INSIGHT

Trial Exam Paper

2009

PHYSICS

Written examination 1

STUDENT NAME:

QUESTION AND ANSWER BOOK

Reading time: 15 minutes

Writing time: 1 hour 30 minutes

Structure of book

Section	*Number of questions*	*Number of questions to be answered*	*Number of marks*
A – Core – Areas of Study			
1. Motion in one and two dimensions	18	18	40
2. Electronics and photonics	11	11	24
B – Detailed Studies			
1. Einstein's special relativity	13	13	26
OR			
2. Investigating materials and their use in structures	13	13	26
OR			
3. Further electronics	13	13	26
Total			90

- Students are permitted to bring the following items into the examination: pens, pencils, highlighters, erasers, sharpeners, rulers and one scientific calculator.
- Students are NOT permitted to bring sheets of paper or white out liquid/tape into the examination.

Materials provided

- The question and answer book of 41 pages, with a separate data sheet.

Instructions

- Write your **name** in the box provided.
- Remove the data sheet during reading time.
- Answer all the questions in the space provided.
- Always show your working where space is provided.
- Where the answer box has a unit printed in it, give your answer in that unit.
- You must answer all questions in English.

Students are NOT permitted to bring mobile phones or any other electronic device into the examination.

SECTION A – Core

Area of study 1 – Motion in one and two dimensions

Instructions for Section A

Answer **all** questions for **both** Areas of study in this section of the paper.

The following information applies to Questions 1–3.

Edward drives his car at a uniform speed of 15 ms^{-1} around a bend of radius 25 m on a road that is banked at angle θ, as shown in Figure 1. The mass of the car and John combined is 1000 kg.

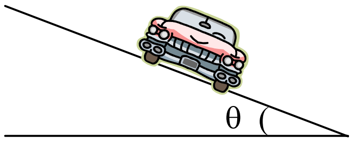


Figure 1

Question 1

What is the magnitude of the acceleration of the car?

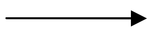
ms^{-2}

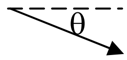
2 marks

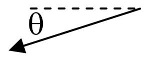
Question 2

Which direction best describes the net acceleration on the car?

A. 

B. 

C. 

D. 

1 mark

Question 3

Edward finds that at a constant speed of 15 ms^{-1}, the car does not slide and is under control. However, at speeds greater than 15 ms^{-1}, the car slides. What is the magnitude of the angle of bank, θ, of the road?

°

3 marks

The following information applies to Questions 4–7.

A train engine of mass 24 tonnes travelling east at 5.0 ms^{-1} collides with an empty carriage of mass 3 tonnes travelling west at 15.0 ms^{-1}, as shown in Figure 2.

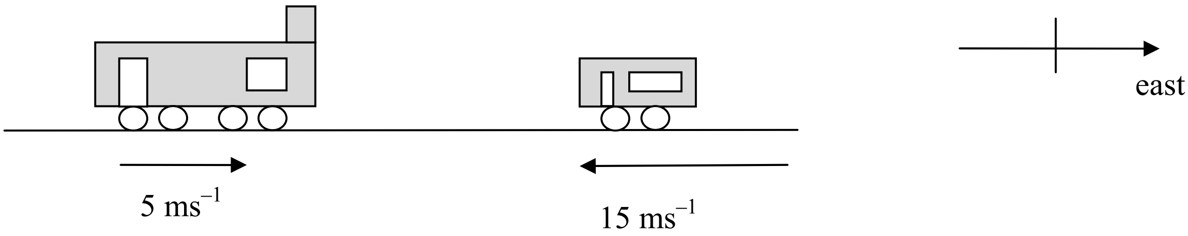


Figure 2

After the collision, the empty carriage is found to be travelling east at a constant speed of 10.0 ms^{-1}.

Question 4

What is the velocity of the engine after collision?

Magnitude: ms^{-1}

Direction:

3 marks

Question 5

Justify with appropriate collisions whether the collision is elastic or inelastic.

3 marks

Question 6

The contact time between engine and carriage is 1 ms. What average force does the engine exert on the carriage?

Magnitude: N

Direction:

2 marks

Question 7

What is the magnitude of the average force the carriage exerts on the engine? Show your working.

2 marks

The following information applies to Questions 8–12.

A skier wishes to have skiing equipment of mass 200 kg transported to the top of the downhill ski slope. The items are pulled on a cart by a rope with a force $\boldsymbol{F}_a$ and, in doing so, a constant friction force of 100 N is encountered, as shown in Figure 3.

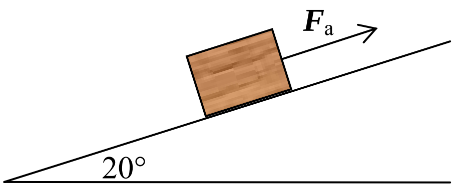


Figure 3

Question 8

For the cart to be towed at a constant speed, what must be the magnitude of the applied force, $\boldsymbol{F}_a$?

N

2 marks

Question 9

What is the work done by the applied force to tow the skiing equipment 100 m up the slope?

J

2 marks

The skier now skis downhill, starting from rest and making no effort to accelerate (Figure 4). The skier finds himself accelerating downhill, encountering a constant friction force of 80 N. The combined mass of the skier, skis and ski equipment is 280 kg.

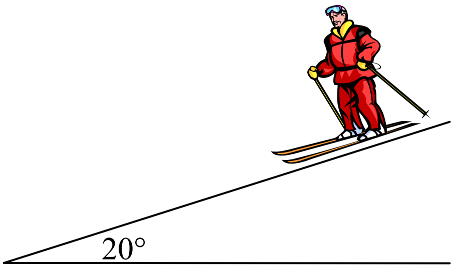


Figure 4

Question 10

What is the magnitude of the acceleration of the skier?

ms^{-2}

2 marks

Question 11

What is the speed of the skier at an instant 50 m down the incline?

ms^{-1}

2 marks

Question 12

What is the kinetic energy of the skier and his skis 50 m downhill from the starting position?

J

2 marks

The following information applies to Questions 13 and 14.

A basketball player launches a ball 2 m above the ground with a speed of 7.5 ms^{-1} at an angle of 50° to the horizontal, at location A. The ball follows a parabolic (projectile) path and goes through a hoop at B, which is at a horizontal distance of 3 m from A and a height of *y* m above ground. Ignore any friction due to air.

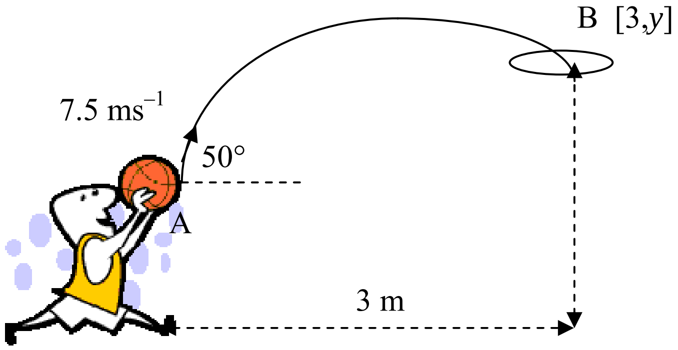


Figure 5

Question 13

How long was the basketball in the air as it travelled from A to B?

s

2 marks

Question 14

What is the height, y, of the hoop above the ground?

m

3 marks

The following information applies to Questions 15 and 16.

A new planet, Madgin, is found in our solar system. It has a mass of 4×10^{27} kg and a radius of 4×10^{8} m.

Question 15

What is the gravitational field strength on the surface of Madgin?

ms^{-2}

2 marks

Question 16

A spaceship, Khir, is geostationary over the 'equator' of the planet Madgin at an altitude of 150 km above the surface. What is the time period of orbit of the satellite?

s

2 marks

The following information applies to Questions 17 and 18.

A Hookean spring is stretched with an increasing force, as shown in Figure 6.

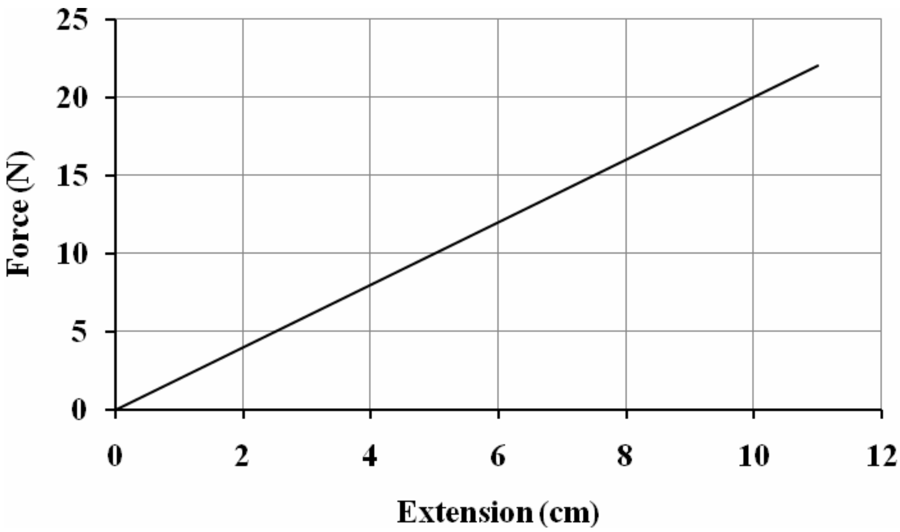


Figure 6

Question 17

From the graphical data provided, estimate the spring constant of the spring.

Nm^{-1}

2 marks

Question 18

What is the work done in stretching the spring from 6.0 cm to 8.0 cm?

J

3 marks

END OF AREA OF STUDY 1
SECTION A – continued
TURN OVER

Area of study 2 – Electronics and photonics

The following information applies to Questions 1–4.

A diode, with the current–voltage characteristics shown in Figure 1, is part of a circuit shown in Figure 2.

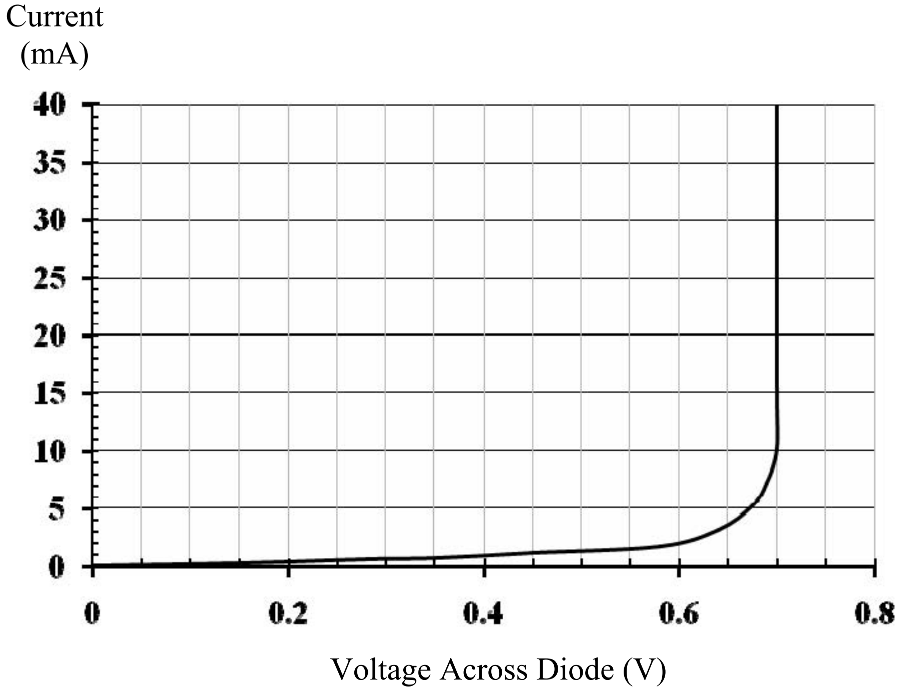


Figure 1

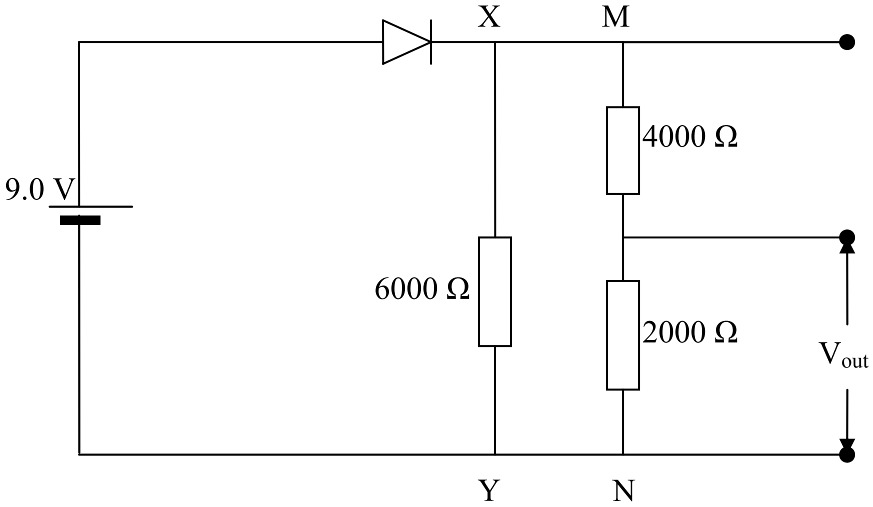


Figure 2

Question 1

Calculate the voltage across the 2000 Ω resistor.

V

3 marks

Question 2

What is the current through the 6000 Ω resistor?

mA

1 mark

The diode is now replaced with a thermistor, as shown in the circuit of Figure 3a. The resistance–temperature characteristic curve of the thermistor is shown in Figure 3b.

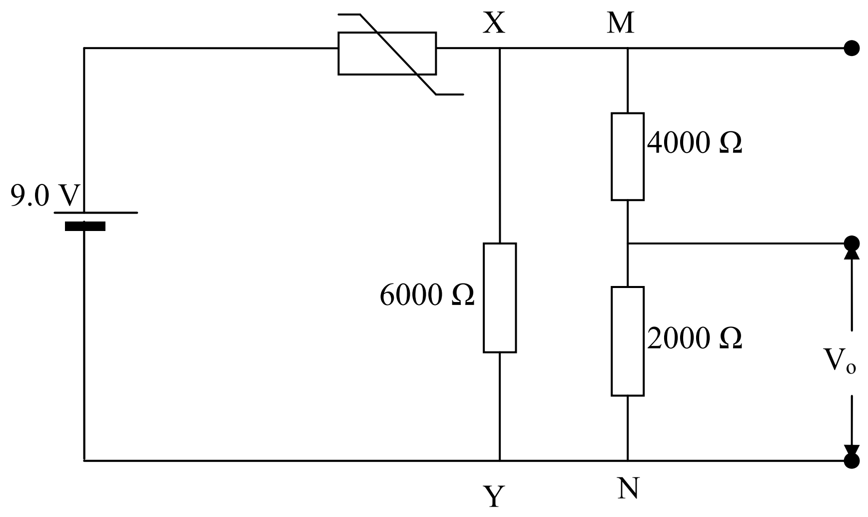


Figure 3a

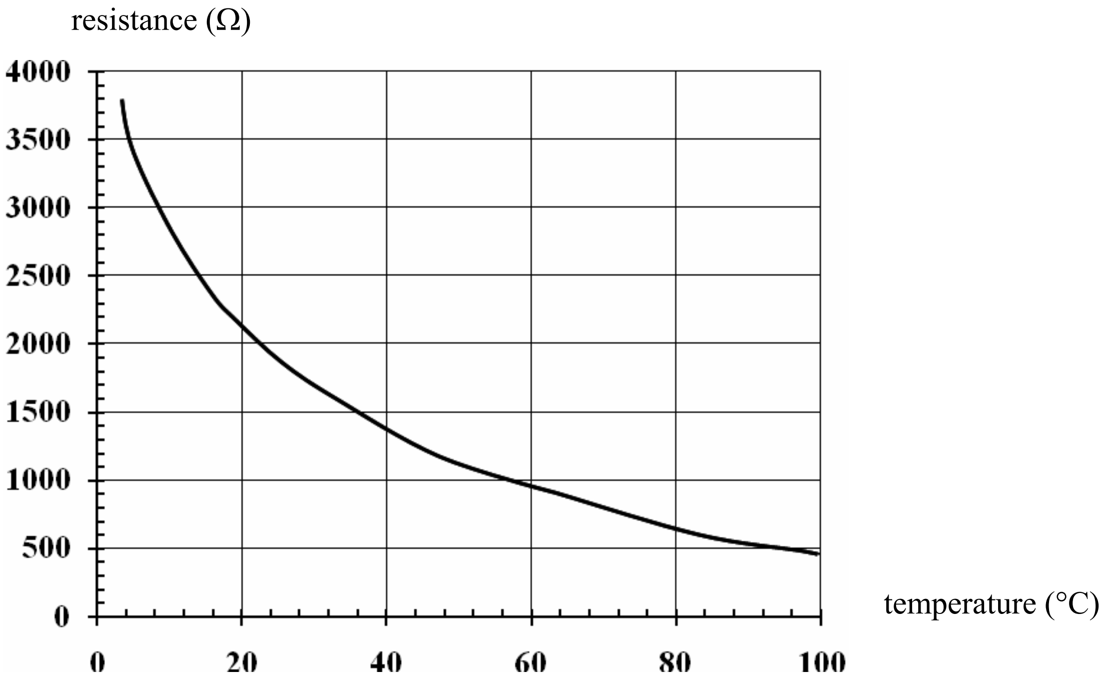


Figure 3b

Question 3

The temperature immediately surrounding the thermistor is 40°C. What is the output voltage V_O now?

____

____

____

____

V

3 marks

Question 4

The temperature surrounding the thermistor now drops. What would be the effect on the voltage output now? Explain your answer.

____

____

____

2 marks

The following information applies to Questions 5 and 6.

An npn transistor amplifier block diagram is shown in Figure 4a. A small AC signal is fed into the amplifier and the output signal is observed by a CRO. The transfer characteristic graph of the amplifier is shown in Figure 4b.

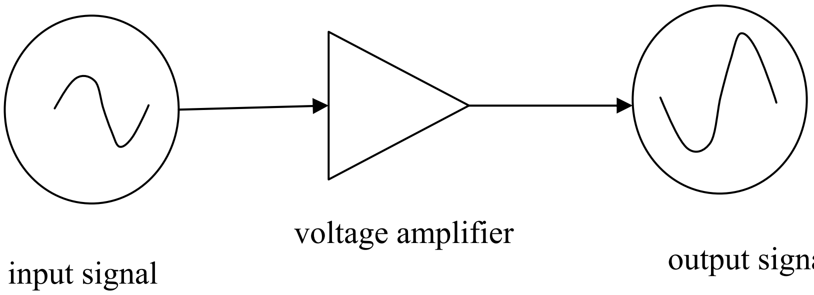


Figure 4a

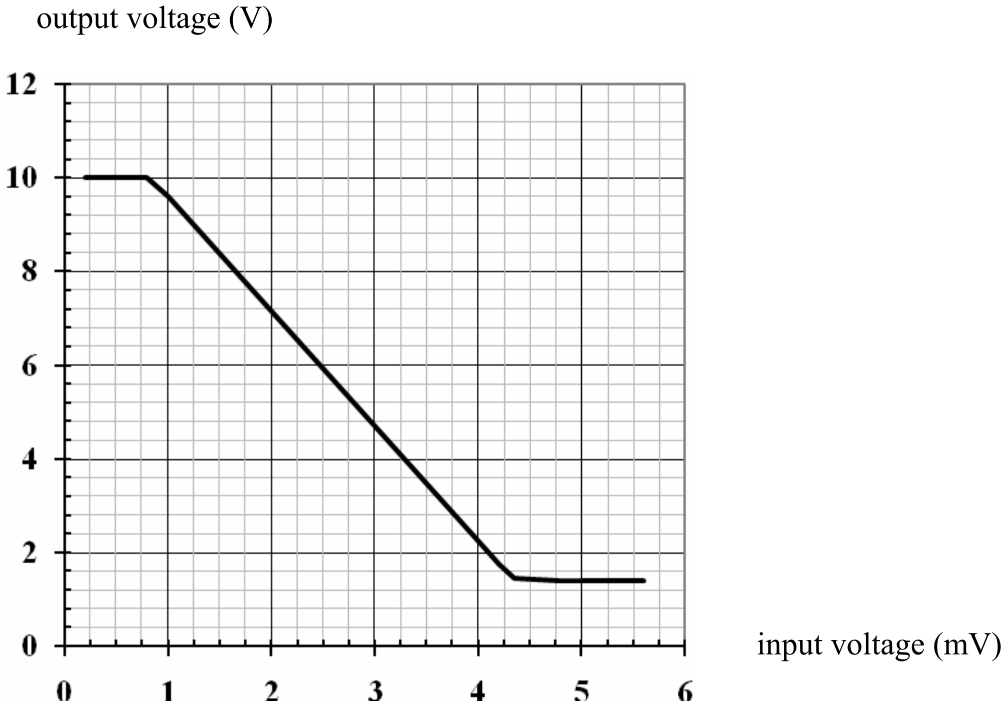


Figure 4b

Question 5

What is the voltage gain of the amplifier? Show your working.

2 marks

Question 6

The input signal is shown in Figure 5a. On the axes provided in Figure 5b, sketch the output wave form you would expect to see. You must show your working in estimating suitable values for the *y*-axis.

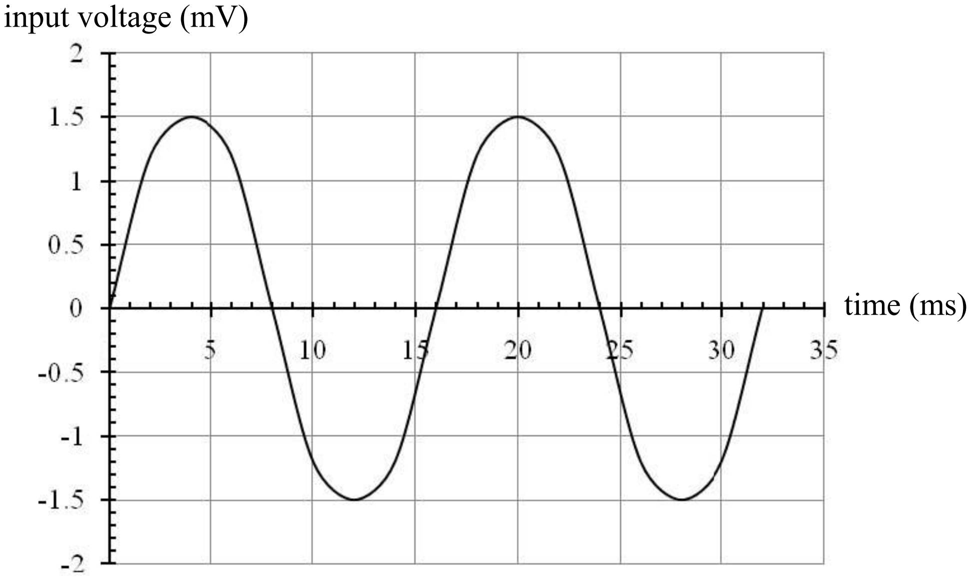


Figure 5a

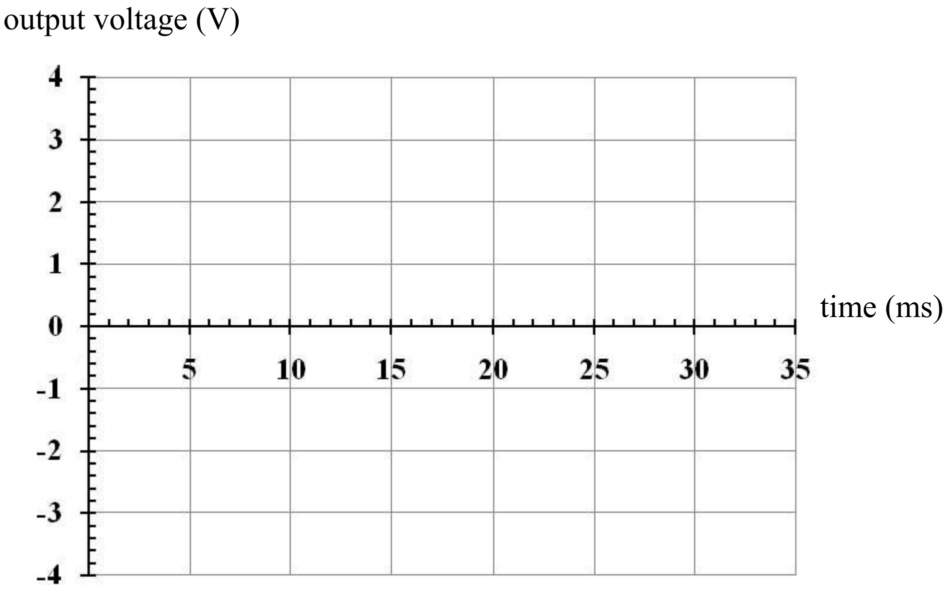


Figure 5b

___

___

___

3 marks

The following information applies to Questions 7–9.

Figure 6a shows the current–voltage characteristic graph for a photodiode at different light intensities, φ. A simplified circuit to detect intruders in a bank is shown in Figure 6b. A constant light beam from a separate DC source shines on the photodiode, resulting in an output voltage, V_{out}, across the resistor. However, when the light beam is momentarily interrupted by the movement of an intruder, the circuit is broken, resulting in an alarm.

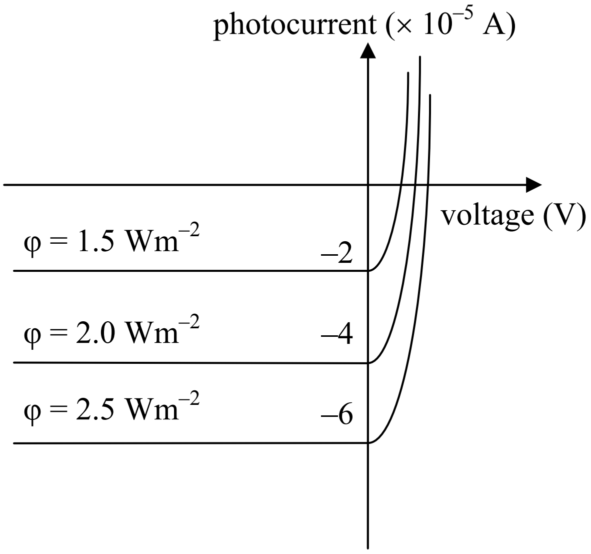


Figure 6a

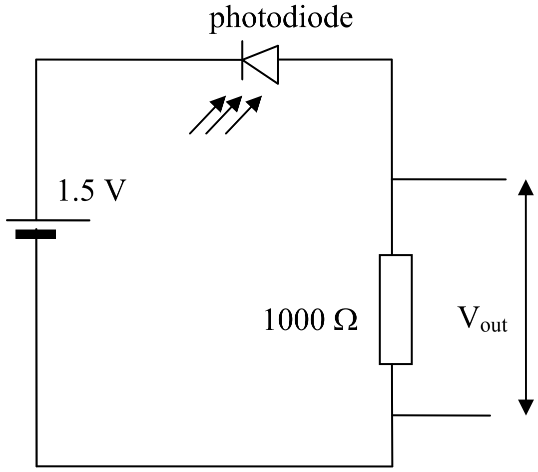


Figure 6b

Question 7

With specific reference to the current–voltage characteristics of the photodiode and its use in the circuit, explain why the photodiode is connected in reverse bias.

2 marks

Question 8

With light of intensity 2 Wm^{-2} shining on the photodiode, what is the output voltage, V_{out}? Show your working.

mV

2 marks

Question 9

As the intensity of light changes to a new value, the output voltage is found to increase. Is this increase in output voltage due to an increase or decrease in light intensity? Explain your answer.

2 marks

The following information applies to Questions 10 and 11.

A laser beam is used as a carrier wave to transmit audiovisual signal from a player to a screen, as shown in a schematic diagram in Figure 7. The transmission system requires two transducers – P and Q.

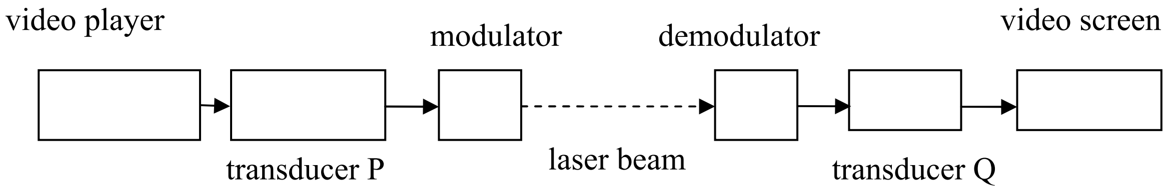


Figure 7

Question 10

Which of the following combinations of transducers is the appropriate choice for the transmission system?

A. LED is transducer P and phototransistor is transducer Q.

B. Photodiode is transducer P and thermistor is transducer Q.

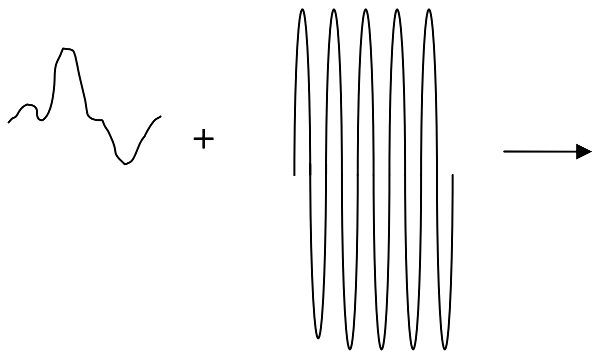
C. LDR is transducer P and LED is transducer Q.

D. Transistor amplifier is transducer P and LDR is transducer Q.

2 marks

Question 11

An input signal needs to be transmitted from a source to a screen, using a laser beam. Show, by explanation and suitable sketch, the effect of modulation and demodulation of the laser carrier beam, and explain how the laser beam would be used to carry the input signal to the screen.



2 marks

END OF SECTION A

SECTION B – Detailed studies

Detailed study 1 – Einstein's special relativity

Instructions for Section B

Choose **one** of the following **Detailed Studies**. Answer **all** the questions on the Detailed Study you have chosen.

Use the following information to answer Questions 1–3.

Muons are unstable subatomic particles that result during the decay of a pion and can themselves decay into positrons and neutrinos. They last for a short lifetime of 2.20 μs before they decay. Muons have an average rest mass of 207 times the rest mass of an electron. The mass of an electron is $m_e = 9.1 \times 10^{-31}$ kg.

Question 1

The lifetime of the muon travelling at 0.9*c*, as measured by an observer in a laboratory, is closest in value to

A. 4.40 μs

B. 0.96 μs

C. 5.04 μs

D. 3.45 μs

2 marks

Question 2

Which one of the following gives the best magnitude of the kinetic energy of a muon travelling at 0.9*c*?

A. 1.9×10^{-11} J

B. 2.2×10^{-11} J

C. 2.8×10^{-11} J

D. 3.1×10^{-11} J

2 marks

Question 3

What is the mass of the muon travelling at 0.9*c*?

A. 2.1×10^{-30} kg

B. 4.3×10^{-28} kg

C. 3.5×10^{-30} kg

D. 5.2×10^{-29} kg

2 marks

Use the following information to answer Questions 4–7.

A space mission is planned to carry passengers to the star Alpha Centauri, about 4 light years (ly) from Earth. A newly developed technology allows the spaceship to travel at 0.6*c*.

Question 4

How long would the journey take, as observed by the tracking station on Earth?

A. 2.4 y

B. 6.67 y

C. 4 y

D. 4.6 y

2 marks

Question 5

What is the distance of Alpha Centauri from Earth, according to the astronauts on the spaceship?

A. 5 ly

B. 6.67 ly

C. 3.2 ly

D. 4 ly

2 marks

Question 6

What is the time taken to travel from Earth to the star, according to the astronauts?

A. 5.33 y

B. 8.34 y

C. 6 y

D. 6.67 y

2 marks

Question 7

An asteroid, 250 m long, passes the space station at a speed of 0.8*c* and flies away harmlessly. To an astronaut on the space station, the length of the asteroid would appear to be

A. 150 m

B. 200 m

C. 300 m

D. 415 m

2 marks

Use the following information to answer Questions 8–11.

An electron is accelerated from rest with 9 gigavolts of potential difference in a linear accelerator. (Giga = 10^9)

Question 8

According to Newtonian physics, what would be its kinetic energy?

A. 1.1×10^{-9} J

B. 2.4×10^{-9} J

C. 1.6×10^{-10} J

D. 3.2×10^{-10} J

2 marks

Question 9

For an electron travelling at 0.9*c*, its relativistic kinetic energy would be

A. more than that calculated by Newtonian physics.

B. less than that calculated by Newtonian physics.

C. the same as that calculated by Newtonian physics.

D. infinitely high.

2 marks

Question 10

In another experiment, a scientist observes the mass of an electron in an accelerator to be 1.5 times its rest mass. Hence, the speed of the electron is closest in value to

A. 0.8*c*

B. 0.9*c*

C. 0.75*c*

D. 0.95*c*

2 marks

Question 11

Which of the following is the best explanation of what may happen as the electron approaches a speed equal to *c*?

A. The force required to accelerate the electron will now approach infinity.

B. The physical dimensions of the electron will now approach infinity.

C. The mass of the electron will be nearly zero.

D. All of the above.

2 marks

Use the following information to answer Questions 12 and 13.

A schematic drawing of the Michelson-Morley experiment is shown in Figure 1.

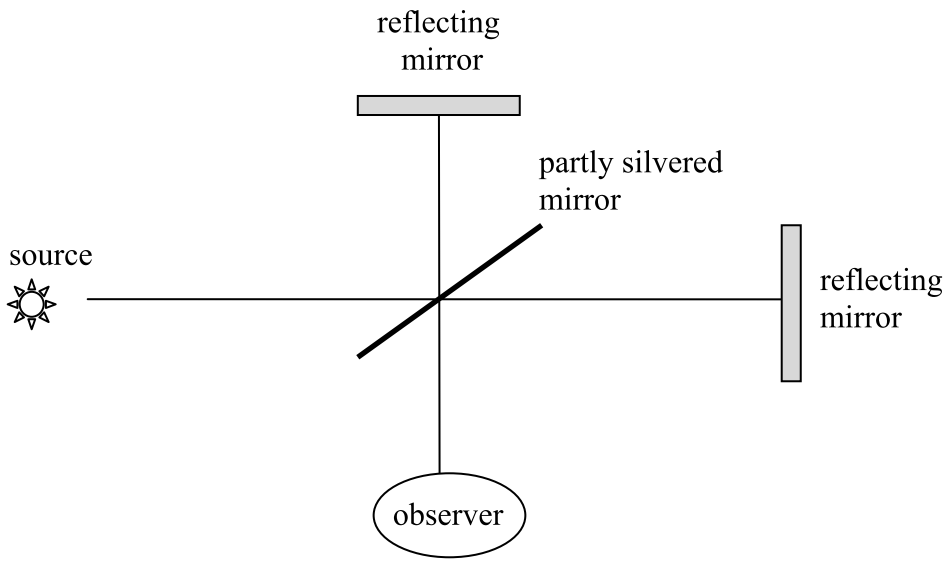


Figure 1

Question 12

If ether existed, then the Michelson-Morely experiment was expected to show that

A. the speed of light was constant in all directions.

B. the speed of light would vary, dependent upon the relative motion of the light beam and Earth.

C. the Earth is an absolute reference frame.

D. the speed of ether is the same as that of Earth.

2 marks

Question 13

From their experiment, Michelson and Morley expected to find

A. the absolute speed of ether.

B. the absolute speed of Earth.

C. the location of an absolute reference frame.

D. the speed of ether with respect to Earth.

2 marks

Detailed study 2 – Investigating materials and their use in structures

Use the following information to answer Questions 1–5.

There are increasing numbers of composite materials being introduced in the marketplace for a variety of applications. The behaviour of new composite materials under loads is an important test for quality control.

Figure 1 shows the behaviour of a new composite material under tension and compression until failure. The data in the graph were collected using tests performed on cylindrical samples of radius 0.5 cm and length 10 cm.

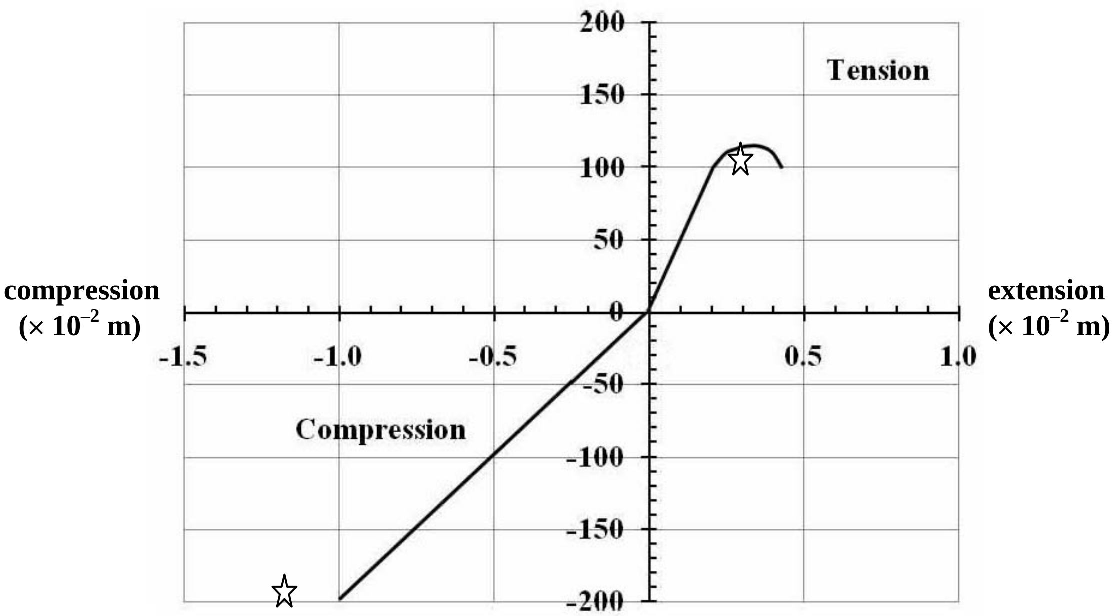


Figure 1

Question 1

Which one of the following best describes the mechanical behaviour of the material?

A. It is stronger in compression and tougher in tension.

B. It is stronger in tension and tougher in compression.

C. It is stronger and tougher in compression than in tension.

D. It is stronger and tougher in tension than in compression.

2 marks

Question 2

Which one of the following gives the best estimate of the tensile strength of the composite material?

A. 115 N

B. 180 N

C. 1.5×10^6 Nm^{-2}

D. 1.4 MPa

2 marks

Question 3

Which one of the following is the best estimate for Young's modulus of the composite material under compression?

A. 10 MPa

B. 30 MPa

C. 20 MPa

D. 25.5 MPa

2 marks

Question 4

What is the strain energy stored in the sample during compression just prior to failure?

A. 100 J

B. 1 J

C. 22 J

D. 0.2 J

2 marks

Question 5

A load of 100 N is suspended from a 10 cm long cylindrical sample of the material of radius 0.5 cm.

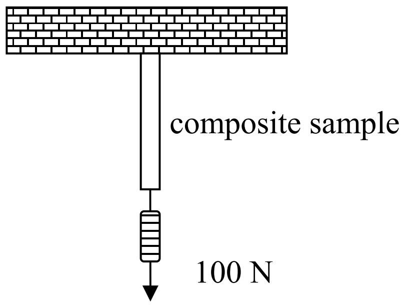


Figure 2

Which one of the following statements best describes the effect on the sample?

A. The stress is 1.27 MPa and the strain is 0.02.

B. The stress is 2.54 MPa and the strain is 0.5.

C. The stress is 100 N and the sample elongates in length by 0.2 cm.

D. The stress is about 1.27 MPa and the sample elongates in length by 0.2 cm.

2 marks

Use the following information to answer Questions 6 and 7.

Two objects, M_1 and M_2, of masses 30 kg and 45 kg respectively, are placed on a flat plank such that the plank makes a see-saw that is perfectly horizontal in equilibrium, as shown in Figure 3. Assume the mass of the plank to have no effect on the calculations in Questions 6 and 7.

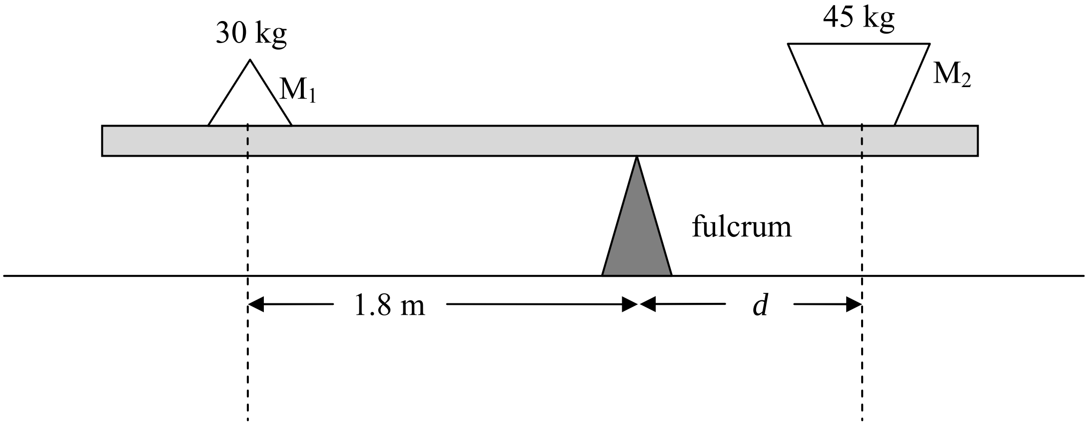


Figure 3

Question 6

What is the distance, d, from object M_2 to the fulcrum?

A. 0.6 m

B. 1.2 m

C. 0.4 m

D. 1.0 m

2 marks

Question 7

What is the normal reaction force exerted by the fulcrum on the plank?

A. 75 N

B. 90 N

C. 750 N

D. 900 N

2 marks

Use the following information to answer Questions 8–10.

From the second floor of an office complex, a platform of mass 1000 kg protrudes out, as shown in Figure 4. The platform is tied to the wall by a rope and is also supported by its insertion into the structure of the wall. An engineer wishes to analyse the stability of the platform and the rope and assumes that an average person standing on the platform has a mass of 70 kg. The platform and the people are in equilibrium.

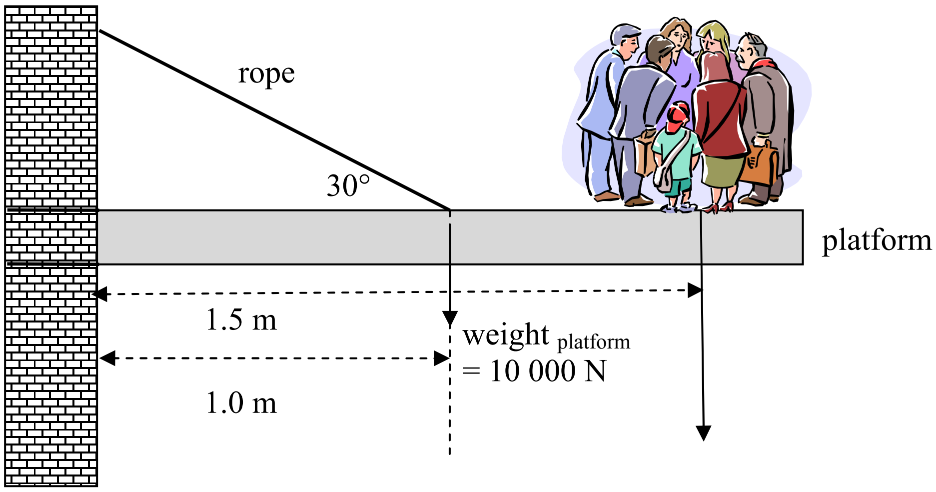


Figure 4

Question 8

If 10 people stand on the platform, as shown in Figure 4, what would be the tension in the rope? (1 kN = 1000 N)

A. 26 kN

B. 30 kN

C. 41 kN

D. 35 kN

2 marks

Question 9

If ten people stand on the platform, as shown in Figure 4, the horizontal component of the reaction force on the platform from the wall is closest in magnitude to

A. 25 kN

B. 30 kN

C. 35 kN

D. 40 kN

2 marks

Question 10

In an independent test on the mechanical properties of the rope, a sample of the rope used in the structure fractured under tension at 50 000 N. The builder wishes to place a safety factor of 2.5 on the use of the rope. The cross-section area of the rope is 5×10^{-4} m^2. The recommended maximum stress for the rope would be closest in value to

A. 25 MPa

B. 30 MPa

C. 35 MPa

D. 40 MPa

2 marks

Use the following information to answer Questions 11–13.

The mechanical properties of a number of materials are shown in Figure 5. The materials have been labelled M1, M2, M3 and M4 and their properties are analysed for building a household driveway. The curves are drawn to the same axes and scale and drawn to fracture.

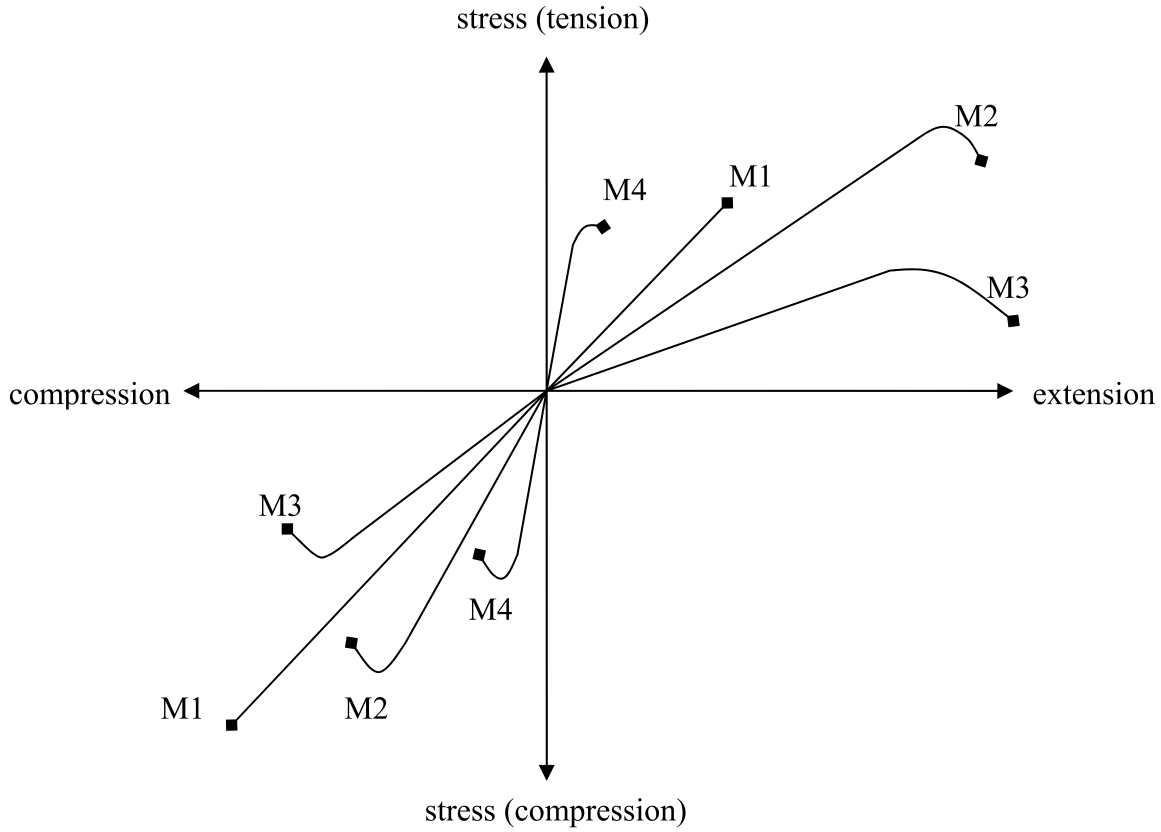


Figure 5

Question 11

Which of the following statements best provides a comparative summary of the materials indicated?

A. M2 is tougher than M1 in compression, and M1 is more flexible than M2 in tension.

B. M1 is stronger than M2 in compression, but weaker than M2 in tension.

C. M1 and M3 are brittle materials.

D. M2, M3 and M4 are all brittle materials.

2 marks

Question 12

Which one of the following statements is true about the Young's modulus, E, of the materials in the elastic region under tension?

A. E decreases in the sequence $E_{M1} > E_{M3} > E_{M2} > E_{M1}$.

B. E increases in the sequence $E_{M1} > E_{M3} > E_{M2} > E_{M1}$.

C. E decreases in the sequence $E_{M4} > E_{M1} > E_{M2} > E_{M3}$.

D. E increases in the sequence $E_{M4} > E_{M1} > E_{M2} > E_{M3}$.

2 marks

Question 13

A composite driveway is recommended with a mesh made of one material placed on the ground and another material poured onto and over it as a filler, as shown in Figure 6.

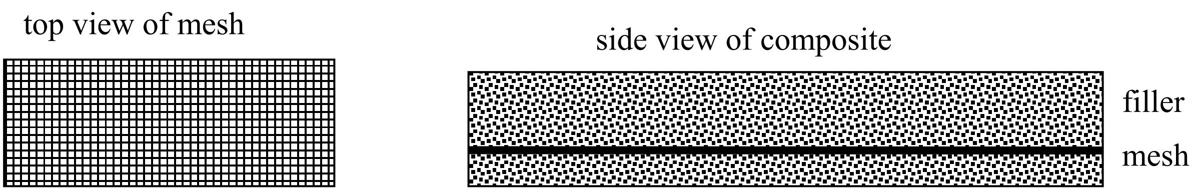


Figure 6

Which of the material combinations would be best suited for the driveway, without any consideration to cost of the material?

A. M1 for mesh and M2 for filler.

B. M1 for filler and M2 for mesh.

C. M3 for filler and M4 for mesh.

D. M4 for filler and M3 for mesh.

2 marks

END OF DETAILED STUDY 2
SECTION B – continued
TURN OVER

Detailed study 3 – Further electronics

Use the following information to answer Questions 1–5.

A capacitor and a resistor form a series RC circuit, as shown in Figure 1. The CRO measures the output voltage across the capacitor. The capacitor is charged by closing the switch and discharged by opening the switch.

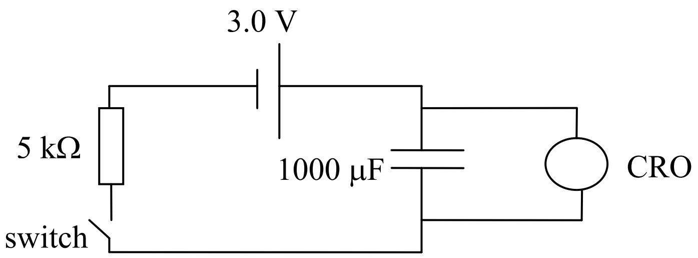


Figure 1

Question 1

What is the time constant for the RC circuit?

A. 2.0 s

B. 5000 s

C. 5 s

D. 200 s

2 marks

Question 2

After charging for a time of 1τ, the voltage across the capacitor is closest in value to

A. 1.9 V

B. 1.5 V

C. 1.3 V

D. 1.1 V

2 marks

Question 3

After discharging for a time of 1τ, the voltage across the capacitor is closest in value to

A. 1.9 V

B. 1.5 V

C. 1.3 V

D. 1.1 V

2 marks

Question 4

At a certain instant during discharging, the CRO measures the voltage across the capacitor as 1.7 V. At this instant what will be the voltage across the resistor?

A. 1.7 V

B. 1.3 V

C. 3.0 V

D. 0.7 V

2 marks

Question 5

The CRO is now connected across the resistor. Which of the following best describes the voltage output across the resistor when the capacitor is being charged?

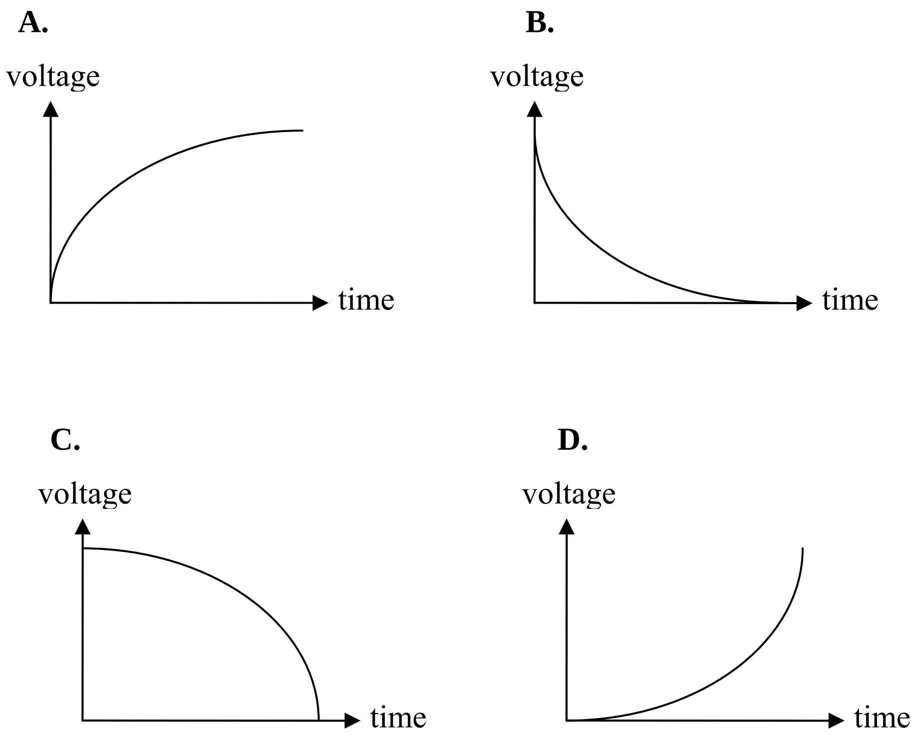


Figure 2

2 marks

Use the following information to answer Questions 6–10.

A DC power supply circuit is assembled using an ideal Zener diode, as shown in Figure 3a. The characteristic graph of the Zener diode is shown in Figure 3b. The unregulated AC supply voltage, V_S, varies between 10 V and 12 V. A CRO is used to measure the output voltage, V_L, across the load resistance R_L.

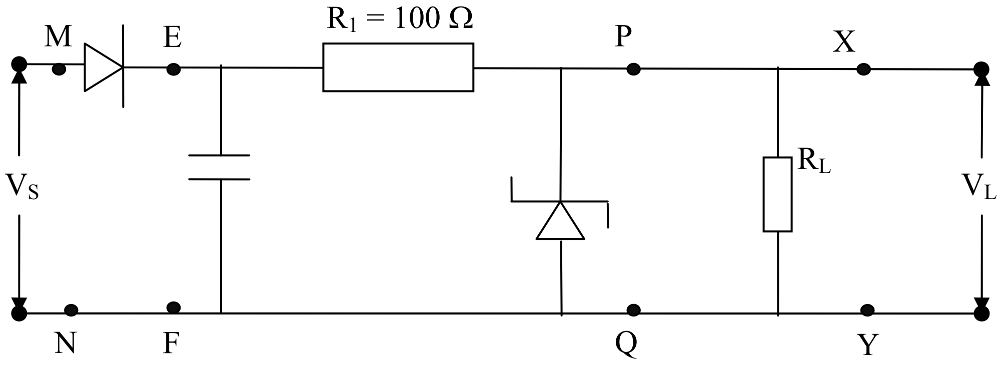


Figure 3a

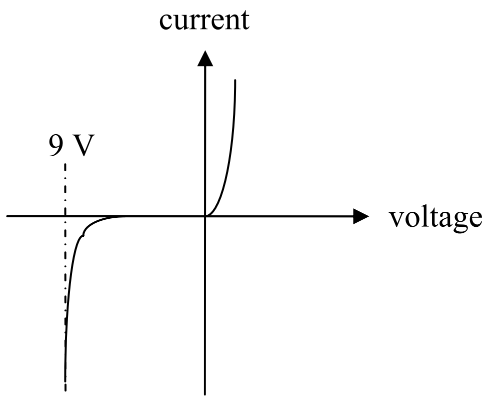


Figure 3b

Question 6

What will be the affect on the voltage V_L and current through the Zener diode if the value of the supply voltage, V_S, is increased to 12.5 V?

A. V_L will increase; current through the Zener diode will decrease.

B. V_L will decrease; current through the Zener diode will remain the same.

C. V_L will remain the same; current through the Zener diode will increase.

D. V_L will remain the same; current through the Zener diode will decrease.

2 marks

Question 7

The CRO is now connected at another part of the circuit such that a trace, shown in Figure 4, is obtained. Connection between which two points is most likely to give the trace shown in Figure 4?

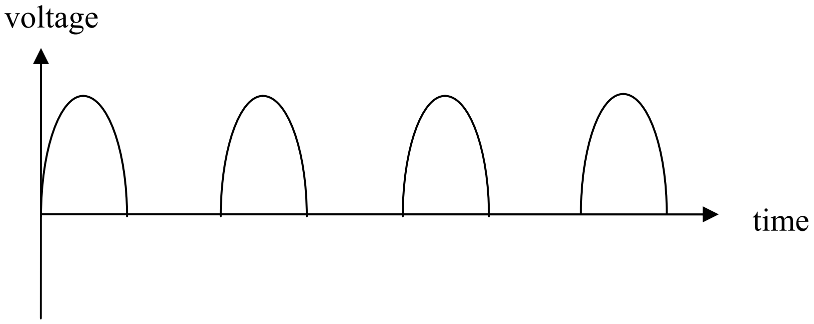


Figure 4

A. Connection between points M and N.

B. Connection between points E and F.

C. Connections between points P and Q.

D. Connection between points X and Y.

2 marks

Question 8

When the supply voltage is at 11.0 V, what will be the current in the resistor R_1?

A. 0.02 A

B. 0.03 A

C. 0.2 A

D. 0.3 A

2 marks

Question 9

When the supply voltage is 11.0 V and the load resistance, R_L, is 2000 Ω, what is the current though the Zener diode?

A. 16.5 mA

B. 15.0 mA

C. 15.5 mA

D. 16.0 mA

2 marks

Question 10

As the value of the load resistance, R_L, increases, which of the following statements best describes the outcome for the Zener diode and the load resistance? The current through the load resistance is I_{load} and the current in the Zener diode is I_{Zener}.

A. V_L increases, I_{load} decreases, I_{Zener} decreases.

B. V_L decreases, I_{load} increases, I_{Zener} increases.

C. V_L stays the same, I_{load} increases, I_{Zener} decreases.

D. V_L stays the same, I_{load} decreases, I_{Zener} increases.

2 marks

Use the following information to answer Questions 11–13.

A DC power supply circuit is constructed, as shown in Figure 5a, using a transformer, resistors, capacitor, and a bridge rectifier. The full-wave bridge rectifier is made with four silicon diodes, which have typical voltage drop of 0.7 V across each diode when fully switched on. The output across the load resistance is measured by a CRO and is found to have a ripple voltage of 0.03 V peak to peak. Figure 5b shows a CRO trace of the input signal.

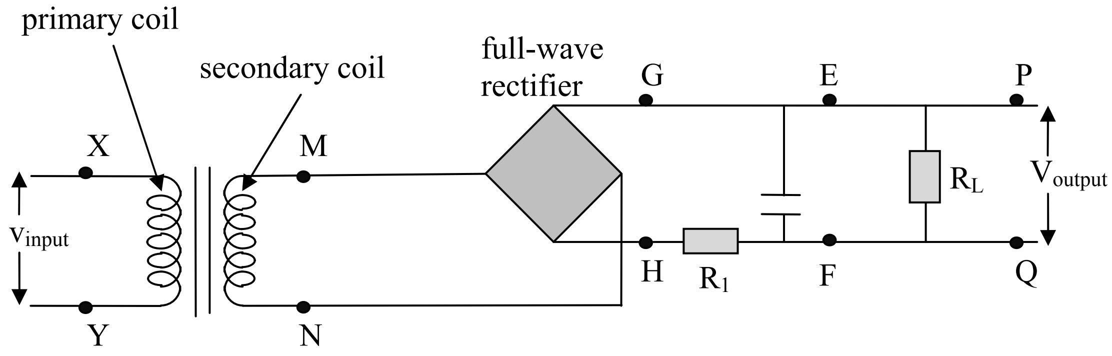


Figure 5a

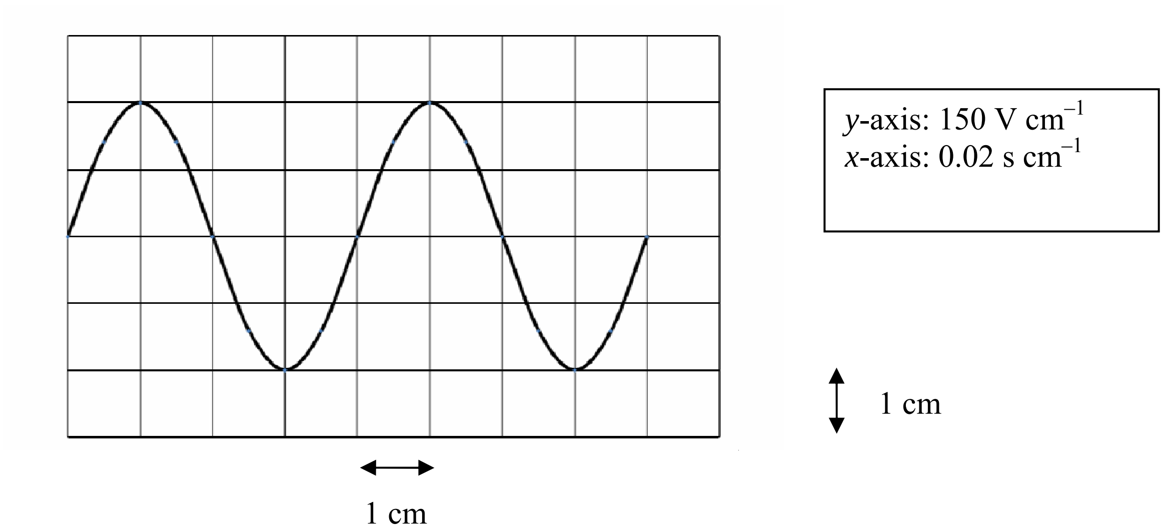


Figure 5b

Question 11

The transformer has a turn-ratio $\frac{N_{primary}}{N_{secondary}} = \frac{10}{1}$. The peak voltage signal across points M and N is closest in value to

A. 21 V

B. 30 V

C. 42 V

D. 45 V

2 marks

Question 12

Which one of the following statements best describes the method to reduce the ripple voltage, V_r?

A. Increase the time constant, τ, of the capacitor–load resistance circuit.

B. Increase the capacitance of the capacitor and decrease the resistance of R_1.

C. Decrease the capacitance of the capacitor and increase the resistance of R_1.

D. Decrease both the resistance R_1 and the capacitance of the capacitor.

2 marks

Question 13

When the peak voltage across points M and N is 12.0 V, the voltage across the points G and H is closest in value to

A. 9.5 V

B. 10.1 V

C. 10.6 V

D. 11.2 V

2 marks

END OF QUESTION AND ANSWER BOOK

INSIGHT
Trial Exam Paper

2009
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.

SECTION A – Core

Area of study 1 – Motion in one and two dimensions

The following information applies to Questions 1–3.

Edward drives his car at a uniform speed of 15 ms^{-1} around a bend of radius 25 m on a road that is banked at angle θ, as shown in Figure 1. The mass of the car and John combined is 1000 kg.

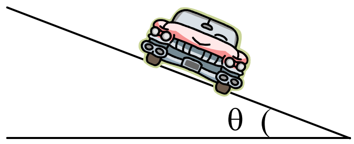


Figure 1

Question 1

What is the magnitude of the acceleration of the car?

Worked solution

$a = \frac{v^2}{R} = \frac{(15)^2}{25} = 9 \text{ ms}^{-2}$ towards centre of the circle

9 ms^{-2}

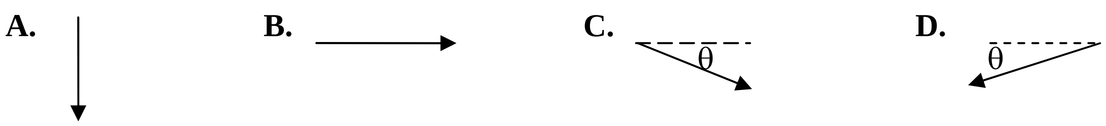
2 marks

Mark allocation

- 1 mark for correct values substituted into correct equation.
- 1 mark for correct answer.

Question 2

Which direction best describes the net acceleration on the car?



B

Worked solution

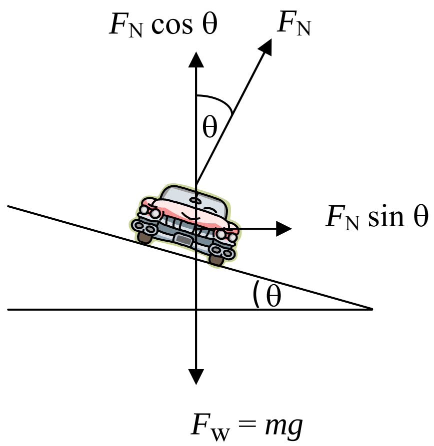
Answer is B. Centripetal acceleration acts towards the centre of the circular path.

1 mark

Question 3

Edward finds that at a constant speed of 15 ms^{-1}, the car does not slide and is under control. However, at speeds greater than 15 ms^{-1}, the car slides. What is the magnitude of the angle of bank, θ, of the road?

Worked Solutions



$F_N \cos\theta = mg$

$F_N \sin\theta = \frac{mv^2}{R}$

$$\therefore \tan\theta = \frac{v^2}{Rg} = \frac{(15)^2}{25 \times 10} = 0.9$$

$$\therefore \theta = \tan^{-1} 0.9 = 42°$$

42°

3 marks

Mark allocation

- 1 mark each for determining the relation of components to centripetal force and weight for a maximum of 2 marks.
- 1 mark for calculating correct value of θ.

Tip

- *Use components of normal force to find net force. The net force on a body moving in a circular path at constant speed is* $\frac{mv^2}{R}$

The following information applies to Questions 4–7.

A train engine of mass 24 tonnes travelling east at 5.0 ms^{-1} collides with an empty carriage of mass 3 tonnes travelling west at 15.0 ms^{-1}, as shown in Figure 2.

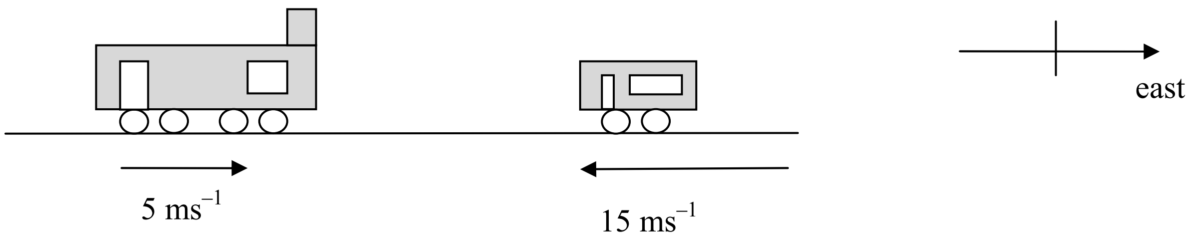


Figure 2

After the collision, the empty carriage is found to be travelling east at a constant speed of 10.0 ms^{-1}.

Question 4

What is the velocity of the engine after collision?

Worked solution

Using conservation of momentum, and taking velocity towards east as positive

$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$
$(24 \times 5) - (3 \times 15) = (24 \times v_1) + (3 \times 10)$
$\therefore\ v_1 = 1.88\ ms^{-1}$ east

Magnitude: 1.88 ms^{-1}

Direction: east

3 marks

Mark allocation

- 1 mark for correct use of conservation of momentum.
- 1 mark for correct magnitude of velocity.
- 1 mark for correct direction.

Tip

- *Use appropriate signs when dealing with vectors such as velocity and momentum.*

Question 5

Justify with appropriate collisions whether the collision is elastic or inelastic.

Worked solution

Kinetic energy before collision = $(\frac{1}{2}mv^2)_{engine} + (\frac{1}{2}mv^2)_{carriage}$

$= (\frac{1}{2} \times 24\,000 \times 5^2) + (\frac{1}{2} \times 3000 \times 15^2) = 637\,500$ J

Kinetic energy after collision = $(\frac{1}{2} \times 24\,000 \times 1.875^2) + (\frac{1}{2} \times 3000 \times 10^2) = 192\,187.5$ J

Kinetic energy is 'lost' during collision. Therefore, the collision is inelastic.

inelastic

3 marks

Mark allocation

- 1 mark each for correct calculation of kinetic energy before and after collision.
- 1 mark for concluding collision is inelastic.

Tip

- *Energy is a scalar quantity. Use brackets to reduce chances of making mathematical errors.*

Question 6

The contact time between engine and carriage is 1 ms. What average force does the engine exert on the carriage?

Worked solution

$F_{av}\Delta t = m\Delta v$

$F_{av} = \left[\frac{m\Delta v}{\Delta t}\right]$ for carriage $= \frac{3000 \times (10-(-15))}{1 \times 10^{-3}} = 7.5 \times 10^7$ N to the right

Magnitude: 7.5×10^7 N

Direction: To the east (i.e. right).

2 marks

Mark allocation

- 1 mark for correct use of formula and magnitude of force.
- 1 mark for correct direction.

Question 7

What is the magnitude of the average force the carriage exerts on the engine? Show your working.

Worked solution

$F_{av} = \dfrac{\Delta p}{\Delta t} = \dfrac{24\,000(1.875 - 5)}{1 \times 10^{-3}} = -7.5 \times 10^{7}$ N (minus sign indicates direction is to the left)

Alternatively, quote Newton's Third Law.

7.5×10^{7} N

2 marks

Mark allocation

- 1 mark for correct value of force.
- 1 mark for working or reasoning.

Tip

- *Use appropriate signs when calculating vector quantities.*

The following information applies to Questions 8–12.

A skier wishes to have skiing equipment of mass 200 kg transported to the top of the downhill ski slope. The items are pulled on a cart by a rope with a force $\boldsymbol{F}_a$ and, in doing so, a constant friction force of 100 N is encountered, as shown in Figure 3.

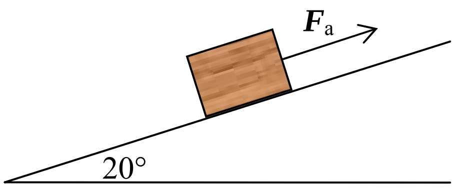
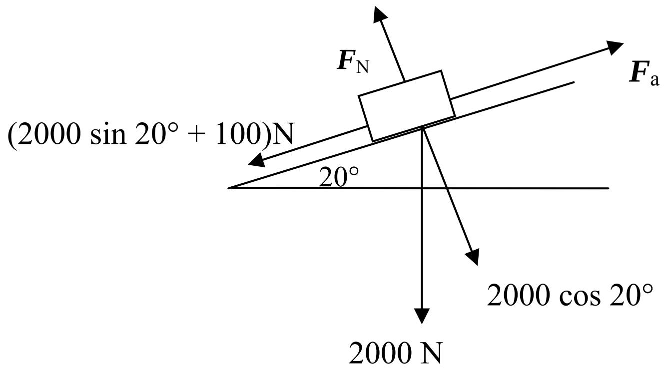


Figure 3

Question 8

For the cart to be towed at a constant speed, what must be the magnitude of the applied force, $\boldsymbol{F}_a$?

Worked solution



$\boldsymbol{F}_a = \boldsymbol{F}_f + \boldsymbol{F}_w \sin \theta$

$= 100 + 2000 \sin 20°$

$= 784$ N

784 N

2 marks

Mark allocation

- 1 mark for correct use of components to find $\boldsymbol{F}_a$.
- 1 mark for correct answer.

Tip

- *Draw a vector diagram showing all forces from centre of mass of the object under consideration.*

Question 9

What is the work done by the applied force to tow the skiing equipment 100 m up the slope?

Worked solution

$W = F \times d$ (in direction of F)
$= 784 \times 100$
$= 78\ 404$ J

78 400 J

2 marks

Mark allocation

- 1 mark for correct values substituted into correct formula.
- 1 mark for correct answer.
- 2 consequential marks if error of Question 8 is carried and formula is used correctly.

The skier now skis downhill, starting from rest and making no effort to accelerate (Figure 4). The skier finds himself accelerating downhill, encountering a constant friction force of 80 N. The combined mass of the skier, skis and ski equipment is 280 kg.

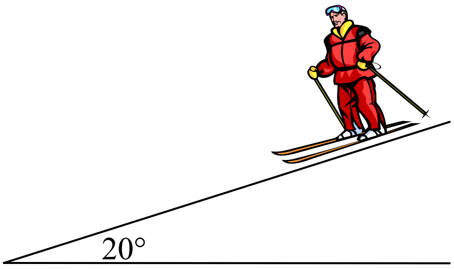
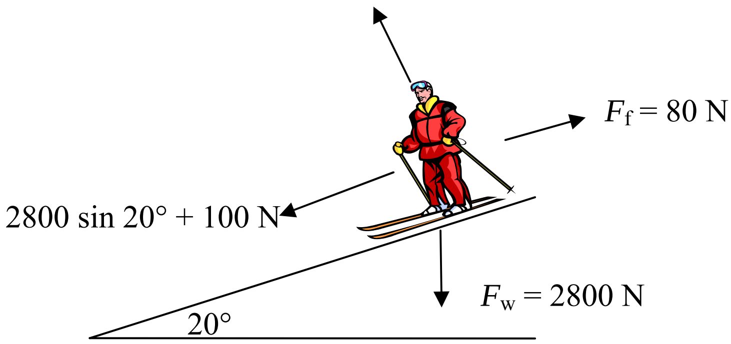


Figure 4

Question 10

What is the magnitude of the acceleration of the skier?

Worked solution



$$a = \frac{F_{net}}{m}$$

$$= \frac{2800\sin 20^{\circ} - 80}{280}$$

$= 3.13\ \text{ms}^{-2}$, down the slope

$3.13\ \text{ms}^{-2}$

2 marks

Mark allocation

- 1 mark for establishing expression for acceleration using correct components.
- 1 mark for correct answer.

Question 11

What is the speed of the skier at an instant 50 m down the incline?

Worked solution

$u = 0$
$v = ?$
$a = 3.13\ \text{ms}^{-2}$
$x = 50\ \text{m}$
$v^2 = u^2 + 2ax$
$v = \sqrt{2ax} = \sqrt{2 \times 3.13 \times 50}$
$= 17.7\ \text{ms}^{-1}$

$17.7\ \text{ms}^{-1}$

2 marks

Mark allocation

- 1 mark for correct values substituted into correct equation.
- 1 mark for correct answer. Accept $17.6\ \text{ms}^{-1}$.

Tip

- *List all quantities given, check their units, and determine which equation of motion to use.*

Question 12

What is the kinetic energy of the skier and his skis 50 m downhill from the starting position?

Worked solution

$u = 0$
$v = 17.7 \text{ ms}^{-1}$
$m = 280 \text{ kg}$

$$E_k = \frac{1}{2} mv^2$$
$$= \frac{1}{2} \times 280 \times (17.7)^2$$
$$= 4.4 \times 10^4 \text{ J}$$

4.4×10^4 J

2 marks

Mark allocation

- 1 mark for correct estimation of final speed. Consequential marks given for incorrect acceleration.
- 1 mark for correct value of kinetic energy. Accept 4.3×10^4 J.

Tips

- *Energy is a scalar quantity.*
- *Equations of motion can be used only when acceleration is constant.*

The following information applies to Questions 13 and 14.

A basketball player launches a ball 2 m above the ground with a speed of 7.5 ms^{-1} at an angle of 50° to the horizontal, at location A. The ball follows a parabolic (projectile) path and goes through a hoop at B, which is at a horizontal distance of 3 m from A and a height of *y* m above ground. Ignore any friction due to air.

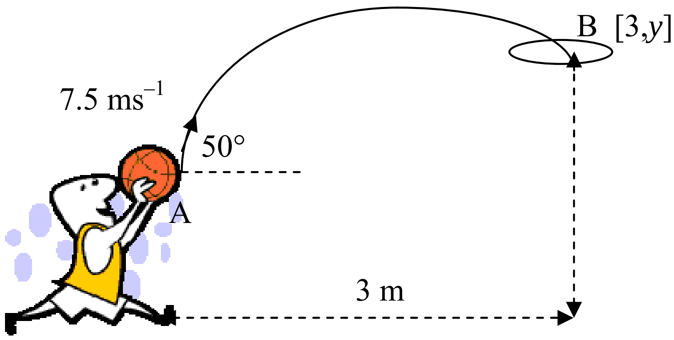


Figure 5

Question 13

How long was the basketball in the air as it travelled from A to B?

Worked solution

For horizontal motion:

$u = 7.5 \cos 50°$
$x = 3$ m
$t = ?$

$$t = \frac{x}{u} = \frac{3}{7.5 \cos 50^{\circ}} = 0.62 \text{ s}$$

0.62 s

2 marks

Mark allocation

- 1 for using correct component of launch velocity.
- 1 mark for correct answer.

Tips

- *Analyse vertical and horizontal motion separately.*
- *Use appropriate signs for vector quantities.*

Question 14

What is the height, y, of the hoop above the ground?

Worked solution

$u_v = 7.5 \sin 50°$
$a = -10\ \text{ms}^{-2}$
$t = 0.62$ s
$h = ?$

$$h = ut + \frac{1}{2}at^2$$

$$= (7.5 \sin 50°)(0.62) - \frac{1}{2} \times 10 \times (0.62)^2 = 1.64 \text{ m}$$

Height above ground = 1.64 + 2 = 3.64 m

3.64 m

3 marks

Mark allocation

- 1 mark for correct values substituted into correct equation.
- 1 mark for correctly evaluating h.
- 1 mark for adding 2 m to h.

Tip

- *Draw a clean diagram showing height of the hoop and the parabolic path of the ball. List all physical quantities given.*

The following information applies to Questions 15 and 16.

A new planet, Madgin, is found in our solar system. It has a mass of 4×10^{27} kg and a radius of 4×10^{8} m.

Question 15

What is the gravitational field strength on the surface of Madgin?

Worked solution

$$g = \frac{GM}{r^2} = \frac{6.7 \times 10^{-11} \times 4 \times 10^{27}}{(4 \times 10^{8})^2} = 1.67 \text{ ms}^{-2}$$

$1.67\ \text{ms}^{-2}$

2 marks

Mark allocation

- 1 mark for correct values substituted into correct equation.
- 1 mark for correct answer.

Question 16

A spaceship, Khir, is geostationary over the 'equator' of the planet Madgin at an altitude of 150 km above the surface. What is the time period of orbit of the satellite?

Worked solution

$$T = \sqrt{\frac{4\pi^2 R^3}{GM}} = \sqrt{\frac{4\pi^2 (4\times 10^8 + 350\times 10^3)^3}{6.67\times 10^{-11}\times 4\times 10^{27}}} = 9.7\times 10^4 \text{ s}$$

9.7×10^4 s

2 marks

Mark allocation

- 1 mark for correct values substituted into correct equation.
- 1 mark for correct answer.

Tips

- *Write all powers of 10 neatly and use brackets to reduce mathematical error.*
- *Remember to add 'radius of the planet' to 'height above surface' when calculating R.*

The following information applies to Questions 17 and 18.

A Hookean spring is stretched with an increasing force, as shown in Figure 6.

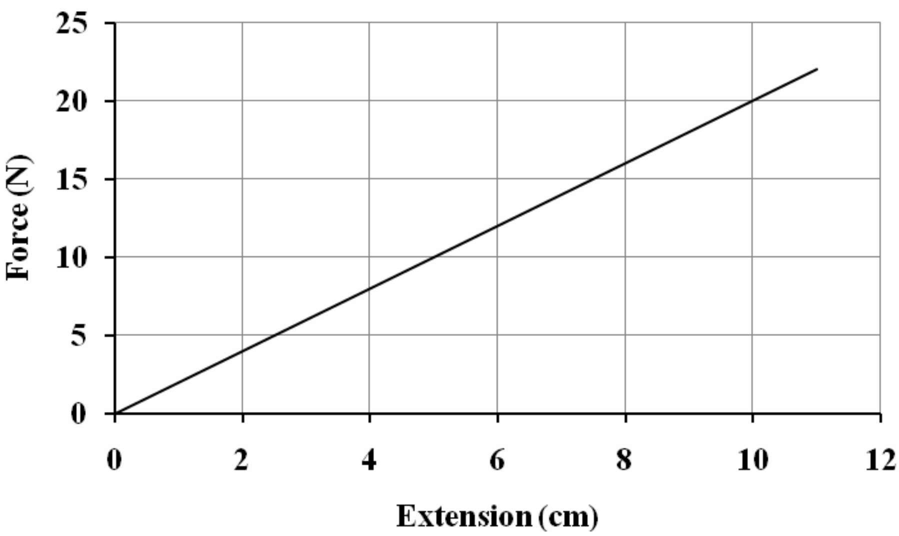


Figure 6

Question 17

From the graphical data provided, estimate the spring constant of the spring.

Worked solution

k = gradient of the graph = 200 Nm^{-1}

200 Nm^{-1}

2 marks

Mark allocation

- 1 mark for recognising k = gradient of graph.
- 1 mark for correct calculation of gradient.

Question 18

What is the work done in stretching the spring from 6.0 cm to 8.0 cm?

Worked solution

The work done is gain in elastic potential energy.

$W = \frac{1}{2}kx_2^2 - \frac{1}{2}kx_1^2 = \frac{1}{2} \times 200 \times (0.08^2 - 0.06^2) = 0.28 \text{ J}$

0.28 J

3 marks

Mark allocation

- 1 mark each for calculating correctly the elastic potential energy for the two stretched lengths.
- 1 mark for correct answer.

Tips

- *Use SI units in all calculations.*
- *Check units of the physical quantities graphed.*

Area of study 2 – Electronics and photonics

The following information applies to Questions 1–4.

A diode, with the current–voltage characteristics shown in Figure 1, is part of a circuit shown in Figure 2.

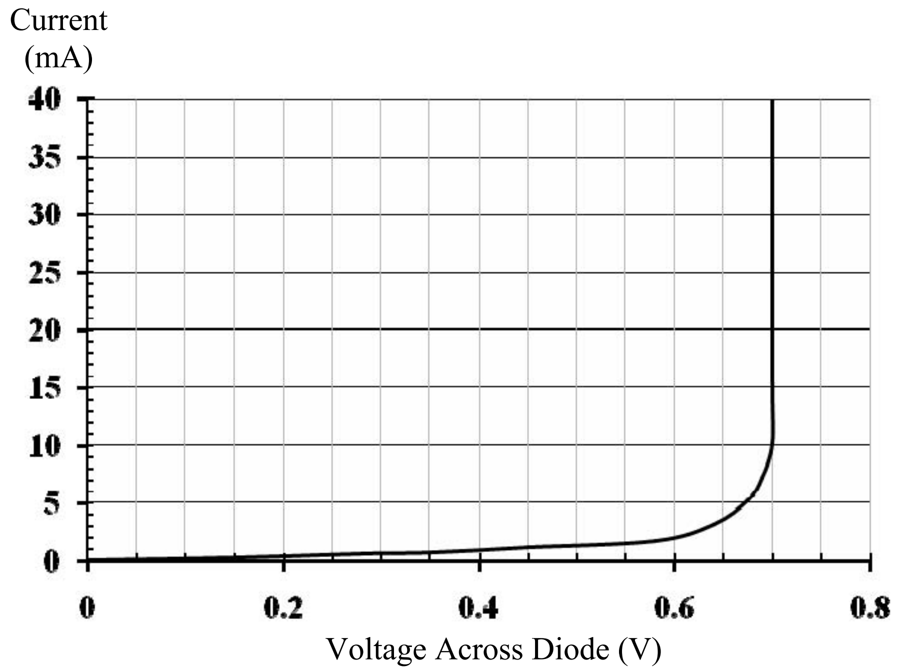


Figure 1

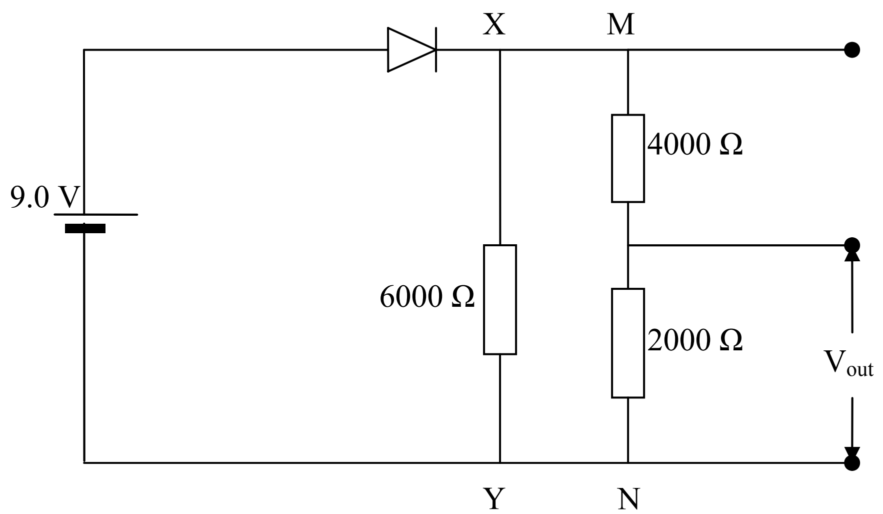


Figure 2

Question 1

Calculate the voltage across the 2000 Ω resistor.

Worked solution

$V_{MN} = 9 - 0.7 = 8.3$ V

$\therefore\ I_{MN} = \dfrac{8.3}{6000} = 1.38$ mA

$\therefore\ V_{out} = 2000 \times 1.38 \times 10^{-3} = 2.77$ V

2.77 V

3 marks

Mark allocation

- 1 mark for correct estimation of V_{MN}.
- 1 mark for correct estimation of I_{MN}.
- 1 mark for correct estimation of V_{out}.

Question 2

What is the current through the 6000 Ω resistor?

Worked solution

I (through the 6000 Ω resistor) = 1.38 mA, same as in the circuit arm MN.

1.38 mA

1 mark

Mark allocation

- 1 mark for correct answer. Consequential marks to be awarded if wrong answer but same as in Question 1.

SECTION A – Area of study 2 – continued
TURN OVER

The diode is now replaced with a thermistor, as shown in the circuit of Figure 3a. The resistance–temperature characteristic curve of the thermistor is shown in Figure 3b.

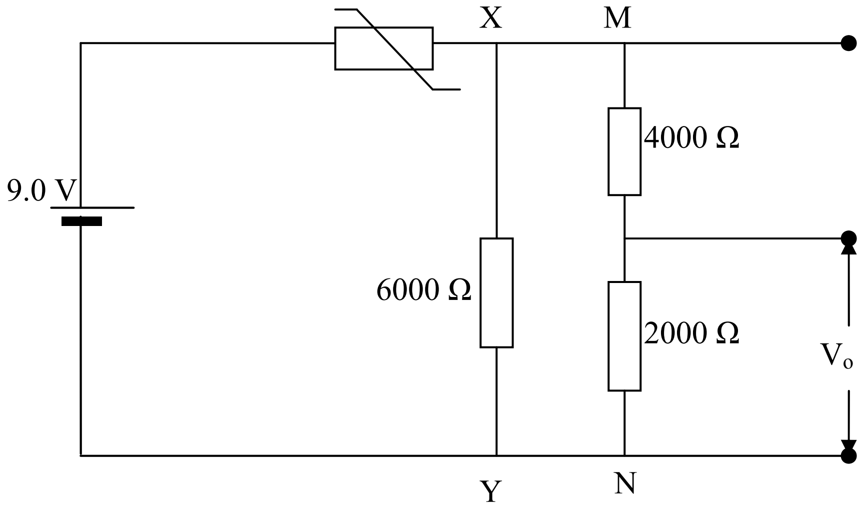


Figure 3a

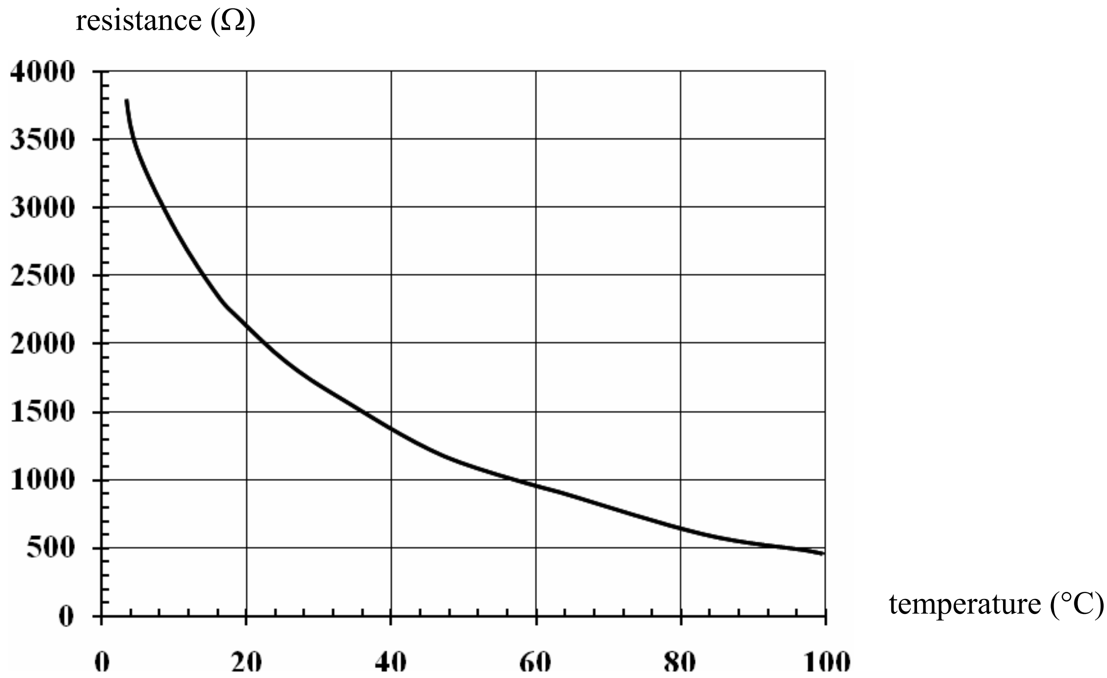


Figure 3b

Question 3

The temperature immediately surrounding the thermistor is 40°C. What is the output voltage V_O now?

Worked solution

Total resistance = 4300 Ω

Current drawn from battery is $\frac{9}{4300}$ = 2.09 mA

Current in the 2000 Ω resistor is 1.05 mA.
$V_o = 2000 \times 1.05 \times 10^{-3}$ V = 2.09 V

2.09 V

3 marks

Mark allocation

- 1 mark for correctly estimating current drawn from the battery.
- 1 mark for correctly estimating current in the resistor.
- 1 mark for correct answer. Accept a range of values from 2.04 to 2.09 V if correct working shown.

Question 4

The temperature surrounding the thermistor now drops. What would be the effect on the voltage output now? Explain your answer.

Worked solution

As temperature around the thermistor decreases, the resistance of the thermistor increases. This causes less current in the circuit, thereby reducing the output voltage.

2 marks

Mark allocation

- 1 mark for explanation – must include reference to temperature–resistance behaviour of the thermistor.
- 1 mark for correct conclusion.

Tips

- *Read all information given, such as that from graphs.*
- *Use Ohm's law systematically.*

The following information applies to Questions 5 and 6.

An npn transistor amplifier block diagram is shown in Figure 4a. A small AC signal is fed into the amplifier and the output signal is observed by a CRO. The transfer characteristic graph of the amplifier is shown in Figure 4b.

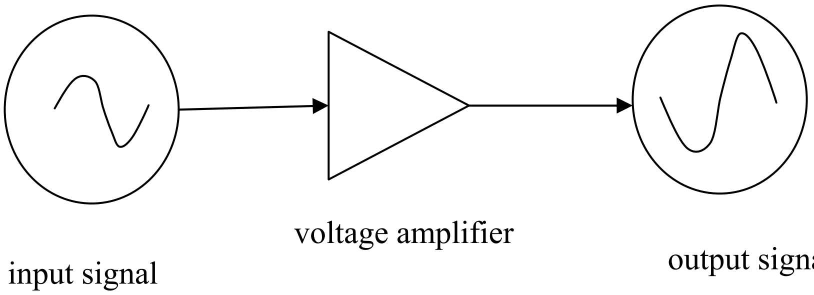


Figure 4a

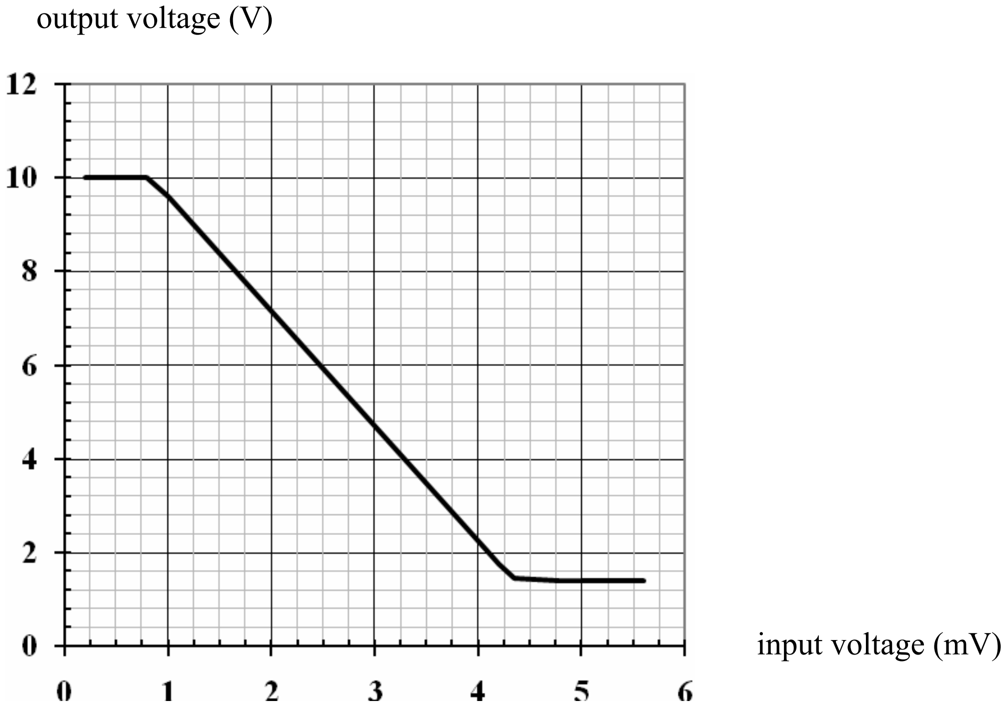


Figure 4b

Question 5

What is the voltage gain of the amplifier? Show your working.

Worked solution

Voltage gain is the gradient of the $\frac{\text{output voltage}}{\text{input voltage}}$ graph = $\frac{(10-1.4)\text{ V}}{3.5\text{ mV}}$ = 2457.14

It has no units.

2457.1

2 marks

Mark allocation

- 1 mark for correct use of input and output values to find gradient.
- 1 mark for answer. Accept a range of values from 2400 to 2700 if working is correct.

Question 6

The input signal is shown in Figure 5a. On the axes provided in Figure 5b, sketch the output wave form you would expect to see. You must show your working in estimating suitable values for the *y*-axis.

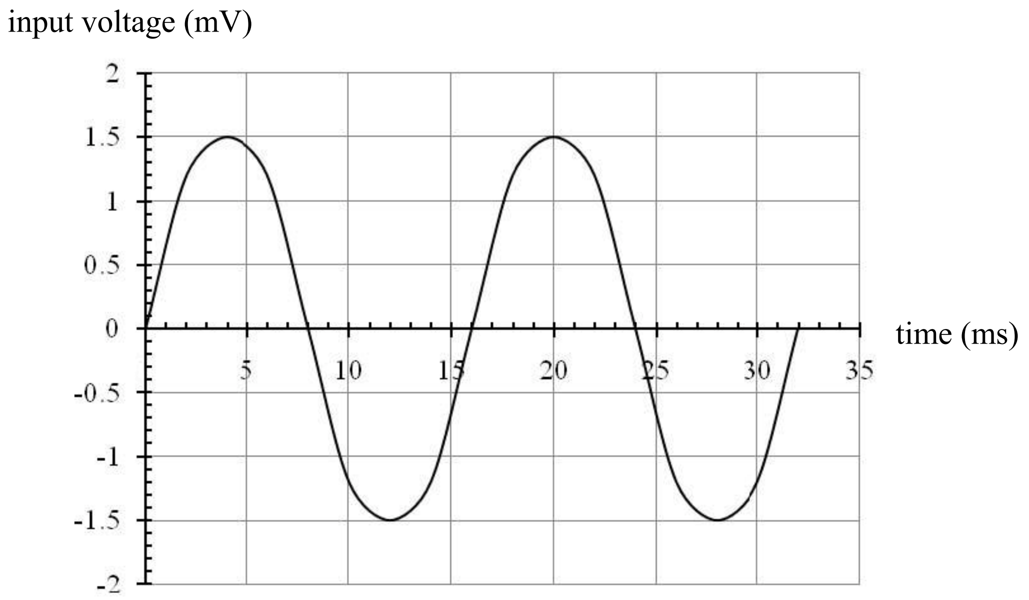


Figure 5a

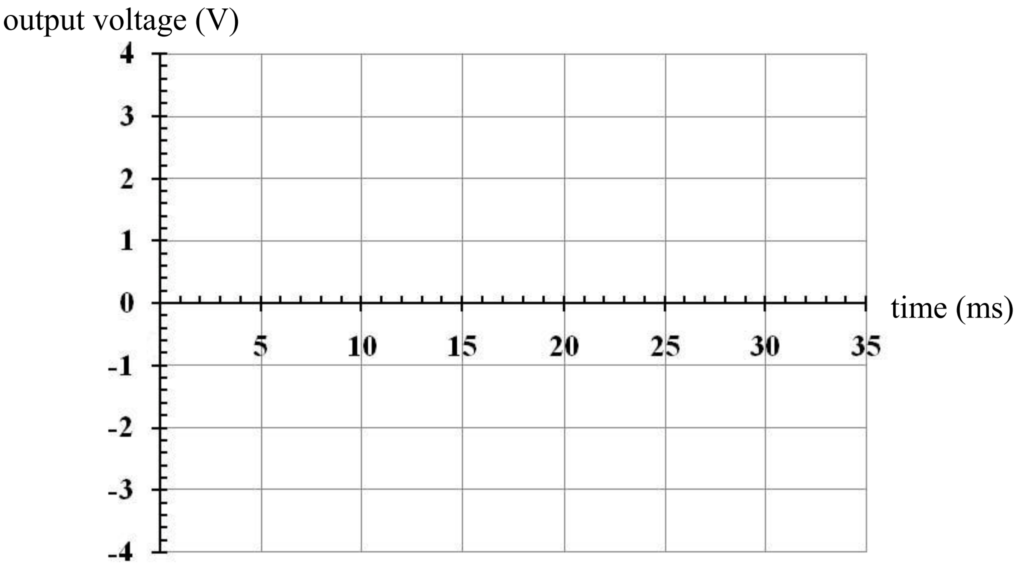
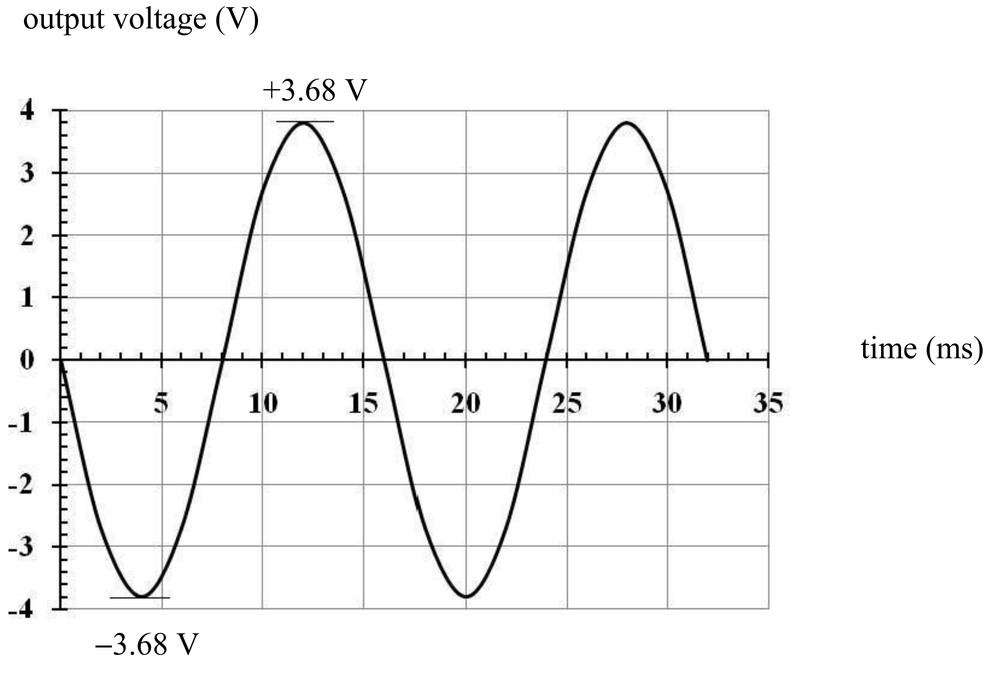


Figure 5b

Worked solution

Peak voltage is 2457.14 × 1.5 V = 3.68 V.

Output graph has same shape and same frequency as the input graph, and is inverted.



3 marks

Mark allocation

- 1 mark for inverting the output.
- 1 mark for keeping the same frequency.
- 1 mark for correct output voltage. Award consequential marks for peak voltage in the range 3.5 to 3.9 V.

Tips

- *Check units of the quantities graphed – ensure they are SI units.*
- *Check whether amplifier is inverting or non-inverting and adjust output accordingly.*
- *Voltage and current gain has no units.*

The following information applies to Questions 7–9.

Figure 6a shows the current–voltage characteristic graph for a photodiode at different light intensities, φ. A simplified circuit to detect intruders in a bank is shown in Figure 6b. A constant light beam from a separate DC source shines on the photodiode, resulting in an output voltage, V_{out}, across the resistor. However, when the light beam is momentarily interrupted by the movement of an intruder, the circuit is broken, resulting in an alarm.

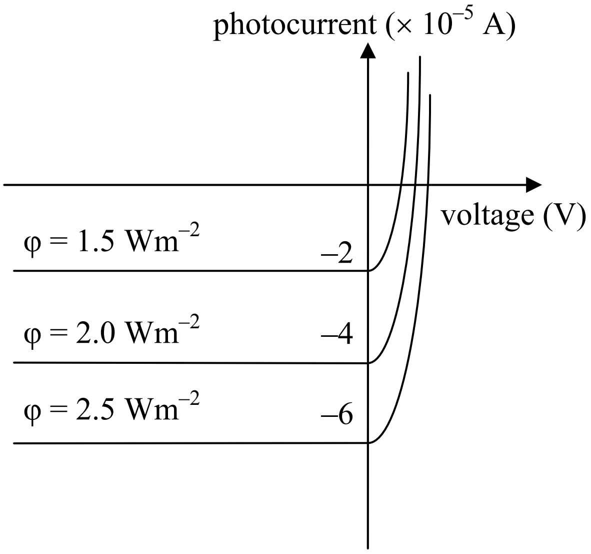


Figure 6a

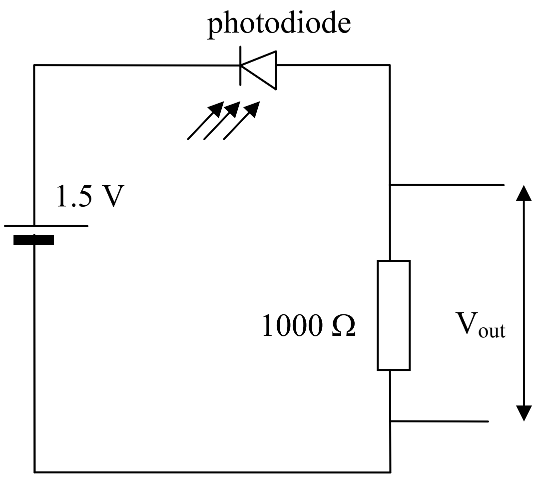


Figure 6b

Question 7

With specific reference to the current–voltage characteristics of the photodiode and its use in the circuit, explain why the photodiode is connected in reverse bias.

Worked solution

When there is no intruder passing across the light source to the photodiode, the light beam shines on the photodiode and there is an output voltage. When the light beam is blocked, the circuit is broken and there is no output voltage. If the diode is in forward bias, there will always be a current and an output voltage. Hence, it is connected in reverse bias.

2 marks

Mark allocation

- 1 mark for explaining why forward bias will not work as an alarm.
- 1 mark for explaining what the photodiode does in forward bias.

Question 8

With light of intensity 2 Wm^{-2} shining on the photodiode, what is the output voltage, V_{out}? Show your working.

Worked solution

From Figure 6a, at 2 Wm^{-2}, photocurrent is 4×10^{-5} A.

Therefore, output voltage $V_{out} = 1000 \times 4 \times 10^{-5}$ V = 0.04 V = 40 mV

40 mV

2 marks

Mark allocation

- 1 mark for correctly reading the photocurrent from Figure 6a.
- 1 mark for correctly using the current in Ohm's law statement and for the correct answer.

Question 9

As the intensity of light changes to a new value, the output voltage is found to increase. Is this increase in output voltage due to an increase or decrease in light intensity? Explain your answer.

Worked solution

Increase.

The increase in output voltage is due to an increase in current, which can occur only when there is an increase in light intensity.

2 marks

Mark allocation

- 1 mark for correct conclusion.
- 1 mark for explanation – which must link increase in current to increase in light intensity.

Tips

- *Photodiode is in reverse bias when used as a sensor.*
- *Check units and scale of physical quantities.*

The following information applies to Questions 10 and 11.

A laser beam is used as a carrier wave to transmit audiovisual signal from a player to a screen, as shown in a schematic diagram in Figure 7. The transmission system requires two transducers – P and Q.

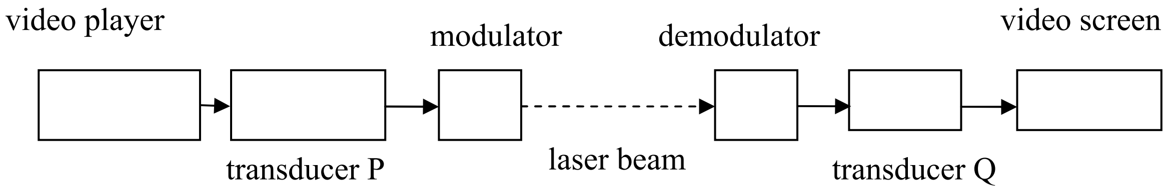


Figure 7

Question 10

Which of the following combinations of transducers is the appropriate choice for the transmission system?

A. LED is transducer P and phototransistor is transducer Q.

B. Photodiode is transducer P and thermistor is transducer Q.

C. LDR is transducer P and LED is transducer Q.

D. Transistor amplifier is transducer P and LDR is transducer Q.

A

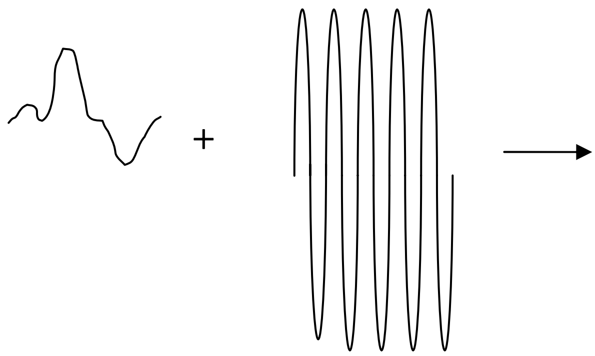
2 marks

Mark allocation

- 2 marks for correct answer. No part marks.

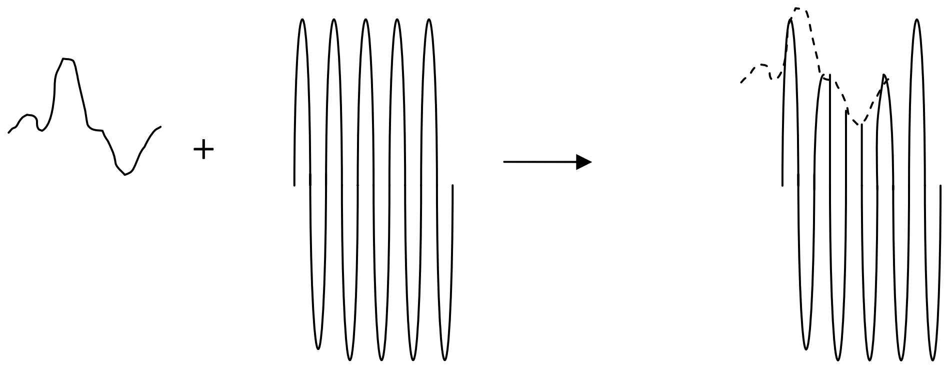
Question 11

An input signal needs to be transmitted from a source to a screen, using a laser beam. Show, by explanation and suitable sketch, the effect of modulation and demodulation of the laser carrier beam, and explain how the laser beam would be used to carry the input signal to the screen.



Worked solution

The laser beam would be the carrier wave that would 'carry' the signal by amplitude modulation. At the receiving end, the laser beam would be removed in a demodulation process. The use of the laser beam would reduce attenuation.



2 marks

Mark allocation

- 1 mark for recognising amplitude modulation for signal and carrier wave.
- 1 mark for explaining demodulation in context.
- Alternatively, 1 mark for explaining modulation and demodulation and 1 mark for appropriate diagram.

Tip

- *Make a list of all transducers discussed in the course, explaining their properties, drawbacks and applications.*

END OF SECTION A

SECTION B – Detailed studies

Detailed study 1 – Einstein's special relativity

Use the following information to answer Questions 1–3.

Muons are unstable subatomic particles that result during the decay of a pion and can themselves decay into positrons and neutrinos. They last for a short lifetime of 2.20 μs before they decay. Muons have an average rest mass of 207 times the rest mass of an electron. The mass of an electron is $m_e = 9.1 \times 10^{-31}$ kg.

Question 1

The lifetime of the muon travelling at 0.9*c*, as measured by an observer in a laboratory, is closest in value to

A. 4.40 μs

B. 0.96 μs

C. 5.04 μs

D. 3.45 μs

C

Worked solution

$$\gamma = \sqrt{\frac{1}{1-\frac{v^2}{c^2}}} = 2.29$$

$t = t_0 \times \gamma = 2.20 \times 2.29$ μs $= 5.04$ μs

2 marks

Question 2

Which one of the following gives the best magnitude of the kinetic energy of a muon travelling at 0.9*c*?

A. 1.9×10^{-11} J

B. 2.2×10^{-11} J

C. 2.8×10^{-11} J

D. 3.1×10^{-11} J

B

Worked solution

$$E_k = m_0c^2(\gamma - 1) = 207 \times 9.1 \times 10^{-31} \times (3 \times 10^8)^2 \times (2.29 - 1)$$
$$= 2.19 \times 10^{-11} \text{ J}$$

2 marks

Question 3

What is the mass of the muon travelling at 0.9*c*?

A. 2.1×10^{-30} kg

B. 4.3×10^{-28} kg

C. 3.5×10^{-30} kg

D. 5.2×10^{-29} kg

B

Worked solution

$m = \gamma m_0$
$= 2.29 \times 207 \times 9.1 \times 10^{-31}$ kg
$= 4.3 \times 10^{-28}$ kg

2 marks

Tips

- *Identify proper time, proper length and rest mass.*
- *Find γ for the speed and use this in your calculations to reduce mathematical errors.*

Use the following information to answer Questions 4–7.

A space mission is planned to carry passengers to the star Alpha Centauri, about 4 light years (ly) from Earth. A newly developed technology allows the spaceship to travel at 0.6*c*.

Question 4

How long would the journey take, as observed by the tracking station on Earth?

A. 2.4 y

B. 6.67 y

C. 4 y

D. 4.6 y

B

Worked solution

$$\text{Time} = \frac{\text{distance}}{\text{speed}}$$
$$= \frac{4 \text{ light years}}{0.6c}$$
$$= 6.67 \text{ years}$$

2 marks

Question 5

What is the distance of Alpha Centauri from Earth, according to the astronauts on the spaceship?

A. 5 ly

B. 6.67 ly

C. 3.2 ly

D. 4 ly

C

Worked solution

$$\gamma_{\text{at } 0.6c} = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}} = 1.25$$

$$L = \frac{L_0}{\gamma} = \frac{4}{1.25}$$

$$= 3.2 \text{ light years}$$

2 marks

Question 6

What is the time taken to travel from Earth to the star, according to the astronauts?

A. 5.33 y

B. 8.34 y

C. 6 y

D. 6.67 y

A

Worked solution

$$t_0 = \frac{t}{\gamma} = \frac{6.67}{1.25}$$

$$= 5.33 \text{ light years}$$

2 marks

Question 7

An asteroid, 250 m long, passes the space station at a speed of 0.8*c* and flies away harmlessly. To an astronaut on the space station, the length of the asteroid would appear to be

A. 150 m

B. 200 m

C. 300 m

D. 415 m

A

Worked solution

$$\gamma_{\text{at } 0.8c} = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}} = 1.66$$

$$L = \frac{L_0}{\gamma} = \frac{250}{1.66}$$

$$= 150 \text{ m}$$

2 marks

Tips

- *Identify proper time, proper length and rest mass.*
- *Find γ for the speed and use this in your calculations to reduce mathematical errors.*

Use the following information to answer Questions 8–11.

An electron is accelerated from rest with 9 gigavolts of potential difference in a linear accelerator. (Giga = 10^9)

Question 8

According to Newtonian physics, what would be its kinetic energy?

A. 1.1×10^{-9} J

B. 2.4×10^{-9} J

C. 1.6×10^{-10} J

D. 3.2×10^{-10} J

C

Worked solution

Kinetic energy would be equal to electrical work done = $qV = 1.6 \times 10^{-19} \times 10^{9} = 1.6 \times 10^{-10}$ J

2 marks

Question 9

For an electron travelling at 0.9*c*, its relativistic kinetic energy would be

A. more than that calculated by Newtonian physics.

B. less than that calculated by Newtonian physics.

C. the same as that calculated by Newtonian physics.

D. infinitely high.

A

Worked solution

Relativistic kinetic energy, $E_k = m_0c^2(\gamma - 1) = 1.1 \times 10^{-13}$ J

Newtonian kinetic energy = $\frac{1}{2}mv^2 = 3.31 \times 10^{-14}$ J

2 marks

Question 10

In another experiment, a scientist observes the mass of an electron in an accelerator to be 1.5 times its rest mass. Hence, the speed of the electron is closest in value to

A. $0.8c$

B. $0.9c$

C. $0.75c$

D. $0.95c$

C

Worked solution

$m = \gamma m_0$

$$\gamma = \frac{m}{m_0} = 1.5 = \sqrt{\frac{1}{1-\frac{v^2}{c^2}}}$$

$\therefore v = 0.745c$

2 marks

Question 11

Which of the following is the best explanation of what may happen as the electron approaches a speed equal to c?

A. The force required to accelerate the electron will now approach infinity.

B. The physical dimensions of the electron will now approach infinity.

C. The mass of the electron will be nearly zero.

D. All of the above.

A

2 marks

Tips

- *Make a table of speeds in terms of c and γ.*
- *γ is never less than 1.*

Use the following information to answer Questions 12 and 13.

A schematic drawing of the Michelson-Morley experiment is shown in Figure 1.

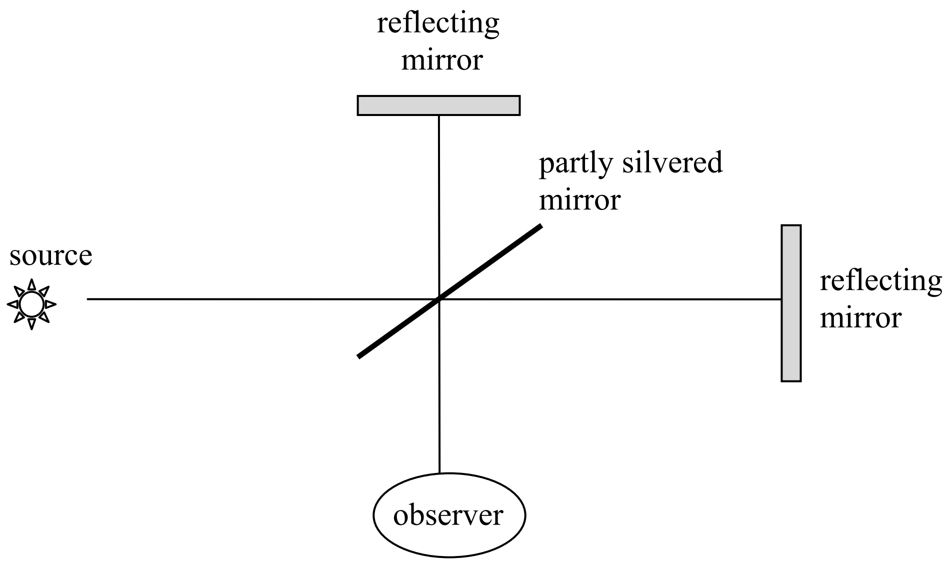


Figure 1

Question 12

If ether existed, then the Michelson-Morely experiment was expected to show that

A. the speed of light was constant in all directions.

B. the speed of light would vary, dependent upon the relative motion of the light beam and Earth.

C. the Earth is an absolute reference frame.

D. the speed of ether is the same as that of Earth.

B

2 marks

Question 13

From their experiment, Michelson and Morley expected to find

A. the absolute speed of ether.

B. the absolute speed of Earth.

C. the location of an absolute reference frame.

D. the speed of ether with respect to Earth.

D

2 marks

Tip

- *Make a summary of the Michelson-Morley experiment and other findings of special relativity.*

END OF DETAILED STUDY 1

Detailed study 2 – Investigating materials and their use in structures

Use the following information to answer Questions 1–5.

There are increasing numbers of composite materials being introduced in the marketplace for a variety of applications. The behaviour of new composite materials under loads is an important test for quality control.

Figure 1 shows the behaviour of a new composite material under tension and compression until failure. The data in the graph were collected using tests performed on cylindrical samples of radius 0.5 cm and length 10 cm.

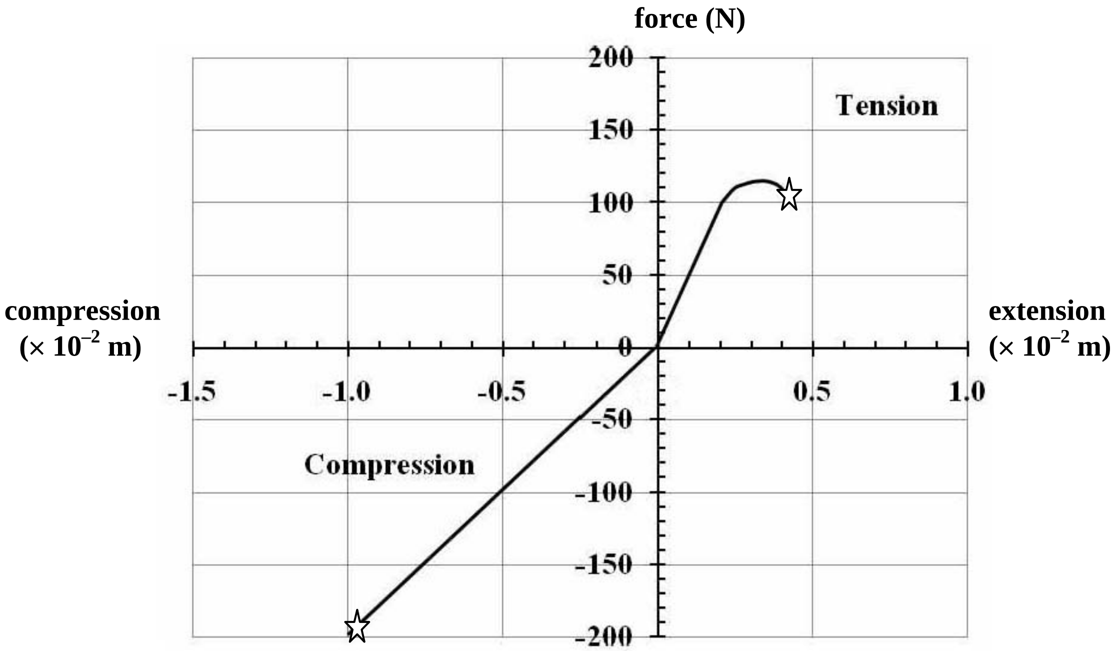


Figure 1

Question 1

Which one of the following best describes the mechanical behaviour of the material?

A. It is stronger in compression and tougher in tension.

B. It is stronger in tension and tougher in compression.

C. It is stronger and tougher in compression than in tension.

D. It is stronger and tougher in tension than in compression.

C

Worked solution

From the graph, more force is needed in compression than tension to break samples of identical dimensions; hence, the material is stronger in compression. The area made by the graph with the *x*-axis until failure is greater in compression than tension; hence, the material is tougher in compression.

2 marks

Tip

- *Summarise the physical terms, such as 'toughness', 'strength' and 'strain energy', used in this detailed study.*

Question 2

Which one of the following gives the best estimate of the tensile strength of the composite material?

A. 115 N

B. 180 N

C. 1.5×10^6 Nm^{-2}

D. 1.4 MPa

D

Worked solution

Reading from the graph, fracture under tension occurs at 200 N. Strength is quoted in MPa and is

$$\sigma = \frac{F}{A} = \frac{110}{\pi \times 0.05^2}$$
$$= 1.4 \times 10^6 \text{ Nm}^{-2}$$
$$= 1.4 \text{ MPa}$$

2 marks

Tips

- *1 MPa = 10^6 Nm^{-2}*
- *Strength is measured as the maximum stress that a material can withstand.*

Question 3

Which one of the following is the best estimate for Young's modulus of the composite material under compression?

A. 10 MPa

B. 30 MPa

C. 20 MPa

D. 25.5 MPa

D

Worked solution

Young's modulus, $E = \frac{\sigma}{\varepsilon} = \frac{200}{\pi(0.005^2)} \div \frac{1\times10^{-2}}{10/100}$
$= 25.5$ MPa

2 marks

Tip

- *Use SI units – change cm to m.*

Question 4

What is the strain energy stored in the sample during compression just prior to failure?

A. 100 J

B. 1 J

C. 22 J

D. 0.2 J

B

Worked solution

Elastic strain energy stored is the area between the graph and *x*-axis until compression failure. Hence:

$$= \frac{1}{2}(1 \times 10^{-2} \times 200) = 1 \text{ J}$$

2 marks

Question 5

A load of 100 N is suspended from a 10cm long cylindrical sample of the material of radius 0.5 cm.

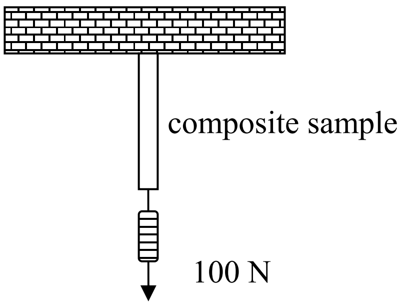


Figure 2

Which one of the following statements best describes the effect on the sample?

A. The stress is 1.27 MPa and the strain is 0.02.

B. The stress is 2.54 MPa and the strain is 0.5.

C. The stress is 100 N and the sample elongates in length by 0.2 cm.

D. The stress is about 1.27 MPa and the sample elongates in length by 0.2 cm.

A

Worked solution

$$\text{Stress, } \sigma = \frac{F}{A} = \frac{100}{\pi \times 0.005^2}$$
$$= 1.27 \text{ MPa}$$

Extension (from the graph) = 0.2 cm

$$\therefore \text{ Strain, } \varepsilon = \frac{0.2}{10} = 0.02$$

2 marks

Tips

- *Differentiate between 'strain energy' and 'strain energy per unit volume'.*
- *1 MPa = 10^6 Pa = 10^6 Nm^{-2}*
- *Differentiate between Young's modulus for compression and extension.*

Use the following information to answer Questions 6 and 7.

Two objects, M_1 and M_2, of masses 30 kg and 45 kg respectively, are placed on a flat plank such that the plank makes a see-saw that is perfectly horizontal in equilibrium, as shown in Figure 3. Assume the mass of the plank to have no effect on the calculations in Questions 6 and 7.

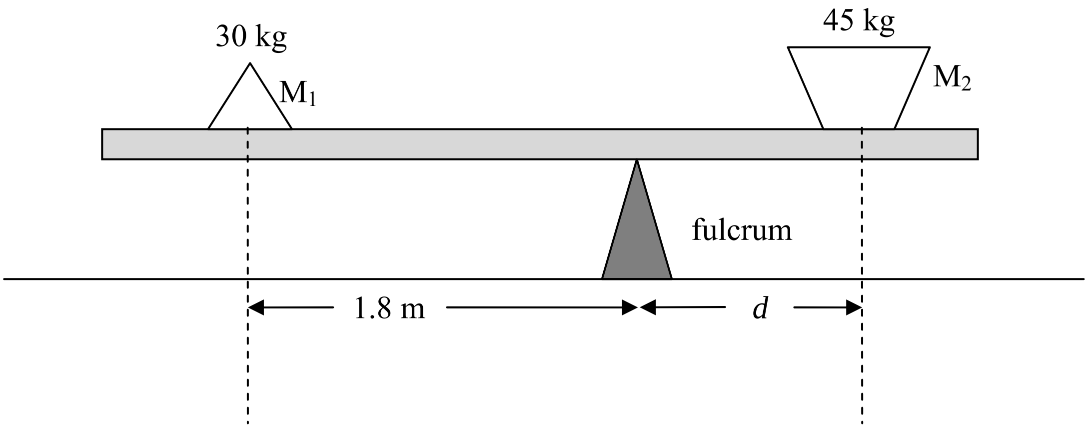


Figure 3

Question 6

What is the distance, d, from object M_2 to the fulcrum?

A. 0.6 m

B. 1.2 m

C. 0.4 m

D. 1.0 m

B

Worked solution

Taking moments around the fulcrum,

$30 \times 1.8 = 45 \times d$
$d = 1.2$ m

2 marks

Question 7

What is the normal reaction force exerted by the fulcrum on the plank?

A. 75 N

B. 90 N

C. 750 N

D. 900 N

C

Worked solution

For the plank to be in equilibrium, the sum of all forces on the plank must equal zero.
Therefore, the reaction force is 300 + 450 N = 750 N.

2 marks

Tips

- *An object in equilibrium has translation and rotational equilibrium, $\Sigma \mathbf{F} = 0$ and $\Sigma \boldsymbol{\tau} = 0$.*
- *Use correct signs when dealing with vectors.*

Use the following information to answer Questions 8–10.

From the second floor of an office complex, a platform of mass 1000 kg protrudes out, as shown in Figure 4. The platform is tied to the wall by a rope and is also supported by its insertion into the structure of the wall. An engineer wishes to analyse the stability of the platform and the rope and assumes that an average person standing on the platform has a mass of 70 kg. The platform and the people are in equilibrium.

Question 8

If 10 people stand on the platform, as shown in Figure 4, what would be the tension in the rope? (1 kN = 1000 N)

A. 26 kN

B. 30 kN

C. 41 kN

D. 35 kN

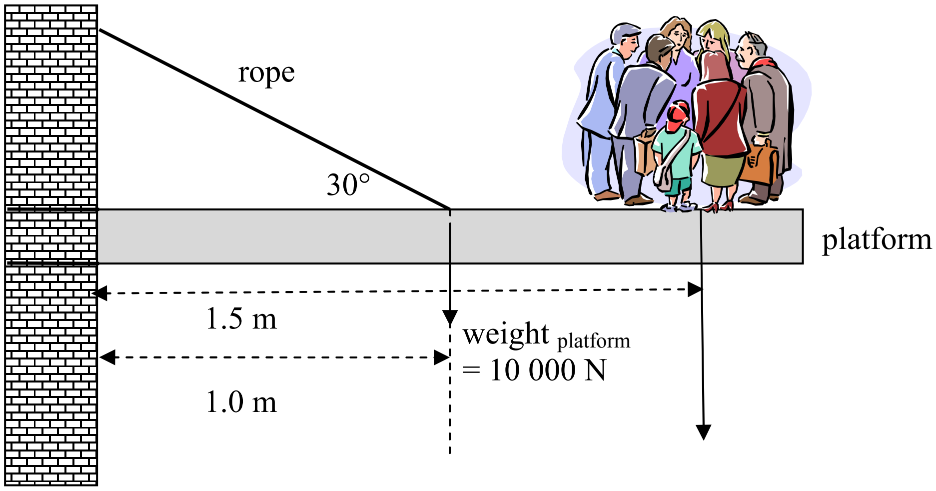


Figure 4

C

Worked solution

Taking moments about the insertion point of the platform and the wall,

$(7000 \times 1.5) + (10\,000 \times 1) = T \sin 30^{\circ} \times 1$
$T = 41\,000 \text{ N} = 41 \text{ kN}$

2 marks

Tip

- *Torque is a vector quantity. Allocate clockwise torque as negative and anticlockwise torque as positive.*

Question 9

If ten people stand on the platform, as shown in Figure 4, the horizontal component of the reaction force on the platform from the wall is closest in magnitude to

A. 25 kN

B. 30 kN

C. 35 kN

D. 40 kN

C

Worked solution

Since the platform is in equilibrium, the horizontal component of the reaction force will be equal to the horizontal component of the tension in the rope = $T \cos 30^{o}$

= 35 506 N

= 35.5 kN

The closest value to this is 35 kN.

2 marks

Question 10

In an independent test on the mechanical properties of the rope, a sample of the rope used in the structure fractured under tension at 50 000 N. The builder wishes to place a safety factor of 2.5 on the use of the rope. The cross-section area of the rope is 5×10^{-4} m^2. The recommended maximum stress for the rope would be closest in value to

A. 25 MPa

B. 30 MPa

C. 35 MPa

D. 40 MPa

D

Worked solution

Stress, $\sigma = \frac{F}{A} = \frac{50\,000}{5 \times 10^{-4}} = 100 \text{ MPa}$

Recommended maximum stress = $\frac{100 \text{ MPa}}{2.5}$ = 40 MPa

2 marks

Tip

- *Safety factors result in a lower recommended maximum stress.*

Use the following information to answer Questions 11–13.

The mechanical properties of a number of materials are shown in Figure 5. The materials have been labelled M1, M2, M3 and M4 and their properties are analysed for building a household driveway. The curves are drawn to the same axes and scale and drawn to fracture.

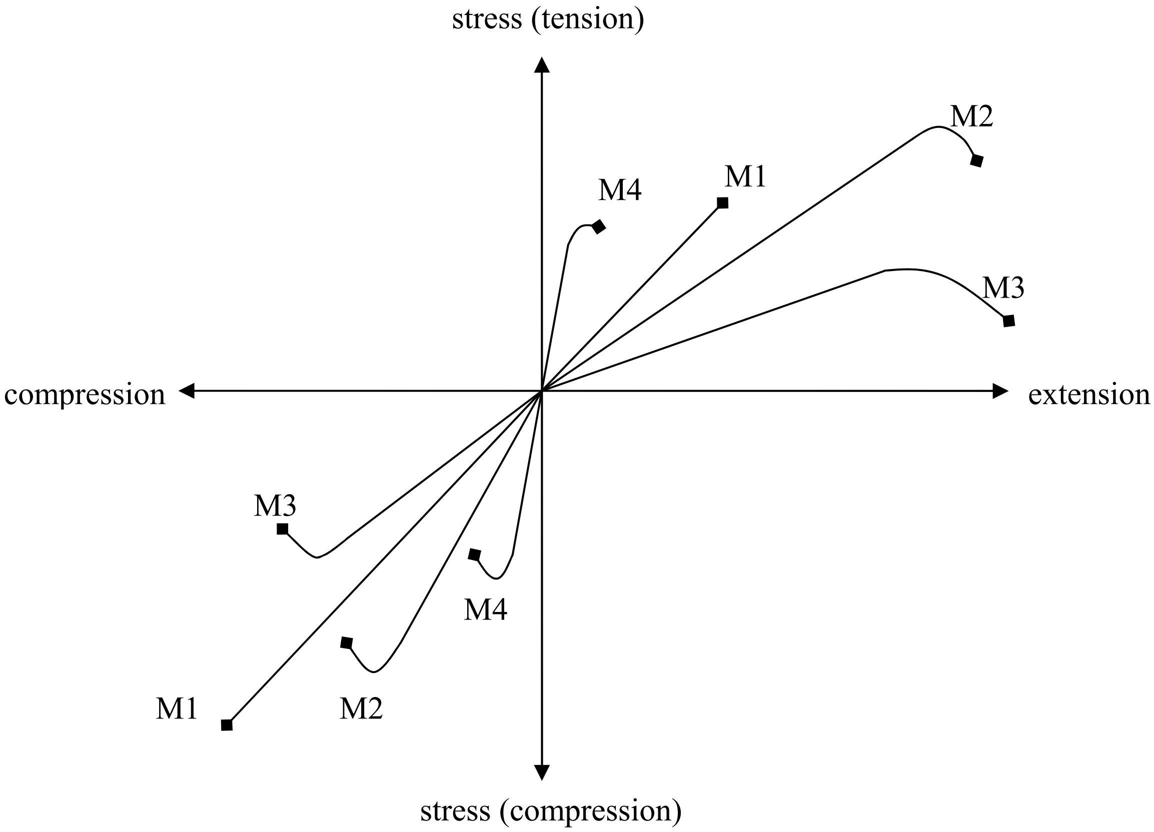


Figure 5

Question 11

Which of the following statements best provides a comparative summary of the materials indicated?

A. M2 is tougher than M1 in compression, and M1 is more flexible than M2 in tension.

B. M1 is stronger than M2 in compression, but weaker than M2 in tension.

C. M1 and M3 are brittle materials.

D. M2, M3 and M4 are all brittle materials.

B

Worked solution

Examine the graph for gradient and maximum strength (stress).

2 marks

Question 12

Which one of the following statements is true about the Young's modulus, E, of the materials in the elastic region under tension?

A. E decreases in the sequence $E_{M1} > E_{M3} > E_{M2} > E_{M1}$.

B. E increases in the sequence $E_{M1} > E_{M3} > E_{M2} > E_{M1}$.

C. E decreases in the sequence $E_{M4} > E_{M1} > E_{M2} > E_{M3}$.

D. E increases in the sequence $E_{M4} > E_{M1} > E_{M2} > E_{M3}$.

C

Worked solution

Young's modulus is the gradient of the stress–strain graph in the elastic (linear) region. The highest gradient for tensile behaviour is the greatest value for Young's modulus.

2 marks

Tip

- *Summarise the physical terms used in this detailed study such as 'brittle', 'flexible' and 'tougher'.*

Question 13

A composite driveway is recommended with a mesh made of one material placed on the ground and another material poured onto and over it as a filler, as shown in Figure 6.

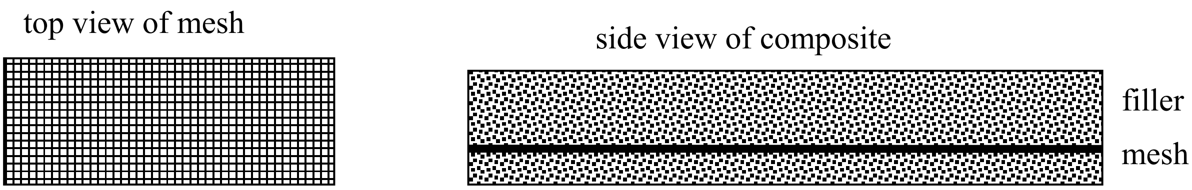


Figure 6

Which of the material combinations would be best suited for the driveway, without any consideration to cost of the material?

A. M1 for mesh and M2 for filler.

B. M1 for filler and M2 for mesh.

C. M3 for filler and M4 for mesh.

D. M4 for filler and M3 for mesh.

B

Worked solution

The bottom of the driveway is under tension; hence, M2 is the best choice for the mesh. It has some flexibility (e.g. steel). The material M1 is strong under compression and, hence, is suitable as filler (e.g. concrete), albeit being brittle.

2 marks

Tip

- *For composite materials, determine which part of the structure is under compression and which is under tension. Then select appropriate material for this.*

END OF DETAILED STUDY 2
SECTION B – continued

Detailed study 3 – Further electronics

Use the following information to answer Questions 1–5.

A capacitor and a resistor form a series RC circuit, as shown in Figure 1. The CRO measures the output voltage across the capacitor. The capacitor is charged by closing the switch and discharged by opening the switch.

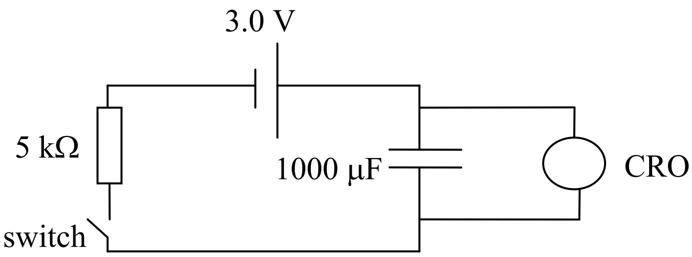


Figure 1

Question 1

What is the time constant for the RC circuit?

A. 2.0 s

B. 5000 s

C. 5 s

D. 200 s

C

Worked solution

Time constant, $\tau = RC = 5000 \times 1000 \times 10^{-6} = 5$ s

2 marks

Question 2

After charging for a time of 1τ, the voltage across the capacitor is closest in value to

A. 1.9 V

B. 1.5 V

C. 1.3 V

D. 1.1 V

A

Worked solution

In 1τ of charging time, the capacitor charges 63% of supply voltage = $0.63 \times 3 = 1.89$ V.

2 marks

Question 3

After discharging for a time of 1τ, the voltage across the capacitor is closest in value to

A. 1.9 V

B. 1.5 V

C. 1.3 V

D. 1.1 V

D

Worked solution

In 1τ of discharging time, the capacitor is 37% of supply voltage = 0.37 × 3 = 1.11 V.

2 marks

Question 4

At a certain instant during discharging, the CRO measures the voltage across the capacitor as 1.7 V. At this instant what will be the voltage across the resistor?

A. 1.7 V

B. 1.3 V

C. 3.0 V

D. 0.7 V

B

Worked solution

The voltage drop across the resistor and capacitor add up to supply voltage. Hence, voltage across the resistor is 3 – 1.7 = 1.3 V.

2 marks

Question 5

The CRO is now connected across the resistor. Which of the following best describes the voltage output across the resistor when the capacitor is being charged?

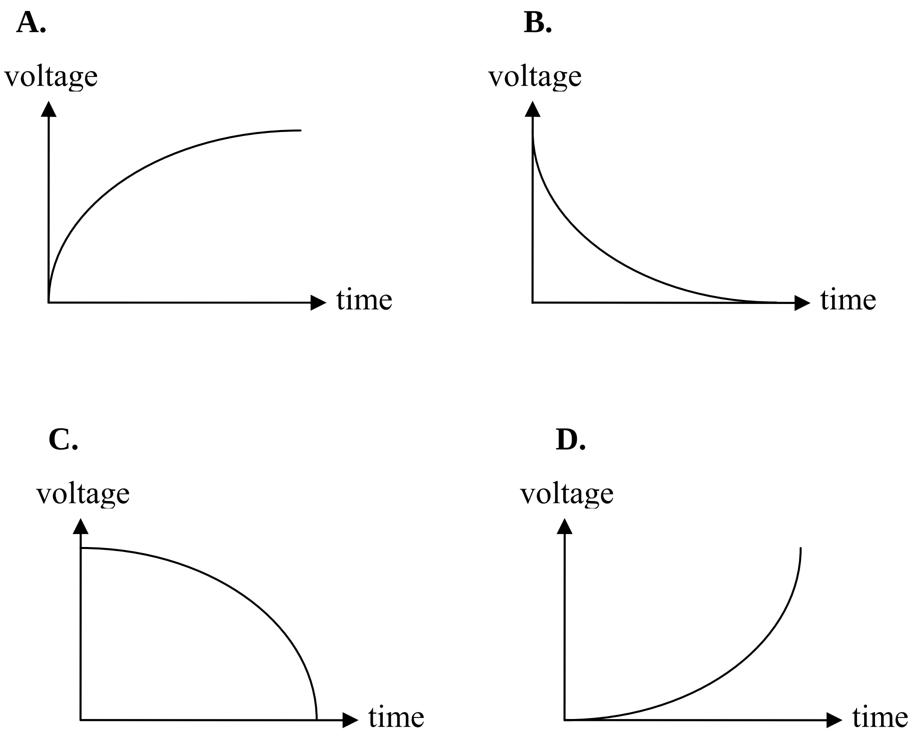


Figure 2

B

Worked solution

The sum of voltage across resistor and capacitor = supply voltage. Hence, as the capacitor voltage rises, the resistor voltage drops.

2 marks

Tip

- *In RC circuits, note the difference between voltage drop across resistor and that across capacitor.*

Use the following information to answer Questions 6–10.

A DC power supply circuit is assembled using an ideal Zener diode, as shown in Figure 3a. The characteristic graph of the Zener diode is shown in Figure 3b. The unregulated AC supply voltage, V_S, varies between 10 V and 12 V. A CRO is used to measure the output voltage, V_L, across the load resistance R_L.

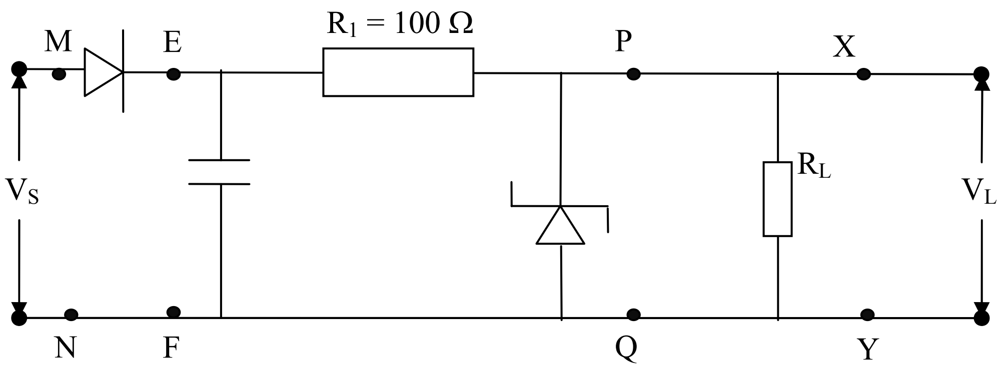


Figure 3a

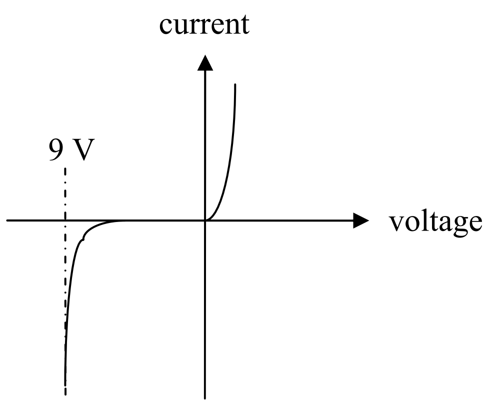


Figure 3b

Question 6

What will be the affect on the voltage V_L and current through the Zener diode if the value of the supply voltage, V_S, is increased to 12.5 V?

A. V_L will increase; current through the Zener diode will decrease.

B. V_L will decrease; current through the Zener diode will remain the same.

C. V_L will remain the same; current through the Zener diode will increase.

D. V_L will remain the same; current through the Zener diode will decrease.

C

Worked solution

Voltage drop across the Zener diode has to stay the same. Hence, current through it increases.

2 marks

Question 7

The CRO is now connected at another part of the circuit such that a trace, shown in Figure 4, is obtained. Connection between which two points is most likely to give the trace shown in Figure 4?

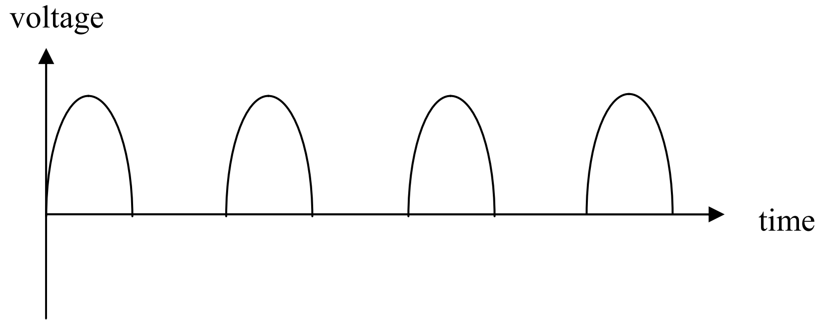


Figure 4

A. Connection between points M and N.

B. Connection between points E and F.

C. Connections between points P and Q.

D. Connection between points X and Y.

B

Worked solution

The diode acts as a half-wave rectifier. Figure 4 has no smoothing, so the output is before the capacitor – between points E and F.

2 marks

Question 8

When the supply voltage is at 11.0 V, what will be the current in the resistor R_1?

A. 0.02 A

B. 0.03 A

C. 0.2 A

D. 0.3 A

A

Worked solution

Voltage across Zener diode $V_{Zener} = 9.0$ V. Hence, there is a 2.0 V drop across the resistor R_1.

$\therefore I_{R1} = \frac{2}{100} = 0.02$ A

2 marks

Question 9

When the supply voltage is 11.0 V and the load resistance, R_L, is 2000 Ω, what is the current though the Zener diode?

A. 16.5 mA

B. 15.0 mA

C. 15.5 mA

D. 16.0 mA

C

Worked solution

Since there is 9.0 V across the Zener diode and the load resistor, R_L

Current in the load resistor = $\frac{9}{2000}$ = 0.0045 A

Voltage across the resistance R_1 must be 2.0 V.

Hence, current through the resistor R_1 = $\frac{2.0}{100}$ = 0.02 A

Therefore, current through Zener diode = 0.02 – 0.0045 = 0.0155 A = 15.5 mA

2 marks

Question 10

As the value of the load resistance, R_L, increases, which of the following statements best describes the outcome for the Zener diode and the load resistance? The current through the load resistance is I_{load} and the current in the Zener diode is I_{Zener}.

A. V_L increases, I_{load} decreases, I_{Zener} decreases.

B. V_L decreases, I_{load} increases, I_{Zener} increases.

C. V_L stays the same, I_{load} increases, I_{Zener} decreases.

D. V_L stays the same, I_{load} decreases, I_{Zener} increases.

D

Worked solution

Since the voltage across the Zener diode must remain constant, current through the Zener diode must increase as less current flows through the load resistor.

2 marks

Tips

- *Current supplied by battery must equal the sum of currents in parts of the circuit.*
- *Voltage is the same across components in parallel.*

Use the following information to answer Questions 11–13.

A DC power supply circuit is constructed, as shown in Figure 5a, using a transformer, resistors, capacitor, and a bridge rectifier. The full-wave bridge rectifier is made with four silicon diodes, which have typical voltage drop of 0.7 V across each diode when fully switched on. The output across the load resistance is measured by a CRO and is found to have a ripple voltage of 0.03 V peak to peak. Figure 5b shows a CRO trace of the input signal.

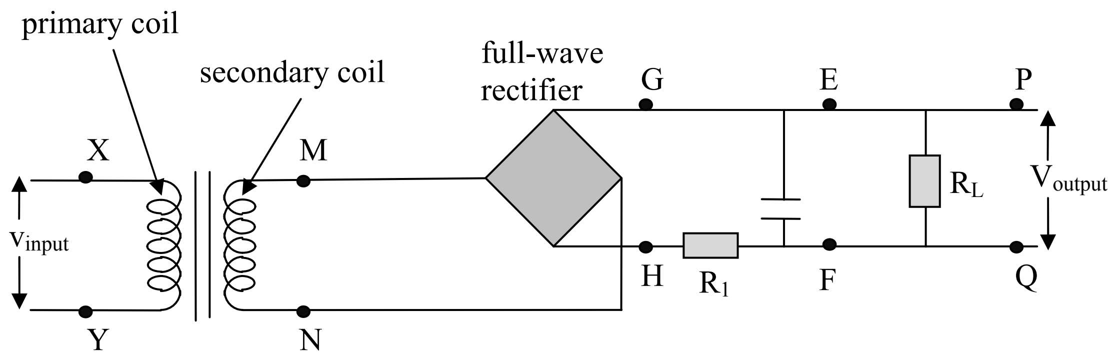


Figure 5a

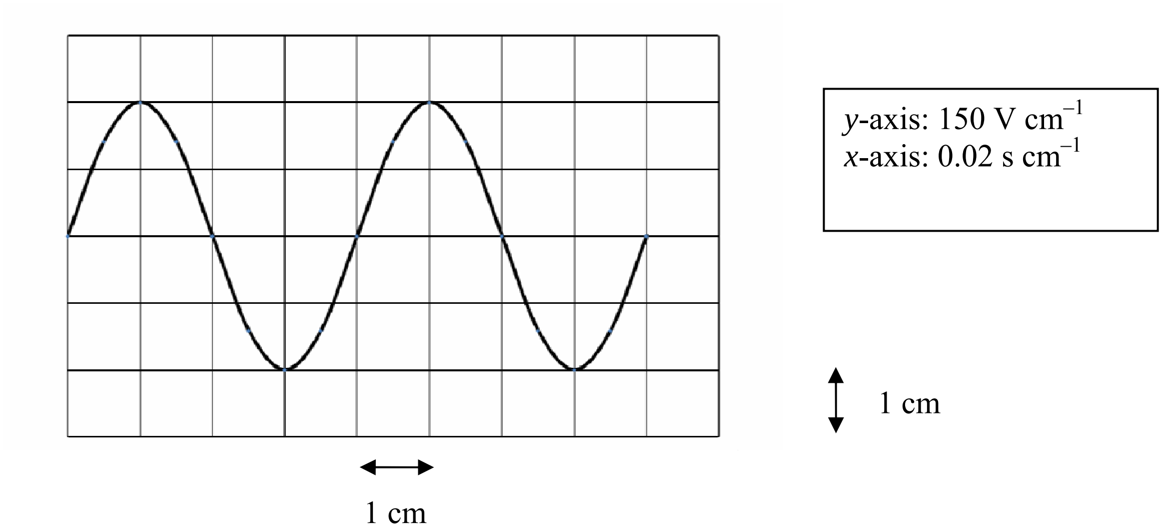


Figure 5b

Question 11

The transformer has a turn-ratio $\frac{N_{\text{primary}}}{N_{\text{secondary}}} = \frac{10}{1}$. The peak voltage signal across points M and N is closest in value to

A. 21 V

B. 30 V

C. 42 V

D. 45 V

B

Worked solution

From Figure 5b, the input voltage is 300 V.

The transformer in use is a step-down transformer and the voltage will reduce in the same ratio as number of turns, i.e. by a factor of 10. Hence, peak voltage difference across points M and N is 30 V.

2 marks

Question 12

Which one of the following statements best describes the method to reduce the ripple voltage, V_r?

A. Increase the time constant, τ, of the capacitor–load resistance circuit.

B. Increase the capacitance of the capacitor and decrease the resistance of R_1.

C. Decrease the capacitance of the capacitor and increase the resistance of R_1.

D. Decrease both the resistance R_1 and the capacitance of the capacitor.

D

Worked solution

Ripple voltage, $V_r = \frac{V_{\text{max}} T}{\text{RC}}$. Therefore, the ripple voltage will reduce if RC reduces.

2 marks

Question 13

When the peak voltage across points M and N is 12.0 V, the voltage across the points G and H is closest in value to

A. 9.5 V

B. 10.1 V

C. 10.6 V

D. 11.2 V

C

Worked solution

Voltage drop across the full-wave rectifier is close to $0.7 \times 2 = 1.4$ V.

Voltage across points G and H is $12.0 - 1.4$ V $= 10.6$ V.

2 marks

Tips

- *Voltage drop across a silicon diode is typically 0.7 V.*
- *A bridge rectifier has a voltage drop of about 1.4 V across diode, whereas a half-wave rectifier has about 0.7 V.*

END OF SOLUTIONS BOOK