VICTORIAN CURRICULUM AND ASSESSMENT AUTHORITY

Victorian Certificate of Education 2017

SUPERVISOR TO ATTACH PROCESSING LABEL HERE

Letter

STUDENT NUMBER

PHYSICS
Written examination

Monday 5 June 2017

Reading time: 10.00 am to 10.15 am (15 minutes)
Writing time: 10.15 am to 12.45 pm (2 hours 30 minutes)

QUESTION AND ANSWER BOOK

Structure of book

Section	*Number of questions*	*Number of questions to be answered*	*Number of marks*
A – Motion in one and two dimensions	6	6	40
Electronics and photonics	5	5	22
Electric power	5	5	36
Interactions of light and matter	5	5	30
B – Materials and their use in structures	11	11	22
			Total 150

- Students are permitted to bring into the examination room: pens, pencils, highlighters, erasers, sharpeners, rulers, pre-written notes (one folded A3 sheet or two A4 sheets bound together by tape) and one scientific calculator.
- Students are NOT permitted to bring into the examination room: blank sheets of paper and/or correction fluid/tape.

Materials supplied
- Question and answer book of 43 pages.
- Formula sheet.
- Answer sheet for multiple-choice questions.

Instructions
- Write your **student number** in the space provided above on this page.
- Check that your **name** and **student number** as printed on your answer sheet for multiple-choice questions are correct, **and** sign your name in the space provided to verify this.
- Unless otherwise indicated, the diagrams in this book are **not** drawn to scale.
- All written responses must be in English.

At the end of the examination
- Place the answer sheet for multiple-choice questions inside the front cover of this book.
- You may keep the formula sheet.

Students are NOT permitted to bring mobile phones and/or any other unauthorised electronic devices into the examination room.

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SECTION A

SECTION B

SECTION A – Core studies

Instructions for Section A

Answer **all** questions in this section in the spaces provided. Write using blue or black pen.
Where an answer box has a unit printed in it, give your answer in that unit.
You should take the value of g to be 10 m s^{-2}.
Where answer boxes are provided, write your final answer in the box.
In questions worth more than 1 mark, appropriate working should be shown.
Unless otherwise indicated, the diagrams in this book are **not** drawn to scale.

Area of study – Motion in one and two dimensions

Question 1 (8 marks)
A tugboat is towing two barges (unpowered boats) connected by cables, as shown in Figure 1.
The tugboat has a mass of 100 tonnes and each barge has a mass of 200 tonnes.

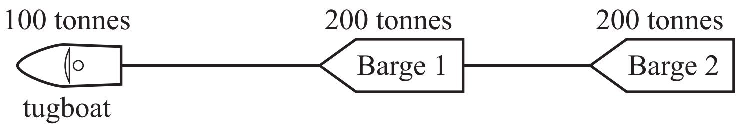


Figure 1

The tugboat starts from rest and accelerates at 0.50 m s^{-2}.

a. Calculate the distance that the tugboat and its barges travel in the first 10 s. 2 marks

m

b. Calculate the force applied by the tugboat's engine. Ignore any friction. 2 marks

N

c. Calculate the tension in the cable connecting the tugboat and Barge 1. 2 marks

N

d. Calculate the impulse given by Barge 1 to Barge 2 in the first 10 s of motion. Include an appropriate unit. 2 marks

Question 2 (6 marks)

Some students conduct experiments involving two trolleys, Trolley A and Trolley B. Trolley A has a mass of 2.0 kg and Trolley B has a mass of 1.0 kg.

a. In their first experiment, Trolley A is moving to the right at 3.0 m s^{-1} and Trolley B is moving to the right at 1.0 m s^{-1}, as shown in Figure 2. The trolleys collide, but do not stick together in the collision. After the collision, Trolley A is moving to the right at 2.0 m s^{-1}.

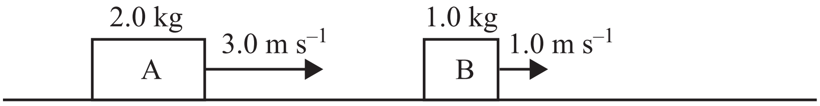


Figure 2

Calculate the speed of Trolley B after the collision. Show your working. 3 marks

m s^{-1}

b. In their second experiment, Trolley A is moving to the right at 4.0 m s^{-1} and Trolley B is stationary, as shown in Figure 3. The trolleys collide and, after this collision, Trolley A is moving to the right at 2.0 m s^{-1} and Trolley B is moving to the right at 4.0 m s^{-1}.

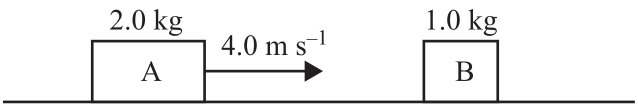


Figure 3

i. Explain the terms ‘elastic’ and ‘inelastic’ as applied to collisions. 1 mark

ii. Determine whether this collision is elastic or inelastic. 2 marks

Question 3 (7 marks)

An amusement park has a car ride consisting of vertical partial circular tracks, as shown in Figure 4a. The track is arranged so that the car remains upright at both the top and bottom positions. The track has a radius of 12.0 m and its lowest point is point P.

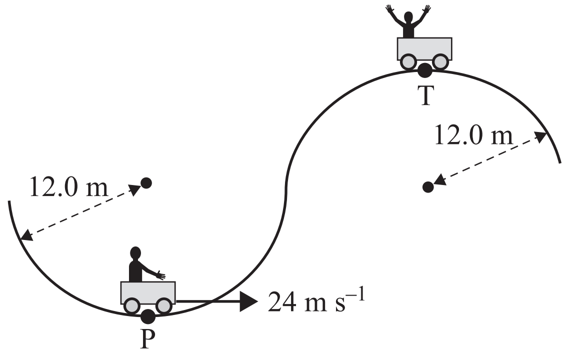


Figure 4a

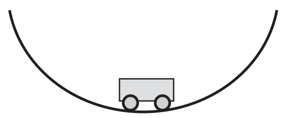


Figure 4b

a. On the diagram in Figure 4b, draw labelled arrows showing all of the forces on the car at point P and draw the resultant force with a dotted arrow labelled F_R. 3 marks

b. At point P, the car is moving at 24 m s^{-1}.

Calculate the force of the car seat on a passenger of mass 50 kg as the car passes point P. Show your working. 2 marks

N

c. Emily says that if the car moves at the correct speed at the top, point T, a person can feel weightless at that point.

Roger says this is nonsense; a person can only feel weightless in deep space, where there is no gravity.

Who is correct? Justify your answer. 2 marks

Question 4 (7 marks)

A spring has a spring constant, *k*, of 20 N m^{-1}. Point P shows the unstretched length of the spring.

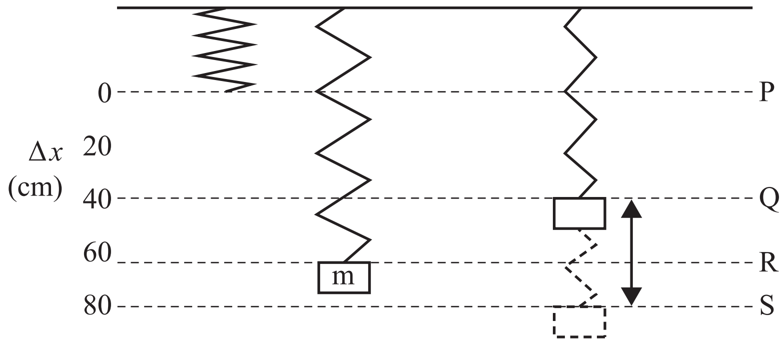


Figure 5a **Figure 5b**

not to scale

a. A mass, m, is hung from the spring.

It extends the spring 0.60 m to point R, as shown in Figure 5a.

Calculate the mass of m. 2 marks

kg

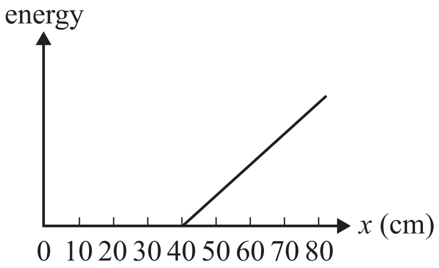
b. The mass is now raised to point Q and released, so that it oscillates between points Q and S, as shown in Figure 5b.

Calculate the change in spring potential energy in moving from point Q to point S. Show your working. 2 marks

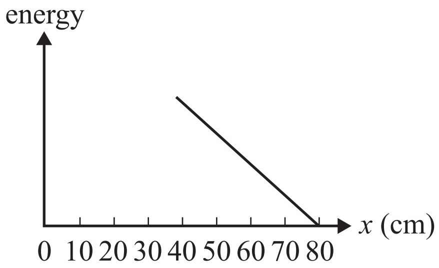
J

c. Eight graphs, **A.–H.**, are shown below.

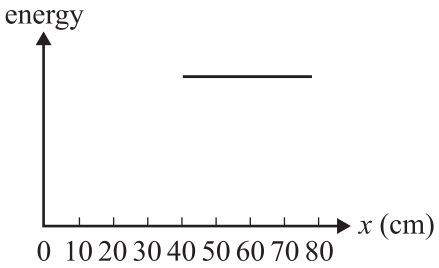
A.



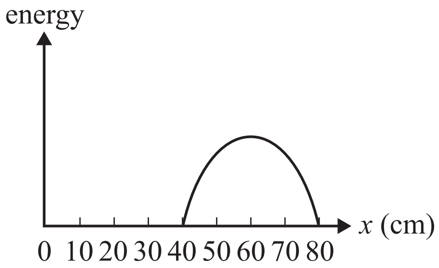
B.



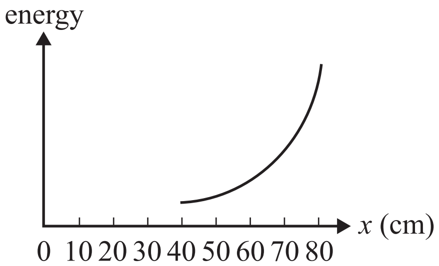
C.



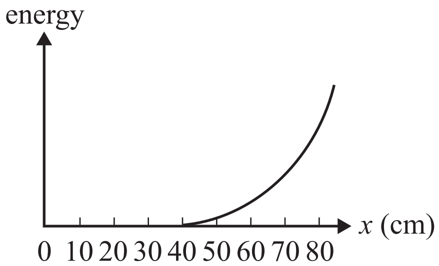
D.



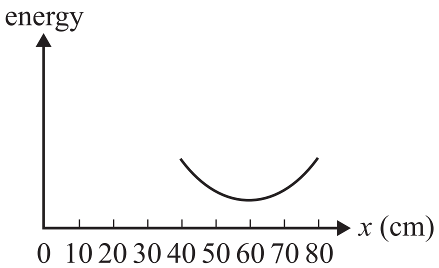
E.



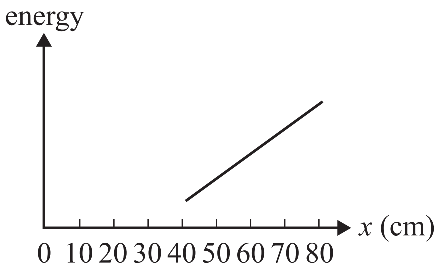
F.



G.



H.



In the boxes provided below, indicate which graph(s) (**A.–H.**) would show the total energy, the gravitational potential energy (take the zero of gravitational potential energy at the lowest point, S), the kinetic energy and the spring potential energy as the mass oscillates. 3 marks

Total energy

Gravitational potential energy

Kinetic energy

Spring potential energy

Question 5 (6 marks)

An archer shoots arrows at a target 5.0 m away.

a. Initially, the archer shoots the arrows horizontally, as shown in Figure 6. The arrow leaves the bow 1.0 m above the ground. Assume the arrows travel with a constant horizontal component of 12 m s^{-1}.

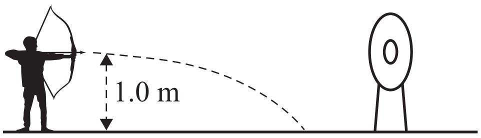


Figure 6

The archer finds that the arrows are hitting the ground rather than reaching the target.

Calculate how far horizontally from the launching point the arrows will hit the ground. 2 marks

m

b. The target is moved. In order to hit the target at this new position, the archer finds that he needs to shoot the arrows at an angle of 30° above the horizontal, as shown in Figure 7. The arrows still leave the bow at 12 m s^{-1}.

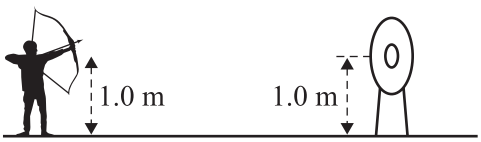


Figure 7

Calculate the horizontal distance to the target. Show your working. 2 marks

m

c. A bow can be treated as a simple spring, as shown in Figure 8a. The force–distance graph of the bow is shown in Figure 8b. The *x*-axis shows the distance the archer pulls back the bow string.

An arrow has a mass of 0.03 kg.

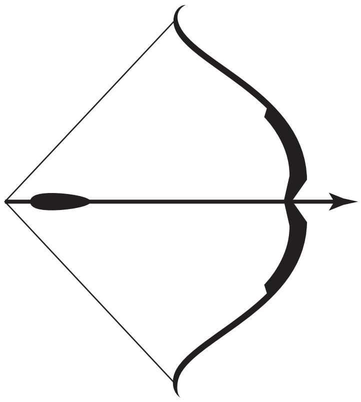


Figure 8a

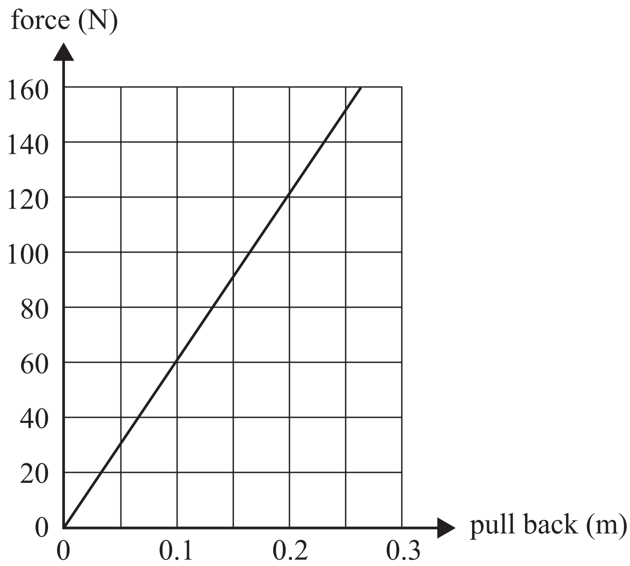


Figure 8b

The bow is pulled back 0.20 m and released.

Calculate the speed at which the arrow leaves the bow. 2 marks

____

____

____

$m\ s^{-1}$

Question 6 (6 marks)

The dwarf planet Pluto has an orbital period of 248 Earth years (1 Earth year = 365 days). Assume the orbit is exactly circular.

The mass of the sun is 2.0×10^{30} kg.

$G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}

a. Calculate Pluto's orbital period. 1 mark

s

b. Calculate Pluto's distance from the centre of the sun. Ignore the radius of the sun. Show your working. 3 marks

m

c. An astronaut can throw a ball 5.0 m into the air on Earth.

The acceleration due to gravity on Pluto is 0.62 m s^{-2}.

Estimate how high the astronaut could throw the ball on Pluto. Show your working. 2 marks

m

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Area of study – Electronics and photonics

Question 7 (8 marks)

Students set up the circuit shown in Figure 9.

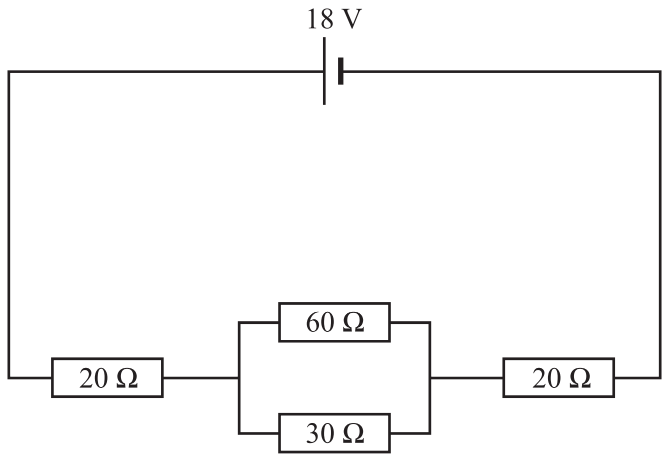


Figure 9

a. Calculate the potential difference across the 30 Ω resistor. 2 marks

V

b. Calculate the current flowing through the 60 Ω resistor. 2 marks

A

The students modify the circuit, changing the resistor and battery values, and replacing one resistor with a diode, as shown in Figure 10.

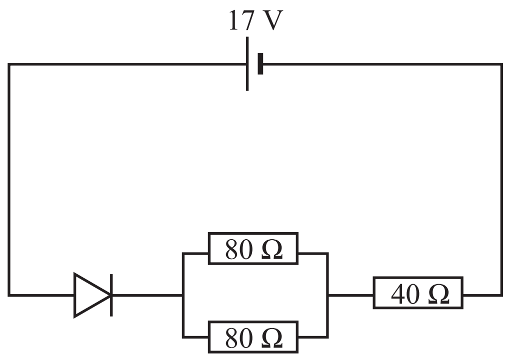


Figure 10

The characteristics of the diode are shown in Figure 11.

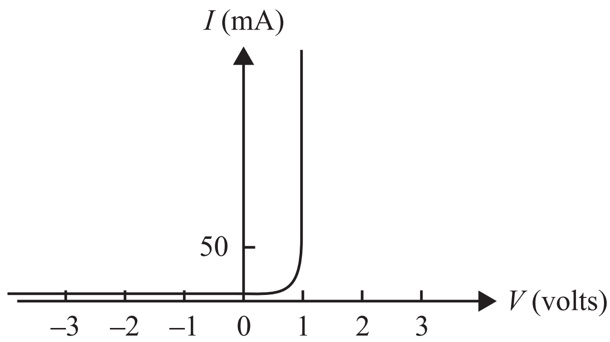


Figure 11

The students note that the current through the diode is greater than 50 mA.

c. Calculate the potential difference across **one** of the 80 Ω resistors. 2 marks

V

d. Calculate the current flowing through **one** of the 80 Ω resistors. 2 marks

A

Question 8 (4 marks)

The current-voltage characteristics of a light-emitting diode (LED) are shown in Figure 12.

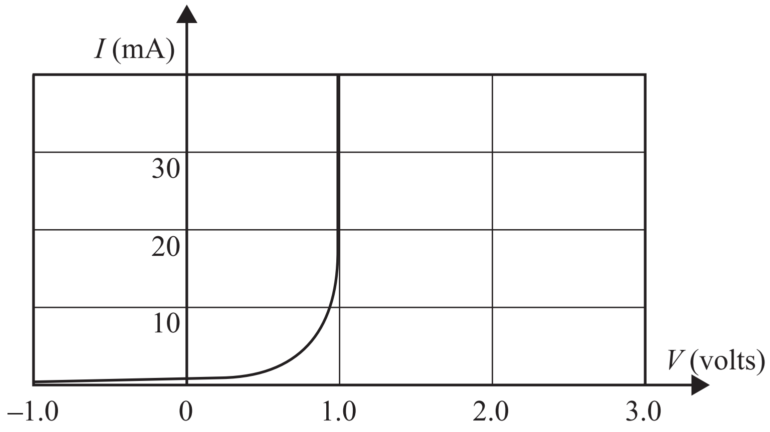


Figure 12

Students connect the LED into a circuit, as shown in Figure 13.

The resistor has a value of 500 Ω.

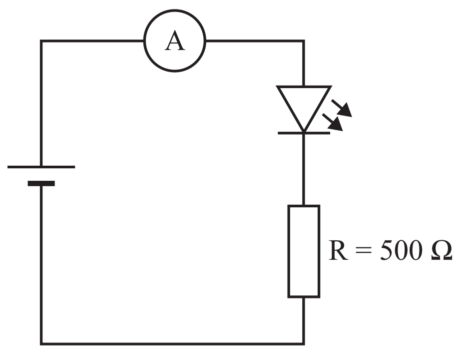


Figure 13

The students observe that the power dissipated in the resistor is 0.050 W.

a. Calculate the voltage of the battery in the circuit. Show your working. 3 marks

V

b. The battery is now reversed.

Calculate the potential difference across the LED. 1 mark

V

Question 9 (2 marks)

Students construct a circuit to demonstrate an aspect of modulation, as shown in Figure 14. There is a sliding contact on resistor R_1. This varies the resistance of R_1 in the circuit.

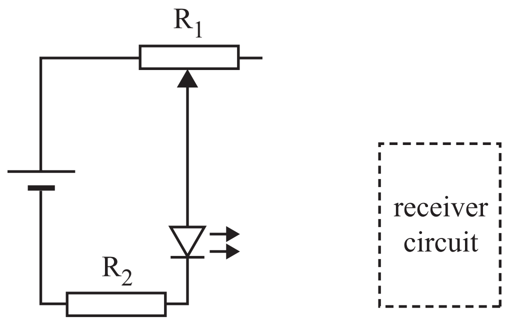


Figure 14

The sliding contact is moved backwards and forwards so that the resistance of R_1 in the circuit varies with time, as shown in Figure 15.

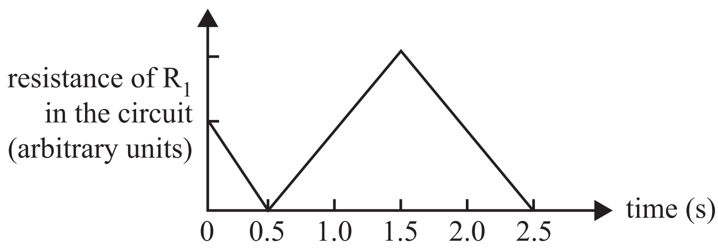
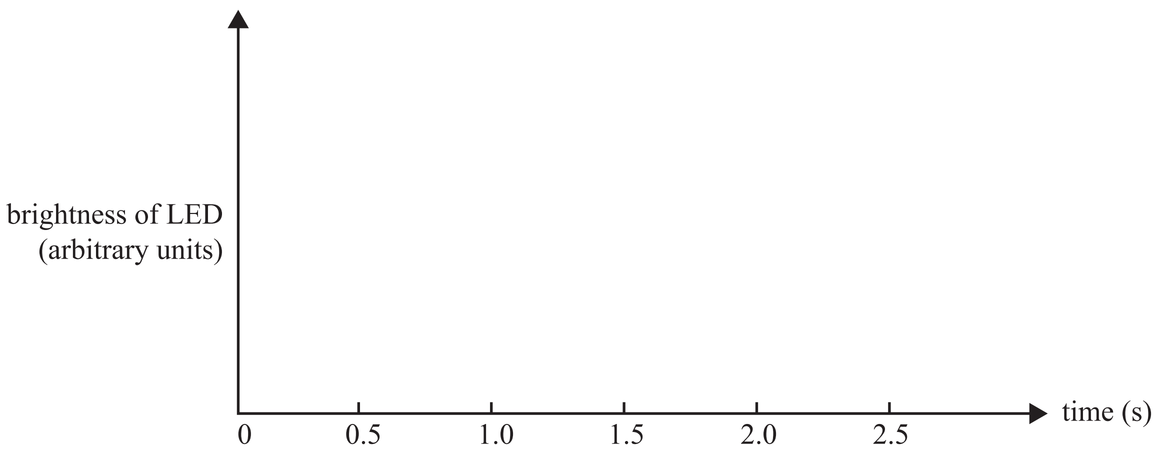


Figure 15

On the axes provided below, draw the variation in the brightness of the LED over time. Assume the LED is always conducting.



Question 10 (4 marks)

Students are using a light-dependent resistor (LDR), a battery and a resistor to build a control circuit. The characteristics of the LDR are shown in Figure 16.

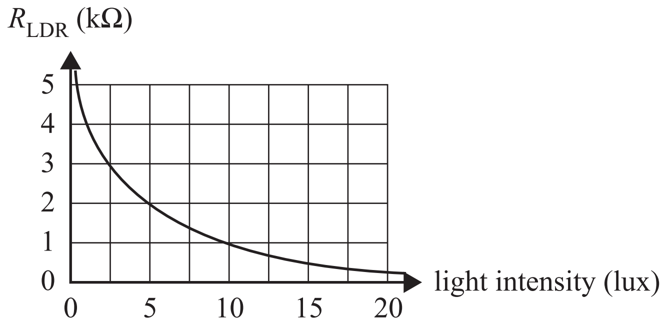


Figure 16

The students test the LDR using the circuit shown in Figure 17.

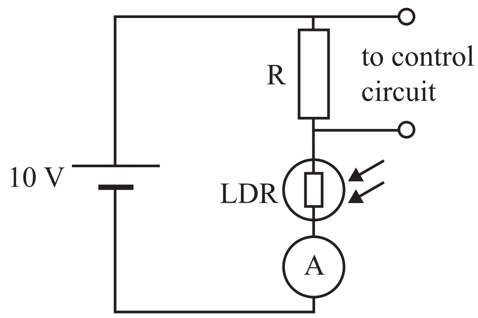


Figure 17

At a light intensity of 5 lux, they find there is a voltage of 6.0 V across the resistor R.

a. Calculate the size of the resistor R. Show your working. 2 marks

kΩ

b. The control circuit switches off an outdoor lamp when the voltage across the resistor is 7.5 V or more.

At what light intensity would the lamp switch on? Show your working. 2 marks

lux

Question 11 (4 marks)

A voltage amplifier has the input-output characteristics shown in Figure 18.

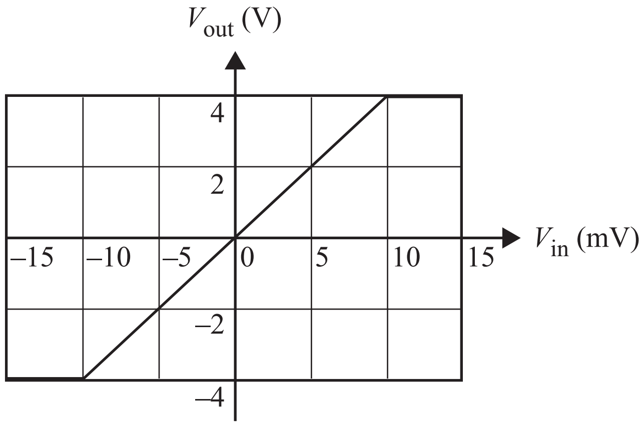


Figure 18

a. Calculate the gain of the amplifier in its linear region. 2 marks

b. For a sinusoidal output signal free of clipping, calculate the maximum RMS voltage that can be applied to the input of the amplifier. 2 marks

mV

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Area of study – Electric power

Question 12 (5 marks)

Figure 19a shows two solenoids and Figure 19b shows a small magnetic compass.

The same current flows through both solenoids. Ignore Earth's magnetic field.

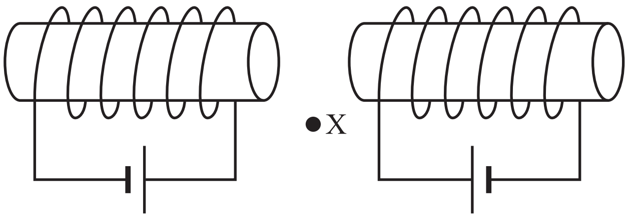
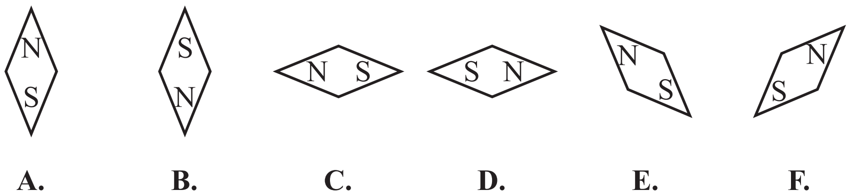


Figure 19a

Figure 19b

Use the directions **A.–F.** below to answer **part a.** and **part b.**



a. The small magnetic compass is placed at point X in Figure 19a.

Which of the directions **A.–F.** best shows how the compass will point? Give a reason for your answer. 2 marks

b. A wire carrying a current, I, vertically upwards is placed midway between the two solenoids, as shown in Figure 20.

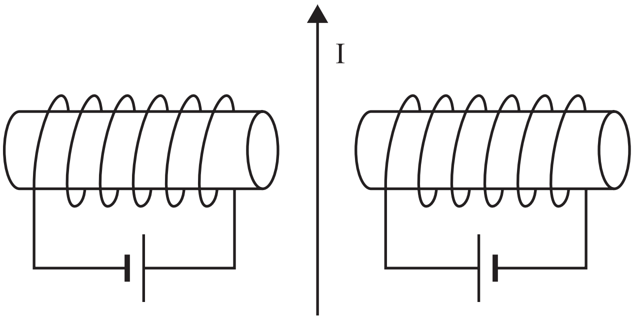


Figure 20

Which of the options **A.–G.** below best shows the direction of the electromagnetic force on the wire? Explain your answer. 3 marks

A. upwards

B. downwards

C. into page

D. out of page

E. left

F. right

G. force will be zero

Question 13 (6 marks)

Students build a simple electric motor consisting of a single coil and a split-ring commutator, as shown in Figure 21.

The magnetic field between the pole pieces is a constant 0.02 T.

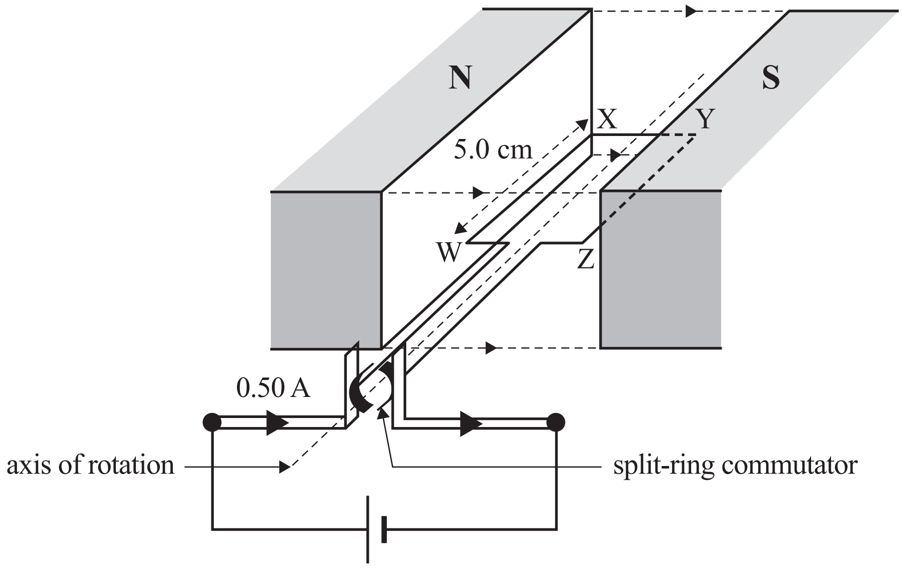


Figure 21

a. Calculate the magnitude of the force on the side WX. 2 marks

N

b. Will the coil rotate in a clockwise or anticlockwise direction as seen by an observer at the split-ring commutator? Explain your answer. 2 marks

c. Explain the role of the split-ring commutator in the operation of the electric motor. 2 marks

Question 14 (11 marks)

A square loop of side 10 cm is allowed to move horizontally through a region of a magnetic field. This is shown in Figure 22.

Assume the magnetic field is uniform and does not extend beyond the limits of the magnets.

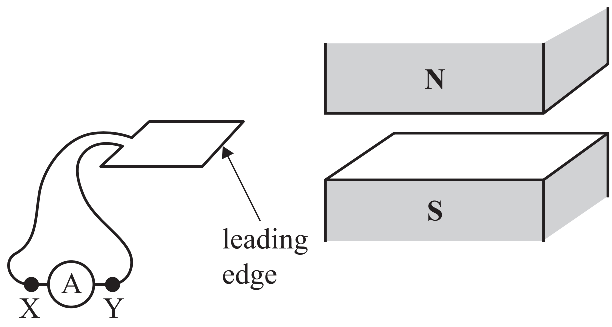


Figure 22

The arrangement is shown as viewed from above in Figure 23a.

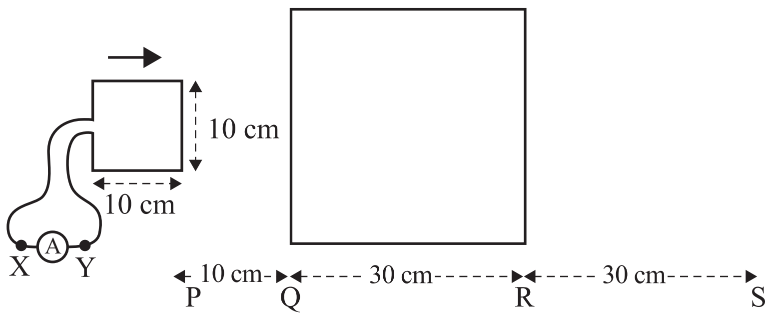


Figure 23a

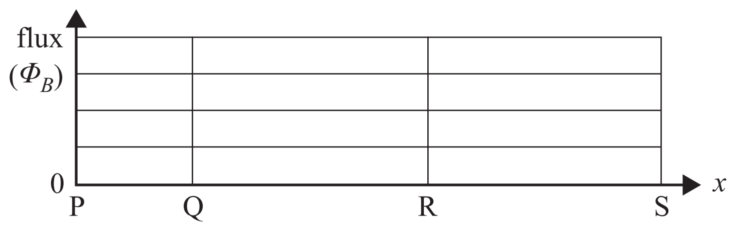


Figure 23b

Figure 23c

a. On the graph provided in Figure 23b, sketch the magnitude of the flux threading the loop as the loop moves with its leading edge moving from P to S. 2 marks

b. On the graph provided in Figure 23c, sketch the induced emf as the loop moves with its leading edge moving from P to S. 2 marks

c. Making reference to any relevant physical law, determine whether the current will flow from X to Y or from Y to X through the meter A as the loop moves into the magnetic field. Explain your answer. 4 marks

d. The magnetic field has a uniform value of 2.0×10^{-3} T and the loop has a resistance of 2.0 Ω. The loop takes 0.50 s to move into the magnetic field.

Calculate the average current in the meter A as the loop moves into the magnetic field. Show your working. 3 marks

A

Question 15 (9 marks)

A farmer wishes to run a power line from his house to a cowshed to operate a large coolroom.

The voltage available at the house is 240 V_{RMS} AC.

The power line wires have a total resistance of 6.0 Ω.

The coolroom machinery has a constant resistance of 10 Ω and is designed to operate on 240 V_{RMS} AC.

The installation is shown in Figure 24.

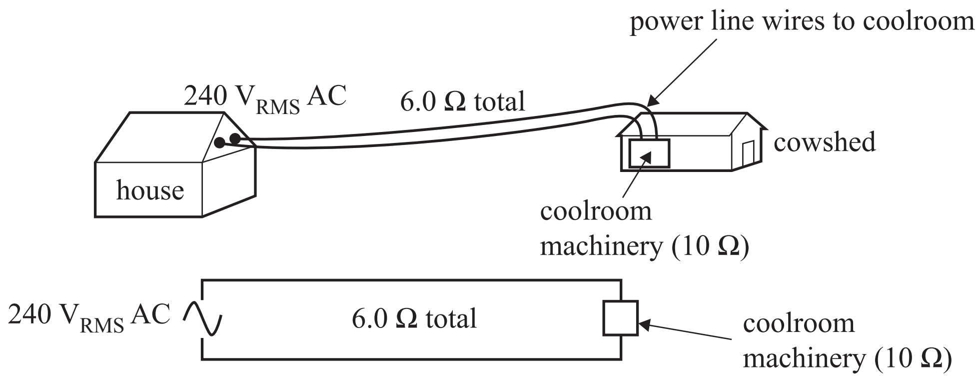


Figure 24

a. Calculate the power of the coolroom machinery when it is operating correctly as designed. 2 marks

W

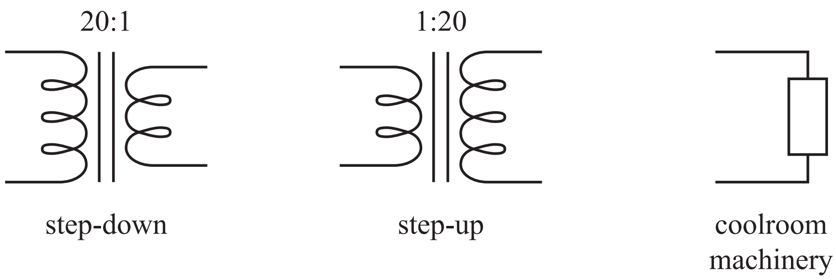
b. Calculate the power used by the coolroom machinery in the arrangement shown in Figure 24. Show your working. 4 marks

W

c. The farmer says the coolroom machinery is not operating correctly. An electrician says this is due to loss of voltage in the power line wires and the transmission voltage needs to be higher. The electrician has two transformers available: a step-down of 20:1 and a step-up of 1:20.

In the space provided below, sketch how these transformers should be installed in the system to improve the operation of the coolroom machinery in the cowshed.

Use the symbols below in your diagram. 3 marks



Question 16 (5 marks)

A student constructs a simple alternator. The alternator is shown in Figure 25a. Its output signal, as seen on an oscilloscope, is shown in Figure 25b.

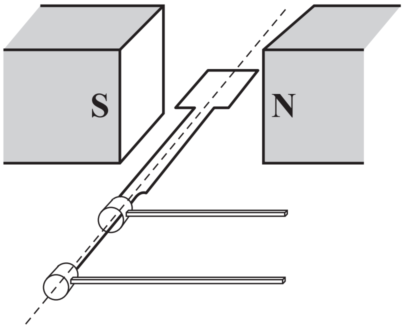


Figure 25a

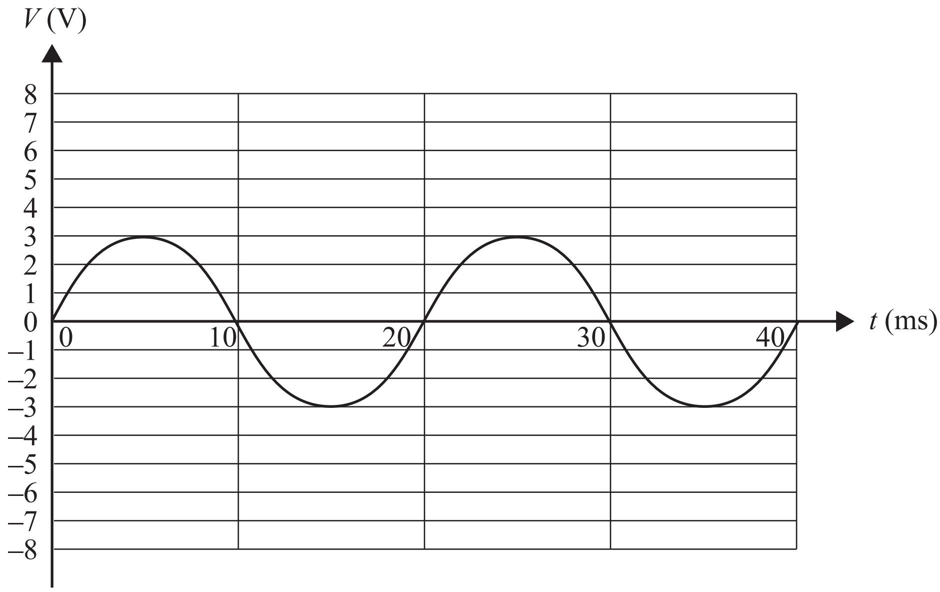


Figure 25b

a. Using the graph in Figure 25b, determine the frequency of the output signal. Show your working. 2 marks

Hz

b. The speed of rotation is now doubled.

On Figure 25b, sketch what the student will now see on the oscilloscope. 3 marks

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Area of study – Interactions of light and matter

Question 17 (7 marks)

A teacher uses a microwave set that has wavelength $\lambda = 3.0$ cm to demonstrate Young's experiment.

The apparatus is shown in Figure 26.

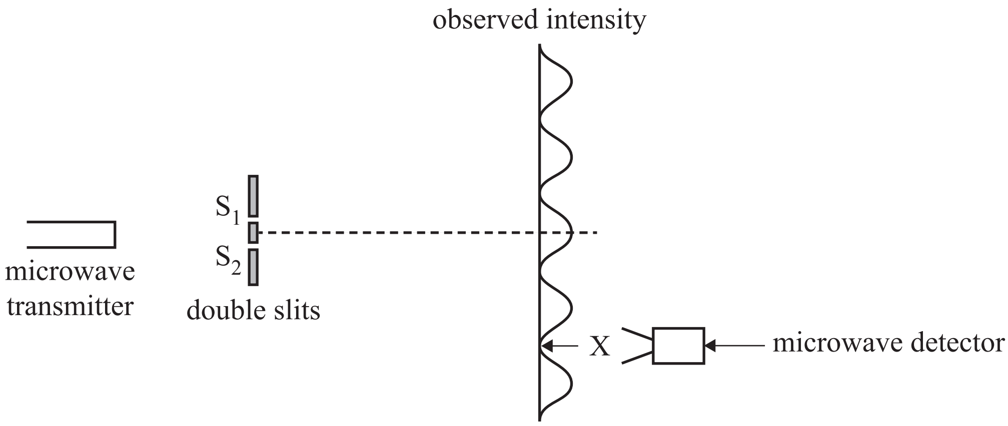


Figure 26

a. The microwave detector is placed at point X (the second nodal line out from the centre). A minimum intensity is observed.

Estimate the path difference $S_1X - S_2X$. 2 marks

cm

b. Explain the importance of Young's experiment in the development of the wave model of light. 3 marks

c. The teacher replaces the double slit with a single slit of width w and measures the width, y cm, of the diffraction pattern at point P, as shown in Figure 27.

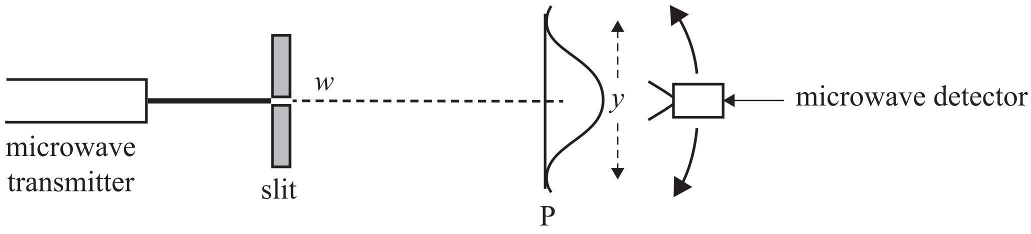


Figure 27

The microwave set has two wavelength settings: 3.0 cm and 6.0 cm. The teacher changes the setting from 3.0 cm to 6.0 cm.

Describe the effect of changing the wavelength setting on the pattern as observed. Explain your answer. 2 marks

Question 18 (11 marks)

Students set up the apparatus shown in Figure 28 to study the photoelectric effect. The apparatus consists of a light source, a filter and a photocell (a metal emitting plate on which light falls and a collecting electrode/collector, all enclosed in a vacuum tube).

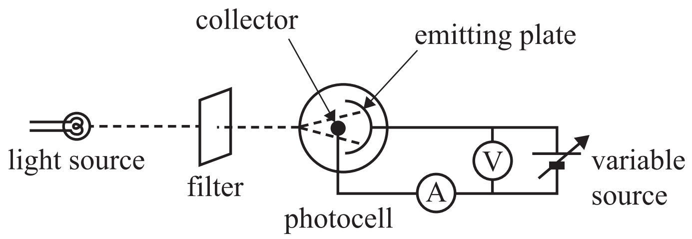


Figure 28

a. The students allow light of 500 nm to shine on the photocell.

Determine the energy of each photon of this light. 2 marks

eV

The students then begin the experiment with the collector negative, with respect to the emitting plate. They gradually reduce the voltage to zero and then increase it to positive values. They measure the current in ammeter A and plot the graph as shown in Figure 29.

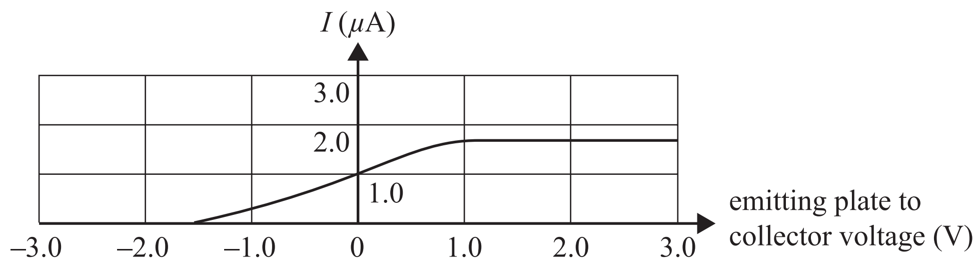


Figure 29

b. Using the graph in Figure 29, determine the maximum kinetic energy of the emitted photoelectrons. 1 mark

eV

c. Determine the work function of the metal of the emitting plate. Show your working. 2 marks

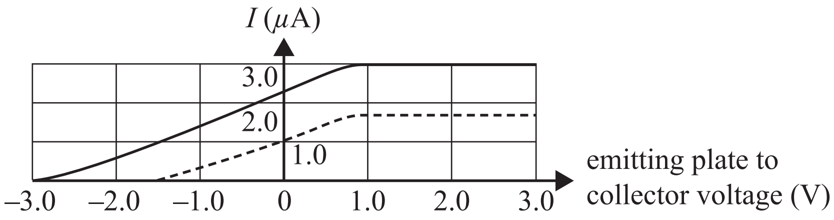
eV

d. Explain why the graph in Figure 29 is a flat, straight line beyond V = +1.0 V. 2 marks

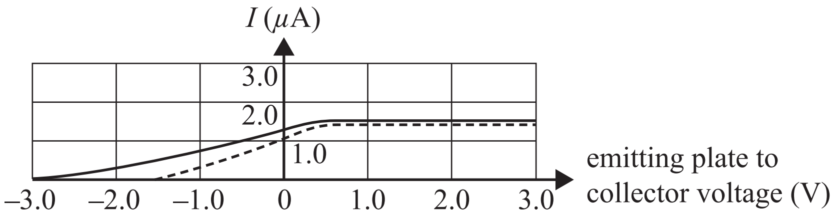
e. The students double the intensity of the light, keeping the frequency the same, and plot the results on a graph, with the original current shown as a dashed line.

Which one of the following graphs (**A.–D.**) will they now obtain? 1 mark

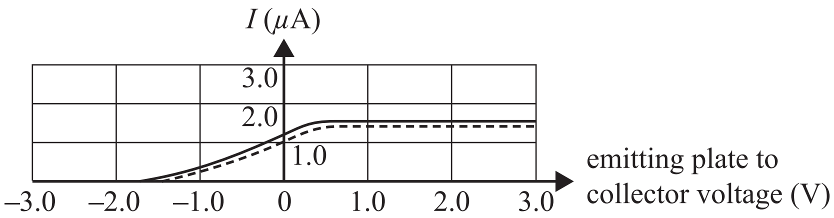
A.



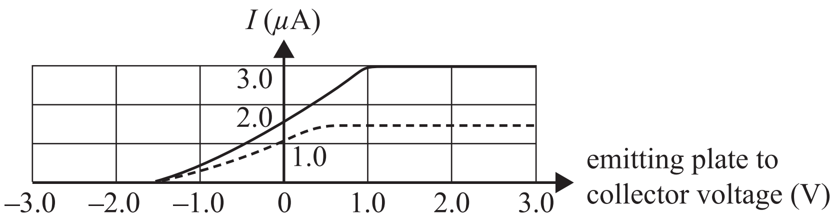
B.



C.



D.



f. Explain your answer to **part e.**, with reference to the particle model and the wave model of light. 3 marks

Question 19 (5 marks)

Students use a piece of apparatus to study electron diffraction. The apparatus consists of an evacuated tube, with an electron gun at one end, a crystal in front of the electron gun and a screen at the other end. The apparatus is shown in Figure 30.

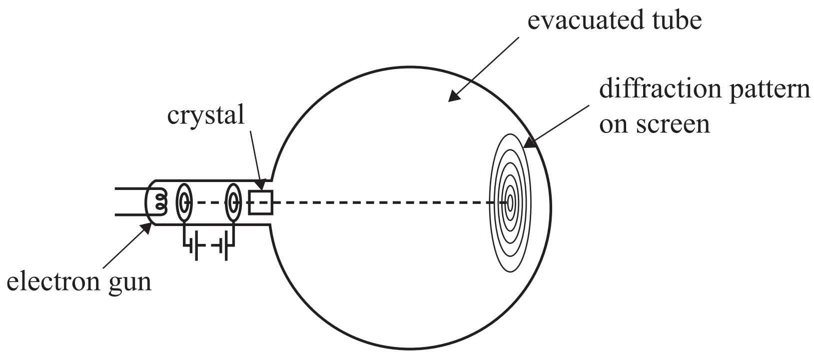


Figure 30

The electrons are accelerated by a voltage to a speed of 2.0×10^7 m s^{-1}. The mass of an electron is 9.1×10^{-31} kg.

a. Calculate the de Broglie wavelength of these electrons. Show your working. 2 marks

nm

b. X-rays can produce the same diffraction pattern as electrons.

Calculate the energy that the X-rays must have to produce the same diffraction pattern as electrons with a de Broglie wavelength of 0.10 nm. Show your working. 3 marks

eV

Question 20 (3 marks)

Figure 31 shows the energy levels for a sodium atom.

Figure 31
not to scale

A sodium atom is excited to the $n = 3$ state.

List all of the photon energies, in eV, that could be emitted as the sodium atom returns to the ground state.

Question 21 (4 marks)

De Broglie suggested that the quantised energy states of atoms could be explained in terms of electrons forming standing waves.

Describe how the concept of standing waves can help explain the quantised energy states of an atom. You should include a diagram.

END OF SECTION A
TURN OVER

SECTION B

Instructions for Section B

Answer **all** questions in pencil on the answer sheet provided for multiple-choice questions.
Choose the response that is **correct** for the question.
A correct answer scores 2; an incorrect answer scores 0.
Marks will **not** be deducted for incorrect answers.
No marks will be given if more than one answer is completed for any question.
Unless otherwise indicated, the diagrams in this book are **not** drawn to scale.

Detailed study – Materials and their use in structures

Use the following information to answer Questions 1–6.

An engineer is testing samples of different cable materials, A, B and C.
Each sample she tests has a cross-sectional area of 4.0×10^{-3} m^2 and a length of 0.50 m.
The results from each test were recorded and, from these, a stress-strain graph for each material was constructed, as shown in Figure 1.

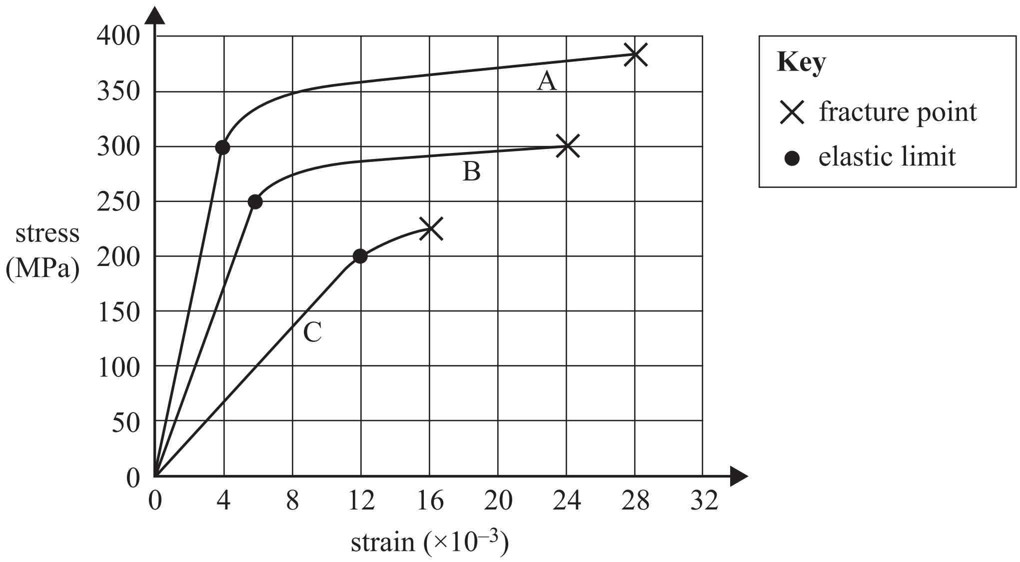


Figure 1

Question 1
Which material shows elastic behaviour over the largest range of strain values?

A. A
B. B
C. C
D. cannot be determined from the data

Question 2

Which material is the most ductile?

A. A

B. B

C. C

D. cannot be determined from the data

Question 3

Based on the data, which one of the following best gives Young's modulus for Material C?

A. 17 Pa

B. 1.7×10^{4} Pa

C. 1.3×10^{10} Pa

D. 1.7×10^{10} Pa

Question 4

Which material is the toughest?

A. A

B. B

C. C

D. cannot be determined from the data

Question 5

Which one of the following best gives the force required to break the sample of Material B?

A. 300 N

B. 1.2×10^{6} N

C. 3.0×10^{8} N

D. 1.2×10^{10} N

Question 6

The sample of Material C has a force of 2.0×10^{5} N applied to it.

Which one of the following best gives the extension (stretch from original length) of the sample?

A. 5.0×10^{-4} m

B. 1.5×10^{-3} m

C. 1.5×10^{-2} m

D. 0.50 m

Question 7

A cable is wound around a drum. The drum is held stationary at the left end by a brake and a load is hanging from the right end, as shown in Figure 2.

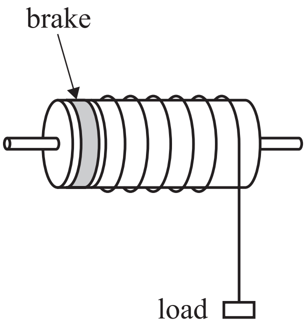


Figure 2

Which one of the following best describes the stress in the drum?

A. shear

B. elastic

C. ductile

D. tension

Use the following information to answer Questions 8–10.

A lookout platform is constructed using a 5 tonne (5000 kg) unreinforced concrete beam supported by a cable, as shown in Figure 3. Ignore the mass of the cable. The link at O is flexible to allow for a small amount of rotation as the cable expands and contracts.

At a particular time, a group of people with a combined mass of 500 kg stand at point Q, the very end of the platform.

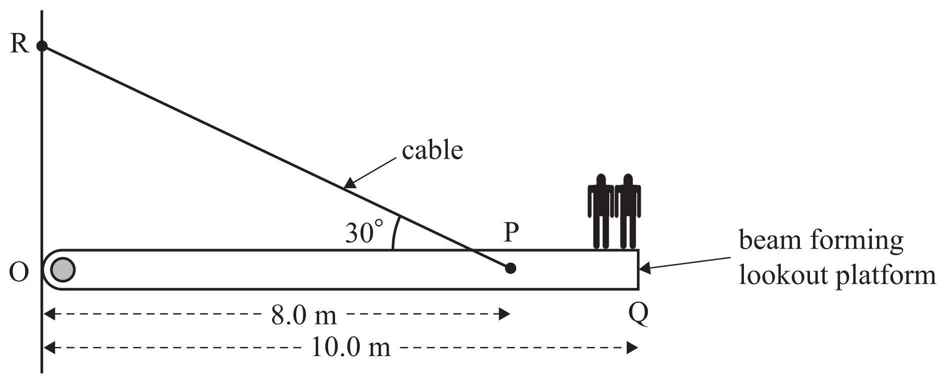


Figure 3

Question 8

Which one of the following best gives the torque about O due to the beam alone?

A. 2.5×10^3 N m

B. 5.0×10^3 N m

C. 2.5×10^5 N m

D. 4.0×10^5 N m

Question 9

Which one of the following best gives the tension in the cable RP?

A. 5.0×10^3 N

B. 5.0×10^4 N

C. 6.3×10^4 N

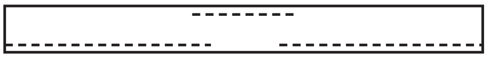
D. 7.5×10^4 N

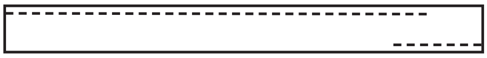
Question 10

Engineers find the unreinforced concrete beam is sagging dangerously in some places. To overcome this, they replace it with a reinforced concrete beam.

Which one of the following gives the best placement for steel reinforcing rods in the concrete beam?

A. 

B. 

C. 

D. 

Question 11

Figure 4 shows the design for a truss bridge that is to be constructed using steel girders.

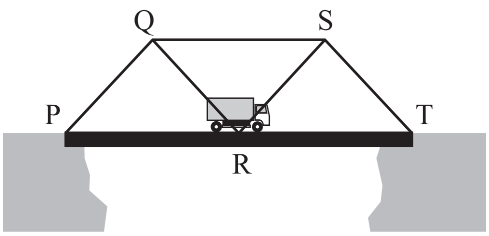


Figure 4

Road authorities want the mass of the bridge to be reduced. An engineer has suggested replacing some of the steel girders with steel cables.

Which of the following best shows the steel girders that could safely be replaced with steel cables?

A. QR and SR

B. QR, SR and QS

C. PQ, QS and ST

D. PQ and ST

END OF QUESTION AND ANSWER BOOK

VICTORIAN CURRICULUM
AND ASSESSMENT AUTHORITY

Victorian Certificate of Education
2017

PHYSICS

Written examination

Monday 5 June 2017
Reading time: 10.00 am to 10.15 am (15 minutes)
Writing time: 10.15 am to 12.45 pm (2 hours 30 minutes)

FORMULA SHEET

Instructions

- A question and answer book is provided with this formula sheet.

Students are NOT permitted to bring mobile phones and/or any other unauthorised electronic devices into the examination room.

1	velocity; acceleration	$v = \frac{\Delta x}{\Delta t}; \quad a = \frac{\Delta v}{\Delta t}$
2	equations for constant acceleration	$v = u + at$ $x = ut + \frac{1}{2}at^2$ $v^2 = u^2 + 2ax$ $x = \frac{1}{2}(v+u)t$
3	Newton's second law	$\Sigma F = ma$
4	circular motion	$a = \frac{v^2}{r} = \frac{4\pi^2 r}{T^2}$
5	Hooke's law	$F = -kx$
6	elastic potential energy	$\frac{1}{2}kx^2$
7	gravitational potential energy near the surface of Earth	mgh
8	kinetic energy	$\frac{1}{2}mv^2$
9	Newton's law of universal gravitation	$F = G\frac{M_1 M_2}{r^2}$
10	gravitational field	$g = G\frac{M}{r^2}$
11	acceleration due to gravity at Earth's surface	$g = 10 \text{ m s}^{-2}$
12	voltage; power	$V = RI \qquad P = VI = I^2R$
13	resistors in series	$R_T = R_1 + R_2$
14	resistors in parallel	$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$
15	transformer action	$\frac{V_1}{V_2} = \frac{N_1}{N_2}$
16	AC voltage and current	$V_{RMS} = \frac{1}{\sqrt{2}}V_{peak} \qquad I_{RMS} = \frac{1}{\sqrt{2}}I_{peak}$
17	magnetic force	$F = I\,l\,B$

18	electromagnetic induction	emf: $\varepsilon = -N\dfrac{\Delta\Phi}{\Delta t}$ flux: $\Phi = BA$
19	transmission losses	$V_{\text{drop}} = I_{\text{line}} R_{\text{line}}$ $P_{\text{loss}} = I^2_{\text{line}} R_{\text{line}}$
20	mass of the electron	$m_e = 9.1 \times 10^{-31}$ kg
21	charge on the electron	$e = -1.6 \times 10^{-19}$ C
22	Planck's constant	$h = 6.63 \times 10^{-34}$ J s $h = 4.14 \times 10^{-15}$ eV s
23	speed of light	$c = 3.0 \times 10^{8}$ m s^{-1}
24	photoelectric effect	$E_{K\,\text{max}} = hf - W$
25	photon energy	$E = hf$
26	photon momentum	$p = \dfrac{h}{\lambda}$
27	de Broglie wavelength	$\lambda = \dfrac{h}{p}$
28	speed, frequency and wavelength	$v = f\lambda$
29	energy transformations for electrons in an electron gun (<100 keV)	$\frac{1}{2}mv^2 = eV$
30	radius of electron path	$r = \dfrac{mv}{eB}$
31	magnetic force on a moving electron	$F = evB$
32	electric field between charged plates	$E = \dfrac{V}{d}$
33	stress	$\sigma = \dfrac{F}{A}$
34	strain	$\varepsilon = \dfrac{\Delta L}{L}$
35	Young's modulus	$E = \dfrac{\text{stress}}{\text{strain}}$
36	universal gravitational constant	$G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}
37	mass of Earth	$M_E = 5.98 \times 10^{24}$ kg
38	radius of Earth	$R_E = 6.37 \times 10^{6}$ m

TURN OVER

39	mass of the electron	$m_e = 9.1 \times 10^{-31}$ kg
40	charge on the electron	$e = -1.6 \times 10^{-19}$ C
41	speed of light	$c = 3.0 \times 10^{8}$ m s^{-1}

Prefixes/Units

p = pico = 10^{-12}

n = nano = 10^{-9}

μ = micro = 10^{-6}

m = milli = 10^{-3}

k = kilo = 10^{3}

M = mega = 10^{6}

G = giga = 10^{9}

t = tonne = 10^{3} kg

END OF FORMULA SHEET