SUPERVISOR TO ATTACH
PROCESSING LABEL HERE

Write your **student number** in the boxes above. **Letter**

Physics

Question and Answer Book

VCE Examination – Thursday 14 November 2024

- Reading time is **15 minutes**: 9.00 am to 9.15 am
- Writing time is **2 hours 30 minutes**: 9.15 am to 11.45 am

Approved materials

- One scientific calculator
- Pre-written notes (one folded A3 sheet or two A4 sheets bound together by tape)

Materials supplied

- Question and Answer Book of 48 pages
- Formula Sheet
- Multiple-Choice Answer Sheet

Instructions

- Follow the instructions on your Multiple-Choice Answer Sheet.
- At the end of the examination, place your Multiple-Choice Answer Sheet inside the front cover of this book.

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

Contents

VICTORIAN CURRICULUM AND ASSESSMENT AUTHORITY

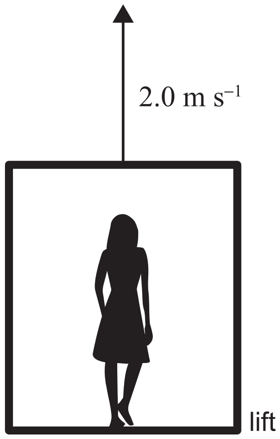
VICTORIA State Government

Section A – Multiple-choice questions

Instructions

- Answer **all** questions in pencil on your Multiple-Choice Answer Sheet.
- Choose the response that is **correct** or that **best answers** the question.
- A correct answer scores 1; an incorrect answer scores 0.
- Marks will **not** be deducted for incorrect answers.
- No marks will be given if more than one answer is completed for any question.
- Unless otherwise indicated, the diagrams in this book are **not** drawn to scale.

Question 1



Jo is standing inside a lift that is travelling vertically upwards at a constant speed of $2.0\ \mathrm{m\ s^{-1}}$ as shown.

Jo has a mass of $75\ \mathrm{kg}$.

Which one of the following is closest to the force exerted on Jo by the lift floor?

A. $0\ \mathrm{N}$

B. $590\ \mathrm{N}$

C. $740\ \mathrm{N}$

D. $890\ \mathrm{N}$

Question 2

A space-based observatory (SBO) of mass M has a circular orbital radius R around Earth. Modifications to the SBO have doubled its mass, but its orbital speed is kept constant.

Which one of the following is closest to the orbital radius of the SBO after the modifications have been made?

A. $\dfrac{R}{4}$

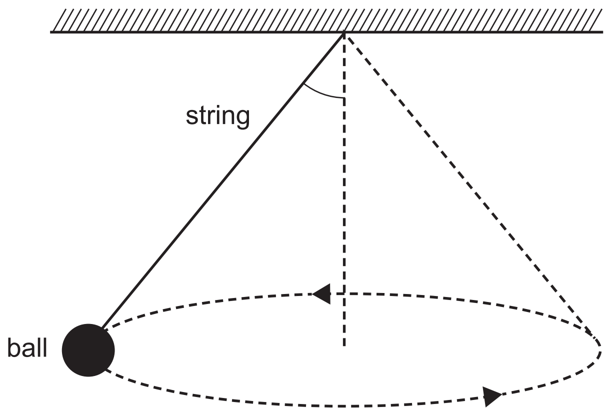
B. R

C. $2R$

D. $4R$

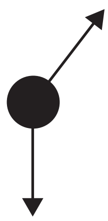
Question 3

The diagram below shows a small ball travelling at a constant speed on a horizontal circular path while suspended from the ceiling by a string.



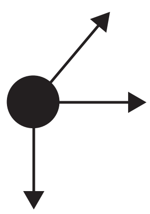
Which one of the following best represents the force(s) acting on the ball as seen from a front-on view?

A.

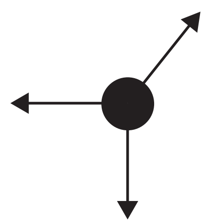


B.

C.

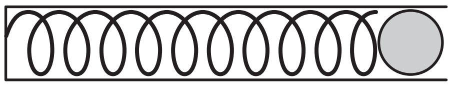


D.

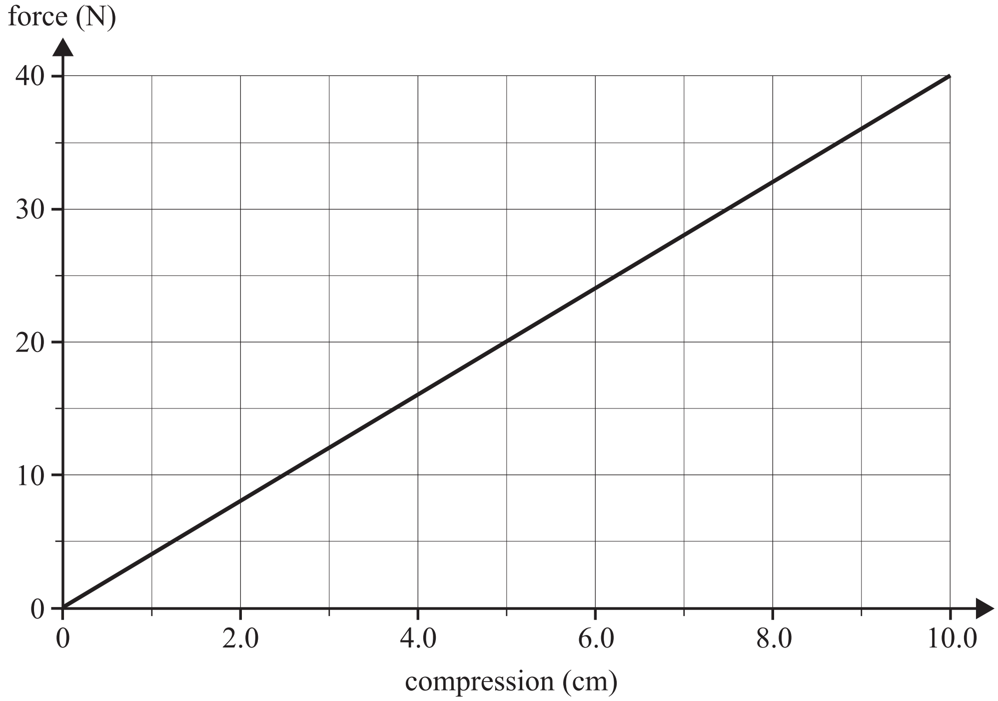


Question 4

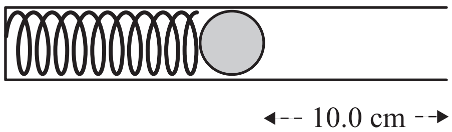
The diagram below shows a $50\ \text{g}$ ball and a spring inside a horizontal launching tube. Assume that the launching tube is frictionless and the mass of the spring is negligible.



A force vs compression graph for the spring is shown below. Consider the spring to be ideal.



The spring is initially compressed by a distance of $10.0\ \text{cm}$, with the ball in contact with the compressed spring. A short time later the spring is released.



Which one of the following is closest to the speed of the ball as it leaves the tube?

A. $2.8\ \text{m s}^{-1}$

B. $4.9\ \text{m s}^{-1}$

C. $8.9\ \text{m s}^{-1}$

D. $12.6\ \text{m s}^{-1}$

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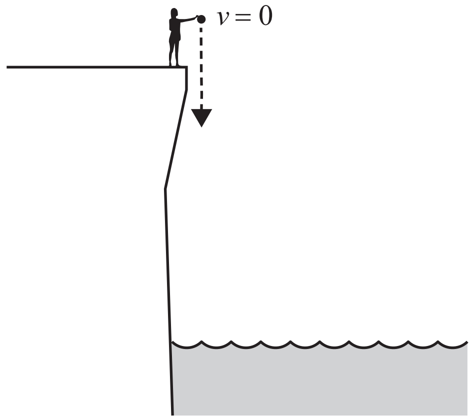
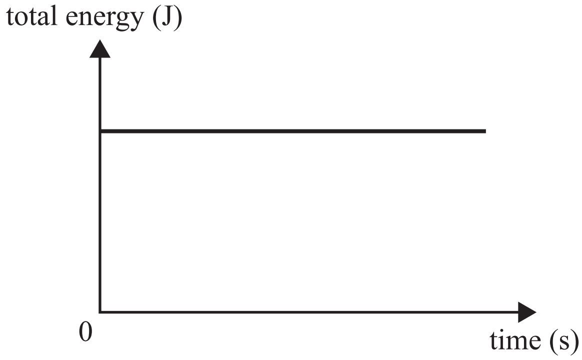
Question 5

A rock is dropped from rest at the top of a cliff towards the ocean, as shown below.

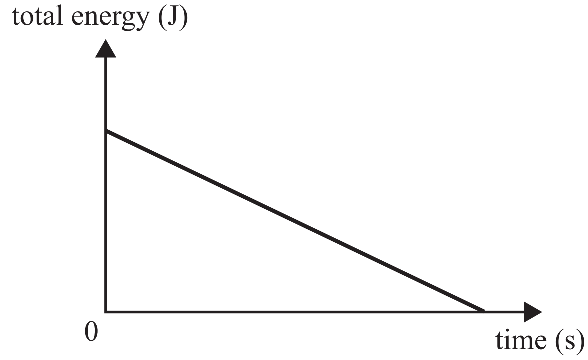


Which one of the following graphs best represents the rock's total energy as it falls towards the ocean from the top of the cliff? Ignore air resistance.

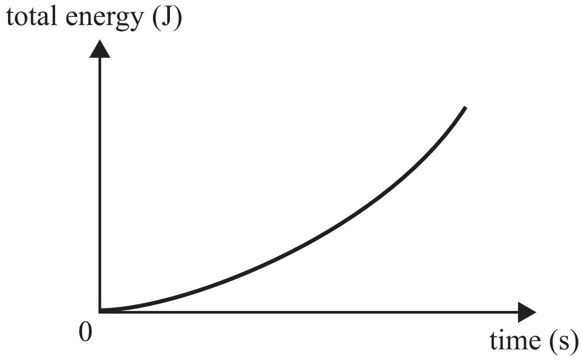
A.



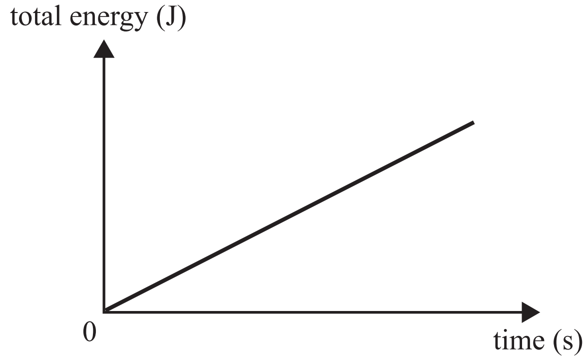
B.



C.



D.



Question 6

Two magnets are placed as shown in the diagram below. The magnets are identical and point X is exactly halfway between the two S poles.

Which one of the following best describes the strength of the magnetic field at point X?

A. It is very close to zero.

B. It is half the magnetic field strength due to one magnet only.

C. It is twice the magnetic field strength due to one magnet only.

D. It is about the same as the magnetic field strength due to one magnet only.

Question 7

Diagram A shows a single loop of wire carrying a current, I, within a uniform magnetic field.

Diagram B shows the same loop rotated clockwise through 90°.

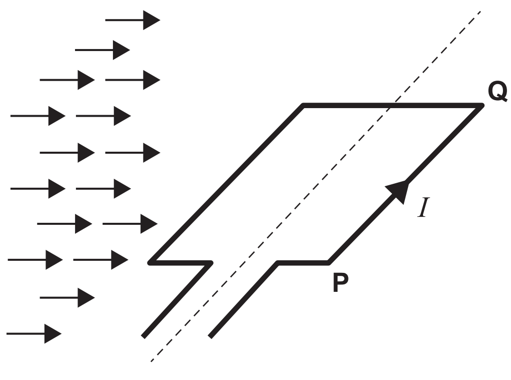


Diagram A

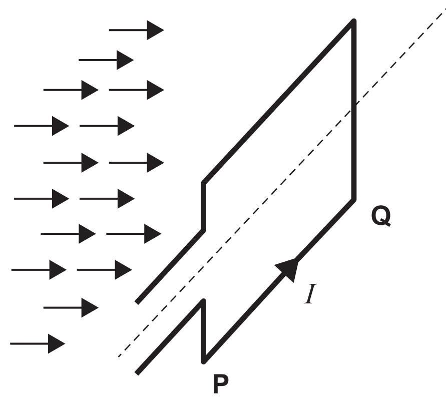


Diagram B

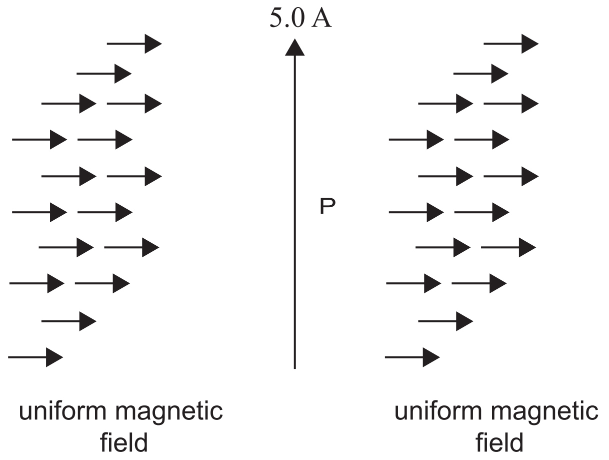
The magnitude of the force, F, on side PQ and the magnitude of the torque, τ, on the loop in Diagram B (F_B and τ_B) are compared to those in Diagram A (F_A and τ_A).

Which one of the following rows in the table below best describes the comparison?

	Force	Torque
A.	$F_A = F_B$	$\tau_A = \tau_B$
B.	$F_A > F_B$	$\tau_A < \tau_B$
C.	$F_A < F_B$	$\tau_A = \tau_B$
D.	$F_A = F_B$	$\tau_A > \tau_B$

Question 8

A straight wire, P, $4.0\ \text{cm}$ long and carrying a current of $5.0\ \text{A}$, is completely placed in a uniform magnetic field of magnitude $2.0 \times 10^{-3}\ \text{T}$, as shown below.



Which one of the following is closest to the magnitude of the force acting on the $4.0\ \text{cm}$ long wire in the magnetic field?

A. $4.0 \times 10^{-2}\ \text{N}$

B. $4.0 \times 10^{-3}\ \text{N}$

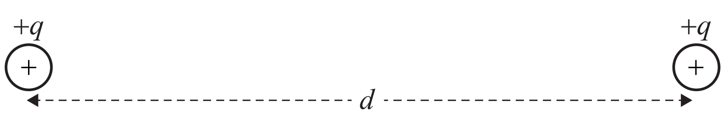
C. $4.0 \times 10^{-4}\ \text{N}$

D. $4.0 \times 10^{-6}\ \text{N}$

Question 9

Two equal positive electric charges separated by a distance, d, exert a force, F, on each other.

The distance is changed so that the two charges now exert a force of $6F$ on each other.



Which one of the following is closest to the new distance between the charges?

A. $0.17d$

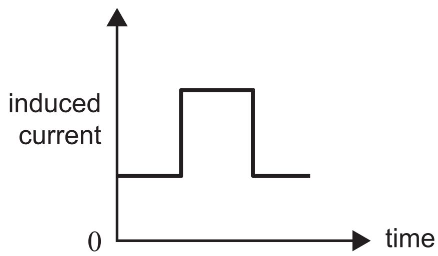
B. $0.41d$

C. $0.54d$

D. $0.78d$

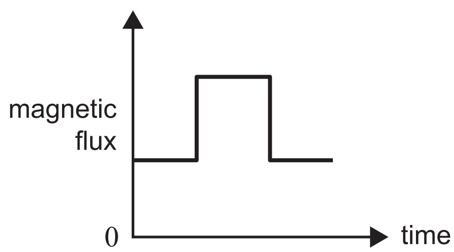
Question 10

The graph below shows the induced current through a coil of conducting wire as a function of time.

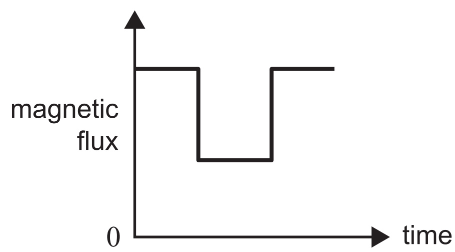


Which one of the following magnetic flux graphs corresponds to the graph of the induced current shown above?

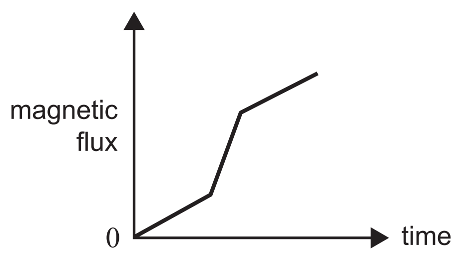
A.



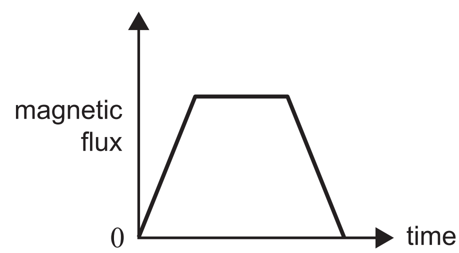
B.



C.



D.



Question 11

In Victoria, the electrical energy generated at the Loy Yang A power station is transmitted to Melbourne, approximately $170\ \mathrm{km}$ away, using $500\ \mathrm{kV}$ transmission lines.

Which one of the following best describes the reason for the use of high-voltage transmission of electrical energy over long distances?

A. Transformers can be used to increase the voltage.

B. High voltages reduce energy losses in the transmission lines.

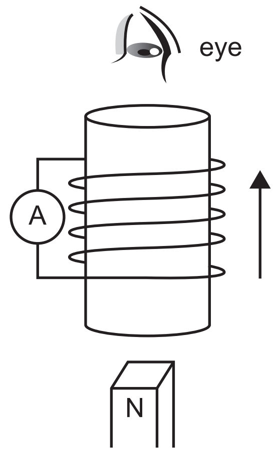
C. High voltages can easily carry the large power required by cities.

D. High voltages reduce the overall total resistance in the transmission lines.

Do not write in this area.

Question 12

The diagram below shows a coil moving upwards from the north pole of a stationary bar magnet.



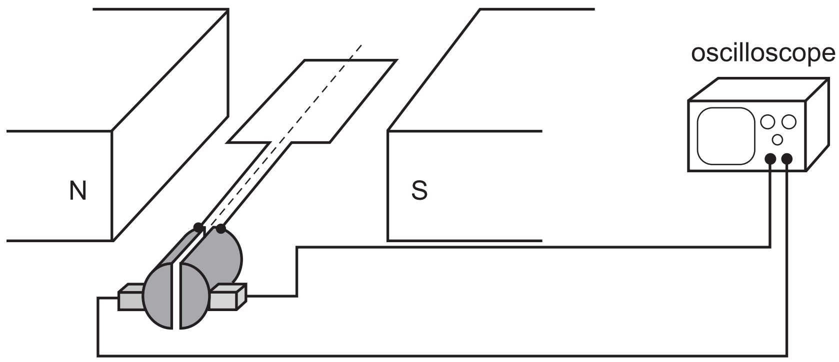
Which one of the following correctly identifies both the direction of the induced current, as observed from the top of the coil, and the direction of the magnetic field produced by the induced current inside the coil, as observed from the side of the coil?

	Current direction	Induced magnetic field direction
A.	clockwise	↓
B.	clockwise	↑
C.	anticlockwise	↑
D.	anticlockwise	↓

Question 13

The diagram below shows a simple generator made from a loop of wire, a commutator and magnets.

A mechanical energy source rotates the loop smoothly. The magnetic field is constant and uniform. The output is displayed on an oscilloscope.

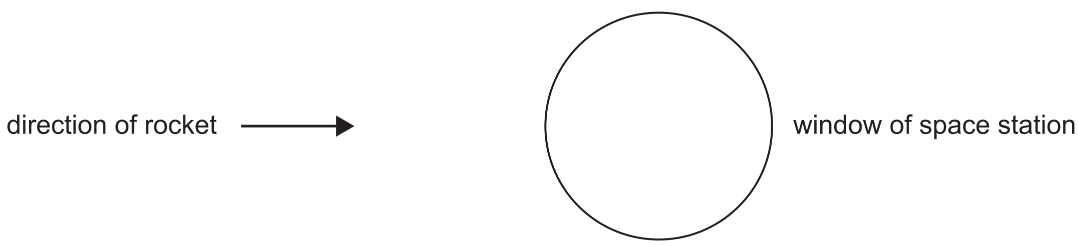


Which one of the following best describes the output that will be observed on the oscilloscope?

A. DC voltage with a varying value
B. AC voltage with a varying value
C. AC voltage with a constant value
D. DC voltage with a constant value

Question 14

A rocket passes a space station at a horizontal speed of $0.85c$ parallel to the side of the space station. There is a circular window on the space station, as shown in the diagram below.



A person inside the passing rocket observes and measures the window of the space station.

Which one of the following statements best describes the measurements taken of the window of the space station?

A. Both the horizontal and vertical measurements will be less than the actual window.
B. Both the horizontal and vertical measurements will be the same as the actual window.
C. The horizontal measurement will be the same as the actual window but the vertical measurement will be less than the actual window.
D. The horizontal measurement will be less than the actual window but the vertical measurement will be the same as the actual window.

Question 15

At the Australian Synchrotron, electrons are accelerated to close to the speed of light, c, by the linear accelerator.

Consider electrons that enter the Australian Synchrotron booster ring with a Lorentz factor $\gamma = 200$, and as a result of further acceleration in that ring reach a much higher value, with a Lorentz factor $\gamma = 2000$.

Which one of the following best describes the effect of the booster ring on each electron's speed and energy?

A. The electron's speed increases by a large amount and its energy increases by a large amount.

B. The electron's speed increases by a small amount and its energy increases by a large amount.

C. The electron's speed increases by a large amount and its energy increases by a small amount.

D. The electron's speed increases by a small amount and its energy increases by a small amount.

Question 16

Diagram P below shows five energy levels of an atom, with five transitions indicated. Diagram Q shows four possible sets of spectral frequency lines.

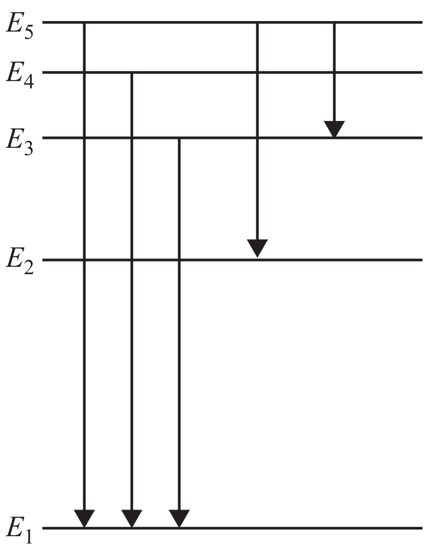


Diagram P

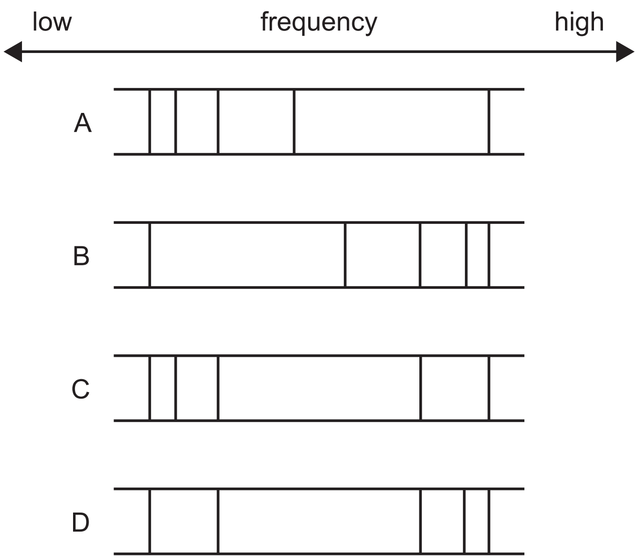


Diagram Q

Which one of the frequency spectra shown in Diagram Q best corresponds to the transitions shown in Diagram P?

A. spectrum A

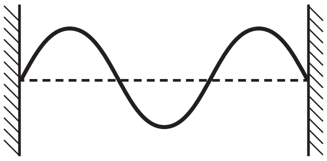
B. spectrum B

C. spectrum C

D. spectrum D

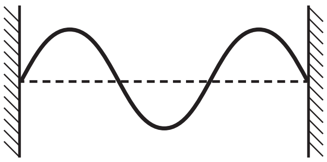
Question 17

The diagram below shows a standing wave on a stretched string between two fixed ends at time $t = 0$. The frequency of vibration of the string is $50\ \text{Hz}$.

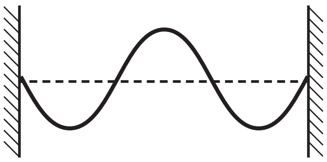


Which one of the following diagrams correctly shows the position of the string at time $t = 0.010\ \text{s}$?

A.

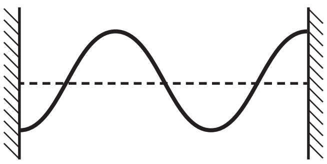


B.



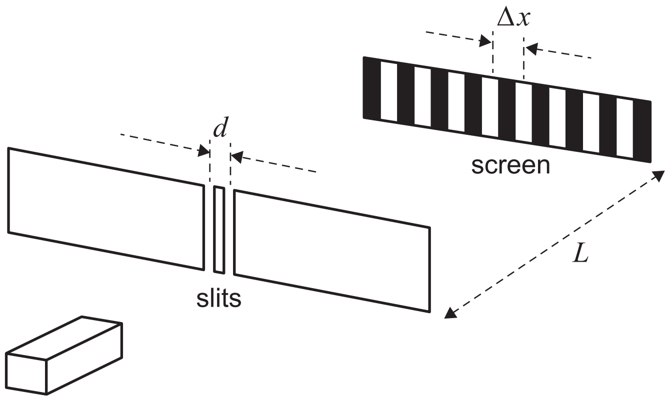
C.

D.



Question 18

An interference pattern produced by monochromatic light is viewed on a screen placed a distance, L, from a double slit system with a slit separation, d. The distance between the centres of two adjacent bright bands is Δx.



The distance, L, is doubled and the slit separation, d, is halved.

Which one of the following is closest to the new distance between the centres of two adjacent bright bands?

A. $\dfrac{\Delta x}{4}$

B. Δx

C. $2\Delta x$

D. $4\Delta x$

Do not write in this area.

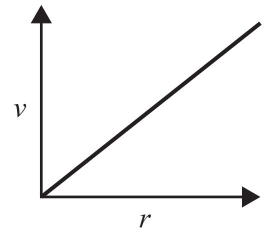
Question 19

The orbital velocity, v, of a satellite in an orbital radius, r, around a planet of mass M is given by

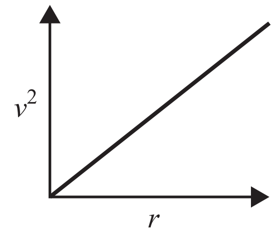
$$v = \sqrt{\frac{GM}{r}}$$

Which one of the following linear graphs is consistent with this relationship?

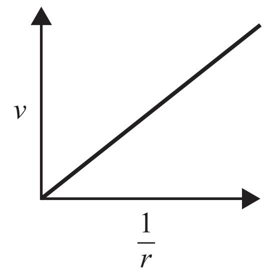
A.



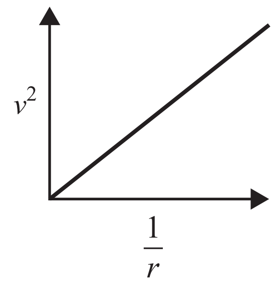
B.



C.



D.



Question 20

Data can be described as precise when

A. it is the result of a careful investigation.

B. the experiment is repeated many times, and the results show little variation.

C. the same experimental methodology is used by different investigators.

D. it is close to the scientifically accepted value of the quantity being measured.

End of Section A

Section B

Instructions

- Answer **all** questions in the spaces provided.
- Write your responses in English.
- Where an answer box is provided, write your final answer in the box.
- If an answer box has a unit printed in it, give your answer in that unit.
- In questions where more than one mark is available, appropriate working **must** be shown.
- Unless otherwise indicated, the diagrams in this book are **not** drawn to scale.

Question 1 (3 marks)

Tug boats often have to tow other boats around the Port of Melbourne.

Boat 1, a tug boat, with a mass of 2.5×10^5 kg, is towing two larger boats, as shown in Figure 1.

All three boats are moving in a straight line and Boats 2 and 3 do not have their engines on.

Boat 2 has a mass of 5.0×10^5 kg and Boat 3 has a mass of 6.0×10^5 kg.

A resistance force of 1.2×10^4 N acts on Boat 2 and a resistance force of 1.4×10^4 N acts on Boat 3.

The tension in Rope 1 is 9.2×10^4 N.

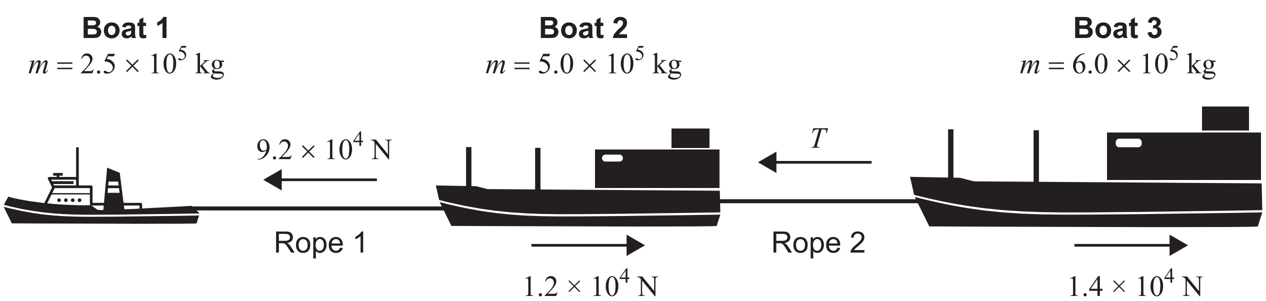


Figure 1

a. Show that the acceleration of the two boats being towed, Boat 2 and Boat 3, is 6.0×10^{-2} m s^{-2}. 1 mark

b. Calculate the tension, T, in Rope 2. Show your working. 2 marks

N

Question 2 (4 marks)

Engineers are testing a new high-speed electric vehicle (EV) on a high-speed test track.

In one test, the EV travels around a circular banked track with a radius of 1.2 km.

The angle of bank is $33°$. This is shown in Figure 2.

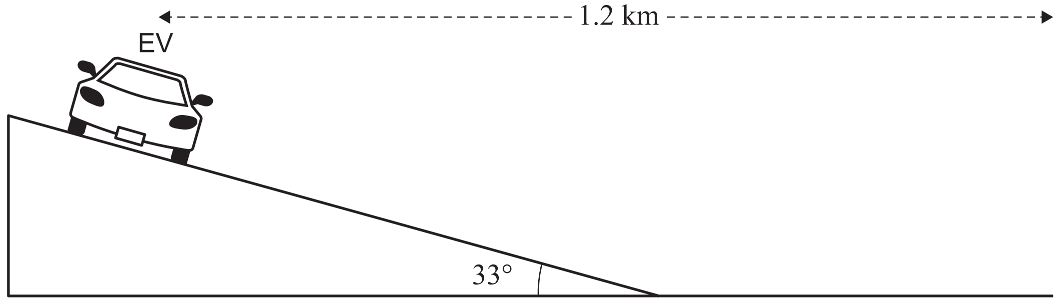


Figure 2

a. Calculate the maximum speed the car can travel around this banked track if there is no sideways friction between the wheels and the track. Show your working. 3 marks

m s^{-1}

b. Explain how the normal force from the banked track provides the centripetal force on the car. 1 mark

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Examination continues on the next page.

Question 3 (7 marks)

A golf ball near the edge of a cliff is hit at a speed of 48 m s^{-1} and at an angle of $35°$ to the horizontal, as shown in Figure 3.

The golf ball lands on the ground 6.2 s after it is hit. Ignore air resistance.

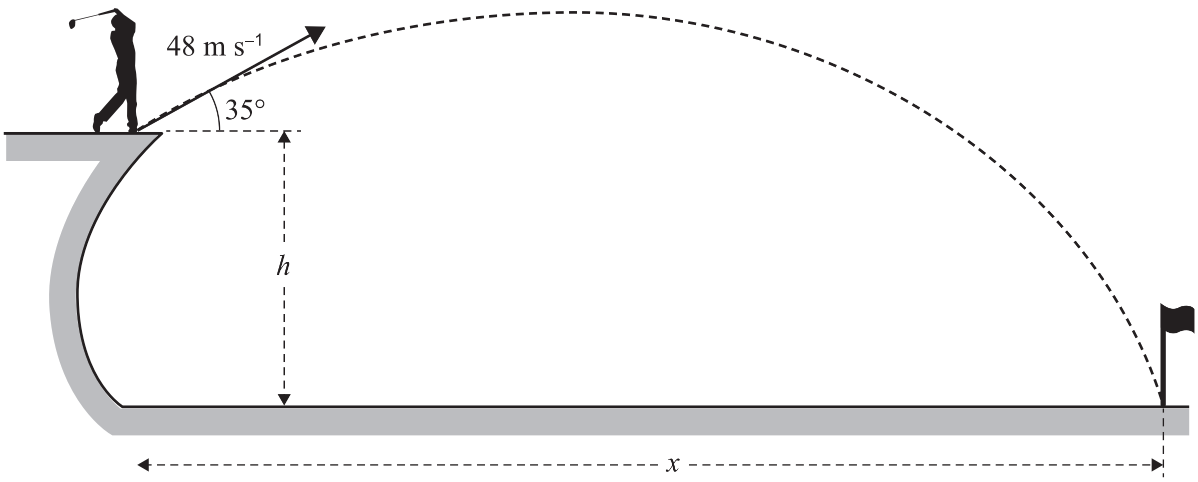

Figure 3

a. Determine the height, h, of the cliff. 3 marks

m

b. Calculate the horizontal distance, x, that the golf ball travels before it reaches the ground below. 2 marks

m

c. Describe how, in real life, air resistance would affect the golf ball's flight path. 2 marks

Question 4 (4 marks)

The safety of passenger cars can be assessed using simulated collisions, with a crash test dummy in the passenger's seat.

Figure 4 shows a dummy, without a seatbelt, in a car travelling towards a fixed solid wall.

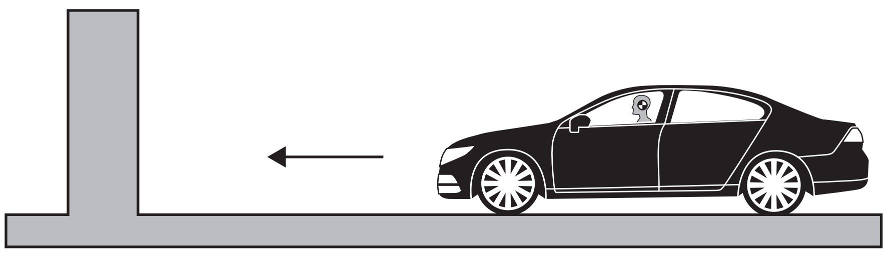

Figure 4

During an initial test, the dummy is seated in a car with no front airbags fitted.

When the car hits the wall, the dummy experiences a force as it collides with the interior dashboard of the car. This force varies with time as shown on the graph in Figure 5.

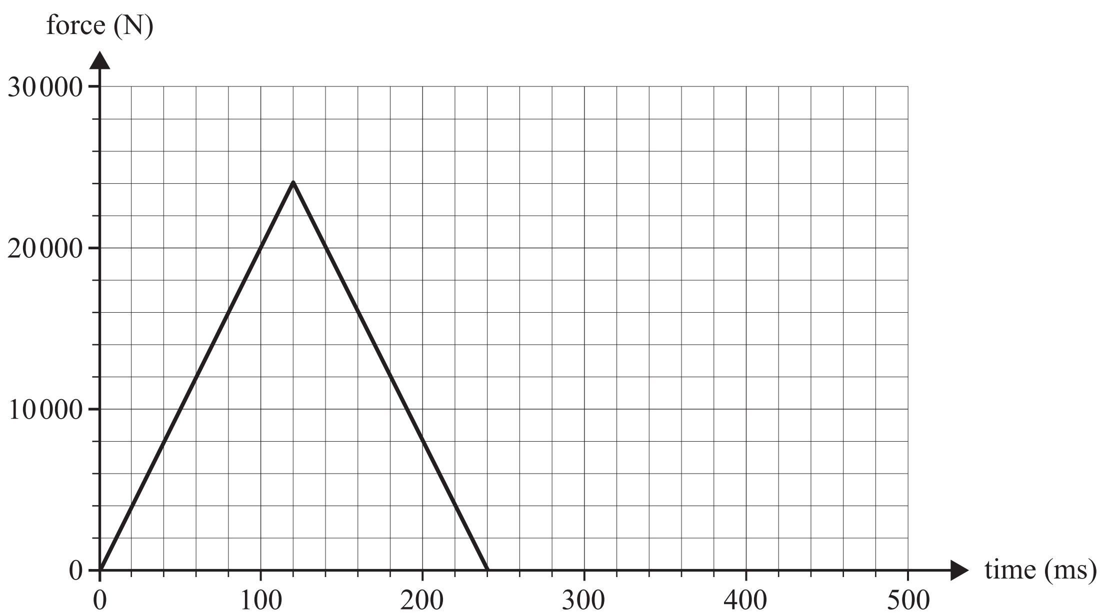

Figure 5

a. Determine the impulse on the dummy during this initial test. 2 marks

N s

b. In a second test, the dummy is seated in an identical car travelling at the same speed as the initial test, again without a seatbelt, but with front airbags fitted.

The collision duration for the dummy in this second test as it collides with the airbag is double the time of the initial test without the airbags.

The results of the initial test are shown as dashed lines on Figure 6 below.

Sketch on Figure 6 how the force on the dummy could vary with time during this second test. 2 marks

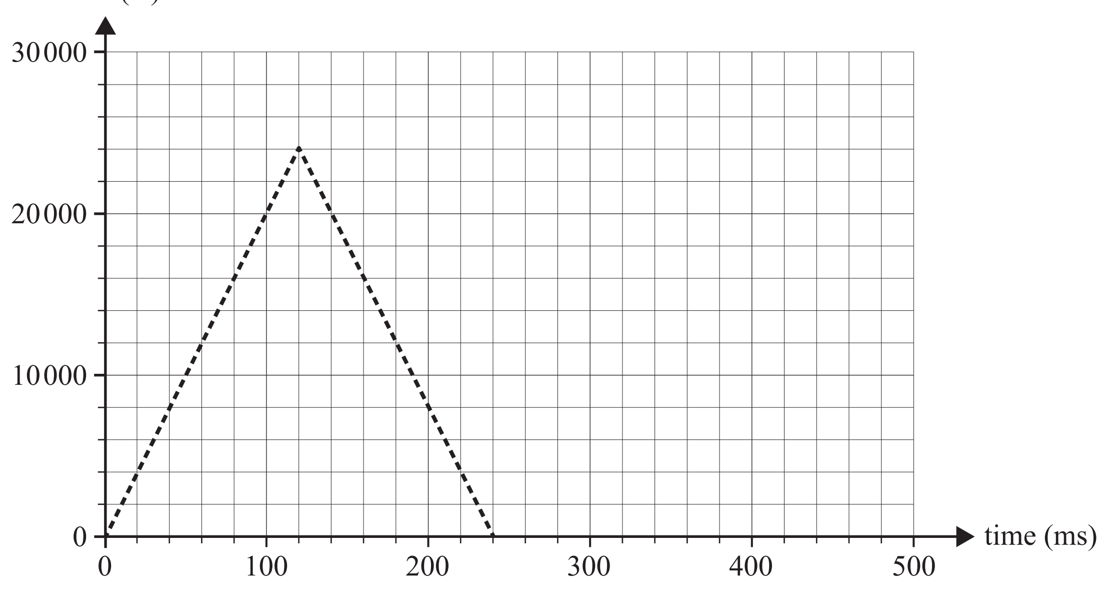

Figure 6

Question 5 (4 marks)

A basketball of mass $0.63\ \mathrm{kg}$, travelling vertically down, hits the floor at a speed of $12\ \mathrm{m\ s^{-1}}$ and rebounds at a speed of $10\ \mathrm{m\ s^{-1}}$, as shown in Figure 7.

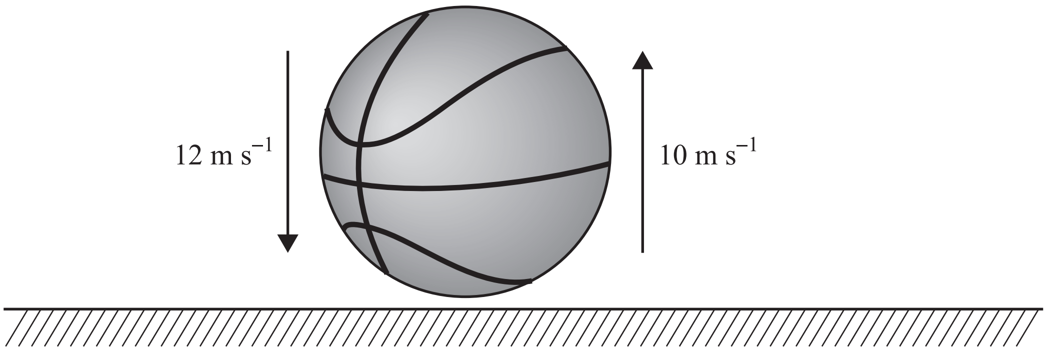

Figure 7

a. Calculate the magnitude and direction of the change in momentum of the basketball. 2 marks

direction	$\mathrm{kg\ m\ s^{-1}}$

b. Is the collision elastic or inelastic? Justify your answer. No calculations are required. 2 marks

Question 6 (3 marks)

Jenny and Kwan are discussing how the International Space Station (ISS) supply-craft missions operate. The station is resupplied with food, water, air, fuel, scientific equipment and other necessities every three months.

Kwan suggests that the supply craft could initially be put into a circular orbit relative to the ISS, as shown in Figure 8, before it eventually docks.

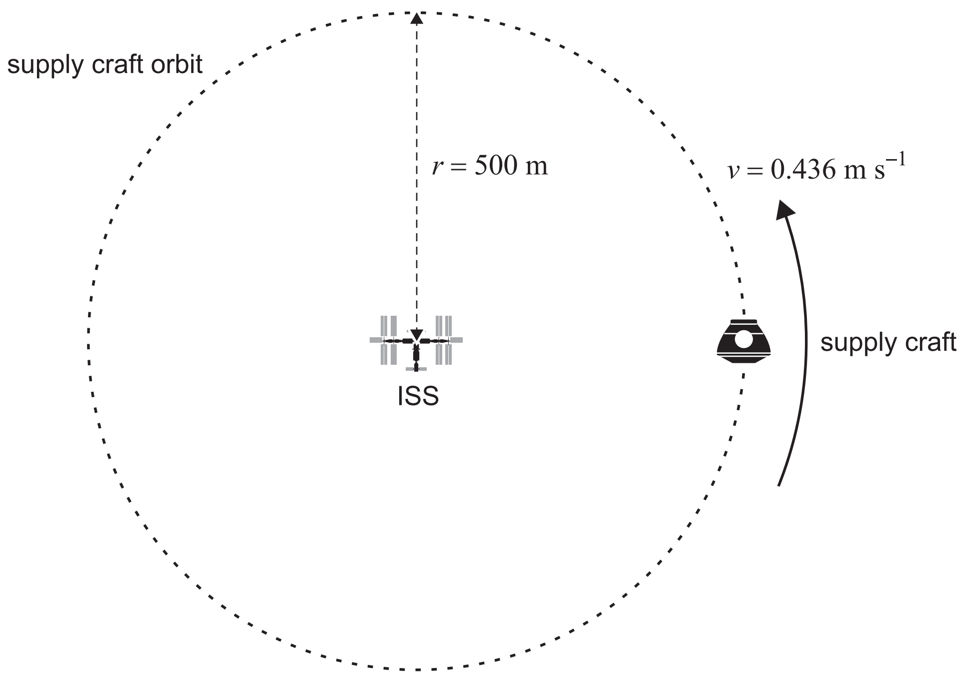

Figure 8

The centripetal force needed to keep the supply craft in orbit, Kwan argues, is provided by the gravitational attraction between the supply craft and the ISS.

Kwan calculates that an orbital radius of 500 m could be achieved with the supply craft travelling at a speed of 0.436 m s^{-1}.

The mass of ISS is 4.50×10^5 kg, and the mass of the supply craft is 1.50×10^4 kg.

Will Kwan's suggestion work? Justify your answer with appropriate calculations.

Question 7 (6 marks)

An electron is accelerated from rest through an electric field. It enters an area of constant magnetic field, B, of magnitude 5.00 mT, which is perpendicular to the electron's path.

Once within the magnetic field, the electron follows a circular path of radius 1.50 cm, as shown in Figure 9.

You may ignore relativistic effects.

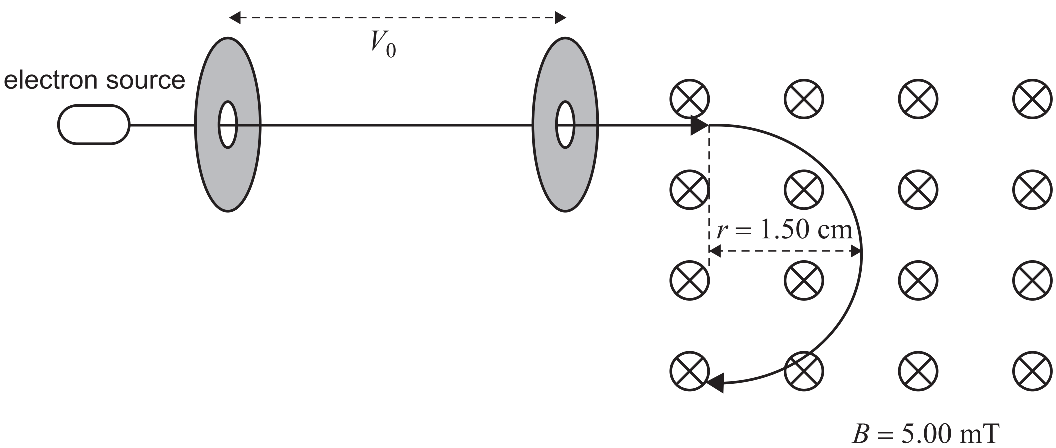

Figure 9

a. Show that the electron's speed, v, as it enters the magnetic field is $1.32 \times 10^7 \text{ m s}^{-1}$. 1 mark

b. Calculate the accelerating voltage, V_0, needed for the electron to reach a speed of $1.32 \times 10^7 \text{ m s}^{-1}$. 2 marks

V

c. The electron is replaced by a proton travelling at the same speed.

A proton has a mass of 1.67×10^{-27} kg and a charge of $+1.60 \times 10^{-19}$ C.

Describe the path the proton takes after entering the constant magnetic field compared to the path taken by the electron.

Justify your answers. No calculations are required. 3 marks

Question 8 (6 marks)

Electrical activity in thunderstorms can be modelled as charge separation, causing an electric field to form between the base of the thundercloud and the ground, similar to two charged parallel plates.

Figure 10 shows the base of a thundercloud that is $850\ \mathrm{m}$ above the ground.

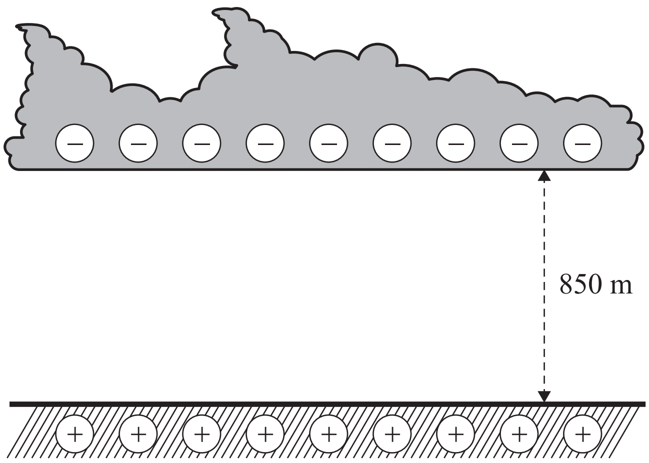

Figure 10

a. Using arrows, sketch on Figure 10 above at least **five** electric field lines between the ground and the base of the thundercloud. 2 marks

b. The potential difference between the ground and the base of the thundercloud is $1.20\ \mathrm{GV}$.

Calculate the magnitude of the electric field between the ground and the base of the thundercloud. 2 marks

$\mathrm{V\ m^{-1}}$

c. A $1.20\ \text{GV}$ lightning bolt discharges to Earth from the thundercloud with a current of $30.0\ \text{kA}$ for a duration of $60.0\ \mu\text{s}$.

Calculate the total energy transferred by this lightning bolt.

Give your answer to three significant figures. 2 marks

J

Do not write in this area.

Question 9 (5 marks)

Students build a simple DC electric motor, consisting of a single coil of wire in a uniform magnetic field. The coil is initially at rest, and orientated in a horizontal position, as shown in Figure 11. The coil can be rotated about the axis of rotation shown.

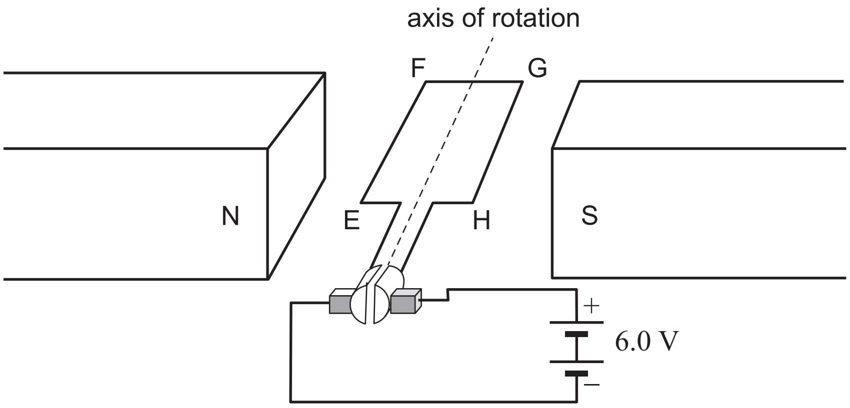

Figure 11

a. Describe **one** orientation of the coil, if any, where the magnetic force on side FG is zero.

Justify your answer. 2 marks

b. Describe **one** starting orientation of the coil, if any, where the coil will not start to rotate from rest.

Justify your answer. 2 marks

c. Suggest **one** way that the torque of the DC electric motor could be increased using exactly the same single coil and the same $6.0\ \text{V}$ battery as shown in Figure 11. 1 mark

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Examination continues on the next page.

Question 10 (7 marks)

Two Physics students, Aroha and Taylor, are investigating electromagnetic induction.

They use the apparatus shown in Figure 12, which consists of a single coil of wire in a uniform magnetic field connected to slip rings X and Y.

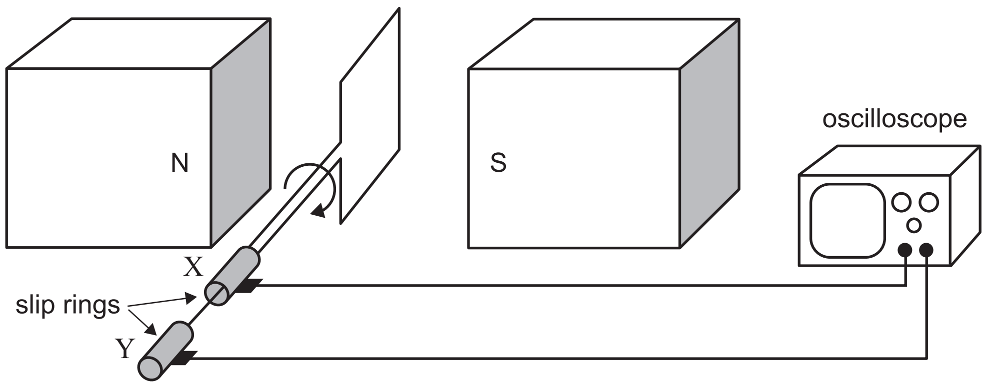

Figure 12

a. Explain the purpose of the slip rings shown in Figure 12. 2 marks

b. Taylor rotates the single coil of wire within the uniform magnetic field at a constant rate while Aroha measures the output voltage, ε, versus time, t, on an oscilloscope.

The oscilloscope display is shown in Figure 13.

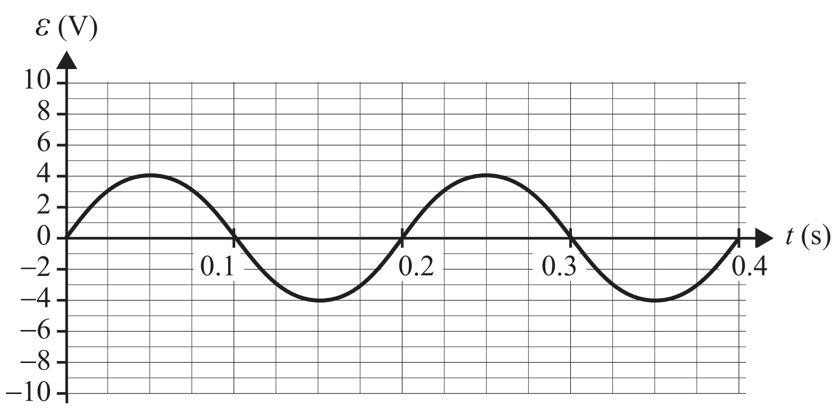

Figure 13

From the oscilloscope trace shown in Figure 13, determine the peak-to-peak voltage produced by the apparatus and the frequency of rotation of the single coil. 2 marks

V

Hz

c. Taylor makes a modification to the apparatus in Figure 12. Aroha sees the new oscilloscope trace as shown in Figure 14. The dotted line shows the original voltage before any changes are made by Taylor.

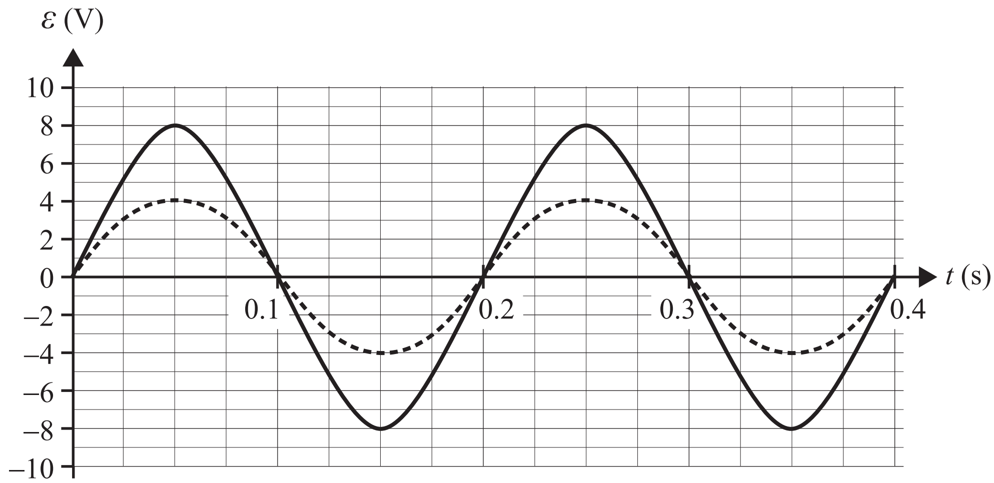

Figure 14

Explain **two** possible ways that Taylor could have modified the apparatus to create the oscilloscope trace shown in Figure 14. Justify your answers. 3 marks

Question 11 (5 marks)

Jia charges a $36\ \mathrm{V}$ battery used for her electric bicycle from a mains $230\ \mathrm{V_{RMS}}$ power point.

The transformer part of the battery charger circuit is shown schematically in Figure 15.

Assume that the transformer is ideal.

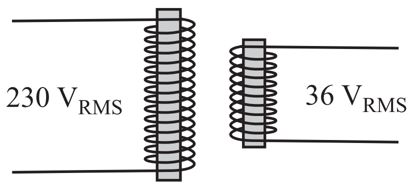

Figure 15

a. Calculate the number of turns required on the secondary coil if there are 460 turns in the primary coil. 1 mark

b. The RMS output current from the transformer to charge the battery is $0.80\ \mathrm{A}$.

Calculate the RMS input current to the transformer. 2 marks

A

c. Explain why the transformer requires AC input and would not work if the input was constant DC. 2 marks

Question 12 (6 marks)

A general store in country Victoria is connected to the mains $230\ \mathrm{V}$ electricity supply. The owners decide to install an array of solar photovoltaic (PV) panels to decrease their electricity bills.

The maximum output of each PV panel is rated as $600\ \mathrm{W}$ in full sunlight, with a maximum voltage output of $20\ \mathrm{V}$.

The owners install 50 PV panels connected in a 10×5 array, as shown in Figure 16.

The array consists of a bank of five strings connected in parallel, with each single string consisting of 10 PV panels connected in series. The total output of the array is connected to an inverter.

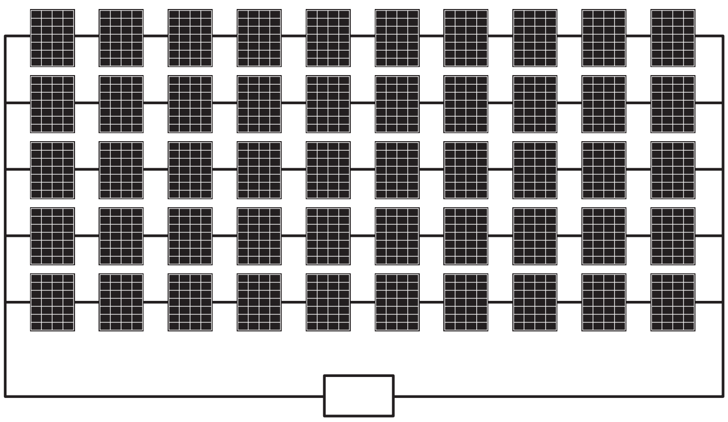

Figure 16

a. Calculate the maximum possible total output power from this array.

Give your answer in kW. 1 mark

kW

b. Calculate the maximum output voltage, and maximum output current, from **one** string of 10 PV panels connected in series in full sunlight. Show your working. 3 marks

V

A

c. Determine the maximum output voltage, and maximum output current, from the whole array in full sunlight. 1 mark

V

A

d. What is the function of the inverter? 1 mark

Question 13 (9 marks)

When energetic cosmic rays from space interact with Earth's upper atmosphere, subatomic particles known as muons are produced.

These muons are unstable and have been observed to rapidly decay. They decay with a mean lifetime of $2.20\ \mu s$.

As a result of their short half-life, physicists have used the muons produced in Earth's upper atmosphere to test Einstein's special theory of relativity.

In one experiment, physicists placed a muon detector at the top of a mountain at a height of $6500\ m$.

The muons produced in the upper atmosphere, at a height of $9700\ m$ above Earth's surface, travel downwards at a speed of $0.985c$.

This is shown in Figure 17.

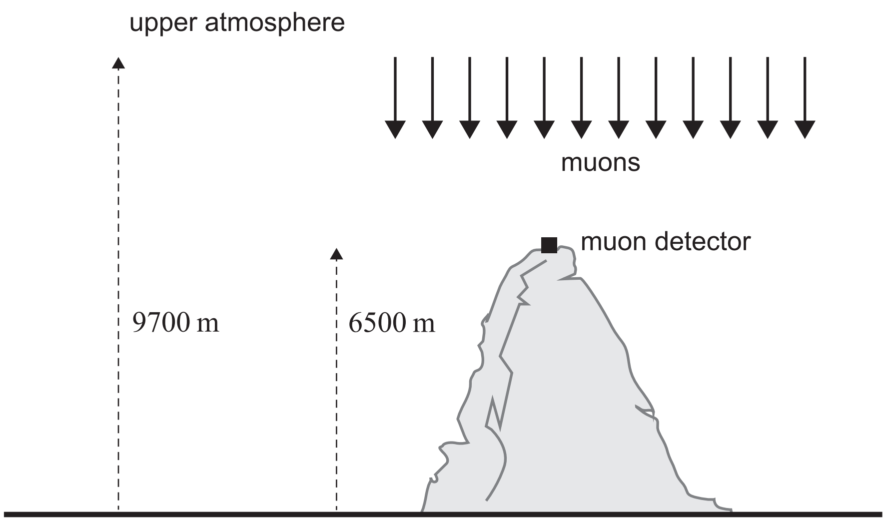

Figure 17

a. Using classical mechanics, show that a muon would reach the muon detector at the top of the mountain in $10.8\ \mu s$. 1 mark

b. According to classical mechanics, is a muon likely to reach the muon detector at the top of the mountain? Justify your answer. 2 marks

Use the following information to answer parts c, d and e.

Experiments conducted by physicists show that a significant number of muons, created at a height of 9700 m above Earth's surface and travelling at a speed of $0.985c$, consistently arrive at the muon detector at the top of the mountain.

c. Calculate the Lorentz factor (γ) for a muon travelling at $0.985c$. 2 marks

d. What is the mean half-life of the muon in the physicists' frame of reference? 1 mark

e. Explain how Einstein's special theory of relativity accounts for the experimental evidence that a significant number of muons, created at a height of 9700 m and travelling at a speed of $0.985c$, consistently arrive at the muon detector at the top of the mountain. 3 marks

Question 14 (3 marks)

PET (positron emission tomography) scanners are used in medical imaging. They rely on an electron and a positron colliding and completely annihilating each other to produce two gamma rays. The electron and positron have the same mass.

a. Assuming that the electron and positron are travelling at a negligible speed when they collide, calculate the total energy released in the annihilation. 2 marks

J

b. The two gamma rays produced travel in opposite directions with exactly the same wavelength and energy, as shown in Figure 18.

Figure 18

Explain why the gamma rays travel in opposite directions. 1 mark

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Question 15 (8 marks)

An electron gun forms part of a transmission electron microscope, which uses the wave properties of electrons to study specimens that are too small to be observed using an optical microscope.

Figure 19 shows a beam of electrons passing from an electron gun through two plates, Plate A and Plate B. The electrons reach Plate A with negligible speed and are accelerated by the potential difference between the plates, V_0, emerging from Plate B with a speed, v.

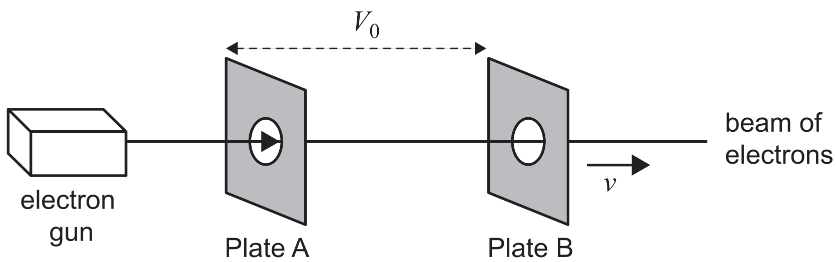

Figure 19

The de Broglie wavelength of the electrons in a particular beam is 2.00×10^{-10} m.

a. Calculate the momentum of an electron in the beam. 2 marks

kg m s^{-1}

b. The electron beam is passed through a crystal with an interatomic spacing of 3.00×10^{-10} m.

Two Physics students, Sally and Max, are discussing their predictions for diffraction patterns produced by the electron beam.

Sally claims that since the wavelength is less than the interatomic spacing, there will not be a detectable diffraction pattern formed. Max disagrees and claims that they will obtain a useful diffraction pattern.

Who is correct? Justify your answer. 2 marks

Question 15 continues on the next page.

Use the following information to answer parts c and d.

Sally and Max now change the potential difference in the electron gun to generate electrons with an energy of 600 eV and a corresponding de Broglie wavelength of $5.01 \times 10^{-11} \text{ m}$.

This adjusted electron beam is then directed through a thin foil, resulting in the diffraction pattern shown in Figure 20a.

The students decide to contrast this pattern with the pattern produced by passing X-rays through an identical foil, shown in Figure 20b. They note that the electrons and the X-rays produce patterns with the same dimensions.

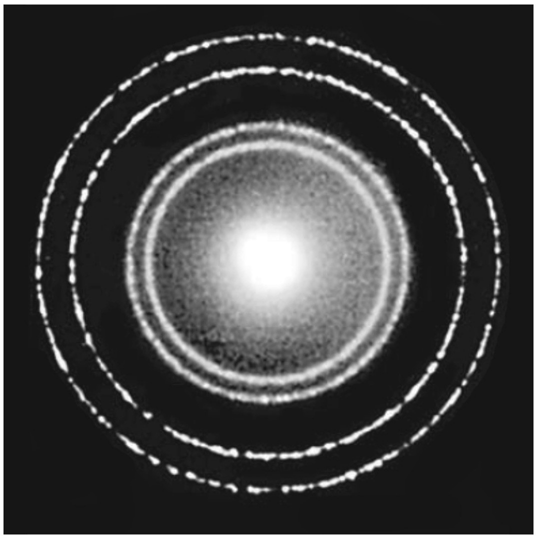

Figure 20a

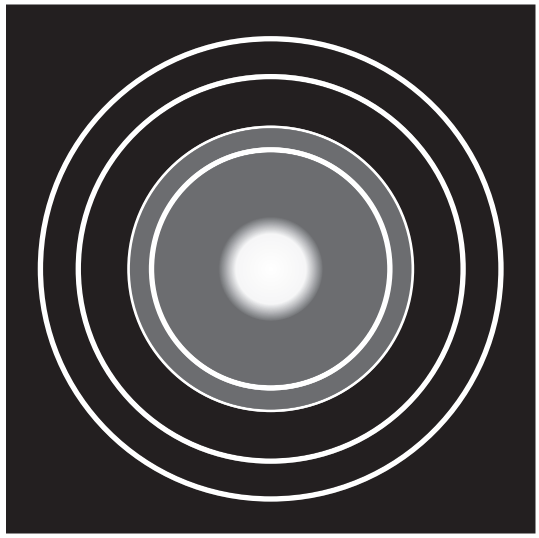

Figure 20b

c. Explain how the electrons and the X-rays can produce almost identical patterns. 2 marks

d. Calculate the energy, in eV, of the X-ray photons used to produce the image shown in Figure 20b. 2 marks

eV

Question 16 (20 marks)

Nicola is conducting an experiment to investigate the photoelectric effect using the apparatus shown in Figure 21.

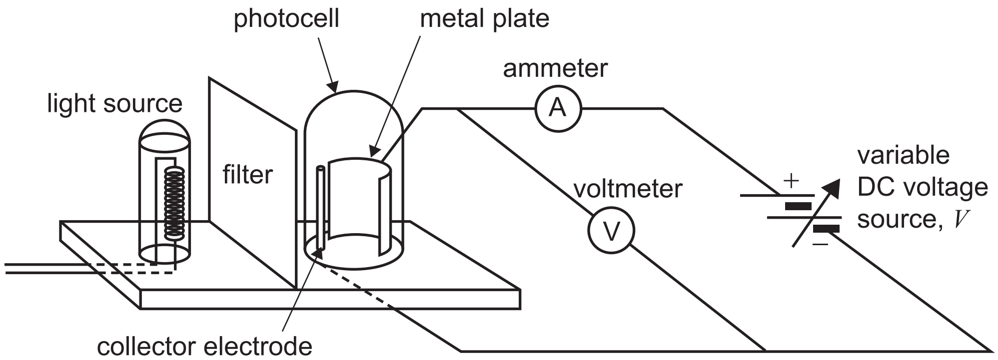

Figure 21

She uses various filters to shine electromagnetic radiation of particular frequencies on the photocell.

Nicola increases the voltage, V, until the current reaches zero and records this voltage. She repeats this process for different frequencies.

a. The variables in this experiment can be classified as controlled, dependent or independent.

Complete the table below by providing **one** variable from the experiment for each classification. 3 marks

Classification	Variable
controlled	
dependent	
independent	

Question 16 continues on the next page.

Use the following information to answer parts b–e.

Nicola's results for the experiment are shown in the table below:

Frequency (Hz)	Voltage (V)
6.0×10^{14}	0.1
7.0×10^{14}	0.5
8.0×10^{14}	0.9
9.0×10^{14}	1.2
10.0×10^{14}	1.4

The uncertainty in the measurement of the voltage is ± 0.1 V.

b. On the axes below (Figure 22), plot Nicola's data, including uncertainty bars, and draw a straight line of best fit. 3 marks

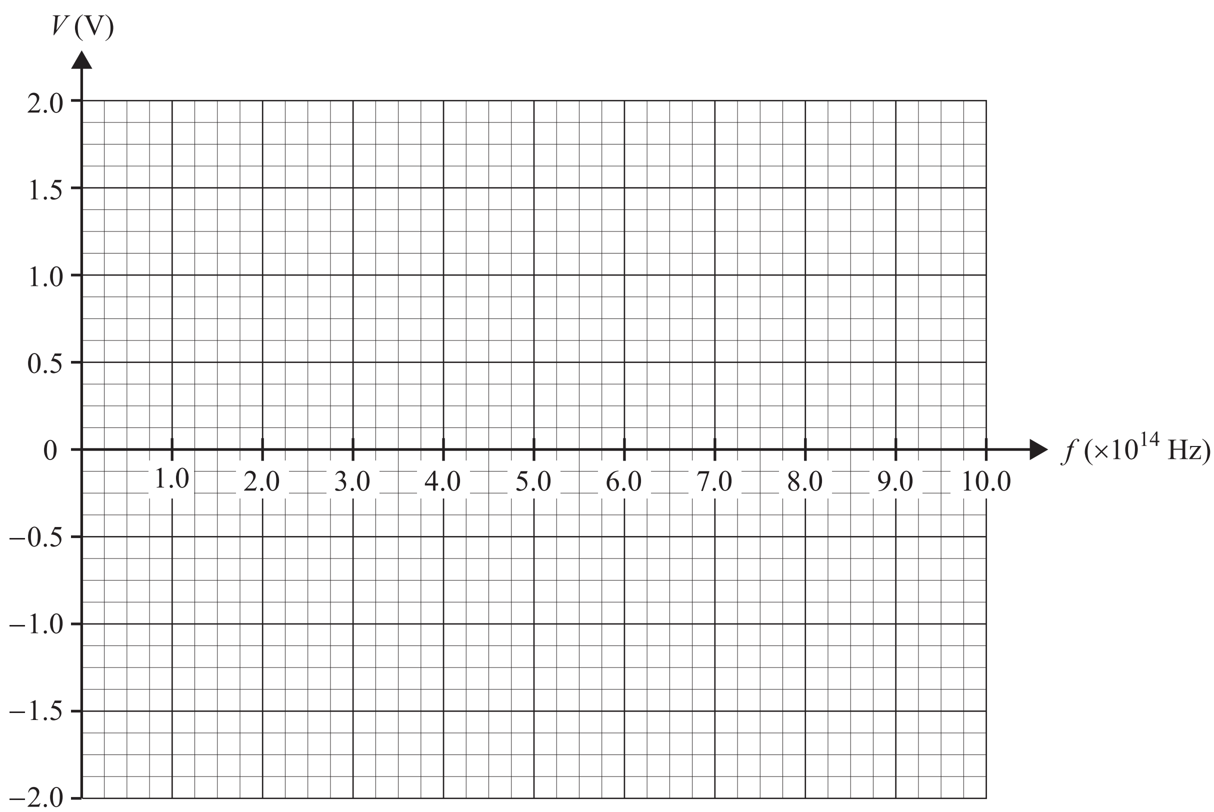

Figure 22

c. From your graph, determine the value Nicola would find for each of the following:

i. Planck's constant. Show your working. 2 marks

eV s

ii. threshold frequency. 1 mark

Hz

iii. work function of the metal. 1 mark

eV

d. Explain what information is given about the emitted photoelectrons by the recorded voltage measurements. 2 marks

e. If Nicola had carried out the investigation using a photocell with a plate made from a different metal, explain what effect, if any, this would have had on the graph drawn on Figure 22 in **part b** on the page 44. 1 mark

Question 16 continues on the next page.

Use the following information to answer parts f and g.

In carrying out her investigation, Nicola initially used a green filter and produced a graph of photocurrent, I, in milliamperes, versus voltage, V, in volts, as shown in Figure 23.

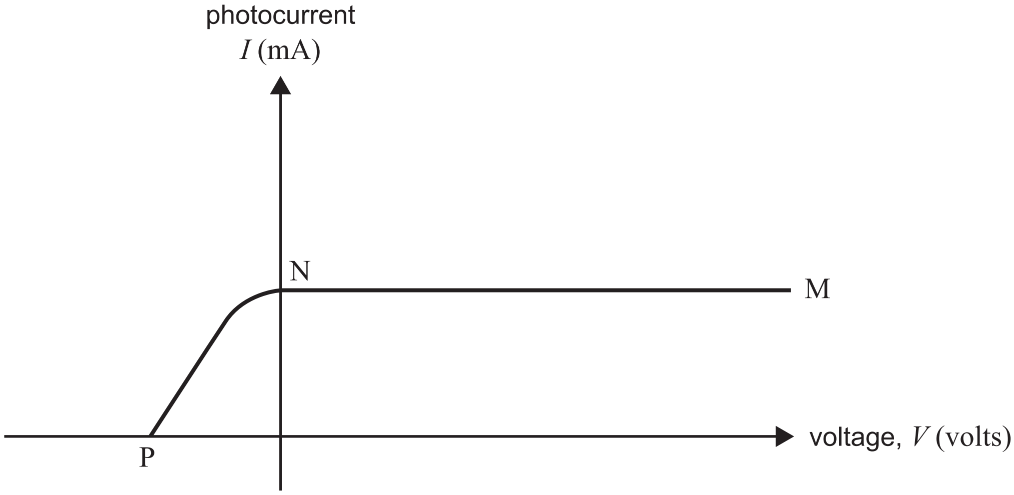

Figure 23

She then replaced the green filter with a blue filter, keeping the light output power of the blue light at the photocell exactly the same as the light output power of the green light.

f. Will the position of P, as shown on the graph in Figure 23, move to the left, remain the same, or move to the right? Justify your answer. No calculations or numerical values are required. 2 marks

g. Will the horizontal line NM on the graph shown in Figure 23 indicate a photocurrent that is greater than, the same as, or lower than the line for green light? Justify your answer. No calculations or numerical values are required. 2 marks

h. The results of photoelectric effect experiments provided strong evidence for the particle-like nature of light.

State **one** feature of the results that provided this evidence. Your response should explain:

- why the wave model does not satisfactorily explain this feature
- how the particle-like nature of light does explain this feature. 3 marks

End of Question and Answer Book

Physics

2024 Formula Sheet

You may keep this Formula Sheet.

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Motion and related energy transformations

velocity; acceleration	$v = \frac{\Delta s}{\Delta t}; \quad a = \frac{\Delta v}{\Delta t}$
equations for constant acceleration	$v = u + at$ $s = ut + \frac{1}{2}at^2$ $s = vt - \frac{1}{2}at^2$ $v^2 = u^2 + 2as$ $s = \frac{1}{2}(u + v)t$
Newton's second law	$\Sigma F = ma$
uniform circular motion	$F_{\text{net}} = \frac{mv^2}{r} \qquad v = \frac{2\pi r}{T}$
Hooke's law	$F = -kx$
elastic potential energy	$E_{\text{s}} = \frac{1}{2}kx^2$
gravitational potential energy	$E_{\text{g}} = mg\Delta h$
kinetic energy	$E_{\text{k}} = \frac{1}{2}mv^2$
Newton's law of universal gravitation	$F_{\text{g}} = G\frac{m_1 m_2}{r^2}$
gravitational field	$g = G\frac{M}{r^2}$
impulse	$F\Delta t = m\Delta v$
momentum	$p = mv$

Einstein's special theory of relativity

Lorentz factor	$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$
time dilation	$t = \gamma t_0$
length contraction	$L = \frac{L_0}{\gamma}$
relativistic rest energy	$E_0 = mc^2$
relativistic total energy	$E_{\text{total}} = E_{\text{k}} + E_0 = \gamma mc^2$
relativistic kinetic energy	$E_{\text{k}} = (\gamma - 1)mc^2$

Fields and application of field concepts

uniform electric field between charged plates	$E = \frac{V}{d}$
energy transformations of charges in an electric field	$\frac{1}{2}mv^2 = qV$
field of a point charge	$E = k\frac{Q}{r^2}$
electric force on a charged particle	$F = qE$
Coulomb's law	$F = k\frac{q_1 q_2}{r^2}$
magnetic force on a moving charge	$F = qvB$
magnetic force on a current-carrying conductor	$F = nIlB$
radius of a charged particle in a uniform magnetic field	$r = \frac{mv}{qB}$

Generation and transmission of electricity

current; power	$I = \frac{V}{R}$; $P = VI$
resistors in series	$R_T = R_1 + R_2 + \ldots$
resistors in parallel	$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots$
ideal transformer action	$\frac{N_1}{N_2} = \frac{V_1}{V_2} = \frac{I_2}{I_1}$
AC voltage and current	$V_{RMS} = \frac{1}{\sqrt{2}}V_{peak}$ $I_{RMS} = \frac{1}{\sqrt{2}}I_{peak}$
electromagnetic induction	$\varepsilon = -N\frac{\Delta\Phi_B}{\Delta t}$ $\Phi_B = B_\perp A$
transmission losses	$V_{drop} = I_{line}R_{line}$ $P_{loss} = I^2_{line}R_{line}$

Waves

wave equation	$v = f\lambda$
constructive interference	path difference $= n\lambda$
destructive interference	path difference $= \left(n + \frac{1}{2}\right)\lambda$
interference pattern spacing	$\Delta x = \frac{\lambda L}{d}$ when $L >> d$

The nature of light and matter

photoelectric effect	$E_{\mathrm{k\,max}} = hf - \phi$
photon energy	$E = hf = \dfrac{hc}{\lambda}$
photon momentum	$p = \dfrac{h}{\lambda}$
de Broglie wavelength	$\lambda = \dfrac{h}{p}$

Data

acceleration due to gravity at Earth's surface	$g = 9.81\ \mathrm{m\ s^{-2}}$
mass of the electron	$m_{\mathrm{e}} = 9.11 \times 10^{-31}\ \mathrm{kg}$
magnitude of the charge of the electron	$q_{\mathrm{e}} = 1.60 \times 10^{-19}\ \mathrm{C}$
Planck's constant	$h = 6.63 \times 10^{-34}\ \mathrm{J\ s}$ $\quad h = 4.14 \times 10^{-15}\ \mathrm{eV\ s}$
speed of light in a vacuum	$c = 3.00 \times 10^{8}\ \mathrm{m\ s^{-1}}$
universal gravitational constant	$G = 6.67 \times 10^{-11}\ \mathrm{N\ m^2\ kg^{-2}}$
mass of Earth	$M_{\mathrm{E}} = 5.97 \times 10^{24}\ \mathrm{kg}$
radius of Earth	$R_{\mathrm{E}} = 6.37 \times 10^{6}\ \mathrm{m}$
Coulomb constant	$k = 8.99 \times 10^{9}\ \mathrm{N\ m^2\ C^{-2}}$

Metric (SI) multipliers

p = pico = 10^{-12}	n = nano = 10^{-9}	μ = micro = 10^{-6}	m = milli = 10^{-3}
k = kilo = 10^{3}	M = mega = 10^{6}	G = giga = 10^{9}	T = tera = 10^{12}

Unit conversions

1 tonne (t) = 10^{3} kg
1 kilowatt hour (kW h) = 3.6×10^{6} J

Nomenclature

force due to gravity	F_{g}
terminology for force	$F_{\text{on A by B}}$
normal force	F_{N}

End of Formula Sheet