigarettes had a positive effect on both the growth and health of beards."

However, a news report on the study revealed that the scientists were given $10 000 each if their experiment produced results supporting the idea that smoking has positive outcomes for beard growth.

Using this information, comment on the validity of the study. (3 MARKS)

Question 7 (6 MARKS)

Enya is doing a set of experiments to measure the force due to gravity on a selection of household objects: a 4.0 kg pot plant, an 8.0 kg record-player, a 10 kg space heater, and a 14 kg humidifier. She wants to determine if the acceleration due to gravity is different in her apartment compared to the accepted value. It is known that the force due to gravity is related to mass by the equation $F_g = mg$, where F_g is the force due to gravity, m is the mass, and g is the acceleration due to gravity.

a. Identify one type of data Enya is collecting by performing this experiment. (1 MARK)

b. In her first attempt to perform this experiment, all of Enya's data was 50% higher than the values she would have obtained if she had performed her experiment without error. Identify the type of error present in Enya's first attempt. (1 MARK)

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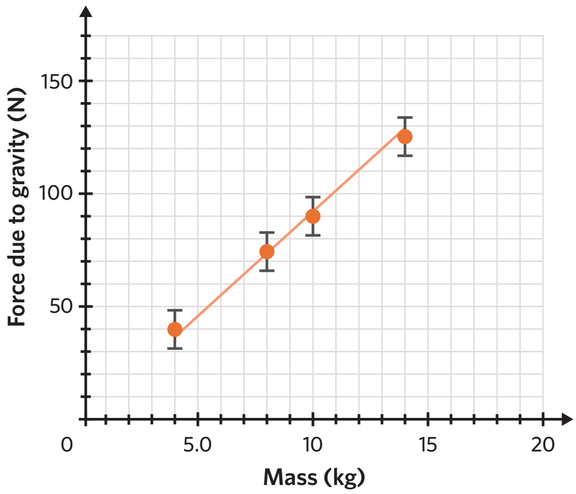
c. The provided graph represents Enya's second attempt at performing this experiment. She now obtains results much closer to her prediction.

Use the graph to determine the experimental value of g. (2 MARKS)



d. After Enya posts on social media about her discovery that the value of g cannot be the accepted value (in her location) of 9.8 m s^{-2}, an interested group of scientists analyse her results and try to repeat the experiment. However, using the same method and test material they get the result: $g = 9.79 \pm 0.05$ N kg^{-1}. Comment on the reproducibility of Enya's experiment. (2 MARKS)

Question 8 (14 MARKS)

Cathal wants to determine the amount of energy it takes to heat samples of metal from room temperature (22°C) to 300°C. He has five different masses of scrap metal starting at 100 g and increasing in mass by 50 g increments up to 300 g. He heats each sample to 300°C three times, waiting for it to cool back to 22°C before attempting to heat it again. Cathal uses the same bunsen burner to heat each sample and records the total amount of energy it requires.

a. Identify the independent and dependent variables, and one controlled variable in this experiment. (3 MARKS)

Cathal records the following table of data.

Mass of metal sample (g)	Energy required (× 10^3 J, ±1.0 × 10^3)			
	1st attempt	2nd attempt	3rd attempt	Average
100	12.0	11.0	13.0	12.0
150	19.0	19.0	18.0	18.7
200	25.0	24.0	24.0	24.3
250	31.0	32.0	30.0	31.0
300	37.0	35.0	39.0	37.0

b. Comment on the repeatability of Cathal's experiment and suggest one way to improve its repeatability. (2 MARKS)

c. On a set of axes:

- Plot a graph of metal average energy used against sample mass.
- Include uncertainty bars for each data point.
- Draw a line of best fit.
- Include appropriate scales, labels, and units for both axes. (6 MARKS)

d. Considering that the theoretical value for the energy required to heat the 100 g sample is 12.4×10^3 J and the 150 g sample is 18.5×10^3 J, compare the accuracy and precision of Cathal's sets of measurements for these masses. (3 MARKS)

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ESSENTIAL PRIOR KNOWLEDGE

Questions and answers

These questions are designed to quickly break down any misconceptions and alert us to any knowledge that is ‘essential’ to understanding the coming lesson’s content. There is one question for each essential prior knowledge dot point on the lesson’s first page.

Image: New Africa/Shutterstock.com

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Essential prior knowledge questions

1B Wave fundamentals

Question 1

Which of the following is the definition of a wave?

A. The transfer of energy from one place to another through oscillations of particles.

B. The movement of matter from one place to another through a random path.

Question 2

Light is an electromagnetic transverse wave and sound is a mechanical longitudinal wave.

A. True

B. False

Question 3

To convert from nanometres (nm) to metres (m)

A. multiply by 10^6.

B. multiply by 10^9.

1C Everyday electromagnetism

Question 4

Electromagnetic waves are also known as

A. light.

B. water waves.

Question 5

Frequency is the number of wave cycles completed per unit of time and wavelength is the distance covered by one complete wave cycle.

A. True

B. False

1D Refraction and reflection

Question 6

How fast does light travel in a vacuum?

A. Light cannot travel in a vacuum.

B. 3×10^8 m s^{-1}

Question 7

Which of the following could be classified as an electromagnetic wave?

A. light

B. ocean waves

Question 8

Which of the following properties do waves possess?

A. speed (m s^{-1}), frequency (Hz), and wavelength (m)

B. mass (kg), time (s), and force (N)

Question 9

What is the value of θ in the following equation?

$\sin(\theta) = \frac{3}{4}$

A. 1.31°

B. 48.6°

1E White light and optical phenomena

Question 10

What two regions of the electromagnetic spectrum are directly next to the visual region of the spectrum?

A. ultraviolet and infrared

B. microwave and radiowave

C. infrared and X-ray

Question 11

When a ray of light travels from a medium with a higher refractive index to a lower refractive index, it bends

A. away from the normal.

B. towards the normal.

Question 12

Total internal reflection means that

A. most of the light incident on the boundary is reflected.

B. all the light incident on the boundary is reflected.

2B How thermal energy moves

Question 13

Electromagnetic waves require a medium to travel through. Is this statement true or false?

A. True

B. False

Question 14

The internal energy of a system is made up of potential energy and which other energies?

A. translational kinetic energy

B. rotational kinetic energy

C. vibrational kinetic energy

D. All of the above

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2C How heat affects temperature

Question 15

An increase in temperature of one degree celsius is equivalent to an increase of

A. 274.15 K.

B. 1 K.

Question 16

Conduction is the transfer of heat via

A. electromagnetic waves.

B. movement of molecules in fluids.

C. contact between objects.

3A Thermal radiation

Question 17

How can the electromagnetic spectrum be best described?

A. the range of all electromagnetic waves ordered by frequency and wavelength

B. the portion of light visible to the human eye

Question 18

Which of the following emits thermal radiation?

A. only objects with a temperature greater than 0°C

B. all objects with a temperature greater than 0 K

Question 19

Which of the following is an example of an inversely proportional relationship?

A. As the frequency of a wave doubles, the period of the wave cycle halves.

B. As the radius of a circle doubles, the circumference of the circle doubles.

3B Global warming and climate change

Question 20

Which of the following is not an example of a method of heat transfer?

A. conduction

B. convection

C. reflection

D. radiation

Question 21

Water is absorbing thermal energy but is not increasing in temperature. Which of the following is the best reason for this?

A. The energy is being used to change the state of matter.

B. The energy is unable to be lost by the water when it is at 100°C.

Question 22

A hotter object when compared to a colder one will emit

A. a larger amount of energy as thermal radiation.

B. a smaller amount of energy as thermal radiation.

4B Nuclear half-life

Question 23

When a nucleus decays, does it become more or less stable?

A. more

B. less

Question 24

Which of the following will always eventually undergo radioactive decay?

A. an isotope

B. a radioisotope

Question 25

Which of the following represents the statement: $\frac{1}{32}$?

A. $\left(\frac{1}{2}\right)^5$

B. $\frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2}$

C. Both of the above

4C Types of nuclear radiation

Question 26

Why do some atoms undergo radioactive decay?

A. as they are unstable

B. as they have an unbalanced charge

Question 27

What are the charges of protons and neutrons, respectively?

A. Both are positively charged.

B. Protons are not charged, neutrons are positively charged.

C. Protons are positively charged, neutrons are not charged.

4D Radiation and the human body

Question 28

Which of the following has the greatest penetrating power?

A. alpha radiation

B. beta radiation

C. gamma radiation

Question 29

Which of the following has the greatest ionisation power?

A. alpha radiation

B. beta radiation

C. gamma radiation

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PRIOR KNOWLEDGE

5A Nuclear energy

Question 30

In atomic nuclei, what are the dominant forces and their roles?

A. strong force (attractive), electrostatic force (repulsive)

B. gravity (repulsive), magnetic (repulsive)

5B Fission

Question 31

How do the reactants and products of fission reactions compare to each other?

A. The reactants are small nuclei and energy, and the products are larger nuclei and protons.

B. The reactants are neutrons and a large nucleus, and the products are small nuclei and neutrons.

Question 32

The surface area of a shape is

A. the total area on the surface or faces of the shape.

B. the amount of area it occupies in physical space.

6A Fundamentals of electricity

Question 33

The electrostatic force

A. repels like charges and attracts opposite charges.

B. attracts like charges and has no effect on opposite charges.

6B Resistance and Ohm's Law

Question 34

Which of the following statements correctly describes current and voltage?

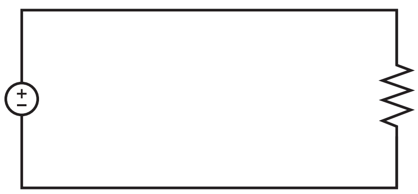
A. Current is the rate of flow of electric charge and voltage is the amount of potential energy per unit charge between two points.

B. Current is the movement of energy and voltage is how much energy is being moved.

6C Series circuits

Question 35

What circuit components are present in this circuit diagram?



A. voltage source, resistor and wires

B. light bulb and switch

Question 36

What is the formula for electric power in a circuit?

A. $P = IV$

B. $P = \frac{V}{I}$

Question 37

Ohm's Law tells us that, at a constant voltage,

A. current increases as resistance increases.

B. current decreases as resistance increases.

Question 38

Which of the following correctly describes a proportional relationship?

A. As the wavelength of an electromagnetic wave increases, the frequency decreases.

B. As the net force acting on an object increases, the acceleration of the object increases.

6D Parallel circuits

Question 39

The voltage delivered to a circuit component is dependent on the current flowing through it.

A. True

B. False

Question 40

A light bulb, which requires 10 A, glows when it is connected in series to a 5.0 voltage supply. What is the minimum power consumption of the light bulb?

A. 2.0 W

B. 50 W

Question 41

A circuit component with a low resistance is more difficult for current to flow through compared to one with a higher resistance.

A. True

B. False

Question 42

The voltage and current is measured in a circuit at two points: before and after a resistor. Which of the following statements is correct?

A. The voltage and current is the same at both points.

B. The voltage decreases between the two points, but the current remains the same.

C. The voltage is the same at both points, but the current decreases.

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6E Combination circuits

Question 43

In a series circuit, the sum of the voltage drops across the components is equal to the total voltage supplied.

A. True

B. False

Question 44

A simple circuit contains a single resistor with voltage drop of 2 V whilst 3 A of current flows through it. What is the power consumed by the resistor?

A. 6 J

B. 6 W

Question 45

Two identical components, connected in series, will experience the same voltage drop.

A. True

B. False

Question 46

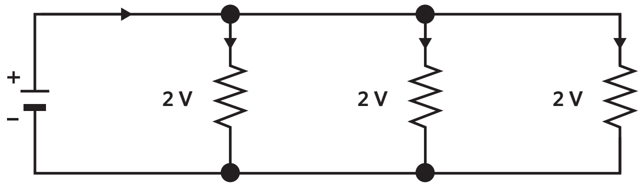
Current is identical at each point of a series circuit.

A. True

B. False

Question 47

A parallel circuit is composed of three resistors, each having a voltage drop of 2 V. What is the total voltage supply?



A. 2 V

B. 6 V

7A Applications of electric circuits

Question 48

Current is measured across a resistor and voltage is measured through a resistor.

A. True

B. False

Question 49

What is current flowing through a resistor with a resistance of 8.0 Ω and a voltage drop of 12 V?

A. 0.67 A

B. 1.5 A

C. 96 A

Question 50

What is the total equivalent resistance of three resistors, $R_1 = 2\ \Omega$, $R_2 = 4\ \Omega$ and $R_3 = 12\ \Omega$, connected in series?

A. 18 Ω

B. 1.2 Ω

7B Household electricity

Question 51

Voltage is a measure of

A. joules per second.

B. joules per coulomb.

C. coulombs per second.

Question 52

Current requires the physical movement of charge carriers.

A. True

B. False

Question 53

A resistor, with resistance $R = 30\ \Omega$, has a current $I = 3.0$ A flowing through it. What is the potential difference across the resistor?

A. 70 V

B. 90 V

Question 54

In a series circuit with multiple resistors of different resistances, the

A. voltage drop is the same across each resistor.

B. current is the same through each resistor.

Question 55

In a parallel circuit, increasing the number of branches increases the equivalent resistance of the circuit.

A. True

B. False

7C Electrical safety

Question 56

Which one of the following is an accurate description of an electric current?

A. protons flowing in a wire

B. electrons flowing in a wire

Question 57

In a series circuit, which one of the following does not change as current flows through one component to the next?

A. power

B. voltage

C. current

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Question 58

Which one of the following wires is responsible for carrying current towards an electrical component?

A. active wire

B. earth wire

C. neutral wire

Question 59

A DC voltage source provides a constant voltage supply to a circuit.

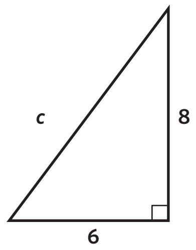
A. True

B. False

8A Describing motion

Question 60

What is the value of *c* in this triangle?

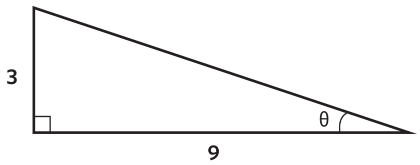


A. 10

B. 12

Question 61

What is the value of θ in this triangle?



A. 19°

B. 72°

8B Graphing motion

Question 62

Which of the following is a vector quantity?

A. 10 m

B. 10 m north

Question 63

If an object is accelerating then

A. its velocity is changing.

B. it is speeding up.

C. it is slowing down.

Question 64

Which of the following is the best description of the gradient of a linear graph between two points?

A. change in y-value divided by the change in x-value

B. change in x-value divided by the change in y-value

8C The constant acceleration equations

Question 65

A person throws a ball up in the air from a building, before it falls and hits the ground. Which of the following is true?

A. The displacement and distance travelled by the ball will be the same.

B. The distance travelled by the ball will be greater than the displacement.

Question 66

Which of the following objects has a greater magnitude of acceleration?

A. a car moving at a constant speed of 100 km h^{-1}

B. a plane braking as it lands on the runway

Question 67

What does the signed area below a velocity time graph represent?

A. distance travelled

B. displacement

9A Forces

Question 68

Which of the following is a vector quantity?

A. acceleration

B. mass

Question 69

Acceleration describes

A. how fast something is travelling.

B. the rate at which velocity is changing over time.

9B Momentum and impulse

Question 70

Velocity describes

A. only the speed of an object.

B. both the speed and direction of movement of an object.

Question 71

A net force will cause

A. an object to remain moving.

B. an acceleration, changing an object's motion.

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Question 72

If a hand pushes a ball to the right with a force of 50 N, what is the force that the ball will push the hand with?

A. 50 N to the left

B. 50 N to the right

9C Force vectors in two dimensions

Question 73

To describe a force, we need

A. its magnitude only.

B. its magnitude and direction.

Question 74

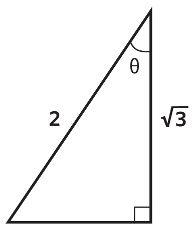
A car of mass 300 kg undergoes an acceleration of 2.50 m s^{-2}. What is the net force acting on the car?

A. 120 N

B. 750 N

Question 75

What is the value of θ in the triangle below?



A. 30°

B. 60°

Question 76

A right angle triangle has a side of length 3.0 cm, and another of length 8.0 cm. What is the length of the hypotenuse?

A. 8.5 cm

B. 9.7 cm

9D Inclined planes and connected bodies

Question 77

What is the magnitude of the force due to gravity acting on a golf ball, which has mass 0.50 kg?

A. 19.6 N

B. 4.9 N

Question 78

Newton's second law of motion states that, for a given force

A. the acceleration of an object is proportional to its mass.

B. the acceleration of an object is inversely proportional to its mass.

Question 79

A force of magnitude 60 N is acting at an angle of 30° to the horizontal. What is the vertical component of the force?

A. 30 N

B. 52 N

9E Torque

Question 80

A 50 N force to the right is applied to an object, and a 30 N force to the left. What is the magnitude of the net force acting on the object?

A. 20 N

B. 80 N

Question 81

A 100 N force is applied at 30° to the horizontal. What is the component of the force perpendicular to the horizontal?

A. 50 N

B. 68 N

9F Equilibrium

Question 82

A force of magnitude 12 N acts at a 30° angle to the horizontal. What is the horizontal component of the force?

A. 6.0 N

B. 10 N

Question 83

A force of magnitude 8.2 N acts at a perpendicular distance of 3.6 m from a pivot point. What is the magnitude of the torque applied?

A. 3.6 N m

B. 8.2 N m

C. 30 N m

10B Work and gravitational potential energy

Question 84

How is the force due to gravity acting on an object found?

A. $F = mg$

B. $F = m \times 9.8$

Question 85

A 50 N force is applied at an angle 40 degrees to the horizontal. How is the horizontal component of the force calculated?

A. $F_h = 50 \times \cos(40°)$

B. $F_h = 50 \times \sin(40°)$

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Question 86

A tennis ball, of mass 0.50 kg, is travelling at 45 m s^{-1}. What is its kinetic energy?

A. 5.0×10^2 J

B. 1.0×10^3 J

Question 87

The law of conservation of energy states that

A. energy is not always conserved.

B. energy must always be conserved in a closed system.

10C Springs

Question 88

What is the magnitude of the force due to gravity acting on a 200 kg car?

A. 200 N

B. 1960 N

Question 89

A car rolls down a hill and loses gravitational potential energy. What happens to the total energy of the car?

A. remains constant

B. decreases with gravitational potential energy

Question 90

If the velocity of a car doubles how would its kinetic energy change?

A. double

B. quadruple

Question 91

How do we know when an object has zero gravitational potential energy?

A. By convention we say that the lowest point in our system is the location of zero gravitational potential energy.

B. When the object is resting on the floor.

Question 92

Which of the following is an accurate definition of work?

A. The amount of force it requires to move an object one metre.

B. The change in mechanical energy of an object.

10D Applications of motion: case study

Question 93

Which equation would be most appropriate to use to find out the distance that a car travels in 20 s, given that it is not accelerating?

A. $v^2 = u^2 + 2as$

B. $s = vt$

Question 94

Which of the following statements about impulse is correct?

A. Objects in a collision experience the same impulse but in opposite directions.

B. Impulse is a scalar quantity.

Question 95

Which of the following is the equation for kinetic energy of an object?

A. $KE = \frac{1}{2}mv^2$

B. $KE = \frac{1}{2}k(\Delta x)^2$

11D Representing and analysing data

Question 96

The variable that is expected to be affected by the independent variable in an experiment is the

A. controlled variable.

B. dependent variable.

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Essential prior knowledge answers

1B	1. A	2. A	3. B		
1C	4. A	5. A			
1D	6. B	7. A	8. A	9. B	
1E	10. A	11. A	12. B		
2B	13. B	14. D			
2C	15. B	16. C			
3A	17. A	18. B	19. A		
3B	20. C	21. A	22. A		
4B	23. A	24. B	25. C		
4C	26. A	27. C			
4D	28. C	29. A			
5A	30. A				
5B	31. B	32. A			
6A	33. A				
6B	34. A				
6C	35. A	36. A	37. B	38. B	
6D	39. A	40. B	41. B	42. B	
6E	43. A	44. B	45. A	46. A	47. A
7A	48. B	49. B	50. A		
7B	51. B	52. A	53. B	54. B	55. B
7C	56. B	57. C	58. A	59. A	
8A	60. A	61. A			
8B	62. B	63. A	64. A		
8C	65. B	66. B	67. B		
9A	68. A	69. B			
9B	70. B	71. B	72. A		
9C	73. B	74. B	75. A	76. A	
9D	77. B	78. B	79. A		
9E	80. A	81. A			
9F	82. B	83. C			
10B	84. A	85. A	86. A	87. B	
10C	88. B	89. A	90. B	91. A	92. B
10D	93. B	94. A	95. A		
11D	96. B				

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ANSWERS

CONTENTS

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1A Introduction to waves

Progress questions

1. B **2.** C **3.** B **4.** C

5. C **6.** A **7.** B, E, M, M, M, E

Deconstructed exam-style

8. A

9. C

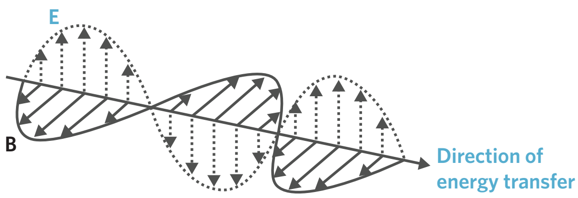
10. [The particle oscillates left and right.[1]][Its initial position (3 cm from the speaker) is the point about which the oscillations occur.[2]]

- I have explicitly addressed the oscillation of the air particle.[1]
- I have explicitly addressed the initial position of the particle.[2]

Exam-style

11. D. The power line poles will oscillate left and right about the same point.

12. a.



b. 3.0×10^8 m s^{-1}

13. [The wave is transverse[1]][as the displacement is perpendicular to the direction the wave is travelling.[2]]

- I have explicitly addressed whether the wave is longitudinal or transverse.[1]
- I have used the relevant theory: direction of oscillation compared to the direction of wave travel.[2]

14. C. Light always travels at 3.0×10^8 m s^{-1} through a vacuum.

Key science skills

15. D. 'Precise but inaccurate' suggests the results will be clustered tightly but not close to the true value (bullseye).

FROM LESSON 11C

1B Wave fundamentals

Progress questions

1. A **2.** B **3.** D **4.** B

5. B **6.** A **7.** B **8.** B

9. D **10.** C

Deconstructed exam-style

11. B

12. B

13. A

14. $A = 8$ cm (1 MARK)

Need correct units to gain full mark

$\lambda = 0.06$ m (1 MARK)

$v = f\lambda$

$18 = f \times 0.06$

$f = \frac{18}{0.06} = 3 \times 10^2$ Hz (1 MARK)

Exam-style

15. $v = f\lambda \Rightarrow 340 = 135 \times \lambda$ (1 MARK)

$\lambda = 2.52$ m (1 MARK)

16. a. Whole spring: displacement-distance graph.

One point: displacement-time graph.

b. $A = 0.10$ m

c. $\lambda = 4.0$ m

d. $T = 6.0$ s

e. $f = \frac{1}{T} = \frac{1}{6.0} = 0.17$ Hz or s^{-1}

17. a. $v = \frac{\lambda}{T} = \frac{500}{30.0} = 16.7$ m s^{-1}

b. $f = \frac{1}{T} = \frac{1}{30.0} = 3.33 \times 10^{-2}$ Hz

18. a. $v = \frac{\lambda}{T} \Rightarrow 3.0 \times 10^8 = \frac{0.040}{T}$

$T = 1.3 \times 10^{-10}$ s

b. The waves with $\lambda = 0.040$ m have a greater energy, as they have a greater frequency.

19. [Wave speed is dependent only on the medium in which the wave is propagating, so will not change when frequency changes.[1]]

- I have used the relevant theory: the dependence of wave speed on the medium.[1]

20. a. $\lambda = 4$ m from either graph

b. For lowest possible frequency, the wave has moved through $\frac{1}{4}$ of a cycle in 0.25 s (1 MARK)

$\frac{1}{4}T = 0.25$ s

$T = 1$ s

$f = \frac{1}{T} = 1$ Hz (1 MARK)

c. $v = f\lambda = 1 \times 4 = 4$ m s^{-1}

21. a. *A*: up (1 MARK)

B: up (1 MARK)

C: down (1 MARK)

b. Same location on the wave

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22. $f = 450 \times 10^6$ Hz (1 MARK)

$v = f\lambda$

$3.0 \times 10^8 = 450 \times 10^6 \times \lambda$ (1 MARK)

$\lambda = 0.67$ m, the question requires the answer to be in centimetres.

$\lambda = 67$ cm (1 MARK)

23. $v = f\lambda = 534 \times 0.500 = 267$ m s^{-1} (1 MARK)

The unknown gas is carbon dioxide. (1 MARK)

24. [Dominique should make the period shorter[1]][as by decreasing period she would increase frequency of her note.[2]]

- I have explicitly addressed the question.[1]
- I have used the relevant theory: the relationship between period and frequency.[2]

Key science skills

25. [Izzy has more accurate data and Emma has more precise data.[1]][Izzy's average (696.2 nm) is closer than Emma's average (696.8 nm) to the actual wavelength (695 nm).[2]][The range of Emma's measurements (5 nm) is smaller than Izzy's range (17 nm).[3]]

- I have explicitly addressed the question.[1]
- I have used the relevant theory: the definition of accuracy.[2]
- I have used the relevant theory: the definition of precision.[3]
- I have used the provided data in my answer.

FROM LESSON 11C

Previous lessons

26. [Image *M* is an example of a transverse wave.[1]][In image *M*, the oscillations are perpendicular to the direction of wave travel.[2]]

- I have explicitly addressed which image shows a transverse wave.[1]
- I have used the relevant theory: oscillations perpendicular to direction of travel in transverse waves.[2]

FROM LESSON 1A

1C Everyday electromagnetism

Progress questions

1. A **2.** B **3.** B **4.** D

5. D **6.** A

Deconstructed exam-style

7. C

8. D

9. [Ultraviolet light has a much shorter wavelength/higher frequency/higher energy than infrared or vice-versa.[1]] [Generally humans are unable to see infrared or ultraviolet light as their wavelengths are outside the visible spectrum.[2]]

- I have used the relevant theory: the relationship between wavelength/frequency/energy.[1]
- I have used the relevant theory: humans have a narrow range of waves that are visible.[2]

Exam-style

10. Radio station sends a radio wave signal → Presenter speaks (1 MARK)

Radio receives radio waves → Translator hears the spoken words (1 MARK)

Radio emits sound → Translator communicates in sign language (1 MARK)

11. Radio, microwaves, infrared, orange light, ultraviolet, x-rays

12. Gamma, ultraviolet, blue light, red light, infrared, radio

13. D. Green has the second longest wavelength of the visible colours that mercy emits.

Key science skills

14. 658 nm $= 658 \times 10^{-9}$ m (1 MARK)

$658 \times 10^{-9} = 6.6 \times 10^{-7}$ m (1 MARK)

FROM LESSON 11B

Previous lessons

15. Electromagnetic waves do not need a medium to propagate.

OR

Electromagnetic waves can travel through a vacuum.

FROM LESSON 1A

16. B. All the components of the electromagnetic spectrum in vacuum will have the same speed.

$c = 3.0 \times 10^8$ m s^{-1}

FROM LESSON 1A

1D Refraction and reflection

Progress questions

1. A **2.** D **3.** B **4.** B

5. C **6.** A **7.** C **8.** B

9. C

Back to contents

Deconstructed exam-style

10. B

11. C

12. A

13. Find the speed of light in saltwater.

$v = f\lambda = 510 \times 10^{-9} \times 4.085 \times 10^{14}$

$v = 2.08 \times 10^{8}$ (1 MARK)

Find the refractive index of the saltwater.

$n_1 = \frac{c}{v} = \frac{3.00 \times 10^{8}}{2.08 \times 10^{8}} = 1.44$ (1 MARK)

⇒ Refractive index of plastic, n_2, must be less than the refractive index for saltwater but for the critical angle to exist, and must be greater than or equal to 1 since 1 is the lowest possible refractive index. (1 MARK)

$1 \leq n_2 < 1.44$ (1 MARK)

Exam-style

14. $n = \frac{c}{v}$

$v = \frac{c}{n} = \frac{3.00 \times 10^{8}}{1.60} = 1.88 \times 10^{8}\ \text{m s}^{-1}$

15. $n_2 = n_1 \sin(\theta_c)$

$n_{cladding} = 1.7 \times \sin(48°) = 1.3$

16. $n_1 \sin(\theta_1) = n_2 \sin(\theta_2)$

$1.00 \times \sin(45.0°) = n_{glass} \times \sin(30.0°)$ (1 MARK)

$n_{glass} = \frac{\sin(45.0°)}{\sin(30.0°)} = 1.41$ (1 MARK)

17. $n_1 \sin(\theta_1) = n_2 \sin(\theta_2)$

$1.32 \times \sin(42.0°) = 1.40 \times \sin(\theta_r)$ (1 MARK)

$\theta_r = \sin^{-1}\left(\frac{1.32 \times \sin(42.0°)}{1.40}\right) = 39.1°$ (1 MARK)

18. $n_1 \sin(\theta_c) = n_2$

$1.46 \times \sin(\theta_c) = 1.28$ (1 MARK)

$\theta_c = \sin^{-1}\left(\frac{1.28}{1.46}\right) = 61.2°$ (1 MARK)

19. [When the laser light passes into the stream of water, it can be guided by total internal reflection since water has a higher refractive index than air.[1]] [Each subsequent reflection inside the stream will experience total internal reflection if it is incident at greater than the critical angle.[2]]

- I have explicitly addressed how the light is guided by the stream.[1]
- I have used the relevant theory: total internal reflection and critical angle.[2]

20. $n_1 \sin(\theta_c) = n_2$

$n_{glass} \sin(50°) = 1.00$

$n_{glass} = \frac{1.00}{\sin(50°)} = 1.3$ (1 MARK)

$n_{glass} < n_{water}$

⇒ Total internal reflection would not be possible anymore since it would require that $n_{glass} > n_{water}$ (1 MARK)

21. D. Crossing the boundary from medium 1 into medium 2, light refracts towards the normal

$\Rightarrow n_1 < n_2$

Crossing the boundary from medium 2 into medium 3, light refracts away from the normal

$\Rightarrow n_3 < n_2$

Since the boundaries are parallel and $\theta_3 > \theta_1$, Snell's Law indicates $n_3 < n_1$

$\Rightarrow n_3 < n_1 < n_2$

Since $n \propto \frac{1}{v}$, $v_3 > v_1 > v_2$

22. $v_2 = 1.2 \times v_1$

$n_1 v_1 = n_2 v_2$

$\frac{n_1}{n_2} = \frac{v_2}{v_1} = 1.2$ (1 MARK)

$n_1 \sin(\theta_1) = n_2 \sin(\theta_2)$

$1.2 \sin(\theta_i) = \sin(60°)$ (1 MARK)

$\theta_i = \sin^{-1}\left(\frac{\sin(60°)}{1.2}\right) = 46°$ (1 MARK)

23. Since both boundaries the light passes through are parallel, the angle of refraction from the first boundary will be the angle of incidence on the second boundary.

By Snell's Law at the first boundary:
$n_{air} \sin(\theta_{air}) = n_{glass} \sin(\theta_{glass})$

By Snell's Law at the second boundary:
$n_{glass} \sin(\theta_{glass}) = n_{water} \sin(\theta_{water})$

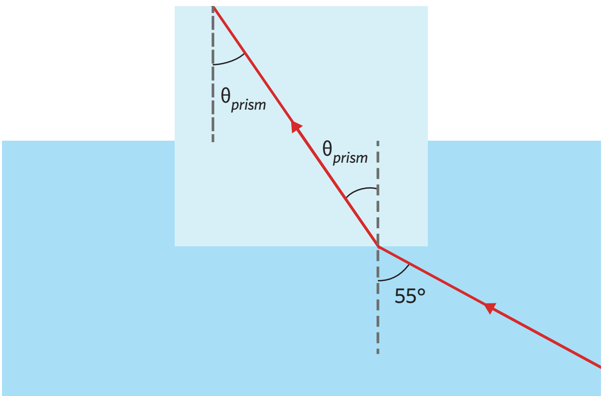
$n_{air} \sin(\theta_{air}) = n_{water} \sin(\theta_{water})$ (1 MARK)

$1.00 \times \sin(30°) = 1.33 \times \sin(\theta_{water})$

$\theta_{water} = \sin^{-1}\left(\frac{1.00}{1.33} \times \sin(30°)\right) = 22°$ (1 MARK)

$\theta_{air} - \theta_{water} = 30 - 22 = 8°$ (1 MARK)

24. Since both boundaries the light passes through are parallel, the angle of refraction from the first boundary will be the angle of incidence on the second boundary.



$n_1 v_1 = n_2 v_2$ implies that $\frac{n_1}{n_2} = \frac{v_2}{v_1}$

$\Rightarrow \frac{n_{water}}{n_{prism}} = \frac{v_{prism}}{v_{water}} = 0.8$ and $\frac{n_{air}}{n_{prism}} = \frac{v_{prism}}{v_{air}} = 0.6$ (1 MARK)

$\Rightarrow n_{water} = 0.8 \times n_{prism}$ and $n_{air} = 0.6 \times n_{prism}$

1D ANSWERS

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By Snell's Law at the water-prism boundary:

$$n_{water}\sin(55°) = n_{prism}\sin(\theta_{prism})$$

$$\theta_{prism} = \sin^{-1}\left(\frac{n_{water}}{n_{prism}}\sin(55°)\right) = \sin^{-1}(0.8 \times \sin(55°)) = 41°$$

(1 MARK)

The critical angle for the prism-air boundary will have:

$$n_{prism}\sin(\theta_c) = n_{air}$$

$$\theta_c = \sin^{-1}\left(\frac{n_{air}}{n_{prism}}\right) = \sin^{-1}(0.6) = 36°$$ (1 MARK)

⇒ The light will totally internally reflect since $\theta_{prism} > \theta_c$

(1 MARK)

Key science skills

25. a. Dependent: angle of refraction (1 MARK)

Independent: angle of incidence (1 MARK)

Controlled: laser wavelength **OR** incident medium refractive index **OR** diamond refractive index (1 MARK)

b. Use two points on a line of best fit to determine the gradient.

$$gradient = \frac{rise}{run} = \frac{0.39 - 0.15}{0.90 - 0.35}$$ (1 MARK)

$gradient = 0.44$ (1 MARK)

Depending on the line of best fit drawn, answers between 0.38 and 0.50 are acceptable.

c. $n_1\sin(\theta_1) = n_2\sin(\theta_2)$

$$\frac{n_2}{n_1} = \frac{\sin(\theta_1)}{\sin(\theta_2)}$$

In this case, $\sin(\theta_1) = \sin(\theta_i)$, $\sin(\theta_2) = \sin(\theta_r)$, $n_1 = 1.00$, and $n_2 = n_{diamond}$

$$\Rightarrow n_{diamond} = \frac{\sin(\theta_i)}{\sin(\theta_r)} = \frac{run}{rise} = \frac{1}{gradient}$$

$$n_{diamond} = \frac{1}{0.44} = 2.3$$ (1 MARK)

The diamond is not real since $2.3 < 2.80$. (1 MARK)

FROM LESSONS 11A & 11E

Previous lessons

26. [Frequency is the number of wave cycles completed in a unit of time.[1]][Wavelength is the distance covered by one complete wave cycle, or the distance between two crests/two troughs.[2]] [Frequency is determined entirely by the wave source.[3]]

- I have used the relevant theory: wave frequency.[1]
- I have used the relevant theory: wavelength.[2]
- I have explicitly addressed which property is completely determined by wave source.[3]

FROM LESSON 1B

27. C. The x-ray region of the electromagnetic spectrum is the second most energetic after gamma radiation.

FROM LESSON 1C

1E White light and optical phenomena

Progress questions

1. D	**2.** C	**3.** C	**4.** B
5. C	**6.** A	**7.** B	**8.** A

9. I, II and III

Deconstructed exam-style

10. C

11. B

12. [As the light passes into the prism it does not disperse.[1]] [This is because the light hits the prism parallel to the normal so no refraction occurs.[2]][When the light leaves the prism, each frequency of light refracts differently and therefore the white light disperses.[3]][Despite being white light within the prism, the difference in the refractive indexes of the medium for each frequency of light allows dispersion to occur.[4]]

- I have explicitly addressed what happens to the white light as it passes into the prism.[1]
- I have used the relevant theory: refraction and dispersion.[2]
- I have explicitly addressed what happens to the white light as it passes out of the prism.[3]
- I have used the relevant theory: refraction and dispersion.[4]

Exam-style

13. Total internal reflection

14. D. Total internal reflection can only occur when travelling from a medium of higher refractive index to a medium of lower refractive index.

15. [Rainbows are a result of refraction and reflection occurring[1]] [however, these processes are not ideal and light escapes at each boundary which does not reach the observer.[2]][This means the light that we see as a rainbow is only a small percentage of the Sun's light.[3]]

- I have used the relevant theory: refraction and reflection.[1]
- I have explicitly addressed the inefficiency in these processes.[2]
- I have related my answer to the context of the question.[3]

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16. [Diamonds exhibit a colourful shine because white light shone onto the diamond is dispersed into its constituent colours.[1]] [White light consists of a continuous spectrum of the colours within the visible spectrum of light,[2]] [and these colours are dispersed by the diamond because the diamond's refractive index is dependent on the frequency (colour) of light.[3]]

- I have explicitly addressed why diamonds have a colourful shine.[1]
- I have used the relevant theory: white light.[2]
- I have used the relevant theory: colour dispersion.[3]

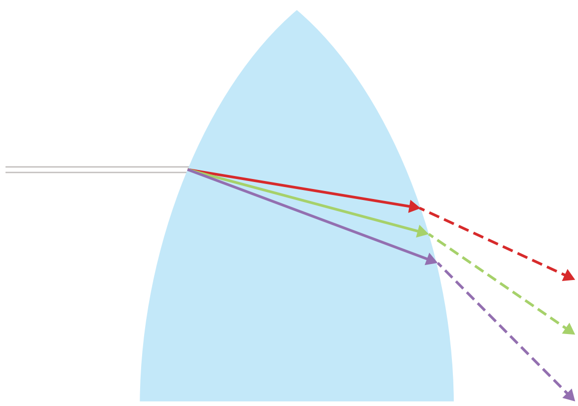
17. [Katya is correct and Mo is incorrect.[1]] [Rainbows are created through the dispersion of white light through numerous raindrops.[2]] [As a person gets closer to a rainbow, you see a rainbow formed by different raindrops.[3]] [This means that you can never reach the end of a rainbow as it is not a static object but an illusion that moves with you.[4]]

- I have explicitly addressed whether Katya or Mo is correct.[1]
- I have used the relevant theory: rainbows.[2]
- I have explicitly addressed rainbows as an illusion.[3]
- I have related my answer to the context of the question.[4]

18. a. [Because the higher frequency colour (violet) is refracted more towards the normal than the lower frequency colour (red),[1]] [it can be concluded that the refractive index of the lens decreases as frequency decreases.[2]]

- I have used the relevant theory: refraction.[1]
- I have explicitly addressed the relationship between refractive index and frequency.[2]

b.



- I have drawn three arrows.
- I have drawn the arrows such that they separate further and do not cross.

19. A. At point P the light changes direction, suggesting total internal reflection occurred.

20. Point S

21. [The mirage will form above the actual object.[1]] [It forms here as the angle of the ray reaching the eye is coming from above the eye.[2]] [As the human brain believes this to be a straight line, we see the image at the end of this straight line, above the actual position of the object.[3]]

- I have explicitly addressed where the mirage will form.[1]
- I have referenced the angle of the ray with respect to the eye.[2]
- I have used the relevant theory: mirages.[3]

Key science skills

22. a. [No, the experiment is not valid[1]] [because there is more than one independent variable in this experiment.[2]]

- I have explicitly addressed the validity of the experiment.[1]
- I have used the relevant theory: experimental validity and independent variables.[2]

b. [After choosing a single independent variable, Toni should take multiple measurements of the distance between the red and purple light for each lens.[1]] [Increasing the amount of measurements increases the validity of results by helping to account for the variability of the data and personal error.[2]]

- I have explicitly addressed a change to the experimental design.[1]
- I have used the relevant theory: validity.[2]

FROM LESSON 11C

Previous lessons

23. From the graph:

Amplitude = 0.2 m (1 MARK)

Wavelength = 6 m (1 MARK)

FROM LESSON 1B

24. $T = \frac{1}{f} = \frac{1}{10} = 0.10$ s

FROM LESSON 1B

25. $n_1 \sin(\theta_1) = n_2 \sin(\theta_2) \Rightarrow 1.20 \times \sin(47°) = 1.33 \times \sin(\theta_2)$ (1 MARK)

$\theta_2 = 41°$ (1 MARK)

FROM LESSON 1D

Chapter 1 review

Section A

1. D. The amplitude of the graph is the maximum displacement in one direction and the wavelength can be found from the distance between two peaks or troughs. The frequency cannot be determined from a displacement-distance graph.

2. B. Using the electromagnetic spectrum, blue light has a shorter wavelength than radio waves.

3. D. All electromagnetic waves travel at $c = 3.0 \times 10^8$.

4. A. White light consists of all components of the visible light spectrum. Infrared light is not part of the visible spectrum.

5. C. As the angle of incidence of light travelling from medium 1 to water is different from the angle of refraction when light travels from water to medium 2, the two mediums must be made of different materials.

Section B

6. Any two of the following: all travel at the $c = 3.0 \times 10^8\ \text{m s}^{-1}$ in a vacuum; can travel through a vacuum (no medium required); have an associated wavelength, frequency and energy; transfer energy; behave as a transverse waves; or other properties not covered in Chapter 1.

7. One year $= 60 \times 60 \times 24 \times 365 = 3.15 \times 10^7$ s

$v = \frac{s}{t} \Rightarrow s = vt = 3.0 \times 10^8 \times 3.15 \times 10^7 \times 0.75 = 7.1 \times 10^{15}$ m

8. $n_1 v_1 = n_2 v_2$

$1.30 \times v_1 = 1.40 \times v_2$ (1 MARK)

$\frac{v_2}{v_1} = \frac{1.30}{1.40} = 0.9285 = 0.929$ (1 MARK)

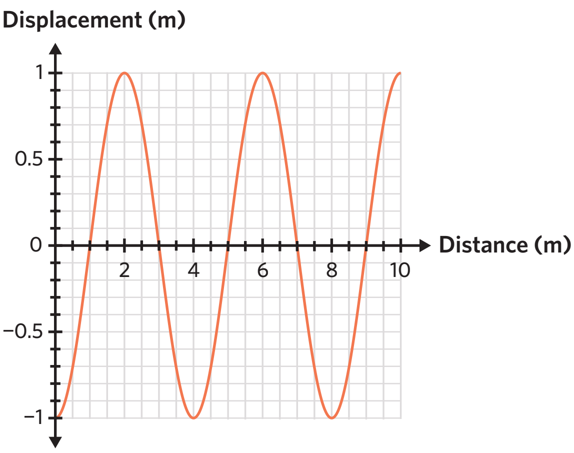
9. a. From the displacement-distance graph $\lambda = 4$ m and from the displacement-time graph $T = 4$ s (1 MARK)

$v = \frac{\lambda}{T} = \frac{4}{4} = 1\ \text{m s}^{-1}$ (1 MARK)

b. Particle C is moving upwards.

c. The displacement-time graph must show the movement of a particle which has displacement 0 m at $t = 0$ s and has its displacement decrease just after $t = 0$ s. Particle E is the only particle which fits this description.

d.



- I have labelled both axes including units.
- I have used an appropriate and consistent scale on both axes.
- I have drawn a sinusoidal wave with an amplitude of 1 m and a wavelength of 4 m.
- I have drawn a graph which starts with a minimum at $d = 0$ m and ends with a maximum at $d = 10$ m.

10. [$n_A < n_B$[1]][as, from B to A, the ray bends away from the normal.[2]] [Note that the direction of the ray's travel is not important, since if it travelled instead from A to B then it would be bending towards from the normal, again implying that $n_A < n_B$.[3]]

- I have explicitly addressed the relationship between the refractive indices.[1]
- I have used the relevant theory: refraction.[2]
- I have explicitly addressed the significance of the ray's direction of travel.[3]

11. a. $n_{internal} > n_{external}$ **OR** $n_{core} > n_{cladding}$ (1 MARK)

Angle of incidence must be greater than the critical angle. (1 MARK)

b. Red (since it has the lowest refractive index so it travels fastest).

12. a. [Dispersion is occuring.[1]][Dispersion is the process of white light being separated into its constituent colours when each colour refracts by a different amount as it enters and leaves a medium.[2]]

- I have explicitly addressed the relevant phenomenon.[1]
- I have used the relevant theory: dispersion of white light.[2]

b. [A rainbow is a result of the combination of numerous rays of light from thousands of raindrops.[1]][Although each raindrop disperses the light, due to the differing angles that the wavelengths of light leave the raindrop, only one wavelength will reach the observer from each raindrop.[2]][This means that many raindrops are required to see the overall effect of each colour of a rainbow as it appears.[3]]

- I have explicitly addressed the need for multiple raindrops.[1]
- I have used the relevant theory: rainbows and dispersion.[2]
- I have related my answer to the context of the question.[3]

13. [Mirages occur below the object (inferior) when the air gets gradually warmer below a certain height.[1]][Mirages form above the object (superior) when the air gets gradually warmer above a certain height.[2]][In this scenario, the air gets gradually warmer both above and below the midpoint of the tree's height, therefore it should be possible for the observer to see both a superior and an inferior mirage.[3]]

- I have explicitly addressed how inferior mirages form.[1]
- I have explicitly addressed how superior mirages form.[2]
- I have addressed whether a superior and/or inferior mirage will form.[3]

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2A Temperature fundamentals

Progress questions

1. liquid, gas, changes to fit the container it's in, more spread out, increases, move and collide randomly

2. A

3. B

4. average, translational kinetic

5. B **6.** A **7.** C **8.** A

Deconstructed exam-style

9. D

10. B

11. [Initially, the particles in the cup of coffee have greater average translational kinetic energy than in her hand because the coffee is at a greater temperature.[1]] [As the cup warms the hand, the average translational kinetic energy of the particles in the cup of coffee decreases and the average translational kinetic energy of the particles in her hand increases.[2]] [When thermal equilibrium is reached, the average translational kinetic energy of the particles in each system will be equal.[3]]

- I have explicitly addressed the average translational kinetic energies at the beginning.[1]
- I have explicitly addressed the average translational kinetic energies as the coffee warms her hand.[2]
- I have explicitly addressed the average translational kinetic energies at thermal equilibrium.[3]

Exam-style

12. 735 K = (735 − 273.15)°C = 462°C

13. a. −170°C = (−170 + 273.15) K = 103 K

b. ΔT = 450°C − (−170°C) = 620°C = 620 K

14. [Temperature is a measure of the average translational kinetic energy of the random disordered motion of the particles in a system.[1]] [Hence, the average translational kinetic energy of the atoms and molecules will be greater during the day than during the night.[2]]

- I have used the relevant theory: temperature as a measure of average translational kinetic energy of particles.[1]
- I have explicitly addressed the kinetic energy of atoms and molecules during the day compared with during the night.[2]

15. [Archie is incorrect.[1]] [Temperature is a measure of the average translational kinetic energy of the random disordered motion of the atoms and molecules in a system.[2]] [The collective change in speed of the basketball, and its particles as a result, is not related to the particles' random disordered motion.[3]]

- I have explicitly addressed whether Archie is correct.[1]
- I have used the relevant theory: temperature as a measure of average translational kinetic energy of particles.[2]
- I have related my answer the the context of the question.[3]

16. a. The internal energy of the water in the Olympic pool would be greater than the internal energy of water in the backyard pool. This is because the Olympic pool has a greater volume, and more water particles than a backyard pool.

b. The average translational kinetic energy of the water molecules in the backyard pool would be the same as the average translational kinetic energy of the water molecules in the Olympic pool. This is because the pools are at the same temperature.

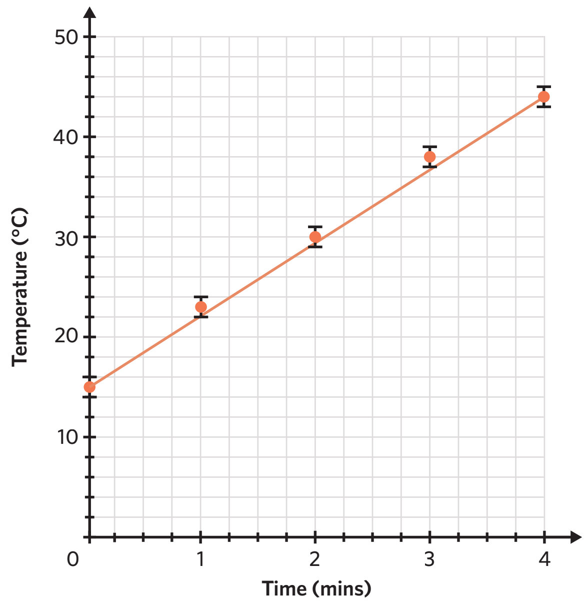
17. [Particles in water (a liquid) are free to move around each other, whereas particles in ice (a solid) are stuck together,[1]] [which explains the macroscopic properties of liquids being able to change shape and solids having a fixed shape.[2]] [Hence, liquid water can flow as a thin stream into a bottle and then take the bottle's shape, whereas ice cannot.[3]]

- I have used the relevant theory: the kinetic theory of matter for solids and liquids.[1]
- I have used the relevant theory: the macroscopic properties of solids and liquids.[2]
- I have explicitly addressed the properties of water that allow it to fill the bottle easily.[3]

Key science skills

18. a. $\textit{Uncertainty} = \frac{1}{2} \times \textit{smallest division on scale} = \frac{1}{2} \times 2°\text{C} = \pm 1°\text{C}$

b.



- I have drawn time on the horizontal axis and temperature on the vertical axis.
- I have used an appropriate and consistent scale so the data takes up at least half of each axis.

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- I have plotted each point of data.
- I have included correct uncertainty bars.
- I have drawn a line of best fit that passes through all the uncertainty bars.

FROM LESSONS 11C & 11D

Previous lessons

19. In order from highest energy to lowest: 4.9×10^{-8} m, 4.1×10^{-7} m, 5.7×10^{-7} m, 5.2×10^{-4} m, 7.5×10^{-3} m.

FROM LESSON 1C

20. a. $v = \frac{\Delta s}{\Delta t} \Rightarrow 3.0 \times 10^8 = \frac{d}{(8 \times 60) + 19}$ (1 MARK)

$d = 1.5 \times 10^{11}$ m (1 MARK)

b. Microwaves, visible light, ultraviolet, X-rays, gamma rays.

FROM LESSON 1E

2B How thermal energy moves

Progress questions

1. B

2. B

3. B

4. temperatures; in contact; heat; internal energy

5. loss; heat; insulators

6. fluids; different temperatures; rise above; less dense

7. B

8. D

9. C

Deconstructed exam-style

10. D

11. A

12. [Sabrina is correct.[1]][As the heated fluid will be on top, it will not move since hotter fluid only rises above colder fluid.[2]] [As convection requires movement of fluid, convection cells will not be able to form.[3]]

- I have explicitly addressed who is correct.[1]
- I have used the relevant theory: hotter fluid rises above colder fluid.[2]
- I have used the relevant theory: requirements for convection.[3]

Exam-style

13. D. Convection is when heat transfer occurs as a result of the movement of fluids.

14. B. Rate of conduction is proportional to temperature difference. $1.5 \times 100 = 150 \text{ J s}^{-1}$.

15. [Heat will flow from Zev's head to the ice pack through conduction.[1]][Zev's head and the ice pack are in physical contact, and the particles that make up Zev's head are hotter than those in the ice pack.[2]][They will therefore transfer translational kinetic energy to the particles that make up the ice pack by colliding with them, increasing the ice pack's internal energy and lowering the internal energy of Zev's head.[3]]

- I have explicitly addressed the kind of heat transfer taking place.[1]
- I have used the relevant theory: conditions for conduction.[2]
- I have used the relevant theory: the mechanism of conduction.[3]

16. $\Delta T_i = T_{plate} - T_{mitt} \Rightarrow \Delta T_i = 340 - 300 = 40.0$ K (1 MARK)

Rate of heat flow halved and $\frac{Q}{t} \propto \Delta T \Rightarrow \Delta T_f = \frac{1}{2} \times \Delta T_i = \frac{1}{2} \times 40.0$ (1 MARK)

$\Delta T_f = 20$ K (1 MARK)

17. a. Yes

Thermal radiation is the primary form of heat transfer between the fire and Jim. Radiation does not require matter, so he will still feel a similar amount of warmth.

b. Convection

The hot air surrounding the fire rises due to its lower density, helping heat anything above the fire, but not to its side. This is convection.

18. a. Aluminium

Pure metals are good thermal conductors.

b. [Plastic should be used as it is a better insulator.[1]] [This reduces the rate of heat flow compared to a conductor like aluminium.[2]]

- I have explicitly addressed whether plastic or aluminium should be used for the piping.[1]
- I have used the relevant theory: conductors and insulators.[2]

19. a. Hotter

Net heat flows from hotter objects to colder objects, increasing the colder objects' internal energy.

b. [Objects in thermal equilibrium are at the same temperature ($\Delta T = 0$).[1]][From the relation $\frac{Q}{t} \propto \Delta T$, this means $\frac{Q}{t}$ (the rate of heat flow due to conduction), must also be zero.[2]]

- I have used the relevant theory: the relationship between thermal equilibrium and temperature.[1]
- I have explicitly addressed that the relevant relation shows there will be no net flow of heat.[2]

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20. a. [The conduction occurs through physical contact with the air.[1]] [A greater surface area means a greater area of contact,[2]] [which increases the rate of conduction with the air and cools the fins quicker.[3]]

- I have used the relevant theory: conditions for conduction.[1]
- I have referenced the fins' high area of contact with the air.[2]
- I have explicitly addressed the purpose of having a high surface area.[3]

b. [The fins transfer the heat through conduction to the air.[1]] [The fan then blows away this heated air, which is forced convection.[2]]

- I have referenced how the heat is transferred from the fins to the air.[1]
- I have explicitly addressed the role of the fan.[2]

Key science skills

21. a. 3

When adding values, we use the number of decimal places of the value with the fewest number of decimal places. That is 0.3 + 5.7 + 4.502 = 10.502 but we take 10.5 (one decimal place) because 0.3 and 5.7 have only one decimal place.

b. 2

When multiplying numbers, we use the number of significant figures of the value with the fewest significant figures. Since one of the numbers (time) has only two significant figures, we can have only two significant figures for the answer.

FROM LESSON 11B

Previous lessons

22. [Ultraviolet waves have a higher frequency[1]] [and a shorter wavelength in comparison to infrared waves.[2]] [Ultraviolet waves are produced by the Sun, and are what give us sunburn.[3]] [Infrared waves are used in TV remotes and thermal cameras.[4]]

- I have explicitly addressed the difference between ultraviolet waves and infrared waves: frequency.[1]
- I have explicitly addressed the difference between ultraviolet waves and infrared waves: wavelength.[2]
- I have provided an example of where ultraviolet waves can be found in everyday life (note that there are many possible examples).[3]
- I have provided an example of where infrared waves can be found in everyday life (note that there are many possible examples).[4]

FROM LESSON 1C

23. a. $961.8 + 273.15 = 1234.95 = 1235.0$ K

b. [As the metal melts, the temperature of the metal increases, and therefore the translational kinetic energy of the atoms increases.[1]] [If energy is added to the system, the total energy of the system must increase. Therefore the total internal energy of the silver atoms must increase as well.[2]]

- I have used the relevant theory: average kinetic energy increases with temperature.[1]
- I have used the relevant theory: internal energy.[2]

FROM LESSON 2A

2C How heat affects temperature

Progress questions

1. B	**2.** X	**3.** Y	**4.** B
5. D	**6.** B	**7.** B	**8.** A
9. C	**10.** B		

Deconstructed exam-style

11. C	**12.** B	**13.** D	**14.** A

15. $Q_{water} = 0.100 \times 4.2 \times 10^3 \times (0 - 12) = -5.04 \times 10^3$ J (1 MARK)

$Q_{Lf} = -0.100 \times 3.34 \times 10^5 = -3.34 \times 10^4$ J (1 MARK)

$Q_{ice} = 0.100 \times 2.1 \times 10^3 \times \left(T_f - 0\right) = 2.1 \times 10^2 \times T_f$ (1 MARK)

$Q_{total} = Q_{water} + Q_{Lf} + Q_{ice}$

$-40 \times 10^3 = -5.04 \times 10^3 - 3.34 \times 10^4 + 2.1 \times 10^2 \times T_f$

$T_f = -7.40$°C (1 MARK)

Exam-style

16. $Q = mc\Delta T = 0.300 \times 7.2 \times 10^2 \times 4.0$ (1 MARK)

$Q = 8.6 \times 10^2$ J (1 MARK)

17. $Q = mc\Delta T \Rightarrow 5500 = 0.015 \times 450 \times \Delta T$ (1 MARK)

$\Delta T = 815$ K or °C (1 MARK)

18. a. For a gas condensing to a liquid, use the latent heat of vaporisation.

$Q = mL_v = 1.5 \times 1.1 \times 10^5$ (1 MARK)

$Q = 1.65 \times 10^5 = 1.7 \times 10^5$ J released (1 MARK)

b. The total heat released is the sum of the latent heat of vaporisation (while condensing) and the heat released while the liquid cools.

$Q_{total} = Q_{Lv} + Q_{liquid} \Rightarrow 2.0 \times 10^5 = 1.65 \times 10^5 + Q_{liquid}$ (1 MARK)

$Q_{liquid} = 0.35 \times 10^5 = 3.5 \times 10^4$ J released as the liquid cools (1 MARK)

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19. [Xi is incorrect and Ruth is correct.[1]][The potential energy portion of the internal energy has increased as the solid melts to a liquid.[2]][The temperature has not increased because the translational kinetic energy portion of the internal energy has not changed.[3]]

- I have explicitly addressed whether each statement is correct.[1]
- I have explicitly stated that changing state from ice to water increases the potential energy.[2]
- I have explicitly stated why temperature does not change when a substance melts.[3]

20. a. Use any two points on this section of the graph to calculate the gradient.

$gradient = \frac{y_2 - y_1}{x_2 - x_1} = \frac{40 - 0}{(250 - 0) \times 10^3}$ (1 MARK)

$gradient = 1.6 \times 10^{-4}$ K J^{-1} (1 MARK)

b. Consider the section of the graph corresponding to solid lead.

For solid lead: $gradient = \frac{rise}{run} = \frac{\Delta T}{Q}$

The equation relating Q and ΔT is $Q = mc\Delta T$

$gradient = \frac{\Delta T}{Q} = \frac{1}{mc}$ (1 MARK)

$1.6 \times 10^{-4} = \frac{1}{5.0 \times c}$ (1 MARK)

$c = 1250 = 1.3 \times 10^3$ J kg^{-1} K^{-1} (1 MARK)

c. The heat absorbed when 5.0 kg of lead melts is given by the heat input for the flat section of the graph.

$Q_{Lf} = (1500 - 250) \times 10^3 = 1.25 \times 10^6$ J (1 MARK)

$Q_{Lf} = mL_f \Rightarrow 1.25 \times 10^6 = 5.0 \times L_f$

$L_f = 2.50 \times 10^5$ J kg^{-1} (1 MARK)

To two significant figures:

$L_f = 2.5 \times 10^5$ J kg^{-1} (1 MARK)

21. [Rubbing alcohol evaporates more quickly than water[1]] [because of rubbing alcohol's lower values for specific latent heat of vaporisation and boiling point compared with water.[2]] [This means that higher energy particles escape from the liquid at a greater rate, which causes its temperature to drop at a greater rate and feel cooler to the touch.[3]]

- I have explicitly addressed the reason that rubbing alcohol feels colder than water.[1]
- I have referenced the data from the table.[2]
- I have used the relevant theory: the process of evaporative cooling.[3]

22. $Q_{Lf} = mL_f = 0.9 \times 3.3 \times 10^5 = 2.97 \times 10^5$ J (1 MARK)

$Q_{total} = Q_{Lf} + Q_{water}$

$4.0 \times 10^5 = 2.97 \times 10^5 + 0.90 \times 4.2 \times 10^3 \times (T_f - 0.0)$ (1 MARK)

$T_f = 27$°C (1 MARK)

23. The heat released by the steam as it condenses is transferred to the glass.

$Q_{Lv} = Q_{glass}$

$(mL_v)_{steam} = (mc\Delta T)_{glass}$ (1 MARK)

$0.050 \times 2.3 \times 10^6 = 4.0 \times 840 \times \Delta T$ (1 MARK)

$\Delta T = 34$ K or °C (1 MARK)

24. Consider the 1.2 kg of water as it cools:

$Q_{cooling} = mc\Delta T = 1.2 \times 4.2 \times 10^3 \times (T_f - 20)$ (1 MARK)

Consider the 200 g of ice as it melts:

$Q_{Lf} = mL_f = 0.200 \times 3.3 \times 10^5 = 6.6 \times 10^4$ J (1 MARK)

Consider the 200 g of melted ice (now water) as it warms:

$Q_{warming} = mc\Delta T = 0.200 \times 4.2 \times 10^3 \times (T_f - 0)$ (1 MARK)

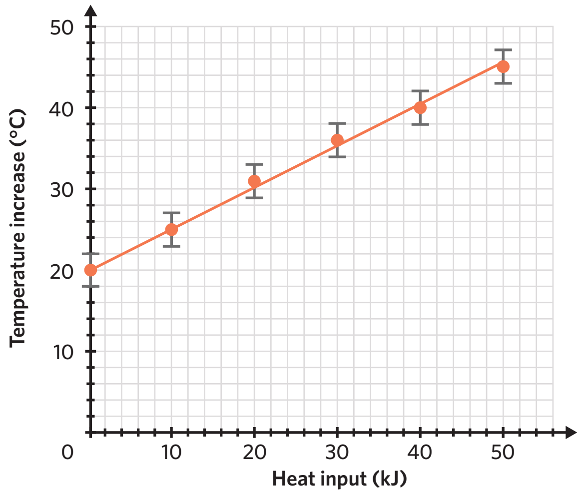
The ice and the water must have the same final temperature. The sum of the heat released by the water (which is a negative value) and the total heat absorbed by the ice must be zero.

$1.2 \times 4.2 \times 10^3 \times (T_f - 20) + 6.6 \times 10^4$
$+ 0.200 \times 4.2 \times 10^3 \times (T_f - 0) = 0$ (1 MARK)

$T_f = 5.92 = 5.9$°C (1 MARK)

Key science skills

25. a.



- I have labelled both axes and included correct units.
- I have included an appropriate and consistent scale on both axes.
- I have plotted each data point.
- I have drawn correctly sized uncertainty bars.
- I have drawn a straight line of best fit which passes through all uncertainty bars.

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b. Use any two points on the line of best fit to calculate the gradient.

$gradient = \frac{y_2 - y_1}{x_2 - x_1} = \frac{44 - 22}{(47 - 3) \times 10^3} = 5.0 \times 10^{-4}\ \text{K J}^{-1}$

(1 MARK)

$gradient = \frac{rise}{run} = \frac{\Delta T}{Q}$

The equation relating Q and ΔT is $Q = mc\Delta T \Rightarrow gradient = \frac{1}{mc}$

$5.0 \times 10^{-4} = \frac{1}{0.400 \times c}$ (1 MARK)

$c = 5000 = 5.0 \times 10^3\ \text{J kg}^{-1}\ \text{K}^{-1}$ (1 MARK)

Depending on the line of best fit drawn, answers between $4.3 \times 10^3\ \text{J kg}^{-1}\ \text{K}^{-1}$ and $6.0 \times 10^3\ \text{J kg}^{-1}\ \text{K}^{-1}$ are acceptable.

FROM LESSONS 11D & 11E

Previous lessons

26. $n_1 \sin(\theta_1) = n_2 \sin(\theta_2)$

$1.33 \times \sin(60.0°) = n_{glass} \times \sin(49.0°)$ (1 MARK)

$n_{glass} = \frac{1.33 \times \sin(60°)}{\sin(49°)} = 1.53$ (1 MARK)

FROM LESSON 1D

27. [Due to the contact between the hotplate, the pot, and the soup,[1]] [the heat travels via conduction into the soup.[2]] [As the particles of the soup heat up, their kinetic energies increase, therefore decreasing their densities,[3]] [causing them to rise and transfer thermal energy throughout via convection.[4]]

- ✓ ✗ I have used the relevant theory: heat transfer via contact.[1]
- ✓ ✗ I have explicitly addressed what the first heat transfer is.[2]
- ✓ ✗ I have used the relevant theory: increasing temperature causes less density.[3]
- ✓ ✗ I have explicitly addressed what the second heat transfer is.[4]

FROM LESSON 2B

Chapter 2 review

Section A

1. A. $1000\ \text{K} = (1000 - 273.15)°\text{C}$

2. A. The tiles feel cold because heat is transferred quickly via conduction to the tiles since Lloyd's feet are in direct contact with the tiles. Socks do not conduct heat as well.

3. D. Being at the same temperature, being in thermal equilibrium, and having no net heat transfer are all equivalent descriptions of the relationship between two objects. If the laptop is in thermal equilibrium with the smartphone and the smartphone is in thermal equilibrium with the tablet, then the laptop must also be in thermal equilibrium with the tablet.

4. B. The water continues to absorb heat but it does not increase the kinetic energy, which determines temperature.

5. D. $Q = mc\Delta T \Rightarrow 9450 = 1.5 \times 4.2 \times 10^3 \times \Delta T \Rightarrow \Delta T = 1.5°\text{C}$

6. B. The heat produced by a heater rises due to convection.

7. B. Temperature difference is proportional to the rate of energy transfer. Therefore increasing the temperature difference by a factor of 1.25 would increase the rate of energy transfer by 1.25.

$1400 \times 1.25 = 1750\ \text{J}$

Section B

8. [Compared to cooler air, hotter air has a greater average translational kinetic energy,[1]] [meaning the particles space themselves further apart, making it less dense and therefore causing it to rise.[2]] [A hot air balloon uses this principle to work by heating up the air inside of the balloon and hence creating a lift force through the difference in density between the air inside the balloon and outside the balloon.[3]]

- ✓ ✗ I have used the relevant theory: kinetic theory of matter.[1]
- ✓ ✗ I have used the relevant theory: how temperature relates to density.[2]
- ✓ ✗ I have addressed the question: how hot air balloons work.[3]

9. a. $Q = mc\Delta T = 0.120 \times 900 \times (10.0 - 25.0)$ (1 MARK)

$Q = -1.62 \times 10^3\ \text{J}$

1.62×10^3 J was transferred from the goblet. (1 MARK)

b. The quantity of heat transferred from the goblet is the same as the quantity transferred to the water. (1 MARK)

$Q = mc\Delta T \Rightarrow 1.62 \times 10^3 = m \times 4.18 \times 10^3 \times (6.9 - 5.0)$ (1 MARK)

$m = 0.204\ \text{kg} = 2.0 \times 10^2\ \text{g}$ (1 MARK)

10. [When the wind blows, it increases the rate of evaporation[1]] [because it encourages the water molecules with the greatest kinetic energy to escape.[2]] [This decreases the average translational kinetic energy, and hence temperature, of the remaining water more rapidly so that heat will be transferred from Tobias' skin to the water more rapidly.[3]]

- ✓ ✗ I have explicitly addressed the effect of the wind.[1]
- ✓ ✗ I have referenced a kinetic energy model.[2]
- ✓ ✗ I have used the relevant theory: how evaporation causes cooling.[3]

11. a. $Q_{melt} = mL = 10.0 \times 2.47 \times 10^5\ \text{J}$

$Q_{melt} = 2.47 \times 10^6\ \text{J}$

b. $Q_{total} = Q_{liquid} + Q_{melt} \Rightarrow Q_{liquid} = Q_{total} - Q_{melt}$

$Q_{liquid} = 3.00 \times 10^6 - 2.47 \times 10^6 = 5.30 \times 10^5\ \text{J}$ (1 MARK)

$Q_{liquid} = mc\Delta T \Rightarrow 5.30 \times 10^5 = 10.0 \times 8.20 \times 10^2 \times \Delta T$ (1 MARK)

$\Delta T = 64.6°\text{C} \Rightarrow T_f = T_i + \Delta T = 1538 + 64.6 = 1603$

$= 1.60 \times 10^3\ °\text{C}$ (1 MARK)

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12. [Because mudbrick is dense (has a lot of mass), and has a high specific heat capacity, it would take a lot of energy to increase its temperature substantially.[1]] [In summer, heat from inside and outside the house would be conducted away by the mudbrick, with little change in temperature of the mudbrick itself. This results in a cooler interior.[2]] [In winter, any heat inside the house would be conducted away by the mudbrick, making it very difficult to heat up the home efficiently.[3]]

- I have used the relevant theory: heat energy is proportional to specific heat capacity and mass.[1]
- I have addressed the question: why mudbrick houses are good for summer.[2]
- I have addressed the question: why mudbrick houses are not ideal for winter.[3]

13. Let the boiling point of the substance be defined as the initial temperature (T_i).

If 5.96×10^5 J of energy was used in total, and 5.60×10^5 J of that energy was used to cause the state change, then:

$Q = 5.96 \times 10^5 - 5.60 \times 10^5 = 3.6 \times 10^4$ J was used for heating the temperature up after the state change. (1 MARK)

$Q = mc\Delta T$ (1 MARK)

Solve for ΔT:

$3.6 \times 10^4 = 2.00 \times 450 \times \Delta T$

$\Delta T = 40°\text{C}$ (1 MARK)

Solve for T_i:

$\Delta T = T_f - T_i$

$40 = 1.58 \times 10^3 - T_i$

$T_i = 1.54 \times 10^3$ °C (1 MARK)

Convert from degrees celsius to kelvin:

$T_i = 1.54 \times 10^3 + 273.15 = 1813.15 = 1.81 \times 10^3$ K
(1 MARK)

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3A Thermal radiation

Progress questions

1. B
2. A
3. A
4. A
5. D
6. B

Deconstructed exam-style

7. A
8. D
9. C
10. $\lambda_{max\ diff} = \lambda_{cooler} - \lambda_{hotter}$

$\Rightarrow \lambda_{max\ diff} = \lambda_{copper} - \lambda_{iron} = \frac{b}{T_c} - \frac{b}{T_I}$ (1 MARK)

$\lambda_{max\ diff} = \frac{b}{T_c} - \frac{b}{T_I} = \frac{2.898 \times 10^{-3}}{560 + 273.15} - \frac{2.898 \times 10^{-3}}{680 + 273.15}$ (1 MARK)

$\lambda_{max\ diff} = 4.38 \times 10^{-7}$ m (1 MARK)

Difference in peak wavelength emitted is 438 nm. (1 MARK)

Exam-style

11. $\lambda_{max} = \frac{b}{T} = \frac{2.898 \times 10^{-3}}{7.0 \times 10^{3}}$ (1 MARK)

$\lambda_{max} = 4.14 \times 10^{-7} = 4.1 \times 10^{-7}$ m (1 MARK)

12. [Over time, the temperature of the cup of tea will slowly decrease.[1]] [A decrease in temperature means the amount of thermal radiation emitted by the cup also decreases.[2]] [According to Wien's Law, $\lambda_{max} = \frac{b}{T}$, the peak wavelength emitted will increase.[3]]

- I have explicitly addressed the temperature of the tea will decrease.[1]
- I have explicitly addressed the decrease in thermal radiation emitted.[2]
- I have explicitly addressed the increase in peak wavelength emitted.[3]

13. a. [The reason the colour changes from "metallic silver" to red is because the majority of visible light coming from the metal changes from being reflected light to emitted light.[1]] [The reason the colour changes from red to orange to white is because the proportion of light emitted at each wavelength changes.[2]] [The intensity of light emitted increases as temperature increases.[3]]

- I have explicitly addressed the change in colour from "metallic silver" to red.[1]
- I have explicitly addressed the change in colour from red to white.[2]
- I have explicitly addressed the relationship between temperature and intensity of radiation.[3]

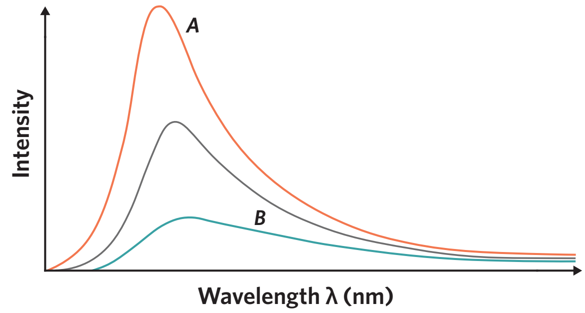
b. $\lambda_{max} = \frac{b}{T} \Rightarrow 680 \times 10^{-9} = \frac{2.898 \times 10^{-3}}{T}$ (1 MARK)

$T = 4.261 \times 10^{3} = 4.26 \times 10^{3}$ K (1 MARK)

14. a. [Object A is at a higher temperature,[1]] [as it has a shorter peak wavelength, $\lambda_{max} = \frac{b}{T}$,[2]] [and the area under its intensity-wavelength graph is greater, proportional to a greater amount of energy emitted.[3]]

- I have explicitly addressed object A is at a higher temperature.[1]
- I have used relevant theory: length of peak wavelength.[2]
- I have used relevant theory: the relationship between energy and area under intensity-wavelength graph.[3]

b.



- I have drawn a curve in between A and B at all points.
- I have drawn the peak of the curve between the peaks of A and B.
- I have drawn a graph of appropriate shape.

15. a. $T = 1280 + 273.15 = 1553.15 = 1553$ K (1 MARK)

$\lambda_{max} = \frac{b}{T} = \frac{2.898 \times 10^{-3}}{1553} = 1.8660 \times 10^{-6} = 1.866 \times 10^{-6}$ m (1 MARK)

b. [All objects emit radiation across the entire spectrum.[1]] [Since the peak wavelength sits outside the visible spectrum,[2]] [the intensity of visible light emitted by the glass around the longer wavelength (red) part of the visible spectrum is higher than the shorter wavelength (blue).[3]]

- I have used the relevant theory: objects emit thermal radiation across the entire spectrum.[1]
- I have referenced the peak wavelength.[2]
- I have used the relevant theory: the intensity of light near the peak wavelength is high.[3]

16. [Luna is incorrect.[1]] [A warmer object will emit a greater amount of energy at each wavelength than one that is cooler.[2]] [Selene is also incorrect.[3]] [A warmer object will emit a greater proportion of its energy at shorter wavelengths than a cooler object, as its peak wavelength is shorter $\left(\lambda_{max} = \frac{b}{T}\right)$.[4]]

- I have explicitly stated Luna is incorrect.[1]
- I have used the relevant theory: warmer objects emit more energy at every wavelength.[2]
- I have explicitly stated Selene is incorrect.[3]
- I have used the relevant theory: warmer objects emit a greater proportion of energy at all wavelengths.[4]

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17. a. [According to Wien's Law, $\lambda_{max} = \frac{b}{T}$, the two stars emit the maximum proportion of radiation at different wavelengths due to their differing temperatures.[1]][The star that shines blue is likely to have a peak wavelength shorter than or equal to the wavelength of blue light,[2]][whereas the star that shines red is likely to have a peak wavelength longer than or equal to red light.[3]]

- I have used relevant theory: Wien's Law.[1]
- I have explicitly addressed the blue star may have a peak wavelength shorter than or equal to the wavelength of blue light.[2]
- I have explicitly addressed the red star may have a peak wavelength longer than or equal to the wavelength of red light.[3]

b. $\lambda_{max} = \frac{b}{T} \Rightarrow 475 \times 10^{-9} = \frac{2.898 \times 10^{-3}}{T}$ (1 MARK)

$T = 6101 = 6.10 \times 10^{3}$ K (1 MARK)

Key science skills

18. [Asteri's data is more precise than Stella's data.[1]][This is because the range of Asteri's data (382 nm) is less than the range of Stella's data (534 nm).[2]]

- I have explicitly addressed whether Stella or Asteri has the more precise data.[1]
- I have used the relevant theory: the definition of precision.[2]

FROM LESSON 11C

Previous lessons

19. $n = \frac{c}{v} \Rightarrow 1.80 = \frac{3.00 \times 10^{8}}{v}$

$v = 1.67 \times 10^{8}$ m s^{-1} (1 MARK)

$v = f\lambda \Rightarrow 1.67 \times 10^{8} = f \times 8.80 \times 10^{-7}$ (1 MARK)

$f = 1.89 \times 10^{14}$ Hz (1 MARK)

FROM LESSON 1D

20. [Convection is taking place.[1]][This is because the steam from the coffee is hotter than the surrounding air, so rises above it.[2]]

- I have explicitly stated convection is taking place.[1]
- I have used the relevant theory: difference in temperature between steam and surrounding air.[2]

FROM LESSON 2B

3B Global warming and climate change

Progress questions

1. reflected; absorbed; transmitted
2. True, False, True, True
3. A
4. B
5. C
6. Emitting CO_2, Emitting other greenhouse gases, Changing ozone concentrations, Change in solar energy reaching earth, Changing surface albedo, Emitting aerosoles

Deconstructed exam-style

7. C
8. B
9. [Change in global temperatures is proportional to incoming solar energy minus outgoing Earth energy.[1]][Therefore radiative equilibrium is reached[2]][when incoming solar energy is equal to outgoing Earth energy.[3]]

- I have used the relevant theory: Change in global temperatures is proportional to incoming solar energy minus outgoing Earth energy.[1]
- I have related my answer to the context of the question.[2]
- I have explicitly addressed that incoming solar energy is equal to outgoing Earth energy.[3]

Exam-style

10. a. Any four of the following: warming trend, heat waves, bush fires, coral reef destruction, cyclones, flooding, droughts, reduced food production, reduced snow, mountain ecosystems loss, decrease in freshwater, sea level rise, coastal flooding, ocean acidification.

b. Any two of the following: greenhouse gas emission, changing land usage/albedo, increasing tropospheric (lower atmosphere) ozone levels, increasing stratospheric (upper atmosphere) water vapour.

11. a. P = Earth, Q = Sun

b. 0.55 μm

Any answer between 0.5 μm and 0.6 μm is acceptable for full marks.

c. Electromagnetic radiation

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12. [Change in global temperatures is dependent on incoming solar energy minus outgoing Earth energy[1]][therefore if outgoing Earth energy decreases while incoming solar energy remains the same global temperatures must increase.[2]]

- I have used the relevant theory: change in global temperatures is dependent on incoming solar energy minus outgoing Earth energy.[1]
- I have related my answer to the context of the question.[2]

13. a. [Water vapour transfers energy through convection.[1]] [As evaporated water rises to the upper atmosphere, so does its energy.[2]]

- I have used the relevant theory: convection.[1]
- I have related my answer to the context of the question.[2]

b. [Changing evaporation patterns causes a change in rainfall patterns.[1]][The frequency and severity of droughts and floods are dependent on the rainfall patterns of a regional climate.[2]]

- I have referenced changing evaporation patterns leading to changing rainfall patterns.[1]
- I have used the relevant theory: linking rainfall patterns to droughts and floods.[2]
- I have related my answer to the context of the question.

14. a. [The movement of heat through convection determines the climate of regions across the globe.[1]][An example of this is the climate of Europe being warmer due to The Gulf Stream current transferring heat from the equator to Europe.[2]]

- I have used the relevant theory: the influence of convection on climate.[1]
- I have referenced the Gulf Stream current warming western Europe.[2]
- I have related my answer to the context of the question.

b. [Cooler temperatures will likely lead to a disruption in food production[1]][and a change in the frequency and severity of storms.[2]]

- I have explicitly addressed a consequence of disrupting the Gulf Stream.[1]
- I have explicitly addressed a second consequence of disrupting the Gulf Stream.[2]

15. a. [Changing Earth's albedo affects the amount of energy Earth absorbs and reflects.[1]][For energy to transform into a different form it must first be absorbed by matter.[2]]

- I have used the relevant theory: definition of albedo.[1]
- I have used the relevant theory: energy transformation.[2]

b. [With a higher albedo, farmland will convert less of the electromagnetic radiation into thermal energy.[1]] [Therefore, cutting down forests, when only considering albedo,[2]][would result in reduced global temperatures.[3]]

- I have used the relevant theory: energy transformation.[1]
- I have related my answer to the context of the question.[2]
- I have explicitly addressed the effect of cutting down forests on global temperatures.[3]

Key science skills

16. [Bronte's claim is correct, and Endrico's is incorrect.[1]] [Theories are explanations of physical phenomena that have been repeatedly supported by experimental evidence.[2]][Hypotheses are proposed explanations of relationships that are yet to be tested.[3]]

- I have explicitly addressed who is correct.[1]
- I have used the relevant theory: definition of a theory.[2]
- I have used the relevant theory: definition of a hypothesis.[3]

FROM LESSON 11A

Previous lessons

17. [Yes, a mirage could form in this context.[1]][The heat of the road would heat up the air above it creating a temperature and density gradient in the air, the conditions for a mirage to form.[2]]

- I have explicitly addressed if a mirage could form.[1]
- I have used the relevant theory: formation of a mirage.[2]

FROM LESSON 1E

18. $\lambda_{max} = 9760 \text{ nm} = 9760 \times 10^{-9} = 9.760 \times 10^{-6} \text{ m}$

$\lambda_{max} = \frac{b}{T} \Rightarrow 9.760 \times 10^{-6} = \frac{2.898 \times 10^{-3}}{T}$ (1 MARK)

$T = 296.9 \text{ K}$ (1 MARK)

$T = 296.9 - 273.15 = 23.78 = 23.8°\text{C}$ (1 MARK)

FROM LESSON 2C

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Chapter 3 review

Section A

1. A. $\lambda_{max} = \frac{b}{T} \Rightarrow 230 \times 10^{-9} = \frac{2.898 \times 10^{-3}}{T}$

$T = 12\,600$ K

2. D. Greenhouse gases are both naturally occurring and produced by human activity.

3. A. The red flame has the longest peak wavelength of emission, so is the coolest ($\lambda_{max} = \frac{b}{T}$). The cooler flame will produce a greater proportion of its energy in longer wavelengths, including the infrared region.

4. B. Flood frequency and severity is likely to increase due to extreme precipitation.

5. A. With darker soil the Moon would absorb more visible light. Since visible light is a major part of the Sun's spectrum, we expect the Moon's albedo to be decreased, increasing the energy absorbed.

Section B

6. **a.** Diesel vehicle

b. Electric vehicle

c. [If the electricity used to power the car is produced with no net CO_2 emission, there is no longer an associated CO_2 release when it is driven.[1]] [By changing from a petrol to electric vehicle, the CO_2 produced when driving is eliminated.[2]] [Reducing the amount of greenhouse gases produced while driving will reduce individual impact on global warming.[3]]

- I have used the relevant theory: CO_2 release by the electric vehicle.[1]
- I have explicitly addressed the electric vehicle would release less CO_2 to the atmosphere.[2]
- I have explicitly addressed reducing greenhouse gases will reduce impact on global warming.[3]

7. **a.** [The studio light is likely to be at higher temperature.[1]] [This is as temperature is inversely proportional to peak wavelength according to Wien's Law.[2]] [Since white light is a combination of the entire visible spectrum and is made up of larger proportions of shorter wavelength radiation than yellow light, the source of the white light is hotter.[3]]

- I have explicitly addressed which light will be at a higher temperature.[1]
- I have referenced Wien's law.[2]
- I have used the relevant theory: electromagnetic spectrums of real bodies.[3]

b. $\lambda_{max} = \frac{b}{T} = \frac{2.898 \times 10^{-3}}{3500}$ (1 MARK)

$\lambda_{max} = 828.0$ nm (1 MARK)

8. **a.** [According to Wien's law, $\lambda_{max} = \frac{b}{T}$, the blue flame must be at a higher temperature than the red flame, as its λ_{max} is shorter.[1]] [The blue flame will emit a greater amount of energy as it is hotter,[2]] [and therefore boil the beaker of water quicker.[3]]

- I have explicitly addressed the blue flame is at a higher temperature.[1]
- I have explicitly addressed the hotter flame will emit a greater amount of energy.[2]
- I have explicitly addressed blue flame will boil the water quicker.[3]

b. $\lambda_{max} = \frac{b}{T}$

$\Rightarrow$ Gradient of a λ_{max} vs $\frac{1}{T}$ graph is Wien's constant, b.

(1 MARK)

$gradient = b = \frac{rise}{run} = \frac{(6.6 - 5.2) \times 10^{-9}}{(2.4 - 1.8) \times 10^{-6}}$ (1 MARK)

$b = 2.3 \times 10^{-3}$ m K (1 MARK)

c. [This method is least accurate at temperatures where the peak wavelength of emitted light is not in the visible range.[1]] [The observed wavelength of light is where the greatest amount of visible light is emitted, but not where the greatest amount of light is emitted.[2]] [The human eye is not able to see the peak wavelength of light emitted as it is not in the visible spectrum.[3]]

- I have explicitly addressed temperatures at which visual analysis is least accurate.[1]
- I have used the relevant theory: observed peak wavelength.[2]
- I have explicitly addressed peak wavelengths outside the visible spectrum cannot be observed.[3]

9. **a.** [Greenhouse gases absorb and re-emit much of Earth's radiation.[1]] [By re-emitting radiation back to the Earth, greenhouse gases prevent energy from escaping the Earth, thereby increasing its temperature through the greenhouse effect.[2]]

- I have explicitly addressed greenhouse gases and their relationship to the Earth's and solar radiation.[1]
- I have used the relevant theory: greenhouse gases.[2]

b. [Venus experiences the greatest greenhouse effect.[1]] [This may be due to having the greatest amount of naturally occurring greenhouse gases in its atmosphere.[2]]

- I have explicitly stated Venus experience the greatest greenhouse effect.[1]
- I have used relevant theory: greenhouse effect is due to the presence of greenhouse gases.[2]

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c. [The long chains of sulphur dioxide and water vapour could reflect the incoming light before reaching the surface.[1]] [This would reduce the amount of sunlight absorbed by the earth, reducing the temperature of the surface.[2]]

- I have explicitly stated the long chains will reflect incoming sunlight.[1]
- I have used relevant theory: reduction in sunlight absorbed will reduce the average temperature of the Earth.[2]

Unit 1 AOS 1 review

Section A

1. C. The waves with the highest energy are the furthest right on the electromagnetic spectrum.

   FROM LESSON 1C

2. D. Objects being cooled release heat to the environment, and the object that is cooled with the higher specific heat capacity will release more heat.

   FROM LESSON 2C

3. C. The peak wavelength of the Sun is either in wavelength less than or equal to that of red light. The intensity of radiation emitted decreases as the wavelength increases. X-rays have the shortest wavelength in the list, so will have the lowest intensity.

   FROM LESSON 3A

4. A. $\frac{Q}{t}$ is the rate heat is being transferred via conduction. Since ΔT changes by a factor of and $\frac{\Delta T_f}{\Delta T_i} = \frac{-12-(-18)}{-6-(-18)} = \frac{1}{2}$ and $\frac{Q}{t} \propto \Delta T$, $\frac{Q}{t}$ also changes by a factor of $\frac{1}{2}$. So $\frac{Q_f}{t_f} = \frac{\Delta T_f}{\Delta T_i} \times \frac{Q_i}{t_i} = \frac{1}{2} \times 2 = 1\ \text{J s}^{-1}$.

   FROM LESSON 2B

5. D. For a mirage to form, the temperature, and therefore the density, of the air must either decrease or increase with height.

   FROM LESSON 1E

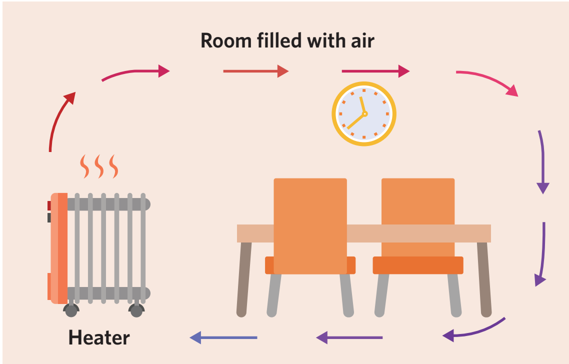
Section B

6. [Thermal radiation will be affected by the reflectivity of the liquid,[1]] [conduction will be affected by the thermal capacity,[2]] [and convection will be affected by the viscosity.[3]]

   - I have explicitly addressed which property affects thermal radiation.[1]
   - I have explicitly addressed which property affects conduction.[2]
   - I have explicitly addressed which property affects convection.[3]

   FROM LESSON 2B

7. a.



- I have drawn arrows representing hot air rising from the radiator to the top of the room.
- I have drawn arrows that loop around the boundaries of the room, representing the warm air cooling and falling back to the ground.
- I have drawn arrows that return to the heater, representing the cool air replacing the air rising from the heater.

b. [As the heater is at a higher temperature than the room, the average translational energy of the heater's particles are greater than the room's particles.[1]] [Over time the kinetic energy from the particles in the heater is transferred to the particles in the room.[2]] [As the average translational kinetic energy of the particles in the room increases, the temperature of the room will increase too.[3]]

- I have explicitly stated the average translational energy of the heater's particles are greater than the room's particles.[1]
- I have used the relevant theory: energy transfer.[2]
- I have explicitly stated the temperature of the room will increase.[3]

c. [Placing heaters on the ground and air conditioners closer to the ceiling creates the conditions for a convection cell to form in the room.[1]] [This allows warm air to rise and cool air to fall which creates better conditions for cooling or heating the space.[2]]

- I have used the relevant theory: convection cell.[1]
- I have used the relevant theory: favourable conditions for cooling or heating the space.[2]

FROM LESSONS 2A & 2B

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8. a. Use any two points on the line for honey to calculate the gradient.

$$gradient = \frac{y_2 - y_1}{x_2 - x_1} = \frac{76 - 20}{(40 - 0) \times 10^3}$$

$gradient = 1.4 \times 10^{-3}$ K J^{-1} (1 MARK)

$Q = mc\Delta T \Rightarrow \frac{\Delta T}{Q} = \frac{1}{mc} \Rightarrow$ gradient of Δt vs Q graph is $\frac{1}{mc}$

$1.4 \times 10^{-3} = \frac{1}{0.300 \times c}$ (1 MARK)

$c = 2.38 \times 10^3 = 2.4 \times 10^3$ J kg^{-1} K^{-1} (1 MARK)

b. Use any two points on the line for honey to get Q and ΔT for the new water sample.

$Q = mc\Delta T \Rightarrow (40 - 0) \times 10^3 = m \times 4200 \times (76 - 20)$ (1 MARK)

$m = 0.170 = 0.17$ kg (1 MARK)

FROM LESSON 2C

9. a. [The greenhouse effect is the capturing of thermal energy from the Sun by greenhouse gases in the Earth's atmosphere.[1]] [Humans have increased the amount of greenhouse gases in the environment through the burning of fossil fuels,[2]] [increasing the greenhouse effect, and therefore the temperature, on Earth.[3]]

- I have explicitly addressed the greenhouse effect.[1]
- I have explicitly addressed how human activity has increased greenhouse gases in the atmosphere.[2]
- I have used the relevant theory: greenhouse effect's impact on temperature.[3]

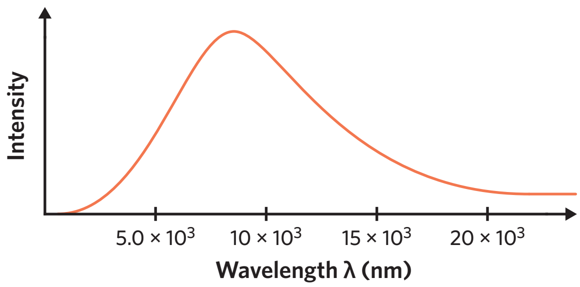
b. Constructing cities with an albedo lower than their environment increases the amount of thermal energy absorbed by the Earth.

c. $\lambda_{max} = \frac{b}{T} = \frac{2.898 \times 10^{-3}}{41.9 + 273.15}$ (1 MARK)

$\lambda_{max} = 9.20 \times 10^{-6}$ m (1 MARK)

Peak wavelength is at 9.2×10^3 nm. (1 MARK)

d.



- I have drawn the peak of the curve at $\lambda = 9.2 \times 10^3$ nm.
- I have drawn a graph of appropriate shape.
- I have correctly labelled the horizontal and vertical axes.
- I have drawn the horizontal axis with consistent spacing.

FROM LESSONS 3A & 3B

10. a. $v = f\lambda \Rightarrow 3.0 \times 10^8 = f \times 550 \times 10^{-9}$ (1 MARK)

$f = 5.45 \times 10^{14} = 5.5 \times 10^{14}$ Hz (1 MARK)

b. [The bus will absorb the light from the green laser.[1]] [A red object reflects red light, and absorbs all other incident wavelengths, including green light.[2]]

- I have explicitly addressed the bus will absorb the green light.[1]
- I have used relevant theory: red object absorbs all wavelengths of light than are not red.[2]

c. $n_1\sin(\theta_1) = n_2\sin(\theta_2)$

$1.46 \times \sin(75°) = 1.43 \times \sin(\theta_2)$ (1 MARK)

$\theta_2 = \sin^{-1}\left(\frac{1.46 \times \sin(75°)}{1.43}\right) = 80.46° = 80.5°$ (1 MARK)

As $\theta_2 < 90°$, total internal reflection will not occur. (1 MARK)

d. [The observer cannot see the light because the ray is being totally internally reflected which means no light is escaping.[1]] [This occurs when the incident angle of the ray is larger than the critical angle.[2]]

- I have explicitly addressed why the observer cannot see the ray.[1]
- I have used the relevant theory: total internal reflection and critical angle.[2]

FROM LESSONS 1B, 1C & 1D

11. a. [When a beam of white light enters a raindrop, the light disperse in the water.[1]] [Some of the light escapes the raindrop,[2]] [and some of the light is internally reflected.[3]]

- I have explicitly addressed light disperses when entering a raindrop.[1]
- I have used the relevant theory: light escapes the raindrop.[2]
- I have used the relevant theory: light internally reflects.[3]

b. [Inside the raindrop, different frequencies of light have different refractive indexes.[1]] [As the violet component of light has a shorter wavelength than red light, it has a greater refractive index.[2]] [According to Snell's law, the violet component of light will have a lesser angle of refraction than the red component of light when entering the raindrop.[3]]

- I have used the relevant theory: refractive index of light dependent on frequency in a raindrop.[1]
- I have explicitly addressed violet light has a greater refractive index than red light.[2]
- I have used the relevant theory: Snell's Law.[3]

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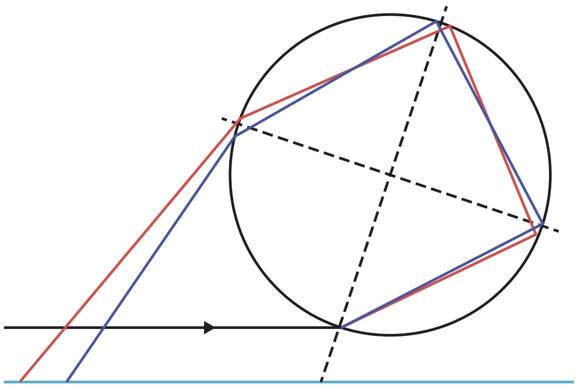
c.



✓ ✗ I have drawn the angle of refraction of the violet component of light entering the raindrop greater than red light.

✓ ✗ I have drawn the internal angle of reflections equivalent to incident angles.

✓ ✗ I have drawn two internal reflections.

FROM LESSONS 1D & 1E

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4A Nuclear stability and the fundamental forces

Progress questions

1. repulsive; attractive; quarks; nucleons

2.

	Acts on protons	Acts on neutrons	Acts noticeably at long distances	Acts noticeably at short distances
Strong force	✓	✓	✗	✓
Weak force	✓	✓	✗	✓
Electro-magnetic force	✓	✗	✓	✓

3. C

4. C

5. Q-*N* (number of neutrons); P-*Z* (number of protons); R-$N = Z$ line; S-Unstable isotopes; T-Stable isotopes

Deconstructed exam-style

6. C

7. C

8. [The isotope carbon-12 will be stable[1]][since it has less than 20 protons, and an equal number of protons and neutrons.[2]] [The isotope thorium-232 will be unstable[3]][since it has 90 protons and all atoms with 84 or more protons are inherently unstable.[4]]

   - I have explicitly addressed whether the carbon-12 isotope is stable or unstable.[1]
   - I have used the relevant theory: nuclear stability for atoms with 20 or less protons.[2]
   - I have explicitly addressed whether the thorium-232 isotope is stable or unstable.[3]
   - I have used the relevant theory: nuclear stability for atoms with 84 or more protons.[4]

Exam-style

9. a. require more neutrons than protons to be stable.

   b. are usually stable if they have an equal number of protons and neutrons.

   c. are inherently unstable.

10. a. The isotope has 15 protons and 15 neutrons.

    Since it has less than 20 protons, it will most likely be stable if it has an equal number of protons and neutrons **OR** reference Figure 2 (1 MARK)

    Stable (1 MARK)

    b. The isotope has 45 protons and 45 neutrons.

    Since it has more than 20 protons, it will require more neutrons than protons to be stable **OR** reference Figure 2 (1 MARK)

    Unstable (1 MARK)

    c. The isotope has 87 protons and 223 nucleons.

    Since it has more than 84 protons, it is inherently unstable **OR** reference Figure 2 (1 MARK)

    Unstable (1 MARK)

    d. The isotope has 85 nucleons, 48 neutrons, and therefore 37 protons.

    Reference Figure 2 (Note: is possibly stable since it has more neutrons than protons) (1 MARK)

    Stable (1 MARK)

11. [A nucleus with too many protons will experience a greater repulsive electrostatic force between the protons than the attractive strong force between the nucleons.[1]][This makes the nucleus unstable since it is less strongly held together.[2]]

    - I have used the relevant theory: electrostatic and strong forces in the nucleus.[1]
    - I have explicitly addressed the instability of the nucleus.[2]

12. [A general isotope of an atom may have either a stable or unstable nucleus.[1]][A radioisotope will undergo radioactive decay so it must have an unstable nucleus.[2]]

    - I have used the relevant theory: isotopes.[1]
    - I have used the relevant theory: radioisotopes.[2]

13. [Genevieve is correct.[1]][Jana claims that the nucleus is stable if it has an equal number of protons and neutrons. However, this only true for elements with 20 or less protons, so she is incorrect.[2]][As gold has 79 protons, which is more than 20, Genevieve is correct that this stability rule does not apply.[3]]

    - I have explicitly addressed who is correct.[1]
    - I have used the relevant theory: nuclear stability for atoms with 20 or less protons.[2]
    - I have used the relevant theory: nuclear stability for atoms with greater than 20 protons.[3]

Key science skills

14. a. Independent variable

    b. Dependent variable

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c. [An atomic element is defined by the number of protons it has, and the stability of its isotopes is individually determined by the properties of each isotope's nucleus.[1]][This allows the independent axis to identify the elements, and the vertical axis to then identify the corresponding isotopes.[2]]

- I have used the relevant theory: atomic nuclei.[1]
- I have used the relevant theory: relationship between horizontal and vertical axes.[2]

FROM LESSON 11A

Previous lessons

15. a. [Violet, blue, green, yellow, orange, red.[1]][Shorter wavelengths refract more which places them lower down in this spectrum.[2]]

- I have explicitly addressed the colour order of light.[1]
- I have used the relevant theory: refraction.[2]

b. [Dispersion is occuring.[1]][Dispersion is the process of white light being separated into its constituent colours when each colour refracts by a different amount as it enters and leaves a medium.[2]]

- I have explicitly addressed the relevant phenomenon.[1]
- I have used the relevant theory: dispersion of white light.[2]

FROM LESSON 1E

16. $\lambda_{max} = \frac{b}{T}$

$T = 1420°\text{C} = (1420 + 273.15)\text{ K} = 1693.15\text{ K}$

$\lambda_{max} = \frac{2.898 \times 10^{-3}}{1693.15}$ (1 MARK)

$\lambda_{max} = 1.711 \times 10^{-6}\text{ m}$ (1 MARK)

This is not within the visible spectrum of light. (1 MARK)

FROM LESSON 3A

4B Nuclear half-life

Progress questions

1. C 2. B 3. A 4. B

5. A 6. C

Deconstructed exam-style

7. A. $\frac{6.0}{24} = 0.25$

8. A. $\frac{1}{2} \times \frac{1}{2} = \left(\frac{1}{2}\right)^{2.0} = 0.25 \Rightarrow n = 2.0$

9. B. $t_{1/2} = \frac{T}{n} = \frac{28\ days}{2.0\ half\text{-}lives} = 14$ days

10. Use the known data to calculate the half-life.

$m = m_0\left(\frac{1}{2}\right)^n \Rightarrow 6.0 = 24 \times \left(\frac{1}{2}\right)^n$

$n = 2.0$ half-lives until only 6.0 mg remains. (1 MARK)

$t_{1/2} = \frac{T}{n} = \frac{28\ days}{2.0\ half\text{-}lives} = 14$ days (1 MARK)

Use the half-life to calculate the time required.

$m = m_0\left(\frac{1}{2}\right)^n \Rightarrow 1.5 = 24 \times \left(\frac{1}{2}\right)^n$

$\left(\frac{1}{2}\right)^n = \frac{1.5}{24} = 0.0625 = \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} = \left(\frac{1}{2}\right)^{4.0}$

$n = 4.0$ half-lives until only 1.5 mg remains. (1 MARK)

$T = n \times t_{1/2} = 4.0 \times 14$ days $= 56$ days (1 MARK)

Exam-style

11. a. $m = m_0 \times \left(\frac{1}{2}\right)^n = 0.840 \times \left(\frac{1}{2}\right)^3 = 0.105$ g

b. The amount that remains is:

$m = m_0 \times \left(\frac{1}{2}\right)^n = 0.840 \times \left(\frac{1}{2}\right)^4 = 0.0525$ g (1 MARK)

The amount that has decayed is:

$m_0 - m = 0.840 - 0.0525 = 0.7875 = 0.788$ g (1 MARK)

12. a. $n = \frac{T}{t_{1/2}} = \frac{56}{8.0} = 7$ half-lives (1 MARK)

$N = N_0\left(\frac{1}{2}\right)^n = 5.0 \times 10^{10} \times \left(\frac{1}{2}\right)^7 = 3.9 \times 10^8$ atoms (1 MARK)

b. $N = N_0\left(\frac{1}{2}\right)^n \Rightarrow 6.25 \times 10^9 = 5.0 \times 10^{10} \times \left(\frac{1}{2}\right)^n$ (1 MARK)

$\left(\frac{1}{2}\right)^n = \frac{6.25 \times 10^9}{5.0 \times 10^{10}} = 0.125 = \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} = \left(\frac{1}{2}\right)^3$

$n = 3$ half-lives until only 6.25×10^9 atoms remain. (1 MARK)

$T = n \times t_{1/2} = 3 \times 8.0$ days $= 24$ days (1 MARK)

13. a. $t_{1/2} = 200$ s

b. 20 minutes $= 20 \times 60$ s $= 1200$ s

$n = \frac{T}{t_{1/2}} = \frac{1200}{200} = 6$ half-lives (1 MARK)

$A = A_0\left(\frac{1}{2}\right)^n = 160 \times 10^3 \times \left(\frac{1}{2}\right)^6 = 2.50 \times 10^3$ Bq (1 MARK)

c. $n = \frac{T}{t_{1/2}} = \frac{400}{200} = 2$ half-lives (1 MARK)

$m = m_0\left(\frac{1}{2}\right)^n = 40 \times \left(\frac{1}{2}\right)^2 = 10$ g (1 MARK)

14. $n = \frac{T}{t_{1/2}} = \frac{90}{15} = 6$ half-lives (1 MARK)

$A = A_0\left(\frac{1}{2}\right)^n \Rightarrow 5000 = A_0\left(\frac{1}{2}\right)^6$ (1 MARK)

$A_0 = 3.2 \times 10^5$ Bq (1 MARK)

15. a. $\frac{1}{4}$ of the initial activity

b. [The activity of a substance is proportional to the amount of that substance remaining.[1]][This means that the proportion of the activity decreases at the same rate as substance itself.[2]]

- I have explicitly addressed that activity is proportional to amount of substance remaining.[1]
- I have used the relevant theory: the relationship between activity and number of nuclei.[2]

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16. a. $m = m_0 \times \left(\frac{1}{2}\right)^n \Rightarrow 0.15 = 0.60 \times \left(\frac{1}{2}\right)^n$ (1 MARK)

$\left(\frac{1}{2}\right)^n = \frac{0.15}{0.60} = \frac{1}{4} = \left(\frac{1}{2}\right)^2$ (1 MARK)

$T = n \times t_{1/2} = 2 \times 5730 = 11\,460$ years (1 MARK)

b. [It is not exact.[1]][As radioactive decay is a random process we can only know approximately how long the femur has been around through calculating the decay of carbon-14.[2]]

- I have explicitly addressed whether the calculation reflects the true age of the bone.[1]
- I have used the relevant theory: radioactive decay as a random process.[2]

17. Use the known data to calculate the half-life.

$m = m_0\left(\frac{1}{2}\right)^n \Rightarrow 12.5 = 50 \times \left(\frac{1}{2}\right)^n$

$n = 2$ half-lives until only 12.5 mg remains. (1 MARK)

$t_{1/2} = \frac{T}{n} = \frac{10.6\ years}{2\ half\text{-}lives} = 5.3$ years (1 MARK)

Use the half-life to calculate the time required.

$m = m_0\left(\frac{1}{2}\right)^n \Rightarrow 6.25 = 50 \times \left(\frac{1}{2}\right)^n$ (1 MARK)

$\left(\frac{1}{2}\right)^n = \frac{6.25}{50} = 0.125 = \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} = \left(\frac{1}{2}\right)^3$

$n = 3$ half-lives until only 6.25 mg remains. (1 MARK)

$T = n \times t_{1/2} = 3 \times 5.3$ years $= 15.9$ years (1 MARK)

Key science skills

18. a. Choose two points from the graph that are well separated to calculate gradient.

$gradient = \frac{rise}{run} = \frac{4 - 9}{300 - 0}$ (1 MARK)

$gradient = -0.0167$ (1 MARK)

b. Given the equation $\log(A) = -\frac{0.693}{t_{1/2}} \times t + 9$ (which can be compared with $y = mx + c$), the gradient must be $-\frac{0.693}{t_{1/2}}$ (1 MARK)

$-\frac{0.693}{t_{1/2}} = -0.0167$ (1 MARK)

$t_{1/2} = 41.58 = 42$ days (1 MARK)

FROM LESSONS 11D & 11E

Previous lessons

19. [Heat describes the flow of energy between systems due to a difference of temperature[1]][whereas temperature is a measure of the amount of kinetic energy that the molecules inside a substance have.[2]][We use the change in temperature to describe and calculate the heat being transferred between systems.[3]]

- I have used the relevant theory: definition of heat.[1]
- I have used the relevant theory: definition of temperature.[2]
- I have explicitly addressed the connection between heat and temperature.[3]

FROM LESSON 2A

20. [Raveena is correct and Kyle is incorrect.[1]][Compared to natural or cyclical climate change, temperatures are increasing and the climate is changing at an unprecedented rate.[2]][This change has only happened since the industrial revolution and there is strong evidence and scientific consensus to confirm that human activity is the cause of this change.[3]]

- I have explicitly addressed which claim is correct.[1]
- I have used the relevant theory: human activity and climate change.[2]
- I have referenced scientific consensus on the cause of climate change.[3]

FROM LESSON 3B

4C Types of nuclear radiation

Progress questions

1. A
2. B
3. B
4. C
5. C
6. B
7. B
8. B
9. A
10. B
11. A

Deconstructed exam-style

12. B

13. C

14. C

15. Parent nuclide: $Z = 90$, $A = 232$

6 alpha decays: Z decreases by $6 \times 2 = 12$, A decreases by $6 \times 4 = 24$ (1 MARK)

4 beta minus decays: Z increases by $4 \times 1 = 4$, A does not change (1 MARK)

Therefore, daughter nuclide: $Z = 90 - 12 + 4 = 82$, $A = 232 - 24 + 0 = 208$

Daughter nuclide is ${}^{208}_{82}\mathrm{Pb}$ (1 MARK)

Exam-style

16. a. ${}^{0}_{-1}e + {}^{0}_{0}\bar{v}$

b. ${}^{4}_{2}\mathrm{He}$

c. ${}^{0}_{0}\gamma$

d. ${}^{0}_{+1}e + {}^{0}_{0}v$

17. a. The alpha particle has a charge of +2 and a mass number of 4.

Daughter nuclide proton number $= Z - 2 = 78 - 2 = 76$ (chemical symbol is Os)

Daughter nuclide mass number $= A - 4 = 175 - 4 = 171$ (1 MARK)

${}^{171}_{76}\mathrm{Os}$ (1 MARK)

4C ANSWERS

b. The beta minus particle and antineutrino together have a total charge of −1 and a total mass number of 0.

Daughter nuclide proton number $= Z + 1 = 88 + 1 = 89$ (chemical symbol is Ac)

Daughter nuclide mass number $= A - 0 = 228 - 0 = 228$ (1 MARK)

$^{228}_{89}\text{Ac}$ (1 MARK)

c. The beta plus particle and neutrino together have a total charge of +1 and a total mass number of 0.

Daughter nuclide proton number $= Z - 1 = 12 - 1 = 11$ (chemical symbol is Na)

Daughter nuclide mass number $= A - 0 = 23 - 0 = 23$ (1 MARK)

$^{23}_{11}\text{Na}$ (1 MARK)

d. The gamma photon has a total charge of 0 and a total mass number of 0.

Daughter nuclide proton number $= Z - 0 = 53 - 0 = 53$ (chemical symbol is I)

Daughter nuclide mass number $= A - 0 = 125 - 0 = 125$ (1 MARK)

$^{125}_{53}\text{I}$ (1 MARK)

18. a. Parent nuclide proton number $= Z + 0 = 10 + 0 = 10$ (chemical symbol is Ne)

Parent nuclide mass number $= A + 0 = 22 + 0 = 22$ (1 MARK)

$^{22}_{10}\text{Ne}$ (1 MARK)

b. Parent nuclide proton number $= Z - 1 = 28 - 1 = 27$ (chemical symbol is Co)

Parent nuclide mass number $= A + 0 + 0 = 60 + 0 + 0 = 60$ (1 MARK)

$^{60}_{27}\text{Co}$ (1 MARK)

c. Parent nuclide proton number $= Z + 2 = 91 + 2 = 93$ (chemical symbol is Np)

Parent nuclide mass number $= A + 4 = 233 + 4 = 237$ (1 MARK)

$^{237}_{93}\text{Np}$ (1 MARK)

d. Parent nuclide proton number $= Z + 1 = 35 + 1 = 36$ (chemical symbol is Kr)

Parent nuclide mass number $= A + 0 + 0 = 74 + 0 + 0 = 74$ (1 MARK)

$^{74}_{36}\text{Kr}$ (1 MARK)

19. a. Alpha decay produces a daughter nuclide and an alpha particle.

Daughter nuclide proton number $= Z - 2 = 85 - 2 = 83$ (chemical symbol is Bi)

Daughter nuclide mass number $= A - 4 = 215 - 4 = 211$ (1 MARK)

$^{215}_{85}\text{At} \rightarrow {}^{211}_{83}\text{Bi} + {}^{4}_{2}\text{He}$ (1 MARK)

b. Beta plus decay produces a positron and a neutrino.

Daughter nuclide proton number $= Z - 1 = 29 - 1 = 28$ (chemical symbol is Ni)

Daughter nuclide mass number $= A - 0 = 64 - 0 = 64$ (1 MARK)

$^{64}_{29}\text{Cu} \rightarrow {}^{64}_{28}\text{Ni} + {}^{0}_{+1}e + {}^{0}_{0}\nu$ (1 MARK)

c. Beta minus decay produces an electron and an antineutrino.

Daughter nuclide proton number $= Z + 1 = 87 + 1 = 88$ (chemical symbol is Ra)

Daughter nuclide mass number $= A - 0 = 223 - 0 = 223$ (1 MARK)

$^{223}_{87}\text{Fr} \rightarrow {}^{223}_{88}\text{Ra} + {}^{0}_{-1}e + {}^{0}_{0}\overline{\nu}$ (1 MARK)

d. Gamma decay produces a gamma photon.

Daughter nuclide proton number $= Z - 0 = 34 - 0 = 34$ (chemical symbol is Se)

Daughter nuclide mass number $= A - 0 = 72 - 0 = 72$ (1 MARK)

$^{72}_{34}\text{Se} \rightarrow {}^{72}_{34}\text{Se} + {}^{0}_{0}\gamma$ (1 MARK)

20. a. Parent nuclide: $Z = 237, A = 93$

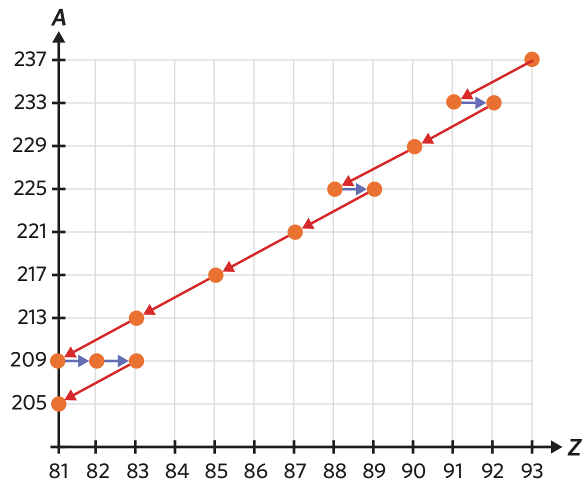
8 alpha decays: Z decreases by $8 \times 2 = 16$, A decreases by $8 \times 4 = 32$ (1 MARK)

4 beta minus decays: Z increases by $4 \times 1 = 4$, A does not change (1 MARK)

Therefore, daughter nuclide: $Z = 93 - 16 + 4 = 81$, $A = 237 - 32 + 0 = 205$

Daughter nuclide is $^{205}_{81}\text{Tl}$ (1 MARK)

b.



I have shown the initial parent nuclide as $^{237}_{93}\text{Np}$ and the final daughter nuclide as $^{205}_{81}\text{Tl}$.

I have drawn the correct sequence of alpha and beta decays.

I have drawn alpha decays as arrows pointing down 4 units and left 2 units.

I have drawn beta minus decays as arrows pointing right 1 unit.

I have correctly labelled the horizontal and vertical axes and have drawn the axes with consistent spacing.

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21. Beam A – Alpha radiation (1 MARK)

Beam B – Beta radiation (beta plus or beta minus) (1 MARK)

Beam C – Gamma radiation (1 MARK)

22. [Alpha decay would be represented by an arrow pointing down two units and left two units.[1]] [Beta minus decay would be represented by an arrow pointing down one unit and right one unit.[2]] [Beta plus decay would be represented by an arrow pointing up one unit and left one unit.[3]]

- I have used the relevant theory: alpha decay.[1]
- I have used the relevant theory: beta minus decay.[2]
- I have used the relevant theory: beta plus decay.[3]

23. [Ruby is correct.[1]] [Ruby claims that plastic would be sufficient to block the source of alpha particles due to their low penetrating ability.[2]] [Tom is incorrect as it is not necessary to use a more dense material, such as lead[3]]

- I have explicitly addressed who is correct.[1]
- I have used the relevant theory: alpha decay.[2]
- I have used the relevant theory: alpha decay.[3]

24. [The thicker the sheet of metal is, the more beta particles will be blocked by it causing the amount detected to fall.[1]] [This information can be transmitted to the rollers, increasing the pressure until desired thickness is achieved according to beta particle count.[2]]

- I have used the relevant theory: beta decay.[1]
- I have explicitly addressed a link between particle detection and roller pressure.[2]

Key science skills

25. a. 6 significant figures

b. $5.00\ \text{MeV} = 5.00 \times 10^{6}\ \text{eV}$ (1 MARK)

$= 5.00 \times 10^{6}\ \text{eV} \times 1.602 \times 10^{-19}\ \text{J eV}^{-1}$

$= 8.01 \times 10^{-13}\ \text{J}$ (1 MARK)

FROM LESSON 11B

Previous lessons

26. C

FROM LESSON 2A

27. [An isotope is an atom of an element that has a different number of neutrons (but the same number of protons) compared to another atom of the element.[1]] [A radioisotope is the kind of isotope that will undergo radioactive decay.[2]]

- I have used the relevant theory: isotopes.[1]
- I have used the relevant theory: radioisotopes.[2]

FROM LESSON 4A

4D Radiation and the human body

Progress questions

1. C	2. A	3. B	4. C
5. A	6. B	7. D	8. B
9. A	10. B	11. A	

Deconstructed exam-style

12. A

13. C

14. Ava:

$H = D \times w_r = 1.2 \times 20 = 24\ \text{Sv}$

$E = \sum(H \times w_t) = 24 \times 0.040 = 0.96\ \text{Sv}$ (1 MARK)

Charlotte:

$H = D \times w_r = 1.2 \times 1.0 = 1.2\ \text{Sv}$

$E = \sum(H \times w_t) = 1.2 \times 0.12 = 0.14\ \text{Sv}$ (1 MARK)

They are likely to have similar short term effects, as their absorbed doses are the same. (1 MARK)

Ava is likely to have worse long term effects, having absorbed a higher equivalent and effective dose. (1 MARK)

Exam-style

15. B. Alpha has the greatest radiation weighting factor, 20, and beta and gamma have the same, 1.

16. C. The lung has the highest tissue weighting factor in the list, 0.12, followed by the lung, 0.040, and the brain, 0.010.

17. [Radiation from sources outside the body must be able to penetrate the skin to have an ionising impact on internal cells,[1]] [whereas radiation from sources within the body are able to ionise cells without penetrating skin.[2]]

- I have addressed relevant theory: ionising ability of radioactive source outside the body.[1]
- I have addressed relevant theory: ionising ability of radioactive source inside the body.[2]

18. a. $H = D \times w_r = 0.060 \times 1.0 = 0.060\ \text{Sv}$ (1 MARK)

$E = \sum(H \times w_t) = 0.060 \times 0.12 = 7.2 \times 10^{-3}\ \text{Sv}$ (1 MARK)

b. The absorbed dose is relatively small (<1 Gy), so is unlikely to have any short term effects on the person.

19. [The emitted radiation is likely to be beta radiation.[1]] [As the radiation is able to penetrate plastic, it cannot be alpha radiation. The noticeable burns and eye irritation suggest a reasonable level of cell damage but only on surface tissues, so it can not be gamma radiation.[2]]

- I have explicitly addressed the type of radiation emitted.[1]
- I have used the relevant theory: impact and penetrating power of alpha, beta, and gamma radiation.[2]

20. a. alpha decay

b. [The seed barrier is typically made of thin metal, which an alpha particle is not able to penetrate,[1]] [so will be unable to reach the affected tumour and thus will not be able to kill any cancerous cells.[2]]

- I have addressed relevant theory: alpha radiation penetrating power.[1]
- I have explicitly addressed that the alpha particles will not be able to reach the affected tumour and kill cells.[2]

c. The side effects are likely minimal, as the alpha particles will not be able to damage any healthy cells either.

21. a. [The radioactive source is absorbed from both outside and inside the body by Davide,[1]] [but only from outside the body by Ekin-Su.[2]]

- I have explicitly addressed where the radioactive source is for Davide.[1]
- I have explicitly addressed where the radioactive source is for Ekin-Su.[2]

b. [Alpha particles' ionising impact is high when when the radioactive source is inside the body, but not outside the body.[1]] [Davide, would see an increase in absorbed dose, as well as effective and equivalent dose compared to Ekin-Su, as the radioactive source is within their body.[2]] [Davide is more likely to experience greater both short and long term effects as a result of this absorption compared to Ekin-Su.[3]]

- I have addressed relevant theory: alpha radiation ionising ability.[1]
- I have explicitly addressed an increase in absorbed, effective and equivalent dose absorbed by Davide compared to Ekin-Su.[2]
- I have explicitly addressed an increased likelihood of both short and long term effects by Davide compared to Ekin-Su.[3]

22. $E = \sum(H \times w_t)$

$3.4 \times 10^{-2} = H \times 0.01$ (1 MARK)

$H = \frac{E}{w_{t,\,brain}} = \frac{3.4 \times 10^{-2}}{0.01} = 3.4\ \text{Sv}$

$H = D \times w_r$

$3.4 = D \times 1$ (1 MARK)

$D = \frac{H}{w_r} = \frac{3.4}{1} = 3.4\ \text{Gy}$ (1 MARK)

Somewhere around 50% of people would experience death at some point from such exposure, so it is extremely unlikely the gamma imaging would take place with such high absorption dose measurements. (1 MARK)

Key science skills

23. [It is likely a systematic error is causing higher than expected values for the radiation,[1]] [perhaps due to the calibration of the digital device.[2]]

- I have explicitly addressed a systematic error is responsible for the difference in values.[1]
- I have explicitly addressed a specific reason for the error.[2]

FROM LESSON 11C

Previous lessons

24. C. It is impossible to tell because the balls are different sizes, and the rate of conduction depends on the surface area as well as temperature and material.

FROM LESSON 2B

25. $n = \frac{T}{t_{1/2}} = \frac{4 \times 24}{7} = 13.7$ (1 MARK)

$$N_0 = \frac{N}{\left(\frac{1}{2}\right)^n} = \frac{8.2 \times 10^{-3}}{\left(\frac{1}{2}\right)^{13.7}} = 1.1 \times 10^2\ \text{g}$$

1.1×10^2 g was the initial mass of the substance. (1 MARK)

FROM LESSON 4B

Chapter 4 review

Section A

1. A. The strong force acts over very short distances.

2. D. A neutron turns into a proton, so the sum of protons and neutrons (mass number) stays the same and the number of protons increases by 1.

3. B. Each β^- emission corresponds to an increase in the atomic number by 1 (and no change in the mass number) and the α emission corresponds to a decrease in the atomic number by 2 and a decrease in the mass number by 4.

4. D. After one half-life, that activity halves to 50% of its original value. After a second half-life, that activity halves again to 25% of its original value, which is a decrease of 75%.

5. C. Ionising impact depends on both penetrating power and ionising ability.

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Section B

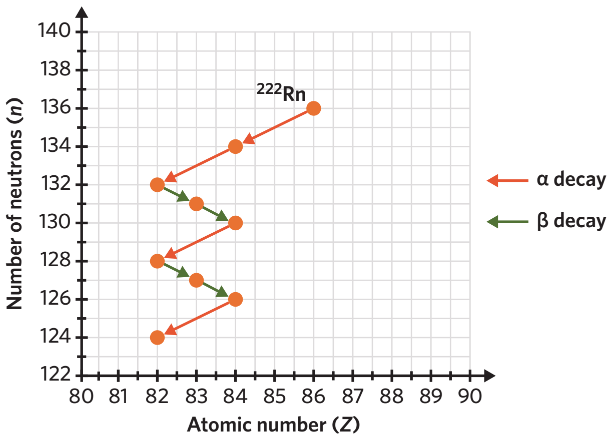
6. [A nucleus is stable if the strong force binding the nucleons (protons and neutrons) is greater than the electrostatic repulsion between the protons.[1]][Large nuclei tend to be less stable than small nuclei because the strong force acts over much shorter distances than the electrostatic force,[2]][which means that the electrostatic repulsion is the dominant force between nucleons in large nuclei whereas the strong force is the dominant force in small nuclei.[3]]

- I have explicitly addressed what makes a nucleus stable.[1]
- I have used the relevant theory: the ranges of the strong force and the electrostatic force.[2]
- I have explicitly addressed the reason that large nuclei are less stable than small nuclei.[3]

7. [A nucleus becomes smaller when it emits alpha (α) radiation.[1]] [It loses two protons and two neutrons in the process.[2]]

- I have explicitly addressed which form of radiation makes the nucleus smaller.[1]
- I have explicitly addressed the changes to the nucleus that occur.[2]

8.



- I have represented each alpha decay with an arrow that indicates a decrease by 2 along both the horizontal and vertical axes.
- I have represented each beta minus decay with an arrow that indicates an increase by 1 along the horizontal axis and a decrease by 1 along the vertical axis.
- I have started the decay series from a horizontal value of 86 and a vertical value of 136.
- I have shown the decays in the correct order.

9. **a.** The atomic number has decreased by 1, so β^+ decay must have occurred.

$${}^{40}_{19}\text{K} \rightarrow {}^{40}_{18}\text{Ar} + \beta^+ + \nu$$

- I have included the correct mass number for K.
- I have completed the equation with $\beta^+ + \nu$ or ${}^{0}_{+1}e + \nu$.

b. The atomic number has decreased by 2, so α decay must have occurred.

$${}^{218}_{85}\text{At} \rightarrow {}^{214}_{83}\text{Bi} + \alpha$$

- I have included the correct mass number for Bi.
- I have completed the equation with α or ${}^{4}_{2}\text{He}$.

10. Use the known data to calculate the half-life.

$$A = A_0\left(\tfrac{1}{2}\right)^n \Rightarrow 200 = 1600 \times \left(\tfrac{1}{2}\right)^n$$

$$\left(\tfrac{1}{2}\right)^n = \frac{200}{1600} = 0.125 = \tfrac{1}{2} \times \tfrac{1}{2} \times \tfrac{1}{2} = \left(\tfrac{1}{2}\right)^3$$

$$\left(\text{or use } n = \frac{\log(0.125)}{\log\left(\frac{1}{2}\right)} = 3\right)$$

$n = 3$ half-lives until the activity is 200 Bq. (1 MARK)

$$t_{1/2} = \frac{T}{n} = \frac{6\ hours}{3\ half\text{–}lives} = 2 \text{ hours}$$ (1 MARK)

Use the half-life to calculate the number of half-lives that have passed at 10 pm.

$$n = \frac{T}{t_{1/2}} = \frac{10\ hours}{2\ hours} = 5 \text{ half-lives}$$ (1 MARK)

$$A = A_0\left(\tfrac{1}{2}\right)^n \Rightarrow A = 1600 \times \left(\tfrac{1}{2}\right)^5 = 50 \text{ Bq}$$ (1 MARK)

11. [Alpha radiation is unable to penetrate very far through tissue[1]] [unlike gamma or beta radiation.[2]][This means that the effect of the radiation can be targeted close to the location where the source is placed.[3]]

- I have used the relevant theory: penetrating power.[1]
- I have explicitly compared alpha radiation to gamma and beta radiation.[2]
- I have related my answer to the context of the question.[3]

12. **a.** $D = \frac{E_r}{m}$

$3.1 = \frac{E_r}{1.12}$

$E_r = 3.5$ J

b. $H = D \times w_r$

$H = 3.1 \times 1.0 = 3.1$ Sv (1 MARK)

$E = \sum(H \times w_t) = 3.1 \times 0.010 = 0.031 = 3.1 \times 10^{-2}$ Sv (1 MARK)

c. [Anastasia is likely to have worse short term effects,[1]] [as her absorbed dose is greater.[2]]

- I have explicitly mentioned who is likely to have worse short term effects.[1]
- I have used the relevant theory: absorbed dose.[2]

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5A Nuclear energy

Progress questions

1. C
2. A
3. B
4. C
5. A
6. fusion; larger; high; fission; neutrons
7. I, II, IV

Deconstructed exam-style

8. B
9. C
10. A
11. [From the binding energy curve, ${}^{4}_{2}He$ has an approximate binding energy per nucleon of 11×10^{-13} J, so its approximate total binding energy (with 4 nucleons) is $4 \times 11 \times 10^{-13} = 4.4 \times 10^{-12}$ J.[1]] [${}^{3}_{1}H$ has an approximate binding energy per nucleon of 4.5×10^{-13} J, so its approximate total binding energy (with 3 nucleons) is $3 \times 4.5 \times 10^{-13} = 1.4 \times 10^{-12}$ J. The binding energy of ${}^{1}_{1}H$ is 0 J.[2]] [This means the approximate binding energy of the reactants is $1.4 \times 10^{-12} + 0 = 1.4 \times 10^{-12}$ J.[3]] [This shows that the binding energy of the products is higher than the binding energy of the reactants, so the reaction must release energy.[4]]

- I have referenced the binding energy of the product.[1]
- I have referenced the binding energy of each reactant.[2]
- I have referenced the total binding energy of the reactants.[3]
- I have explicitly addressed why the reaction releases energy.[4]

Exam-style

12. a. Both b. Fusion c. Both d. Fission
    e. Fission f. Fusion g. Both h. Fission
13. C. $237 + 1 = 159 + 72 + 4 + x \times 1 \Rightarrow x = 238 - 235 = 3$
14. a. Greater.

    In a reaction that releases energy, the binding energy of the products is greater than that of the reactants.

    b. May be greater or lesser.

    Fusion reactions can produce or consume energy overall, so the binding energy of the products may be greater or lesser than that of the reactants.
15. [The energy released in the reaction depends on the difference in binding energies between the reactants and the products.[1]] [In both processes the reactant is the same and the products are the same and hence have the same binding energies,[2]] [so we would expect both reaction pathways to release the same amount of energy.[3]]

- I have used the relevant theory: binding energy in reactions.[1]
- I have referenced how both pathways have the same reactant and products.[2]
- I have explicitly addressed the difference in energy between the two pathways.[3]

Key science skills

16. [It would not be appropriate to fit a line of best fit.[1]] [The data points show that there is not a linear trend, rather there is an obvious curve and so the students should not plot a line of best fit.[2]]

- I have explicitly addressed whether a line of best fit is appropriate.[1]
- I have justified my answer with the relevant theory: lines of best fit.[2]

FROM LESSON 11E

Previous lessons

17. [Air conditioners are commonly placed at high positions to distribute cool air most effectively using convection.[1]] [The air from an air conditioner is cooler and denser than the rest of the air in the space so it will sink (move downwards) which displaces the warmer air, pushing it upwards towards the air conditioning system.[2]]

- I have referenced the appropriate form of heat transfer.[1]
- I have used the relevant theory: convection.[2]

FROM LESSON 2B

18. [William is correct and Ernest is incorrect.[1]] [While a sheet of paper would be enough to prevent the penetration of alpha particles, since they penetrate poorly, it would not stop beta radiation.[2]] [A thin layer of aluminium would prevent the penetration of both alpha and beta radiation, hence aluminium would be an appropriate choice of shielding.[3]]

- I have explicitly addressed who is correct.[1]
- I have related my answer to the context of the question.[2]
- I have used the relevant theory: the different forms of radiation's ability to penetrate each of the shielding materials.[3]

FROM LESSON 4C

5B Fission

Progress questions

1. D
2. C
3. less, decrease

4. larger, less, decrease

5. B

6. I, II, IV

Deconstructed exam-style

7. B

8. B

9. I, II

10. [Control rods are used to absorb neutrons to slow fissile chain reactions in nuclear power plants.[1]] [Without control rods, if the fissile fuel mass were to become highly supercritical, there would be very little that could be done externally to bring it back to criticality or subcriticality quickly.[2]] [In such an event the fuel could either eventually bring itself back to critical or subcritical levels of reaction, or it could cause a nuclear meltdown and do immense damage to the environment near the power plant.[3]]

- I have addressed the role of control rods in fission power production.[1]
- I have used the relevant theory: neutron absorption and criticality.[2]
- I have explicitly addressed the possible outcomes of the power plant going into a supercritical state.[3]

Exam-style

11. a. True. By absorbing neutrons, they stop those neutrons from being captured by fissile nuclei.

    b. True. Increasing the availability of fissile material means neutrons are more likely to be captured.

    c. False. It is possible for a supercritical mass to have fissile material removed from it and for it to become critical or remain supercritical.

    d. False. Most neutrons produced in fission reactions typically have so much energy it is unlikely they can be captured before escaping.

    e. True. Decreasing the surface area means on average, neutrons will have to travel longer paths in fissile material before they can escape.

12. It will decrease the neutron multiplication factor.

13. [A fissile mass that is critical has a fission chain reaction that is sustained without the number of reactions increasing or decreasing.[1]] [It is affected by the mass/shape of the fissile mass.[2]]

- I have used the relevant theory: criticality.[1]
- I have stated a property of fissile masses that affects their criticality.[2]

14. [Over time, the amount of fissile material will decrease as it is used up in fission reactions.[1]] [This makes it more difficult for neutrons to trigger fission reactions as there are less available fissile nuclei that can absorb them,[2]] [so the neutron multiplication factor will decrease and therefore the mass will become subcritical.[3]]

- I have referenced how the amount of available fissile material will decrease over time.[1]
- I have used the relevant theory: criticality and neutrons.[2]
- I have explicitly addressed the effect on the fission chain reaction in the fissile mass.[3]

15. a. [We cannot determine from this information whether the mass would be supercritical, critical, or subcritical after fuel is removed.[1]] [Since the mass was initially supercritical, it initially had neutron multiplication factor $k > 1$.[2]] [Removing fuel will decrease k, but we do not have enough information to say what k will be after the fuel removal.[3]]

- I have explicitly addressed that the state of the fissile mass cannot be determined.[1]
- I have used the relevant theory: criticality and neutron multiplication factor.[2]
- I have used the relevant theory: effect of mass on criticality.[3]

b. [The mass will be subcritical after fuel is removed.[1]] [Since the mass was initially critical, it initially had neutron multiplication factor $k = 1$.[2]] [Removing fuel will decrease k, so after fuel removal, k will be less than 1.[3]]

- I have explicitly addressed that the mass will be subcritical.[1]
- I have used the relevant theory: criticality and neutron multiplication factor.[2]
- I have used the relevant theory: effect of mass on criticality.[3]

16. [Aftyn is correct and Julia is incorrect.[1]] [Julia is incorrect because a thin slab has a large surface area which decreases the neutron multiplication factor, therefore more fuel is required for the fission chain reaction to reach the desired size.[2]] [Aftyn is correct because making a fissile mass more spherical will decrease the surface area and increase the neutron multiplication factor, therefore less fuel is required for the fission chain reaction to reach the desired size.[3]]

- I have explicitly addressed that Aftyn is correct and Julia is incorrect.[1]
- I have referenced the effect of mass and shape on criticality to address why Julia is incorrect.[2]
- I have referenced the effect of mass and shape on criticality to address why Aftyn is correct.[3]

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Key science skills

17. a. Independent: Mass of neutron moderators used (1 MARK)
Dependent: Neutron multiplication factor (1 MARK)

b. [It would not be appropriate for the scientists to draw a line of best fit,[1]] [because the data shows a nonlinear trend.[2]]

- I have explicitly addressed that a line of best fit would not be appropriate.[1]
- I have used the relevant theory: lines of best fit.[2]

c. This is likely to have introduced random error.

FROM LESSONS 11A, 11C, & 11D

Previous lessons

18. $\frac{\Delta T_f}{\Delta T_i} = \frac{100}{400} = \frac{1}{4} \Rightarrow \Delta T_f = \frac{1}{4}\Delta T_i$ (1 MARK)

The difference in temperature changed by a factor of $\frac{1}{4}$ and therefore the rate of heat transfer has also changed by a factor of $\frac{1}{4}$. (1 MARK)

FROM LESSON 2B

19. D. Reducing the radiation weighting factor of the radioactive source will reduce the equivalent dose absorbed, according to $H = D \times w_r$.

FROM LESSON 4D

Chapter 5 review

Section A

1. A 2. C 3. D 4. III
5. II, III 6. B

Section B

7. [Subcriticality is the state of a fissile mass when it is unable to sustain a fission chain reaction,[1]] [whereas supercriticality is the state of a fissile mass when its fission chain reaction is growing.[2]]

- I have used the relevant theory: subcriticality.[1]
- I have used the relevant theory: supercriticality.[2]

8. a. [Due to the strong force between nucleons, energy is required to separate a nucleus into its constituent nucleons.[1]] [This means that the nucleons collectively have more energy than the nucleus, and because of mass-energy equivalence, the nucleons collectively have more mass than the nucleus.[2]]

- I have used the relevant theory: forces in atomic nuclei.[1]
- I have used the relevant theory: mass energy equivalence.[2]

b. Nuclear binding energy is the energy equivalent of mass defect.

9. a. Moveable control rods

b. Graphite moderator

c. To make it easier for fissile nuclei to capture them.

10. [Aphisit is incorrect,[1]] [since the fission of $^{62}_{28}Ni$ would have products lower on the binding energy per nucleon curve than its reactant, so it would not release energy.[2]] [Lynn is also incorrect,[3]] [since the fusion of $^{62}_{28}Ni$ with itself produces a nucleus with 124 nucleons, which is lower on the binding energy per nucleon curve than the $^{62}_{28}Ni$ reactant, so it would not release energy.[4]]

- I have explicitly addressed that Aphisit is incorrect.[1]
- I have used the relevant theory: fission on binding energy curves.[2]
- I have explicitly addressed that Lynn is incorrect.[3]
- I have used the relevant theory: fusion on binding energy curves.[4]

11. a. [A neutron that travels in the direction towards where the new mass is added would have to travel further through fissile material to escape, compared to before the mass was added.[1]] [Therefore the neutron multiplication factor would increase.[2]]

- I have used the relevant theory: neutron paths and fission.[1]
- I have explicitly addressed that the neutron multiplication factor would increase.[2]

b. [Neutron moderation increases the neutron multiplication factor of a fissile mass,[1]] [while making a fissile mass less spherical decreases its neutron multiplication factor.[2]] [This means that the shape change of the fissile mass will offset the effect of the neutron moderation to some degree,[3]] [so Ayrton is likely to underestimate the effect of neutron moderation on neutron multiplication factor.[4]]

- I have used the relevant theory: neutron moderation.[1]
- I have used the relevant theory: shape and criticality.[2]
- I have related the effects of the neutron moderation and the change in shape.[3]
- I have explicitly addressed that Ayrton will likely underestimate the effect of neutron moderation.[4]

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12. a. [Fusion reactions have products with more nucleons than their reactants, so the nuclei produced by this reaction will have more nucleons than Se-78.[1]][Near Se-78, the binding energy per nucleon tends to decrease with increasing nucleon number,[2]][so the product nucleus of this reaction will likely have a lower binding energy per nucleon than Se-78, and consequently a lower binding energy than the reactants.[3]] [Reactions only produce energy if the binding energy of the products is greater than that of the reactants, so it is unlikely that this reaction will produce energy as is desired.[4]]

- I have used the relevant theory: fusion reactants and products.[1]
- I have used the relevant theory: features of binding energy curves.[2]
- I have related the binding energies of the reactants and the products.[3]
- I have explicitly addressed why it is unlikely this reaction will produce energy.[4]

b. [This assertion is incorrect,[1]][since the additional energy will speed up neutrons making them harder to capture.[2]]

OR

[This assertion is incorrect,[1]][since the additional energy does not increase the supply of reactants for fission reactions of fissile nuclei.[2]]

- I have explicitly stated the assertion is incorrect.[1]
- I have addressed why the assertion is incorrect.[2]

Unit 1 AOS 2 review

Section A

1. A. Ionising ability is greater for radiation with greater mass and charge.

FROM LESSON 4C

2. C. Fission is the only reaction listed that can have free neutrons as both reactants and products.

FROM LESSON 5A

3. D. Inserting a control rod will reduce neutron multiplication factor and making the mass spherical will increase neutron multiplication factor.

FROM LESSON 5B

4. A. $n = \frac{T}{t_{1/2}} = \frac{45}{4.58 \times 60} = 0.164$ half-lives

$m = m_o\left(\frac{1}{2}\right)^n = 1.54 \times 10^3\left(\frac{1}{2}\right)^{0.164} = 1.374 \times 10^3 = 1.37 \times 10^3$ g

FROM LESSON 4B

5. C. Both alpha and beta radiation would cause too much damage to the patient's cells. Ingesting a gamma ray source rather than absorbing it from outside the body would allow the doctor to see how it flows through the body, rather than pass straight through the targeted area.

FROM LESSON 4D

Section B

6. a. [The reactants of nuclear fusion are two or more smaller nuclei.[1]][These must be brought close enough together to where the strong force overpowers the electrostatic force, fusing the nuclei together.[2]][This produces a larger nucleus than that of the reactants.[3]]

- I have explicitly stated the reactants of fusion reactions.[1]
- I have addressed how fusion reactions occur.[2]
- I have explicitly stated the products of fusion reactions.[3]

FROM LESSON 5A

b. Any of the following: fission has multiple nuclei as products but fusion has one, fission has one nucleus as a reactant but fusion has multiple, fission can have neutrons as products/reactants, fission reactions are used for nuclear power generation, fusion reactions typically release more energy per nucleon, fission reactions typically release more energy, any other correct difference.

FROM LESSON 5A

c. Any of the following: fission reactions are used for nuclear power generation, fusion reactions typically release more energy per nucleon, fission reactions typically release more energy, any other correct difference.

FROM LESSON 5A

7. a. $A = A_0\left(\frac{1}{2}\right)^n \Rightarrow 1.0 \times 10^2 = 1.28 \times 10^4 \times \left(\frac{1}{2}\right)^n$ (1 MARK)

$\left(\frac{1}{2}\right)^n = \frac{1}{128} = \left(\frac{1}{2}\right)^7 \Rightarrow n = 7.0$ (1 MARK)

Therefore Axel would have to wait $7.0 \times 1.19 = 8.3$ days. (1 MARK)

FROM LESSON 4B

b. $m = m_0\left(\frac{1}{2}\right)^n \Rightarrow 15.0 \times 10^{-3} = 60.0 \times 10^{-3} \times \left(\frac{1}{2}\right)^n$ (1 MARK)

$\left(\frac{1}{2}\right)^n = \frac{1}{4} = \left(\frac{1}{2}\right)^2 \Rightarrow n = 2.0$ (1 MARK)

$n = \frac{T}{t_{1/2}} \Rightarrow 2.0 = \frac{23.0}{t_{1/2}}$

$t_{1/2} = 11.5$ days $= 11.5 \times 24 = 276$ hours

The half-life of phosphorus-32 is 276 hours. (1 MARK)

FROM LESSON 4B

c. [The half life is the length of time over which any given nuclide will have a 50% chance of decaying. As such, approximately half of the original sample will have undergone radioactive decay.[1]][Axel is incorrect, because he thinks that exactly (instead of approximately) half of the nuclides will decay.[2]]

- I have used the relevant theory: half-lives' probabilistic nature.[1]
- I have explicitly stated why Axel is incorrect.[2]

FROM LESSON 4B

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8. [The blue curve represents the strong nuclear force and the red curve represents the electrostatic force.[1]][For small nuclear separations, the strong force is repulsive, for slightly larger separations it is attractive, and for large separations it is attractive but weak.[2]][For small nuclear separations, the electrostatic force is strong and repulsive, and for larger nuclear separations the electrostatic force is repulsive but weaker.[3]]

- I have explicitly stated which force each of the curves represents.[1]
- I have described the behaviour of the strong force for difference nuclear separations.[2]
- I have described the behaviour of the electrostatic force for different nuclear separations.[3]

FROM LESSON 4A

9. a. The decay chain can be written as

$^{227}_{89}\text{Ac} \rightarrow {}^{207}_{82}\text{Pb} + m \times {}^{4}_{2}\alpha + n \times {}^{0}_{-1}\text{e}$ (1 MARK)

Use the mass number to determine the number of alpha particles released:

$227 = 207 + 4 \times m$

$m = \frac{227 - 207}{4} = 5$ (1 MARK)

Use the atomic number and charge to determine the number of beta minus particles (electrons) released:

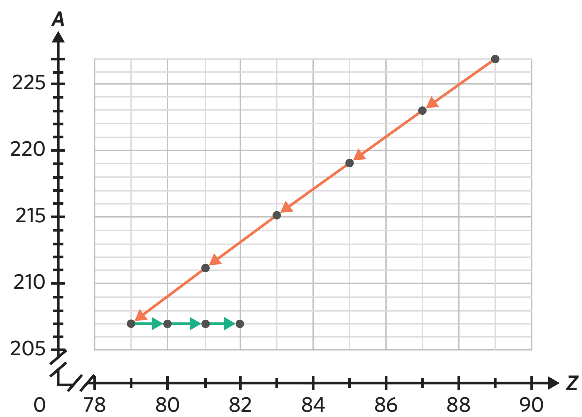
$89 = 82 + 5 \times 2 - n$

$n = 3$ (1 MARK)

There are 5 alpha particles and 3 beta minus particles released.

FROM LESSON 4C

b.



- I have shown the initial parent nuclide as $^{227}_{89}\text{Ac}$ and the final daughter nuclide as $^{207}_{82}\text{Pb}$.
- I have drawn the correct sequence of alpha and beta decays.
- I have drawn alpha decays as arrows pointing down 4 units and left 2 units.
- I have drawn beta minus decays as arrows pointing right 1 unit.
- I have correctly labelled the horizontal and vertical axes and have drawn the axes with consistent spacing.

FROM LESSON 4C

10. a. $D = \frac{E}{m} = \frac{1.00}{75}$ (1 MARK)

$D = 0.133$ Gy (1 MARK)

$H = D \times w_r \Rightarrow 2.7 = 0.133 \times w_r$ (1 MARK)

$w_r = 20.3 = 20$ (1 MARK)

The smoke alarm must have an alpha radioactive source. (1 MARK)

FROM LESSON 4D

b. [The alpha particles are not able to penetrate through human skin,[1]][and are therefore not likely to have a noticeable health effect on the owner of the house.[2]]

- I have used relevant theory: penetrating ability of alpha particles.[1]
- I have explicitly addressed the owner is not likely to be affected by the radioactive source.[2]

FROM LESSON 4C

c. [The source of alpha particles can be used in the design of a targeting alpha compound.[1]][By attaching the alpha source to a targeting compound, it would be able to directly kill the cancerous cells,[2]][and will have a minimal effect on nearby healthy cells.[3]]

- I have explicitly identified the creation of a targeting alpha compound.[1]
- I have used the relevant theory: use of a targeting alpha compound.[2]
- I have explicitly identified the impact of the radiation on nearby healthy cells.[3]

FROM LESSON 4D

11. a. [In order for an atom's nucleus to separate into its unbound nucleons, the nucleons need to gain energy in order to overcome the strong nuclear force keeping them together.[1]][From $E = mc^2$, we know that an increase in a particle's energy increases its mass.[2]][So, since the unbound nucleons have more energy, they will have a larger total mass than the original nucleus.[3]]

- I have referenced the energy required to overcome the strong nuclear force.[1]
- I have used the relevant theory: mass-energy equivalence.[2]
- I have explicitly addressed why the original atom will be lighter than the unbound nucleons.[3]

FROM LESSON 5A

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b. [The products of a fission reaction will be to the left of the reactants on the binding energy curve.[1]] [Since binding energy per nucleon increases to the left of uranium-235, the products of a U-235 fission reaction will likely have a higher binding energy per nucleon (and together a higher total binding energy) than U-235.[2]] [Any reaction whose products have a higher binding energy than its reactants will release energy, therefore the fission of U-235 releases energy.[3]]

- I have used the relevant theory: fission on a binding energy curve.[1]
- I have used the relevant theory: shape of a binding energy curve.[2]
- I have explicitly addressed why fission of U-235 will release energy.[3]

FROM LESSON 5A

c. [Neutron moderation reduces the speed (kinetic energy) of neutrons, making it easier for them to be captured by fissile nuclei.[1]] [This means they increase the proportion of neutrons that are able to cause fission reactions.[2]]

- I have used the relevant theory: neutron moderation.[1]
- I have addressed how neutron moderation affects chain reactions.[2]

FROM LESSON 5B

d. [This machine will increase the number of fission reactions occurring in the fissile mass.[1]] [The neutron multiplication factor will either stay the same or decrease after this device is turned on,[2]] [since the average number of fission reactions triggered by other fission reactions will either stay the same or decrease.[3]]

- I have addressed the effect of additional free neutrons on the number of fission reactions.[1]
- I have stated the effect on the neutron multiplication factor.[2]
- I have explained the effect on the neutron multiplication factor.[3]

FROM LESSONS 5A & 5B

Back to contents

6A Fundamentals of electricity

Progress questions

1. I, III, IV
2. D
3. B
4. A
5. B
6. B
7. II, III
8. D
9. C
10. water, energy, water wheel, power-consuming component
11. cars, energy, all
12. C
13. B

Deconstructed exam-style

14. A
15. C
16. B
17. $V = \frac{E}{Q} \Rightarrow 40 \times 10^3 = \frac{400 \times 10^3}{Q}$

$Q = \frac{400 \times 10^3}{40 \times 10^3} = 10.0 = 10\ \text{C}$ (1 MARK)

$P = \frac{E}{t} \Rightarrow P = \frac{400 \times 10^3}{2.0}$

$P = 200 \times 10^3 = 2.0 \times 10^5\ \text{W}$ (1 MARK)

The power delivered per coulomb of charge is given by $\frac{P}{Q}$ (1 MARK)

$\frac{P}{Q} = \frac{2.0 \times 10^5}{10} = 2.00 \times 10^4 = 2.0 \times 10^4\ \text{W C}^{-1}$ (1 MARK)

Exam-style

18. $V = \frac{E}{Q} \Rightarrow 5.0 = \frac{E}{3.0}$ (1 MARK)

$E = 5.0 \times 3.0 = 15.0 = 15\ \text{J}$ (1 MARK)

19. a. $P = VI \Rightarrow 220 = 20 \times I$ (1 MARK)

$I = \frac{220}{20} = 11.0 = 11\ \text{A}$ (1 MARK)

b. $P = \frac{E}{t} \Rightarrow 220 = \frac{E}{12}$ (1 MARK)

$E = 220 \times 12 = 2640 = 2.6 \times 10^3\ \text{J}$ (1 MARK)

c. $I = \frac{Q}{t} \Rightarrow 11 = \frac{Q}{12}$

$Q = 11 \times 12 = 132$ (1 MARK)

$n_e = \frac{Q}{e} = \frac{132}{1.6 \times 10^{-19}} = 8.25 \times 10^{20} = 8.3 \times 10^{20}$ electrons (1 MARK)

20. a. Ammeter. It is measuring the rate that the 'charge carriers' move through a location.

b. Replacing a voltage source with one with a higher voltage. Pumps are analogous to a voltage source, so pump strength is analogous to the voltage provided.

21. a. Voltage. Parallel connections are used to measure voltage, not current.

b. Current. Series connections are used to measure current, not voltage.

22. 1 hour = 60 × 60 = 3600 s

$P = \frac{E}{t} = \frac{3.6 \times 10^3}{3600} = 1.0\ \text{W}$ (1 MARK)

$P = VI \Rightarrow 1.0 = V \times 2.0$ (1 MARK)

$V = \frac{1.0}{2.0} = 0.500 = 0.50\ \text{V}$ (1 MARK)

OR

1 hour = 60 × 60 = 3600 s

$I = \frac{Q}{t} \Rightarrow 2.0 = \frac{Q}{3600}$

$Q = 7.2 \times 10^3\ \text{C}$ (1 MARK)

$V = \frac{E}{Q} = \frac{3.6 \times 10^3}{7.2 \times 10^3}$ (1 MARK)

$V = 0.500 = 0.50\ \text{V}$ (1 MARK)

23. [The cell transforms stored chemical energy into the electric potential energy it transfers to the circuit.[1]][The electric potential energy is transferred through the wires by the movement of charge carriers.[2]][The light bulb then transforms the electric potential energy of the charge carriers in the circuit into light and thermal energy.[3]]

- I have explicitly addressed the storage and transformation of energy in the battery.[1]
- I have used the relevant theory: flow of energy in a circuit.[2]
- I have explicitly addressed the transformation of energy at the light bulb.[3]

24. a. $P_1 = \frac{E}{t_1} \Rightarrow 10 = \frac{E}{8.0}$

$E = 10 \times 8.0 = 80\ \text{J}$ (1 MARK)

$P_2 = \frac{E}{t_2} \Rightarrow 20 = \frac{80}{t_2}$ (1 MARK)

$t_2 = \frac{80}{20} = 4.00 = 4.0\ \text{s}$ (1 MARK)

b. [Since the same source was used, the voltage across each component was equal.[1]][This is because ideal sources provide a constant potential difference.[2]][Since $P = VI$, the second component drew twice as much current as the first.[3]]

- I have explicitly addressed the voltage of each component.[1]
- I have used the relevant theory: ideal voltage sources provide constant potential difference.[2]
- I have explicitly addressed the current of each component.[3]

25. $V = \frac{E}{Q} \Rightarrow 66 \times 10^3 = \frac{500 \times 10^6}{Q}$ (1 MARK)

$Q = \frac{500 \times 10^6}{66 \times 10^3} = 7.57 \times 10^3 = 7.6 \times 10^3\ \text{C}$ (1 MARK)

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26. [Kendall is correct.[1]][Electric charge is a property of subatomic particles and cannot be transferred between subatomic particles.[2]] [Therefore, because current is a flow of charge, there must be physical movement of charged particles for there to be a current.[3]]

- I have explicitly addressed who is correct.[1]
- I have used the relevant theory: electric charge is a property of subatomic particles.[2]
- I have used the relevant theory: electric current as the movement of charged particles.[3]

27. Since the power halves for every kilometre of transmission line,

$P_{end} = \left(\frac{1}{2}\right)^{length} P_{start}$ (1 MARK)

$2.0 \times 10^{-6} = \left(\frac{1}{2.0}\right)^{3.0} \times P_{start} = \frac{1}{8} \times P_{start}$

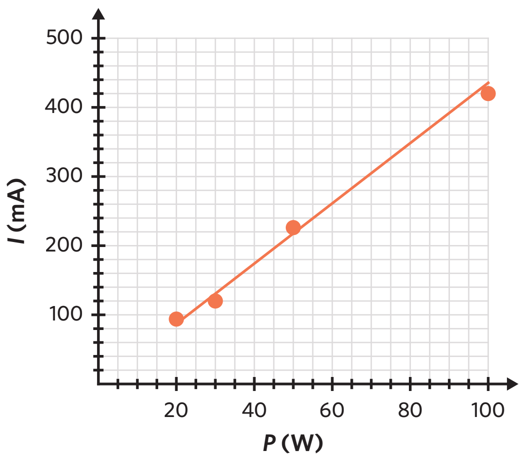
$P_{start} = 2.0 \times 10^{-6} \times 8 = 16.0 \times 10^{-6} = 1.6 \times 10^{-5}$ W (1 MARK)

$P = IV \Rightarrow 1.6 \times 10^{-5} = 4.0 \times 10^{-3} \times V$ (1 MARK)

$V = \frac{1.6 \times 10^{-5}}{4.0 \times 10^{-3}} = 0.004 = 4.0 \times 10^{-3}$ V (1 MARK)

Key science skills

28. a.



- I have plotted power on the horizontal axis and current on the vertical axis.
- I have included axis labels and appropriate units.
- I have included an appropriate and consistent scale on the axes.
- I have plotted each data point.
- I have included a line of best fit.

b. $P = VI$

$gradient = \frac{rise}{run} = \frac{I}{P} = \frac{1}{V}$

Using two points on the line of best fit:

$gradient = \frac{rise}{run} = \frac{(260 - 220) \times 10^{-3}}{60 - 50} = 4.0 \times 10^{-3}$ (1 MARK)

$V = \frac{1}{4.0 \times 10^{-3}} = 250 = 2.5 \times 10^{2}$ V

The camera network is operating at 2.5×10^{2} V. (1 MARK)

Note that a range of answers is acceptable based on the points chosen from the line of best fit.

FROM LESSONS 11D & 11E

Previous lessons

29. a. $Q = mc\Delta T \Rightarrow Q = 1.2 \times 6.3 \times 10^{3} \times (40 - 20)$ (1 MARK)

$Q = 1.51 \times 10^{5} = 1.5 \times 10^{5}$ J (1 MARK)

b. [The water will cool first[1]][as the heat capacity of water is lower than that of the unknown liquid.[2]][This means it takes less of an energy change for the same change in temperature, and so it both heats and cools faster.[3]]

- I have explicitly addressed which liquid will cool first.[1]
- I have referred to the heat capacity of both water and the unknown substance.[2]
- I have used the relevant theory: specific heat capacity.[3]

FROM LESSON 2C

30. C. The shape of the binding energy curve shows the trend described in C.

FROM LESSON 5A

6B Resistance and Ohm's law

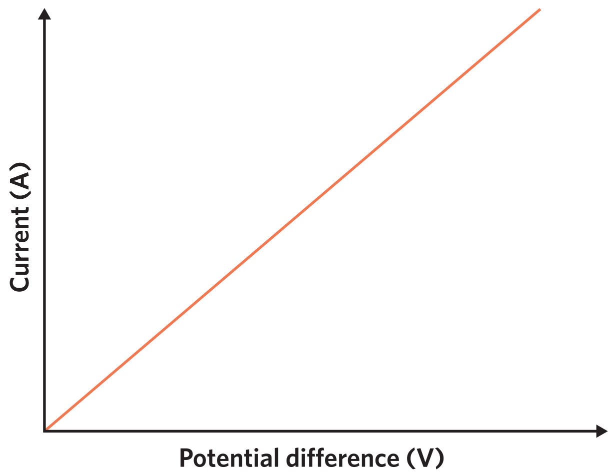
Progress questions

1. I, II, IV
2. B
3. A
4. II, III

Deconstructed exam-style

5. C
6. B
7. B

8.



- I have drawn a line with a positive and linear gradient passing through the origin.
- I have included axis labels and appropriate units.

6B ANSWERS

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Exam-style

9. $V = IR$

$12 = 0.20 \times R$ (1 MARK)

$R = \frac{12}{0.20} = 60.0 = 60\ \Omega$ (1 MARK)

10. $V = IR$

$V = 40 \times 10^{-3} \times 90$ (1 MARK)

$V = 3.6$ V (1 MARK)

11. **a.** Device *P* is ohmic.

We know this because the plot is linear (with a constant gradient) and passes through the origin.

b. Use any two points from the graph for *P* to calculate the ratio of voltage to current:

$R = \frac{V}{I}$

$R = \frac{5.0}{0.020}$ (1 MARK)

$R = 2.5 \times 10^{2}\ \Omega$ (1 MARK)

c. From the graph: when $V = 5.0$ V, $I = 3.0$ A

$V = IR$

$5.0 = 3.0 \times R$ (1 MARK)

$R = \frac{5.0}{3.0} = 1.67 = 1.7\ \Omega$ (1 MARK)

12. $V = IR$

$900 = I \times 12 \times 10^{-6}$ (1 MARK)

$I = \frac{900}{12 \times 10^{-6}} = 7.5 \times 10^{7}$ A (1 MARK)

13. **a.** $3I$

b. $\frac{1}{2}I$

c. V

14.

	Circuit 1	Circuit 2	Circuit 3	Circuit 4
Potential difference	12 V	1.3 V (1 MARK)	5.4 V	9.6 V
Current	6 A	30 mA	0.6 A (1 MARK)	320 mA
Resistance	2 Ω (1 MARK)	44 Ω	9 Ω	30 Ω (1 MARK)

15. $V = IR$

$60 = 3.0 \times R$ (1 MARK)

$R = 20\ \Omega$

Given the charger is ohmic, resistance is constant:

$V = IR$

$45 = I \times 20$ (1 MARK)

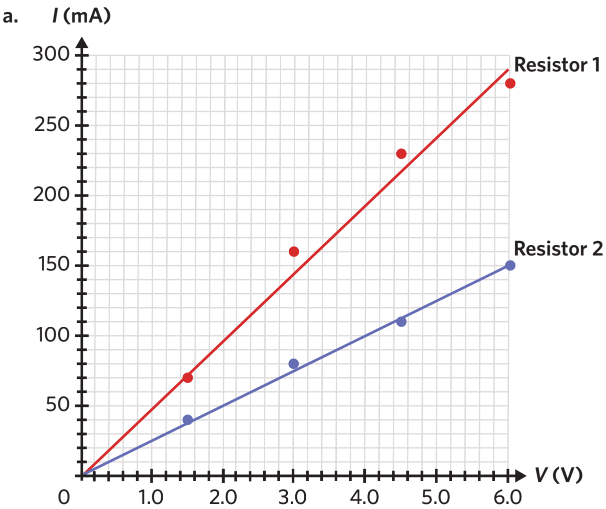
$I = \frac{45}{20} = 2.25 = 2.3$ A (1 MARK)

16. [Daisy is correct, and Max could be either correct or incorrect.[1]] [The resistance of an object depends on both the resistivity of the material it's made of as well as its geometry.[2]] [This means that Max may be correct or incorrect since resistivity is not the only factor determining the resistance of their resistors, so either of their resistors could have higher resistance depending on their geometry.[3]] [Daisy is correct since she states that because their resistors have different shapes, it is possible that this factor could make her resistors have a higher resistance than Max's.[4]]

- I have explicitly addressed who is correct.[1]
- I have used the relevant theory: resistance.[2]
- I have explicitly addressed why Max may be correct or incorrect.[3]
- I have explicitly addressed why Daisy is correct.[4]

Key science skills

17. **a.**



- I have plotted potential difference on the horizontal axis and current on the vertical axis.
- I have included axis labels and appropriate units.
- I have included an appropriate and consistent scale on the axes.
- I have plotted each data point.
- I have included two lines of best fit.
- I have labelled each line of best fit with its corresponding resistor number.

b. Resistor 2 has a greater resistance.

The gradient of the *I-V* graph for a resistor (an ohmic device) represents $\frac{1}{R}$, so a smaller gradient corresponds to a greater resistance.

FROM LESSONS 11D & 11E

6B ANSWERS

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Previous lessons

18. Infrared

FROM LESSON 3A

19. [If each fissile mass had the same mass (amount of fissile material), we would expect the neutron multiplication factor of the spherical mass to be higher than that of the cylindrical mass, due to its higher surface area.[1]][For the cylindrical mass to reach the same neutron multiplication factor as the spherical mass, more fissile fuel would need to be added to it to increase k.[2]][Therefore a spherical mass would require less fuel to reach criticality compared to a thin cylindrical mass.[3]]

- I have used the relevant theory: effect of shape on criticality.[1]
- I have used the relevant theory: effect of mass on criticality.[2]
- I have explicitly stated a spherical mass would require less fuel to reach criticality.[3]

FROM LESSON 5B

6C Series circuits

Progress questions

1. I, III **2.** D **3.** C **4.** D

5. A **6.** B

Deconstructed exam-style

7. C

8. B

9. B

10. $R_T = R_{eq} = 200 + 400 + 100 = 700\ \Omega$ (1 MARK)

$V_T = IR_T \Rightarrow 14.0 = I \times 700$

$I = 2.00 \times 10^{-2}$ A (1 MARK)

$V_3 = IR_3 = 2.00 \times 10^{-2} \times 100 = 2.00$ V (1 MARK)

$P_3 = V_3 I = 2.00 \times 2.00 \times 10^{-2} = 4.00 \times 10^{-2}$ W (1 MARK)

Exam-style

11. a. $R_T = R_{eq} = R_1 + R_2 = 10 + 20 = 30\ \Omega$ (1 MARK)

$V_T = IR_T \Rightarrow 12 = I \times 30$

$I = 0.40$ A (1 MARK)

b. $V_2 = IR_2 = 0.40 \times 20 = 8.0$ V

12. $R_T = R_{eq} = R_1 + R_2 = 60 + 20 = 80\ \Omega$ (1 MARK)

$V_T = IR_T \Rightarrow 12 = I \times 80$

$I = 0.15$ A (1 MARK)

$V_1 = IR_1 = 0.15 \times 60 = 9.0$ V (1 MARK)

13. Since the switch is open, no current flows.

$P_2 = V_2 I = 0$ W

14. $V_2 = IR_2 \Rightarrow 4.0 = I \times 400$

$I = 0.010$ A (1 MARK)

$V_1 = IR_1 = 0.010 \times 200 = 2.0$ V (1 MARK)

$V_{supply} = V_T = V_1 + V_2 = 2.0 + 4.0 = 6.0$ V (1 MARK)

OR

$V_2 = IR_2 \Rightarrow 4.0 = I \times 400$

$I = 0.010$ A (1 MARK)

$R_T = R_{eq} = R_1 + R_2 = 200 + 400 = 600\ \Omega$ (1 MARK)

$V_{supply} = V_T = IR_T = 0.010 \times 600 = 6.0$ V (1 MARK)

OR

$R_T = R_{eq} = 200 + 400 = 600\ \Omega$ (1 MARK)

$R_2 = \frac{2}{3} \times R_T$

$V_n \propto R_n \Rightarrow V_2 = \frac{2}{3} \times V_T$ (1 MARK)

$V_{supply} = V_T = \frac{3}{2} \times 4.0 = 6.0$ V (1 MARK)

15. [Sione is correct, and Bruno is incorrect.[1]][Adding components increases the total resistance of the circuit.[2]][For a constant voltage, this decreases the current flow according to Ohm's law ($V = IR$).[3]]

- I have explicitly addressed who is correct.[1]
- I have used the relevant theory: equivalent resistance in series circuits.[2]
- I have used the relevant theory: current in series circuits.[3]

16. $R_T = R_{eq} = x + 2x + x = 4x$

$V_n \propto R_n$

$R_1 = x = \frac{1}{4}R_T \Rightarrow V_1 = \frac{1}{4} \times V_T = \frac{1}{4} \times 20 = 5$ V (1 MARK)

$R_2 = 2x = \frac{2}{4}R_T \Rightarrow V_2 = \frac{2}{4} \times V_T = \frac{1}{2} \times 20 = 10$ V (1 MARK)

$R_3 = x = \frac{1}{4}R_T \Rightarrow V_3 = \frac{1}{4} \times V_T = \frac{1}{4} \times 20 = 5$ V (1 MARK)

17. Using $V_n \propto R_n$, $P = VI$, and the fact that I is constant in a series circuit:

$P_n \propto R_n$ and $R_3 = \frac{1}{8} \times R_T \Rightarrow P_3 = \frac{1}{8} \times P_T$ (1 MARK)

$P_3 = \frac{1}{8} \times 10 = 1.25$ W (1 MARK)

18. a. $R_T = R_{eq} = 1.0 \times 10^3 + 30 + 25 = 1055\ \Omega$ (1 MARK)

$V_T = 4 \times 1.5 = 6.0$ V

$V_T = IR_T \Rightarrow 6.0 = I \times 1055$

$I = 0.0057$ A $= 5.7$ mA (1 MARK)

Since $I < 7.00$ mA, the remote control unit will not overheat. (1 MARK)

b. $R_T = R_{eq} = R_{new} + 30 + 25$ (1 MARK)

Let $I = 7.00$ mA to determine the resistance required to prevent overheating.

$V_T = IR_T \Rightarrow 6.0 = 7.00 \times 10^{-3} \times (R_{new} + 30 + 25)$ (1 MARK)

$R_{new} = 802\ \Omega$. Therefore, the minimum resistance that will still prevent overheating is the 810 Ω resistor. (1 MARK)

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c. $R_T = R_{eq} = 1.0 \times 10^3 + 30 = 1030\ \Omega$ (1 MARK)

$V_T = 4 \times 1.5 + 0.33 = 6.33$ V

$V_T = IR_T \Rightarrow 6.33 = I \times 1030$

$I = 0.00615$ A (1 MARK)

$P_{antenna} = V_{antenna} I = 0.33 \times 0.00615 = 0.0020$ W

$P_{antenna} = 2.0$ mW (1 MARK)

19. [Introducing a second resistor at point *C* will increase the total resistance of the circuit.[1]][This will decrease the current through the whole circuit, including light bulb *B*, according to Ohm's law ($V = IR$).[2]][Hence, the power delivered to light bulb *B* will be reduced [3]][and it will be dimmer.[4]]

- I have used the relevant theory: resistors in series.[1]
- I have used the relevant theory: current in series circuits.[2]
- I have used the relevant theory: power in series circuits.[3]
- I have explicitly addressed what will happen to the brightness of the globe.[4]

Key science skills

20. [Mahua should repeat the current measurement for each number of resistors multiple times and take the average.[1]][The effect of random error is reduced by taking an average of multiple measurements since the random errors in each measurement tend to cancel out.[2]]

- I have explicitly addressed a way to reduce the effects of random error.[1]
- I have used the relevant theory: random error.[2]

Previous lessons

21. $K = C + 273.15 = 1700 + 273.15 = 1973.15$ K (1 MARK)

$\lambda_{max} = \frac{b}{T} = \frac{2.89 \times 10^{-3}}{1973.15} = 1.46 \times 10^{-6}$ m (1 MARK)

FROM LESSON 3A

22. 1 hour = 60 × 60 = 3600 s

$P = \frac{E}{t} = \frac{7.2 \times 10^3}{3600} = 2.0$ W (1 MARK)

$P = VI \Rightarrow 2.0 = V \times 1.0$

$V = 2.0$ V (1 MARK)

OR

$V = \frac{E}{Q}$ and $I = \frac{Q}{t} \Rightarrow E = VIt$

1 hour = 60 × 60 = 3600 s

$7.2 \times 10^3 = V \times 1.0 \times 3600$ (1 MARK)

$V = 2.0$ V (1 MARK)

OR

1 hour = 60 × 60 = 3600 s

$I = \frac{Q}{t} \Rightarrow 1.0 = \frac{Q}{3600}$

$Q = 3.6 \times 10^3$ C (1 MARK)

$V = \frac{E}{Q} = \frac{7.2 \times 10^3}{3.6 \times 10^3}$

$V = 2.0$ V (1 MARK)

FROM LESSON 6A

6D Parallel circuits

Progress questions

1. II, IV
2. B
3. C
4. B
5. A
6. C
7. D
8. R_4, R_3, R_2, R_1

Deconstructed exam-style

9. A

10. C

11. A

12. $\frac{1}{R_{eq}} = \frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{200} + \frac{1}{300} + \frac{1}{400}$

$R_T = 92.3\ \Omega$ (1 MARK)

$V_T = I_T R_T \Rightarrow 240 = I_T \times 92.3$

$I_T = \frac{240}{92.3} = 2.60$ A

$P_T = V_T I_T = 240 \times 2.60 = 624$ W (1 MARK)

$V_{300\,\Omega} = I_{300\,\Omega} \times R_{300\,\Omega} \Rightarrow 240 = I_{300\,\Omega} \times 300$

$I_{300\,\Omega} = \frac{240}{300} = 0.800$ A

$P_{300\,\Omega} = V_{300\,\Omega} \times I_{300\,\Omega} = 240 \times 0.800 = 192$ W (1 MARK)

$\frac{P_{300\,\Omega}}{P_T} = \frac{192}{624} = 0.308 = 30.8\%$ (1 MARK)

Exam-style

13. a. $\frac{1}{R_T} = \frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{600} + \frac{1}{400} + \frac{1}{800}$ (1 MARK)

$R_T = 184.6 = 185\ \Omega$ (1 MARK)

b. $\frac{1}{R_T} = \frac{1}{R_{eq}} = \frac{1}{R_4} + \frac{1}{R_5} = \frac{1}{100} + \frac{1}{100 \times 10^3}$ (1 MARK)

$R_T = 99.9 = 1.0 \times 10^2\ \Omega$ (1 MARK)

14. a. $\frac{1}{R_T} = \frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{50} + \frac{1}{100} + \frac{1}{50}$

$R_T = 20\ \Omega$ (1 MARK)

$V_T = I_T R_T \Rightarrow 9.0 = I_T \times 20$

$I_T = \frac{9.0}{20} = 0.450 = 0.45$ A (1 MARK)

b. $V_T = I_{100\,\Omega} R \Rightarrow 9.0 = I_{100\,\Omega} \times 100$ (1 MARK)

$I_{100\,\Omega} = \frac{9.0}{100} = 0.090$ A (1 MARK)

15. $I_n \propto \frac{1}{R_n} \Rightarrow I_1 = 4 \times I_2 \Rightarrow I_T = I_1 + I_2 = 5 \times I_2$

$I_2 = \frac{1}{5} \times I_T = \frac{1}{5} \times 5.0$ (1 MARK)

$I_2 = 1.0$ A (1 MARK)

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16. a. $\frac{1}{R_T} = \frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{20} + \frac{1}{40} + \frac{1}{20}$

$R_T = 8.0\ \Omega$ (1 MARK)

$V_T = I_T R_T \Rightarrow 9.0 = I_T \times 8.0$

$I_T = \frac{9.0}{8.0} = 1.13\ \text{A}$ (1 MARK)

$P_T = V_T I_T = 9.0 \times 1.13$

$P_T = 10.2 = 10\ \text{W}$ (1 MARK)

b. $V_T = I_{20\ \Omega} R \Rightarrow 9.0 = I_{20\ \Omega} \times 20$

$I_{20\ \Omega} = 0.45\ \text{A}$ (1 MARK)

$P_{20\ \Omega} = V_T I_{20\ \Omega} = 9.0 \times 0.45 = 4.05\ \text{W}$

Power dissipated by the two 20 Ω resistors is $2 \times P_{20\ \Omega} = 2 \times 4.05 = 8.1\ \text{W}$. (1 MARK)

17. [Joanne should choose the set with fewer bulbs.[1]][In parallel circuits, adding more components (in this case bulbs) draws more current and thus uses more power, so the set with fewer bulbs will use less power.[2]]

- I have explicitly addressed which set of lights Joanne should choose.[1]
- I have used the relevant theory: power in parallel circuits.[2]

18. a. [The diagram shows a parallel circuit.[1]][Points A and B on the diagram are nodes at which current is split into different branches.[2]]

- I have explicitly addressed the type of circuit.[1]
- I have used the relevant theory: characteristics of a parallel circuit.[2]

b. $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{10} + \frac{1}{20}$ (1 MARK)

$R_T = 6.7\ \Omega$ (1 MARK)

c. Given that $V_2 = V_T$:

$V_2 = I_2 R_2 \Rightarrow 450 = I_2 \times 20$

$I_2 = \frac{450}{20} = 23\ \text{A}$ (1 MARK)

$P_2 = I_2 V_2 = 23 \times 450$ (1 MARK)

$P_2 = 1.0 \times 10^4\ \text{W}$ (1 MARK)

OR

Given that voltage and resistance are already known,

$V_2 = I_2 R_2 \Rightarrow I_2 = \frac{V_2}{R_2}$

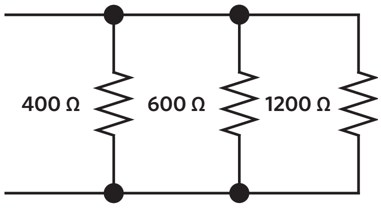
$P_2 = I_2 V_2 = \frac{V_2}{R_2} \times V_2 = \frac{V_2^2}{R_2}$ (1 MARK)

$P_2 = \frac{450^2}{20}$ (1 MARK)

$P_2 = 1.0 \times 10^4\ \text{W}$ (1 MARK)

19. For a 200 Ω resistor: $\frac{1}{R_T} = \frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots = \frac{1}{200}$

$\frac{1}{400} + \frac{1}{600} + \frac{1}{1200} = \frac{6}{1200} = \frac{1}{200}$ (1 MARK)



- I have drawn resistors connected in parallel.
- I have selected resistor values that have an equivalent resistance of 200 Ω.

Key science skills

20. Independent: number of 1 kΩ resistors (1 MARK)

Dependent: total current (1 MARK)

Controlled: source voltage **OR** ammeter connection (1 MARK)

FROM LESSON 11A

Previous lessons

21. [For a constant global temperature, the energy trapped within the atmosphere and the energy emitted via radiation has to balance.[1]][The industrial revolution has greatly altered this balance through the emission of additional greenhouse gases.[2]][This has caused energy to be trapped in the atmosphere for a greater amount of time, increasing the Earth's average temperature.[3]]

- I have explicitly addressed the requirement for a constant global temperature.[1]
- I have used the relevant theory: increased greenhouse gas due to the industrial revolution.[2]
- I have referenced the impact of greenhouse gases on global temperature.[3]

FROM LESSON 3B

22. a. [Rebecca is incorrect in their report as Ohm's Law, rearranged to $I = \frac{V}{R}$, is not solely about the relationship between current and voltage[1]][since the equation also demonstrates a linear trend for this relationship given a constant resistor.[2]][As resistor 1 displays a curved current-voltage graph, it is non-Ohmic whilst resistor 2 obeys Ohm's Law and so is Ohmic.[3]]

- I have explicitly addressed Ohm's Law.[1]
- I have used the relevant theory: interpretation of Ohm's Law.[2]
- I have stated which resistor is non-Ohmic and Ohmic.[3]

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b. Rearranging Ohm's Law, $I = \frac{V}{R}$.

$\Rightarrow$ Gradient of a current-resistance graph is $\frac{1}{R}$.

For the graph of R_1, $gradient = \frac{rise}{run} = \frac{1}{R}$ (1 MARK)

Picking two points lying on the straight line, $\frac{5.0 - 0}{20 - 0} = \frac{1}{R}$

$\Rightarrow R_1 = 4.0\ \Omega$ (1 MARK)

FROM LESSON 6B

6E Combination circuits

Progress questions

1. S-series; T-parallel; U-parallel; V-series
2. A
3. B
4. C
5.

Step no.	Action
2	Find total equivalent resistance of the circuit
1	Find the equivalent resistance of the parallel resistors
4	Find the current passing through R_4 using Ohm's law or $I_n \propto \frac{1}{R_n}$
3	Find the total current using Ohm's law

Deconstructed exam-style

6. B
7. C
8. A
9. $R_T = R_1 + (R_2 || R_3) + R_4 = 100 + \frac{1}{\frac{1}{400} + \frac{1}{400}} + 30.0 = 330\ \Omega$ (1 MARK)

$V_4 = \frac{R_4}{R_T} \times V_T = \frac{30.0}{330} \times 230 = 20.9$ V (1 MARK)

$I_4 = I_T = \frac{V_T}{R_T} = \frac{230}{330} = 0.697$ A (1 MARK)

$P_4 = V_4 I_4 = 20.9 \times 0.697 = 14.6$ W (1 MARK)

OR

$R_T = R_1 + (R_2 || R_3) + R_4 = 100 + \frac{1}{\frac{1}{400} + \frac{1}{400}} + 30.0 = 330\ \Omega$ (1 MARK)

$I_4 = I_T = \frac{V_T}{R_T} = \frac{230}{330} = 0.697$ A (1 MARK)

$V_4 = I_4 R_4 = 0.697 \times 30.0 = 20.9$ V (1 MARK)

$P_4 = V_4 I_4 = 20.9 \times 0.697 = 14.6$ W (1 MARK)

Exam style

10. $V_{1\&2} = V_1 = I_1 R_1 = 1.0 \times 12 = 12$ V (1 MARK)

$V_{3\&4} = V_T - V_{1\&2} = 48 - 12 = 36$ V

$R_{3\&4} = R_3 + R_4 = 14 + 10 = 24$ V (1 MARK)

$I_T = I_{3\&4} = \frac{V_{3\&4}}{R_{3\&4}} = \frac{36}{24} = 1.5$ A (1 MARK)

$I_2 = I_T - I_1 = 1.5 - 1.0 = 0.5$ A (1 MARK)

$R_2 = \frac{V_2}{I_2} = \frac{V_{1\&2}}{I_2} = \frac{12}{0.5} = 24 = 2 \times 10^1\ \Omega$ (1 MARK)

11. **a.** $R_{upper} = R_1 + R_2 = 2.0 + 1.0 = 3.0\ \Omega$

$R_{lower} = R_3 + R_4 = 7.0 + 6.0 = 13.0\ \Omega$

$\frac{1}{R_T} = \frac{1}{R_{upper}} + \frac{1}{R_{lower}} = \frac{1}{3.0} + \frac{1}{13.0}$ (1 MARK)

$R_T = 2.44 = 2.4\ \Omega$ (1 MARK)

b. $P_T = I_T^2 R_T$ (1 MARK)

$20 = I_T^2 \times 2.44$ (1 MARK)

$I_T = \sqrt{\frac{20}{2.44}} = 2.86 = 2.9$ A (1 MARK)

12. **a.** $R_{right} = R_2 + R_3 = 25 + 30 = 55\ \Omega$

$\frac{1}{R_T} = \frac{1}{R_{left}} + \frac{1}{R_{right}} = \frac{1}{10} + \frac{1}{55}$ (1 MARK)

$R_T = 8.46 = 8.5\ \Omega$ (1 MARK)

b. $V_T = I_T R_T$

$75 = I_T \times 8.46$ (1 MARK)

$I_T = \frac{75}{8.46} = 8.87 = 8.9$ A (1 MARK)

c. $V_{right} = I_{right} R_{right}$

$75 = I_{right} \times 55$

$I_{right} = \frac{75}{55} = 1.36$ A (1 MARK)

$V_2 = I_2 R_2 = 1.36 \times 25 = 34.1 = 34$ V (1 MARK)

13. **a.** $R_{upper} = R_1 || R_2 = \frac{1}{\frac{1}{10} + \frac{1}{25}} = 7.14\ \Omega$ (1 MARK)

$R_{lower} = R_3 || R_4 = \frac{1}{\frac{1}{35} + \frac{1}{20}} = 12.7\ \Omega$ (1 MARK)

$R_T = R_{upper} + R_{lower} = 7.14 + 12.7 = 19.8\ \Omega$ (1 MARK)

b. $V_T = I_T R_T$

$24 = I_T \times 19.8$ (1 MARK)

$I_T = 1.21 = 1.2$ A (1 MARK)

c. $V_{upper} = I_{upper} R_{upper} = 1.21 \times 7.14 = 8.639$ V (1 MARK)

$V_1 = V_{upper} = I_1 R_1$

$8.639 = I_1 \times 10$

$I_1 = \frac{8.639}{10} = 0.8639 = 0.86$ A (1 MARK)

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d. $V_2 = V_{upper} = I_2R_2 \Rightarrow I_2 = \frac{V_{upper}}{R_2}$

$I_2 = \frac{8.57}{25} = 0.34\text{ A}$ (1 MARK)

$\frac{P_1}{P_2} = \frac{I_1V_1}{I_2V_2} = \frac{I_1V_{upper}}{I_2V_{upper}} = \frac{I_1}{I_2}$ (1 MARK)

$\frac{P_1}{P_2} = \frac{0.86}{0.34} = 2.53 = 2.5$ (1 MARK)

14. **a.** $R_{6,7} = R_6 + R_7 = 4.0 + 4.0 = 8.0\ \Omega$

$R_{5,6,7} = R_5||R_{6,7} = \frac{1}{\frac{1}{8.0} + \frac{1}{8.0}} = 4.0\ \Omega$

$R_{4\ to\ 7} = R_4 + R_{5,6,7} = 5.0 + 4.0 = 9.0\ \Omega$

$R_{2,3} = R_2 + R_3 = 7.0 + 3.0 = 10.0\ \Omega$

$R_{2\ to\ 7} = R_{2,3}||R_{4\ to\ 7} = \frac{1}{\frac{1}{10.0} + \frac{1}{9.0}} = 4.7\ \Omega$ (1 MARK)

$R_T = R_1 + R_{2\ to\ 7} = 5.0 + 4.7 = 9.7\ \Omega$ (1 MARK)

b. $R_{4,5} = R_4||R_5 = \frac{1}{\frac{1}{20} + \frac{1}{60}} = 15\ \Omega$

$R_{4,5,6} = R_{4,5} + R_6 = 15 + 50 = 65\ \Omega$

$R_{2,3} = R_2 + R_3 = 200 + 50 = 250\ \Omega$

$R_{2\ to\ 6} = R_{2,3}||R_{4,5,6} = \frac{1}{\frac{1}{250} + \frac{1}{65}} = 52\ \Omega$ (1 MARK)

$R_T = R_1 + R_{2\ to\ 6} = 30 + 52 = 82\ \Omega$ (1 MARK)

c. $R_{eq\ 1,2} = R_1||R_2 = \frac{1}{\frac{1}{200} + \frac{1}{600}} = 150\ \Omega$

$R_{eq\ 3,4} = R_3||R_4 = \frac{1}{\frac{1}{30} + \frac{1}{70}} = 21\ \Omega$ (1 MARK)

$R_T = R_{eq\ 1,2} + R_{eq\ 3,4} = 150 + 21 = 171\ \Omega$ (1 MARK)

15. $R_{eq\ 1,3} = R_1||R_3 = \frac{1}{\frac{1}{40} + \frac{1}{20}} = 13\ \Omega$ (1 MARK)

$R_T = R_{eq\ 1,3} + R_2 = 13 + 30 = 43\ \Omega$ (1 MARK)

$V = IR \Rightarrow 10 = I_T \times 43$

$I_T = \frac{10}{43} = 0.233 = 0.23\text{ A}$ (1 MARK)

16. $R_{3,4} = R_3 + R_4 = 15 + 15 = 30\ \Omega$

$R_{eq\ 2,3,4} = R_2||R_{3,4} = \frac{1}{\frac{1}{10} + \frac{1}{30}} = 7.5\ \Omega$

$R_T = R_1 + R_{eq\ 2,3,4} + R_5 = 7.5 + 7.5 + 15 = 30\ \Omega$ (1 MARK)

$V = IR \Rightarrow I_T = \frac{V_T}{R_T} = \frac{30}{30} = 1.0\text{ A}$ (1 MARK)

$V_{2,3,4} = I_TR_{eq\ 2,3,4} = 1.0 \times 7.5 = 7.5\text{ V}$

$I_{2,3,4} = \frac{V_{2,3,4}}{R_{eq\ 3,4}} = \frac{7.5}{30} = 0.25\text{ A}$ (1 MARK)

$V_4 = I_4R_4 = I_{2,3,4}R_4 = 0.25 \times 15 = 3.8\text{ V}$ (1 MARK)

17. $R_{3,4} = R_3 + R_4 = 10 + 2.0 \times 10^3 = 2.0 \times 10^3$

$R_{eq\ 2,3,4} = R_2||R_{3,4} = \frac{1}{\frac{1}{30} + \frac{1}{2.0 \times 10^3}} = 30\ \Omega$

$R_T = R_1 + R_{eq\ 2,3,4} + R_5 = 20 + 30 + 15 = 65\ \Omega$ (1 MARK)

$V_1 = \frac{R_1}{R_T} \times V_T = \frac{20}{65} \times 120 = 37\text{ V}$ (1 MARK)

$V_{2,3,4} = \frac{R_{eq\ 2,3,4}}{R_T} \times V_T = \frac{30}{65} \times 120 = 55\text{ V}$ (1 MARK)

$V_5 = \frac{R_5}{R_T} \times V_T = \frac{15}{65} \times 120 = 28\text{ V}$ (1 MARK)

Since R_2 has a much smaller resistance than $R_{3,4}$, almost all of the total current will flow through R_2. Since $P = VI$, and resistors 1, 2, and 5 all have approximately equal current flowing through them, the resistor out of these with the highest voltage drop will consume the most power. Therefore, R_2 will consume the most power. (1 MARK)

Key science skills

18. [Experiment 1 has the more precise and the more accurate results.[1]] [The results from experiment 1 have an average (5.54 mA) closer to the actual current (5.5 mA) than the average of experiment 2 (5.64 mA).[2]] [The results from experiment 1 have a smaller range (0.2 mA) than the results of experiment 2 (0.8 mA).[3]]

- I have explicitly addressed the question.[1]
- I have used the relevant theory: the definition of accuracy.[2]
- I have used the relevant theory: the definition of precision.[3]
- I have used the provided data in my answer.

FROM LESSON 11C

Previous lessons

19. Two of: rising average temperatures, increased occurrences of floods, more extreme droughts, more extreme and frequent fire seasons, more extreme weather generally. (2 MARKS)

FROM LESSON 3B

20. $R_T = R_1 + R_2 + R_3 = 10 + 30 + 5.0 = 45.0\ \Omega$ (1 MARK)

$I_T = \frac{V_T}{R_T} = \frac{9}{45.0} = 0.2\text{ A}$ (1 MARK)

FROM LESSON 6C

Chapter 6 review

Section A

1. B. Current is equal at all points in a series circuit, and the potential difference across two separate resistors in parallel is equal.

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2. B. $P = VI \Rightarrow 45 = 240 \times I \Rightarrow I = 0.1875$ A

$Q = I \times t = 0.1875 \times 1 = 0.1875$ C

$n_e = \frac{-Q}{-e} = \frac{0.1875}{1.60 \times 10^{-19}} = 1.172 \times 10^{18} = 1.2 \times 10^{18}$ electrons

OR

$E = P \times t = 45 \times 1 = 45$ J

$V = \frac{E}{Q} \Rightarrow 240 = \frac{45}{Q}$

$Q = 0.1875$ C

$n_e = \frac{-Q}{-e} = \frac{0.1875}{1.60 \times 10^{-19}} = 1.172 \times 10^{18} = 1.2 \times 10^{18}$ electrons

3. A. The voltage drop across each resistor remains at 15 V (the supply voltage) both when in series and in parallel. Adding a resistor in parallel will decrease the total resistance and therefore increase the total current in the circuit.

4. C. The equivalent resistance of parallel resistors is always smaller than the smallest resistance of an individual arm.

5. D. $\frac{1}{R_A} = \frac{1}{3+3} + \frac{1}{6} = \frac{1}{3} \Rightarrow R_A = 3\ \Omega$

$R_{eq} = 11 = R_A + R_B = 3 + R_B \Rightarrow R_B = 8\ \Omega$

$\frac{1}{R_B} = \frac{1}{5+5} + \frac{1}{X} \Rightarrow \frac{1}{8} = \frac{1}{10} + \frac{1}{X}$

$X = 40\ \Omega$

Section B

6. a. $V = IR \Rightarrow 35.0 = I \times 8.00 \times 10^4$ (1 MARK)

$I = 4.375 \times 10^{-4}$ A

$P = VI = 35.0 \times 4.375 \times 10^{-4}$ W (1 MARK)

$P = 1.53 \times 10^{-2}$ W (1 MARK)

b. $\frac{1}{R_T} = \frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{8.00 \times 10^4} + \frac{1}{8.00 \times 10^4}$ (1 MARK)

$R_{eq} = 4.00 \times 10^4\ \Omega$

$V_T = I_T R_{eq} \Rightarrow 35.0 = I_T \times 4.00 \times 10^4$ (1 MARK)

$I_T = \frac{35.0}{4.00 \times 10^4} = 8.75 \times 10^{-4}$ A (1 MARK)

7. [Both students are able to determine the total power usage of the circuit.[1]][Since $P = VI$, determining the power usage across elements requires the voltage and current used by those elements.[2]][Erin is able to determine the power provided by the battery, and Jack is able to determine the power used by the circuit elements.[3]][The power provided by the battery is equal to the power used by the circuit elements, so they both can calculate the total power usage.[4]]

- I have explicitly addressed whether each student can determine the total power usage of the circuit.[1]
- I have used the relevant theory: measuring the power used by circuit elements.[2]
- I have referred to the elements that the students are measuring.[3]
- I have related my answer to the context of the question.[4]

8. Consider the parallel circuit of the 100 Ω and 200 Ω resistors:

$R_1 = \left(\frac{1}{100} + \frac{1}{200}\right)^{-1} = 66.66\ \Omega$ (1 MARK)

Consider the parallel circuit of R_1 and the two 300 Ω resistors:

$R_2 = \left(\frac{1}{66.6} + \frac{1}{300+300}\right)^{-1} = 59.99\ \Omega$ (1 MARK)

Consider the parallel circuit of the 400 Ω and 500 Ω resistors:

$R_3 = \left(\frac{1}{400} + \frac{1}{500}\right)^{-1} = 222.22\ \Omega$ (1 MARK)

Consider the parallel circuit of R_2 and R_3:

$R_{eq} = \left(\frac{1}{222.22} + \frac{1}{59.99}\right)^{-1} = 47.2\ \Omega$ (1 MARK)

Therefore the equivalent resistance between X and Y is 47.2 Ω.

9. a. $R_2 : R_3 = 600 : 200 = 3 : 1$

$I_n \propto \frac{1}{R_n} \Rightarrow I_2 : I_3 = 1 : 3$ (1 MARK)

$I_T = I_2 + I_3 \Rightarrow I_2 = \frac{1}{4} I_T$

$I_X : I_Y = I_2 : I_T = 1 : 4$ (1 MARK)

b. Consider the parallel circuit of the 600 Ω and 200 Ω resistors:

$R_{eq1} = \left(\frac{1}{600} + \frac{1}{200}\right)^{-1} = 150\ \Omega$ (1 MARK)

$R_T = R_{eq2} = R_1 + R_{eq1} = 400 + 150 = 550\ \Omega$

$I_T = \frac{V_T}{R_{eq}} = \frac{12.0}{550} = 0.0218$ A (1 MARK)

$V_1 = I_T R_1 = 0.0218 \times 400 = 8.73$ V (1 MARK)

OR

Consider the parallel circuit of the 600 Ω and 200 Ω resistors:

$R_{eq1} = \left(\frac{1}{600} + \frac{1}{200}\right)^{-1} = 150\ \Omega$ (1 MARK)

$R_T = R_{eq2} = R_1 + R_{eq1} = 400 + 150 = 550\ \Omega$

$V_1 = \frac{R_1}{R_T} \times V_T = \frac{400}{550} \times 12.0 = 8.73$ V (1 MARK)

c. $V_T = V_1 + V_3 \Rightarrow 12.0 = 8.73 + V_3$

$V_3 = 3.27$ V (1 MARK)

$I_T = \frac{V_T}{R_T} = \frac{12.0}{400 + 150} = 0.0218$ A

Since $I_X : I_Y = 1 : 4$, $I_3 = \frac{3}{4} I_T = \frac{3}{4} \times 0.0218 = 0.0164$ A (1 MARK)

$P_3 = V_3 I_3 = 3.27 \times 0.0164 = 0.0535 = 0.054$ W (1 MARK)

d. $R_T = R_{eq2} + R_L$ (1 MARK)

$I_T = \frac{V_T}{R_T} = \frac{12.0}{550 + R_L}$ (1 MARK)

Current through A_Y is equal to $I_T \Rightarrow 15 \times 10^{-3}$ A $= \frac{12.0}{550 + R_L}$

$R_L = 250\ \Omega$ (1 MARK)

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7A Applications of electric circuits

Progress questions

1. B **2.** B **3.** B **4.** C

5. real; maximum; significant

6. I, III **7.** B **8.** B **9.** A

Deconstructed exam-style

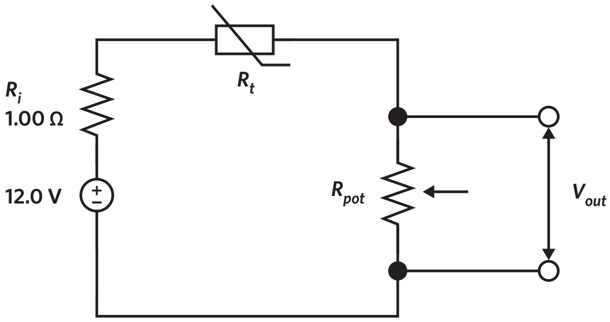
10. C

11. B

12. D

13. We need the output voltage to increase with temperature, so make the thermistor R_1. (1 MARK)

Circuit design:



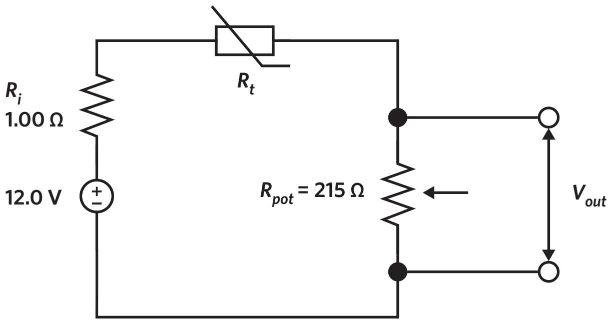
At 24.0°C, $R_t = 300\ \Omega$, $V_{out} = 5.00$ V

Since the battery has internal resistance:

$$V_{out} = \frac{R_{pot}}{(R_i + R_t) + R_{pot}} \times 12.0 = 5.00 \text{ V} \quad \text{(1 MARK)}$$

$$\frac{R_{pot}}{(1.00 + 300) + R_{pot}} \times 12.0 = 5.00 \Rightarrow R_{pot} = 215\ \Omega \quad \text{(1 MARK)}$$

Final circuit:



(1 MARK)

Exam-style

14. $V_R = 5.0 - 2.0 = 3.0$ V (1 MARK)

$$I_{max} = \frac{V_R}{R_{min}} \Rightarrow 20 \times 10^{-3} = \frac{3.0}{R_{min}}$$

$R_{min} = 150 = 1.5 \times 10^2\ \Omega$ (1 MARK)

15. $I = 0$ A

There is no current through the thermistor due to the orientation of the diode in the thermistor arm.

16. At 900 lux, $R_{LDR} = 15\ \Omega$ (1 MARK)

Since the threshold voltage is met, $V_{LED} = 2.0$ V (1 MARK)

Treat R_1 and the LDR as a voltage divider:

$$V_{LDR} = \frac{R_{LDR}}{R_1 + R_{LDR}} \times V_{in} = \frac{15}{20 + 15} \times (50 - 2.0) \quad \text{(1 MARK)}$$

$V_{LDR} = 20.6 = 21$ V (1 MARK)

17. [The voltage provided by a source with an internal resistance is smaller than an ideal source of the same voltage.[1]] [The internal resistance limits the maximum current a source can provide, unlike an ideal source which has no maximum current.[2]]

- I have explicitly addressed the effect of internal resistance on the voltage supplied by a source.[1]
- I have explicitly addressed the effect of internal resistance on the current supplied by a source.[2]

18. Parallel resistors: $R_{eq} = \left(\frac{1}{100} + \frac{1}{100}\right)^{-1} = 50\ \Omega$

$R_T = R_{eq} + R_{therm} = 50 + R_{therm}$ (1 MARK)

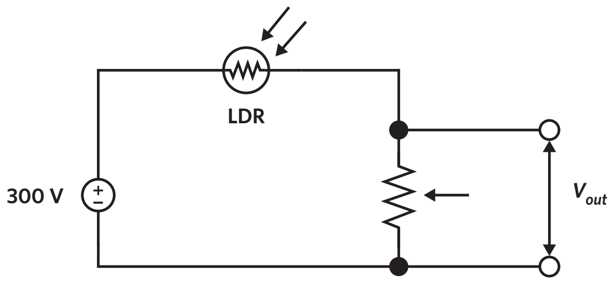
$V_T = I_T R_T \Rightarrow 7.0 = 100 \times 10^{-3} \times (50 + R_{therm})$

$R_{therm} = 20\ \Omega$ (1 MARK)

Using the graph, for $R_{therm} = 20\ \Omega$, $T = 5.0$°C (1 MARK)

19. Since R_{LDR} decreases with intensity, make the LDR R_1 of a voltage divider. (1 MARK)

Circuit design:

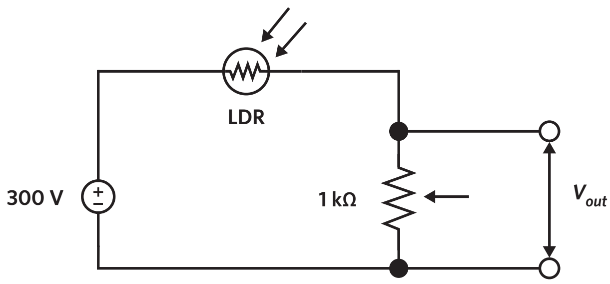


At 500 lux, $R_{LDR} = 2 \times 10^3\ \Omega$, $V_{out} = 100$ V

$$V_{out} = \frac{R_{pot}}{R_{LDR} + R_{pot}} \times 300 = 100 \text{ V} \quad \text{(1 MARK)}$$

$\Rightarrow R_{pot} = 1000\ \Omega = 1$ kΩ (1 MARK)

Final circuit:



(1 MARK)

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Key science skills

20. [Mariam is correct and Mateo is incorrect.[1]][For an experiment to be valid, it needs to measure the effect of the independent variable on the dependent variable.[2]][While Mateo's claim is a good point, it is not the correct definition of validity.[3]][The stages of an experiment that contribute to validity are experimental design, conduction, and how the results are processed and analysed.[4]]

- I have explicitly addressed who is correct and who is incorrect.[1]
- I have explicitly addressed Mariam's claim of what it means for an experiment to be valid.[2]
- I have explicitly addressed Mateo's claim of what it means for an experiment to be valid.[3]
- I have used the relevant theory: experimental stages affecting validity.[4]

FROM LESSON 11C

Previous lessons

21. [Without greenhouse gases, the temperature of the our climate would be significantly decreased,[1]][as greenhouse gases trap outgoing solar radiation from leaving the Earth's atmosphere.[2]]

- I have explicitly addressed the role of greenhouse gases in our atmosphere.[1]
- I have used the relevant theory: the greenhouse effect.[2]

FROM LESSON 3B

22. $V = IR$

$12 = 8.3 \times R$ (1 MARK)

$R = 1.446 = 1.4\ \Omega$ (1 MARK)

FROM LESSON 6B

7B Household electricity

Progress questions

1. A **2.** B **3.** C **4.** A

5. C **6.** A **7.** A **8.** B

9. C

Deconstructed exam-style

10. A

11. C

12. B

13. $V_{RMS} = \frac{1}{\sqrt{2}} \times V_{peak}$

$V_{RMS} = \frac{1}{\sqrt{2}} \times 300 = 212\text{ V}$ (1 MARK)

$P = \frac{V_{RMS}{}^2}{R} = \frac{212^2}{80} = 562.5\text{ W}$ (1 MARK)

$P = 562.5\text{ W} = 0.563\text{ kW}$ (1 MARK)

$E = P \times t$

$E = 0.563 \times 4.0 = 2.25 = 2.3\text{ kWh}$ (1 MARK)

Exam-style

14. a. 6.0 minutes = 0.10 hours

$P = \frac{E}{t} = \frac{0.16\text{ kW h}}{0.10\text{ h}}$ (1 MARK)

$P = 1.6\text{ kW}$ (1 MARK)

b. $0.16\text{ kWh} = 0.16 \times 3.6 \times 10^6\text{ J} = 5.76 \times 10^5 = 5.8 \times 10^5\text{ J}$

15. From the graph, $V_{peak} = 3.5 \times 0.40 = 1.40\text{ V}$ (1 MARK)

$V_{RMS} = \frac{1}{\sqrt{2}} \times V_{peak} = \frac{1}{\sqrt{2}} \times 1.40 = 0.989 = 0.99\text{ V}$ (1 MARK)

16. [The only way to use the lights would be to have them all switched on at once, since a single break in the series circuit would prevent current flowing to any of them.[1]][They would also all glow less bright because the equivalent resistance of the circuit would be much larger than when connected in parallel (the voltage would need to be divided between the lights).[2]]

- I have used the relevant theory: current in series.[1]
- I have used the relevant theory: resistance in series.[2]

17. a. $P = I_{RMS}{}^2 R$

$242 = I_{RMS}{}^2 \times 50$ (1 MARK)

$I_{RMS} = \sqrt{\frac{242}{50}} = 2.20 = 2.2\text{ A}$ (1 MARK)

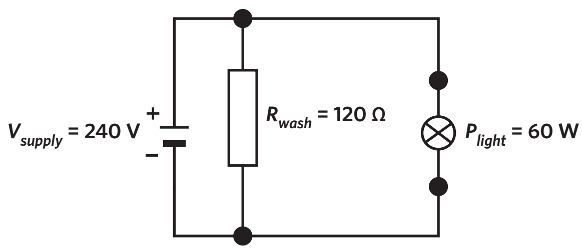
b. $I_{peak} = I_{RMS} \times \sqrt{2} = 2.2 \times \sqrt{2} = 3.11 = 3.1\text{ A}$

c. $242\text{ W} = 0.242\text{ kW}$

$E = P \times t = 0.242 \times 2.5$ (1 MARK)

$E = 0.605 = 0.61\text{ kWh}$ (1 MARK)

18. a.



- I have drawn a complete circuit diagram with a resistor and a light bulb connected to a power supply in parallel.
- I have shown the voltage of the power supply.
- I have shown the resistance of the washing machine (represented by a resistor).
- I have shown the power of the light bulb.

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b. Consider the washing machine:

$I_{wash} = \frac{V_{supply}}{R_{wash}} = \frac{240}{120} = 2.00 = 2.0 \text{ A}$ (1 MARK)

Consider the light bulb:

$P_{light} = V_{supply} I_{light}$

$60 = 240 \times I_{light}$

$I_{light} = 0.25 \text{ A}$ (1 MARK)

$I_{supply} = I_{wash} + I_{light} = 2.0 + 0.25 = 2.25 = 2.3 \text{ A}$ (1 MARK)

Key science skills

19. a. [Arden's data is more accurate[1]][because the average of their data $\left(\frac{0.18 + 0.18 + 0.20 + 0.20 + 0.18}{5} = 0.19\right)$ is closer to the true value than Jacinta's data $\left(\frac{0.15 + 0.23 + 0.25 + 0.19 + 0.19}{5} = 0.20\right)$.[2]]

- I have explicitly addressed which data set is more accurate.[1]
- I have justified my answer with relevant data.[2]

b. [Arden's data is more precise,[1]][because the range of their data $(0.20 - 0.18 = 0.02)$ is smaller than the range of Jactina's data $(0.25 - 0.15 = 0.10)$.[2]]

- I have explicitly addressed which data set is more precise.[1]
- I have justified my answer with relevant data.[2]

FROM LESSON 11C

Previous lessons

20. [This isotope of iron will be unstable[1]][as it has $Z = 26$ (>20) but also has $N = Z$ $(N = 52 - 26 = 26)$.[2]][Only elements with $Z \leq 20$ follow the $N = Z$ stability rule. An iron isotope should have more neutrons than protons to be stable.[3]]

- I have explicitly addressed if the isotope is stable or unstable.[1]
- I have used the relevant theory: nuclear notation.[2]
- I have used the relevant theory: nuclear stability.[3]

FROM LESSON 4A

21. a. $V_{supply} = IR_T$

$6 = I \times 300$ (1 MARK)

$I = \frac{6}{300} = 0.020 = 0.02 \text{ A}$ (1 MARK)

b. $P = VI$

Since each resistor has equal resistance, $V_1 = 2.0 \text{ V}$. (1 MARK)

$P_1 = 2.0 \times 0.020 = 0.040 \text{ W}$ (1 MARK)

c. $V_{supply} = IR_T$

$6.0 = I \times (100 + 100)$

$I = \frac{6.0}{200} = 0.030 \text{ A}$ (1 MARK)

$P_{new} = V_1 I$

$P_{new} = 3.0 \times 0.030 = 0.090 = 0.09 \text{ W}$ (1 MARK)

0.090 W is greater than 0.040 W, therefore the power across the new configuration is higher than that of the old configuration. (1 MARK)

FROM LESSON 6C

7C Electrical safety

Progress questions

1. B	**2.** B	**3.** A	**4.** A
5. A	**6.** A	**7.** A	**8.** B
9. A	**10.** A	**11.** B	**12.** B

Deconstructed exam-style

13. C	**14.** A	**15.** C	**16.** B

17. [The RCD is most likely to protect Regina.[1]][It will detect a difference between the currents flowing in the active wire and the neutral wire[2]][and then switch the circuit off.[3]]

- I have explicitly addressed which safety design will protect Regina.[1]
- I have used the relevant theory: what triggers an RCD.[2]
- I have used the relevant theory: what happens when an RCD is triggered.[3]

Exam-style

18. [The earth wire is designed for this situation[1]][to protect people against electric shock.[2]]

- I have explicitly addressed which safety feature is designed for this situation.[1]
- I have used the relevant theory: prevention of electric shock.[2]

19. a. [Polly's conclusion is incorrect: a short circuit is not a shock hazard.[1]][A short circuit involves a lower resistance path so that the current in the circuit is greater,[2]][but this does not necessarily increase the chance of current flowing through a person to cause an electric shock.[3]]

- I have explicitly addressed whether Polly's conclusion is correct.[1]
- I have used the relevant theory: short circuits.[2]
- I have used the relevant theory: cause of electric shock.[3]

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b. [An RCD switches off a circuit only when there is a difference between the currents flowing in the active and neutral wires.[1]] [A short circuit provides a lower resistance path between the active and neutral wires but not an alternative path to either of the wires, so they will carry the same current as each other.[2]]

- I have used the relevant theory: how an RCD works.[1]
- I have used the relevant theory: short circuits.[2]

20. [This device is a fuse.[1]] [The thinner wire in the fuse melts when the current is higher than it is rated at due to the additional heat created by the higher current.[2]]

- I have used the relevant theory: the design of the fuse.[1]
- I have used the relevant theory: reason why the thinner wire melts.[2]

21. a. [A fuse or circuit breaker will cause a break in the circuit only if the current exceeds the intended value of that circuit, which will happen only if the resistance of the new pathway via the earth connection is low enough.[1]] [The fuse or circuit breaker is designed to protect against overheating which can cause fires and damage to appliances.[2]]

- I have used the relevant theory: conditions that would cause a break in the circuit.[1]
- I have explicitly addressed the hazard that a fuse/circuit breaker protects against.[2]

b. [An RCD should break the circuit in this case because current is leaving the circuit via the earth wire, which means there will be a difference between the currents in the active and neutral wires.[1]] [An RCD protects against electric shock.[2]]

- I have used the relevant theory: why an RCD causes a break in the circuit.[1]
- I have explicitly addressed the hazard that an RCD protects against.[2]

22. [A 9 V battery cell does not produce enough current to cause a severe shock when a human touches it[1]] [because the resistance of a human in this case is far greater than the resistance of the light bulb and so the current is far lower.[2]]

- I have explicitly addressed the reason that a 9 V battery cell is safe to touch.[1]
- I have used the relevant theory: the relationship between resistance and current.[2]

Key science skills

23. $Avg. = \frac{5.4 + 5.1 + 5.5 + 5.6 + 5.9}{5} = 5.5$ A (1 MARK)

$Max.\ true\ value = 5.0 + 0.2 = 5.2$ A

$Min.\ error = 5.5 - 5.2 = 0.3$ A (1 MARK)

FROM LESSON 11C

Previous lessons

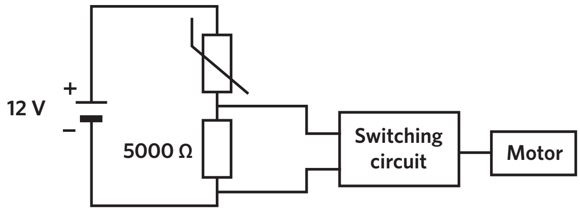
24. [The nucleus contains positively charged protons experiencing repulsive electrostatic forces, which tries to force the nucleus apart.[1]] [This repulsion is balanced by the strong nuclear force between nucleons.[2]]

- I have used the relevant theory: the force of repulsion.[1]
- I have used the relevant theory: the force responsible for nucleus stability .[2]

FROM LESSON 4A

25. a. 2500 Ω

b.



- I have labelled all the required components: one resistor, the thermistor and the switching circuit.[1]
- I have labelled the resistor with the correct resistance.[2]

FROM LESSON 7A

Chapter 7 review

Section A

1. C. $E = P \times t = 6 \times 120 \times (60 \times 60 \times 12.0) = 3.11 \times 10^7$ J

$E = \frac{3.11 \times 10^7}{3.6 \times 10^6} = 8.64$ kWh

2. D. $V_{RMS} = \frac{V_{peak}}{\sqrt{2}}$

$100 = \frac{V_{peak}}{\sqrt{2}}$

$V_{peak} = 141$ V

3. D. Circuit breakers cause a break in the circuit by opening a switch when the current flowing through the circuit exceeds the rated value. This protects appliances from burning out, but does not prevent electric shock.

4. A. In VCE Physics we assume wires have negligible resistance unless otherwise stated. Therefore the only explanation for the lower voltage drop would be an internal resistance within the power source.

5. B. No current flows through the arm containing the LEDs. The current through the right arm is given by

$I = \frac{V_T}{R_{eq}} = \frac{12}{200 + 400} = 0.020$ A or 20 mA.

Section B

6. a. $E = \frac{12.50}{0.36} = 34.72$ kWh (1 MARK)

$P = \frac{E}{t} = \frac{34.72 \times 10^3 \times 60 \times 60}{3.0 \times 60 \times 60} = 11.6 = 12$ kW (1 MARK)

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b. Decrease by a factor of 4.

$P = VI$, so if the power decreases by a factor of 4, then the voltage would also have to decrease by a factor of 4.

7. a. [RCDs are ineffective against short circuits.[1]] [An RCD switches off the circuit when there is a difference between the current flowing through the active and neutral wires, however a short circuit does not create such a difference.[2]]

I have explicitly addressed whether or not the RCD is effective against short circuits.[1]

I have used the relevant theory: RCD operation under short circuit conditions.[2]

b. [Circuit breakers are effective against short circuits.[1]] [A circuit breaker switches off the circuit when an excess current flows through it. In a short circuit, the path of zero resistance causes a large current, which will be detected by the circuit breaker.[2]]

I have explicitly addressed whether or not the circuit breaker is effective against short circuits.[1]

I have used the relevant theory: circuit breaker operation under short circuit conditions.[2]

c. [Earth wires are ineffective against short circuits.[1]] [The earth wire provides a pathway for leaking current to flow to the ground, however the short circuit does not create a pathway for current to leak from the device.[2]]

I have explicitly addressed whether or not the earth pin is effective against short circuits.[1]

I have used the relevant theory: earth wire operation under short circuit conditions.[2]

8. a. From the graph, $V_{LED} = 1.5 \text{ V}$ (1 MARK)

Consider one arm of the parallel circuit:

$V_T = V_1 + V_{arm} \Rightarrow 6.0 = V_1 + 3 \times V_{LED}$

$V_1 = 1.5 \text{ V}$ (1 MARK)

$V_1 = I_1 R_1 \Rightarrow 1.5 = I_1 \times 100$

$I_1 = 0.015 \text{ A} = 15 \text{ mA}$ (1 MARK)

b. On: LEDs D, E and F (1 MARK)

Off: LEDs A, B and C (1 MARK)

9. $V_{RMS} = \frac{V_{peak}}{\sqrt{2}} = \frac{250}{\sqrt{2}} = 176.8 \text{ V}$ (1 MARK)

$I_{RMS} = \frac{V_{RMS}}{R} = \frac{176.8}{1.3 \times 10^3} = 0.136 \text{ A}$

$P = V_{RMS} I_{RMS} = 176.8 \times 0.136 = 24.04 \text{ W} = 0.024 \text{ kW}$ (1 MARK)

8 PM to 8 AM is 12 hours $\Rightarrow t = 12 \text{ h}$

$Cost = E \times rate = P \times t \times 0.36 = 0.024 \times 12 \times 0.36 = 0.103 = 0.10$

It costs \$0.10 to run the Christmas lights. (1 MARK)

10. a. [So that the switching circuit voltage increases to reach its threshold voltage as the temperature increases, the voltage drop across the thermistor should decrease with increasing temperature.[1]] [Since resistance is proportional to voltage by $V = IR$, this means that B is the correct thermistor to use.[2]]

I have used the relevant theory the required change in thermistor voltage drop as temperature increases.[1]

I have explicitly stated thermistor B should be used.[2]

b. From the graph, at 10°C, $R_{TH} = 2.0 \times 10^2 \ \Omega$ (1 MARK)

Using the voltage divider equation,

$V_{switching\ circuit} = \frac{R_2}{R_2 + R_{TH}} \times V_T = \frac{1.2 \times 10^3}{1.2 \times 10^3 + 2.0 \times 10^2} \times 240 \text{ V}$

(1 MARK)

$V_{switching\ circuit} = 205.7 = 2.1 \times 10^2 \text{ V}$ (1 MARK)

c. Consider the parallel circuit considering of R_2 and switching circuit:

$R_{eq} = \left(\frac{1}{1.2 \times 10^3} + \frac{1}{2.4 \times 10^3}\right)^{-1} = 800 \ \Omega$ (1 MARK)

$R_T = R_{eq} + R_{TH} = 800 + R_{TH} \ \Omega$

$I_T = \frac{V_T}{R_T} \Rightarrow 200 \times 10^{-3} = \frac{240}{800 + R_{TH}}$

$R_{TH} = 400 = 4.0 \times 10^2 \ \Omega$ (1 MARK)

From the graph, when $R_{TH} = 4.0 \times 10^2 \ \Omega$, the temperature is 6.5°C. (1 MARK)

Unit 1 AOS 3 review

Section A

1. B. Voltage is the energy per unit charge. Suppose there are n coulombs of charge in the dome.

Then $V = \frac{E}{Q} = \frac{1.2 \times 10^3 \times n}{n} = 1.2 \times 10^3 \text{ V}$.

FROM LESSON 6A

2. B. $V_{RMS} = \frac{V_{peak}}{\sqrt{2}} = \frac{5.00 \times 10^2}{\sqrt{2}} = 354 \text{ V}$

FROM LESSON 7B

3. D. In the series circuit, the supply voltage will be split between each LED so that the voltage drop across a single LED will be smaller than the threshold voltage. This means that in the series circuit, neither LED will light up. In the parallel circuit, both LEDs will have a voltage drop equal to their threshold voltage, so they will light up.

FROM LESSON 7A

4. D. The wiring of the multimeter changes depending on what it is being used to measure.

FROM LESSON 6A

5. C. For both ohmic and non-ohmic devices, given the values of two of the current, voltage, and resistance, we can use Ohm's Law to solve for the third value.

FROM LESSON 6B

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Section B

6. a. $P = \frac{E}{\Delta t} \Rightarrow 30.0 = \frac{E}{1.00}$

$E = 30.0$ J

$V = \frac{E}{Q} \Rightarrow 12.0 = \frac{30.0}{n \times 1.6 \times 10^{-19}}$ (1 MARK)

$n = 1.56 \times 10^{19} = 1.6 \times 10^{19}$ electrons (1 MARK)

b. $P = \frac{E}{\Delta t} = \frac{30.0}{3 \times 1.00} = 10.0$ W

FROM LESSON 6A

7. a. Non-ohmic

For an ohmic device, the gradient of the *I-V* graph (the resistance) is constant.

FROM LESSON 6B

b. From the *I-V* graph, a current of 15 mA correlates to a voltage across the LED of 3.5 V. (1 MARK)

$V_{280\,\Omega} = I_{280\,\Omega} R_{280\,\Omega} = 15 \times 10^{-3} \times 280 = 4.2$ V (1 MARK)

$V_{battery} = V_{LED} + V_{280\,\Omega} = 3.5 + 4.2 = 7.7$ V (1 MARK)

c. [The LED component converts electrical energy into light energy,[1]][whilst the resistor converts electrical energy into thermal energy.[2]]

- I have used the relevant theory: energy conversion of an LED.[1]
- I have used the relevant theory: energy conversion of a resistor.[2]

FROM LESSONS 6A & 7A

8. a. 0 V

There is no potential difference across the voltmeter (all of it is dropped across the open switch).

FROM LESSON 6A

b. The voltmeter measures the voltage drop across R_2.

$V_T = IR_T \Rightarrow I = \frac{V_T}{R_T} = \frac{12.0}{1200 + 600} = 6.67 \times 10^{-3}$ A (1 MARK)

$V_2 = IR_2 = 6.67 \times 10^{-3} \times 600 = 4.00$ V (1 MARK)

OR

$V_2 = \frac{R_2}{R_1 + R_2} \times V_T \Rightarrow V_2 = \frac{600}{1200 + 600} \times 12.0$ (1 MARK)

$V_2 = 4.00$ V (1 MARK)

FROM LESSONS 6B & 6C

c. $V_{motor} = I_{motor} R_{motor} \Rightarrow I_{motor} = \frac{V_{motor}}{R_{motor}} = \frac{4.0}{170} = 2.35 \times 10^{-2}$ A (1 MARK)

$V_T = V_1 + V_{motor} \Rightarrow V_1 = 12.0 - 4.0 = 8.0$ V (1 MARK)

$V_2 = I_2 R_2 \Rightarrow I_2 = \frac{V_2}{R_2} = \frac{4.0}{600} = 6.67 \times 10^{-3}$ A (1 MARK)

$I_1 = I_2 + I_{motor} = 6.67 \times 10^{-3} + 2.35 \times 10^{-2} = 30.2 \times 10^{-3}$ A (1 MARK)

$V_1 = I_1 R_1 \Rightarrow R_1 = \frac{V_1}{I_1} = \frac{8.0}{30.2 \times 10^{-3}} = 264.94 = 2.6 \times 10^2\ \Omega$ (1 MARK)

FROM LESSONS 6B, 6C & 6D

9. a. [If household appliances are wired in series, one appliance being switched off or a fault in the circuit would cause all other appliances in the circuit to stop working.[1]][Adding components in series increases the equivalent resistance of the circuit and therefore decreases the current flowing at a given supply voltage. This would mean the overall power consumption of devices is much lower, for example meaning that lightbulbs would shine more dimly than intended (or not at all).[2]]

- I have explicitly referenced what happens when a component breaks for a series circuit.[1]
- I have used the relevant theory: current and power consumption in a series circuit.[2]

FROM LESSONS 6A & 7B

b. [The fact that the appliances do not have an earth pin means that they are not grounded. If the uninsulated exterior of one of the appliances is in contact with the active wire, the path of least resistance for the electricity would be through the user to the ground.[1]][The current of an electric shock is what determines its severity.[2]][Since the resistance of wet skin is less than that of dry skin, if a member of the family made contact with a 'live' appliance's exterior when it was wet, a high and therefore dangerous current would flow through them.[3]]

- I have used the relevant theory: earth wires.[1]
- I have used the relevant theory: effects of voltage and current on electric shocks.[2]
- I have explicitly addressed the use of the appliances in wet conditions.[3]

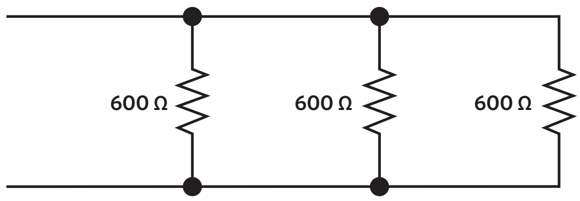
FROM LESSON 7C

10. a. For a total equivalent resistance of 200 Ω:

$\frac{1}{R_T} = \frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots + \frac{1}{R_n} \Rightarrow \frac{1}{200} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots + \frac{1}{R_n}$

$\frac{1}{600} + \frac{1}{600} + \frac{1}{600} = \frac{3}{600} = \frac{1}{200}$

$\frac{1}{R_T} = \frac{1}{200} \Rightarrow R_T = 200\ \Omega$ (1 MARK)



- I have drawn resistors connected in parallel or series as required.
- I have selected resistor positions that have an equivalent resistance of 200 Ω.

FROM LESSON 6D

b. The equivalent resistance of the 100 Ω, 200 Ω and 300 Ω resistors is given by

$\frac{1}{R_T} = \frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \Rightarrow \frac{1}{R_T} = \frac{1}{100} + \frac{1}{200} + \frac{1}{300}$

$R_T = \frac{1}{\frac{1}{100} + \frac{1}{200} + \frac{1}{300}} = 54.5\ \Omega$

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c. [It is impossible for the circuit to have an equivalent resistance of 75 Ω with its current configuration.[1]] [Adding an arm to a parallel circuit must decrease the equivalent resistance,[2]] [so since the equivalent resistance of the three known resistors, 54.5 Ω, is less than 75 Ω, it is not possible for the equivalent resistance to be 75 Ω.[3]]

- I have explicitly addressed that the student is incorrect.[1]
- I have used the relevant theory: equivalent resistance of parallel circuits.[2]
- I have explicitly stated the equivalent resistance cannot increase above the present value, which is less than 75 Ω.[3]

FROM LESSON 6D

11. a. Find the total equivalent resistance of the circuit:

Resistors *C*, *D* and *E* are in series, so $R_{eq1} = R_C + R_D + R_E$

$R_{eq1} = 8.00 + 8.00 + 8.00 = 24.00\ \Omega$

R_{eq1} is in parallel with resistor *B*: $\frac{1}{R_{eq2}} = \frac{1}{R_{eq1}} + \frac{1}{R_B}$

$R_{eq2} = \frac{1}{\frac{1}{24.00} + \frac{1}{8.00}} = 6.00\ \Omega$

R_{eq2} is in series with resistor *A*, so $R_T = R_{eq2} + R_A$

$R_T = 6.00 + 8.00 = 14.00$

Consider component *A*:

$V_T = I_A R_T \Rightarrow I_A = \frac{V_T}{R_T} = \frac{4 \times 3.0}{14.00} = 0.857\text{ A}$ (1 MARK)

$V_A = I_A R_A = 0.857 \times 8.00 = 6.86\text{ V}$ (1 MARK)

$V_B = V_T - V_A = 12.0 - 6.86 = 5.14\text{ V}$ (1 MARK)

$V_B = I_B R_B \Rightarrow I_B = \frac{V_B}{R_B} = \frac{5.14}{8.00} = 0.643 = 0.64\text{ A}$ (1 MARK)

FROM LESSON 6E

b. Consider the loop through resistors *A*, *C*, *D* and *E*:

As resistors *C*, *D* and *E* are in series: $V_C = V_D = V_E$

$V_T = V_A + V_C + V_D + V_E$

$12 = 0.8571 \times 8.00 + 3 \times V_D$ (1 MARK)

$V_D = 1.71\text{ V}$ (1 MARK)

$V_D = I_D R_D \Rightarrow 1.71 = I_D \times 8.00$

$I_D = 0.214\text{ A}$ (1 MARK)

$P_D = V_D I_D = 1.71 \times 0.214 = 0.367 = 0.37\text{ W}$ (1 MARK)

FROM LESSON 6E

12. a. When *illumination* = 10 lx, $R_{LDR} = 1.0 \times 10^4\ \Omega$ (1 MARK)

$V_{out} = \frac{R_2}{R_1 + R_2} \times V_T \Rightarrow 6.0 = \frac{1.0 \times 10^4}{R + 1.0 \times 10^4} \times 24$ (1 MARK)

$R = 3.0 \times 10^4$ (1 MARK)

Noting that the resistor must take up 3 times the voltage the LDR takes up and therefore stating it will have 3 times the resistance is also acceptable.

FROM LESSON 7A

b. [V_{out} will increase.[1]] [The graph shows that as the illumination decreases, R_{LDR} increases.[2]] [So, because $V_{out} = \frac{R_{LDR}}{R_1 + R_{LDR}} \times V_{in}$, the output voltage must increase for a fixed value of R_1.[3]]

- I have explicitly addressed how V_{out} changes as daylight decreases.[1]
- I have explicitly addressed how the resistance of the LDR changes as daylight decreases.[2]
- I have used the relevant theory: $V_{out} = \frac{R_2}{R_1 + R_2} \times V_{in}$.[3]

FROM LESSON 7A

c. [Randall should increase the resistance of *R*.[1]] [This change means more of the voltage will drop across the resistor, and less across the LDR,[2]] [so the LDR will require a higher resistance and hence a lower light level for the same value of V_{out}.[3]]

- I have explicitly addressed whether Randall should increase or decrease the resistance of *R*.[1]
- I have explicitly addressed how a change in the resistor's resistance will affect the voltage across the switching circuit.[2]
- I have referred to the fact that the LDR requires a lower light level for a higher resistance.[3]

FROM LESSONS 6C & 7A

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8A Describing motion

Progress questions

1. C
2. C
3. B and C
4. D
5. Displacement; velocity; speed; velocity; time
6. D
7. B

Deconstructed exam-style

8. B
9. C
10. D
11. A
12. B

13. $v = \frac{\Delta s}{\Delta t}$

$v_{flat} = \frac{s_{flat}}{t_{flat}}$

$t_{flat} = \frac{s_{flat}}{6.0}$

$v_{hills} = \frac{s_{hills}}{t_{hills}}$

$t_{hills} = \frac{s_{hills}}{4.0}$ (1 MARK)

$t_{total} = t_{flat} + t_{hills} + t_{break} \Rightarrow 9.0 = t_{flat} + t_{hills} + 1$ (1 MARK)

Distance hiked up hills is half the distance hiked on flat ground, $\Rightarrow s_{flat} = 2s_{hills}$ (1 MARK)

$9.0 = \frac{2s_{hills}}{6.0} + \frac{s_{hills}}{4.0} + 1 \Rightarrow s_{hills} = \frac{96}{7} = 13.7 = 14$ km (1 MARK)

$s_{flat} = 2s_{hills} = 2 \times 13.7 = 27$ km

$s_{total} = s_{flat} + s_{hills} = 14 + 27 = 41$ km

$v_{avg} = \frac{s_{total}}{t_{total}} = \frac{41}{9.0} = 4.6 \text{ km h}^{-1}$

Since they travel from A to B, their average velocity is 4.6 km h^{-1} to the east. (1 MARK)

Exam-style

14. $v = \frac{\Delta s}{\Delta t} \Rightarrow t = \frac{\Delta s}{v} = \frac{100}{5.0} = 20$ seconds

15. a. $25 + 25 = 50$ m

b. Since she starts and ends at the same place, $s = 0$ m.

c. $v = \frac{\Delta s}{\Delta t} = \frac{0}{40} = 0 \text{ m s}^{-1}$

16. $\Delta s = \sqrt{10^2 + 7.0^2} = \sqrt{149} = 12.2$ km (1 MARK)

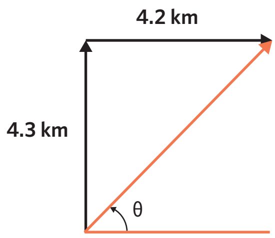
$\Delta t = 100 \text{ minutes} = \frac{100}{60} = 1.67$ hours (1 MARK)

$v = \frac{\Delta s}{\Delta t} = \frac{12.21}{1.67} = 7.3 \text{ km h}^{-1}$ (1 MARK)

17. [Velocity and speed are similar in the sense that they quantify the rate at which an object moves over time.[1]] [However, velocity is a vector quantity whilst speed is a scalar quantity.[2]] [Also, velocity is the change in displacement with respect to time, whereas speed is the change in distance travelled with respect to time.[3]] [When an object does not change direction, the magnitudes of these two values will be the same, however when it does, they will no longer be equal.[4]]

- I have explicitly addressed how velocity and speed are similar.[1]
- I have explicitly addressed that velocity is a vector quantity and speed is a scalar quantity.[2]
- I have explicitly addressed how velocity and speed are different.[3]
- I have justified my answer by describing when velocity and speed are different.[4]

18. a.



$\Delta s = \sqrt{a^2 + b^2} = \sqrt{4.3^2 + 4.2^2} = 6.01 = 6.0$ km (1 MARK)

$\theta = \tan^{-1}\left(\frac{4.3}{4.2}\right) = 45.6 = 46°$ (1 MARK)

Her displacement is 6.0 km, 46° from the horizontal. (1 MARK)

b. $\Delta s = 6.01 \text{ km} = 6.01 \times 10^3$ m (1 MARK)

$\Delta t = (47 + 47) = 94 \text{ minutes} = 94 \times 60 = 5640$ seconds (1 MARK)

$v_{avg} = \frac{\Delta s}{\Delta t} = \frac{6.01 \times 10^3}{5640} = 1.06 = 1.1 \text{ m s}^{-1}$, 46° from the horizontal. (1 MARK)

19. a. The swimmer's speed is:

$speed_{swim} = 3.2 \text{ km h}^{-1} = \frac{3.2}{3.6} = 0.888$
$= 0.89 \text{ m s}^{-1}$ (1 MARK)

The runner's speed is:

$t_{run} = 4 \text{ minutes} = 4 \times 60 = 240$ seconds

$speed_{run} = \frac{distance}{time} = \frac{200}{240} = 0.833 = 0.83 \text{ m s}^{-1}$ (1 MARK)

Therefore, the swimmer has a greater average speed. (1 MARK)

b. $v_{avg} = \frac{\Delta s}{\Delta t} = \frac{60}{240} = 0.25 \text{ m s}^{-1}$ to the left.

20. a. displacement from B to C $= 2 \times r = 2 \times 1.5 = 3.0$ km (1 MARK)

$t = 100 \text{ s} = \frac{100}{60 \times 60} = 0.028$ hours (1 MARK)

$v_{avg} = \frac{\Delta s}{\Delta t} = \frac{3}{0.028} = 107 = 1.1 \times 10^2 \text{ km h}^{-1}$ (1 MARK)

The driver has exceeded the limit. (1 MARK)

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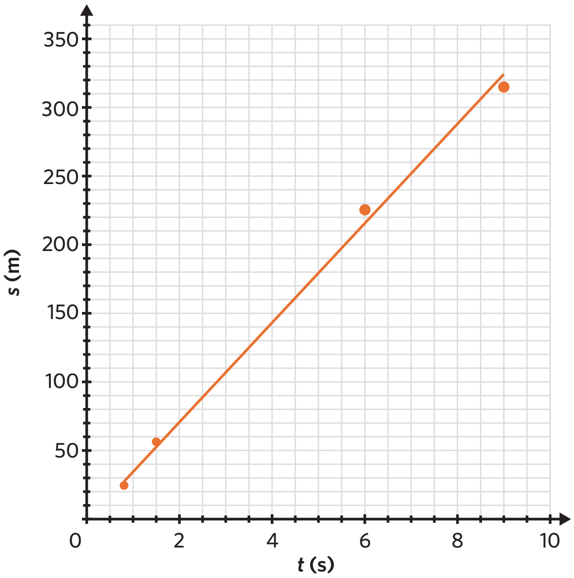
b. [The velocity is different to the speed because there is a change in direction over the time interval.[1]] [This means that the displacement will be different from the distance travelled.[2]] [In this case, the velocity is 1.1×10^2 km h^{-1}. We can find speed by calculating the distance travelled (half the circumference of a circle) and dividing by the time:

$$speed = \frac{distance\ travelled}{time} = \frac{\frac{1}{2} \times 2 \times \pi \times 1.5}{0.028} = 170 \text{ km h}^{-1}$$[3]]

- I have explicitly addressed why the velocity is different to the speed.[1]
- I have explicitly addressed that the displacement and distance are different.[2]
- I have justified my answer using relevant calculations.[3]

Key science skills

21. a.



- I have correctly labelled both axes and included units.
- I have used an appropriate and consistent scale on the axes.
- I have correctly plotted each point of data.
- I have included a line of best fit.

b. $gradient = \frac{rise}{run} = \frac{\Delta s}{\Delta t} = v$. The gradient represents the magnitude of the velocity. (1 MARK)

Use any two points on the line of best fit:

$$gradient = \frac{360 - 0}{10 - 0} = 36 \text{ m s}^{-1}$$ (1 MARK)

Depending on the line of best fit drawn, answers between 34 m s^{-1} and 38 m s^{-1} are acceptable.

FROM LESSONS 11D & 11E

Previous lessons

22. $n = \frac{T}{t_{1/2}} = \frac{31.62}{5.27} = 6.0$ half-lives (1 MARK)

$$N = N_0 \times \left(\frac{1}{2}\right)^n = 8.0 \times \left(\frac{1}{2}\right)^{6.0} = 0.125 = 0.13 \text{ kg}$$ (1 MARK)

0.13 kg of cobalt-60 will remain after 30 years.

FROM LESSON 4B

23. $V_{LED} = 2.0$ V

$P = VI \Rightarrow 0.35 = 2.0 \times I$

$I = 0.175$ A (1 MARK)

$V = IR \Rightarrow 8.0 = 0.175 \times R$ (1 MARK)

$R = 45.7 = 46\ \Omega$ (1 MARK)

FROM LESSON 7A

8B Graphing motion

Progress questions

1. A **2.** B **3.** B **4.** B

5. I; III

6. II; III

7. acceleration; velocity; does not have to

8. I

Deconstructed exam-style

9. B **10.** C **11.** A **12.** B

13. $\Delta v = area\ under\ acceleration - time\ graph = 5a$ m s^{-1} (1 MARK)

$\Delta v = v_2 - v_1 \Rightarrow v_2 - 0 = 5a \Rightarrow v_2 = 5a$ m s^{-1} (1 MARK)

$\Delta s = area\ under\ velocity - time\ graph = \frac{1}{2} \times 5a \times 5 = \frac{25}{2}a$ m (1 MARK)

$\Delta s = \frac{25}{2}a = 150 \Rightarrow a = \frac{150}{12.5} = 12.0 = 12$ m s^{-2} (1 MARK)

Exam-style

14. a. v_{avg} is the gradient of a displacement-time graph.

$$v_{avg} = \frac{s_2 - s_1}{t_2 - t_1} = \frac{12 - 0}{8.0 - 0} = 1.5 \text{ m s}^{-1}$$

b. As the graph is linear, $v_{int} = v_{avg} = 1.5$ m s^{-1}

15. a. a_{avg} is the gradient of a velocity-time graph.

$$a_{avg} = \frac{v_2 - v_1}{t_2 - t_1} = \frac{0 - 10}{1.5 - 0} = -6.67 = -6.7 \text{ m s}^{-2}$$

The magnitude of the average acceleration is 6.7 m s^{-2}.

b. Δs is the signed area under a velocity-time graph.

$\Delta s = \frac{1}{2} \times b \times h = \frac{1}{2} \times 10 \times 1.5 = 7.5$ m (1 MARK)

The model car travels 7.5 m up the ramp before coming to a stop. (1 MARK)

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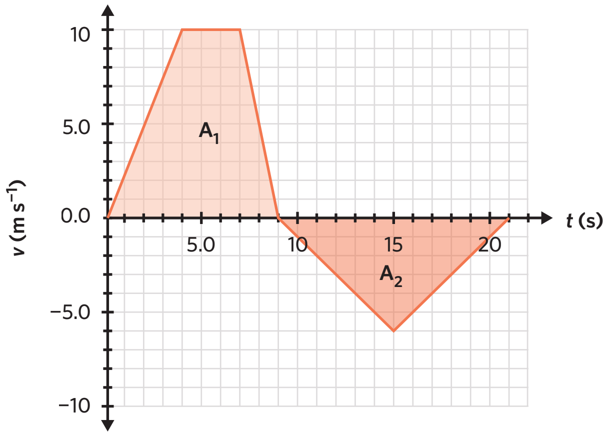
16.



Δs is the signed area under a velocity-time graph.

$\Delta s = A_1 - A_2 = \left(\frac{(9 + (7 - 4))}{2} \times 10\right) - \left(\frac{1}{2} \times (21 - 9) \times 6\right) = 24\,\text{m}$

(1 MARK)

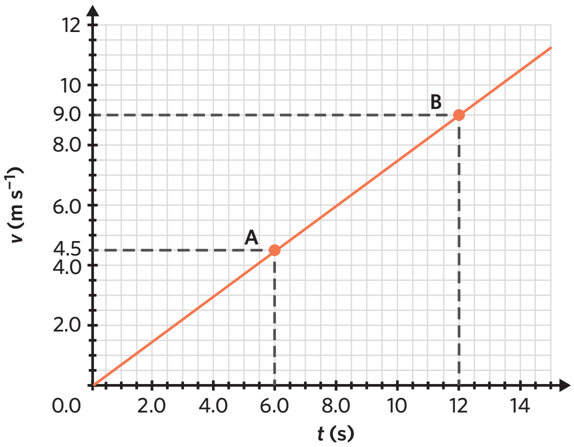
Therefore Kate finishes 24 m in front of her starting position.
(1 MARK)

17. **a.** $v_{avg} = \frac{\Delta s}{\Delta t} = \frac{(7.5 - 0)}{(10 - 0)} = 0.75\text{ m s}^{-1}$

b. $v_{avg} = \frac{\Delta s}{\Delta t} = \frac{(0 - 0)}{(30 - 0)} = 0\text{ m s}^{-1}$

c. $average\ speed = \frac{distance}{time} = \frac{7.5 + 7.5 + 7.5 + 7.5}{30} = 1.0\text{ m s}^{-1}$

18. **a.**



I have correctly labelled both axes and included units.

I have drawn a straight line for the velocity-time graph.

The line passes through the points (6.0, 4.5) and (12, 9.0).

b. Δs is the signed area under a velocity-time graph.

$\Delta s = \frac{(4.5 + 9.0)}{2} \times (12 - 6.0) = 40.5 = 41\text{ m}$

19. Δs is the signed area under a velocity-time graph.

$\Delta s = \left(\frac{1}{2} \times 17 \times 1.73\right) - \left(\frac{1}{2} \times (4.5 - 1.73) \times 27.1\right)$
$= -22.8 = -23\text{ m}$ (1 MARK)

The value of h is 23 m. (1 MARK)

20. Δs is the signed area under a velocity-time graph.

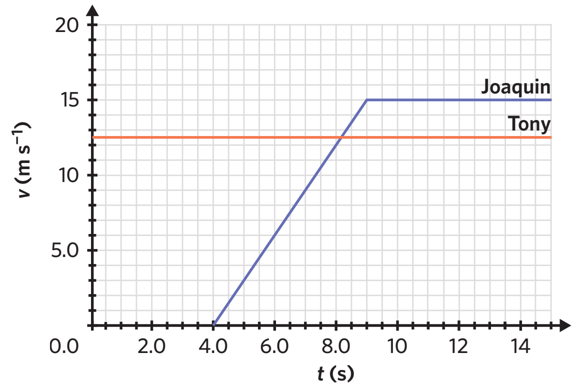
There are approximately 23 squares under the curve, and each has an area of $0.50 \times 2.5 = 1.25$ m. (1 MARK)

$\Delta s = 1.25 \times 23 = 28.75 = 29\text{ m}$ (1 MARK)

Therefore the car will pass the test. (1 MARK)

A range of Δs values between 26.25 m and 31.25 m is acceptable, depending on the number of squares counted.

21. **a.**

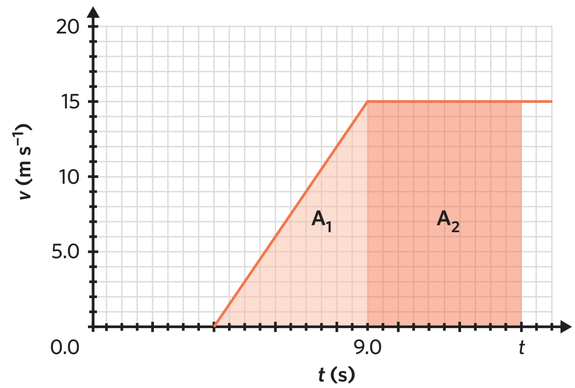


I have correctly labelled both axes and included units.

I have correctly drawn the shape of Tony's velocity-time graph.

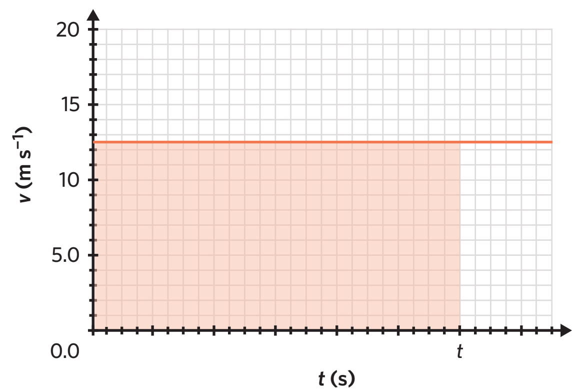
I have correctly drawn the shape of Joaquin's velocity-time graph.

b. When Joaquin catches up to Tony, they have travelled the same displacement, and hence the area under both their velocity-time graphs will be equal. Suppose he catches Tony after t seconds.



$displacement_{Joaquin} = \frac{(t - 9.0) + (t - 4.0)}{2} \times 15 = 15t - 97.5$

(1 MARK)



$displacement_{Tony} = 12.5t$ (1 MARK)

$displacement_{Joaquin} = displacement_{Tony} \Rightarrow 15t - 97.5 = 12.5t$

$t = 39$ s (1 MARK)

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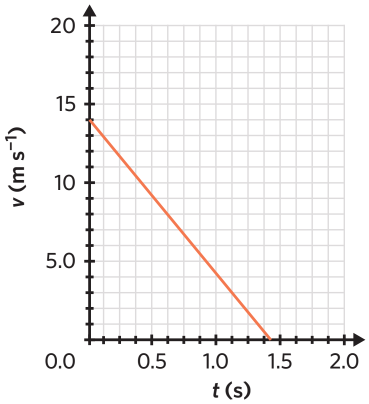
22. a.



- I have correctly labelled both axes and included units.
- I have used an appropriate and consistent scale on the axes.
- I have drawn a straight line for the velocity-time graph.
- The y-intercept of the line is at (0, 14.0) and the x-intercept is (1.43, 0).

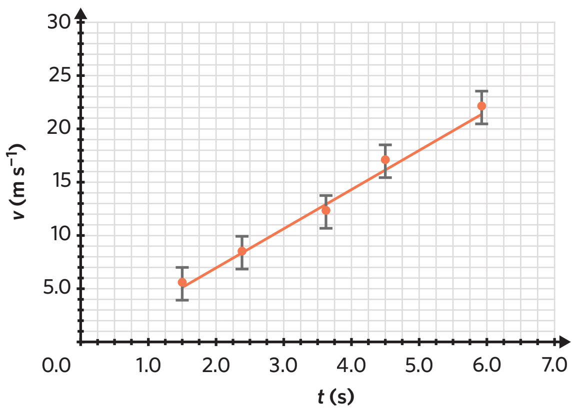
b. Δs is the signed area under a velocity-time graph.

$\Delta s = \frac{1}{2} \times b \times h = \frac{1}{2} \times 14.0 \times 1.43 = 10.0$ m (1 MARK)

The maximum height of the ball is 10.0 m. (1 MARK)

Key science skills

23.



- I have correctly labelled both axes and included units.
- I have used an appropriate and consistent scale on the axes.
- I have correctly plotted each point of data.
- I have included accurate uncertainty bars.
- I have included a line of best fit that passes through all of the uncertainty bars.

FROM LESSON 11D

Previous lessons

24. The time it takes for half a radioactive sample to decay.

FROM LESSON 4B

25. a. $V_{pc} = IR_{pc} \Rightarrow 5.0 = I \times 4.0$

$I = 1.25 = 1.3$ A

b. $V_{source} = V_{LDR} + V_{pc} \Rightarrow 12 = V_{LDR} + 5.0$

$V_{LDR} = 7.0$ V (1 MARK)

$V_{LDR} = IR_{LDR} \Rightarrow 7.0 = 1.25 \times R_{LDR}$ (1 MARK)

$R_{LDR} = 5.6\ \Omega$ (1 MARK)

FROM LESSON 7B

8C The constant acceleration equations

Progress questions

1. C **2.** B **3.** B **4.** A

5. C

Deconstructed exam-style

6. D **7.** B **8.** C **9.** D

10. A

11. $v^2 = u^2 + 2as$ (1 MARK)

$v = -\sqrt{(6.0)^2 + 2(-9.8)(-3)} = -9.7$ m s^{-1} (1 MARK)

$v = u + at \Rightarrow -9.7 = 6.0 - 9.8t$

$t = \frac{-9.7 - 6.0}{-9.8} = 1.6$ s (1 MARK)

The time taken for the dive is 1.6 seconds, which is less than the required 1.75 seconds. Therefore he would under-rotate. (1 MARK)

Exam-style

12. Given: $u = 0$ m s^{-1}, $t = 6.0$ s, $v = 45$ m s^{-1}; Needed: s

$s = \frac{1}{2}(u + v)t$

$s = \frac{1}{2}(0 + 45) \times 6.0$ (1 MARK)

$s = 135 = 1.4 \times 10^2$ m (1 MARK)

13. Given: $a = 2.50$ m s^{-2}, $v = 24.0$ m s^{-1}, $t = 10.0$ s; Needed: s

$s = vt - \frac{1}{2}at^2$

$s = 24.0 \times 10.0 - \frac{1}{2} \times 2.50 \times 10.0^2$ (1 MARK)

$s = 115$ m (1 MARK)

14. Given: $t = 2.5$ s, $a = -9.8$ m s^{-2}, $v = -11$ m s^{-1}; Needed: u

$v = u + at$

$-11 = u + (-9.8) \times 2.5$ (1 MARK)

$u = 13.5 = 14$ m s^{-1} (1 MARK)

Initially velocity is 14 m s^{-1} upwards (1 MARK)

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15. **a.** Given: $v = -18 \text{ m s}^{-1}$, $s = -15$ m, $a = -9.8 \text{ m s}^{-2}$; Needed: u

$v^2 = u^2 + 2as$

$(-18)^2 = u^2 + 2 \times (-9.8) \times (-15)$ (1 MARK)

$u = 5.5 \text{ m s}^{-1}$ (1 MARK)

b. [Pebbles' claim is invalid.[1]][As the initial velocity of the water balloon is not equal to zero, she must have thrown the balloon, not dropped it.[2]]

I have explicitly addressed whether Pebbles' claim is true.[1]

I have referenced the initial velocity of the water balloon to support my answer.[2]

16. Given: $v = 0 \text{ m s}^{-1}$, $t = 18$ s, $a = -0.35 \text{ m s}^{-2}$; Needed: s

$s = vt - \frac{1}{2}at^2$

$s = 0 \times 18 - \frac{1}{2} \times (-0.35) \times 18^2$ (1 MARK)

$s = 56.7 = 57$ m (1 MARK)

$57 \text{ m} > 40 \text{ m}$

Therefore, Santush's bowl will not stop at the edge of the green and he will not win the game. (1 MARK)

17. **a.** Given: $u_{Mavis} = v_{Mavis} = \frac{54}{3.6} = 15 \text{ m s}^{-1}$, $a_{2\,police} = 5.0 \text{ m s}^{-2}$, $u_{police} = 0.0 \text{ m s}^{-1}$; Needed: t

Displacement of Mavis

$v_{Mavis} = \frac{s}{t} \Rightarrow 15 = \frac{s}{t}$

$s = 15t$ (1 MARK)

Displacement of police officer (s_1, t_1 whilst eating his doughnut, s_2, t_2 whilst accelerating, s_3 and t_3 whilst at constant speed)

$s_{total} = s_1 + s_2 + s_3$

$s_1 = 0.0$ m (as police officer is stationary)

$s_2 = u_{police}t_2 + \frac{1}{2}a_{2\,police}{t_2}^2 = 0.0 \times 4.0 + \frac{1}{2} \times 5.0 \times 4.0^2$
$= 40$ m (1 MARK)

$v = u + at_2 = 0.0 + 5.0 \times 4.0 = 20 \text{ m s}^{-1}$

He is stationary for 10 seconds and accelerating for 4.0 seconds, therefore he travels at a constant speed for $t_3 = t - 14$ seconds.

$v = \frac{s_3}{t_3} \Rightarrow 20 = \frac{s_3}{(t-14)}$

$s_3 = 20(t - 14) = 20t - 280$ (1 MARK)

$s_{total} = 0.0 + 40 + 20t - 280$

The police officer catches Mavis when their displacements are equal.

$15t = 40 + 20t - 280$ (1 MARK)

$t = 48$ s (1 MARK)

b. $s = 15t = 15 \times 48$ (1 MARK)

$s = 720 = 7.2 \times 10^2$ m (1 MARK)

18. Given: $s_{total} = 60$ m, $t_{total} = 9.0$ s, $t_{acceleration} = 3.0$ s, $u = 0 \text{ m s}^{-1}$; Needed: a

Displacement, s_1, whilst accelerating:

$s_1 = ut + \frac{1}{2}a{t_{acceleration}}^2 = 0 \times 3.0 + \frac{1}{2} \times a \times 3.0^2 = 4.5a$ m
(1 MARK)

Displacement, s_2, whilst at constant velocity:

$v = u + at_{acceleration} = 0 + a \times 3.0 = 3.0a \text{ m s}^{-1}$ (1 MARK)

$v = \frac{s_2}{\Delta t} \Rightarrow 3.0a = \frac{s_2}{6.0}$

$s_2 = 18a$ m (1 MARK)

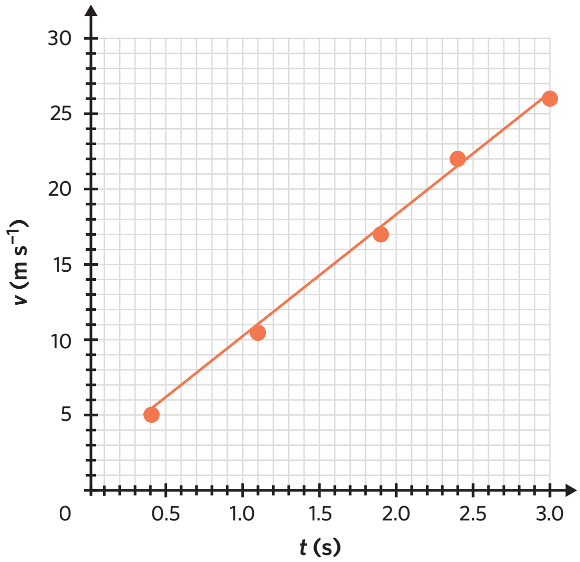
$s_{total} = s_1 + s_2 \Rightarrow 60 = 4.5a + 18a$

$a = \frac{60}{18 + 4.5} = 2.67 = 2.7 \text{ m s}^{-2}$

The minimum acceleration Zeviana Jones could have is 2.7 m s^{-2}.
(1 MARK)

Key science skills

19. **a.**



I have correctly labelled both axes and included units.

I have used an appropriate and consistent scale so the data takes up at least half of each axis.

I have correctly plotted each point of data.

I have drawn a straight line of best fit.

b. $gradient = \frac{rise}{run} = \frac{\Delta v}{\Delta t}$

$a = \frac{\Delta v}{\Delta t} \Rightarrow gradient = a$ (1 MARK)

Using any two points on the line of best fit:

$gradient = \frac{24 - 7.0}{2.7 - 0.6} = 8.1$

$a = 8.1 \text{ m s}^{-2}$ (1 MARK)

c. **i.** primary

ii. quantitative

FROM LESSONS 11A, 11D & 11E

8C ANSWERS

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Previous lessons

20. [One type of radioactive decay is alpha radiation.[1]][This is the emission of an alpha particle, which consists of two protons and two neutrons.[2]][Alpha radiation has the highest ionisation ability but the lowest penetrating ability.[3]]

OR

[One type of radioactive decay is beta radiation.[1]][This is the emission of an electron or a positron.[2]][Beta radiation has a relatively moderate ionisation ability and relatively moderate penetrating ability.[3]]

OR

[One type of radioactive decay is gamma radiation.[1]]
[This is the emission of high frequency electromagnetic waves.[2]]
[Gamma radiation has the lowest ionisation ability but the highest penetrating ability.[3]]

- ✓ ✗ I have named one of the three types of radioactive decay: alpha, beta or gamma radiation.[1]
- ✓ ✗ I have referenced what the type of radioactive decay consists of.[2]
- ✓ ✗ I have referenced the ionisation and penetrating ability of the type of radioactive decay.[3]

FROM LESSON 4C

21. Two of: duration of shock, the size of the current through the person, the person's resistance, the current's path through the body (eg. through the heart).

FROM LESSON 7C

Chapter 8 review

Section A

1. C. Given: $u = 15\ \text{m s}^{-1}$, $a = -9.8\ \text{m s}^{-2}$, $v = 0\ \text{m s}^{-1}$; Needed: s

$v^2 = u^2 + 2as \Rightarrow 0^2 = 15^2 + 2 \times (-9.8) \times s$

$s = 11\ \text{m}$

Maximum height $= 30 + 11 = 41\ \text{m}$

2. C. Due to the symmetry of motion with constant acceleration, the ball will have the same speed as when it was first thrown.

3. B. The displacement-time graph is linear. This means that the gradient, which represents the velocity, is constant and so the toy car is not accelerating.

4. A. When the gradient of the velocity-time graph is positive, the acceleration will be positive. Similarly, when the gradient of the velocity-time graph is negative, the acceleration will be negative. When the velocity is constant then the acceleration will be zero.

5. B. $\Delta s = \textit{signed area under graph}$

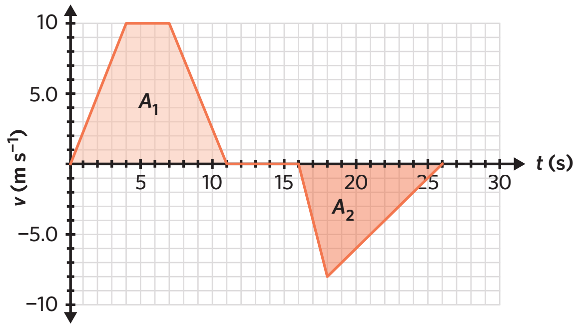
$\Delta s = \left(\frac{(60 + (40 - 20)}{2} \times 6.0\right) - \left(\frac{1}{2} \times 40 \times 3\right) = 180\ \text{m}$

Section B

6. **a.** $a = \frac{\Delta v}{\Delta t} = \frac{v_2 - v_1}{t_2 - t_1} = \frac{0.0 - 10}{11 - 7.0} = -2.5\ \text{m s}^{-2}$ (1 MARK)

$a = 2.5\ \text{m s}^{-2}$ to the east (1 MARK)

b.



$d = \textit{area under graph} = A_1 + A_2$

$d = \left(\frac{11 + (7.0 - 4.0)}{2} \times 10\right) + \left(\frac{1}{2} \times 10 \times 8.0\right)$ (1 MARK)

$d = 110\ \text{m} = 1.1 \times 10^2\ \text{m}$ (1 MARK)

c. $\Delta s = \textit{signed area under graph} = A_1 - A_2$

$\Delta s = \left(\frac{11 + (7.0 - 4.0)}{2} \times 10\right) - \left(\frac{1}{2} \times 10 \times 8.0\right)$ (1 MARK)

$\Delta s = 30\ \text{m}$ to the west (1 MARK)

d. $v_{avg} = \frac{\Delta s}{\Delta t} = \frac{30}{26} = 1.2\ \text{m s}^{-1}$ to the west

7. **a.** Given: $s = 300\ \text{m}$, $t = 14.0\ \text{s}$, $u = 0\ \text{m s}^{-1}$; Needed: a

$s = ut + \frac{1}{2}at^2 \Rightarrow 300 = 0 \times 14.0 + \frac{1}{2} \times a \times 14.0^2$ (1 MARK)

$a = 3.061 = 3.06\ \text{m s}^{-2}$ (1 MARK)

b. As $\textit{speed} = \frac{\textit{distance}}{\textit{time}}$, we must find the total distance travelled by the car during the accelerating (s_1) and decelerating (s_2) period.

$\textit{total distance} = s_1 + s_2 = 300 + s_2$, need to find s_2

Accelerating period:

Given: $a = 3.061\ \text{m s}^{-2}$, $t = 14.0\ \text{s}$, $u = 0\ \text{m s}^{-1}$; Needed: v

$v = u + at = 0 + 3.061 \times 14.0 = 42.86\ \text{m s}^{-1}$ (1 MARK)

Decelerating period:

Given: $u = 42.86\ \text{m s}^{-1}$, $v = 0\ \text{m s}^{-1}$, $t = 7.50\ \text{s}$; Needed: s_2

$s_2 = \frac{1}{2}(u + v)t = \frac{1}{2}(42.86 + 0) \times 7.50 = 161\ \text{m}$ (1 MARK)

$\textit{total distance} = 300 + 161 = 461\ \text{m}$

$\textit{speed} = \frac{\textit{distance}}{\textit{time}} = \frac{461}{14.0 + 7.5} = 21.4\ \text{m s}^{-1}$ (1 MARK)

c. B. The distance travelled begins at zero and increases over both the accelerating and decelerating periods. During acceleration, the gradient of the distance-time graph increases and during deceleration the gradient decreases.

d. E. The car accelerates and decelerates in a uniform manner, so the velocity-time graph must be linear for each section.

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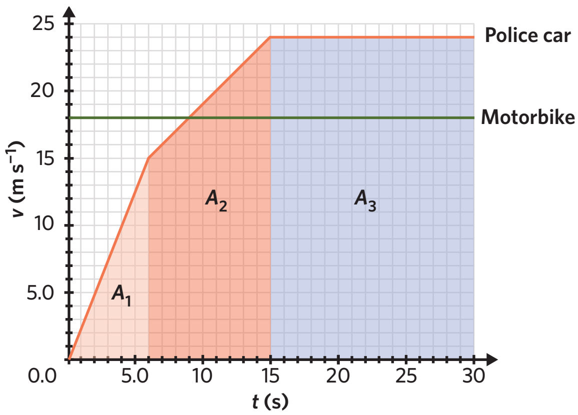
8. a. $a = \frac{\Delta v}{\Delta t} = \frac{v_2 - v_1}{t_2 - t_1} = \frac{19 - 0}{10 - 0} = 1.9 \text{ m s}^{-2}$

b. The acceleration decreases, indicated by the gradient decreasing, but is still positive, so the velocity will continue to increase.

c. The police car will reach the motorbike when they have travelled the same distance. This is given by the area under the graph.

$s_{motorbike} = 18 \times t$ (1 MARK)



$s_{police} = A_1 + A_2 + A_3$

$s_{police} = \left(\frac{1}{2} \times 6.0 \times 15\right) + \left(\left(\frac{15 + 24}{2}\right) \times (15 - 6.0)\right) + 24 \times (t - 15)$ (1 MARK)

$s_{police} = 220.5 + 24 \times (t - 15)$

$18 \times t = 220.5 + 24 \times (t - 15)$ (1 MARK)

$t = 23$ s (1 MARK)

9. a. E. Both water balloons accelerate at the same rate, g, so their velocity-time graphs will have the same gradient. The yellow water balloon has an initial velocity of 2.0 m s^{-1} and starts after the red water balloon, so its graph will begin later.

b. Take downwards as the positive direction.

For the red water balloon:

Given: $s = 20$ m, $a = 9.8$ m s^{-2}, $u = 0$ m s^{-1}; Needed: t

$s = ut + \frac{1}{2}at^2 \Rightarrow 20 = 0 \times t + \frac{1}{2} \times 9.8 \times t^2$

$t_{red\ total} = 2.02$ s (1 MARK)

For the yellow water balloon:

Given: $s = 20$ m, $a = 9.8$ m s^{-2}, $u = 2.0$ m s^{-1}; Needed: v

$v^2 = u^2 + 2as = 2.0^2 + 2.0 \times 9.8 \times 20$

$v = 19.9$ m s^{-1} (1 MARK)

Given: $s = 20$ m, $v = 19.9$ m s^{-1}, $u = 2.0$ m s^{-1}; Needed: t

$s = \frac{1}{2}(u + v)t \Rightarrow 20 = \frac{1}{2}(2.0 + 19.9) \times t$

$t = 1.83$ s

$t_{yellow\ total} = 1.83 + 0.50 = 2.33$ s (1 MARK)

The red water balloon will hit the ground before the yellow water balloon as $2.02 < 2.33$. (1 MARK)

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9A Forces

Progress questions

1. C
2. B
3. A
4. C
5. A
6. B
7. Demi's force should begin at *Y*. Sharni's force should begin at *U*. The force due to gravity should begin at *W*. The normal force should begin at *Z*.
8. B
9. C
10. C
11. gravitational field; mass; attractive; gravity; centre of mass; towards the centre of Earth
12. C, D, B, A
13. A
14. B
15. Define to the left as positive: A-positive; B-negative; C-negative

    OR

    Define to the right as positive: A-negative; B-positive; C-positive
16. C

Deconstructed exam-style

17. C
18. D
19. $F_{net} = F_3 + F_4 - F_1 - F_2$ (1 MARK)

    $F_{net} = 80 + 200 - 150 - 150 = -20$ N (1 MARK)

    $a = \frac{F_{net}}{m} = \frac{-20}{5.0} = -4.0$ m s^{-2} (1 MARK)

    The acceleration of the rope is 4.0 m s^{-2} to the left. (1 MARK)

Exam-style

20. A. The aeroplane is flying at a constant speed which means that the net force in the direction that the plane is flying must be equal to zero.
21. C. As both blocks are connected, they will accelerate at the same rate. According to Newton's second law, if two objects accelerate at the same rate, the lighter object will experience a lesser net force. In this case, the lighter object is half as heavy, meaning it will have a net force of half the magnitude of the heavier object.
22. $a = \frac{F_{net}}{m} = \frac{120}{20} = 6.0$ m s^{-2}
23. $F_{net} = ma = 60.0 \times 7.60 = 456$ N
24. [The action force is the gravitational force acting on Liesel due to Earth,[1]] [hence the reaction force is the gravitational force acting on Earth due to Liesel.[2]]

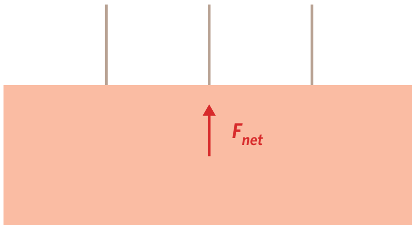
    - I have explicitly addressed the action gravitational force.[1]
    - I have explicitly addressed the reaction gravitational force.[2]
    - I have used the relevant theory: Newton's third law.
25. **a.** Define up as the positive direction.

    $F_{net} = 18 + 18 + 18 - F_g = 18 + 18 + 18 - mg$ (1 MARK)

    $F_{net} = 18 + 18 + 18 - 4.6 \times 9.8 = 8.9$ N (1 MARK)

    $a = \frac{F_{net}}{m} = \frac{8.9}{4.6} = 1.9$ m s^{-2} (1 MARK)

    b.



    - I have drawn and labelled the net force arrow.
    - I have drawn an arrow pointing upwards to indicate the net force direction.
    - I have drawn an arrow with the appropriate length to represent the relative force magnitude.
26. The total mass of the system is the mass of the tractor plus the mass of the trailer

    $m = 500 + 2000 = 2500$ kg (1 MARK)

    $F = ma = 2500 \times 0.5000 = 1250$ N (1 MARK)
27. **a.** Take up as the positive direction.

    $F_{net} = F_N - F_g = 0 \Rightarrow F_N = F_g$ since the box is not accelerating. (1 MARK)

    $F_N = mg = 30 \times 9.8 = 294$ N

    The magnitude of the normal force is 2.9×10^2 N. (1 MARK)

    b. $F_{net} = ma = 30 \times -9.8 = -294$ N (1 MARK)

    $F_{net} = F_N - F_g \Rightarrow -294 = F_N - 294$

    $F_N = 0$ N (1 MARK)

    c. $F_{net} = ma = 30 \times 2.0 = 60$ N (1 MARK)

    $F_{net} = F_N - F_g \Rightarrow 60 = F_N - 294$

    $F_N = 354 = 3.5 \times 10^2$ N (1 MARK)

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28. [A Newton's third law action-reaction pair consists of two forces that act on two different objects.[1]] [The force due to gravity on the ball by the Earth and the normal force on the ball both act on the same object which means that they cannot be a Newton's third law action-reaction pair.[2]]

- I have used the relevant theory: Newton's third law action-reaction pairs.[1]
- I have explicitly addressed why the force due to gravity and the normal force are not an action-reaction pair.[2]
- I have referenced Newton's third law.

29. [When a stream of air is ejected from a spacesuit, a force is applied by the spacesuit on the stream of air. According to Newton's third law, a reaction force exists on the spacesuit by the stream of air.[1]] [According to Newton's second law, this reaction force will result in an acceleration of the suit itself.[2]]

- I have used the relevant theory: Newton's third law.[1]
- I have explicitly addressed how the spacesuit is accelerated by a stream of air.[2]

30. The object will reach maximum speed when the drag force equals the force due to gravity, since the net force will become zero and in accordance with Newton's first law it will no longer accelerate. (1 MARK)

$F_g = mg = 1.5 \times 9.8 = 14.7$ N (1 MARK)

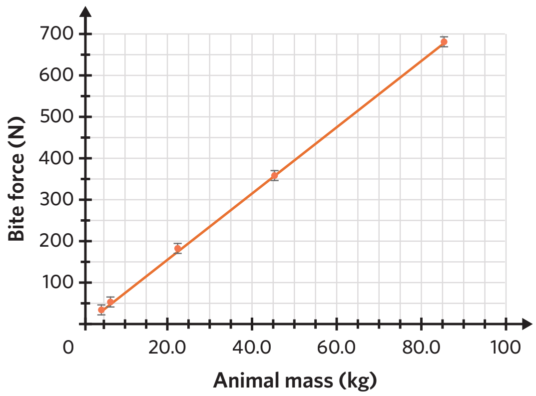
From the graph, $F_{drag} = 14.7$ N at approximately 38 m s^{-1}.

Therefore the maximum speed of the object will be 38 m s^{-1}. (1 MARK)

Any answer between 37 m s^{-1} to 39 m s^{-1} is acceptable to obtain full marks.

Key science skills

31. a.



- I have plotted mass on the horizontal axis and force on the vertical axis.
- I have included axis labels and appropriate units.
- I have included an appropriate and consistent scale on the axes.
- I have plotted each data point.
- I have included correctly sized uncertainty bars.
- I have included a line of best fit that passes through all uncertainty bars.

b. [The relationship between animal mass and bite force is linear[1]] [and positive.[2]]

- I have explicitly addressed that the relationship is linear.[1]
- I have explicitly addressed that the relationship is positive.[2]

FROM LESSON 11D

Previous lessons

32. a. Alpha decay

b. Beta plus decay

c. Beta minus decay

FROM LESSON 4C

33. a. $d = 3 \times 350.0 = 1050$ m

b. $s = \Delta x = 0$ m

c. $v_{avg} = \frac{s}{t} = \frac{0}{2 \times 60} = 0$ m s^{-1}

FROM LESSON 8A

9B Momentum and impulse

Progress questions

1. C **2.** C **3.** A **4.** B

5. vector, velocity, same, a net force acting on

6. C

7. equal, left

8. C

Deconstructed exam-style

9. D. $P_{iA} = m_A u_A = 2.0 \times 10 = 20$ kg m s^{-1} to the right

10. A. $P_{iB} = m_B u_B = 5.0 \times 0 = 0$ kg m s^{-1}

11. D. $\sum p_i = p_A + p_B = m_A u_A + m_B u_B = 2.0 \times 10 + 5.0 \times 0$

$= 20$ kg m s^{-1} **OR** N s to the right

12. C. $\sum p_f = (m_A + m_B) \times v \Rightarrow 20 = (2.0 + 5.0) \times v_B$

$v = 2.86 = 2.9$ m s^{-1} to the right

13. B. $\Delta p_B = m_B \times (v_B - u_B) = 5.0 \times (2.86 - 0)$

$= 14.3 = 14$ kg m s^{-1} to the right

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14. $\sum p_i = p_A + p_B = m_A u_A + m_B u_B = 2.0 \times 10 + 5.0 \times 0$

$= 20$ kg m s^{-1} **OR** N s to the right (1 MARK)

By the law of conservation of momentum, $\sum p_i = \sum p_f$.

$\sum p_f = 20$ kg m s^{-1} **OR** N s to the right

Find the velocity of the blocks after the collision.

$\sum p_f = (m_A + m_B) \times v \Rightarrow 20 = (2.0 + 5.0) \times v_B$ (1 MARK)

$v = 2.86 = 2.9$ m s^{-1} to the right (1 MARK)

The impulse given to block B is the same as its change in momentum.

$I_B = \Delta p_B = m_B \Delta v = m_B \times (v - u_B)$

$I_B = 5.0 \times (2.86 - 0) = 14.3 = 14$ kg m s^{-1} **OR** N s to the right (1 MARK)

$I = F_{avg} \Delta t \Rightarrow 14.3 = F_{avg} \times 4.0 \times 10^{-2}$ (1 MARK)

$F_{avg} = 357 = 3.6 \times 10^2$ N (1 MARK)

Exam-style

15. $p = mv = 3.5 \times 10 = 35$ (1 MARK)

$p = 35$ kg m s^{-1} **OR** N s to the south (1 MARK)

16. C. $I = m\Delta v = F\Delta t$

$0.040 \times 50 = F \times (1 \times 10^{-3})$

$F_{avg} = 2.0 \times 10^3$ N

17. D. $m\Delta v = F\Delta t$

$(45 \times 10^{-3}) \times 41 = F \times (0.50 \times 10^{-3})$

$F_{avg} = 3.7 \times 10^3$ N

18. a. Take up as positive.

$\Delta v = +3.3 - (-3.6) = 6.9$ m s^{-1} (1 MARK)

$F = m\frac{\Delta v}{\Delta t} = 50 \times 10^{-3} \times \frac{6.9}{40 \times 10^{-3}}$ (1 MARK)

$F = 8.6$ N (1 MARK)

The force is acting upwards. (1 MARK)

b. The momentum is transferred to the earth.

19. a. Take to the right as positive.

$\sum p_i = \sum p_f$ (1 MARK)

$1200 \times 10 = 2200 \times 6.5 + 1200 \times v_f$ (1 MARK)

$v_f = \frac{1200 \times 10 - 2200 \times 6.5}{1200} = -1.9$ m s^{-1} (1 MARK)

The speed is 1.9 m s^{-1}, and the car is moving to the left. (1 MARK)

b. Take the right as positive.

$F\Delta t = m\Delta v$

$F \times 40 \times 10^{-3} = 2200 \times 6.5$ (1 MARK)

$F = \frac{2200 \times 6.5}{40 \times 10^{-3}} = 3.58 \times 10^5$ N (1 MARK)

The force is acting to the right. (1 MARK)

c. Newton's third law states $F_{on\ van\ by\ car} = -F_{on\ car\ by\ van}$

Take the right as positive. $\Rightarrow F_{on\ car\ by\ van} = -3.58 \times 10^5$ N. (1 MARK)

The force is acting to the left. (1 MARK)

20. a. $\sum p_i = p_{car} + p_{F1} = m_{car} u_{car} + m_{F1} u_{F1}$

$\sum p_i = 1900 \times 20 + 750 \times (-80)$ (1 MARK)

$\sum p_i = 2.2 \times 10^4$ kg m s^{-1} **OR** N s to the left (2 MARKS)

b. $\sum p_f = \sum p_i = -2.2 \times 10^4$ kg m s^{-1} **OR** N s

$\sum p_f = mv = (m_{car} + m_{F1}) \times v$

$-2.2 \times 10^4 = (1900 + 750) \times v$ (1 MARK)

$v = -8.30$ m s^{-1} (1 MARK)

$v = 8.30$ m s^{-1} to the left (1 MARK)

21. a. $\Delta p = m\Delta v = 10\,000 \times (0 - 25) = -2.5 \times 10^5$

$\Delta p = 2.5 \times 10^5$ kg m s^{-1}

b. $I = F_{avg} \Delta t \Rightarrow 2.5 \times 10^5 = 12\,500 \times \Delta t$ (1 MARK)

$\Delta t = 20$ s (1 MARK)

c. $p_i = mu = 10\,000 \times 25 = 2.5 \times 10^5$ kg m s^{-1} **OR** N s (1 MARK)

$p_f = mv = 10\,000 \times 0 = 0$ kg m s^{-1} **OR** N s (1 MARK)

d. [Momentum is conserved in this situation.[1]][The impulse given to the truck by the earth is equal and opposite to the impulse given to the earth by the truck, and hence momentum is conserved.[2]]

I have explicitly addressed whether momentum is conserved.[1]

I have used the relevant theory: the law of conservation of momentum.[2]

22. a. Take the right as positive.

$I = \Delta p = m_{ball} \Delta v = 0.050 \times (62 - (-30)) = 4.6$ (1 MARK)

$I = 4.6$ kg m s^{-1} **OR** N s (1 MARK)

b. The impulse on the tennis racket will be equal in magnitude but opposite in direction to the impulse on the tennis ball.

$I_{racket} = -I_{ball}$

$I_{racket} = 4.6$ kg m s^{-1} **OR** N s to the left (2 MARKS)

c. $I = F_{avg} \Delta t \Rightarrow 4.6 = 230 \times \Delta t$ (1 MARK)

$\Delta t = 0.020$ s (1 MARK)

d. The force on the racket will have the same magnitude but opposite direction to the force on the ball,

$F_{on\ racket\ by\ ball} = -F_{on\ ball\ by\ racket}$

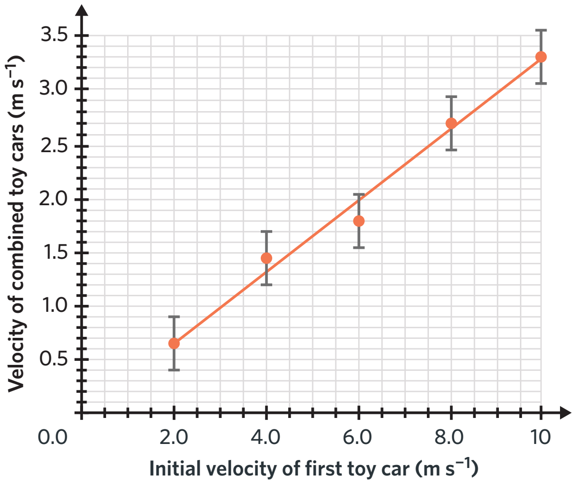
$F_{on\ racket\ by\ ball} = 230$ N to the left (2 MARKS)

23. [The initial momentum is $p_i = 1.2 \times u_1$ and the final momentum is $p_f = -1.5 \times v_1 + 3.0 \times v_2$.[1]][Therefore due to the conservation of momentum, the momentum of the 3.0 kg block after the collision is $3.0 \times v_2 = 1.2 \times u_1 + 1.5 \times v_1$.[2]]

- I have referenced the initial and final momentum of the system.[1]
- I have used the relevant theory: the law of conservation of momentum.[2]
- I have justified my answer with calculations.

Key science skills

24. a.



- I have correctly labelled both axes including units.
- I have included an appropriate and consistent scale.
- I have correctly plotted each point of data.
- I have included correct uncertainty bars.
- I have drawn a line of best fit.

b. $m_1 \times u = (m_1 + m_2) \times v \Rightarrow 1 \times u = (1 + m_2) \times v$

$gradient = \frac{rise}{run} = \frac{v}{u} = \frac{1}{1 + m_2}$ (1 MARK)

Using any two points on the line of best fit:

$gradient = \frac{y_2 - y_1}{x_2 - x_1} = \frac{3.3 - 0.8}{10.0 - 2.5} = 0.333$ (1 MARK)

$0.333 = \frac{1}{1 + m_2}$ kg

$m_2 = 2$ kg (1 MARK)

FROM LESSON 11D & 11E

Previous lessons

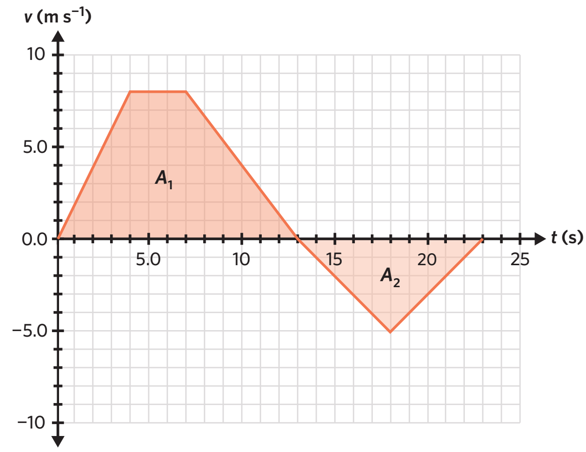
25. B. Options C and D refer to either effective or equivalent doses, and have no relation to absorbed dose without knowing the radiation source. 0.5 Gy is not a sufficient absorbed dose to cause significant short time effects.

FROM LESSON 4D

26. a. a_{avg} = gradient of velocity vs. time graph

$a_{avg} = \frac{rise}{run} = \frac{8 - 0}{4 - 0} = 2 \text{ m s}^{-2}$

b.



$\Delta s = area\ under\ graph = A_1 - A_2$ (1 MARK)

$\Delta s = \left(\frac{1}{2} \times 4.0 \times 8.0\right) + (3.0 \times 8.0) + \left(\frac{1}{2} \times 6.0 \times 8.0\right) - \left(\frac{1}{2} \times 10 \times 5.0\right) = 39 \text{ m}$ (1 MARK)

Therefore Ken finishes 39 m from where he started. (1 MARK)

FROM LESSON 8B

9C Force vectors in two dimensions

Progress questions

1. B
2. A
3. A
4. D
5. A
6. C
7. B

Deconstructed exam-style

8. B
9. A
10. B
11. C

12. $F_{net} = 0 \Rightarrow F_1 + F_2 + F_3 = 0$

$F_3 = -F_1 - F_2 = -(F_1 + F_2)$ (1 MARK)

We will find the third force by first finding $F_1 + F_2$

$F_{1x} = -30 \times \cos(59°) = -15.45$ N,
$F_{1y} = 30 \times \sin(59°) = 25.72$ N (1 MARK)

$F_{2x} = 23 \times \cos(27°) = 20.49$ N,
$F_{2y} = -23 \times \sin(27°) = -10.44$ N (1 MARK)

Now add the components in the x- and y-directions:

$F_x = F_{1x} + F_{2x} = -15.45 + 20.49 = 5.04$ N (1 MARK)

$F_y = F_{1y} + F_{2y} = 25.72 + (-10.44) = 15.27$ N (1 MARK)

Determine the components of F_3 given $F_3 = -(F_1 + F_2)$:

$F_{3x} = -5.04$ N

$F_{3y} = -15.27$ N

Use components to determine the magnitude of the resultant force:

$F_3 = \sqrt{(-5.04)^2 + (-15.27)^2} = 16$ N (1 MARK)

$\theta = \tan^{-1}\left(\frac{F_{3y}}{F_{3x}}\right) = \tan^{-1}\left(\frac{-15.27}{-5.04}\right) = 72°$ (1 MARK)

The third force is 16 N at 72° below the negative horizontal axis.

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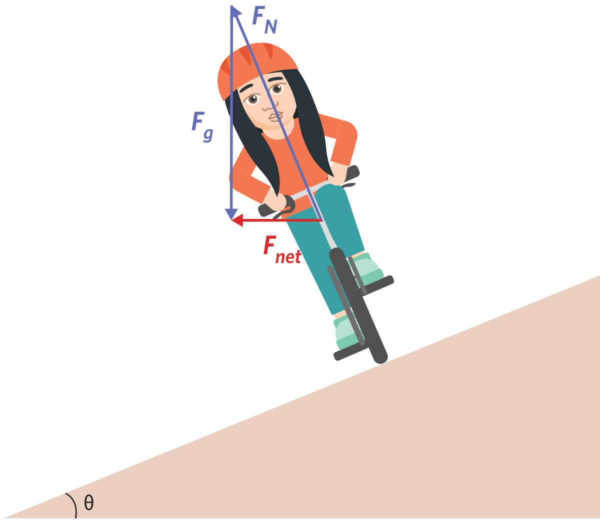
Exam-style

13.



I have drawn the addition of F_N and F_g in a tip-to-tail manner.

I have drawn the resultant force from the tail of F_N to the tip of F_g.

OR

I have drawn the F_N and F_g in a tail-to-tail manner as the sides of a parallelogram.

I have drawn the resultant force from the tails of F_N and F_g to the opposing corner.

14. Taking the right as the positive direction:
$F_{net} = 10 + 4 + (-8) = 6$ N

I have drawn a vector with direction to the right.

I have labelled the magnitude of the force.

15. a. In the x-direction: $F_x = F_b - F_d = 230 - 145 = 85$ N (1 MARK)

In the y-direction: $F_y = F_a - F_c = 190 - 150 = 40$ N (1 MARK)

Magnitude of $F_{net} = \sqrt{F_x{}^2 + F_y{}^2} = \sqrt{85^2 + 40^2} = 93.9$ N (1 MARK)

b. $\theta = \tan^{-1}\left(\frac{F_y}{F_x}\right) = \tan^{-1}\left(\frac{40}{85}\right) = 25.2°$

16. Take up and to the right as positive.

Find the components of the 50 N force:

$F_{50x} = 50 \times \cos(45°) = 35.36$ N (1 MARK)

$F_{50y} = -50 \times \sin(45°) = -35.36$ N (1 MARK)

Find the net force in the x- and y-directions:

$F_{net\,x} = F_{50x} + (-60) = 35.36 + (-60) = -24.64$ N (1 MARK)

$F_{net\,y} = 70 + F_{50y} = 70 + (-35.36) = 34.64$ N (1 MARK)

Magnitude of $F_{net} = \sqrt{F_{net\,x}{}^2 + F_{net\,y}{}^2}$
$= \sqrt{(-24.64)^2 + (34.64)^2} = 43$ N (1 MARK)

$\theta = \tan^{-1}\left(\frac{F_{net\,y}}{F_{net\,x}}\right) = \tan^{-1}\left(\frac{34.64}{-24.64}\right) = -55°$

The force acts as an angle of 55° from the negative x-axis. (1 MARK)

17. Take to the right as positive.

As the 70 N force is acting to balance the horizontal components of the 45 N forces, we will only consider the horizontal direction.

Horizontal component of the two 45 N forces:
$F_{45x} + F_{45x} = 2 \times 45 \times \cos(\theta)$ (1 MARK)

$F_{net} = F_{45x} + F_{45x} - 70 = 0 \text{ N} \Rightarrow 2 \times 45 \times \cos(\theta) - 70 = 0$ (1 MARK)

$\theta = \cos^{-1}\left(\frac{70}{2 \times 45}\right) = 38.9 = 39°$ (1 MARK)

18. a. Take up and to the right as positive.

Resolve A and B in the x-y directions.

$A_x = -70 \times \cos(27°)$, $A_y = -70 \times \sin(27°)$ (1 MARK)

$B_x = 45 \times \cos(72°)$, $B_y = 45 \times \sin(72°)$ (1 MARK)

Find the net force in the x- and y-directions.

$F_{net\,x} = A_x + B_x = (-70 \times \cos(27°)) + (45 \times \cos(72°))$
$= -48.46$ N (1 MARK)

$F_{net\,y} = A_y + B_y = (-70 \times \sin(27°)) + (45 \times \sin(72°))$
$= 11.02$ N (1 MARK)

Magnitude of $F_{net} = \sqrt{F_{net\,x}{}^2 + F_{net\,y}{}^2}$
$= \sqrt{(-48.46)^2 + (11.02)^2} = 49.7 = 50$ N (1 MARK)

b. $F = ma \Rightarrow a = \frac{F_{net}}{m} = \frac{49.7}{5.0}$ (1 MARK)

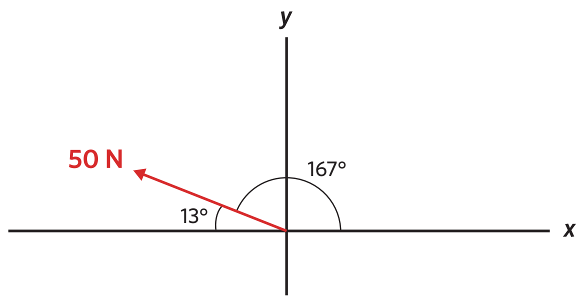
$a = 9.94 = 9.9 \text{ m s}^{-2}$ (1 MARK)

c. $\theta = \tan^{-1}\left(\frac{F_{net\,y}}{F_{net\,x}}\right) = \tan^{-1}\left(\frac{11.02}{48.46}\right) = 12.81 = 13°$ (1 MARK)

θ represents the angle made with the negative x axis, due to direction of net force.

Angle with positive x-axis
$= 180 - \theta = 180 - 12.81 = 167 = 1.7 \times 10^{2}°$ (1 MARK)

d.



I have drawn a vector with the correct magnitude.

I have drawn a vector with the correct angle.

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Key science skills

19. [Forcia has more accurate data and Victor has more precise data.[1]] [Forcia's average (5.51 N) is closer than Victor's average (5.43 N) to the actual force (5.50 N), so her data is more accurate.[2]] [The range of Victor's measurements (0.04 N) is smaller than Forcia's range (0.22 N), so his data is more precise.[3]]

- I have explicitly addressed who is more accurate and who is more precise.[1]
- I have used the relevant theory: the definition of accuracy.[2]
- I have used the relevant theory: the definition of precision.[3]
- I have used the provided data in my answer.

FROM LESSON 11C

Previous lessons

20. D. $H = E \times w_r = 4.5 \times 20 = 90$ Sv

The unit for the equivalent dose is not Gy.

FROM LESSON 4D

21. a. $v = u + at = 0 + 7.0 \times 5.0$ (1 MARK)

$v = 35\text{ m s}^{-1}$ (1 MARK)

b. $v^2 = u^2 + 2as$ (1 MARK)

$0^2 = 35^2 + 2 \times (-10) \times s$

$s = 61.3 = 61$ m (1 MARK)

Hence, the BMW will stop before making contact with the elephant 75 m away. (1 MARK)

FROM LESSON 8C

9D Inclined planes and connected bodies

Progress questions

1. B	**3.** B	**5.** A	**7.** B
2. B	**4.** A	**6.** C	**8.** A

Deconstructed exam-style

9. A	**10.** B	**11.** B	**12.** D

13. Consider the truck when finding tension, T.

$F_{net\ truck} = m_{truck}a = 5.0 \times 10^3 \times 5.0 \times 10^{-2} = 2.5 \times 10^2$ N

$F_{net\ truck} = 1000 - T \Rightarrow 2.5 \times 10^2 = 1000 - T$ (1 MARK)

$T = 7.5 \times 10^2$ N (1 MARK)

Consider the whole system when finding the driving force, F_x.

$F_{net} = m_{total}a = (5.0 \times 10^3 + 2.0 \times 10^3) \times 5.0 \times 10^{-2} = 3.5 \times 10^2$ (1 MARK)

$F_{net} = 1000 - F_x \Rightarrow 3.5 \times 10^2 = 1000 - F_x$ (1 MARK)

$F_x = 6.5 \times 10^2$ N (1 MARK)

Exam-style

14. a. Force due to gravity, F_g (1 MARK)

Normal force, F_N (1 MARK)

b. $F_{g\parallel} = mg\sin(\theta) = 20 \times 9.8 \times \sin(30°)$ (1 MARK)

$F_{g\parallel} = 98$ N (1 MARK)

c. $F_N = mg\cos(\theta) = 20 \times 9.8 \times \cos(30°)$ (1 MARK)

$F_N = 170 = 1.7 \times 10^2$ N (1 MARK)

15. a. Combined system: $F_{net} = F_d = (m_A + m_B) \times a = (2500 + 1000) \times 2.0$ (1 MARK)

$F_d = 7000 = 7.0 \times 10^3$ N (1 MARK)

b. Boat system: $F_{net} = T = m_B \times a = 1000 \times 2.0$ (1 MARK)

$T = 2000 = 2.0 \times 10^3$ N (1 MARK)

16. a. Combined system: $a = 0 \Rightarrow F_{net} = 0$ (1 MARK)

$F_{net} = F_d - 800 - 300 = 0$

$F_d = 1100 = 1.10 \times 10^3$ N (1 MARK)

b. Car system: $a = 0 \Rightarrow F_{net} = 0$

$F_{net} = T - 300 = 0$

$T = 300$ N

c. Car system: $F_{net} = T - F_f = ma$

$F_{net} = T - 300 = 1500 \times 2.0$ (1 MARK)

$T = 3300 = 3.3 \times 10^3$ N (1 MARK)

d. [The tension force acting on the bus will be equal in magnitude but opposite in direction to the tension acting on the car.[1]] [Hence, the tension force will be 3.3×10^3 N acting to the right.[2]]

- I have used the relevant theory: Newton's third law.[1]
- I have specifically addressed the magnitude and direction of the tension force.[2]

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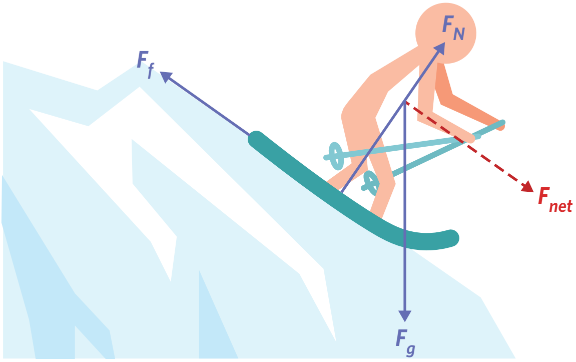
17. a.



- I have drawn the force due to gravity vector straight down from the centre of mass.
- I have drawn the normal force vector perpendicular to the inclined plane from the point of contact.
- I have drawn the friction force vector acting up the inclined plane from the point of contact.
- I have drawn the net force vector as a dotted line acting down the inclined plane from the centre of mass.
- I have drawn the force vectors to an appropriate size.
- I have correctly labelled each force.

b. $F_{net} = F_{g\parallel} - F_f = mg\sin(\theta) - F_f$ (1 MARK)

$F_{net} = 80 \times 9.8 \times \sin(15°) - 75 = 128 = 1.3 \times 10^2$ N (1 MARK)

c. $F_{net} = ma \Rightarrow 128 = 80 \times a$

$a = 1.60 = 1.6$ m s^{-2}

18. a. 0 N. As the shopping cart is moving at a constant speed down the hill, the net force acting on it is zero.

b. $F_N = mg\cos(\theta) = 70.0 \times 9.8 \times \cos(10.0°)$ (1 MARK)

$F_N = 676 = 6.8 \times 10^2$ N (1 MARK)

The normal force acts perpendicular to the hill. (1 MARK)

c. $F_{g\parallel} = mg\sin(\theta) = 70.0 \times 9.8 \times \sin(10.0°)$ (1 MARK)

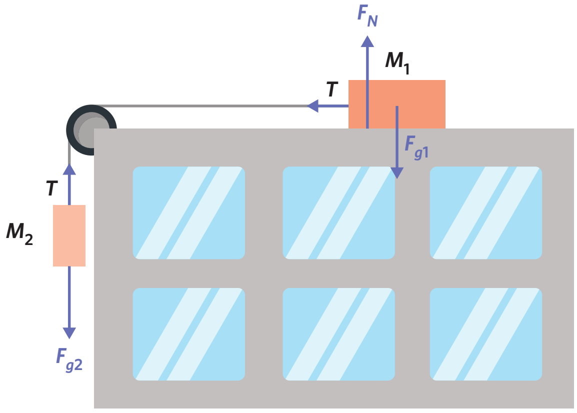
$F_{g\parallel} = 119 = 1.2 \times 10^2$ N (1 MARK)

d. The car is not accelerating $\Rightarrow F_{net} = 0$ N

$F_{net} = F_{g\parallel} - F_f \Rightarrow 0 = 119 - F_f$ (1 MARK)

$F_f = 119 = 1.2 \times 10^2$ N (1 MARK)

19. a.



- I have drawn a force due to gravity vector acting vertically down from the centre of each box.
- I have drawn a tension force vector acting along the string from both boxes.
- I have drawn the normal force vector acting vertically up from the point of contact of box one.
- I have correctly labelled each force.

b. Combined system: $F_{net} = F_{g2} = m_2 g = 60.0 \times 9.8 = 588$ N (1 MARK)

$F_{net} = (m_1 + m_2) \times a$

$588 = (85.0 + 60.0) \times a$ (1 MARK)

$a = 4.06 = 4.1$ m s^{-2} (1 MARK)

c. M_1 system: $F_{net\,M1} = m_1 a = T$

$T = 85 \times 4.06 = 344.7 = 3.4 \times 10^2$ N

d. Combined system: $F_{net} = F_{g2} - F_f = m_2 g - F_f$

$F_{net} = (m_1 + m_2) \times a$

$m_2 g - F_f = (m_1 + m_2) \times a$ (1 MARK)

$60.0 \times 9.8 - F_f = (85.0 + 60.00) \times 1.0$ (1 MARK)

$F_f = 443 = 4.4 \times 10^2$ N (1 MARK)

Key science skills

20. a. $uncertainty = \frac{1}{2} \times smallest\ gradation\ on\ scale = \frac{1}{2} \times 0.2$

$uncertainty = 0.1$ seconds

b. The consistent delay of 0.6 seconds in the stopwatch is a systematic error (1 MARK)

It could be reduced by using a more accurate measurement device such as a digital stopwatch (1 MARK)

FROM LESSON 11C

9D ANSWERS

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Previous lessons

21. [Mass defect is the difference in mass between a nucleus and its constituent nucleons,[1]][whereas binding energy is the energy required to split a nucleus into its constituent nucleons.[2]]

- I have addressed the relevant theory: mass defect.[1]
- I have addressed the relevant theory: binding energy.[2]

FROM LESSON 5A

22. Define to the right as positive.

$F_{net} = ma = 18 \times 2.0 = 36$ N (1 MARK)

$F_{net} = F - F_f \Rightarrow 36 = F - 12$ (1 MARK)

$F = 48$ N to the right (1 MARK)

FROM LESSON 9A

9E Torque

Progress questions

1. D	**2.** B	**3.** C	**4.** B
5. C	**6.** C	**7.** B	

Deconstructed exam-style

8. A. $F_g = mg = 77 \times 9.8$ N

9. C. $\tau_1 = r_\perp F = r \times F_g$ clockwise

10. B. $\tau_2 = r_\perp F = rF\sin(\theta) = r \times F_g \times \sin(60°)$ anticlockwise

11. B. $\tau_{net} = \tau_2 - \tau_1 = r \times F_g \times \sin(60°) - r \times F_g$

12. Consider the force due to gravity from each friend:

$F_g = mg = 77 \times 9.8 = 754.6$ N (1 MARK)

Consider the two torques acting on the Ferris wheel:

$\tau_1 = r_\perp F = r \times 754.6$ clockwise (1 MARK)

$\tau_2 = rF\sin(\theta) = r \times 754.6 \times \sin(60°)$ anticlockwise (1 MARK)

Consider the net torque acting on the Ferris wheel due to τ_1 and τ_2:

$\tau_{net} = r \times 754.6 \times \sin(60°) - r \times 754.6$

$805 = r \times 754.6 \times \sin(60°) - r \times 754.6$ (1 MARK)

$r = 7.96 = 8.0$ m (1 MARK)

Exam-style

13. a. $\tau = r_\perp F = 25.0 \times 10^{-2} \times 125$ (1 MARK)

$\tau = 31.25 = 31.3$ N m (1 MARK)

b. $\tau = r_\perp F \Rightarrow 31.25 = 35.0 \times 10^{-2} \times F$ (1 MARK)

$F = 89.29 = 89.3$ N (1 MARK)

14. $\tau = r_\perp F \Rightarrow 1200 = r_\perp \times 900$ (1 MARK)

$r_\perp = 1.33$ m (1 MARK)

15. F_F creates a clockwise torque, F_H creates an anticlockwise torque.

$\tau_{net} = \tau_H - \tau_F = F_H r_H - F_F r_F = 35 \times 2.8 - 25 \times 3.8$ (1 MARK)

$\tau_{net} = 3.0$ N m (1 MARK)

Net torque is 3.0 N m, and the door will rotate anticlockwise. (1 MARK)

16. [When the force is directed towards the axis of rotation in direction *A*, it is parallel to the object and the torque will be zero.[1]][As the force rotates towards the perpendicular direction, the torque will increase until it is at a maximum in direction *C* (when the force acts perpendicular to the line between the pivot point and the point where the force is applied).[2]][The torque will then decrease until the force acts away from the axis of rotation in direction *E*: here it is parallel to the object and the torque will be zero.[3]]

- I have explicitly addressed the torque when the force acts in direction *A*.[1]
- I have explicitly addressed the torque as the force changes to act in direction *C*.[2]
- I have explicitly addressed the torque as the force changes to act in direction *E*.[3]

17. $F_g = mg = 500 \times 9.8 = 4.90 \times 10^3$ N (1 MARK)

4.0 m is the lever arm $r_\perp$

$\tau = r_\perp F_g = 4.0 \times 4.9 \times 10^3$ (1 MARK)

$\tau = 1.96 \times 10^4 = 2.0 \times 10^4$ N m in the anticlockwise direction (1 MARK)

OR

$F_g = mg = 500 \times 9.8 = 4.90 \times 10^3$ N (1 MARK)

$\sin(\theta) = \frac{opposite}{hypotenuse} = \frac{4.0}{5.0} = 0.80$

$\tau = rF_g\sin(\theta) = 5.0 \times 4.90 \times 10^3 \times 0.80$ (1 MARK)

$\tau = 1.96 \times 10^4 = 2.0 \times 10^4$ N m in the anticlockwise direction (1 MARK)

18. a. Take the anticlockwise direction as positive.

$\tau_{net} = \tau_{150} - \tau_{50} = rF\sin(\theta) - r_\perp F$ (1 MARK)

$\tau_{net} = 0.90 \times 150 \times \sin(70°) - 0.60 \times 50$ (1 MARK)

$\tau_{net} = 96.9 = 97$ N m in the anticlockwise direction (1 MARKS)

b. Take the anticlockwise direction as positive.

$\tau_{net} = \tau_{150} - \tau_{50} = rF\sin(\theta) - r_\perp F$ (1 MARK)

$100 = 0.90 \times 150 \times \sin(\theta) - 0.60 \times 50$ (1 MARK)

$\theta = 74.4 = 74°$ (1 MARK)

19. a. $\tau = rF\sin(\theta) = 85 \times 10^{-2} \times 25 \times \sin(120°)$ (1 MARK)

$\tau = 18.4 = 18$ N m in the anticlockwise direction (1 MARK)

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b. [If the force on the umbrella was increased by a factor of 2, the torque will also increase by a factor of 2.[1]] [This is because torque is directly proportional to the force as seen in the equation $\tau = r_{\perp}F$.[2]]

- I have explicitly addressed the factor by which torque increases.[1]
- I have used the relevant theory: torque is directly proportional to force.[2]

c. [For the maximum torque to act on the umbrella, the force should be directed perpendicular to the handle of the umbrella.[1]] [This is because torque is proportional to the sine of the angle between the force and the line between the pivot point and the point of application of the force, as seen in the equation $\tau = rF\sin(\theta)$,[2]] [and this has a maximum value of 1 at 90°.[3]]

- I have explicitly addressed the direction of force which will cause the maximum torque.[1]
- I have used the relevant theory: torque with non-perpendicular forces.[2]
- I have used the relevant theory: torque is at a maximum when perpendicular.[3]

Key science skills

20. a. Independent variable: force applied to bottle opener (1 MARK)

Dependent variable: torque on bottle cap (1 MARK)

Controlled variable: the angle at which the force is applied **OR** the bottle opener used **OR** the bottle used (1 MARK)

b. Radha could use a more precise torque sensor.

c. Radha could take multiple measurements for each level of force applied, and calculate an average value.

FROM LESSONS 11A & 11C

Previous lessons

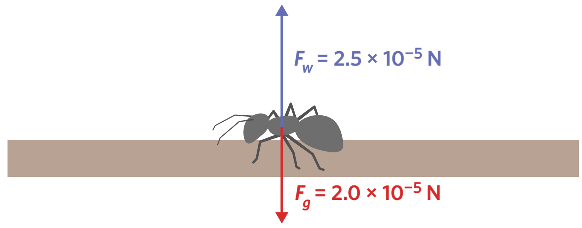
21. D. Nuclear fission involves splitting a large nucleus into two smaller nuclei, with a net release of energy.

FROM LESSON 5A

22. a. $F_g = mg = 2.0 \times 10^{-6} \times 9.8$ (1 MARK)

$F_g = 1.96 \times 10^{-5} = 2.0 \times 10^{-5}$ N downwards (1 MARK)

b.



- I have drawn the force due to gravity, F_g, acting vertically downwards and originating at the centre of the ant.
- I have drawn the force due to the wind, F_w, acting vertically upwards.
- I have drawn the force due to gravity slightly smaller than the force due to the wind.
- I have correctly labelled the force due to gravity and force due to the wind vectors.

c. Take up as positive:

$F_{net} = F_w - F_g = 2.5 \times 10^{-5} - 1.96 \times 10^{-5}$

$F_{net} = 5.4 \times 10^{-6}$ N (1 MARK)

$F_{net} = ma \Rightarrow 5.4 \times 10^{-6} = 2.0 \times 10^{-6} \times a$ (1 MARK)

$a = 2.7$ m s^{-2} (1 MARK)

FROM LESSON 9A

9F Equilibrium

Progress questions

1. B	**2.** B	**3.** C	**4.** D
5. B	**6.** C	**7.** B	

Deconstructed exam-style

8. A. The force from the suspended mass is directed vertically downwards with a magnitude of 45 g N. The perpendicular (horizontal) distance from point I to the line of action (FE) is 2.5 m (5.0 × sin(30°)).

9. A. The tension force acts perpendicularly to the beam. The distance from point I to point G is 3.5 m.

10. A. The force due to gravity on the beam is directed vertically downwards with a magnitude of 10g. We treat it as acting halfway along the length of the beam, so the perpendicular (horizontal) distance from point I to the line of action is half the horizontal length of the beam $\left(\frac{2.5}{2} = 1.25 \text{ m}\right)$.

11. Around point I: $\Sigma\tau_{cw} = \Sigma\tau_{acw} \Rightarrow \tau_{GH} = \tau_{FE} + \tau_{g\ beam}$

$r_G T_{GH} = r_{F\perp} F_{FE} + r_{centre\perp} F_{g\ beam}$ (1 MARK)

$3.5 \times T_{GH} = 2.5 \times 45 \times 9.8 + \frac{2.5}{2} \times 10 \times 9.8$ (1 MARK)

$T_{GH} = 350 = 3.5 \times 10^2$ N (1 MARK)

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Exam-style

12. B. When resolved into components, arrangements A, C and D have no possibility for net force in the vertical direction to equal zero.

13. [The feet of the clown must be the same distance from the ball,[1]] [so that the clockwise torque due to the right foot is balanced by the anticlockwise torque due to the left foot.[2]]

- I have explicitly stated the two feet must be the same distance from the ball.[1]
- I have used the relevant theory: rotational equilibrium.[2]

14. Around Y: $\sum\tau_{cw} = \sum\tau_{acw} \Rightarrow r_{xy}F_x = r_{centre}F_g$

$12.0 \times F_x = 3.0 \times 2000 \times 9.8$ (1 MARK)

$F_x = 4900 = 4.9 \times 10^3$ N (1 MARK)

15. a. Translational equilibrium: $\sum F = 0 \Rightarrow F_1 + F_2 = F_{g,\,slab}$

$F_{g,\,slab} = mg = 40.0 \times 10^3 \times 9.8 = 392\,000$ N (1 MARK)

$F_{1st\ pillar} = F_{2nd\ pillar} = \frac{1}{2} \times 3.92 \times 10^5 = 2.0 \times 10^5$ N (1 MARK)

b. Around pillar 1: $\sum\tau_{cw} = \sum\tau_{acw}$
$\Rightarrow r_{centre}F_{g\ slab} + r_{truck}F_{truck} = rF_2$

$20 \times 40.0 \times 10^3 \times 9.8 + 30 \times 6.0 \times 10^3 \times 9.8 = 40.0 \times F_2$ (1 MARK)

$F_2 = 240\,100 = 2.4 \times 10^5$ N (1 MARK)

Translational equilibrium: $\sum F = 0 \Rightarrow F_1 + F_2 = F_{g\ slab} + F_{truck}$

$F_1 + 240\,100 = 40.0 \times 10^3 \times 9.8 + 6.0 \times 10^3 \times 9.8$ (1 MARK)

$F_1 = 210\,700 = 2.1 \times 10^5$ N (1 MARK)

16. a. Around the centre: $\sum\tau_{cw} = \sum\tau_{acw} \Rightarrow r \times F_{55\ kg} = d \times F_{70\ kg}$ (1 MARK)

$2.5 \times 55 \times 9.8 = d \times 70 \times 9.8$ (1 MARK)

$d = 1.96 = 2.0$ m (1 MARK)

b. Translational equilibrium: $\sum F = 0 \Rightarrow F_N = F_{55\ kg} + F_{70\ kg}$

$F_N = 55 \times 9.8 + 70 \times 9.8$ (1 MARK)

$F_N = 1225 = 1.2 \times 10^3$ N (1 MARK)

17. [Angus is incorrect and Dom is incorrect.[1]] [An object, such as a seesaw, may have no net force acting on it but still undergo rotational acceleration, and therefore have a net torque.[2]] [An object, such as an accelerating car, with a net force acting on it is not necessarily undergoing rotational acceleration, and therefore has no net torque acting on it.[3]]

- I have explicitly stated Angus and Dom are incorrect.[1]
- I have given an example of rotational acceleration without linear acceleration.[2]
- I have given an example of linear acceleration without rotational acceleration.[3]

18. [When an object of unknown mass is placed on one plate, known masses can be placed on the other until the scale is stationary.[1]] [At this point, the torque due to both objects must be equal, as the scale is in rotational equilibrium.[2]] [As the distance of the plates from the pivot point is the same, the unknown mass must be equivalent to the mass of the known objects in the opposing plate.[3]]

- I have explicitly stated the unknown mass must be balanced by the known masses on an opposing plate.[1]
- I have used the relevant theory: no net torque in rotational equilibrium.[2]
- I have explicitly stated the distance from the pivot point of both is the same, so must have the same mass on both plates.[3]

19. D. The system is in equilibrium.

20. Around E: $\sum\tau_{clockwise} = \sum\tau_{anticlockwise} \Rightarrow \tau_G = \tau_H$

$r_G F_{Gy} = r_H F_H \Rightarrow 0.15 \times F_{Gy} = 0.55 \times 30 \times 9.8$

$F_{Gy} = 1078$ N (1 MARK)

Calculate the horizontal component of the force.

$F_{Gy} = F_{Gx}\tan(\theta) \Rightarrow 1078 = F_{Gx} \times \tan(50°)$ (1 MARK)

$F_{Gx} = 904.5$ N

$\sum F = 0 \Rightarrow F_{Ex} - F_{Gx} = 0 \Rightarrow F_{Ex} = 904.5 = 9.0 \times 10^2$ N (1 MARK)

Key science skills

21. [The type of error is systematic error,[1]] [because it affects all results equally.[2]]

- I have explicitly addressed the type of error.[1]
- I have used the relevant theory: systematic errors.[2]

FROM LESSON 11C

Previous lessons

22. Any two of: making the mass more spherical, adding fissile material to the mass, removing neutron absorbing material if it is present, adding neutron moderators. (2 MARKS)

FROM LESSON 5B

23. $\sum p_i = 1500 \times 20 + 500 \times 0 = 3.0 \times 10^4$ kg m s^{-1} or N s (1 MARK)

$\sum p_f = \sum p_i = 3.0 \times 10^4$ kg m s^{-1} or N s

$\sum p_f = mv = (m_{train} + m_{car}) \times v$

$3.0 \times 10^4 = (1500 + 500) \times v$ (1 MARK)

$v = 15$ m s^{-1} (1 MARKS)

$v = 15$ m s^{-1} to the right (1 MARK)

FROM LESSON 9B

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Chapter 9 review

Section A

1. C. Find the resultant force in the horizontal direction then solve using Pythagoras: $F = \sqrt{21^2 + (32.9 - 23.8)^2} = 23$ N

2. A. $a = \frac{F_{net}}{m} = \frac{2.54 \times 10^4}{1.20 \times 10^3} = 21.2$ m s^{-2}

3. C. $F_{on\ A\ by\ B} = m_A g = 7.0 \times 9.8 = 68.6 = 69$ N.
Brick B pushes upwards on brick A.

4. D. Force due to gravity on PR acts 5.0 m from P.

Around point P, $\sum\tau_{clockwise} = \sum\tau_{anticlockwise}$
$\Rightarrow 5.0 \times 3000 \times 9.8 = 3.0 \times F_{QS}$

$F_{QS} = 49\,000 = 5.0 \times 10^4$ N

5. C. In scenario B: before the collision, $\sum p_i = m_1 u$; after the collision, $\sum p_f = (m_1 + m_2)v$. Since $\sum p_i = \sum p_f$ and $m_1 + m_2 > m_1$, this means that $v < u$.

Section B

6. a. Since cart is not accelerating in vertical direction:

$F_N = F_g = mg = 30 \times 9.8 = 2.9 \times 10^2$ N

b. Define to the right as the positive direction.

$F_{net} = ma \Rightarrow 450 - 400 = 30 \times a$ (1 MARK)

$a = 1.7$ m s^{-2} to the right (1 MARK)

7. [Newton's first law of motion states that an object in motion will continue moving with the same velocity unless acted upon by a net external force.[1]] [As the bike is initially in motion but does not remain in motion, there must be an external force slowing the bike down.[2]]

- I have referenced Newton's first law of motion correctly.[1]
- I have explicitly addressed why there must be a force acting.[2]

8. $F_{net} = ma = mg\sin\theta - F_f$

$m \times 0.500 = m \times 9.8 \times \sin(28.0°) - 320$ (1 MARK)

$m = 78.0$ kg (1 MARK)

9. a. Consider the combined system:

As $F_{net} = 0$, $T_2 = 75 + 75$ N

$T_2 = 150$ N

b. Consider the left-hand storage unit:

$m_1 a = T_1 - 75 \Rightarrow 15 \times 0.30 = T_1 - 75$ (1 MARK)

$T_1 = 79.5 = 80$ N (1 MARK)

$\Rightarrow T_1 = 80$ N to the right (1 MARK)

10. a. Define positive velocity as to the right.

$\sum p_i = m_X u_X + m_Y u_Y = (4.5 \times 10^3) \times (7.0)$
$+ (2.6 \times 10^3) \times (-3.7)$

$\sum p_i = 2.19 \times 10^4$ kg m s^{-1} to the right (1 MARK)

By the law of conservation of momentum, $\sum p_i = \sum p_f$

$\sum p_f = 2.19 \times 10^4$ kg m s^{-1} to the right

$\sum p_f = m_{total} v = (m_X + m_Y) \times v$

$2.19 \times 10^4 = (4.5 \times 10^3 + 2.6 \times 10^3) \times v$ (1 MARK)

$v = 3.08 = 3.1$ m s^{-1} to the right (1 MARK)

b. $I_Y = \Delta p_Y = m_Y(v_Y - u_Y) = 2.6 \times 10^3 \times (3.08 - (-3.7))$
$= 1.76 \times 10^4$ kg m s^{-1} to the right (1 MARK)

$I_Y = F_{avg}\Delta t \Rightarrow 1.76 \times 10^4 = 25\,000 \times \Delta t$

$\Delta t = 0.71$ s (1 MARK)

c. [It is impossible for Z to remain stationary since this would be a violation of the law of conservation of momentum.[1]] [The initial momentum of carts X and Y is 2.2×10^4 kg m s^{-1} to the right from part a, and since Z is stationary its initial momentum is 0 kg m s^{-1}. Therefore, the final momentum of the system X-Y-Z must also be to the right.[2]] [This cannot be the case if the combined carts have zero velocity immediately after the collision.[3]]

- I have used the relevant theory: the law of conservation of momentum.[1]
- I have justified my answer by referring to the initial and final momentums of the system.[2]
- I have explicitly addressed the reason why Z remaining stationary is impossible.[3]

11. a. Around point E, $\sum\tau_{anticlockwise} = \sum\tau_{clockwise}$

$r_{EG} T_{FG\perp} = r_{beam} F_{g\ beam} + r_{EH} F_{g\ mass}$

$0.50 \times T_{FG\perp} = 1.0 \times 20 \times 9.8 + 2.0 \times 250 \times 9.8$ (1 MARK)

$T_{FG\perp} = 10\,192$ N (1 MARK)

$T_{FG\perp} = T_{FG}\sin(45°) \Rightarrow 10\,192 = T_{FG}\sin(45°)$

$T_{FG} = 14\,414 = 1.4 \times 10^4$ N (1 MARK)

b. $T_{max} = 20\,000 \Rightarrow T_{max\perp} = 20\,000 \times \sin(45°)$

$T_{max\perp} = 14\,142$ N (1 MARK)

Around point E, $\sum\tau_{anticlockwise} = \sum\tau_{clockwise}$

$r_{EG} T_{max\perp} = r_{007} F_{g007} + r_{beam} F_{gbeam} + r_{EH} F_{gmass}$

$0.5 \times 14\,142 = 1.25 \times m \times 9.8 + 1.0 \times 20 \times 9.8$
$+ 2.0 \times 250 \times 9.8$ (1 MARK)

$m = 161 = 1.6 \times 10^2$ kg (1 MARK)

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10A Kinetic energy and conservation of energy

Progress questions

1. A
2. B
3. D
4. D
5. D
6. B
7. B
8. C

Deconstructed exam-style

9. B
10. D
11. B
12. B

13. $KE_i = \frac{1}{2}mv^2 = \frac{1}{2} \times 60 \times 14^2$ (1 MARK)

$KE_i = 5.9 \times 10^3$ J (1 MARK)

$KE_i = SPE_f + GPE_f$

$5.9 \times 10^3 = SPE_f + 1200$ (1 MARK)

$SPE_f = 5.9 \times 10^3 - 1.2 \times 10^3 = 4.7 \times 10^3$ J (1 MARK)

Exam-style

14. a. $KE = \frac{1}{2}mv^2 = \frac{1}{2} \times 2.0 \times 15^2$ (1 MARK)

$KE = 225 = 2.3 \times 10^2$ J (1 MARK)

b. $KE = \frac{1}{2}mv^2 = \frac{1}{2} \times 2.0 \times 50^2$ (1 MARK)

$KE = 2500 = 2.5 \times 10^3$ J (1 MARK)

15. $\Delta KE = \frac{1}{2}m(v^2 - u^2) = \frac{1}{2} \times (0.50 \times 1000) \times \left(\left(\frac{60}{3.6}\right)^2 - \left(\frac{100}{3.6}\right)^2\right)$ (1 MARK)

$\Delta KE = -1.2 \times 10^5$ J (1 MARK)

In order for the car to slow down it converts kinetic energy into other forms of energy, mainly heat and sound. (1 MARK)

16. Bicycle:

$KE = \frac{1}{2}mv^2 = \frac{1}{2} \times 160 \times 17^2$

$KE = 2.3 \times 10^4$ J (1 MARK)

Motorbike:

$KE = \frac{1}{2}mv^2 = \frac{1}{2} \times 400 \times 10^2$

$KE = 2.0 \times 10^4$ J (1 MARK)

Therefore, the bicycle (2.3×10^4 J) has a greater kinetic energy than the motorbike (2.0×10^4 J). (1 MARK)

17. $KE_i = \frac{1}{2}mv^2 = \frac{1}{2} \times 75 \times 10^2$ (1 MARK)

$KE_i = 3750 = 3.8 \times 10^3$ J (1 MARK)

$KE_i = SPE_f$

$SPE_f = 3.8 \times 10^3$ J (1 MARK)

18. a. $KE = \frac{1}{2}mv^2 \Rightarrow 22 = \frac{1}{2} \times m \times (20)^2$ (1 MARK)

$m = 0.110 = 0.11$ kg (1 MARK)

b. [Both drumsticks have the same initial kinetic energy, $KE = \frac{1}{2}mv^2$, before they hit the drum, as they have the same velocity and mass.[1]][Drumstick *A* will have a greater kinetic energy after hitting the drum than drumstick *B*, as its rebound velocity is greater.[2]][Therefore more energy will be transferred to sound energy in the cymbal than the snare drum, as energy must be conserved.[3]][As the cymbal has a greater sound energy than the snare drum, it will be louder in volume.[4]]

- I have explicitly stated both drumsticks have the same initial kinetic energy.[1]
- I have explicitly stated drumstick *A* will have a greater kinetic energy after hitting the drum.[2]
- I have addressed relevant theory: conservation of energy.[3]
- I have explicitly stated the cymbal will produce a greater sound energy and therefore be louder.[4]

c. $E_i = E_f \Rightarrow KE_i = KE_f + SE_f$

$KE_{i\,SA} + KE_{i\,SB} = KE_{f\,SA} + KE_{f\,SB} + SE_f$ (1 MARK)

$2 \times 22 = \left(\frac{1}{2} \times 0.11 \times 12^2\right) + \left(\frac{1}{2} \times 0.11 \times 8.0^2\right) + SE_f$ (1 MARK)

$SE_f = 32.6 = 33$ J (1 MARK)

Key science skills

19. [The results of Ted's experiment will be invalid.[1]][This is because his experimental design has more than one independent variable changing at the same time (mass of the car and height dropped from),[2]][which means that the effect that the mass of the car has on the dependent variable (final velocity) cannot be determined.[3]]

- I have explicitly addressed the validity of the experiment.[1]
- I have justified my answer by stating that there are independent variables.[2]
- I have justified my answer by stating how this will affect the dependent variable.[3]

FROM LESSON 11C

Previous lessons

20. A mass that is supercritical has a fission chain reaction which is growing in number of reactions per unit time.

Neutron multiplication factor is a measure of how a fission chain reaction is growing, shrinking, or being sustained.

Neutron moderators reduce the energy of neutrons through collisions with them.

Increasing surface area decreases the neutron multiplication factor of a fissile mass. (2 MARKS)

FROM LESSON 5B

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21. Block is stationary, so $F_{net} = 0$ (1 MARK)

$F_{net} = F_{ds} - F_f = mg\sin(25°) - 18$

$m \times 9.8 \times \sin(25°) - 18 = 0$ (1 MARK)

$m = 4.3$ kg (1 MARK)

FROM LESSON 9C

10B Work and gravitational potential energy

Progress questions

1. A
2. B
3. A
4. C
5. C
6. B
7. C
8. C
9. B
10. B
11. A

Deconstructed exam-style

12. A

13. C

14. B

15. At the top of the loop-the-loop:

$KE = \frac{1}{2}mv^2 \Rightarrow 2.4 \times 10^5 = \frac{1}{2} \times 1.2 \times 10^3 \times v^2$ (1 MARK)

$v = 20$ m s^{-1} (1 MARK)

$v = \sqrt{-2g\Delta h + u^2} \Rightarrow 20 = \sqrt{-2 \times 9.8 \times (40 - 0) + u^2}$
(1 MARK)

$u = 34.4 = 34$ m s^{-1} (1 MARK)

Exam-style

16. a. Work is done on the books.

b. No work is done.

c. Work is done by the ball.

17. a. P

b. P, Q and R

c. P, Q, R and S

18. a. $\Delta GPE = mg\Delta h \Rightarrow 1.764 \times 10^5 = m \times 9.8 \times (1000 - 750)$

(1 MARK)

$m = 72.0 = 72$ kg (1 MARK)

b. $E_i = E_f \Rightarrow GPE_i = KE_f$

$1.76 \times 10^5 = \frac{1}{2}mv^2$ (1 MARK)

$v = \sqrt{\frac{2 \times 1.764 \times 10^5}{72}} = 70.0 = 70$ m s^{-1} (1 MARK)

OR

$v = \sqrt{-2g\Delta h + u^2} = \sqrt{-2 \times 9.8 \times (750 - 1000) + 0^2}$
(1 MARK)

$v = 70.0 = 70$ m s^{-1} (1 MARK)

19. a. $W = Fs = 40 \times 4.5 = 180 = 1.8 \times 10^2$ J

b. $\Delta KE = W = 1.8 \times 10^2$ J (1 MARK)

$KE_i = 0$ J, since the box starts from rest. $\Rightarrow KE_f = 1.8 \times 10^2$ J
(1 MARK)

20. a. $P = \frac{E}{t} \Rightarrow 7.8 \times 10^5 = \frac{E}{13}$ (1 MARK)

$E = 7.8 \times 10^5 \times 13 = 1.01 \times 10^7 = 1.0 \times 10^7$ J (1 MARK)

Energy produced is 10 MJ (1 MARK)

b. $\eta = \frac{useful\ energy\ out}{total\ energy\ in} \Rightarrow 0.68 = \frac{1.0 \times 10^7}{total\ energy\ in}$ (1 MARK)

$total\ energy\ in = \frac{1.0 \times 10^7}{0.68} = 1.49 \times 10^7 = 1.5 \times 10^7$ J
(1 MARK)

21. [Work is defined as a force that causes a change in the energy of an object.[1]] [Whilst the person is applying a force equal to the gravitational force acting on the object, the force is not causing the object to be displaced in the direction which it is being applied in.[2]] [Therefore the energy of the object is not changing and so no work is being done.[3]]

- I have explicitly addressed what work is.[1]
- I have justified my answer by discussing that the applied force causes no displacement.[2]
- I have explicitly addressed why no work is being done in this context.[3]

22. a. $W = area\ under\ graph = \frac{1}{2} \times 8 \times 120 = 480$ J

b. $\Delta KE = \frac{1}{2}mv^2 - \frac{1}{2}mu^2 = \frac{1}{2} \times 80 \times 0.75^2 = 22.5$ J since the sofa starts from rest. (1 MARK)

Work done by friction opposes work done by Jock.

$\Delta KE = W_{Jock} - W_{friction} = 480 - F_{friction} \times 8.0$ (1 MARK)

$480 - 8.0 \times F_{friction} = 22.5$ J $\Rightarrow F_{friction} = 57$ N (1 MARK)

c. $\eta = \frac{useful\ energy\ out}{total\ energy\ in} = \frac{22.5}{480} = 0.047$

23. a. Total energy is conserved so $E_Q = E_P$

$E_P = KE + GPE = \frac{1}{2}mv^2 + mg\Delta h$

$= \frac{1}{2} \times 950 \times 12.0^2 + 950 \times 9.8 \times 70$ (1 MARK)

$\Rightarrow E_Q = 720\ 100 = 7.2 \times 10^5$ J (1 MARK)

b. $E_{total} = E_R = KE + GPE = KE + mg\Delta h$

$7.2 \times 10^5 = KE + 950 \times 9.8 \times (30 - 0)$ (1 MARK)

$KE = 440\ 800 = 4.4 \times 10^5$ J (1 MARK)

24. a. Energy is conserved: $E_f = GPE_i = mg\Delta h = 25 \times 9.8 \times 2.5$
(1 MARK)

$E_f = 612 = 6.1 \times 10^2$ J (1 MARK)

b. $t = \frac{E_f}{P} = \frac{612.5}{2.0} = 306 = 3.1 \times 10^2$ s (2 MARKS)

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25. a. [Work is done when an applied force causes the displacement of an object parallel to the direction it is acting in.[1]] [In this example, the horizontal component of the tension force displaces the sled to the right, however the vertical component does no work since the sled is not displaced up or down.[2]] [Therefore the magnitude of the force doing work is 25cos(30°) N, and not 25 N.[3]]

- I have explicitly addressed when work is done in terms of force and displacement.[1]
- I have explicitly addressed why the horizontal component of the tension force is the only component that does work.[2]
- I have related my answer to the context of the question.[3]

b. $W = \Delta KE = 150$ J, since the sled starts from rest.

$Fs = 150 \Rightarrow 25\cos(30°) \times s = 150$ (1 MARK)

$s = 6.9$ m (1 MARK)

26. [The change in height in gravitational potential energy is measured from the centre of mass of the jumper.[1]] [The height able to be achieved is dependent on initial kinetic energy, $KE_i = GPE_f = mg\Delta h_f$.[2]] [By reducing the centre of mass to below the bar, we reduce the height required to clear the bar and therefore the amount of energy required, making it easier.[3]]

- I have used the relevant theory: gravitational potential energy.[1]
- I have used the relevant theory: conservation of energy.[2]
- I have explicitly addressed that the jumper is able to clear the bar above the change in height according to energy conservation.[3]

27. a. [Graph A represents the gravitational potential energy of the astronaut as a function of height.[1]] [When the rock's height is a maximum and it is at rest, all its energy is stored as gravitational potential energy and so will be at its maximum.[2]] [When its height is a minimum, its energy has been linearly converted into kinetic energy and it has no gravitational potential energy.[3]]

- I have explicitly addressed which graph shows gravitational potential energy as a function of height.[1]
- I have explicitly addressed the gravitational potential energy at a maximum height.[2]
- I have explicitly addressed the gravitational potential energy at a minimum height.[3]

b. [Graph B represents the kinetic energy of the astronaut as a function of height.[1]] [When the height is a maximum the ball has zero kinetic energy.[2]] [As the ball's height decreases, it loses gravitational potential energy linearly which is converted to kinetic energy since energy must be conserved.[3]]

- I have explicitly addressed which graph shows *KE* as a function of height.[1]
- I have explicitly addressed the kinetic energy at the maximum height.[2]
- I have used the relevant theory: conservation of energy.[3]

c. Energy is conserved, so all initial *GPE* is converted to final *KE*.

(1 MARK)

$KE_f = GPE_i = mg\Delta h = 1.0 \times 1.62 \times (0 - 15) = -24.3$

$KE_f = 24$ J (1 MARK)

d. $v = \sqrt{-2g\Delta h + u^2} = \sqrt{-2 \times 1.62 \times (3.0 - 15) + 0^2}$

(1 MARK)

$v = 6.2$ m s^{-1} (1 MARK)

Key science skills

28. [The experiment is invalid as there is more than one independent variable.[1]] [The size of the ball needs to be a controlled variable in this experiment.[2]] [If Bella uses a ball with the same radius or excludes the 4.0 kg ball from the data, the experiment will be valid.[3]]

- I have explicitly addressed the validity of the experiment.[1]
- I have used the relevant theory: control variables.[2]
- I have explicitly addressed the 4.0 kg ball.[3]

FROM LESSON 11C

Previous lessons

29. $P = VI$

$500 = 120 \times I$ (1 MARK)

$I = 4.17$ A

$Q = It$

$Q = 4.17 \times 10 \times 60$ (1 MARK)

$Q = 2500 = 2.5 \times 10^3$ C (1 MARK)

OR

$E = Pt = 500 \times 10 \times 60$

$E = 3.0 \times 10^5$ J (1 MARK)

$Q = \frac{E}{V} = \frac{3.0 \times 10^5}{120}$ (1 MARK)

$Q = 2500 = 2.5 \times 10^3$ C (1 MARK)

FROM LESSON 6A

30. $F = ma \Rightarrow 90 = (4.0 + 3.5) \times a$ (1 MARK)

$a = \frac{90}{7.5} = 12$ m s^{-2} (1 MARK)

FROM LESSON 9D

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10C Springs

Progress questions

1. B **2.** C **3.** A **4.** C

5. C **6.** C **7.** B **8.** C

9. gradient, area under the graph

Deconstructed exam-style

10. C. $F_s = k\Delta x \Rightarrow 60 = k \times 0.35$

$k = 171 \text{ N m}^{-1}$

11. B. As the bean bag is not moving, its kinetic energy is zero. It is compressing the spring and has non-zero displacement above its final position so it has strain and gravitational potential energy.

12. B. The spring is no longer being compressed so there is zero strain potential energy. As the bean bag is moving and is above the ground, it has both kinetic and gravitational potential energy.

13. C. The law of conservation of energy states that the total initial energy will be equal to the total final energy, hence $SPE_i + GPE_i = KE_f + GPE_f$.

14. $F_s = k\Delta x \Rightarrow 60 = k \times 0.35$

$k = 171 \text{ N m}^{-1}$ (1 MARK)

Consider the initial position to be the compressed spring and final position to be just before striking Hook Slaw.

$KE_i + GPE_i + SPE_i = KE_f + GPE_f + SPE_f$

$SPE_i + GPE_i = KE_f + GPE_f \Rightarrow \frac{1}{2}k(x_i)^2 + mgh_i = \frac{1}{2}mv^2 + mgh_f$ (1 MARK)

$\frac{1}{2} \times 171 \times (\Delta x)^2 + 0.15 \times 9.8 \times 2.60$
$= \frac{1}{2} \times 0.15 \times 6.0^2 + 0.15 \times 9.8 \times 1.50$ (1 MARK)

$\Delta x = 0.11 \text{ m}$ (1 MARK)

Exam-style

15. C. The spring constant is the gradient of a spring force-displacement graph.

$gradient = \frac{rise}{run} = \frac{\Delta F}{\Delta x} = \frac{100 - 0}{0.50 - 0} = 200 \text{ N m}^{-1}$

16. A. The initial kinetic energy of the model car is equal to the strain potential energy of the compressed spring.

Strain potential energy is equal to the area under a spring force-displacement graph.

$area\ under\ graph = SPE = \frac{1}{2} \times 0.80 \times 160 = 64 \text{ J}$

17. B. This is the vertical axis value of the graph at 0.40 m displacement.

$F_s = k\Delta x = 200 \times 0.40 = 80 \text{ N}$

18. a. $F_s = k\Delta x = 200 \times 0.60 = 1.2 \times 10^2 \text{ N}$

b. $SPE = \frac{1}{2}k(\Delta x)^2 = \frac{1}{2} \times 200 \times 0.60^2$ (1 MARK)

$SPE = 36 \text{ J}$ (1 MARK)

c. $KE_i + GPE_i + SPE_i = KE_f + GPE_f + SPE_f$

$SPE_i = KE_f \Rightarrow 36 = \frac{1}{2}mv^2$ (1 MARK)

$36 = \frac{1}{2} \times 0.35 \times v^2$ (1 MARK)

$v = 14 \text{ m s}^{-1}$ (1 MARK)

d. [Strain potential energy begins at a maximum while kinetic energy begins at zero.[1]][As the spring returns to its natural length, strain potential energy is converted into kinetic energy.[2]][After the ball is no longer attached to the spring, kinetic energy is a maximum and strain potential energy is zero.[3]][The total energy of the system remains constant throughout.[4]]

I have explicitly addressed strain potential energy and kinetic energy at the moment of release.[1]

I have explicitly addressed strain potential energy and kinetic energy while the ball is still attached to the spring.[2]

I have explicitly addressed strain potential energy and kinetic energy after the ball is still attached to the spring.[3]

I have explicitly addressed the total energy of the system.[4]

19. a. Any number of masses from one to three can be considered. We will use two.

$F_g = F_s \Rightarrow mg = k\Delta x$

$2 \times 30 \times 10^{-3} \times 9.8 = k \times 20 \times 10^{-2}$ (1 MARK)

$k = 2.94 = 2.9 \text{ N m}^{-1}$ (1 MARK)

b. $\Delta x = total\ length - unstretched\ length = 80 - 50 = 30 \text{ cm}$

$SPE = \frac{1}{2}k(\Delta x)^2 = \frac{1}{2} \times 2.94 \times (30 \times 10^{-2})^2$ (1 MARK)

$SPE = 0.13 \text{ J}$ (1 MARK)

20. a. To find k, use a conservation of energy approach considering the initial position of the ball and when the spring is compressed.

$KE_i + GPE_i + SPE_i = KE_f + GPE_f + SPE_f$

$KE_i + GPE_i = SPE \Rightarrow \frac{1}{2}mu^2 + mgh = \frac{1}{2}k(\Delta x)^2$ (1 MARK)

$\frac{1}{2} \times 0.40 \times 2.0^2 + 0.40 \times 9.8 \times 1.5 = \frac{1}{2} \times k \times (30 \times 10^{-2})^2$ (1 MARK)

$k = 148 = 1.5 \times 10^2 \text{ N m}^{-1}$ (1 MARK)

b. The maximum speed of the ball will be just before it touches the spring, when all its energy is kinetic energy.

$KE_i + GPE_i + SPE_i = KE_f + GPE_f + SPE_f$

$KE_i + GPE_i = KE_f \Rightarrow \frac{1}{2}mu^2 + mgh = \frac{1}{2}mv^2$ (1 MARK)

$\frac{1}{2} \times 0.40 \times 2.0^2 + 0.40 \times 9.8 \times 1.5 = \frac{1}{2} \times 0.40 \times v^2$ (1 MARK)

$v = 5.78 = 5.8 \text{ m s}^{-1}$ (1 MARK)

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c. At the maximum height, gravitational potential energy will be the only form of energy.

$KE_i + GPE_i + SPE_i = KE_f + GPE_f + SPE_f$

$KE_i + GPE_i = GPE_f \Rightarrow \frac{1}{2}mu^2 + mgh = mgs$ (1 MARK)

$\frac{1}{2} \times 0.40 \times 2.0^2 + 0.40 \times 9.8 \times 1.5 = 0.40 \times 9.8 \times s$ (1 MARK)

$s = 1.7$ m (1 MARK)

21. a. To find the spring constant, *k*, consider the initial position from the diagram and the final position where the spring is compressed by 0.20 m.

$KE_i + GPE_i + SPE_i = KE_f + GPE_f + SPE_f$

$KE_i = GPE_f + SPE_f \Rightarrow \frac{1}{2}mu^2 = mg(h + \Delta x) + \frac{1}{2}k(\Delta x)^2$

$\frac{1}{2} \times 10 \times 5.0^2 = 10 \times 9.8 \times (1.0 + 0.20) + \frac{1}{2} \times k \times 0.20^2$
(1 MARK)

$k = 3.7 \times 10^2$ N m^{-1} (1 MARK)

b. Take down as positive

$F_{net} = ma \Rightarrow F_g + F_s = ma$

$mg + k\Delta x = ma \Rightarrow 10 \times 9.8 + 3.7 \times 10^2 \times 0.20 = 10 \times a$
(1 MARK)

$a = 17$ m s^{-2} downwards (1 MARK)

c. Consider the initial position and the final position when the spring is compressed by 0.05 m.

$KE_i + GPE_i + SPE_i = KE_f + GPE_f + SPE_f$

$KE_i = KE_f + GPE_f + SPE_f \Rightarrow \frac{1}{2}mu^2$

$= \frac{1}{2}mv^2 + mg(h + \Delta x) + \frac{1}{2}k(\Delta x)^2$ (1 MARK)

$\frac{1}{2} \times 10 \times 5.0^2 = \frac{1}{2} \times 10 \times v^2 + 10 \times 9.8 \times (1.0 + 0.05)$

$+ \frac{1}{2} \times 3.7 \times 10^2 \times 0.05^2$ (1 MARK)

$v = 2.1$ m s^{-1} (1 MARK)

d. 5.0 m s^{-1} to the left

By the law of conservation of energy, the total final and total initial energy will be equal. As kinetic energy is the only energy at this position and no energy has been lost, the speed will be the same.

22. a. [Acceleration at *W* is greater than 0 and less than 9.8 m s^{-2} and directed mostly downwards.[1]] [Acceleration at *X* is zero.[2]] [Acceleration at *Y* is greater than 0 and directed to the left.[3]]

- I have explicitly addressed the magnitude and direction of the acceleration at *W*.[1]
- I have explicitly addressed the acceleration at *X*.[2]
- I have explicitly addressed the magnitude and direction of the acceleration at *Y*.[3]

b. $KE_i + GPE_i + SPE_i = KE_f + GPE_f + SPE_f$

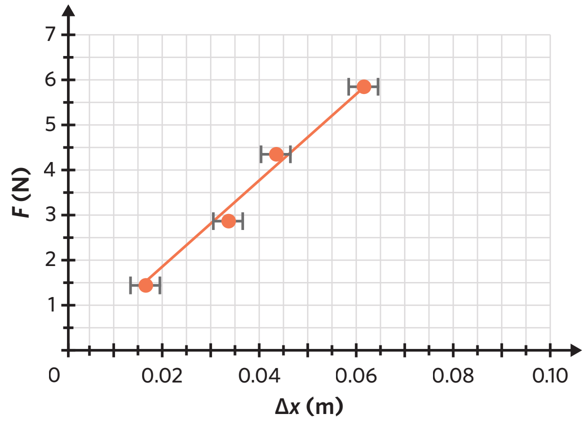
$GPE_i = SPE_f \Rightarrow mgh = \frac{1}{2}kx^2$ (1 MARK)

$5.0 \times 9.8 \times h = \frac{1}{2} \times 100 \times 3.0^2$ (1 MARK)

$h = 9.2$ m (1 MARK)

Key science skills

23. a.



- I have drawn compression on the horizontal axis.
- I have drawn force on the vertical axis.
- I have labelled both axes and included units.
- I have used an appropriate and consistent scale.
- I have plotted each point of data.
- I have included the correct uncertainty bars.
- I have included a straight line of best fit which passes through all uncertainty bars.

b. The spring constant is the gradient of a spring force-compression graph.

Use two points on the line of best fit to determine rise and run.

$gradient = k = \frac{rise}{run} = \frac{3.8 - 0}{0.04 - 0}$ (1 MARK)

$k = 95$ N m^{-1} (1 MARK)

Depending on the line of best fit drawn, answers between 90 N m^{-1} and 100 N m^{-1} are acceptable.

FROM LESSONS 11D & 11E

Previous lessons

24. a. $E = 432 \times 10^3$ J and $t = 10 \times 60 \times 60 = 3.6 \times 10^4$ s (1 MARK)

$P = \frac{E}{t} = \frac{432 \times 10^3}{3.6 \times 10^4} = 12$ W (1 MARK)

b. $P = IV \Rightarrow 12 = 2.0 \times V$ (1 MARK)

$V = 6.0$ V (1 MARK)

FROM LESSON 6A

25. Defining anticlockwise as positive:

$\tau_A = r_A F_A = 0.20 \times 3.0 \times 9.8 = 5.88$ N m (1 MARK)

$\tau_B = r_B F_B = 0.35 \times 2.0 \times 9.8 = 6.86$ N m (1 MARK)

$\sum\tau = \tau_A - \tau_B = 5.88 - 6.86 = -0.98 = 9.8 \times 10^{-1}$ N m clockwise (1 MARK)

FROM LESSON 9E

10D Applications of motion: case study

Progress questions

1. C **2.** A **3.** A **4.** C

5. A **6.** C

Deconstructed exam-style

7. A. $\frac{130}{3.6} = 36.1$ m s^{-1}

8. B. $s = vt = 36.1 \times 1.4 = 50.5$ m

9. B. $s = 100 - 50.5 = 49.5 = 50$ m

10. To be safe, the P-plater must hit the kangaroo at less than 40 km h^{-1} (or 11.1 m s^{-1})

$v^2 = u^2 + 2as = 36.1^2 + 2 \times (-7.71) \times 49.5$ (1 MARK)

$v = \sqrt{36.1^2 + 2 \times (-7.71) \times 49.5} = 23.2$ m s^{-1} (1 MARK)

Since 23.2 m s^{-1} > 11.1 m s^{-1}, the P-plater will not be safe. (1 MARK)

Exam-style

11. D. As kinetic energy is proportional to velocity squared, a car travelling 5.00% faster will have a 10.25% increase in kinetic energy compared to an identical car.

12. A. An increase in speed is the most important factor for the increase in likelihood of a collision.

13. Airbags are designed to improve safety by lowering the impact force on a passenger's head in case of impact.[1] Note that $I = F\Delta t$.[2] The airbag will deform, bringing the head to a rest over a longer period of time.[3] Hence the impact force on the head must be decreased.[4]

- I have explicitly addressed the question.[1]
- I have used the relevant theory: impulse.[2]
- I have referenced that time of impact is increased.[3]
- I have referenced that impact force is decreased.[4]

14. In a car crash, due to the conservation of energy, the kinetic energy of the car transforms into many different forms.[1] A safer car design would have a greater majority of the energy be converted into the deformation of its structure rather than going into its passengers.[2] Such structures that may deform in the case of a crash include the crumple zone and airbags.[3]

- I have referenced the conservation of energy.[1]
- I have used the relevant theory: energy transformation.[2]
- I have used the relevant theory: crumple zones and airbags.[3]

15. a. Use the conservation of momentum $\sum p_i = \sum p_f$

$m_{van}u_{van} + m_{car}u_{car} = (m_{van} + m_{car})v$

$2000 \times 120 + 650 \times 85 = (2000 + 650) \times v$ (1 MARK)

$v = \frac{2000 \times 120 + 650 \times 85}{2000 + 650} = 111$ km h^{-1} to the east (2 MARKS)

b. As $\Delta v_{car} > \Delta v_{van}$, the car has a greater magnitude change in velocity.[1] $\Delta v_{car} = 111 - 85 = 26$ km h^{-1}, and $\Delta v_{van} = 120 - 111 = 9$ km h^{-1}.[2] The car would be more dangerous[3] as a greater change in velocity means that the passengers of the car will experience a greater impact force where $m\Delta v = F\Delta t$.[4]

- I have explicitly addressed which vehicle would have a greater change in velocity.[1]
- I have justified my answer with calculations.[2]
- I have explicitly addressed which vehicle would be safer.[3]
- I have used the relevant theory: impulse.[4]

c. Two cars travelling in the same direction will have a far smaller difference in velocity before a collision.[1] Hence, the change in velocity and impact force on anyone involved in a collision would be less than that of head on collision.[2]

- I have referenced the difference in velocity between the two cars in each scenario.[1]
- I have used the relevant theory: impulse.[2]

16. The occupants in car *B* are more likely to be injured.[1] The severely damaged crumple zone of car *A* is likely to have absorbed more energy during the impact than the minor dents in car *B*.[2] As a result, the occupants in car *B* are likely to have absorbed more of the impact energy than those in car *A*, and are likely to have sustained greater injuries.[3]

- I have explicitly addressed which situation is more likely to result in injury.[1]
- I have used the relevant theory: energy absorption.[2]
- I have used the relevant theory: impact of energy absorption on injury.[3]

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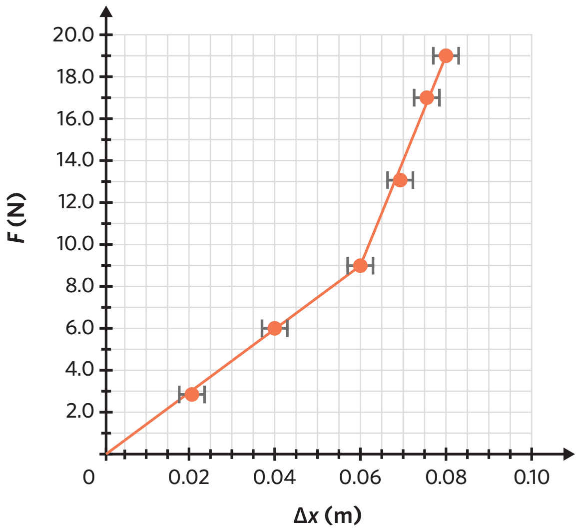
Key science skills

17. a.



- I have plotted mass on the horizontal axis and force on the vertical axis.
- I have included axis labels and appropriate units.
- I have included an appropriate and consistent scale on the axes.
- I have plotted each data point.
- I have included correctly sized uncertainty bars.
- I have included a line of best fit that passes through all uncertainty bars.

b. $PE_{A+B} = \frac{1}{2}bh + \frac{1}{2}(a+b)h = (0.5 \times 0.060 \times 9)$ $+ (0.5 \times (9 + 19) \times 0.02)$ (1 MARK)

$PE_{A+B} = 0.55$ J (1 MARK)

c. [The single spring (A) could provide suspension for small bumps[1]][while the combined spring system ($A + B$) could provide suspension for more severe bumps.[2]]

- I have explicitly addressed how the spring suspension can negotiate small bumps.[1]
- I have explicitly addressed how the spring suspension can negotiate more severe bumps.[2]

FROM LESSONS 11D & 11E

Previous lessons

18. $V = IR \Rightarrow 40 = I \times (12 + 50)$ (1 MARK)

$I = 0.65$ A (1 MARK)

FROM LESSON 6B

19. a. Consider rotational equilibrium: $\sum\tau_{anticlockwise} = \sum\tau_{clockwise}$

Consider the torques measured around point Y: $\tau_{bridge} + \tau_{car}$ $= \tau_{left\ building}$

$r_B \times F_{g\ bridge} + r_C \times F_{g\ car} = r_{left\ building} \times F_X$

$10 \times 5.0 \times 10^4 \times 9.8 + 6.5 \times 2.2 \times 10^3 \times 9.8 = 20 \times F_X$ (1 MARK)

$F_X = 2.52 \times 10^5 = 2.5 \times 10^5$ N (1 MARK)

b. Consider translational equilibrium: $\sum F = 0 \Rightarrow F_X + F_Y$ $= F_{g\ car} + F_{g\ bridge}$

$2.52 \times 10^5 + F_Y = 2.2 \times 10^3 \times 9.8 + 5.0 \times 10^4 \times 9.8$ (1 MARK)

$F_Y = 2.6 \times 10^5$ N (1 MARK)

OR

Consider rotational equilibrium: $\sum\tau_{clockwise} = \sum\tau_{anticlockwise}$

Consider the torques measured around point X: $\tau_{bridge} + \tau_{car}$ $= \tau_{right\ building}$

$r_B \times F_{g\ bridge} + r_C \times F_{g\ car} = r_{right\ building} \times F_Y$

$10 \times 5.0 \times 10^4 \times 9.8 + (20 - 6.5) \times 2.2 \times 10^3 \times 9.8$ $= 20 \times F_Y$ (1 MARK)

$F_Y = 2.6 \times 10^5$ N (1 MARK)

FROM LESSON 9F

Chapter 10 review

Section A

1. A. $m\Delta v = F\Delta t$

$56 \times 10^{-3} \times 50 = 140 \times \Delta t$

$\Delta t = 0.020$ s

2. B. $KE_i + GPE_i = KE_f + GPE_f$

$KE_i = GPE_f \Rightarrow \frac{1}{2}mu^2 = mgh_f$

$\frac{1}{2} \times 300 \times 10^{-3} \times 5.0^2 = 300 \times 10^{-3} \times 9.8 \times h_f$

$h_f = h = 1.3$ m

3. D. By the law of conservation of energy, the total initial and final energies must be equal. With reference to the ground, the ball only has kinetic energy at points A and B. Since no energy was lost due to friction, the speed will be the same as at both points.

4. B. Since $SPE = \frac{1}{2}k(\Delta x)^2$, it is proportional to the square of the extension. So if the extension increases by a factor of 4, the SPE increases by a factor of $4^2 = 16 \Rightarrow SPE = 16 \times 50 = 800$ J.

5. B. $s_{stop} = s_{react} + s_{break}$

$s_{react} = vt = 13.0 \times 1.50 = 19.5$ m

Given: $u = 13.0$ m s^{-1}, $v = 0$ m s^{-1}, $a = -5.00$ m s^{-2}, $s_{break} = ?$

$v^2 = u^2 + 2as \Rightarrow 0^2 = 13.0^2 + 2 \times (-5.00) \times s_{break}$

$s_{break} = 16.9$ m

$s_{stop} = 19.5 + 16.9 = 36.4$ m

$\Rightarrow$ will stop $40.0 - 36.4 = 3.6$ m before the ball

Section B

6. a. $F_{net} = F_{applied} - F_s = 0$

$F_s = k\Delta x \Rightarrow 70 = k \times 0.35$

$k = 2.0 \times 10^2$ N m^{-1}

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b. $KE_i + SPE_i = KE_f + SPE_f$

$KE_f = SPE_i = \frac{1}{2}k(\Delta x)^2 = \frac{1}{2} \times (2.0 \times 10^2) \times 0.35^2 = 12.25$ J
(1 MARK)

Work done by friction $= F_f s = \Delta KE = KE_f$

$3.10 \times s = 12.25$ (1 MARK)

$s = \frac{12.25}{3.10} = 3.95 = 4.0$ m (1 MARK)

7. a. [$\Delta KE = \frac{1}{2}m(v^2 - u^2) = \frac{1}{2} \times 0.450 \times (9^2 - 12^2) = -14.2$ J.[1]] [Bouncing the ball does not violate the law of conservation of energy.[2]] [Whilst the kinetic energy of the ball decreases as its velocity changes, the energy is not lost but dissipated into the ground.[3]]

I have calculated the change in kinetic energy of the ball.[1]

I have explicitly addressed whether energy is conserved.[2]

I have justified my answer by addressing the loss of energy to the ground.[3]

b. $v = \sqrt{-2g\Delta h + u^2} \Rightarrow 0.0 = \sqrt{-2 \times 9.8 \times \Delta h + 9.0^2}$
(1 MARK)

$h = 4.1$ m (1 MARK)

c. Define initial position as the point the ball hits the ground and final position as the maximum height of the ball.

$KE_i + SPE_i + GPE_i = KE_f + SPE_f + GPE_f$

$SPE_i = KE_f + GPE_f \Rightarrow \frac{1}{2}k(\Delta x)^2 = \frac{1}{2}mv^2 + mgh_f$ (1 MARK)

$\frac{1}{2} \times k \times (5.8 \times 10^{-2})^2 = \frac{1}{2} \times (450 \times 10^{-3}) \times 9.0^2$
$+ (450 \times 10^{-3}) \times 9.8 \times (5.8 \times 10^{-2})$ (1 MARK)

$k = 1.1 \times 10^4$ N m^{-1} (1 MARK)

8. a. At the equilibrium position, $F_{net} = F_s - F_g = 0$

$k\Delta x = mg \Rightarrow 300 \times \Delta x = 75.0 \times 9.8$

$\Delta x = 2.5$ m

b. Define initial position as the point he jumps from and final position as the lowest point of the fall.

$KE_i + SPE_i + GPE_i = KE_f + SPE_f + GPE_f$

$GPE_i = SPE_f \Rightarrow mgh_i = \frac{1}{2}k(\Delta x)^2$

$75.0 \times 9.8 \times 65.0 = \frac{1}{2} \times 300 \times (\Delta x)^2$ (1 MARK)

$\Delta x = 17.8$ m (1 MARK)

Therefore the natural length of the bungee cord is $65.0 - 17.8 = 47.2 = 47$ m. (1 MARK)

c. $v = \sqrt{-2g\Delta h + u^2} \Rightarrow v = \sqrt{-2 \times 9.8 \times (0 - 25) + 0^2}$
(1 MARK)

$v = 22$ m s^{-1} (1 MARK)

9. [A larger crumple zone is able to increase the duration of the front on collision.[1]] [As $I = F\Delta t$, increasing the duration of collision will decrease the average force applied.[2]] [The decrease in average force will reduce potential injuries as a result of collision.[3]]

I have explicitly addressed a larger crumple zone will increase the duration of collision.[1]

I have used the relevant theory: relationship between time and force applied.[2]

I have explicitly addressed a reduction in injury as a result of reduced force.[3]

10. [At the bottom of the jump, the only non-zero energy form is strain potential energy.[1]] [In the middle of the jump, both kinetic energy and gravitational potential energy are non-zero.[2]] [At the peak of the jump, the only non-zero energy form is gravitational potential energy.[3]] [The total mechanical energy is equal at all points in the flight.[4]]

I have explicitly addressed strain potential energy is non-zero at the bottom of the jump.[1]

I have explicitly addressed gravitational potential energy and kinetic energy are non-zero in the middle of the jump.[2]

I have explicitly addressed gravitational potential energy is non-zero at the peak of the jump.[3]

I have used the relevant theory: conservation of mechanical energy.[4]

Unit 2 AOS 1 review

Section A

1. B. Distance is the area under a speed-time graph.

distance $= \left(\frac{1.75 + 0.25}{2} \times 24\right) = 24$ m

FROM LESSON 8B

2. B. $I = F\Delta t = m\Delta v$

$F \times 1.5 = 280 \times 24 \Rightarrow F = 4480 = 4.5 \times 10^3$ N $= 4.5$ kN

FROM LESSON 9B

3. C. The net force perpendicular to the plane is given by $F_{net} = F_N - F_g\cos(\theta) = 0$, since the ball's acceleration perpendicular to the plane is 0. This means that $F_g = \frac{F_N}{\cos(\theta)}$, so $F_N < F_g$.

FROM LESSON 9D

4. A. Car A: $u = \frac{60}{3.6} = 16.67$ m s^{-1}, $s = 10$ m, $a = -12$ m s^{-2}, $v = ?$

$v^2 = u^2 + 2as$

$v^2 = (16.67)^2 + 2 \times (-12) \times 10$

$\Rightarrow v = 6.16 = 6.2$ m s^{-1}

Car B: $u = \frac{(60 - 10)}{3.6} = 13.89$ m s^{-1}, $s = 7.5$ m, $a = -12$ m s^{-2}, $v = ?$

$v^2 = u^2 + 2as$

$v^2 = (13.89)^2 + 2 \times (-12) \times 7.5$

$\Rightarrow v = 3.60 = 3.6$ m s^{-1}

FROM LESSON 10D

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5. B. Taking torques about the pivot point, both F_2 and F_3 produce anticlockwise torques whilst F_1 produces no torque. There is no force to provide a clockwise torque so the system cannot be in rotational equilibrium, and therefore, equilibrium.

FROM LESSON 9F

Section B

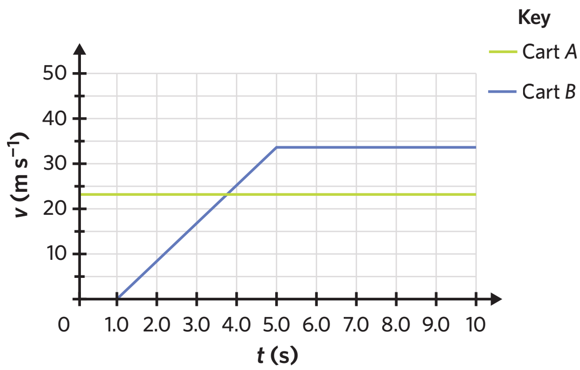
6. a. Given: $v = 39.0\ \text{m s}^{-1}$, $s = 150$ m, $t = 5.50$ s; Needed: u

$s = \frac{1}{2}(u + v)t \Rightarrow 150 = \frac{1}{2}(u + 39.0) \times 5.50$ (1 MARK)

$u = 15.546 = 15.5\ \text{m s}^{-1}$ (1 MARK)

FROM LESSON 8C

b.



First find the final velocity of cart B:

Given: $u = 0\ \text{m s}^{-1}$, $a = 8.5\ \text{m s}^{-2}$, $t = 4.0$ s; Needed: v

$v = u + at = 0 + 8.5 \times 4 = 34\ \text{m s}^{-1}$ (1 MARK)

Δs is the signed area under a velocity-time graph.

$s_A = 24t$, $s_B = \left(\frac{(t - 1.0) + (t - 5.0)}{2} \times 34\right) = 34t - 102$

(1 MARK)

At the end of the track, $s_A = s_B \Rightarrow 24t = 34t - 102$

$t = 10.2$ s (1 MARK)

$s_A = 24 \times 10.2 = 244.8$ m

The track would have to be 2.4×10^2 m long. (1 MARK)

OR

We will take t to be the amount of time passed since cart A started moving.

When $t = 5$ s:

$s_A = ut + \frac{1}{2}at^2 \Rightarrow s_A = 24 \times 5 + \frac{1}{2} \times 0 \times 5^2 = 120$ m;

$s_B = 0 \times (5 - 1) + \frac{1}{2} \times 8.5 \times (5 - 1)^2 = 68$ m (1 MARK)

$s_B < s_A$ so cart B catches up to cart A when $t > 5$ s:

$v_B = u + at \Rightarrow v_B = 0 + 8.5 \times (5 - 1) = 34\ \text{m s}^{-2}$

$s_A = 24 \times t$; $s_B = s_{B, t=5} + v_B(t - 5) = 68 + 34(t - 5)$

(1 MARK)

When cart B catches up to cart A:

$s_A = s_B \Rightarrow 24 \times t = 68 + 34(t - 5) \Rightarrow t = 10.2$ s (1 MARK)

at $t = 10.2$, s: $s_A = 24 \times t = 24 \times 10.2 = 244.8$ m

The track would have to be 2.4×10^2 m long. (1 MARK)

FROM LESSONS 8B & 8C

c. Take the reference height to be at the height Y above the ground.

$GPE_i + KE_i = KE_f$

$mg\Delta h_i + \frac{1}{2}mu^2 = \frac{1}{2}mv^2$

$9.8 \times (25.0 - 15) + \frac{1}{2} \times 15^2 = \frac{1}{2}v^2$ (1 MARK)

$v = 20.5 = 21\ \text{m s}^{-1}$ (1 MARK)

FROM LESSON 10B

7. a. In the horizontal direction:
$F_x = 30.0 + 15.0\cos(45.0°) - 22.5 = 18.11$ N to the right

In the vertical direction:
$F_y = 25.0 - 15.0\sin(45.0°) = 14.39$ N upwards (1 MARK)

Magnitude of $F_{net} = \sqrt{(18.11)^2 + (14.39)^2} = 23.13 = 23.1$ N
(1 MARK)

$\theta = \tan^{-1}\left(\frac{F_y}{F_x}\right) = \tan^{-1}\left(\frac{14.39}{18.11}\right) = 38.47 = 38.5°$ (1 MARK)

FROM LESSON 9C

b. $\tau_{net} = \tau_{anticlockwise} - \tau_{clockwise} = 0$

$0.90 \times 30 + 1.7 \times F - 0.75 \times 45 = 0$ (1 MARK)

$F = 3.97 = 4.0$ N (1 MARK)

FROM LESSON 9F

8. a. Perpendicular to the plane, $F_{net} = 0$

$F_{net} = F_N - mg\cos(35°) = 0$

$\Rightarrow F_N - 2.50 \times 9.8\cos(35°) = 0$ (1 MARK)

$F_N = 20.0 = 20$ N (1 MARK)

FROM LESSON 9D

b. Parallel to the plane, $F_{net} = ma = F_g\sin(35°) - F_f$

$2.50 \times 0.25 = 2.50 \times 9.8 \times \sin(35°) - F_f$ (1 MARK)

$F_f = 13.3 = 13$ N (1 MARK)

FROM LESSON 9D

c. $W = Fs \Rightarrow 16 = F_f \times s = 13.3 \times s$ (1 MARK)

$s = 1.19$ m (1 MARK)

$h = s \times \sin(35°) = 1.19 \times \sin(35°)$ (1 MARK)

$h = 0.683 = 0.68$ m (1 MARK)

FROM LESSON 10B

d. Given: $a = 0.25\ \text{m s}^{-2}$, $s = 1.19$ m, $u = 0\ \text{m s}^{-1}$; Needed: v

$v^2 = u^2 + 2as \Rightarrow v^2 = 2 \times 0.25 \times 1.19$ (1 MARK)

$v = 0.772 = 0.77\ \text{m s}^{-1}$ (1 MARK)

OR

$GPE_i + KE_i = GPE_f + KE_f - W_{fric}$

$GPE_i = KE_f - W_{fric} \Rightarrow mgh = \frac{1}{2}mv^2 - W_{fric}$

$0.250 \times 9.8 \times 0.683 = \frac{1}{2} \times 2.50 \times v^2 - 16$ (1 MARK)

$v = 0.772 = 0.77\ \text{m s}^{-1}$ (1 MARK)

FROM LESSONS 8C & 10B

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e. $p_i = p_A + p_B = 2.50 \times 0.77 + 1.80v = 1.925 + 1.80v$ (1 MARK)

$p_f = (m_A + m_B) \times 0.50 = 2.15$ kg m s^{-1} (1 MARK)

By conservation of momentum, $p_i = p_f$.

$1.925 + 1.80v = 2.15 \Rightarrow v = 0.125 = 0.13$ m s^{-1} (1 MARK)

FROM LESSON 9B

9. [The first stage in coming to a stop is the distance travelled while the driver reacts to the hazard, the reaction distance.[1]] [This is calculated using the constant acceleration formula $s = ut + \frac{1}{2}at^2$, with $s_{reaction} = ut_{reaction}$.[2]] [The second stage in coming to a stop is the distance travelled under braking.[3]] [This is calculated using the constant acceleration formula $s = ut + \frac{1}{2}at^2$, with $s_{braking} = \frac{1}{2}at^2$.[4]]

- I have referenced reaction distance.[1]
- I have used the relevant theory: $s_{reaction} = ut_{reaction}$.[2]
- I have referenced braking distance.[3]
- I have used the relevant theory: $s_{braking} = ut + \frac{1}{2}at^2$.[4]

FROM LESSON 8C & 10D

10. a. $k = gradient = \frac{800 - 0}{1.50 - 0} = 5.33 \times 10^2$ N m^{-1}

FROM LESSON 10C

b. Define the initial position to be at *Y* and the final position to be at *X*.

$GPE_i + KE_i + SPE_i = GPE_f + KE_f + SPE_f$

$SPE_i = GPE_f + KE_f + SPE_f$

$\Rightarrow \frac{1}{2}k(\Delta x_Y)^2 = mgh_f + \frac{1}{2}mv^2 + \frac{1}{2}k(\Delta x_X)^2$

$\frac{1}{2} \times 5.33 \times 10^2 \times 0.75^2 = 0.800 \times 9.8 \times 0.40$

$+ \frac{1}{2} \times 0.800 \times v^2 + \frac{1}{2} \times 5.33 \times 10^2 \times 0.35^2$ (1 MARK)

$v = 16.9 = 17$ m s^{-1} (1 MARK)

FROM LESSON 10C

c. $GPE_i + KE_i = GPE_f + KE_f - W_{by\ air}$

$\frac{1}{2}mu^2 = mgh_f - W_{by\ air}$

$\Rightarrow \frac{1}{2} \times 0.800 \times 17.0^2 = 0.800 \times 9.8 \times 12.5 - W_{by\ air}$ (1 MARK)

$W_{by\ air} = 17.6$ J (1 MARK)

$\frac{W_{by\ air}}{KE_i} = \frac{17.6}{\frac{1}{2} \times 0.800 \times 17.0^2} \times 100 = 15.2 = 15\%$ of its energy is lost to air resistance. (1 MARK)

OR

Given: $u = 17$ m s^{-2}, $a = -9.8$ m s^{-2}, $v = 0$ m s^{-1}; Needed: s

$v^2 = u^2 + 2as \Rightarrow 0^2 = 17^2 - 2 \times 9.8 \times s$ (1 MARK)

$s = 14.74$ m (1 MARK)

The rocket maintains $\frac{12.5}{14.74} = 0.85 = 85\%$ of its initial energy. Therefore it loses 15% of its energy to air resistance. (1 MARK)

FROM LESSONS 8C & 10C

11. a. Given: $u = 0$ m s^{-1}, $a = -9.8$ m s^{-2}, $v = -18.0$ m s^{-1}; Needed: s

$v^2 = u^2 + 2as \Rightarrow (-18.0)^2 = 0^2 - 2 \times 9.8 \times s$ (1 MARK)

$s = -16.5 = -17$ m

Height is 17 m. (1 MARK)

OR

$GPE_i + KE_i = GPE_f + KE_f$

$\frac{1}{2}mu^2 = mgh_f \Rightarrow \frac{1}{2}u^2 = gh_f \Rightarrow \frac{1}{2} \times 18.0^2 = 9.8 \times h_f$ (1 MARK)

$h_f = 16.5 = 17$ m (1 MARK)

FROM LESSONS 8C & 10B

b. [The change in displacement of the ball is zero,[1]] [and so by the conservation of energy, the magnitude of the ball's final velocity will be equal to the magnitude of the ball's initial velocity.[2]] [Therefore the final velocity of the ball will be 15.0 m s^{-1}, less than the 18.0 m s^{-1} she wanted.[3]]

- I have referenced the change in displacement of the ball.[1]
- I have used the relevant theory: conservation of energy.[2]
- I have related my answer to the context of the question.[3]

FROM LESSON 10A

c. Given: $a = 9.8$ m s^{-2}, $v = 18.0$ m s^{-1}, $s = 14.5$ m; Needed: t

Find the initial velocity using $v^2 = u^2 + 2as$

$18.0^2 = u^2 + 2 \times 9.8 \times 14.5$ (1 MARK)

$u = 6.31$ m s^{-1} (1 MARK)

$v = u + at \Rightarrow 18.0 = 6.31 + 9.8 \times t$ (1 MARK)

$t = 1.19 = 1.2$ s (1 MARK)

FROM LESSON 8C

11A Asking questions, identifying variables, and making predictions

Progress questions

1. A
2. II, III
3. B
4. A
5. II, III, IV
6. C
7. B

Exam-style

8. a. Secondary data

   b. Primary data

9. [A scientific law describes the relationship between entities for a particular phenomenon,[1]] [while scientific theory goes into detail about how or why this phenomenon occurs.[2]]

   I have explicitly addressed the definition of a scientific law.[1]

   I have used the relevant theory: the difference between a scientific theory and law.[2]

10. a. Scientific model

    b. Scientific law

    c. Scientific hypothesis

11. a. Volume setting (1 MARK)

    Qualitative (1 MARK)

    b. Maximum distance that phone can be heard (1 MARK)

    Quantitative (1 MARK)

    c. Frequency of the message alert tone **OR** sound sensitivity of the listener's ears **OR** humidity of the air

12. [If the height a ball is dropped from is directly related to the peak of its bounce,[1]] [then the peak of the ball's initial bounce after it is dropped will increase[2]] [when the height it is dropped from increases.[3]]

    I have referenced a predicted physics principle for this experiment.[1]

    I have referenced the predicted change to the dependent variable: the peak of the ball's initial bounce.[2]

    I have referenced the change to the independent variable: the height the ball is dropped from.[3]

11B Scientific conventions

Progress questions

1. I, III, IV, VIII
2. C
3. A
4. A
5. B
6. A
7. B

Exam-style

8. a. 6.0×10^3

   b. 8.9×10^6

   c. 6.4×10^4

9. a. $600 \text{ ms} = 600 \times 10^{-3} \text{ s} = 6.00 \times 10^{-1} \text{ s}$

   b. $0.400 \text{ µg} = 0.400 \times 10^{-6} \text{ kg} = 4.00 \times 10^{-7} \text{ kg}$

   c. $23 \text{ M}\Omega = 23 \times 10^6 \ \Omega = 2.3 \times 10^7 \ \Omega$

   d. $360 \text{ nm} = 360 \times 10^{-9} \text{ m} = 3.60 \times 10^{-7} \text{ m}$

   e. $7.0 \text{ pA} = 7.0 \times 10^{-12} \text{ A}$

10. [Yusif is correct and Nina is incorrect.[1]] [For addition or subtraction, the final answer should use the least amount of decimal places in the data set, whereas for multiplication or division, the final answer uses the least amount of significant figures in the data set.[2]]

    I have explicitly addressed whether Yusif or Nina is correct.[1]

    I have used the relevant theory: conventions for calculations.[2]

11. a. two

    b. $\frac{7.4}{200} = 0.037 = 3.7 \times 10^{-2}$

12. $E = VQ = 6.00 \times 4.00$ (1 MARK)

    $E = 24.00 = 24.0 \text{ J}$ (3 significant figures) (1 MARK)

13. For this question we will need to convert our distance measurement to SI units.

    $0.135 \text{ km} = 0.135 \times 10^3 = 135 \text{ m}$

    $\textit{total distance} = d_h + d_f = 135 + 63.0 = 198 \text{ m}$ (3 significant figures since the least amount of decimal places is zero) (1 MARK)

    $\textit{speed} = \frac{\textit{total distance}}{\textit{time}} = \frac{198}{67.0}$ (1 MARK)

    $\textit{speed} = 2.955 = 2.96 \text{ m s}^{-1}$ (3 significant figures) (1 MARK)

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11C Collecting data

Progress questions

1. A **2.** A **3.** B **4.** C

5. D **6.** D **7.** A **8.** A

Exam-style

9. B

10. D

11. A

12. a. Gen: $\frac{4.0 + 4.5 + 3.6 + 4.3}{4} = 4.1$ V (1 MARK)

Jana: $\frac{3.8 + 4.1 + 4.2 + 3.9}{4} = 4.0$ V (1 MARK)

b. Gen: $4.5 - 3.6 = 0.9$ V (1 MARK)

Jana: $4.2 - 3.8 = 0.4$ V (1 MARK)

c. [Gen's data is more accurate than Jana's data[1]][as Gen's average of 4.1 V is closer to the true voltage of 4.2 V than Jana's average of 4.0 V.[2]]

- I have explicitly addressed which person's data is more accurate.[1]
- I have used the relevant theory: accuracy.[2]

d. [Jana's data is more precise than Gen's data[1]][as the range of Jana's results (0.4 V) is smaller than the range of Gen's results (0.9 V).[2]]

- I have explicitly addressed which person's data is more precise.[1]
- I have used the relevant theory: precision.[2]

13. III, V, VI, VII, IX

14. [Accuracy refers to how well a measurement agrees with the 'true' value of a measurement.[1]][If a measuring device is not properly calibrated, this will introduce a systematic error that will shift measurements uniformly away from their 'true' value.[2]][Therefore, proper calibration can increase accuracy of data.[3]]

- I have used the relevant theory: accuracy.[1]
- I have used the relevant theory: systematic error.[2]
- I have related my answer to the context of the question.[3]

11D Representing and analysing data

Progress questions

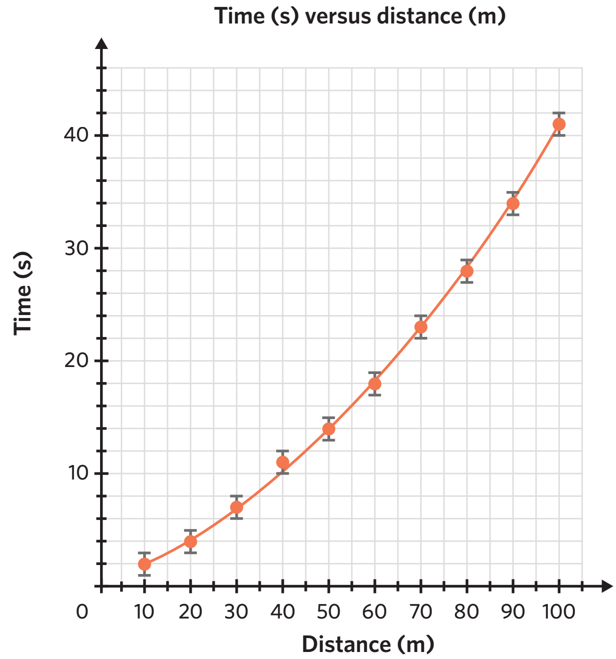
1. A **2.** B **3.** C **4.** B

5. B

Exam-style

6. To linearise the data, Nat should take the square root of the independent variable.

7.



- I have labelled the horizontal axis with the independent variable and included correct units.
- I have labelled the vertical axis with the dependent variable and included correct units.
- I have included an appropriate and consistent scale on both horizontal and vertical axes.
- I have plotted each point of data: (10, 2), (20, 4), (30, 7), (40, 11), (50, 14), (60, 18), (70, 23), (80, 28), (90, 34), (100, 41).
- I have drawn correctly sized uncertainty bars: (vertical: ±1 s).
- I have drawn a non-linear line of best fit which passes through all uncertainty bars.

8. [The line of best fit drawn does not go through all uncertainty bars.[1]][A non-linear line of best fit would ensure that all points are treated equally.[2]][The axes have also not been labelled.[3]][The horizontal axis should be labelled with the independent variable and its respective units. The vertical axis should be labelled with the dependent variable and its respective units.[4]]

- I have used the relevant theory: linear and non-linear lines of best fit.[1]
- I have explicitly addressed how to improve the trendline of the graph.[2]
- I have used the relevant theory: plotting data.[3]
- I have explicitly addressed how to improve the communication of the data.[4]

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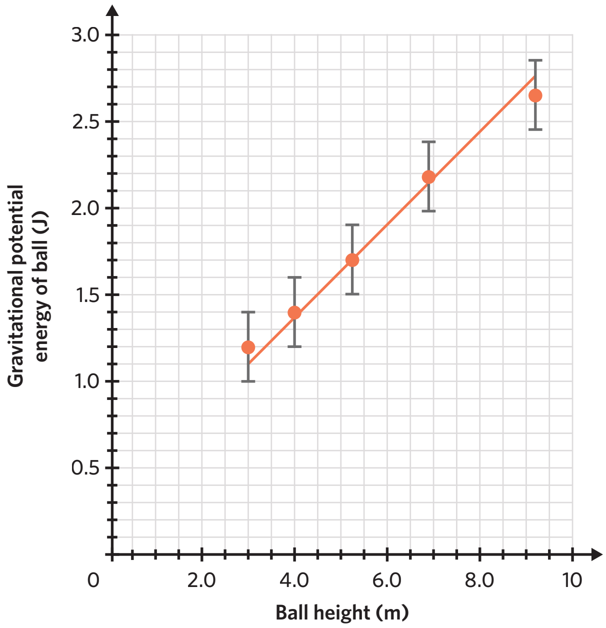
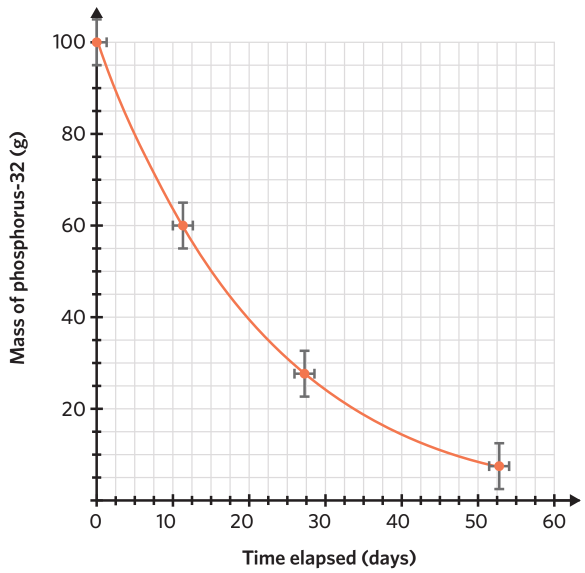
9. [The graph can have a line of best fit.[1]] [A linear line of best fit is valid if a straight line can be drawn through the uncertainty bars of all points.[2]] [Therefore, vertical uncertainty bars of equal size must be drawn on each data point, and then a smooth line must be drawn through all of the uncertainty bars.[3]]

- I have explicitly addressed that the graph can have a line of best fit.[1]
- I have used the relevant theory: lines of best fit.[2]
- I have used the relevant theory: uncertainty bars.[3]



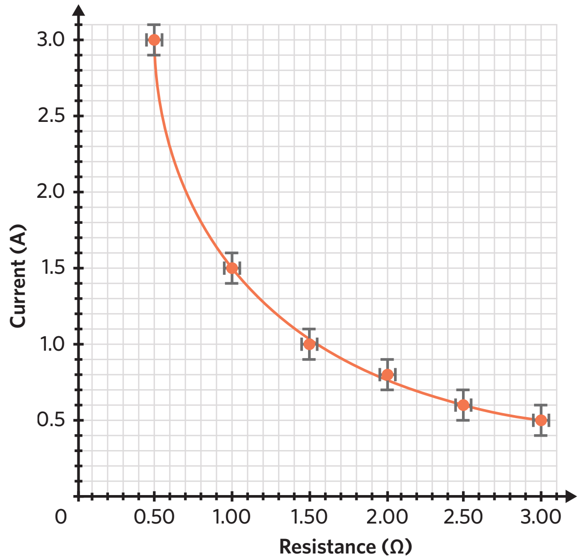
Students are not required to draw the graph, but may do so if it helps visualise the solution.

10. Mass of phosphorus-32 vs time elapsed



- I have labelled the horizontal axis with the independent variable and included correct units.
- I have labelled the vertical axis with the dependent variable and included correct units.
- I have included an appropriate and consistent scale on both axes.
- I have plotted each point of data: (0, 100), (11, 60), (27, 28), (52, 8).
- I have drawn correctly sized uncertainty bars: (horizontal: ±1 day, vertical: ±5 g).
- I have drawn a non-linear line of best fit which passes through all uncertainty bars.

11. a. Current versus resistance



- I have labelled the horizontal axis with the independent variable and included correct units.
- I have labelled the vertical axis with the dependent variable and included correct units.
- I have included an appropriate and consistent scale on both axes.
- I have plotted each point of data: (0.50, 3.0), (1.00, 1.5), (1.50, 1.0), (2.00, 0.8), (2.50, 0.6), and (3.00, 0.5).
- I have drawn correctly sized uncertainty bars: (horizontal: ±0.05 Ω, vertical: ±0.1 A).
- I have drawn a non-linear line of best fit which passes through all uncertainty bars.

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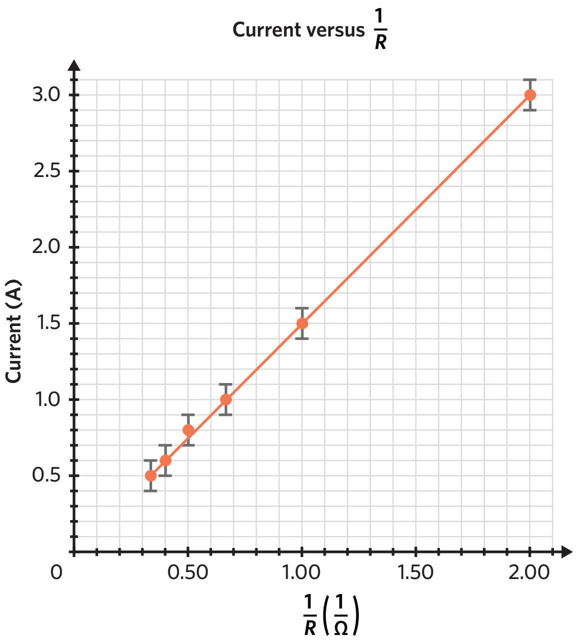
b.



- I have labelled the horizontal axis with the transformed independent variable and included correct units.
- I have labelled the vertical axis with the dependent variable and included correct units.
- I have included an appropriate and consistent scale on both axes.
- I have calculated and plotted each point of data: (2.00, 3.0), (1.00, 1.5), (0.67, 1.0), (0.50, 0.8), (0.40, 0.6), (0.33, 0.5).
- I have drawn correctly sized uncertainty bars: (vertical: ±0.1 A).
- I have drawn a line of best fit which passes through all uncertainty bars.

c. Maneesha is correct that $I \propto \frac{1}{R}$, since a straight line fits the linearised data.

11E Gradients

Progress questions

1. A **2.** D **3.** A **4.** A

5. A

Exam-style

6. $gradient = \frac{y_2 - y_1}{x_2 - x_1} = \frac{2.1 - 8.3}{4.6 - 0.50}$ (1 MARK)

$gradient = -1.51 = -1.5$ (1 MARK)

7. $gradient = \frac{y_2 - y_1}{x_2 - x_1} = \frac{7.6}{2.9}$ (1 MARK)

$gradient = 2.62 = 2.6$ (1 MARK)

8. Use any two points from the line of best fit that are far apart to calculate the gradient.

$gradient = \frac{y_2 - y_1}{x_2 - x_1} = \frac{0.20 - 0.05}{4.0 - 1.0}$ (1 MARK)

$gradient = 0.050\ \text{A V}^{-1}$ (1 MARK)

$gradient = \frac{rise}{run} = \frac{I}{V}$

The original equation is $I = \frac{V}{R} \Rightarrow \frac{I}{V} = \frac{1}{R} \Rightarrow gradient = \frac{1}{R}$ (1 MARK)

$\frac{1}{R} = 0.050 \Rightarrow R = 20.0 = 20\ \Omega$ or V A^{-1} (1 MARK)

9. Use any two points from the line of best fit that are relatively far apart to calculate the gradient.

$gradient = \frac{y_2 - y_1}{x_2 - x_1} = \frac{1.35 - 0.45}{0.70 - 0.22}$ (1 MARK)

$gradient = 1.88\ \text{s m}^{-1/2}$ (1 MARK)

$gradient = \frac{rise}{run} = \frac{T}{\sqrt{L}}$

The original equation is $T = 2\pi\sqrt{\frac{L}{g}} \Rightarrow \frac{T}{\sqrt{L}} = \frac{2\pi}{\sqrt{g}}$

$\Rightarrow gradient = \frac{2\pi}{\sqrt{g}}$ (1 MARK)

$1.88 = \frac{2\pi}{\sqrt{g}} \Rightarrow g = 11.1 = 11\ \text{m s}^{-2}$ (1 MARK)

Depending on the accuracy of the points chosen, answers between $9.0\ \text{m s}^{-2}$ and $14\ \text{m s}^{-2}$ are acceptable.

10. [The student is incorrect.[1]][The value of the gradient is the ratio of the change in the force to the change mass of an object.[2]] [The force increases by a value of g for every unit increase in the mass of an object, but the value of acceleration due to gravity does not change.[3]]

- I have explicitly addressed that the student is incorrect.[1]
- I have used the relevant theory: definition of a gradient.[2]
- I have related my answer to the context of the question.[3]

11. a. Use any two points from the line of best fit that are far apart to calculate the gradient.

$gradient = \frac{y_2 - y_1}{x_2 - x_1} = \frac{9.0 - 3.0}{3.0 - 1.0}$ (1 MARK)

$gradient = 3.00 = 3.0\ \text{m s}^{-2}$ (1 MARK)

b. $gradient = \frac{rise}{run} = \frac{v^2}{d}$

The original equation is $v^2 = 2ad \Rightarrow \frac{v^2}{d} = 2a$

$\Rightarrow gradient = 2a$ (1 MARK)

$2a = 3.0 \Rightarrow a = 1.50 = 1.5\ \text{m s}^{-2}$ (1 MARK)

Chapter 11 review

Section A

1. C. Option A defines a hypothesis. Unlike what is suggested in option B, models have other uses, such as making predictions. Option D defines a scientific theory.

2. B. Resolution is the smallest change in the quantity that may be measured. The ammeter has increments every 1 mA.

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3. B. Convert 1.2×10^9 to 0.12×10^{10} so that both terms are multiplied by the same power of 10.

$5.124 \times 10^{10} - 0.12 \times 10^{10} = 5.004 \times 10^{10} = 5.00 \times 10^{10}$

As the term with the fewest decimal places only has two decimal places, so should the final answer.

4. D. Point S represents an outlier that is known to have been introduced by personal error and can be discarded.

5. A. $gradient = \frac{change\ in\ vertical\ axis}{change\ in\ horizontal\ axis} = \frac{(\Delta v)^2}{\Delta h}$

$gh = \frac{1}{2}v^2 \Rightarrow 2g = \frac{v^2}{h} = gradient$

Section B

6. a. [This statement is an example of a hypothesis.[1]][It makes a prediction about the relationship between smoking and beard growth that can be tested.[2]]

- I have explicitly addressed whether the statement is a scientific model, theory, or hypothesis.[1]
- I have used the relevant theory: the definition of a hypothesis.[2]

b. [This study cannot be considered valid.[1]][As the scientists were provided financial incentive to produce certain results,[2]] [this very likely introduced observer bias into the method (or resulted in poor experimental design or analysis), invalidating the experiment.[3]]

- I have explicitly addressed the validity of the study.[1]
- I have explicitly addressed the financial incentives given to the scientists.[2]
- I have used the relevant theory: validity of experimental design.[3]

7. a. Quantitative data **OR** primary data

b. Systematic error

c. Use any two points from the line of best fit that are far apart to calculate the gradient.

$gradient = \frac{y_2 - y_1}{x_2 - x_1} = \frac{120 - 46}{13 - 5.0}$ (1 MARK)

$gradient = 9.25 = 9.3\ \text{N kg}^{-1}$ or m s^{-2} (1 MARK)

Answers between $9.0\ \text{N kg}^{-1}$ and $9.4\ \text{N kg}^{-1}$ are acceptable.

d. [Enya's experiment is not very reproducible.[1]][This is because when the experiment was repeated by different experimenters in different lab conditions, with the same method and materials, the results were not consistent.[2]]

- I have explicitly addressed the reproducibility of Enya's experiment.[1]
- I have used the relevant theory: reproducibility.[2]

8. a. Independent: mass of metal sample (1 MARK)

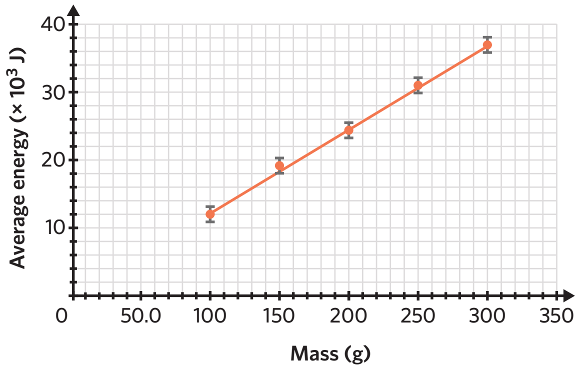
Dependent: energy used by bunsen burner (1 MARK)

Control: bunsen burner/rate sample is heated **OR** temperature sample is heated to **OR** temperature sample is heated from **OR** number of times sample is heated (1 MARK)

b. [This experiment may be considered repeatable as each set of measurements is consistently precise.[1]][However, repeatability could be improved by using different identical metal samples for each trial, instead of reheating the same sample, as heating a sample may alter the physical properties of the material.[2]]

- I have explicitly addressed the repeatability of the experiment.[1]
- I have used the relevant theory: repeatability.[2]

c.



- I have correctly labelled the horizontal axis and included correct units.
- I have correctly labelled the vertical axis and included correct units.
- I have included an appropriate and consistent scale on the horizontal axis.
- I have included an appropriate and consistent scale on the vertical axis.
- I have plotted each point of data: (100, 12.0), (150, 18.7), (200, 24.3), (250, 31.0), (300, 37.0)
- I have drawn correctly sized uncertainty bars: (vertical: $\pm 1 \times 10^3$ J).
- I have drawn a line of best fit which passes through all uncertainty bars.

d. [Accuracy measures how close the average of a set of data is to the predicted value and precision measures how consistently the experimental data was recorded.[1]][The data for the 150 g sample is more accurate as the average is closer to the true value.[2]] [The data for the 150 g sample is also more precise as the range of data taken is smaller.[3]]

- I have used the relevant theory: precision and accuracy.[1]
- I have explicitly addressed the difference in accuracy of the two data sets.[2]
- I have explicitly addressed the difference in precision of the two data sets.[3]

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Concept discussion answers

1A Introduction to waves

- To produce a transverse wave the slinky must be shaken perpendicular to the direction it is facing.
- To produce a longitudinal wave the slinky must be shaken along the same direction the slinky is facing.

1B Wave fundamentals

- Wave speed is the speed a wave propagates through the medium. The material properties of the medium through which a wave travels determines its speed.
- Frequency is the number of times a wave cycle passes a point per second. It is determined by the speed a wave source oscillates at.
- From the wave equation it is known that wavelength is directly proportional to the wave speed and inversely proportional to the frequency. Increasing wave speed leads to an equivalent increase in wavelength while increasing frequency leads to an equivalent decrease in wavelength.

1C Everyday electromagnetism

- Information-carrying signals need to pass (be transmitted) through solid objects and travel long distances. They must also not interfere with other signals.
- Visible light cannot travel through obstacles such as buildings. It would be impractical to have visible light beams shining all around for the sake of communication technology in addition to the light that is used for sight. The visible region of the spectrum is very small, which means there is a limited range of frequencies (bandwidth) to be able to carry different signals.
- Gamma waves have incredibly high energy. This makes them difficult to produce and dangerous to people. They are also unable to travel very far through objects. This makes them unsuitable for communications technology.

1D Refraction and reflection

- Since light from the fish has to pass from water into air to reach Sunny's eyes, it will refract. This means that the path it travels will not be a straight line. However, human eyes construct images based on the assumption that the light that reaches them has come directly from the source, i.e. has travelled in a straight line. This means that where Sunny "sees" the fish is not where the fish is actually located.

1E White light and optical phenomena

- As light shines through the rain, it is reflected multiple times through the raindrop to make the rainbow. At each reflection, some of the light is reflected and some is transmitted through the raindrop and escapes. Light that escapes will be bent towards the ground due to the refractive index of the water. The overall effect of light being redirected means the sky above the rainbow, or between the primary and secondary rainbow, appears to be darker.

2A Temperature fundamentals

- The milk diffuses because of collisions between the milk particles and the water molecules, as they are all in random motion, which randomly spreads the milk particles throughout the tea.
- When the tea is very hot, the water molecules move quickly and collide more often with the milk particles, causing them to spread faster compared to when the tea is cold.

2B How thermal energy moves

- The heat travels via electromagnetic radiation from the Sun to the Earth, where it is absorbed by a particle in a leaf. The hotter leaf transfers this energy to air particles through conduction, which then rise due to the air's increased temperature (and lower density), transferring the energy via convection.
- Energy is carried by the electromagnetic radiation from the Sun, and is absorbed by air particles in Earth's atmosphere. These air particles rise due to the air now having a lower density from being at a higher temperature. The air then passes on the energy through conduction when its particles collide with another substance's particles.

2C How heat affects temperature

- A burn occurs when a large quantity of heat is transferred in a short period of time.
- Steam has a lot more internal energy stored as potential energy than water at 100°C.
- This means that the steam will transfer this large quantity of energy (the latent heat) to the skin that it touches as it condenses, causing severe burns. It does not decrease in temperature while it condenses so it will continue to transfer heat rapidly during this process.
- Water will cool down while it transfers heat, and so the rate of heat transfer will decrease.

3A Thermal radiation

- The dog is warmer than the temperature of the surrounding environment.
- A warmer object will emit a greater intensity of radiation at each wavelength than a cooler object, so will emit a greater intensity of infrared radiation.
- The cooler areas of the dog, likely its bones, will not be as bright as warmer areas of the dog, where the most blood flows.

3B Global warming and climate change

- The Earth's climate system is massive and requires a great amount of energy to increase in temperature by even 0.1°C.
- The rate by which Earth will heat up depends on the magnitude of the energy imbalance. The greater the temperature of the Sun the greater the energy imbalance and faster the Earth will heat up.
- Other factors within our climate system such as greenhouse gases and albedo determine the amount of energy emitted. As the atmosphere heats up these factors will change and therefore affect the time it would take to heat up the Earth.

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4A Nuclear stability and the fundamental forces

- The strong force holds the nucleus together and it holds quarks together to form nucleons. If the strong force did not exist, protons, neutrons, and atoms as a whole could not exist. This would mean that the universe would be composed similarly to how it was less than 10 microseconds after the Big Bang – a soup of quarks!
- The weak force is responsible for beta decay, which means that if it did not exist, isotopes which undergo beta decay would no longer be able to do so. The weak force is also required in the fusion reactions that power the Sun, which would mean the Sun could not exist in a universe without the weak force and so life could not exist on Earth either.

4B Nuclear half-life

- 500 mL of water must flow out of the bottle for the volume to decrease by half (so that 500 mL remains). This will take 5 seconds.
- An additional 250 mL must flow out of the bottle for the volume to decrease to half of 500 mL. This will take an additional 2.5 seconds.
- The amount of time it takes for the volume to halve decreases as volume decreases (because the flow rate is constant), which means that the concept of a half-life does not apply. This differs from radioactive decay where the decay rate depends on the amount of substance remaining so that the time taken for half the substance to decay is always constant.

4C Types of nuclear radiation

- Blue represents nuclides that undergo beta minus decay. This is because they are to the left of the valley of stability (it has fewer protons compared to the nuclides on the valley of stability with the same mass number).
- Orange represents nuclides that undergo beta plus decay. This is because they are to the right of the valley of stability (it has more protons compared to the nuclides on the valley of stability with the same mass number).
- Yellow represents nuclides that undergo alpha decay. These elements are so heavy that they are inherently unstable, so the emission of an alpha particle increases stability. They also contain too many protons (they are to the right of the valley of stability).

4D Radiation and the human body

- Alpha radiation is more likely to kill a cell compared to beta radiation, due to its greater ionising ability.
- Alpha radiation has a lower affected area compared to beta radiation, as it has a lower penetrating ability.
- Alpha radiation is preferred for treatment of cancer, as it is more likely to kill the damaged cells and less likely to affect healthy cells.

5A Nuclear energy

- Stars will burn the most efficient fuel available, which is the fuel that releases the most energy per nucleon. The gradient of the binding energy curve decreases as the nuclei get bigger and so there is less energy released in a fusion reaction. Hence the most efficient fuel will generally be the smallest element which is abundant in the star, so the star will fuse increasingly large nuclei in order of size as they age.
- Once the star reaches elements around iron and nickel, it has produced the most tightly bound nuclei possible with the greatest binding energy per nucleon. There is no possible reaction that could release enough energy to sustain the star and so at this point they will die.
- In order to produce nuclei heavier than nickel through fusion, a net energy input is required. The conditions necessary to supply a sufficient amount of energy are only possible through cataclysmic events such as supernovae.

5B Fission

- If the density of a fissile mass is increased, the fissile nuclei will all be closer together. This means the gaps between fissile nuclei would be smaller.
- If the gaps between fissile nuclei are smaller, it is less likely that neutrons will pass through these gaps rather than being captured by fissile nuclei. This means that the neutron multiplication factor will increase, so increasing the density of a fissile mass increases its neutron multiplication factor.

6A Fundamentals of electricity

- Milliamp (mA) is a measure of current, equal to one thousandth of an ampere (A). Hours (h) is a measure of time. Therefore, mA h is the unit representing current multiplied by time. From $I = \frac{Q}{t}$, we can rearrange this to $Q = It$ and see that mA h is a measure of charge, Q.
- Current is a measure of how much charge is moving through a location over time. Therefore, a higher current will mean that more charge is delivered by the battery in a given period of time. Since a mA h rating measures charge, the battery connected to the circuit drawing more current (Circuit X) will run out faster than the battery connected to the lower current circuit (Circuit Y).

6B Resistance and Ohm's Law

- From Ohm's law, if $R = 0\ \Omega$ then $V = I \times 0 = 0$ V. Using the equation for electrical power, if $V = 0$ V then $P = I \times 0 = 0$ W. So the voltage drop and power used by superconducting components will both be zero.
- If loads were made using only superconducting components, they would not use any power and so would not operate properly, as they receive no energy to operate with. If wires were superconducting components, then the reduced amount of power dissipated across them would make the circuit more efficient.

6C Series circuits

- The equivalent resistance of two series components, when one component has a much greater resistance than the other, is approximately equal to that of the larger resistance component. For example, with $R_1 = 10\ \Omega$ and $R_2 = 1.0 \times 10^3\ \Omega$, $R_{eq} = 10 + 1.0 \times 10^3 = 1.01 \times 10^3 \approx R_2$.
- For an accurate current measurement, we need the equivalent resistance of the component being measured and the ammeter to be as close as possible to the resistance of the component being measured. This means that the ammeter must have much smaller resistance than the component being measured.

6D Parallel circuits

- The ideal circuit layout would be in parallel, not series, for maximum energy efficiency for all household appliances.
- A parallel circuit allows for equal voltage to be distributed across all components, which would allow for Jack's TV, refrigerator and other appliances to receive the same total voltage.

- However, the series arrangement means that appliances closer to the power source, in this case the refrigerator and microwave, preferentially receive voltage before the TV. These appliances cause an excessive voltage drop before the current can flow through the TV.

6E Combination circuits

- In order to maximise the power available to light bulb A, the power lost due to the other components in the two branches must be lowered.
- As $P = IV$, to lower the total power loss of the two branches, their equivalent voltage drops must be lowered. This is best achieved by eliminating the current through the branch of higher resistance.
- As the middle branch contains a parallel set of resistors, its equivalent resistance is less than that of the rightward branch. For minimum voltage drop, an open switch should be placed anywhere along the rightward branch so all the current flows through the branch of minimum resistance.

7A Applications of electric circuits

- Light-dependent resistors increase or decrease their resistance depending on the light intensity of the environment they're in. This means they would be useful in automating functions such as headlights of a car.
- As the light intensity increases, the resistance of an LDR decreases. If a bulb is placed in series with an LDR, the voltage across the bulb will increase as the resistance of the LDR decreases. Therefore, the bulb must be placed in parallel with the LDR, so that the voltage across, and therefore power supplied to, the bulb decreases as the light intensity increases from outside.
- Other functions in a car may include (but are not limited to): windshield wipers, indicators, air-conditioning, heated seating, radio/speakers, and the main computer screen.
- LDRs could be used to automate the brightness of the main computer screen, thermistors could be used to automate the airconditioning and the heated seats, potentiometers could be used to turn the volume up and down on the radio, as well as change the temperature of the air conditioner.

7B Household electricity

- A hand saw cuts through wood by moving relative to the wood.
- It gets this kinetic energy from the hand of the person holding the saw.
- Saw teeth do not need to move from the hand to the wood. The cutting can be done by only a few saw teeth, but the back and forth motion of the hand causes all the teeth to move which provides the energy to cut through the wood.
- Energy can be transformed into thermal energy (or many other forms) by charges moving through the circuit. In the case of thermal energy, the charges collide with each other and the atoms in the conductor to increase the average kinetic energy of the particles, which in turn increases their temperatures.
- Similar to a saw moving back and forth through wood, charges move back and forth across an appliance, transferring energy. As the charges move from a high voltage position before an appliance to a low voltage position after the appliance, the energy difference is transferred to the appliance.

7C Electrical safety

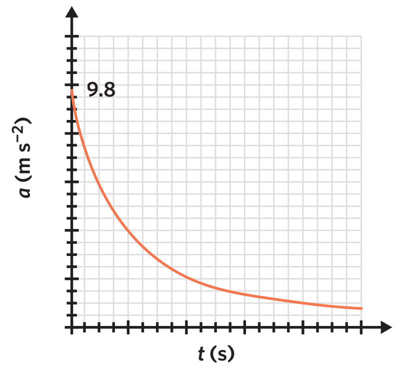
- As long as another safety device does not cause a break in the circuit, the appliance will operate normally because the current can flow from the active wire through the appliance to the earth, which is where a neutral wire ultimately leads to as well.
- However, if an RCD is connected then it will detect a difference between the currents in the active and neutral wires and it will shut down the power on the active wire.
- This configuration poses some dangers. Firstly, the exterior of the appliance would connect to ground via the neutral wire which is a less direct/higher resistance path than the earth wire, which means it would not provide as effective protection. Secondly, since an RCD would switch off the circuit whenever it is used, a user might assume the RCD is faulty and remove it which means there is greater risk of electric shock if something else goes wrong.

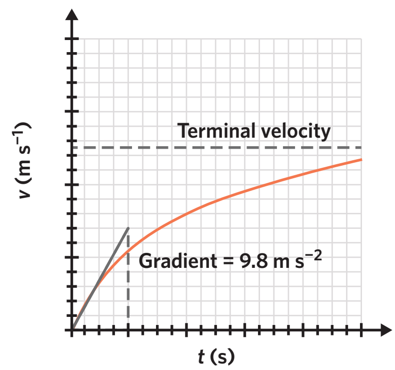
8A Describing motion

- The car travels the distance in a shorter time, hence has a greater average speed than the truck driver.
- The car reaches the next set of traffic lights first since it has a greater acceleration than the truck, and is 'faster'. This means the car reaches the maximum speed before the truck.

8B Graphing motion

- Initially, the magnitude of acceleration would be at, or near, 9.8 m s^{-2}.The longer the basketball has fallen for, the greater the effects of air resistance will be and therefore the more the magnitude of acceleration will decrease.
- This will mean that the change in velocity from one second to the next will get progressively smaller over time as the ball approaches terminal velocity.
- At some point, the change in velocity will reach 0, at which point the velocity will be constant and we would say that the basketball has reached terminal velocity.
- We would expect the acceleration-time graph to therefore look something like this:





CONCEPT DISCUSSION

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8C The constant acceleration equations

- As the word falls (accelerates towards the ground), the letters will stretch vertically. The velocities of water drops at the bottom of the word will be greater than that of those towards the top, since they have been accelerating for a longer period of time.
- This means that for every second that passes, the lower drops will fall a greater distance, which in turn causes the word to stretch.
- Specifically, the bottom portions of each letter will stretch out more than the upper portions. This is because the relationship between displacement and time is quadratic, as is shown in the constant acceleration equation $s = ut + \frac{1}{2}at^2$ (initial velocity and acceleration are constant and equal for all of the water drops).

9A Forces

- When a car is accelerating, there must be a net force acting on the car in the direction it is accelerating. Therefore, the forward force on the car by the road must be greater in magnitude than any resistive forces pushing the car backwards (such as air resistance or friction).
- When a car is not accelerating, the net force on the car is zero. This is true even if the car is in motion, which is a conclusion of Newton's first law. This means that the forward force on the car by the road must be equal in magnitude to any resistive forces.
- According to Newton's third law, if there is a force directed forwards on the car by the road, there must be a friction force directed backwards on the road by the car. The magnitude of the friction force on the road by the car will be the same as the magnitude of the forward force on the car by the road.

9B Momentum and impulse

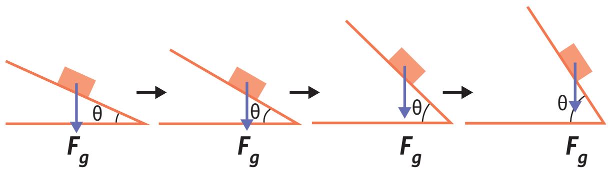
- In both cases, with and without an airbag, the head will experience the same impulse.
- Without an airbag, the head will decelerate and change momentum very quickly as it hits the steering wheel.
  - By the equation $I = F\Delta t$, there will be a very large force on the passengers head making the crash extremely dangerous.
- When using an airbag, the time that the head takes to decelerate will be greatly increased.
  - By the equation $I = F\Delta t$, there will be a greatly reduced force on the passengers head making the crash far safer.

9C Force vectors in two dimensions

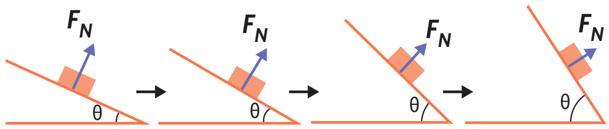
- Whilst the strings in the first situation only have a vertical component of force, the strings at 45° have both vertical and horizontal components.
- As the 100 N force acts vertically downwards, only the vertical components of the force from both situations will act to balance it.
- The horizontal component of the forces through the 45° strings only act to cancel each other out such that the mass does not accelerate from side to side. Therefore the 45° strings have an additional horizontal force component that the vertical strings do not have, meaning that they must provide a larger total force.
- Hence the 45° strings are more likely to break.

9D Inclined planes and connected bodies

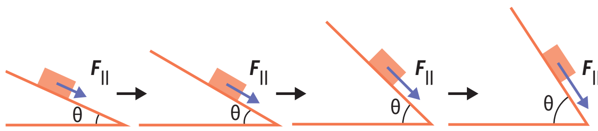
a. The magnitude of the force due to gravity remains constant as the angle is increased. The direction of the force due to gravity remains constant as the angle is increased.



b. The magnitude of the normal force decreases as the angle is increased as the value of cos(θ) decreases. The direction of the normal relative to the horizontal does change as the angle increases, because the normal force always acts perpendicular to the slope.



c. The magnitude of the force down the slope increases as the angle is increased as the value of sin(θ) increases. The direction of the force down the slope relative to the horizontal does change as the angle increases, because the force down the slope always acts parallel and down the slope.



CONCEPT DISCUSSION

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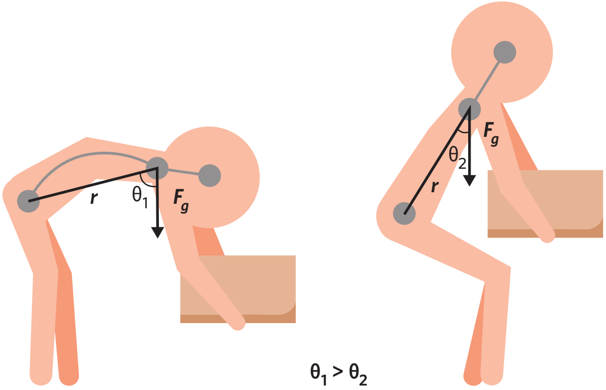
9E Torque

- When lifting something heavy, the force due to gravity will act vertically downwards at the shoulders and cause a torque at the pivot point, the lower back. The distance between the point of rotation and where the force is applied is the same in both scenarios, however the angle of application of the force to our back is smaller when lifting with the knees. This means that the component of the force acting perpendicular to the back will be smaller.



- Knowing that $\tau = rF\sin(\theta)$, the magnitude of the torque will decrease as the value of θ decreases. Hence a decrease in the angle when bending the knees results in a smaller torque acting at the lower back despite the force and distance from the pivot point remaining the same. This results in lifting with the knees being safer than when lifting with the back.

9F Equilibrium

- As the system wants to preserve the state of equilibrium, the centre of mass of the pencil must be between the two fingers. This means that the frictional forces change as you move your fingers to keep the centre of the pencil in between your fingers.
- This would be the same if the pencil was imbalanced with a weight, however the centre of mass would no longer be at the centre of the object. The fingers would instead be spaced around a point further up the pencil towards the mass.

10A The conservation of energy and kinetic energy

- Initially, the ball has gravitational potential energy.
- Throughout the swing, the gravitational potential energy of the ball is transformed to kinetic energy.
- Upon collision with the chain of balls, the kinetic energy of one ball is transformed to the next, until the ball on the end of the chain is free to move off with this kinetic energy.
- During each collision, energy is likely lost to sound energy.

10B Work and gravitational potential energy

- If the Moon were to move away from the Earth, we would expect it to slow down. As it moves away from the Earth, it will convert kinetic energy to gravitational potential energy, as energy is always conserved. This would decrease its speed.
- If the Moon were to move closer to the Earth, we would expect it to speed up. As it moves towards the Earth, it will convert gravitational potential energy to kinetic energy as energy is always conserved. This would increase its speed.

10C Springs

- A shorter and stiffer rubber band will have a larger spring constant, k, than one which is large and stretchy. However, the stiffer rubber band will not be able to be stretched as far as the larger rubber band for the same force so it will have a smaller Δx value.
- The maximum speed will be achieved when the kinetic energy, $\frac{1}{2}mv^2$, of the rubber band is a maximum. As the rubber band is released, the energy stored as strain potential energy is transformed into kinetic energy, so a maximum strain potential energy is desired.
- Knowing that the equation for strain potential energy is $SPE = \frac{1}{2}k(\Delta x)^2$, by increasing the spring constant we will increase SPE in a linear manner, and by increasing the extension we will increase SPE in a quadratic manner.
- Therefore the larger stretchier rubber band would be preferable.

10D Applications of the conservation of energy and momentum

- Due to conservation of momentum, the car and the bus will experience the same impulse. Given that the car has a lesser mass, the car would experience a greater change in velocity. Note that $m\Delta v = F\Delta t$, where m is the mass of the passenger. Hence, the higher the change in velocity, the higher the impact force on the passenger.
- The impulse of the two vehicles is the same, but the portion of the mass that a person in the lighter car makes up is greater than someone in the heavier bus. Hence, a greater portion of the vehicle's impulse will be experienced by someone in the car. Because of this, being in the car would be less safe.

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GLOSSARY

A

absorbed dose radiation energy absorbed per kilogram of tissue p. 144

AC (alternating current) electricity electricity with a periodically alternating direction of current and voltage p. 259

acceleration the rate of change of velocity per unit time (vector quantity) p. 292

accuracy a relative indicator of how well a measurement agrees with the 'true' value of a measurement p. 477

active wire the wire at the end of an AC electrical system with a varying potential; this wire connects to the voltage supply p. 259

activity (radiation) the rate of radioactive decays per unit of time p. 125

aim the purpose of an experiment p. 464

albedo a measure of how much electromagnetic radiation an object reflects versus how much it absorbs p. 98

alpha decay the process by which an unstable nucleus decays into a more stable nucleus by emitting an alpha particle p. 131

alpha particle a particle composed of two protons and two neutrons (the nucleus of a standard helium atom) p. 132

amplitude (waves) the magnitude of an oscillation's maximum value from the neutral point within a wave p. 12

angle of incidence the angle to the normal of a ray approaching a medium boundary p. 31

angle of reflection the angle to the normal of a ray reflected by a medium boundary p. 31

angle of refraction the angle to the normal of a ray refracted by a medium boundary p. 31

anode the electrode of a device conventional current flows into p. 248

average acceleration the average rate of change of velocity per unit time over a given period (vector quantity) p. 296

average velocity the average rate of change of displacement per unit time over a given period (vector quantity) p. 293

B

beta minus decay the process by which an unstable nucleus decays into a more stable nucleus by transforming a neutron into a proton and emitting an electron and an antineutrino p. 133

beta particle an electron (beta minus decay) or a positron (beta plus decay) p. 130

beta plus decay the process by which an unstable nucleus decays into a more stable nucleus by transforming a proton into a neutron and emitting a positron and a neutrino p. 133

binding energy the total energy required to split a nucleus into its constituent nucleons p. 158

boil to convert a substance from liquid to gas at its boiling point p. 77

braking distance the distance a car travels when the brakes are fully applied p. 444

branch the circuit connections between two nodes p. 215

C

cancer harmful tumour caused by uncontrolled cell division p. 146

cathode the electrode of a device conventional current flows out from p. 248

cell microscopic structure that makes up tissues p. 143

charge carrier a charged particle that contributes to an electric current p. 182

charge a fundamental property of subatomic particles responsible for electric interaction p. 184

circuit breaker a safety device that opens a resettable switch, causing a break in an electric circuit, when too much current flows through it p. 262

cladding layer of lower refractive index material forming a protective coating around the inner core of a fibre optic cable p. 37

climate change a long-term change in weather patterns on the regional and global scale p. 97

climate system relationships and interactions between the atmosphere, oceans, snow, land surfaces, and all living organisms p. 97

collision the coming together of two or more objects where each object exerts a force on the other p. 343

component (electrical) any device of an electrical circuit p. 183

compression (spring) a decrease in the spring's length from the natural length p. 429

condense to convert a substance from gas to liquid p. 77

connected bodies two or more objects either in direct contact or attached by a string or similar connection p. 367

constant acceleration acceleration that is constant in both magnitude and direction p. 310

control rod a rod used in fission reactors to help control fission chain reactions p. 167

controlled variable a variable that has been held constant in an experiment p. 463

convection cell a cyclical flow of fluid caused by differences in temperature and hence fluid densities p. 67

convection the transfer of heat through the bulk movement of matter p. 67

conventional current the (hypothetical) direction of flow of positive charge p. 187

crest a point on the wave where the amplitude is a maximum positive value p. 5

critical angle the angle above which total internal reflection occurs p. 33

criticality the state of a fissile mass where the number of fission reactions occurring remains constant p. 164

crumple zone the front section of a car (the bonnet) that is intentionally designed to deform on impact p. 444

current (electric) the rate of movement of charge with respect to time, requiring the movement of charged particles p. 184

D

daughter nuclide the nucleus remaining after radioactive decay occurs p. 131

DC (direct current) electricity electricity with a constant direction of current and voltage p. 259

density mass per unit volume; a measure of how closely packed matter is p. 67

dependent variable a variable that is measured by the experimenter, expected to be impacted by the independent variable p. 463

diode a semiconductor device which limits current flow to one direction p. 248

direct current (DC) electric current that flows in one direction around a circuit p. 183

dispersion the separation of white light into its constituent colours due to the different refractive indices for different frequencies (colours) of light in a given medium p. 40

displacement the change in position of an object (vector quantity) p. 289

displacement the change in position of an object (vector quantity) p. 5

distance the total length of a given path between two points (scalar quantity) p. 289

E

earth wire provides a low-resistance path for current to flow from the outside of the appliance to the ground, in order to avoid an electric shock. p. 262

effective dose a measure of the biological impact of radiation p. 144

electric potential energy potential energy due to the separation of charge p. 188

electric shock the sensation and damage done when electric current flows through a person or other living thing p. 270

electromagnetic spectrum the range of all electromagnetic waves ordered by frequency and wavelength p. 21

electromagnetic wave a wave that consist of perpendicular electric and magnetic field oscillations p. 5

energy efficiency the ratio of useful output energy to input energy in an energy transfer p. 421

energy transformation when energy changes from one form to another p. 97

energy a quantity describing the ability to cause a physical change (scalar) p. 405

energy a quantity describing the ability to cause a physical change (scalar) p. 56

equilibrium position the position a spring is in when the external forces on it are equal to the restoring force of the spring p. 429

equilibrium the state of a system when it is in both translational and rotational equilibrium p. 389

equivalent dose a measure of the organ-specific impact of radiation p. 144

equivalent resistance the effective resistance when two or more resistive components are treated as one component p. 206

error the difference between a measured value and its 'true' value p. 477

evaporate to convert from liquid to gas only at the liquid's surface due to high-energy particles in the liquid escaping p. 80

extension (spring) an increase in the spring's length from the natural length p. 429

F

fibre optic cable a single cable containing one or more optical fibres encased in cladding to protect it from the environment p. 45

fissile mass a mass made out of or containing fissile material p. 164

fissile capable of sustaining a fission chain reaction p. 164

fluid a substance that flows easily; a liquid or gas p. 63

force a push or a pull with an associated magnitude and direction (vector quantity) p. 331

free nucleon a nucleon that is not bound to any other nucleons p. 156

freeze to convert a substance from liquid to solid at its freezing point p. 77

frequency the number of cycles completed per unit of time p. 12

friction a contact force that resists the relative motion of two surfaces which are in contact p. 370

fundamental force a force that is irreducible, all other forces can be derived from the fundamental forces p. 114

fuse a safety device that melts when too much current flows through it, causing a break in an electric circuit p. 262

G

gamma decay the process by which an excited nucleus decays into a more stable nucleus by emitting energy in the form of gamma rays p. 135

gamma rays high-energy photons p. 135

global warming a long-term increase in average global temperature of Earth's climate system since the industrial revolution due to human activities p. 99

gradient the graphical representation of the rate of change of one variable with respect to another p. 493

gradient the slope of a graph p. 302

gravitational force the force experienced by an object due to the gravitational field of another object p. 335

gravitational potential energy the stored energy associated with the position of an object in a gravitational field p. 405

H

half-life the time it takes for half of a radioactive sample to decay p. 121

heat energy that flows between systems due to a difference in temperature p. 57

hypothesis a proposed explanation that predicts a relationship between variables and can be tested through experimentation p. 464

I

illusion a deceptive or misinterpreted sensory experience p. 43

impulse the change in momentum of a body as the result of a force acting over a time (vector) p. 347

inclined plane a flat surface that is at an angle to the horizontal plane p. 367

independent variable a variable that is deliberately manipulated by the experimenter p. 463

instantaneous acceleration the rate of change of velocity per unit time at a single instant in time (vector quantity) p. 307

instantaneous velocity the rate of change of displacement per unit time at a single instant in time (vector quantity) p. 302

intensity the measurable quantity of light p. 91

internal energy the total energy associated with the random motion of particles and the interactions between the particles within a system p. 56

internal resistance the resistance associated with an electric power source p. 246

ionisation energy the energy required to remove an electron from an atom p. 130

ionising impact ability of ionisation to cause damage p. 143

ionising power the ability of a given type of radiation to cause another atom to lose electrons and become an ion p. 132

isolated system a collection of interacting objects for which there is no external exchange of mass and energy p. 343

isotope one of two or more possible forms of an atomic element, which will each have different mass and numbers of neutrons p. 116

K

kinetic energy the energy associated with the motion of an object p. 405

kinetic energy the energy associated with the motion of an object p. 56

L

latent heat the heat absorbed or released to change the state of a substance p. 76

law (scientific) a statement, based on repeated experiments or observations, that describes or predicts a phenomenon. p. 466

light-dependent resistor a variable resistor that decreases resistance as the intensity of light hitting its surface increases p. 252

light-emitting diode a diode that emits light when a potential difference is applied p. 249

line of best fit see linear line of best fit or non-linear line of best fit p. 489

linear line of best fit a straight line that indicates the relationship between the independent and dependent variables on a graph p. 489

linearise the process of transforming data so that, when graphed, a line of best fit can be drawn through the data p. 486

load the amount of electrical energy consumed (in the form of a current) by a transducer p. 247

longitudinal wave a wave in which the oscillations are parallel to the direction of wave travel and energy transmission p. 5

M

magnitude the size or numerical value of a quantity without sign (positive or negative) or direction p. 470

mass defect the difference in mass between a nucleus and its constituent nucleons p. 157

mechanical energy the energy associated with the motion or position of an object p. 405

mechanical wave a wave which requires a material medium p. 7

medical radioisotope radioisotope used in diagnosis or treatment of illness p. 147

medium (waves) a physical substance through which a wave propagates p. 5

medium the physical substance through which energy (e.g. heat or sound) travels p. 68

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melt to convert a substance from solid to liquid p. 77

mirage an optical illusion caused by the refraction of light rays due to changes in air temperature and pressure p. 43

model (scientific) a representation of a physical process that cannot be directly experienced p. 466

momentum a property of a body in motion which is equal to the mass of the body multiplied by its velocity (vector) p. 343

N

natural length the length of a spring when no external forces are acting on it p. 429

net force the vector sum of all forces acting on an object (vector quantity) p. 331

neutral wire the wire at the end of an AC electrical system that is fixed at zero volts p. 259

neutron moderation the process of reducing the speed (and hence kinetic energy) of neutrons p. 167

neutron moderator a material capable of neutron moderation through collisions with neutrons p. 167

neutron multiplication factor at a point in time, the average number of neutrons per fission reaction that will cause further fission reactions p. 165

neutron a subatomic particle found in the nucleus with no electric charge p. 115

Newton's first law states that an object will accelerate only if a nonzero net force (unbalanced force) acts upon it p. 331

Newton's second law states that the net force on an object is proportional to the object's acceleration and mass p. 331

Newton's third law states that for every force there is a reaction force of equal magnitude and opposite direction p. 331

node the intersection point in a circuit where current changes direction p. 216

non-linear line of best fit a curved line that indicates the relationship between the independent and dependent variables on a graph p. 489

normal force the contact force that acts between two objects with equal magnitude on each object and at right angles to the contact surfaces p. 337

normal an imaginary line perpendicular to the medium boundary at the point of incidence p. 30

nuclear fission the process of splitting a single nucleus into several smaller nuclei p. 157

nuclear fusion the process of forcing several smaller nuclei together to form a single large nucleus p. 157

nucleon a proton or a neutron found in an atom's nucleus p. 114

nuclide a nucleus with a specific number of neutrons and protons p. 131

O

observation the acquisition of data using senses such as seeing and hearing or with scientific instruments p. 464

ohmic device an electrical component that has a constant resistance for all voltages p. 199

optical fibre a glass fibre that utilises total internal reflection to transmit light over long distances p. 37

oscillate to move back and forth in a regular motion p. 5

P

parallel circuit an electric circuit that has only parallel connections p. 215

parallel connection an arrangement where multiple components connect the same two points so there are multiple alternative pathways for current to flow p. 192

parent nuclide the original nucleus before radioactive decay occurs p. 131

particle a small, discrete object p. 55

peak wavelength the wavelength of the highest intensity electromagnetic wave released as thermal radiation p. 90

penetrating power an indicator of the extent to which a given type of radiation can penetrate matter before it loses its energy p. 133

period the time taken to complete one cycle p. 12

personal error mistakes in the execution of an experiment or the analysis, caused by a lack of care that negatively impact or invalidate the conclusions of an experiment p. 477

potential difference the difference in electric potential energy per unit charge between two points p. 184

potential energy the energy associated with the position of an object in the presence of a force that could move the object p. 56

potentiometer a variable resistor that changes resistance depending on the manual control of a sliding contact p. 251

power the rate at which an energy transfer takes place with respect to time p. 421

power the rate of change of energy with respect to time p. 188

precision a relative indicator of how closely different measurements of the same quantity agree with each other p. 477

primary data original data collected first-hand by researchers p. 463

product a substance that is formed as the result of a reaction p. 157

propagate the way in which a wave travels p. 7

proton a subatomic particle found in the nucleus with positive electric charge p. 115

Q

qualitative data data that cannot be described by numerical values p. 463

quantitative data data that can be described by numerical values p. 463

quark a type of fundamental particle which protons and neutrons are made of p. 115

R

radiation weighting factor relative biological effectiveness of radiation type p. 144

radiation the transmission of energy in the form of electromagnetic waves or high-speed particles p. 131

radiation the transmission of energy in the form of electromagnetic waves or high-speed particles p. 22

radioactive decay the process of an atomic nucleus becoming more stable by losing energy and emitting particles or photons p. 121

radioisotope an isotope that will undergo radioactive decay p. 117

rainbow an arch of colours caused by the dispersion of the Sun's light through water in the atmosphere p. 42

random error the unpredictable variations in the measurement of quantities p. 478

reactant a substance present at the start of a reaction and is involved in the reaction p. 157

reaction distance the distance a car travels in the time it takes a driver to react to a hazard p. 440

reaction time the time it takes for a driver to react to a hazard p. 440

refraction the change in direction of a wave moving between two mediums with different refractive indices p. 29

refractive index for a given medium, the ratio of the speed of light in a vacuum to the speed of light in that medium p. 29

repeatability the closeness of agreement of results when an experiment is repeated by the same experimenter under the same conditions (using the same equipment and in the same laboratory) p. 480

reproducibility the closeness of agreement of results when an experiment is repeated by a different experimenter under slightly different conditions (using their own equipment and laboratory) p. 480

residual current device (RCD) a safety device that switches off a household electric circuit when it detects a difference between the current flowing in the active and neutral wires p. 271

resistance (electrical) a measure of an object's opposition to the flow of electric current p. 197

resistor an ohmic device with a fixed resistance that opposes the flow of electric current and causes a drop in voltage p. 198

resolution the smallest change in a quantity that is measurable p. 477

RMS (root-mean-square) a measure of a time-varying (such as AC) voltage or current. A constant DC voltage or current with the same value as the RMS would deliver the same average power p. 260

rotational equilibrium the state of a system when the torques on the system sum to zero p. 389

S

safety the ability to minimise the impact force acting on a human body p. 440

scalar quantity a quantity that only has magnitude (size) p. 289

secondary data data that has been previously collected that is now accessible to different researchers p. 463

series circuit an electric circuit that has only series connections p. 206

series connection a connection of components from end to end p. 192

short circuit a situation in which current flows through an unintended path with lower resistance, causing accidental contact between components p. 270

SI unit an accepted standard unit used for measuring a quantity p. 470

significant figures all digits quoted, starting with the first non-zero digit, giving an indication of the confidence in a measurement p. 472

sinusoidal having the form of a sine wave p. 260

specific heat capacity the heat per unit of mass needed to increase the temperature of a substance by one kelvin (or degree Celsius) p. 74

latent heat of fusion the heat per unit of mass required to convert a given substance from a solid into a liquid p. 78

latent heat of vaporisation the heat per unit of mass required to convert a given substance from a liquid into a gas p. 78

speed the rate of change of distance per unit time (scalar quantity) p. 292

spring constant a value that describes the stiffness of a spring p. 429

spring any object that can deform and return to its original shape after external forces has been removed p. 429

state change the process of changing between different states of matter p. 76

state of matter the physical property of an object being either a solid, liquid, or a gas p. 55

stopping distance the distance travelled from when a driver first sees a hazard to when they come to a complete stop p. 440

strain potential energy the energy stored by the deformation of an object p. 405

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strong force the fundamental force that holds quarks together to form nucleons and that holds nucleons together within the nucleus p. 114

subcriticality the state of a fissile mass where the number of fission reactions occurring is decreasing p. 165

supercriticality the state of a fissile mass where the number of fission reactions occurring is increasing p. 165

system a collection of interacting particles or objects p. 56

systematic error a consistent, repeatable deviation in the measured results from the true values, often due to a problem with the experimental design or calibration of equipment p. 478

T

temperature a measure of the average translational kinetic energy of the particles in a system (scalar) p. 56

tension a pulling or stretching force that acts through an object connecting two bodies p. 370

theory (scientific) an explanation of a physical phenomenon that has been repeatedly confirmed by experimental evidence and observation p. 463

thermal conduction the transfer of heat through direct contact p. 66

thermal contact two systems are in thermal contact if there is heat transfer between them p. 63

thermal energy the kinetic energy associated with the movement of microscopic particles. p. 57

thermal equilibrium the state of two (or more) systems having the same temperature so that there is no net flow of thermal energy from one system to the other p. 57

thermal radiation the transfer of heat in the form of electromagnetic radiation p. 68

thermistor a variable resistor that changes resistance with temperature p. 251

tissue weighting factor relative danger of radiation absorption in a particular tissue p. 145

tissue group of specialised cells p. 143

torque the turning effect caused by a force at a distance from a pivot point (vector) p. 379

total internal reflection the reflection of all incident light at a boundary between two mediums p. 33

transducer a component or device that transforms energy between different forms p. 251

translational equilibrium the state of a system when the forces on the system sum to zero p. 389

transmission the transfer of wave energy through or between wave mediums p. 4

transverse wave a wave in which the oscillations are perpendicular to the direction of wave travel and energy transmission p. 5

trendline see linear line of best fit or non-linear line of best fit p. 489

trough a point on the wave where the amplitude is a maximum negative value p. 5

U

uncertainty the qualitative or quantitative judgement of how well an experiment measures what it is intended to measure p. 478

V

vacuum a region that does not contain matter p. 66

vacuum a region that does not contain matter p. 7

validity the degree to which an experiment measures what it intends to measure p. 480

vector quantity a quantity that has both magnitude (size) and direction p. 289

vector resolution breaking down a vector into two perpendicular components p. 355

velocity the rate of change of displacement per unit time (vector quantity) p. 292

voltage divider a circuit with resistance that outputs a voltage smaller than its input voltage p. 245

voltage see potential difference p. 185

W

wave cycle the process of a wave completing one full oscillation, ending up in a final configuration identical to the initial configuration p. 12

wave speed the speed at which a wave transfers its energy through a medium p. 14

wave the transmission of energy via oscillations from one location to another without

the net transfer of matter. p. 4

wavelength the distance covered by one complete wave cycle p. 12

weak force the fundamental force responsible for beta decay by changing the properties of a quark p. 114

work the change in energy caused by a force displacing an object p. 413

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FORMULAS IN THIS BOOK

1B	frequency-period inverse relationship	$f = \frac{1}{T}$
	wave equation (frequency)	$v = f\lambda$
	wave equation (period)	$v = \frac{\lambda}{T}$
1D	refractive index	$n = \frac{c}{v}$
	refractive index and wave speed	$n_1 v_1 = n_2 v_2$
	Snell's Law	$n_1 \sin(\theta_1) = n_2 \sin(\theta_2)$
	critical angle	$n_1 \sin(\theta_c) = n_2$
2A	converting from Celsius to kelvin	$T_{\text{K}} = T_{°\text{C}} + 273.15$
2B	heat flow rate of conduction	$\frac{Q}{t} \propto \Delta T$
2C	specific heat capacity	$Q = mc\Delta T$
	latent heat	$Q = mL$
3A	Wien's Law	$\lambda_{max} = \frac{b}{T}$
4B	radioactive nuclei remaining	$N = N_0 \left(\frac{1}{2}\right)^n$
	radioactivity	$A = A_0 \left(\frac{1}{2}\right)^n$
4D	absorbed dose	$D = \frac{E_r}{m}$
	equivalent dose	$H = D \times w_r$
	effective dose	$E = \Sigma(H \times w_t)$

Back to contents

6A	potential difference	$V = \frac{E}{Q}$
	electric current	$I = \frac{Q}{t}$
	power	$P = \frac{E}{t}$
	electric power	$P = VI$
6B	Ohm's Law	$V = IR$
	electric power	$P = VI = I^2R = \frac{V^2}{R}$
6C	equivalent series resistance	$R_{equivalent} = R_1 + R_2 + \ldots + R_n$
6D	equivalent parallel resistance	$\frac{1}{R_{equivalent}} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots \frac{1}{R_n}$
7A	voltage divider equation	$V_{out} = \frac{R_2}{R_1 + R_2} \times V_{in}$
7B	RMS voltage	$V_{RMS} = \frac{1}{\sqrt{2}} V_{peak}$
	RMS current	$V_{RMS} = \frac{1}{\sqrt{2}} V_{peak}$
8A	speed	$speed = \frac{distance}{time}$
	average velocity	$v_{avg} = \frac{\Delta s}{\Delta t}$
	average acceleration	$a_{avg} = \frac{\Delta v}{\Delta t}$
8C	the constant acceleration equations	$v = u + at$ $v^2 = u^2 + 2as$ $s = \frac{1}{2}(u + v)t$ $s = ut + \frac{1}{2}at^2$ $s = vt - \frac{1}{2}at^2$

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9A	Newton's second law	$F_{net} = ma$
	Newton's third law	$F_{on\ A\ by\ B} = -F_{on\ B\ by\ A}$
	force due to gravity	$F_g = mg$
	the net force	$F_{net} = F_1 + F_2 + F_3 + \ldots$
9B	momentum	$p = mv$
	conservation of momentum	$\Sigma p_i = \Sigma p_f$
	impulse	$\Delta p = m\Delta v$ $\Delta p = F\Delta t$
9E	torque	$\tau = r_{\perp}F$
10A	conservation of energy	$KE_i + GPE_i + SPE_i = KE_f + GPE_f + SPE_f$
	kinetic energy	$KE = \frac{1}{2}mv^2$
	change in kinetic energy	$\Delta KE = \frac{1}{2}m(v^2 - u^2)$
10B	gravitational potential energy	$\Delta GPE = mg\Delta h$
	work	$W = Fs$
10C	Hooke's Law	$F_s = -k\Delta x$
	strain potential energy	$SPE = \frac{1}{2}k(\Delta x)^2$
10D	constant velocity equation	$s = vt$
11E	gradient of a straight line	$gradient = \frac{y_2 - y_1}{x_2 - x_1} = \frac{\Delta y}{\Delta x}$

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Constants

1A	**speed of light in a vacuum**	$c = 3.0 \times 10^8 \text{ m s}^{-1}$
3A	**Wien's constant**	$b = 2.898 \times 10^{-3} \text{ m K}$
7B	**kilowatt-hour**	$1 \text{ kWh} = 3.6 \times 10^6 \text{ J}$
9A	**acceleration of gravity**	$g = 9.8 \text{ m s}^{-2}$