INSIGHT

Trial Exam Paper

2011

PHYSICS

Written examination 1

Worked Solutions

This book presents:

- worked solutions, giving you a series of points to show you how to work through the questions
- mark allocation details
- tips

SECTION A – Core

Area of study 1 – Motion on one and two dimensions

Use the following information to answer questions 1 and 2.

Figure 1 shows a speed versus time graph for a remote-controlled toy car as it moves on a flat surface in a straight line.

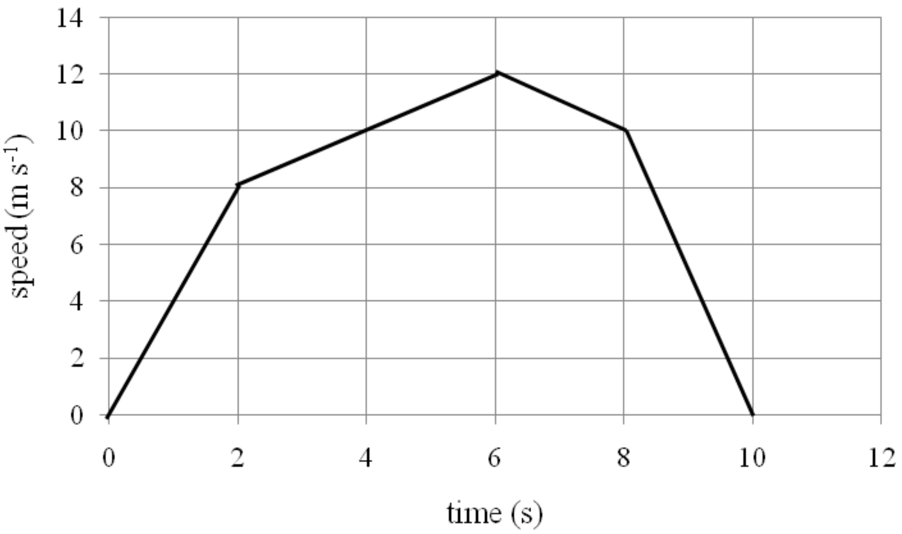


Figure 1

Question 1

Determine the magnitude of the distance travelled by the car in 10 seconds.

Worked solution

Number of area units (rectangles) = 20
Each area unit = 4 m
Therefore, distance travelled = 80 m.

80 m

2 marks

Mark allocation

- 1 mark for identifying that distance is the area under the graph.
- 1 mark for the correct answer.
- Allow use of simple shapes in calculating areas, provided that working is clearly shown.

Question 2

Calculate the magnitude of acceleration of the car in the 5th second of its motion.

Worked solution

Acceleration is the gradient of the graph at 5 s = $\frac{2}{2}$ = 1 m s^{-2}.

1 m s^{-2}

2 marks

Mark allocation

- 1 mark for acknowledging that acceleration is the gradient of the *v*–*t* graph.
- 1 mark for the correct answer.

Tips

- *Check units and axes carefully*.
- *Remember that the gradient of a v–t graph is acceleration and area under the graph is displacement.*
- *Remember to distinguish between scalar and vector quantities.*

Use the following information to answer questions 3–6.

A 4.0 kg cubic block of brass slides from rest on a relatively smooth horizontal floor as it is pulled by a force of 15.0 N acting at an angle of 20°, as shown in Figure 2. There is a constant friction force of 6.0 N acting on the block as it slides forward with uniform acceleration.

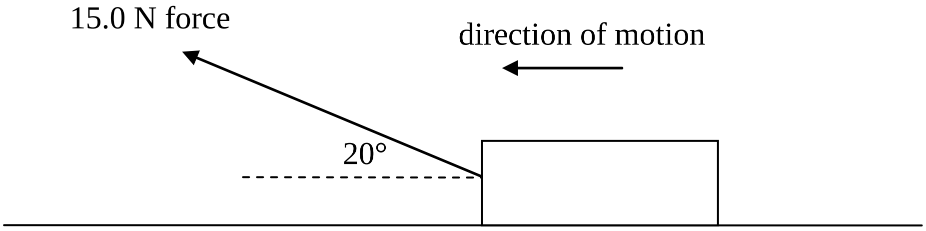


Figure 2

Question 3

Determine the velocity of the block after 3 seconds of motion.

Worked solution

In accordance with Newton's second law:

$$a = \frac{F_{\text{net}}}{m} = \frac{15\cos 20° - 6}{4.0} = 2.02 \text{ m s}^{-2}$$

Using equations of motion: $v = u + at = 0 + (2.02 \times 3) = 6.07 \text{ m s}^{-1}$

6.07 m s^{-1}

3 marks

Mark allocation

- 1 mark for calculating acceleration correctly.
- 1 mark for correctly using acceleration in equation of straight line motion.
- 1 mark for correct answer.

Question 4

Determine the distance travelled by the block in the time interval from 2.0 s to 4.0 s.

Worked solution

Distance travelled in the time interval 2.0 s to 4.0 s is
(Distance travelled in 4.0 s) – (Distance travelled in 2.0 s).

So, $\frac{1}{2}at^2 = \frac{1}{2} \times 2.02 \times (4^2 - 2^2) = 12.12 \text{ m}$

12.12 m

2 marks

Mark allocation

- 1 mark for correctly calculating distance travelled in 4.0 s and in 2.0 s.
- 1 mark for subtracting the two distances and getting the correct answer.
- Or 2 marks to be given if answer is correct and complete calculation is done in a combined step.

Question 5

Calculate the work done by the force of 15.0 N on the block as it moves a distance of 2.0 m.

Worked solution

Work done is:
$W = F\cos\theta \times d = 15\cos 20° \times 2 = 28.2$ J

28.2 J

2 marks

Mark allocation

- 1 mark for correct working.
- 1 mark for correct answer.
- No marks if components of vectors used are incorrect.

Question 6

What is the kinetic energy gained by the block as it travels the first 2.0 m from rest?

Worked solution

Kinetic energy gained = Effective work done
So, $\Delta E_{\mathrm{k}} = (F\cos\theta \times d) - (F_{\mathrm{friction}} \times d) = 28.2 - 12 = 16.2$ J

16.2 J

2 marks

Mark allocation

- 1 mark for subtracting work done and energy loss due to friction.
- 1 mark for the correct answer.

Tips

- *Distinguish between work done and work transformed to mechanical energy. The loss of energy due to friction is not transformed to useful mechanical energy.*
- *Remember to use correct component of vector quantities, such as force.*

Use the following information to answer questions 7–9.

Two trolleys, A and B, of masses 6.0 kg and 3.0 kg, respectively, are initially connected together by a spring and placed on a frictionless air track, as shown in Figure 3. When the connection between the two trolleys is broken suddenly, trolley A is found to move to the left at a constant velocity of 2.0 m s^{-1} and trolley B moves to the right. The direction of motion of each trolley is shown by an arrow in Figure 3. The example can be viewed as an explosion.

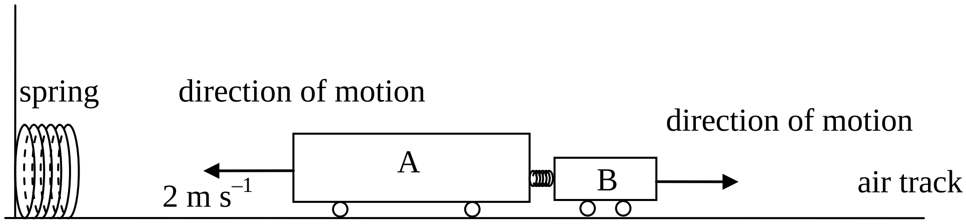


Figure 3

Question 7

Calculate the magnitude of velocity of trolley B just as it moves away from trolley A.

Worked solution

Using conservation of momentum, initial momentum = 0 = final momentum.
$6 \times 2 = 3 \times v_B$, where v_B is the speed of trolley B.
Therefore, v_B = 4 m s^{-1}.

4 m s^{-1}

2 marks

Mark allocation

- 1 mark for using conservation of momentum correctly.
- 1 mark for the correct answer.

Question 8

Determine whether the 'explosion' of trolleys is an elastic or inelastic process? Explain your answer.

Worked solution

In an inelastic process kinetic energy is *not* conserved. The initial kinetic energy is zero. Since kinetic energy is a scalar quantity and both trolleys are moving, the final kinetic energy is not zero. Hence, the process is inelastic.

2 marks

Mark allocation

- 1 mark for concluding that the process is inelastic.
- 1 mark for reasoning based on kinetic energy before and after 'explosion'.

Question 9

As trolley A moves to the left, it strikes a spring attached to a wall such that the spring is compressed by 4.0 mm. The trolley comes to an immediate rest, transferring all its energy to the spring. Estimate the spring constant of the spring.

Worked solution

Kinetic energy of the trolley is converted to elastic energy in the spring.

$\frac{1}{2}mv^2 = \frac{1}{2}kx^2$, where x is the compression of the spring and k is the spring constant.

$\frac{1}{2} \times 6 \times 2^2 = \frac{1}{2}k \times 0.004^2$

So, $k = 1.5 \times 10^6$ N m^{-1}.

1.5×10^6 N m^{-1}

3 marks

Mark allocation

- 1 mark for correct use of conservation of energy expression.
- 1 mark for substituting correct values for kinetic energy and elastic potential energy.
- 1 mark for the correct answer.

Tips

- *Take care to use appropriate signs when dealing with vector quantities.*
- *Remember that momentum is always conserved in a closed system. It is the kinetic energy that may or may not be conserved and this would determine whether the process is inelastic or elastic.*

Use the following information to answer questions 10–12.

A 200 g toy aeroplane flies in the air with constant speed and its motion is controlled by a remote device. Figure 4 shows the view from top as the aeroplane makes a horizontal circle in the air, with uniform speed. It makes 10 revolutions in 25 seconds.

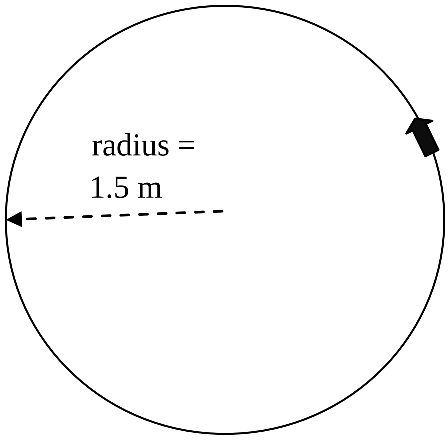


Figure 4

Question 10

Calculate the speed of the aeroplane.

Worked solution

Speed is $v = \frac{2\pi r}{T} = \frac{2\pi \times 1.5}{2.5} = 3.77 \text{ m s}^{-1}$.

3.77 m s^{-1}

2 marks

Mark allocation

- 1 mark for correct use of the expression for speed and time period.
- 1 mark for the correct answer.

Question 11

Determine the magnitude of the net force on the aeroplane as it makes the 10 revolutions in 25 seconds at constant speed while making the horizontal circle.

Worked solution

Centripetal force is $F = \frac{mv^2}{r} = \frac{0.2 \times 3.77^2}{1.5} = 1.89 \text{ N}$.

1.89 N

2 marks

Mark allocation

- 1 mark for correct use of the expression for centripetal force.
- 1 mark for the correct answer.
- 2 consequential marks if wrong value of speed used but all other working is clear.

Question 12

The toy aeroplane now flies in a vertical circle of radius 1.5 m at a constant speed of 5.0 m s^{-1}. Figure 5 shows a side-view of the vertical circle.

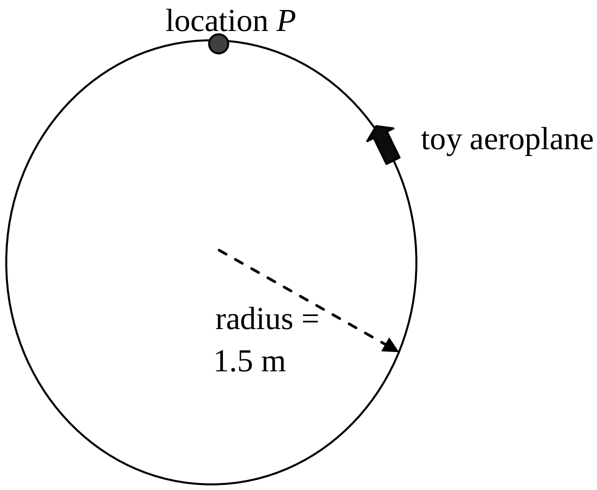


Figure 5

What will be its apparent weight at location *P*, which is the top of the circle? Show your working.

Worked solution

The apparent weight = Normal contact force

So, $\frac{mv^2}{r} - mg = \left(\frac{0.2 \times 5^2}{1.5}\right) - (0.2 \times 10) = 1.33 \text{ N}.$

1.33 N

2 marks

Mark allocation

- 1 mark for correctly using the equation for apparent weight.
- 1 mark for the correct answer.

Tips

- When the normal contact force is zero, the apparent weight is zero.
- When motion occurs in a vertical circle, apparent weight is less at the top of the circle than it is at the bottom of the circle.

Use the following information to answer questions 13–15.

A motorcycle stunt rider uses a 30° ramp to launch his motorcycle from a tower of height *h*, as shown in Figure 6, and lands a distance *R* from the base of the tower. Observers measure the rider's launch speed to be 10.0 m s^{-1} and the time of flight to be 1.4 seconds.

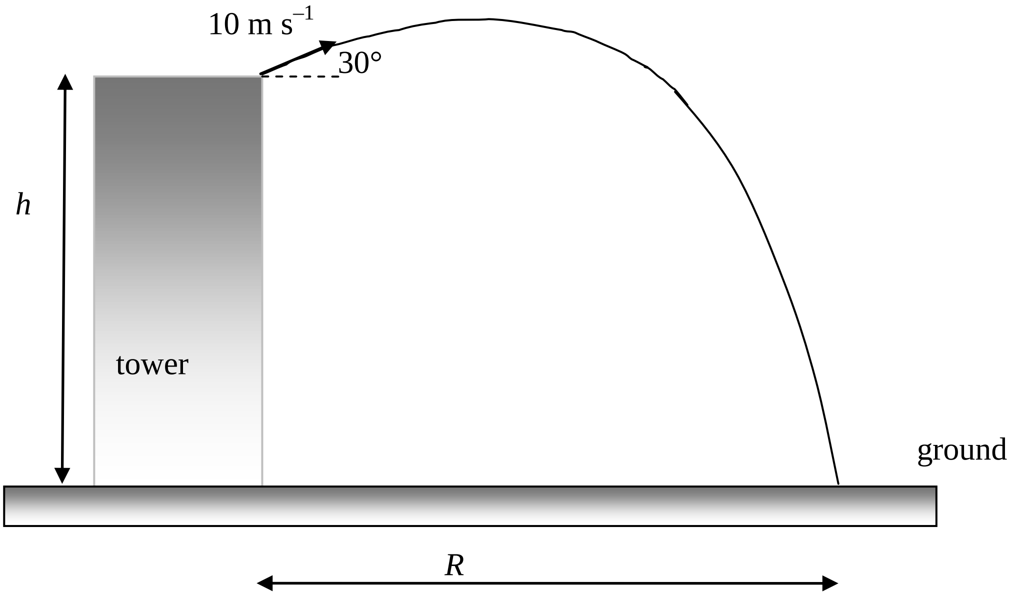


Figure 6

Question 13

Calculate the height, *h*, from which the motorcycle is launched.

Worked solution

Analyse motion in the vertical direction using vertical component of initial speed (taken as positive) and downward motion (taken as negative).

$h = ut + \frac{1}{2}at^2 = 5(1.4) - \frac{1}{2} \times 10 \times 1.4^2 = -2.8 \text{ m}$

Hence, h = 2.8 m.

2.8 m

3 marks

Mark allocation

- 1 mark for correct use of straight-line equation of vertical motion.
- 1 mark for correct use of signs in the equation.
- 1 mark for the correct answer.

Question 14

What is the distance, R, from the base of the tower where the motorcycle lands?

Worked solution

Distance is $R = u_{\text{horizontal}} \times t = 10\cos 30° \times 1.4 = 12.12$ m.

12.12 m

2 marks

Mark allocation

- 1 mark for correctly using the horizontal component of initial speed.
- 1 mark for the correct answer.

Question 15

Determine the height above the ground of the motorcycle at a time 0.70 seconds after launch. Show your working clearly.

Worked solution

Vertical distance travelled from launch is:

$$x = (u_{\text{vertical}} \times t) + \frac{1}{2}at^2$$

$$= (5 \times 10\sin 30° \times 1.4) - \frac{1}{2} \times 10 \times 1.4^2$$

$$= 1.05 \text{ m}$$

Therefore, height above ground = 2.80 m + 1.05 m = 3.85 m.

3.85 m

3 marks

Mark allocation

- 1 mark for applying the correct equation.
- 1 mark for correctly calculating height from launch.
- 1 mark for adding height of the tower.
- Award consequential 3 marks if x is correct but an incorrect value is added from previous answer for height of tower.

Tips

- *Take care to use the correct signs for vector quantities.*
- *Read the question carefully to ensure that you answer what is being asked.*

Use the following information to answer questions 16–18.

A spacecraft of total mass 2500 kg is orbiting Earth in a circular orbit with a uniform speed of 7500 m s^{-1}. In the following questions the data below may be needed.

G 6.67×10^{-11} N m^2 kg^{-2}
M_E 5.98×10^{24} kg
R_E 6.37×10^{6} m

Question 16

How high above the surface of Earth is the spacecraft placed? Give your answer in km.

Worked solution

Net force on the satellite = $G\frac{M_1 M_2}{r^2} = \frac{mv^2}{r}$

Therefore, $r = G\frac{M}{v^2} = \frac{6.67 \times 10^{-11} \times 5.98 \times 10^{24}}{7500^2} = 7.09 \times 10^6$ m, where r = distance from centre of Earth to centre of satellite.

Therefore, distance from surface of Earth is:

$7.09 \times 10^6 - R_E = 7.09 \times 10^6 - 6.37 \times 10^6 = 720$ km

720 km

3 marks

Mark allocation

- 1 mark for correct use of the equation.
- 1 mark for determining r correctly.
- 1 mark for subtracting the radius of Earth (R_E) from r.

Question 17

Calculate the gravitational field strength experienced by the satellite due to its proximity to Earth.

Worked solution

Gravitational field strength is:

$g = G\frac{M}{r^2} = \frac{6.67 \times 10^{-11} \times 5.98 \times 10^{24}}{(7.09 \times 10^6)^2} = 7.93$ N kg^{-1}

7.93 N kg^{-1}

2 marks

Mark allocation

- 1 mark for substituting the correct numerical values into the expression for *g*. No marks if *r* taken as distance from surface of Earth.
- 1 mark for the correct answer.
- Award consequential 2 marks if incorrect value from previous question is used but all else is correct.
- An alternative method using $g = \frac{v^2}{r}$ may also be applied and gives the same answer.

Question 18

As the spacecraft maintains its uniform circular motion in orbit, a 60 kg astronaut in the spacecraft decides to measure her weight and attaches a spring balance to her feet. What will be the reading of the spring balance? Explain your answer.

Worked solution

The spring balance measures apparent weight, which will be zero. It will be zero because the astronaut is in ‘free fall’, where there is no normal reaction force.

0 N

2 marks

Mark allocation

- 1 mark for concluding that apparent weight will be zero.
- 1 mark for correct explanation. There should be mention of zero normal contract force.

Tips

- *Remember that r in the expressions for satellite motion is the distance from centre to centre of two bodies, not from the surface.*
- *Familiarise yourself with the use of your scientific calculator to solve large indices.*
- *Take care to ensure all calculations are in metres, although answers are sometimes required in kilometres.*

Area of study 2 – Electronics and photonics

Use the following information to answer questions 1–3.

A 6.0 V DC power supply powers a diode, a 1000 Ω resistor and a variable resistor, *R*, as shown in Figure 1a. The characteristic graph of the diode is shown in Figure 1b. A voltmeter is connected across the 1000 Ω resistor, as shown.

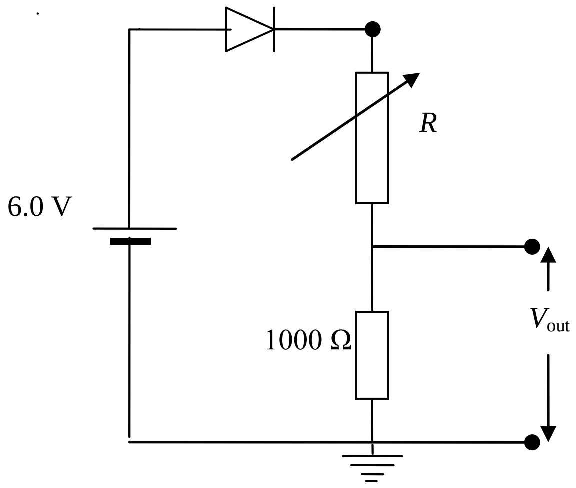


Figure 1a

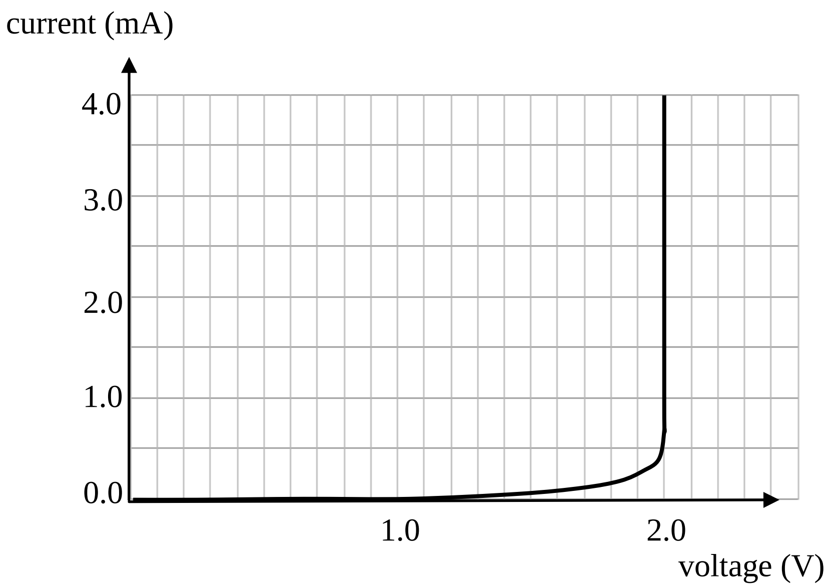


Figure 1b

Question 1

Determine the resistance of the variable resistor when the voltage across the 1000 Ω resistor is 1.0 V.

Worked solution

Voltage across the diode when fully charged is 2.0 V.
Therefore, the voltage across the resistor, *R*, is 6.0 – (2.0 + 1.0) = 3.0 V.
This means that the ratio of voltages between the two resistors is 3 : 1. Since resistances are in the same ratio as voltages, the resistance of the variable resistor must be 3000 Ω.

3000 Ω

2 marks

Mark allocation

- 1 mark for accounting for all three voltage drops.
- 1 mark for the correct answer.

Question 2

Calculate the current through the variable resistor when the voltage across the 1000 Ω resistor is increased to 2.0 V. Give your answer in mA.

Worked solution

Current is $I = \frac{V}{R} = \frac{2.0}{1000} = 2.0\text{ mA}$.
In the series circuit, the current through the two resistors will be the same.

2.0 mA

2 marks

Mark allocation

- 1 mark for correct use of Ohm's law.
- 1 mark for recognising that the current in the two resistors is the same.

Question 3

If the resistance of the variable resistor is reduced, will the voltage across the 1000 Ω resistor increase or decrease? Explain your answer.

Worked solution

Since there is a drop of 2.0 V across the diode, 4.0 V needs to be divided amongst the two resistors. If the resistance of the variable resistor is reduced, then the voltage across it will also reduce. Hence, the voltage across the 1000 Ω resistor will increase.

Increase

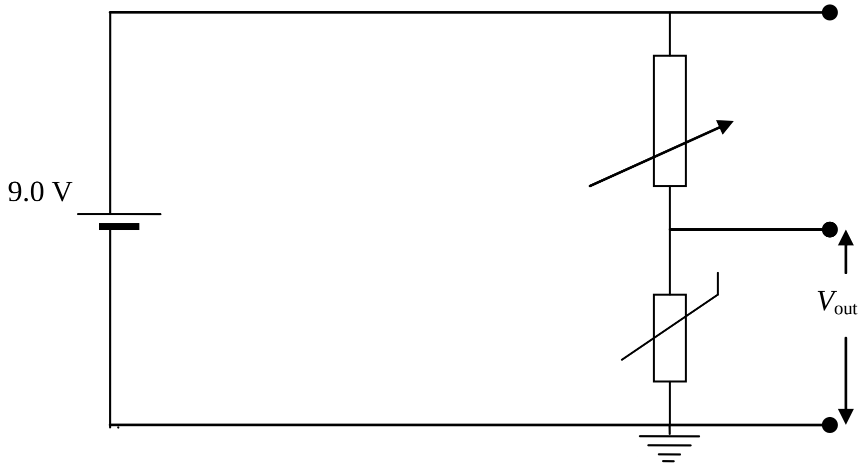
3 marks

Mark allocation

- 1 mark for correct conclusion.
- 2 marks for correct reasoning, with 1 mark awarded for calculation/reasoning of voltages and 1 mark for mentioning relationship between voltage and resistance.

Use the following information to answer questions 4–6.

The temperature in a room is to be maintained below 15°C by use of a cooling system that is controlled by a thermistor. The characteristic graph of the thermistor and the circuit used for it is shown in Figure 2 below.



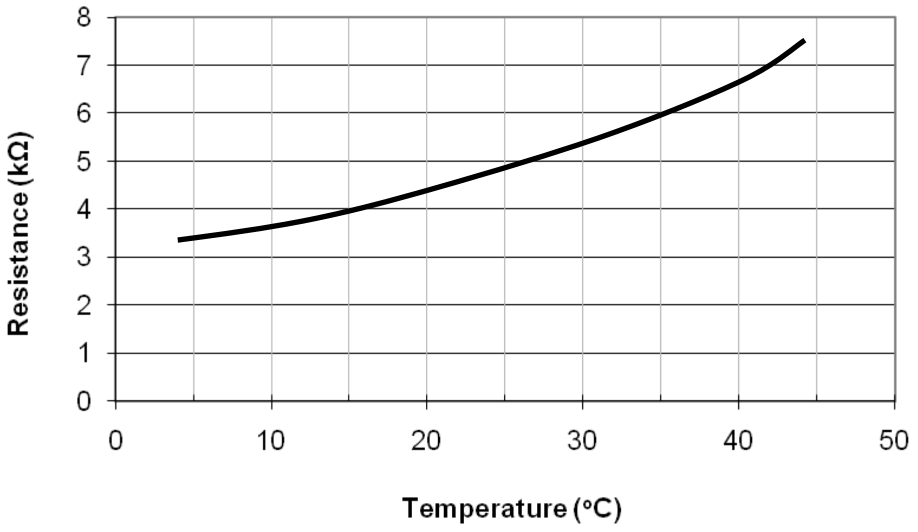


Figure 2

Question 4

What will be the change in temperature of the room for the resistance of the thermistor to increase from 4000 Ω to 6000 Ω?

Worked solution

Temperature at 4000 Ω is 15°C and at 6000 Ω is 35°C.
Therefore, change in temperature is 20°C.

20°C

2 marks

Mark allocation

- 1 mark for correctly identifying the corresponding temperatures.
- 1 mark for subtracting the two temperatures.

Question 5

The cooler circuit is designed in such a way that the cooler comes on when the temperature is ≥ 15°C and the output voltage, V_{out}, is ≥ 3.0 V. At these magnitudes of temperature and voltage output, what will be the value of the variable resistor for the cooler to just come on?

Worked solution

6.0 V must be across the variable resistor. Its resistance must therefore be double that of the thermistor's. Since the thermistor's resistance is 4000 Ω at 15°C, the resistance of the variable resistor must be 8000 Ω.

8000 Ω

2 marks

Mark allocation

- 1 mark for correctly using the voltage divider conditions.
- 1 mark for the correct answer.

Question 6

Shaun finds that 15°C is too warm for the cooler and wishes the cooler to come on at a lower temperature. Should he have the variable resistor at a higher or a lower resistance for the cooler to switch on, assuming the cooler still switches on at 3.0 V?

Worked solution

For cooler to switch on at 3.0 V, there must be a 6.0 V drop across the variable resistor. At lower temperatures the resistance of the thermistor is lower. Since $V \propto R$, the resistance of the variable resistor must also be lower to maintain the correct voltage ratio.

3 marks

Mark allocation

- 1 mark for the correct answer.
- 2 marks for an appropriate explanation; e.g. 1 mark for identifying the 6.0 V drop across the variable resistor and 1 mark for correct reasoning based on either the voltage divider concept or using numerical values.

Tips

- *Remember that voltage across a resister is proportional to its resistance, so that the ratio of two resistances is also the ratio of the voltage divided between them in a voltage divider circuit.*
- *You can use numerical values to gauge whether an output voltage increases or decreases in thermister circuits.*

Use the following information to answer questions 7–9.

The transfer characteristic graph of a transistor amplifier is shown below in Figure 3.

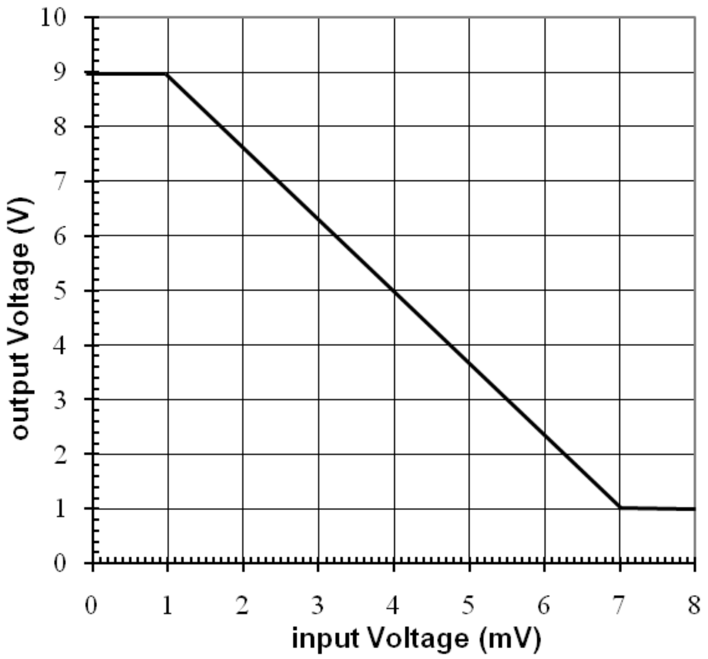


Figure 3

Question 7

Explain whether this amplifier is inverting or non-inverting.

Worked solution

The amplifier is inverting as the voltage gain, shown by the gradient of the graph, is negative. Therefore, the input signal will amplify to an inverting output signal.

2 marks

Mark allocation

- 1 mark for correctly identifying the amplifier as inverting.
- 1 mark for explanation based on gradient being negative.

Question 8

An AC signal, whose voltage waveform is shown below in Figure 4, is now fed into the amplifier and an undistorted amplified signal is obtained. What is the ideal DC voltage that should be provided to the input signal to avoid distortion? Explain your answer, using the term *bias* in an appropriate manner.

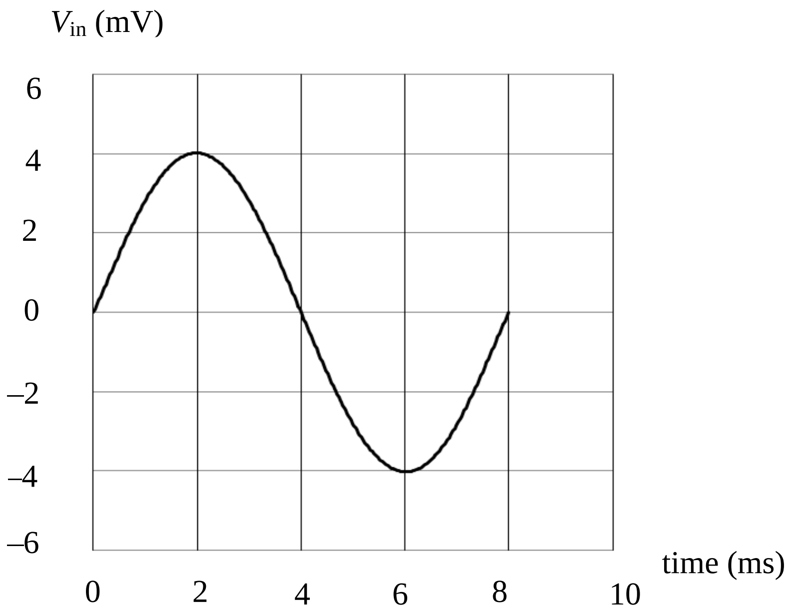


Figure 4

Worked solution

According to the transfer characteristic graph of the amplifier, the maximum range of input voltage is 7 – 1 = 6 mV.
The DC bias is the mid-point of the range; i.e. 4 mV.
The maximum peak value of an AC signal that would be amplified without distortion is ± 3 mV.

4 mV

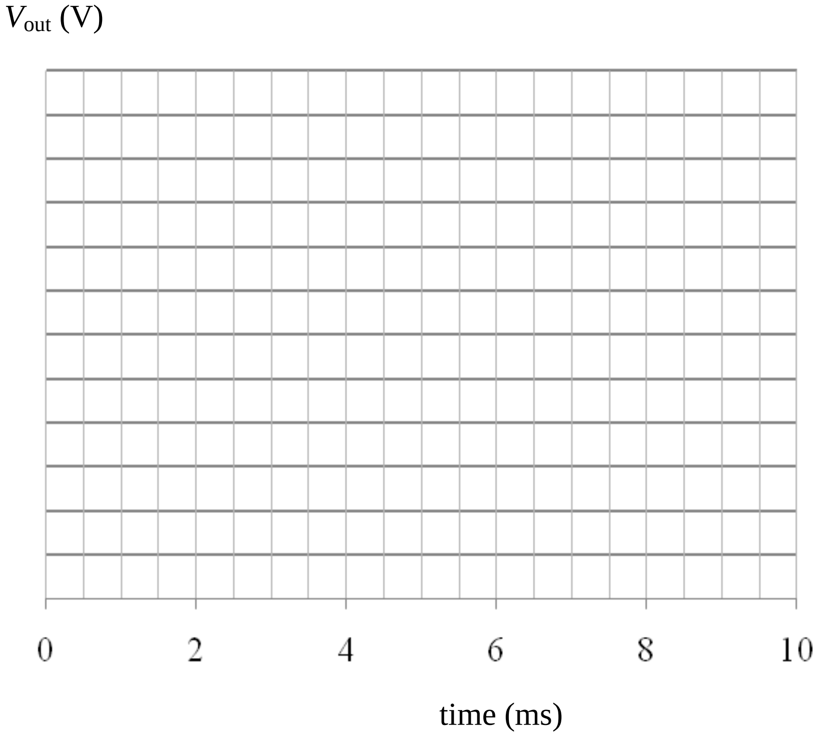
2 marks

Mark allocation

- 1 mark for correct answer.
- 1 mark for explanation that includes the identification of range and the DC bias as mid-point of the range.

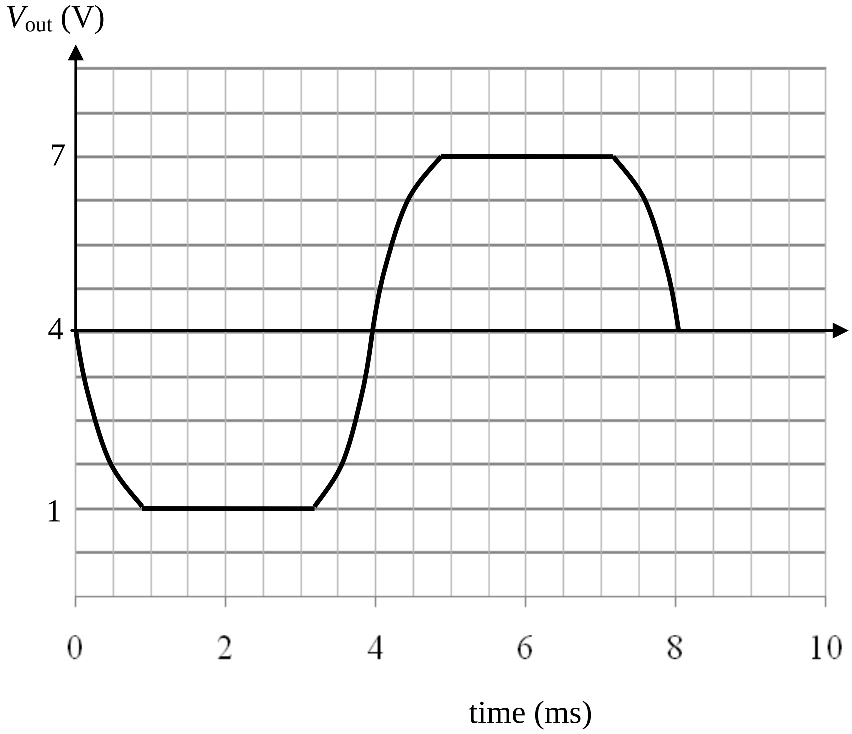
Question 9

Provided that the input signal is fed into the amplifier *with appropriate biasing*, sketch the expected output signal on the axes provided below.



Worked solution

The voltage gain of the amplifier is –1333.33. The signal has a peak voltage of ± 4 mV but only ± 3 mV can be amplified without clipping. Hence, the output will be inverted and clipped. Peak value should have been ± 5.33 V but will be clipped at about ± 4 V. The DC bias of 4 mV means that the signal will be positive and have an output voltage of 4 mV at 0 ms.



3 marks

Mark allocation

- 1 mark for correctly calculating the gain of the amplifier.
- 1 mark for inverting the signal.
- 1 mark for finding correct value of peak voltage.
- Take 1 mark off if time period has changed.

Tips

- *Remember that the amplifier can be inverting (negative gradient) or non-inverting (positive) gradient.*
- *Check the units carefully, particularly as input signal is often in mV and ms.*

Use the following information to answer questions 10 and 11.

Figure 5 shows how an audio signal is sent across a fibre optic link to a loudspeaker. It uses an LED, a photodiode and amplifiers to transmit and receive an intensity-modulated signal. Figure 5 also shows the shape of the signal as it emerges from the amplifier and is fed into the LED.

Figure 5

Question 10

Explain what is meant by the term *modulation* in this context.

Modulation ____

____

Worked solution

In this application, *modulation* is the process by which the time varying signal from the microphone is changed from a voltage–time graph to a time varying light intensity graph for transmission through the fibre optic link.
Furthermore, *demodulation* in this application is the process by which the time varying light signal is changed to a voltage–time signal to be fed into the loudspeaker.

2 marks

Mark allocation

- 1 mark each for correctly identifying the time varying nature of modulation.
- 1 mark for making reference to the relation between voltage input and light output signal.

Question 11

Explain whether the photodiode in the circuit should be connected in *forward bias* or *reverse bias*?

Worked solution

The photodiode should be in reverse bias. When in reverse bias, there is no current (although sometimes a negligible 'dark current' may flow) flowing through the circuit. When light shines on it, current flows through the circuit in proportion to the intensity of light.
In forward bias, a current always flows through the circuit and a proportional change is not practically seen. Hence, a photodiode is always connected in reverse bias.

2 marks

Mark allocation

- 1 mark for correct conclusion.
- 1 mark for appropriate explanation based on 'dark current' and proportional response to light.

Tips

- *Terms like modulation and demodulation must be explained according to the question's context.*
- *Remember that in electronic circuits, photodiodes are always connected in reverse bias.*

END OF SECTION A
TURN OVER

SECTION B – Detailed studies

Detailed study 1: Einstein's special relativity

Use the following information to answer questions 1–3.

Michelson and Morley conducted an experiment to study how light waves propagated through *ether*. The experimental set-up was mounted on a rigid stand such that all components of the equipment are still compared to each other. A diagram of the set-up is shown below in Figure 1.

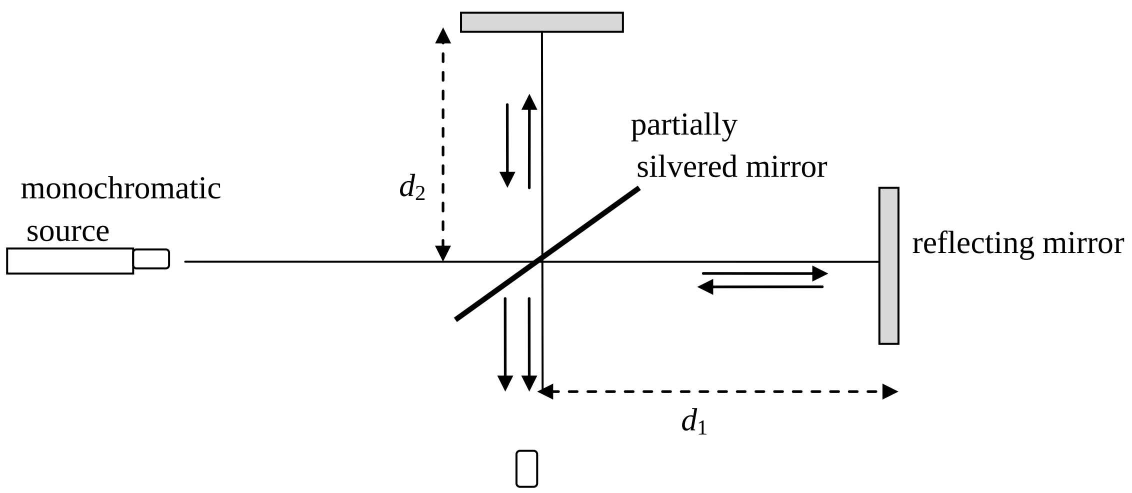


Figure 1

Question 1

Which of the following statements identifies the most important factor in a thorough conduct of the experiment?

A. The partially silvered mirror must transmit 50% of the light and reflect the other 50%.
B. Both reflecting mirrors must reflect 100% of the light.
C. **The distances d_1 and d_2 must be equal.**
D. The experiment must be carried out only on the equator.

Answer is C

Worked solution

Since the question already states that all parts of the equipment are still, the other vital parameter is the path difference between d_1 and d_2, which must be zero. This can occur when $d_1 = d_2$. This is critical to ensure that interference effects, if any, are only due to the relative motion of Earth and *ether* and not due to path difference.

Question 2

The experiment is said to have a ‘null’ outcome. Which of the following statements best describes the conclusion drawn from this result?

A. **Electromagnetic waves do not require a medium to travel.**
B. The speed of light is fastest in a vacuum but is not a constant.
C. The speed of light is constant at all times.
D. Light consists of oscillating electric and magnetic fields.

Answer is A

Worked solution

The ‘null’ result showed that there was no ether. Hence, electromagnetic waves do not require a medium to travel.

Question 3

Which of the following statements best describes an *inertial reference frame* when compared to the frame of an observer?

A. The two frames are stationary with respect to each other.
B. The frames are moving at constant acceleration with respect to each other.
C. With respect to the observer’s frame, the inertial frame is moving with constant acceleration.
D. **Inertial reference frames may move at constant speed or be stationary with respect to each other.**

Answer is D

Worked solution

Although A is also correct, statement D gives a more complete statement. Inertial frames are non-accelerating with respect to each other. Non-inertial reference frames are accelerating.

Tips

- *It is an important study aspect to clearly understand the concepts behind the Michelson–Morley experiment and of inertial reference frame.*
- *Develop conceptual understanding of electromagnetic waves and their propagation.*

Use the following information to answer questions 4–6.

In a linear accelerator laboratory, electrons are being accelerated by magnetic fields. Scientists measure properties of the electron as it is initially produced with zero speed and then systematically increases its speed close to that of the speed of light.

Question 4

Based on the theory of special relativity, which of the following is the best explanation for why an electron cannot reach the speed of light, *c*?

A. Electrons do not consist of an electric or magnetic field and, hence, cannot achieve the speeds of electromagnetic waves.
B. **Its relativistic mass increases as speed increases, limiting the speed to that of below *c*.**
C. As electrons speed up, they gain kinetic energy but lose radiant energy, so they slow down.
D. In its own reference frame, the electron can reach the speed of light, but to an observer in another reference frame, that speed will always be less than *c*.

Answer is B

Worked solution

As electrons speed up, mass dilation occurs, so an infinite acceleration is needed to approach *c*.

Question 5

In one experiment, the mass of an electron is observed to increase by a factor of 5. The speed at which it must be moving is closest to

A. 0.94*c*
B. 0.96*c*
C. **0.98*c***
D. 0.95*c*

Answer is C

Worked solution

Lorentz factor is $\gamma = 5 = \frac{m}{m_o} = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$

Therefore, v = 0.98*c*.

Question 6

For the electron in Question **5**, its kinetic energy is best estimated as

A. 1.1×10^{-13} J
B. 8.2×10^{-14} J
C. 9.9×10^{-13} J
D. $\mathbf{3.3 \times 10^{-13}}$ **J**

Answer is D

Worked solution

$$\begin{aligned}\text{Kinetic energy} &= m_o c^2(\gamma - 1)\\ &= 9.1\times10^{-31}\times(3\times10^{8})^2\times(5-1)\\ &= 3.28\times10^{-13}\text{ J}\end{aligned}$$

Tips

- Particles have mass dilation as they approach *c*.
- Remember to use relativistic calculations for kinetic energy.
- Take care in carrying out calculations for Lorentz factor. You may wish to practise a range of questions on simply calculating the Lorentz factor for various values of *v*.

Use the following information to answer questions 7–11.

An observer on Earth watches two UFO spaceships, U1 and U2, moving initially with constant speeds of 0.85*c* and 0.55*c*, respectively. At this time the spaceships were moving with constant speed in straight-line paths.

Question 7

When the two spaceships are moving in the same direction, their relative velocity with respect to one another is closest to

A. 0.65*c*
B. **0.56*c***
C. 0.54*c*
D. 0.45*c*

Answer is B

Worked solution

Relative velocity, $v_r = \dfrac{v_{U_1} - v_{U_2}}{1 - \dfrac{v_{U_1} \times v_{U_2}}{c^2}} = \dfrac{0.85 - 0.55}{1 - \dfrac{0.85 \times 0.55 c^2}{c^2}} c = 0.56c$

Question 8

When the two spaceships are moving in the opposite directions, their relative velocity with respect to one another is closest to

A. **0.95*c***
B. 0.59*c*
C. 0.89*c*
D. 0.98*c*

Answer is A

Worked solution

Relative velocity, $v_r = \dfrac{v_{U_1} + v_{U_2}}{1 - \dfrac{v_{U_1} \times v_{U_2}}{c^2}} = \dfrac{0.85 + 0.55}{1 - \dfrac{0.85 \times 0.55 c^2}{c^2}} c = 0.954c$

Question 9

It is known that spaceship U1 has a length of 30.0 m. When it passes the observer, she would observe the length to be closest to

A. 10.7 m
B. 39.3 m
C. **15.8 m**
D. 32.6 m

Answer is C

Worked solution

Observed length, $L = L_o\sqrt{1-\frac{v^2}{c^2}}$

$= 30\sqrt{1-0.85^2} = 15.8\text{ m}$

Question 10

At another time, the spaceship U1 changes its speed. The observer now measures the length of spaceship U1 to be 10.0 m. The speed at which the spaceship must be travelling is best estimated as

A. 0.98*c*
B. **0.94*c***
C. 0.88*c*
D. 0.84*c*

Answer is B

Worked solution

Using $L = L_o\sqrt{1-\frac{v^2}{c^2}}$

$10 = 30\sqrt{1-\frac{v^2}{c^2}}$

$v = 0.94c$

Tips

- *Remember that length contracts and time dilates for spaceships.*
- *The relative speed of objects moving towards each other is higher than if they were moving away.*

Question 11

A particle of rest mass 8.3×10^{-26} kg is sighted in a research particle accelerator travelling at 0.96*c*, only to disappear the next instant. If the particle has converted to pure energy, then this energy produced is best estimated as

A. **7.5×10^{-9} J**
B. 8.4×10^{-9} J
C. 1.2×10^{-8} J
D. 2.6×10^{-8} J

Answer is A

Worked solution

The energy produced is $E = mc^2 = 8.3\times10^{-26}\times(3\times10^8)^2 = 7.47\times10^{-9}$ J.

Tip

- *The energy produced is calculated from rest mass, not relativistic mass.*

Question 12

Which one of the following statements is postulated by Einstein’s special theory of relativity?

A. The measured values of length and time are the same in all inertial reference frames.
B. **Newton’s three laws of motion are valid in all inertial reference frames.**
C. The speed of light is constant in a vacuum when either the source or observer is stationary and can be slower if there is relative motion.
D. Newton’s second law of motion will not work in all inertial reference frames.

Answer is B

Worked solution

Measured values are not always the same in all reference frames, although the laws of Physics are. The speed of light is always constant in a vacuum, irrespective of relative motion. Hence, option B is the only correct answer.

Tips

- *Note carefully the relationships between relativistic and proper values for time, length and mass.*
- *Remember Einstein’s postulates; namely, the laws of Physics are the same in all inertial reference frames, and the speed of light in a vacuum is constant in all inertial reference frames.*

Detailed study 2: Materials and their use in structures

Use the following information to answer Question 1.

A steel mesh is often used to reinforce a concrete driveway, as shown in Figure 1. The mesh is placed on the ground and concrete placed over it so that the mesh is on the bottom half of the concrete.

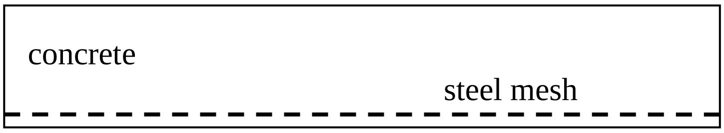


Figure 1

Question 1

Which of the following is the best reason why the steel mesh is placed in this way?

A. Steel is stronger than concrete in compression.
B. Steel is stronger than concrete in tension.
C. Steel will rust if close to the surface.
D. A steel mesh will reduce cracks in the concrete due to natural drying.

Answer is B

Worked solution

The driveway is subjected to tension forces during use. Steel is stronger than concrete in tension. Hence, a mesh of steel is placed at the bottom.

Tips

- *In order to solve problems relating to reinforcement, it is advisable to first determine regions of compression and tension, followed by noting the relative strength of the materials.*

Use the following information to answer questions 2 and 3.

Figure 2 shows a beam of length 2.40 m and mass 80.0 kg balanced horizontally at a point labelled *F*. It carries three masses of 10.0 kg, 15.0 kg and 20.0 kg, as shown. The 10.0 kg mass is 0.80 m from the centre and the 15.0 kg mass is 0.90 m from the centre, as shown.

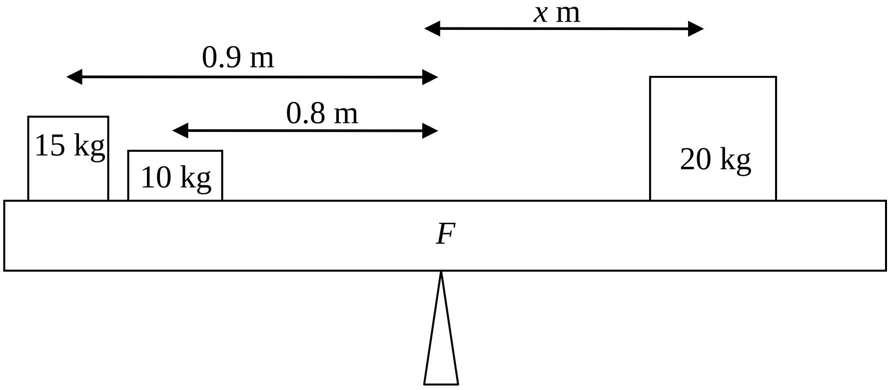


Figure 2

Question 2

The distance from the centre to the mass of 20.0 kg, *x*, is closest to

A. 0.90 m
B. 1.20 m
C. **1.08 m**
D. 0.60 m

Answer is C

Worked solution

$\Sigma\tau$ around the point $F = 0$, where $\tau = F \times d_{\perp}$.

Therefore, $x = \dfrac{(150 \times 0.9) + (100 \times 0.8)}{200} = 1.075\text{ m}$.

Question 3

The reaction force at *F*, the point of support, is closest in magnitude to

A. 150 N
B. 250 N
C. 350 N
D. **450 N**

Answer is D.

Worked solution

All forces in the vertical direction must be balanced.
Hence, reaction force upwards = (10 + 15 + 20) × 10 = 450 N.

Tips

- *Remember to use the correct signs for forces and torques as these are vector quantities.*
- *Draw clear complete force diagrams unless they have already been provided in the question.*

Use the following information to answer questions 4 and 5

Figure 3 shows a picture hanging on a support by two strings and is in equilibrium. The tension in one of the strings is 20 N and it makes an angle of 25° with the horizontal. The other string makes an angle of 30° with the horizontal.

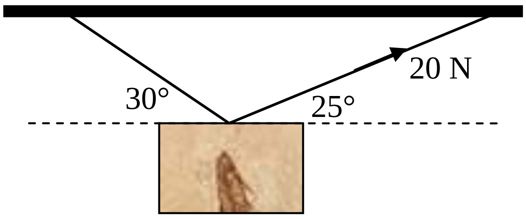


Figure 3

Question 4

The best estimate for the tension in the other string is

A. 22 N
B. **21 N**
C. 19 N
D. 18 N

Answer is B

Worked solution

The horizontal components of the tension forces must be equal and opposite to maintain equilibrium.

$\therefore \text{ Tension} = \dfrac{20\cos 25°}{\cos 35°} = 20.9 \text{ N}.$

Question 5

The best estimate of the mass of the picture to maintain equilibrium is

A. **1.9 kg**
B. 2.5 kg
C. 3.2 kg
D. 4.1 kg

Answer is A

Worked solution

The vertical components of the tension forces must be equal and opposite to the weight in order to maintain equilibrium.

$\text{Mass} = \dfrac{20.9\sin 30° + 20\sin 25°}{10} = 1.89 \text{ kg}$

Tips

- *Ensure your calculator is set to **degrees** and not **radians**.*
- *Remember that mass is in kg and weight is a force in N.*

Use the following information to answer questions 6–9.

Figure 4 shows the force–extension (F vs Δx) behaviour to fracture of four different materials under tension. All samples used in the tests are of identical shape and size. The length of each sample is 0.15 m with a cross-sectional area of 5.0×10^{-5} m^2.

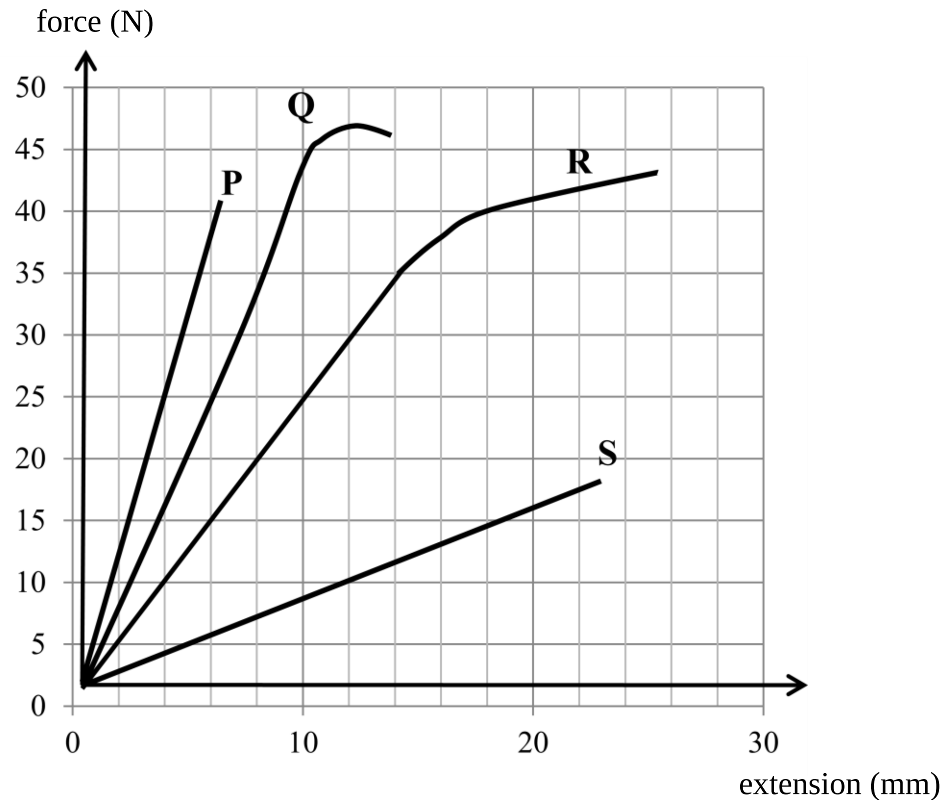


Figure 4

Question 6

Which of the following is the most accurate statement about the toughness of the four materials?

A. Toughness cannot be compared with force–extension graphs.
B. **Material R is tougher than material P.**
C. Material P is tougher than material Q.
D. Material Q is tougher than material R.

Answer is B

Worked solution

The area under the stress–strain graph (σ vs ε) is a measure of toughness. Since all samples used are the same size, the relative areas under the force–extension graph can be taken as a relative measure of toughness. Hence, material R, which has the highest area under the graph, is the toughest material.

Question 7

Young’s modulus of material S is closest in value to

A. 200 MPa
B. 400 MPa
C. **500 MPa**
D. 800 MPa

Answer is C

Worked solution

At a force of 15 N, the extension is 20 mm.

Young’s modulus, $E = \dfrac{\text{stress}}{\text{strain}} = \dfrac{\frac{F}{A}}{\frac{\Delta l}{l}} = \dfrac{F \times l}{\Delta l \times A} = \dfrac{15 \times 0.15}{20 \times 10^{-3} \times 5 \times 10^{-5}} = 500 \text{ MPa}$

Question 8

The correct value of the force constant of sample Q is

A. 47 N
B. 450 N m^{-1}
C. 4.5 N m^{-1}
D. **4.5 × 10^3 N m^{-1}**

Answer is D

Worked solution

The force constant is the gradient of the linear region in the force–extension graph. For sample Q, this is $k = \dfrac{\text{force}}{\text{extension}} = \dfrac{45}{10 \times 10^{-3}} = 4.5 \times 10^3 \text{ N m}^{-1}$.

Question 9

The strain energy per unit volume stored in sample P before fracture is best estimated as

A. 3.2 × 10^4 J m^{-3}
B. 2.6 × 10^4 J m^{-3}
C. 2.2 × 10^4 J m^{-3}
D. **1.6 × 10^4 J m^{-3}**

Answer is D

Worked solution

Strain energy per unit volume is determined as the area under the stress–strain graph. The area under the force–extension graph is the strain energy, and dividing this by the volume of the sample will also give the strain energy per unit volume.

Strain energy per unit volume = $\dfrac{1}{2} \times \dfrac{6 \times 10^{-3} \times 40}{0.15 \times 5 \times 10^{-5}} = 1.6 \times 10^4 \text{ N m}^{-1}$

Question 10

The ratio of the proportionality limit for sample Q to sample R is

A. 2 : 3
B. 3 : 2
C. **9 : 7**
D. 11 : 10

Answer is C

Worked solution

In this instance, the ratio of proportionality limits will be the ratio of the forces to the maximum point of the linear region; i.e. 45 : 35 = 9 : 7.

Tips

- *Clarify relationships between force, extension, stress, strain, Young's modulus and the force constant, k.*
- *Clarify the meaning of terms such as toughness, strain energy and strain energy per unit volume.*
- *Check units carefully.*

Use the following information to answer questions 11 and 12.

A bridge is made from a uniform concrete beam of mass 2500 kg and length 10.0 m. It is supported on two pillars that exert an upward reaction force of F_A and F_B, as shown in Figure 5 below. When a vehicle of mass M_c kg is stationary on the bridge 2.0 m from the centre of the concrete beam, the reaction force F_B is 19 500 N. Since the beam is uniform, the weight of the concrete beam, W_{beam}, can be considered to act through the centre of the beam.

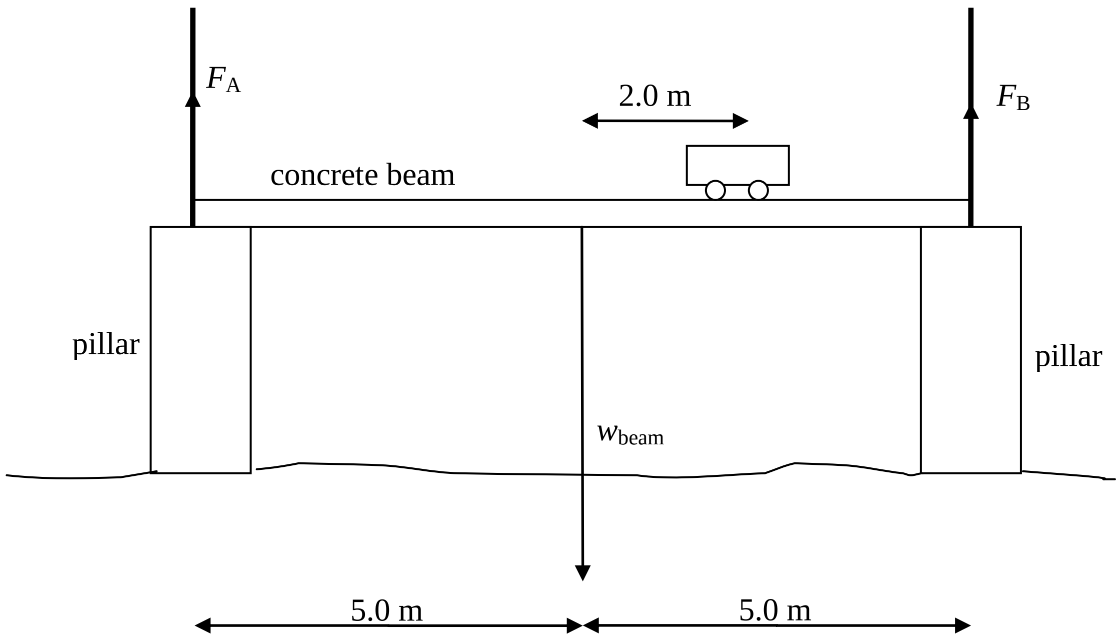


Figure 5

Question 11

The best estimate of the mass, M_c, of the vehicle is

A. 500 kg.
B. **1000 kg.**
C. 1500 kg.
D. 2000 kg.

Answer is B

Worked solution

The vector sum of torques around any point on the structure must be zero. For ease, take torque values from around the pillar shown on the left of the diagram as it has an unknown force. $0 = (25\,000 \times 5) + (M_c \times 10 \times 7) - (19\,500 \times 10)$.
Thus, M_c = 1000 kg.

Question 12

The magnitude of the reaction force F_A is closest to

A. 10 500 N
B. 12 000 N
C. 13 500 N
D. **15 500 N**

Answer is D

Worked solution

The vector sum of upward and downward forces must equal zero.
Thus, 19 500 + F_A = 25 000 + 10 000.
F_A = 15 500 N.

Tips

- *Work systematically when considering rotational or translational equilibrium to ensure that all forces and torques are accounted for.*
- *When taking torques, consider doing so at a point where there is an unknown force, as it may help to simplify the analysis of the problem.*

End of Detailed study 2
SECTION B – continued
TURN OVER

Detailed study 3: Further electronics

Use the following information to answer Questions 1-5

Figure 1a shows an RC circuit consisting of a resistor, 200 μF capacitor, a DC power supply and a switch. The voltage-time behaviour of the resistor and capacitor is measured using a CRO and is shown in Figure 1a.

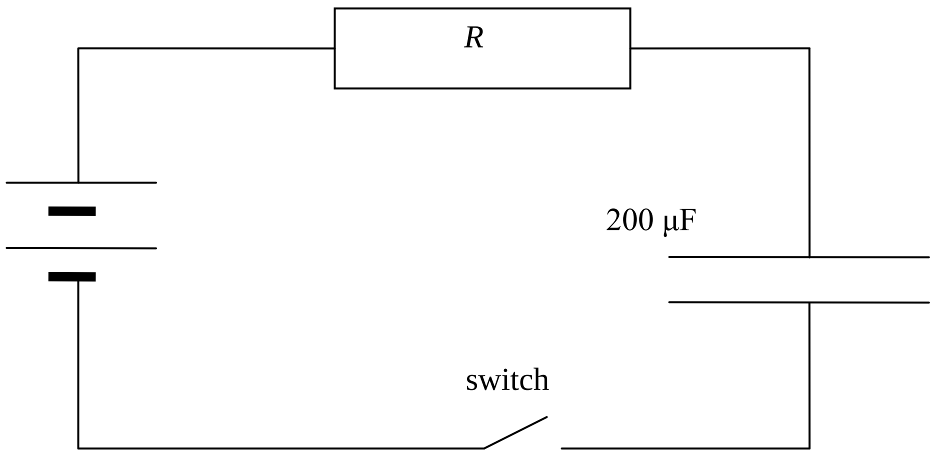


Figure 1a

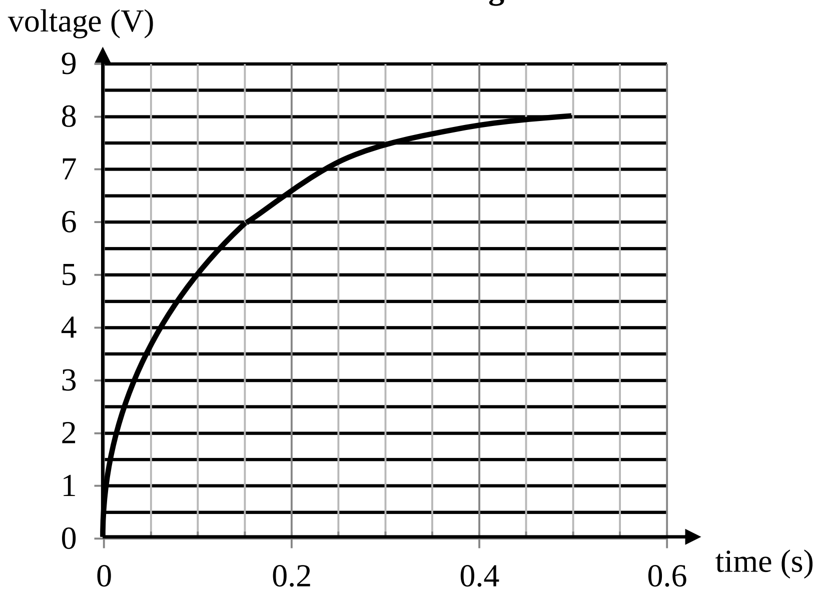


Figure 1b

When the switch is closed, the capacitor charges up and its charging behaviour is shown in Figure 1b.

Question 1

What is the most likely voltage supplied by the battery?

A. 5.0 V
B. 6.0 V
C. 7.0 V
D. **8.0V**

Answer is D
Worked solution

The voltage drop across the capacitor will rise until the entire voltage of the battery is dropped across it. Hence, 8.0 V is the best estimate.

Question 2

The best estimate of the voltage drop across the resistor at 0.15 s is

A. **2.0 V**
B. 4.0 V
C. 6.0 V
D. 8.0V

Answer is A

Worked solution

The voltage across the resistor and the capacitor must add up to 8.0V. At 0.15 s, the voltage across the capacitor is 6.0 V. Hence, the voltage across the resistor must be 2.0 V.

Question 3

The value of the resistor is closest to

A. **500 Ω**
B. 1000 Ω
C. 1500 Ω
D. 5000 Ω

Answer is A

Worked solution

Time constant, $\tau = RC$ = time at 63% of 8.0 V = time at 5.04 V = 0.1 s.

Thus, $R = \frac{\tau}{C} = \frac{0.1}{(200 \times 6)} = 500\,\Omega$.

Question 4

The best value for the charge stored in the capacitor at 0.3 s is

A. 0.5 μC
B. 1.0 mC
C. **1.5 mC**
D. 27 μC

Answer is C

Worked solution

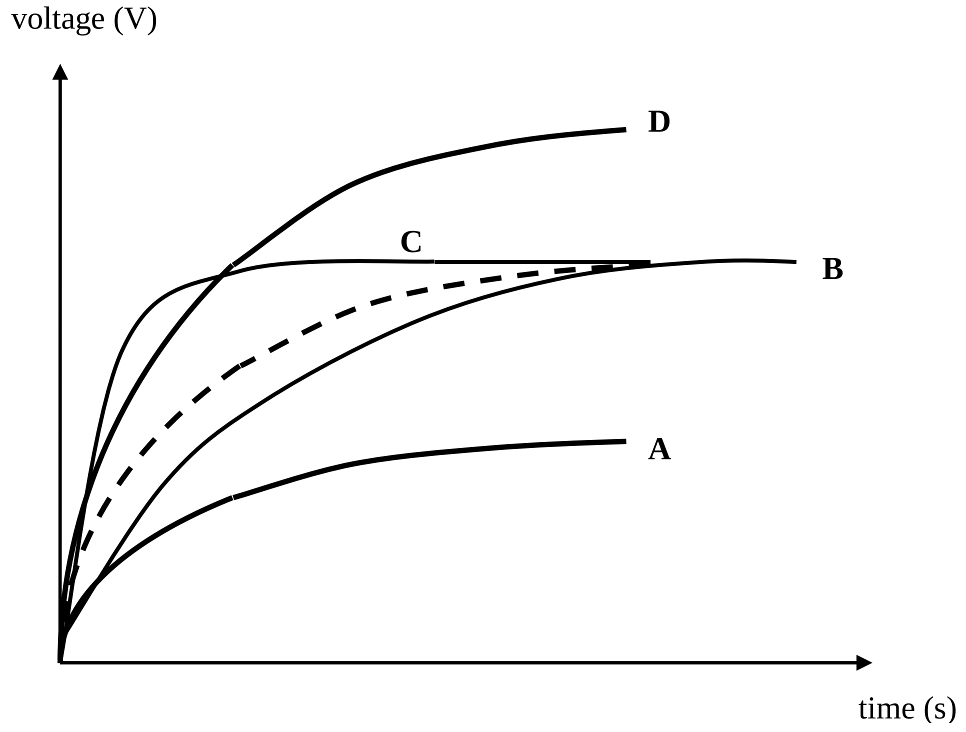
At 0.3 s, the capacitor is charged to 7.5 V.
Charge stored = $CV = 200 \times 10^{-6} \times 7.5 = 1.5$ mC.

End of Detailed study 2

This page is blank

Question 5

Which one of the following is the most likely shape of the capacitor's charging behaviour when the resistor, *R*, is replaced with another resistor of **lower** resistance? For comparison, the original charging behaviour is shown with a dashed line.



Answer is C

Worked solution

The rate of charging is determined by the time constant, $\tau = RC$. As resistance is reduced, the time constant reduces, so the time for complete charging (= 5τ) also reduces. Therefore, the graph reaches the same voltage but more quickly, which is shown best by option C.

Tips

- *Remember that the voltage across the resistor plus the capacitor equals the battery voltage.*
- *Take care with units when reading graphs.*

Use the following information to answer questions 6–8.

Figure 2a shows a circuit for a DC power supply. It consists of a silicon diode, whose characteristic graph is shown in Figure 2b, a 500 μF capacitor and a 1000 Ω load resistor. A CRO may be connected appropriately at various points, such as to measure the waveforms of input voltage V_{in}, across points *a*–*b* and output voltage V_o.

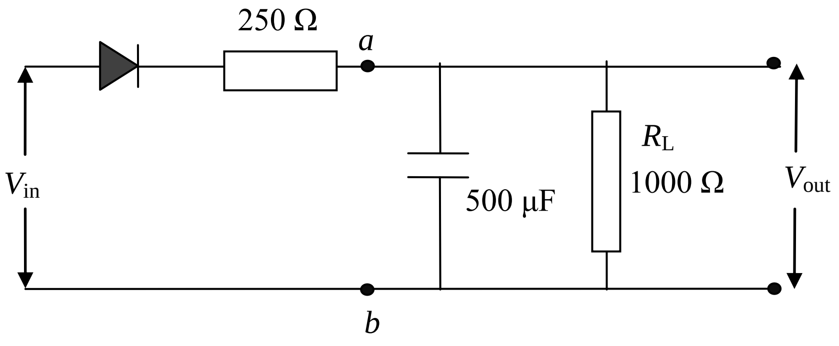


Figure 2a

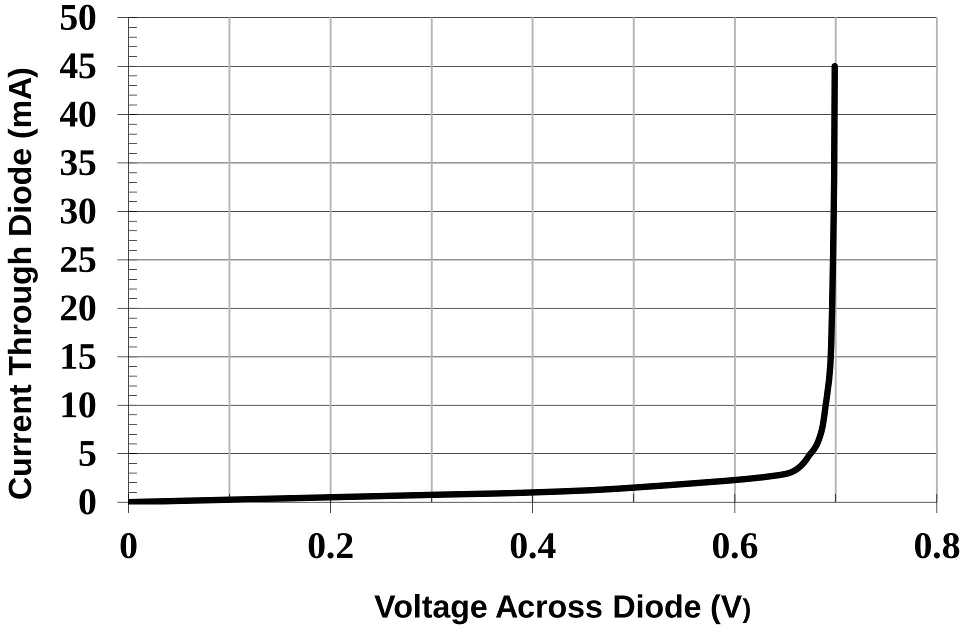


Figure 2 (b)

Question 6

At a certain input voltage waveform, the output voltage recorded by the CRO in position a-b is shown in Figure 3. The current in the 250 Ω resistor was then 4 mA.

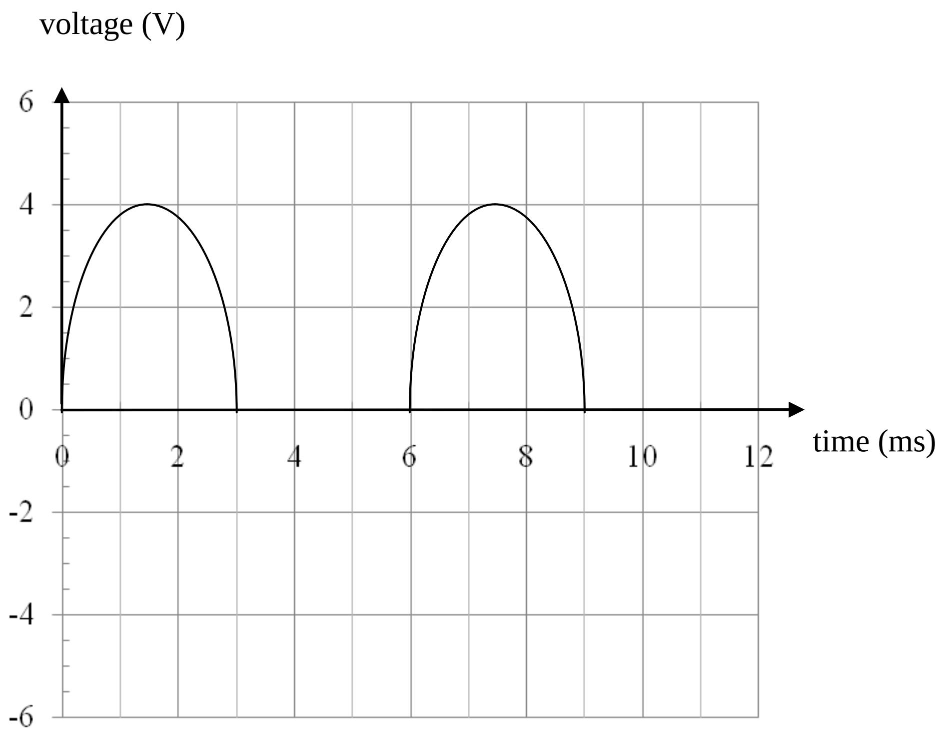


Figure 3

The most likely voltage peak of the input voltage under these conditions is

A. **5.7 V**
B. 5.0 V
C. 4.3 V
D. 4.0 V

Answer is A

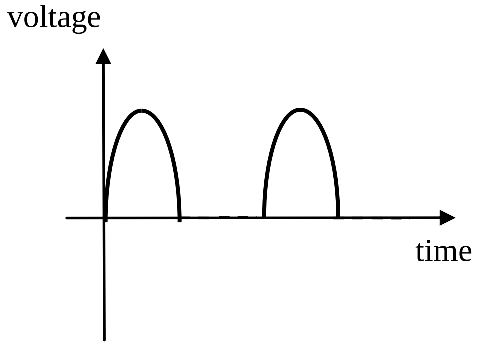
Worked solution

There is a 0.7 V drop across the diode and a 1.0 V drop across the 250 Ω resistor. Hence, the peak voltage supplied must be 4 + 0.7 + 1.0 = 5.7 V.

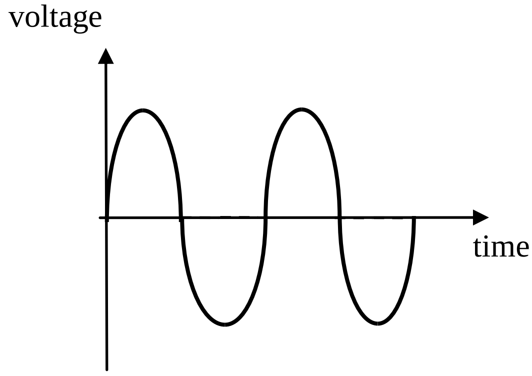
Question 7

If the load resistor is removed from the circuit, the best estimate of the shape of the output voltage waveform is

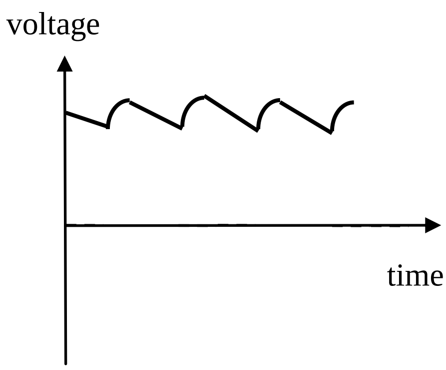
A.



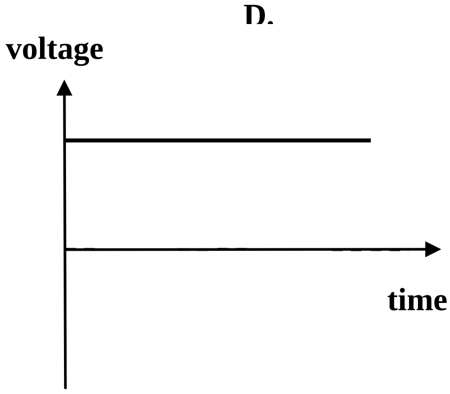
B.



C.



D.



Answer is D

Worked solution

When the load resistor is removed, there is an open circuit, meaning the resistance and hence the time constant becomes infinitely large. Therefore, a smooth output with no ripples is most likely.

Question 8

A different input voltage is now provided to the circuit shown previously in Figure 2a. The waveform of this new input voltage is shown below in Figure 4.

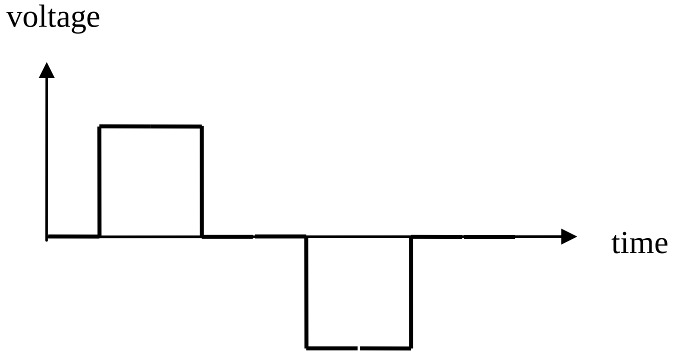
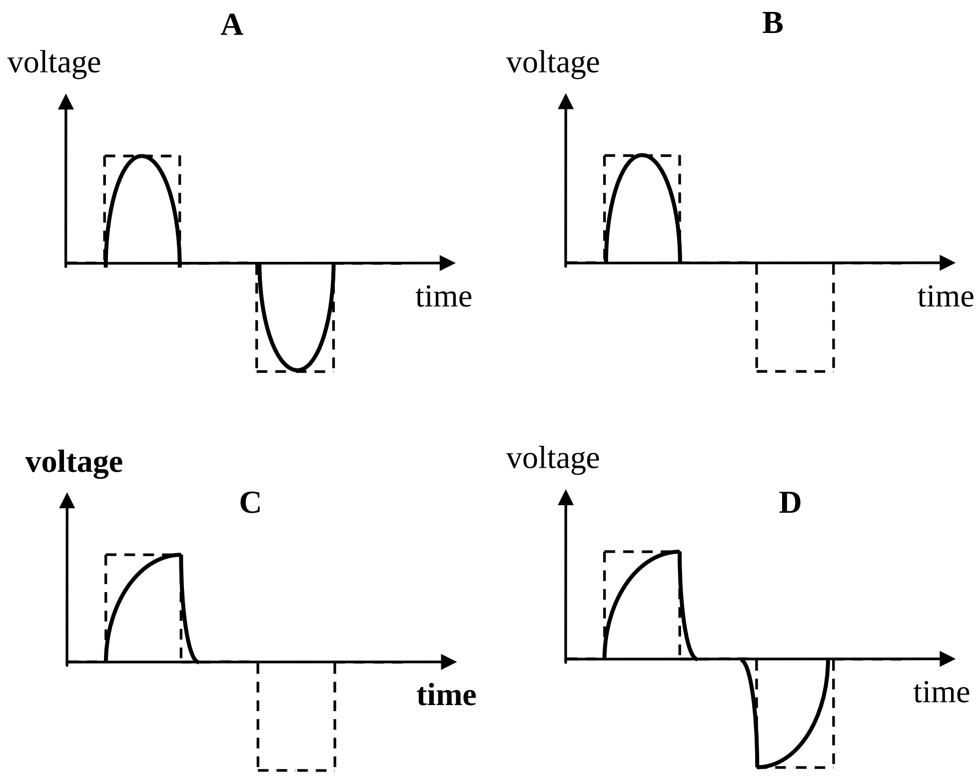


Figure 4

Which one of the following is the most likely shape of the waveform of the output voltage? For comparison, the new input voltage waveform is shown with dashed lines in the figures.



Answer is C

Worked solution

The diode will act as a half-wave rectifier; hence, options A and D are not possible. The *RC* circuit will cause some degree of smoothing, so option C is the most likely output voltage waveform because it shows the charging and discharging voltage waveform expected in an *RC* circuit.

Use the following information to answer questions 9–12.

Figure 5 is an AC to DC regulated voltage power supply, making use of a 100 Ω resistor, a capacitor and a Zener diode. The regulated power is supplied to a 500 Ω load resistor, R_L. The AC supply voltage is 240 V_{RMS} and the voltage supplied to the bridge rectifier is 16 V_{RMS}. The characteristic graph of the Zener diode is also shown in the figure below.

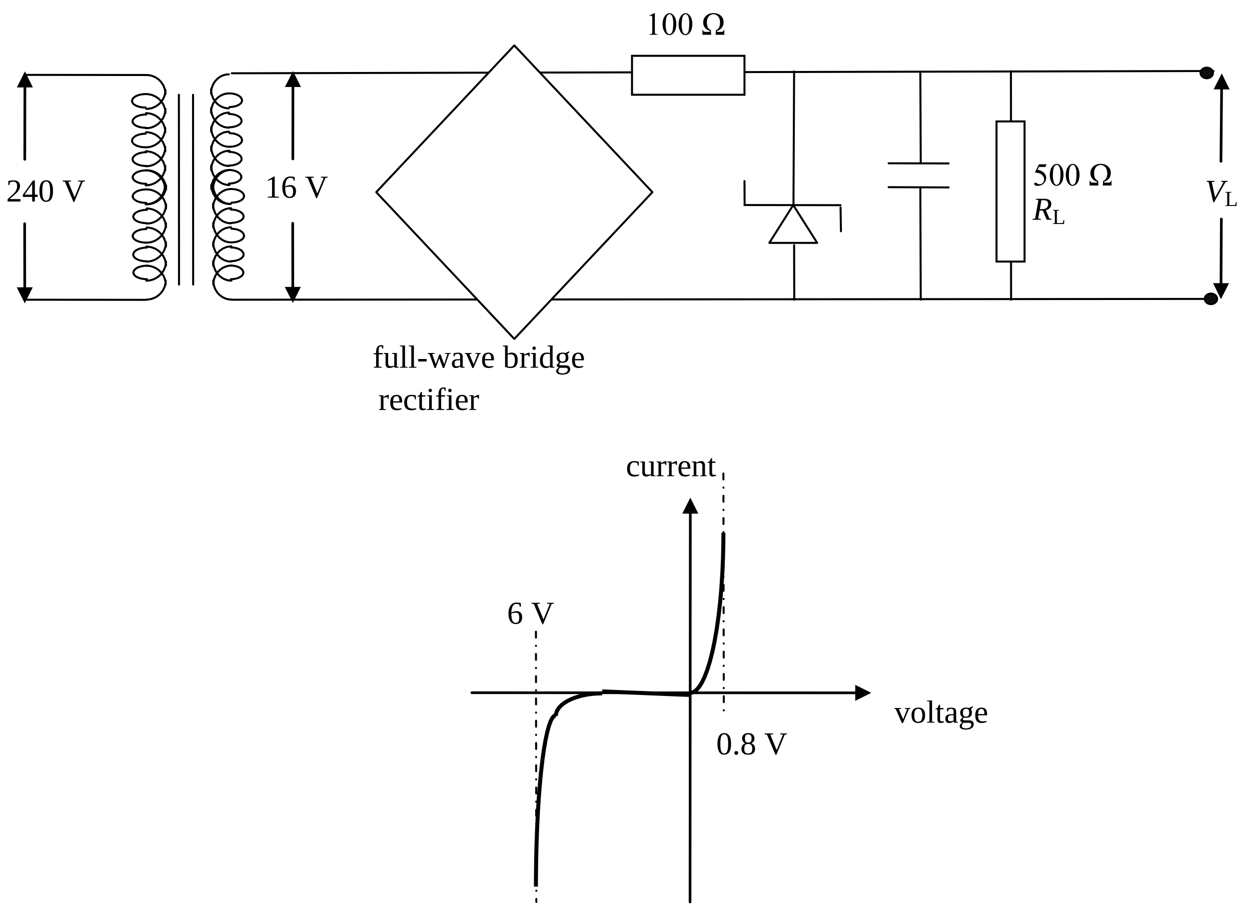


Figure 5

Question 9

What is the correct value of the transformer ratio *number of turns secondary : number of turns primary*?

A. 15 : 1
B. 40 : 1
C. **1 : 15**
D. 1 : 40

Answer is C

Worked solution

Transformer ratio, $\frac{N_s}{N_p} = \frac{16}{240} = 1:15$

Question 10

The current in the 100 Ω resistor is 90 mA. The best estimate for the voltage loss in the rectifier is

A. 1.7 V
B. 1.5 V
C. **1.0 V**
D. 8.2 V

Answer is C

Worked solution

Voltage drop across the resistor is = $100 \times 90 \times 10^{-3}$ V = 9.0 V.
Voltage drop across the Zener diode = 6.0 V.
Therefore, voltage loss in the rectifier = 16 – (9 + 6) = 1.0 V.

Question 11

The correct value for the current in the Zener diode is

A. 90 mA
B. 12 mA
C. 102 mA
D. **78 mA**

Answer is D

Worked solution

Current through the load resistor is = $\frac{6\text{ V}}{500\ \Omega} = 12$ mA.

Therefore, current through the Zener diode = 90 – 12 = 78 mA.

Question 12

The load resistance is now halved. Compared to the current with the initial resistor in place, which one of the following will be the most likely effect on the current through the Zener diode?

A. It will increase by 50%.
B. It will decrease by 50%.
C. It will remain the same.
D. **It will decrease by less than 50%.**

Answer is D

Worked solution

A reduction in load resistance means that more current is in it to maintain the voltage drop. Hence, the amount of current through the Zener diode will reduce. However, the reduction will not be 50%. As resistance reduces to 250 Ω, current through the load resistor = 24 mA and current through the Zener diode = 66 mA, which is a reduction of 12 mA.

Tips

- *Remember to balance current in the circuit and account for all voltage drops.*
- *Remember that the voltage across the Zener diode will remain constant unless there is a significant change in the voltage supply.*
- *The Zener diode is always in reverse bias.*

END OF SOLUTIONS BOOK