Catholic Junior College
JC2 Preliminary Examinations
Higher 2

CANDIDATE NAME	MARK SCHEME
CLASS	2T

PHYSICS
9749/01

Paper 1 Multiple Choice Questions

September 2025

1 hour

Additional Materials: Multiple Choice Answer Sheet

READ THESE INSTRUCTIONS FIRST

Write your name and class in the spaces at the top of this page.
Write in soft pencil.
Do not use staples, paper clips, glue or correction fluid.
Write and shade your name, NRIC / FIN number and HT group on the Answer Sheet (OMR sheet), unless this has been done for you.

There are **thirty** questions on this paper. Answer **all** questions. For each question, there are four possible answers **A**, **B**, **C** and **D**.
Choose the **one** you consider correct and record your choice in **soft pencil** on the separate Answer Sheet (OMR sheet).

Read the instructions on the Answer Sheet carefully.

Each correct answer will score one mark. A mark will not be deducted for a wrong answer.
Any rough working should be done in this booklet.
The use of an approved scientific calculator is expected, where appropriate.

This document consists of **23** printed pages and **1** blank page.

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DATA

speed of light in free space	c =	3.00×10^{8} m s^{-1}
permeability of free space	μ_0 =	$4\pi \times 10^{-7}$ H m^{-1}
permittivity of free space	ε_0 =	8.85×10^{-12} F m^{-1}
		$(1/(36\pi)) \times 10^{-9}$ F m^{-1}
elementary charge	e =	1.60×10^{-19} C
the Planck constant	h =	6.63×10^{-34} J s
unified atomic mass constant	u =	1.66×10^{-27} kg
rest mass of electron	m_e =	9.11×10^{-31} kg
rest mass of proton	m_p =	1.67×10^{-27} kg
molar gas constant	R =	8.31 J K^{-1} mol^{-1}
the Avogadro constant	N_A =	6.02×10^{23} mol^{-1}
the Boltzmann constant	k =	1.38×10^{-23} mol^{-1}
gravitational constant	G =	6.67×10^{-11} N m^2 kg^{-2}
acceleration of free fall	g =	9.81 m s^{-2}

FORMULAE

uniformly accelerated motion	$s = ut + \frac{1}{2}at^2$
	$v^2 = u^2 + 2as$
work done on / by a gas	$W = p\,\Delta V$
hydrostatic pressure	$p = \rho gh$
gravitational potential	$\phi = -\frac{Gm}{r}$
temperature	$T/K = T/°C + 273.15$
pressure of an ideal gas	$p = \frac{1}{3}\frac{Nm}{V}\langle c^2\rangle$
mean translational kinetic energy of an ideal gas molecule	$E = \frac{3}{2}kT$
displacement of particle in s.h.m.	$x = x_0 \sin \omega t$
velocity of particle in s.h.m.	$v = v_0 \cos \omega t$
	$= \pm\omega\sqrt{x_0^2 - x^2}$
electric current	$I = Anvq$
resistors in series	$R = R_1 + R_2 + ...$
resistors in parallel	$1/R = 1/R_1 + 1/R_2 + ...$
electric potential	$V = \frac{Q}{4\pi\varepsilon_0 r}$
alternating current / voltage	$x = x_0 \sin \omega t$
magnetic flux density due to a long straight wire	$B = \frac{\mu_0 I}{2\pi d}$
magnetic flux density due to a flat circular coil	$B = \frac{\mu_0 NI}{2r}$
magnetic flux density due to a long solenoid	$B = \mu_0 nI$
radioactive decay	$x = x_0 \exp(-\lambda t)$
decay constant	$\lambda = \frac{\ln 2}{t_{\frac{1}{2}}}$

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1 Which length is equal to 1 dm?

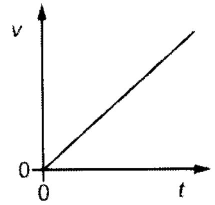
A	1×10^0 mm	B	1×10^1 mm	C	1×10^0 cm	D	1×10^1 cm

Answer: D

1 dm = 1×10^{-1} m = 1×10^2 mm = 1×10^1 cm

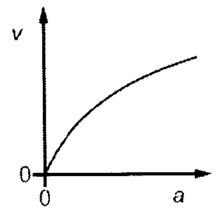
2 A particle accelerates from rest.

The graph shows the variation of the velocity v of the particle with time t.

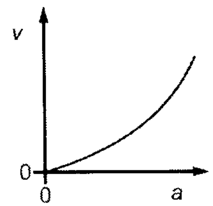


Which graph shows the variation of the velocity v with the acceleration a of the particle?

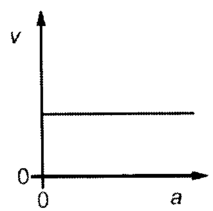
A



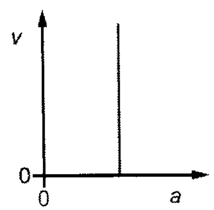
B



C



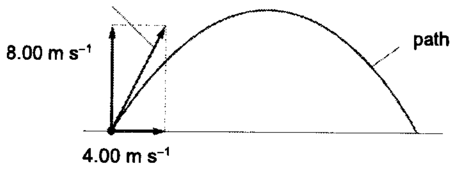
D



Answer: D

The gradient of the v-t graph is positive and constant. Hence, the acceleration is constant with respect to time.
Hence, the v-a graph should be D such that the velocity is increasing at constant a.

3 An astronaut on the Moon, where there is no air resistance, throws a ball. The ball's initial velocity has a vertical component of 8.00 m s^{-1} and a horizontal component of 4.00 m s^{-1}, as shown.



The acceleration of free fall on the Moon is 1.62 m s^{-2}.

What will be the speed of the ball 9.00 s after being thrown?

A	6.60 m s^{-1}	**B**	7.70 m s^{-1}	**C**	10.6 m s^{-1}	**D**	14.6 m s^{-1}

Answer: B

Take upwards and rightwards as positive directions.

Vertical direction:

$v_y = u_y + a_y t$

$= 8.00 + (-1.62)(9.00)$

$= -6.58 \text{ m s}^{-1}$

Horizontal direction:

$v_x = u_x + a_x t$

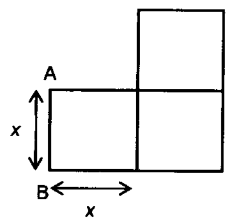
$= 4.00 + (0)(9.00)$

$= 4.00 \text{ m s}^{-1}$

speed after 9.00 s = $\sqrt{(-6.58)^2 + (4.00)^2}$

$= 7.70 \text{ m s}^{-1}$

4 A uniform square metal sheet of length *x* is cut into an 'L' shape.



What is the distance of the centre of gravity of the sheet of metal from side AB?

A	1.0 *x*	**B**	1.2 *x*	**C**	1.5 *x*	**D**	1.8 *x*

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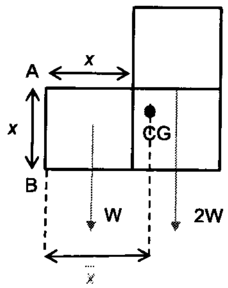
Answer: B



Let the weight of 1 square be W. Hence, the weight of 2 stacked squares on the right will be 2W.

Let the horizontal distance of the CG of the 'L' shape be $\bar{x}$ from B.

Hence, the equivalent weight of the combined L shape will be 3W acting downwards on this CG.

Taking moments about B,

Moment of the combined weight of the L shape about B = Sum of moments of the weight of the individual squares about B.

$3W(\bar{x}) = W(0.5\,x) + 2W(1.5\,x)$

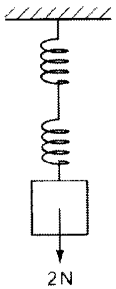
$3\bar{x} = 3.5\,x$

$\bar{x} = 1.2\,x$

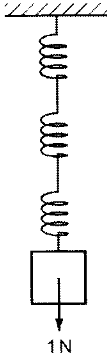
5 **Several identical springs, each having the same spring constant, are joined in four arrangements. A different load is applied to each arrangement.**

Which arrangement has the largest extension?

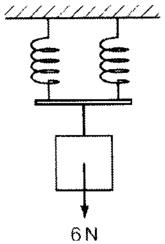
A



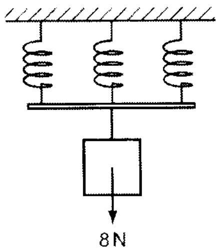
B



C



D



Answer: A

Let k be the spring constant of each of the identical springs.

For a spring system, $F_{net} = k_{eff}(e)$
where F_{net} is the load
k_{eff} is the effective spring constant
e is the extension of the arrangement

For A: $e = 2 / (0.5k) = 4 / k$ (largest)
For B: $e = 1 / (k / 3) = 3 / k$
For C: $e = 6 / 2k = 3 / k$
For D: $e = 8 / 3k = 2.7 / k$ (smallest)

6 **The energy conversions inside a power station burning fossil fuel can be simplified as shown.**

chemical energy W ➔ thermal energy X ➔ electrical energy Y

Which expression gives the efficiency of the power station?

A	$\frac{Y}{W}$	**B**	$\frac{Y}{(W+X)}$	**C**	$\frac{Y}{X}$	**D**	$\frac{Y}{(W+X+Y)}$

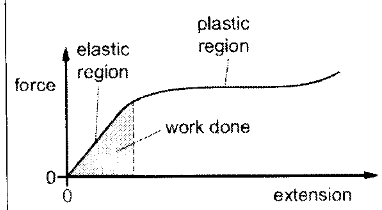
Answer: A

Efficiency = Useful power / Input power
= $(Y/t) / (W/t)$
= Y / W

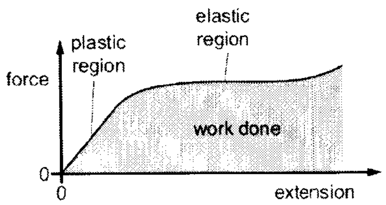
7 **A metal wire is stretched to breaking point and the force–extension graph is plotted.**

Which graph is correctly labelled with the elastic region, the plastic region and the area representing the work done to stretch the wire until it breaks?

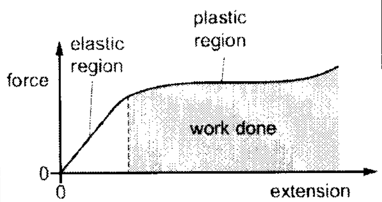
A



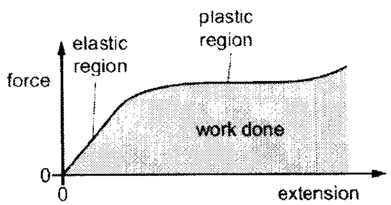
B



C



D



Answer: D

The force is directly proportional to the extension in the elastic region.
The work done is given by the area under the force extension graph. Breaking point is at the end of the graph. Only option D fits the description.

8 The Earth takes 24 hours to complete one rotation on its axis.

What is the angular velocity of the Earth as it rotates on its axis?

A	1.75×10^{-3} rad s^{-1}
B	1.99×10^{-7} rad s^{-1}
C	4.36×10^{-3} rad s^{-1}
D	7.27×10^{-5} rad s^{-1}

Answer: D
$\omega = 2\pi / T$
$= 2\pi / 24 \times 60 \times 60$
$= 7.27 \times 10^{-5}$ rad s^{-1}

9 A stone is attached to a string. The stone is then caused to swing in a vertical circular motion at a constant speed.

Which of the following statements is ***incorrect***?

A	The magnitude of resultant force acting on the stone is constant throughout the circular motion.
B	The acceleration is always directed towards the centre of the circle throughout the circular motion.
C	The kinetic energy of the stone is constant throughout the circular motion.
D	The tension in the string when the stone is at the highest point of the circular motion is higher than that when the stone is at the lowest point.

Answer: D
Centripetal force is constant in magnitude
The centripetal acceleration is always acting towards the centre of circle
K.E. is constant because speed is constant since KE = ½ m v^2

At lowest point, tension – weight = centripetal force
Tension = centripetal force + weight

At highest point, tension + weight = centripetal force
Tension = centripetal force - weight

Tension at the highest point is lower than at the lowest point.

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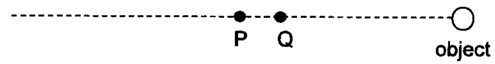
10 Two points P and Q are located a fixed distance apart on a straight line joining them to an object considered as a point mass.



The two points P and Q are moved closer to the point mass, while keeping the separation between them constant.

What happens to the magnitudes of their individual gravitational potentials and to the magnitude of the gravitational field strength between the two points?

	magnitudes of gravitational potentials	magnitudes of gravitational field strength difference
A	both decrease	decreases
B	both decrease	increases
C	both increase	stays the same
D	both increase	increases

Answer: D

Gravitational potential at a point is given by:
$\phi = \frac{-GM}{r}$

As both P and Q move closer to the mass, their distances r decrease, and since ϕ becomes more negative, the magnitudes of the potentials $|\phi|$ increase.

Gravitational field strength is given by:
$g = \frac{GM}{r^2}$

As r decreases, g increases at both P and Q. Because g changes more rapidly with r nearer the mass (steeper gradient), the field strength difference between the two points also increases, even though their separation remains constant.

11 A gas molecule of mass m moves with velocity v and collides elastically with a wall perpendicular to that direction.

If the molecule makes N such collisions per second with the wall, what is the average force F exerted by the molecule on the wall?

A	$F = mvN$	**B**	$F = 2mvN$	**C**	$F = \frac{mv^2}{2}$	**D**	$F = \frac{mv}{N}$

Answer: B
Each elastic collision with the wall causes a change in momentum:
$\Delta p = -mv - (+mv) = -2mv$

According to Newton's 3rd law of motion, the wall experiences a force equal in magnitude but opposite in direction. If the molecule hits the wall N times per second, the rate of change of momentum (i.e., force),

$F = N \times \Delta p = N \times (2mv)$

$= 2mvN$

12 **A piece of metal of mass *m*, specific heat capacity *c* and temperature 20 °C is placed into a liquid of temperature 100 °C. The liquid, which is in a well-insulated container, has mass 3*m* and specific heat capacity 2.5*c*.**

What is the temperature of the liquid when thermal equilibrium is reached?

A	56 °C	**B**	60 °C	**C**	85 °C	**D**	91 °C

Answer: D

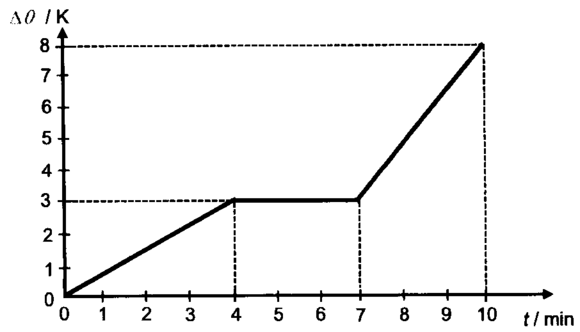
Using $Q = mc\Delta\theta$, heat gained by metal = heat lost by liquid;

$mc(\theta_f - 20) = (3m)(2.5c)(100 - \theta_f)$

$\theta_f - 20 = 750 - 7.5\theta_f$

$\theta_f = 91\ ^{\circ}C$

13 **The graph shows the variation with time *t* of temperature change $\Delta\theta$ for 1 kg of a substance, initially solid at room temperature. The substance receives heat at a uniform rate of 2000 J min⁻¹.**



What can be deduced from this graph?

A	**The specific heat capacity of the substance is greater when liquid than when solid.**
B	**The specific latent heat of fusion of the substance is 6000 J kg^{-1}.**
C	**The substance melts at a temperature of 3 K.**
D	**After 10 min, the substance is all gaseous.**

Answer: B

Option A :

$Q = Pt = mc\Delta\theta$

$P = \frac{mc\Delta\theta}{t}$

Form the graph, $\frac{\Delta\theta}{t}$ is bigger for liquid (7 – 10 min) than solid (1 – 4 min).

Since P and m are constant, therefore specific heat capacity c is smaller when liquid than when solid.

Option B:

$Q = mL$

$2000 \times 3 = 1 \times L$

$L = 6000$ J kg^{-1}

Option C:

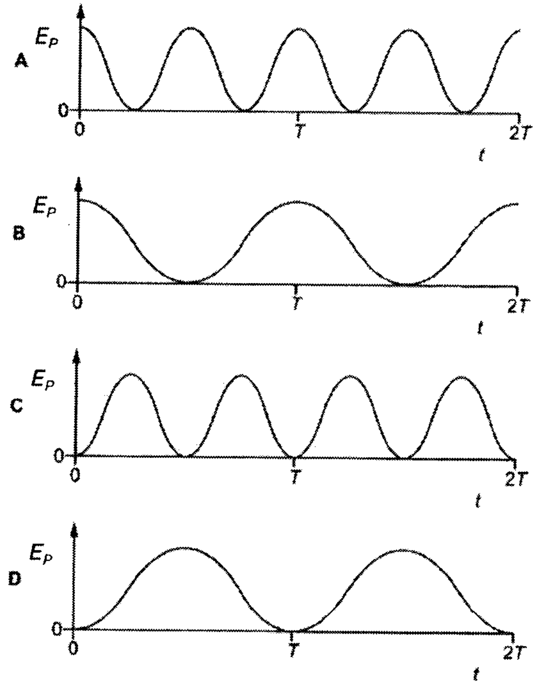
The substance melts after an increase in temperature of 3 K from room temperature. The melting temperature is not 3 K.

Option D:

Unless the graph becomes horizontal again, we are unable to determine when the substance starts to become gaseous.

14 A small pendulum bob is displaced to one side and released from rest at time $t = 0$. The bob then swings with simple harmonic motion with time period T.

Which graph represents the variation with time t of the gravitational potential energy E_P?



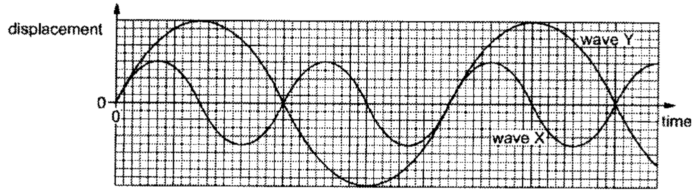
Answer: A

Explanation/Working:

At $t = 0$, the GPE is maximum since it is at the amplitude position.

The GPE is zero at the equilibrium position and in one cycle, the bob passes the equilibrium position twice, and therefore, it should have two minima per period.

15 The graph shows the variation with time of displacement for two transverse waves X and Y travelling through the same medium. For such mechanical waves, intensity is proportional to the square of frequency.



Wave X has frequency f and intensity I.

What is the frequency and intensity of wave Y?

	frequency	intensity
A	$\frac{f}{2}$	$4I$
B	$\frac{f}{2}$	I
C	$2f$	I
D	$2f$	$4I$

Answer: B

Amplitude of Wave X is A
Wave Y has amplitude = $2A$

Using the relationship $I \propto A^2f^2$,

$\frac{I_Y}{I_X} = \left(\frac{2A}{A}\right)^2 \times \left(\frac{\frac{f}{2}}{f}\right)^2 = 4 \times \frac{1}{4} = 1 \rightarrow I_Y = I_X = 1$

16 Two polarising filters are placed next to each other so that their planes are parallel. The first polarising filter has its transmission axis at an angle of 50° to the vertical.

The second polarising filter has its transmission axis at an angle of 20° to the vertical. The angle between the transmission axes of the two polarising filters is 30°.

A beam of vertically polarised light of intensity 8.0 W m^{-2} is incident normally on the first polarising filter.

What is the intensity of the light that is transmitted from the second polarising filter?

A	zero	B	2.5 W m^{-2}	C	2.9 W m^{-2}	D	6.0 W m^{-2}

Answer: B

Light passes through the first polarising filter.

Since the light is initially vertically polarised, the angle with the first filter's axis is 50°.

Using Malus's Law:
$I_1 = I_0 \cos^2(\theta) = 8.0 \times \cos^2(50°) = 8.0 \times (0.6428)^2 = 8.0 \times 0.4132 = 3.31\ W\ m^{-2}$

Light passes through the second polarising filter.
The angle between the transmission axes of the two filters is 30°.
Again using Malus's Law:
$I_2 = I_1 \cos^2(30°) = 3.31 \times (0.8660)^2 = 3.31 \times 0.75 = 2.5\ W\ m^{-2}$

17 Which of the following is **not** an application of the Rayleigh criterion?

A	**Assessing the resolving power of a telescope or microscope.**
B	**Calculating the minimum angular separation between two point sources to distinguish them.**
C	**Determining the angular position of the first minima in single slit diffraction.**
D	**Predicting whether two stars appear distinct in astronomical observations.**

Answer: C

Explanation/Working:

Option C refers to diffraction pattern analysis, not resolution.

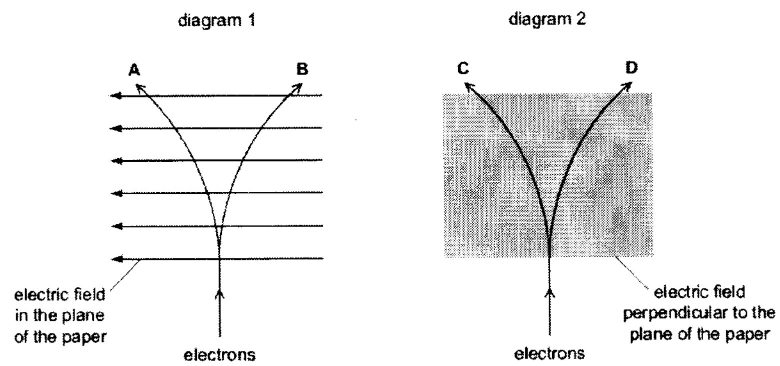
Options A, B, and D are direct applications of the Rayleigh criterion, which concerns resolvability based on angular separation and diffraction limits.

18 **A beam of electrons is directed into an electric field and is deflected by it.**

Diagram 1 represents an electric field in the plane of the paper. Diagram 2 represents an electric field directed perpendicular to the plane of the paper.

The lines A, B, C and D represent possible paths of the electron beam. All paths are in the plane of the paper.

Which line best represents the path of the electrons inside the field?



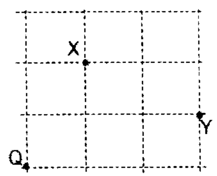
Answer: B

Electrons are negatively charged. In the left diagram, the field points to the left, so the force on electrons is to the right. An upward moving electron will curve towards the right → Path B.

For the diagram on the right, electric field is either in or out of the paper. This will cause electrons to deflect out of the plane of the paper, not along any of the shown paths which lie in the plane.

19 **An isolated point charge is placed at point Q. The electric potential at point X is measured to be 720 V.**

The relative positions of the three points Q, X, and Y are shown on the grid of squares below.



If the electric potential at X is 720 V, what is the electric potential at Y?

A	509 V	**B**	581 V	**C**	720 V	**D**	936 V

Answer: A

Electric potential due to a point charge follows:
$V \propto 1/r$

Distance from Q to X:

$r_X = \sqrt{1^2 + 2^2} = \sqrt{5} = 2.24$

Distance from Q to Y:

$r_Y = \sqrt{3^2 + 1^2} = \sqrt{10} = 3.16$

$\frac{V_Y}{V_X} = \frac{r_X}{r_Y} = \frac{2.24}{3.16} = 0.707$

$V_Y = 720 \times 0.707 = 509$ V

20 A cylindrical piece of wire has resistance *R*. It is stretched uniformly so that its length becomes three times longer, but its volume remains constant.

What is its new resistance in terms of *R*?

A	$\frac{R}{3}$	B	*R*	C	3*R*	D	9*R*

Answer: D

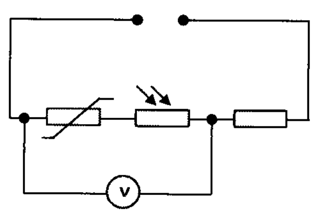
Let original length = L, area = A.
Then original volume = A × L

New length = 3L
New area = A' = original volume/ new length = $\frac{A \times L}{3L} = \frac{A}{3}$

Original resistance:
$R = \frac{\rho \times L}{A}$

New resistance:
$R' = \rho \times \frac{3L}{\frac{A}{3}} = \rho \times (3L \times \frac{3}{A}) = 9 \times (\rho \times \frac{L}{A}) = 9R$

21 A negative temperature coefficient thermistor, an LDR and a fixed resistor are connected in series to a power supply. A voltmeter is placed across the thermistor-LDR combination.



Which conditions of brightness and temperature will produce the smallest reading on the voltmeter?

	temperature	brightness
A	high	high
B	high	low

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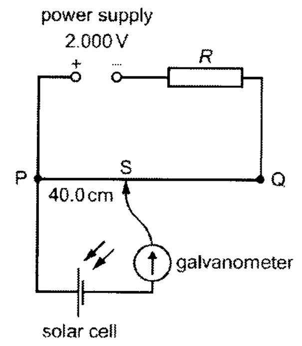
C	low	high
D	low	low

Answer: A

Smallest reading on the voltmeter, the total resistance of the thermistor and the LDR is the lowest.
Lowest resistance of a NTC thermistor occurs when temperature is high
Lowest resistance of LDR occurs when brightness is high

22 A power supply and a solar cell are compared using the potentiometer circuit shown.



The potentiometer wire PQ is 100.0 cm long and has a resistance of 5.00 Ω. The power supply has an e.m.f. of 2.000 V and the solar cell has an e.m.f. of 5.00 mV.

When the galvanometer shows zero deflection, the balance length PS is found to be 40.0 cm.

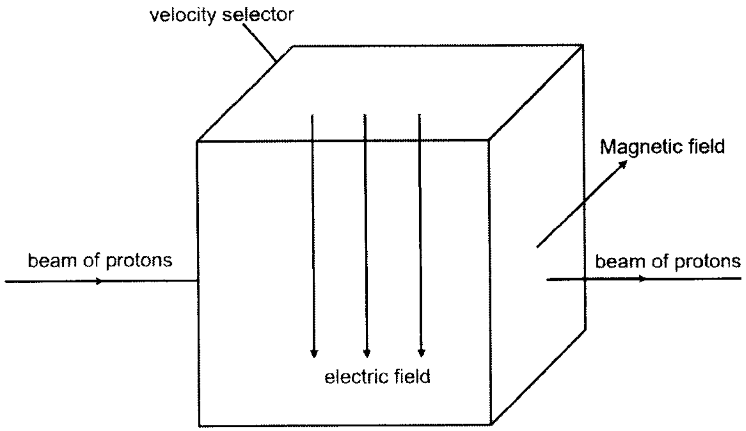
What is the resistance of *R* so that the galvanometer reads zero at this balance length?

A	395 Ω	B	795 Ω	C	995 Ω	D	1055 Ω

Answer: B

At balance point, voltage across 40.0 cm → 5.00×10^{-3} V
Pd across PQ (100 cm) = $\frac{5.00 \times 10^{-3}}{40} \times 100 = 0.0125$
Total voltage across R = 2.000 – 0.0125 V = 1.9875 V
Total resistance = R + 5.00
By potential divider principle: $1.9875 = 2\,\frac{R}{R+5}$
0.99375(R+5) = R
0.99375R + 4.96875 = R
0.00625 R = 4.96875
R = 795 Ω

23 A beam of protons enters a velocity selector as shown. The electric field E acts vertically downwards, and the magnetic field B is directed into the page.



If only protons with a particular speed emerge undeflected, which change would result in the protons being deflected downwards?

A	Increasing the electric field strength only
B	Increasing the magnetic field strength only
C	Increasing both E and B by the same factor
D	Increasing the proton's speed

Answer: A

For no deflection, $E = vB$. Increasing E only makes the electric force greater compared to the magnetic force, causing downward deflection.

24 A rectangular coil of wire lies in a uniform magnetic field of 0.30 T. The field is perpendicular to the plane of the coil. The coil is stretched from dimensions 0.20 m × 0.50 m to 0.20 m × 0.80 m in 2.0 seconds.

What is the average emf induced in the coil during this time?

A	0.009 V	**B**	0.018 V	**C**	0.027 V	**D**	0.036 V

Answer: A

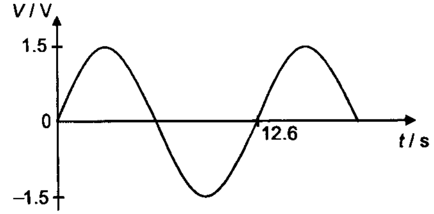
Initial area = 0.20 × 0.50 = 0.10 m²
Final area = 0.20 × 0.80 = 0.16 m²

Change in flux, ΔΦ = B × ΔA = 0.30 × (0.16 - 0.10) = 0.018 Wb

Average emf = ΔΦ / Δt = 0.018 / 2.0 = 0.009 V

[Turn over

25 The variation of an alternating voltage V with time t is shown in the graph below.



Which expression best represents V in terms of t ?

A	$V = 1.5\sin(0.499t)$
B	$V = 1.5\sin(2.01t)$
C	$V = 3.0\sin(0.249t)$
D	$V = 1.5\sin(12.6t)$

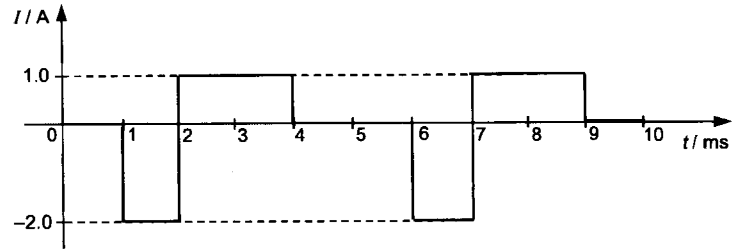
Answer: A

$x = x_0 \sin(\omega t)$

$\omega = \frac{2\pi}{T} = \frac{2\pi}{12.6} = 0.499$ rads^{-1}; $x_0 = 1.5$ V

Therefore, $V = 1.5\sin(0.499t)$.

26 An alternating current with a rectangular waveform as shown in the diagram below flows through a 10 Ω resistor.



What is the average power dissipated by the resistor?

A	0 W	**B**	8 W	**C**	12 W	**D**	28 W

Answer: C

To find I_{rms}; Firstly, you square the graph, then you find the total area over 1 period. Next, find the average area over 1 period, and then you will obtain the answer by taking the square root.

$$I_{r.m.s.} = \sqrt{\frac{(-2.0^2 \times 1) + (1.0^2 \times 2)}{5}}$$
$= 1.09545$ A

Average power $= I_{r.m.s.}{}^2 \times R$
$= 1.09545^2 \times 10$
$= 12$ W

27 A photon of light has frequency *f*, momentum *p*, and speed *c*. The Planck constant is *h*.

Which expressions for the momentum and the energy of the photon are correct?

	momentum	energy
A	hf	pc
B	hf	$\frac{pc}{2}$
C	$\frac{hf}{c}$	pc
D	$\frac{hf}{c}$	$\frac{pc}{2}$

Answer: C

Explanation/Working:

de Broglie equation: $\lambda = \frac{h}{p}$

$\frac{c}{f} = \frac{h}{p}$

$p = \frac{hf}{c}$

Since $E = hf$

$p = \frac{E}{c}$

$E = pc$

28 An electron in an atom transitions from –25.0 eV to –80.0 eV. A photon is emitted in the process.

What is the wavelength of the emitted photon?

A	15.5 nm	**B**	22.6 nm	**C**	49.7 nm	**D**	300 nm

Answer: B

Explanation/Working:

Energy difference

[Turn over

$= -80.0-(-25.0)$ eV $= -55.0$ eV

$= -55.0 \times 1.60 \times 10^{-19}$ J

$= 8.81 \times 10^{-18}$ J

$$\lambda = \frac{hc}{\Delta E} = \frac{(6.63 \times 10^{-34})(3.00 \times 10^{8})}{8.81 \times 10^{-18}} = 2.26 \times 10^{-8} \text{ m}$$

$\lambda = 22.6$ nm

29 Which of the following best describes the Heisenberg's uncertainty principle?

A	The uncertainty principle applies only to microscopic particles like electrons.
B	The uncertainty principle only applies to particles moving close to the speed of light.
C	The product of the uncertainties in position and momentum of a particle has a minimum value.
D	It is possible to reduce the uncertainty in both position and momentum of a particle to zero with advanced measuring techniques.

Answer: C

Explanation/Working:

The HUP applies to all particles, not just electrons (Option A) or objects moving at high speeds (Option B). It is also a limitation of knowledge of the value of the quantities, and not just a technological issue (Option D).

Option C is correct because this is the statement of the inequality $\Delta x \Delta p \geq h$

30 Thorium-232 undergoes the following fission reaction:

$${}^{232}_{90}\text{Th} \rightarrow {}^{140}_{54}\text{Xe} + {}^{90}_{36}\text{Kr} + 2{}^{1}_{0}\text{n}$$

The binding energy per nucleon for the nuclei involved are:

Thorium-232: 7.6 MeV
Xenon-140: 8.3 MeV
Krypton-90: 8.5 MeV

What is the energy released by this fission reaction?

A	1.64×10^{8} J	**B**	2.63×10^{-11} J	**C**	1.47×10^{-12} J	**D**	2.63×10^{-17} J

Answer: B

Explanation/Working:

Thorium-232 has 232 nucleons.

Binding energy = 232 × 7.6 = 1763.2 MeV

Xenon-140: 140 × 8.3 = 1162.0 MeV

Krypton-90: 90 × 8.5 = 765.0 MeV

	Energy released = Binding energy of products − Binding energy of reactants = 1927.0 − 1763.2 = 163.8 MeV 1 MeV = 1.602×10^{-13} J Energy in joules = $163.8 \times 1.602 \times 10^{-13} = 2.63 \times 10^{-11}$ J

END OF PAPER

Catholic Junior College
JC2 Preliminary Examinations
Higher 2

CANDIDATE NAME	MARK SCHEME
CLASS	2T

PHYSICS — 9749/02
Paper 2 Structured Questions

August 2025
2 hours

Candidates answer on the Question Paper.

READ THESE INSTRUCTIONS FIRST
Write your name and class in the spaces at the top of this page.
Write in dark blue or black pen on both sides of the paper.
You may use an HB pencil for any diagrams or graphs.
Do not use staples, paper clips, glue or correction fluid.

The use of an approved scientific calculator is expected, where appropriate.
Answer **all** questions.

The number of marks is given in brackets [ ] at the end of each question or part question.

FOR EXAMINER'S USE		
Q1		/ 10
Q2		/ 8
Q3		/ 12
Q4		/ 8
Q5		/ 9
Q6		/ 11
Q7		/ 22
PAPER 2		/ 80

This document consists of **26** printed pages and **0** blank page.

[Turn over

DATA

speed of light in free space	c =	3.00×10^{8} m s^{-1}
permeability of free space	μ_0 =	$4\pi \times 10^{-7}$ H m^{-1}
permittivity of free space	ε_0 =	8.85×10^{-12} F m^{-1}
		$(1/(36\pi)) \times 10^{-9}$ F m^{-1}
elementary charge	e =	1.60×10^{-19} C
the Planck constant	h =	6.63×10^{-34} J s
unified atomic mass constant	u =	1.66×10^{-27} kg
rest mass of electron	m_e =	9.11×10^{-31} kg
rest mass of proton	m_p =	1.67×10^{-27} kg
molar gas constant	R =	8.31 J K^{-1} mol^{-1}
the Avogadro constant	N_A =	6.02×10^{23} mol^{-1}
the Boltzmann constant	k =	1.38×10^{-23} mol^{-1}
gravitational constant	G =	6.67×10^{-11} N m^{2} kg^{-2}
acceleration of free fall	g =	9.81 m s^{-2}

FORMULAE

uniformly accelerated motion	$s = ut + \frac{1}{2}at^2$
	$v^2 = u^2 + 2as$
work done on / by a gas	$W = p\Delta V$
hydrostatic pressure	$p = \rho gh$
gravitational potential	$\phi = -\frac{Gm}{r}$
temperature	$T/K = T/^{\circ}C + 273.15$
pressure of an ideal gas	$p = \frac{1}{3}\frac{Nm}{V}\langle c^2 \rangle$
mean translational kinetic energy of an ideal gas molecule	$E = \frac{3}{2}kT$
displacement of particle in s.h.m.	$x = x_0 \sin \omega t$
velocity of particle in s.h.m.	$v = v_0 \cos \omega t$
	$= \pm\omega\sqrt{x_0^2 - x^2}$
electric current	$I = Anvq$
resistors in series	$R = R_1 + R_2 + \ldots$
resistors in parallel	$1/R = 1/R_1 + 1/R_2 + \ldots$
electric potential	$V = \frac{Q}{4\pi\varepsilon_0 r}$
alternating current / voltage	$x = x_0 \sin \omega t$
magnetic flux density due to a long straight wire	$B = \frac{\mu_0 I}{2\pi d}$
magnetic flux density due to a flat circular coil	$B = \frac{\mu_0 NI}{2r}$
magnetic flux density due to a long solenoid	$B = \mu_0 nI$
radioactive decay	$x = x_0 \exp(-\lambda t)$
decay constant	$\lambda = \frac{\ln 2}{t_{\frac{1}{2}}}$

[Turn over

Answer **all** questions in the spaces provided.

1 A toy car of mass 0.42 kg is released from rest and accelerates along a straight track towards a wall. It hits the wall and rebounds in the opposite direction. The variation with time t of the momentum p of the toy car when not in contact with the wall is shown in Fig. 1.1

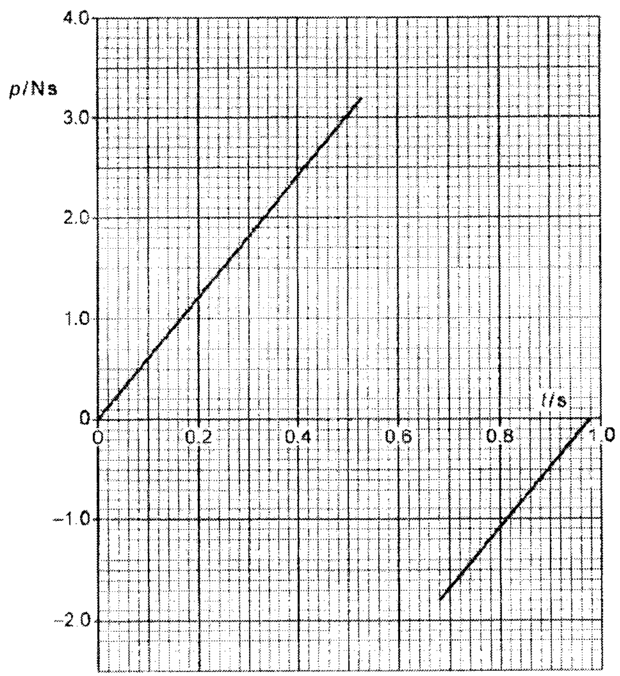


Fig 1.1

(a) Using Fig 1.1, calculate the impulse acting on the toy car during the collision.

impulse = ... N s [2]

Solution:

Impulse = change in momentum

$= p_f - p_i$ M1

$= -1.80 - (3.20)$

$= -5.00$ N s A1

(b) Calculate the magnitude of the average acceleration of the car during the collision and state the direction of this acceleration relative to the initial motion of the car.

average acceleration = ... m s^{-2}

direction = ... [3]

Solution:

$\Delta v = \frac{\Delta p}{m} = \frac{-5.00}{0.42} = -11.9\ m\ s^{-1}$ — M1

$a = \frac{\Delta v}{\Delta t} = \frac{-11.9}{0.15} = -79.3\ m\ s^{-2}$

$|a| = 79.3\ m\ s^{-2}$ — A1

Direction: opposite to the initial motion of the car — A1

(c) Explain why the collision was inelastic.

....

....

....

.... [2]

Solution:

The momentum and hence speed of the car before and after the collision is different. The wall is stationary and hence has no momentum and no KE. — B1

The total initial KE and the total final KE of the system of the car and wall is not the same. — B1

Therefore, collision is inelastic. — A0

(d) Calculate the percentage change in the kinetic energy of the car as a result of the collision.

percentage change = ... % [3]

Solution:

$E_{K,i} = \frac{p_i^2}{2m} = \frac{3.20^2}{2(0.42)} = 12.2\ J$ and $E_{K,f} = \frac{p_f^2}{2m} = \frac{1.80^2}{2(0.42)} = 3.86\ J$ — M1

$\%\Delta E_K = \frac{E_{K,f} - E_{K,i}}{E_{K,i}} \times 100\%$ — C1

$= \frac{3.86 - 12.2}{12.2} \times 100\%$

$= -68.4\%$ — A1

(including -ve sign)

[Total: 10]

2 (a) State what is meant by the centre of gravity of an object.

....

.... [1]

Solution:

The centre of gravity of an object is a point where the **entire** weight of the object is taken to act. — B1

(b) A hollow plastic sphere is attached at one end of a bar. The sphere is partially submerged in water and the bar is attached to a fixed vertical support by a pivot P, as shown in Fig. 2.1.

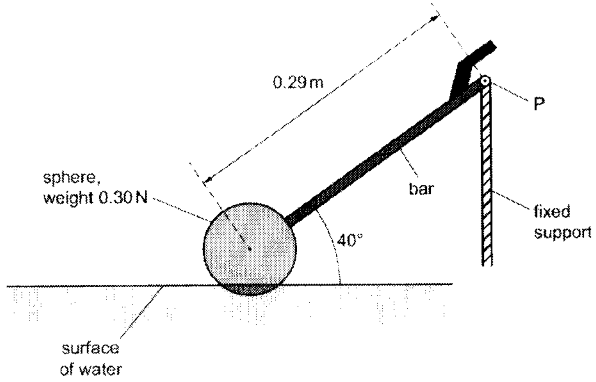


Fig. 2.1 (not to scale)

The sphere has weight 0.30 N. The distance from P to the centre of gravity of the sphere is 0.29 m. The weight of the bar is negligible.

The system shown in Fig. 2.1 is part of a mechanism that controls the amount of water in a tank. Water enters the tank and causes the sphere to rise. This results in the bar becoming horizontal as shown in Fig. 2.2.

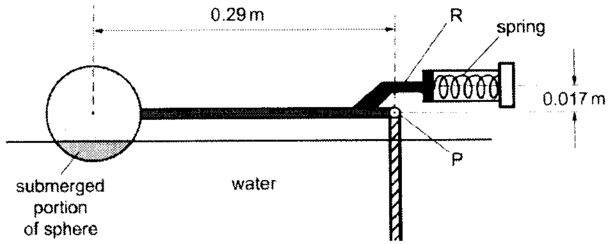


Fig. 2.2 (not to scale)

At the position shown in Fig. 2.2, the system is stationary and in equilibrium. The rod R exerts a force to compress a horizontal spring that controls the water supply to the tank. The spring has a spring constant of 2100 N m^{-1}. R is positioned at a perpendicular distance of 0.017 m above P.

(i) The radius of the sphere is 0.0480 m and 26.0% of the volume of the sphere is submerged.

The density of water is 1.00×10^3 kg m^{-3}.

Show that the upthrust on the sphere is 1.18 N.

[Turn over

[2]

Solution:

Volume V of the sphere $= \frac{4}{3}\pi r^3$

$= \frac{4}{3}\pi(0.0480)^3$

$= 4.63 \times 10^{-4}$ m^3 M1

Upthrust, $U = \rho V g = 1000(0.26)(4.63 \times 10^{-4})(9.81)$ M1

$= 1.18$ N

(ii) For the position shown in Fig 2.2, by taking moments about P, determine the force exerted on the spring by the rod R.

force = ... N [2]

Solution:
The force exerted on the spring by the rod is equal to the force exerted on the rod by the spring. Let the force be F.

Taking moments about P,

$(U - 0.30)(0.29) = F(0.017)$ M1

$(1.18 - 0.30)(0.29) = F(0.017)$

$F = 15$ N A1

(iii) Calculate the elastic potential energy E_P of the compressed spring.

E_P = ... J [2]

Solution:

Compression x of the spring $= F / k$
$= 15 / 2100$ (ecf for F)
$= 0.00715$ m

$E_P = \frac{1}{2} kx^2$
$= \frac{1}{2}(2100)(0.00715)^2$
$= 0.054$ J — M1 A1

(c) **When the sphere moves from the position shown in Fig. 2.1 to the position shown in Fig. 2.2, the upthrust on the sphere does work. Assume that resistive forces are negligible.**

Explain why the work done by the upthrust is not equal to the gain in elastic potential energy of the spring.

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....

.... [1]

Solution:
By conservation of energy, the work done by the upthrust is equal to the sum of the gain in elastic potential energy of the spring and the gain in gravitational potential energy of the sphere.

The gain in gravitational potential energy of the sphere has not been considered. — B1

[Total: 8]

[Turn over

3 (a) Fig. 3.1 shows a string stretched between two fixed points P and Q.

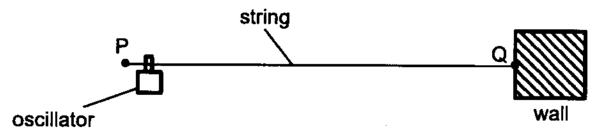


Fig. 3.1

An oscillator is attached near end P of the string. End Q is fixed to a wall. The oscillator has a frequency of 480.0 Hz.

The stationary wave produced on PQ at an instant time *t* is shown in Fig. 3.2. Each point on the string is at its maximum displacement.

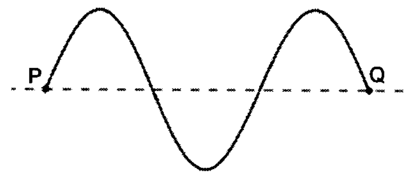
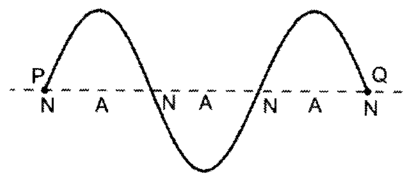


Fig. 3.2

(i) **On Fig. 3.2, label all the nodes with the letter N and the antinodes with the letter A along the dotted line PQ.** [2]

Solution



Correct position of nodes drawn. — B1
Correct position of antinodes drawn. — B1

(ii) **Calculate the lowest possible frequency of the wave that can be formed between end P and Q of the string.**

frequency = ... Hz [3]

Solution

Using $v = f\lambda$, therefore $f = \frac{v}{\lambda}$.

There are 1.5 wavelengths of wave formed between end P and Q for the string in Fig. 3.2.

Length L of string between end P and Q: $L = \frac{3\lambda_3}{2}$

Frequency in Fig. 3.2: $f = \frac{v}{\lambda_3} = \frac{v}{\frac{2L}{3}} = \frac{3v}{2L} = 480.0$ Hz — C1

For lowest possible frequency formed between end P and Q of string, it corresponds to 0.5 wavelength.

Length L of string between end P and Q: $L = \frac{\lambda_1}{2}$

Lowest possible frequency: $f' = \frac{v}{\lambda_1} = \frac{v}{2L} = \frac{3v}{2L}\left(\frac{1}{3}\right) = \frac{480.0}{3}$ — M1

$= 160.0$ Hz — A1

(b) **A loudspeaker is connected to a signal generator. It is then oriented to face a wall as shown in Fig. 3.3. Sound waves are produced between the speaker and the wall to form a stationary wave.**

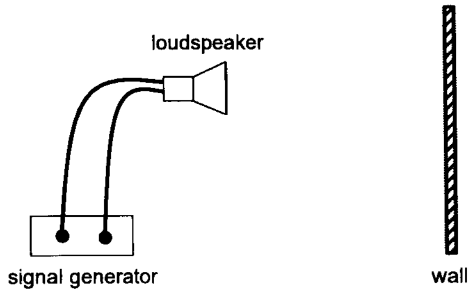


Fig. 3.3

(i) **Explain why there are alternate regions of high and low intensity detected between the loudspeaker and the wall.**

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....

.... [3]

Solution

The sound waves propagate and reflect off the wall, the incident and reflected waves have the same amplitude, wavelength/ frequency/ speed. — B1

[Turn over

They move in opposite direction and overlap/superpose/meet. — B1

When they experience constructive interference, they form regions of high intensity and when they experience destructive interference, they form regions of low intensity. — B1

(ii) **Outline how you would use this setup to obtain the speed of sound waves in air.**

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.... [4]

Solution

A microphone is moved between the speaker and the wall to detect maximum and minimum intensities. The microphone is connected to a cathode ray oscilloscope (CRO). The frequency is calculated from the period obtained from the CRO. — B1

Measure the separation between the positions of adjacent minimum/maximum intensities which is equivalent to half a wavelength. — B1

Repeat the measurements of the distance between these positions and find the average. Multiply the average inter-nodal distance to obtain the wavelength of the wave. — B1

Use $v = f\lambda$ to determine the speed of sound waves in air. — B1

[Total: 12]

4 **A battery B, a variable resistor R and a uniform resistance wire PQ are connected in series, as shown in Fig. 4.1**

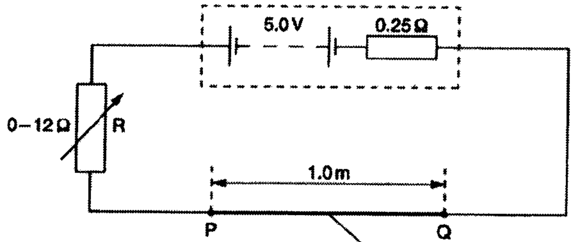

Fig. 4.1

Battery B has electromotive force (e.m.f.) 5.0 V and internal resistance 0.25 Ω.

Wire PQ has length 1.0 m and resistance 3.5 Ω at room temperature.

(a) **The resistance of R is set to 4.0 Ω.**

Calculate, when the circuit is just turned on,

(i) **the potential difference across wire PQ,**

p.d. = ... V [2]

Solution
Current in circuit = 5.0 / (0.25 + 4.0 + 3.5) = 0.645 A — M1
the p.d. across wire PQ = 0.645 (3.5) = 2.26 V — A1

OR,
p.d. across wire PQ = 5.0 – (0.645)(0.25 + 4.0) = 2.26 V

OR,
p.d. across wire PQ = (5.0)(3.5) / (4.0 + 3.5 + 0.25) = 2.26 V

(ii) **the percentage of total power transferred to wire PQ.**

percentage = ... % [2]

Solution

Power transferred to wire PQ = IV = 0.645(2.26)
Power generated by Battery B = IE = 0.645 (5.0)

Percentage power transferred
= [Power transferred to wire PQ/ power generated by Battery B] x 100%
= [0.645 (2.26) / 0.645 (5.0)] x 100% — M1
= 45.2 % — A1

(b) **The temperature of the wire gradually increased from room temperature to maximum steady temperature.**

(i) **Describe and explain the variation in the terminal potential difference (p.d.) across B. Numerical values are not required.**

....

....

....

.... [2]

Solution:
As the temperature increases, its resistance increases,
hence the total resistance increases — B1

and the current decreases
terminal p.d. = E – Ir will be increased — B1
since I decreases and E and r are constants

(ii) **Suggest why the temperature of the wire will reach a steady maximum value.**

....

....

.... [2]

Solution:
When the maximum temperature is reached, the electrical power absorbed is equal to the power dissipated to the surroundings. — B1

There is no net energy absorbed by the wire so the temperature will remain constant. — B1

[Total: 8]

5 (a) **An ideal gas is said to consist of molecules that are hard elastic identical spheres.**

State two further assumptions of the kinetic theory of gases.

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....

.... [2]

Solution

Any two of the following assumptions:
Total volume of molecules negligible compared to the volume of vessel. B1
No intermolecular forces between the molecules. B1
Molecules are in random motion.
Time of collision small compared with the time between collisions.
Larger number of molecules.

(b) **The number of molecules per unit volume in an ideal gas is *n*.**

If it is assumed that all the molecules are moving with speed v_x in the x-direction, the pressure *p* exerted by the gas on the walls of the vessel is given by

$$p = nmv_x^2$$

where *m* is the mass of one molecule.

Explain the reasoning by which this expression is modified to give the formula

$$p = \frac{1}{3}nm\langle c^2\rangle.$$

where $\langle c^2\rangle$ is the mean square speed of the molecules.

....

....

....

.... [2]

Solution

In the actual scenario, there is <u>a range of velocities of molecules</u> in any given direction. Thus, the average of v^2 of the molecules should be considered. B1

Molecules move in random direction and can move in *x*, *y* and *z*-direction. Since the <u>probability of the movement of molecules in either direction is the same,</u> B1

$\langle v_x^2\rangle = \langle v_y^2\rangle = \langle v_z^2\rangle$

$\langle v_x^2\rangle = \frac{1}{3}\langle c^2\rangle$

[Turn over

(c) **The density of an ideal gas is 1.2 kg m^{-3} at a pressure of 1.0 × 10^5 Pa and a temperature of 27 °C.**

(i) **Calculate the root-mean-square (r.m.s.) speed of the molecules of the gas at 27 °C.**

root-mean-square speed = ... m s^{-1} [3]

Solution

Nm = mass of gas

$\rho = \frac{M}{V} = \frac{Nm}{V} = nm$

Therefore, $p = \frac{1}{3}nm\langle c^2\rangle = \frac{1}{3}\rho\langle c^2\rangle$ C1

$1.0\times10^5 = \frac{1}{3}(1.2)\langle c^2\rangle$ M1

$\langle c^2\rangle = 2.5\times10^5$

$C_{r.m.s} = \sqrt{2.5\times10^5}$

$= 500$ m s^{-1} A1

(ii) **Calculate the mean-square speed of the molecules at 207 °C.**

mean-square speed = ... m^2 s^{-2} [2]

Solution

$E = \frac{3}{2}kT = \frac{1}{2}m\langle c^2\rangle$

$\langle c^2\rangle \propto T$

$\frac{\langle c^2\rangle_{207^\circ C}}{\langle c^2\rangle_{27^\circ C}} = \frac{207+273.15}{27+273.15}$ M1

$\langle c^2\rangle_{207^\circ C} = \left(\frac{207+273.15}{27+273.15}\right)(2.5\times10^5)$

$= 4.0\times10^5$ m^2 s^{-2} A1

[Total: 9]

6 (a) **When ultraviolet radiation of a specific frequency is incident on a metal surface, electrons are emitted with a range of kinetic energies up to a maximum value.**

Explain why the emitted electrons have a range of kinetic energies up to a maximum value.

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.... [3]

Solution:

Each photon provides a fixed amount of energy E = hf. **B1**

Electrons at the **surface require the least energy (or work function energy)** to escape and can emerge with the maximum kinetic energy. **B1**

Electrons inside the metal require **greater amounts of energy to escape** (those deeper inside lose energy due to collisions and electrostatic attraction) and hence **emitted with lower KE**. **B1**

(b) **The maximum kinetic energy E_{MAX} of electrons emitted from a metal surface is measured for different wavelengths λ of the electromagnetic radiation. The variation of E_{MAX} with $\frac{1}{\lambda}$ is shown in the Fig. 6.1.**

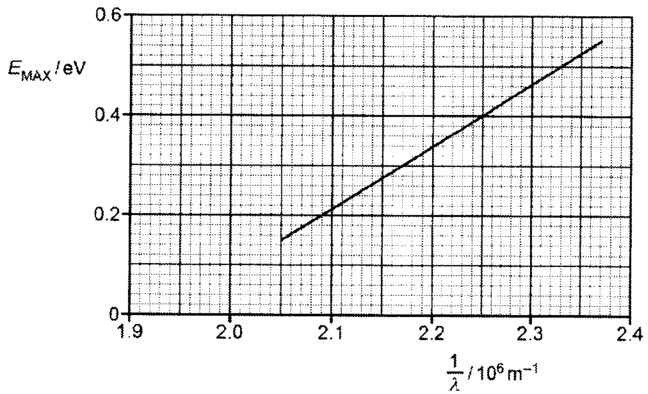


Fig. 6.1

Use the graph to:

[Turn over

(i) **determine the threshold frequency f_0 of the metal.**

f_0 = ... Hz [2]

Solution:

Extrapolate graph and find the x-intercept

For $E_{MAX} = 0, \frac{1}{\lambda} = 1.93 \times 10^6$ **M1**

$f_0 = \frac{c}{\lambda_0} = 3.00 \times 10^8 \times 1.93 \times 10^6$

$= 5.79 \times 10^{14}$ Hz **A1**

(ii) **determine a value for the Planck constant h. Explain your working clearly.**

h = ... J s [3]

Solution:

$E_{MAX} = \frac{hc}{\lambda} - \phi$

gradient = hc **C1**

$= \frac{(0.4 - 0.2) \times 1.6 \times 10^{-19}}{(2.25 - 2.09) \times 10^6} = 2.0 \times 10^{-25}$ **M1**

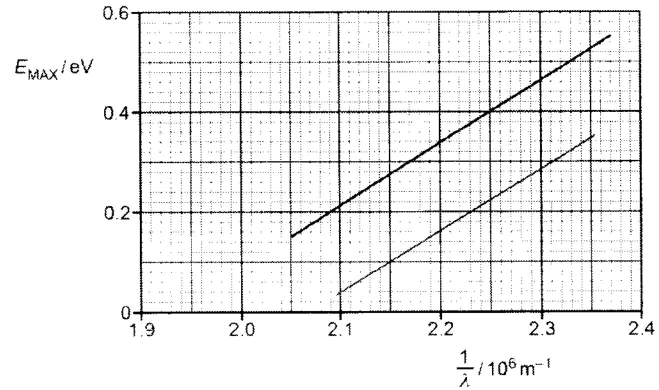
$h = \frac{2.0 \times 10^{-25}}{3 \times 10^8}$

$= 6.7 \times 10^{-34}$ J s **A1**

(c) **The electromagnetic radiation is now incident on a metal with a larger work function energy than the metal in (b).**

On Fig 6.1, sketch the variation with $\frac{1}{\lambda}$ of E_{MAX}. [1]

Solution:



With a larger work function, the threshold frequency required is larger and hence as f_0 is proportional to $\frac{1}{\lambda_0}$, the value of the x axis-intercept is larger. The gradient hc, which is a constant, remains the same.

Straight line with same gradient as original and x-axis intercept greater than 1.93×10^6 m^{-1}. B1

(d) **Infrared radiation of the same intensity is now incident on the same metal surface used in (b).**

Explain why no electrons are emitted from the metal surface.

....

....

....

....[2]

[Total: 11]

Solution:

Infrared photons have **lower energy** than ultraviolet photons because they have a **lower frequency** since($E = hf$). B1

The energy of an infrared photon is **less than the metal's work function**, so no electrons have enough energy to be emitted. B1

[Turn over

7 **Read the passage and answer the questions that follow.**

Zircon ($ZrSiO_4$) crystals found in rocks serve as reliable timekeepers for determining the age of geological formations. These crystals readily incorporate uranium atoms into their crystal lattice during formation but strongly exclude lead. As a result, any lead found in a zircon crystal can be assumed to be the product of radioactive decay, making the crystal an effective record of the time that has passed since it solidified.

Two uranium decay chains are used in zircon dating: uranium-238 (U-238) decaying to lead-206 (Pb-206), and uranium-235 (U-235) decaying to lead-207 (Pb-207). These decay processes follow predictable rates, governed by their half-lives: 4.47 billion years for U-238 and 704 million years for U-235. By measuring the ratio of lead to uranium isotopes in a zircon, geologists can determine its age, and thus the age of the rock in which it was found.

The age of a sample of zircon can be derived from the radioactive decay equation and the measured ratio of the lead to uranium isotopes $\frac{D}{N}$. For each parent isotope, the number of daughter atoms D accumulated over time is given by:

$$D = N_0 - N$$

where N_0 is the initial number of the parent atom and N is the number of remaining parent atoms.

When both decay systems (U-238 to Pb-206 and U-235 to Pb-207) are measured in a single zircon sample, the results can be plotted on a Concordia diagram—a graph of the isotopic ratios $\frac{\text{Pb-206}}{\text{U-238}}$ against $\frac{\text{Pb-207}}{\text{U-235}}$. The curve on this graph, known as the Concordia curve, represents points where both decay systems yield the same age, as shown in Fig. 7.1.

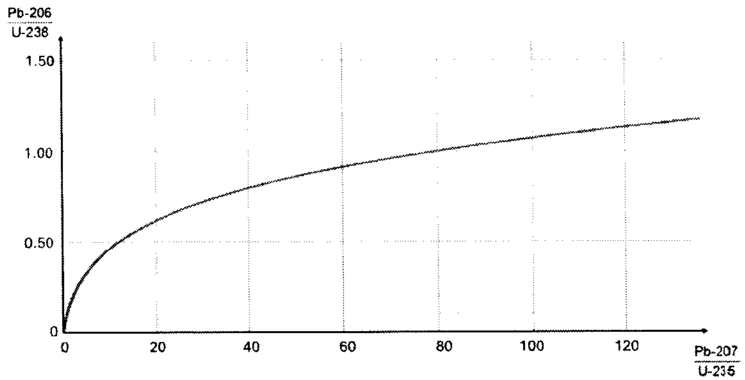


Fig 7.1

A zircon that has remained isolated from chemical changes since its formation will have ratios of isotopes that lie on this curve, and its age can be confidently determined. If the sample has been altered by natural processes, the resulting isotopic ratios will not be on the curve, indicating that further analysis is required.

To determine these isotopic ratios, geologists use a technique called Secondary Ion Mass Spectrometry (SIMS). In SIMS, a focused primary ion beam (typically O^- or Cs^+) bombards the zircon crystal, releasing atoms from its surface. Some of these atoms are ionised, forming secondary ions that include the uranium and lead isotopes of interest. These ions are then accelerated through a potential difference of 10 kV, gaining kinetic energy as they do so.

After acceleration, the ions enter a uniform magnetic field of 0.75 T that is perpendicular to their velocity. The magnetic force causes the ions to move in circular arcs, with their radius determined by their mass-to-charge ratio. The mass spectrometer thus separates the ions by isotope, as ions like $^{206}Pb^+$ and $^{238}U^+$ follow different trajectories and strike the detector at different positions. The relative intensities of the ion signals are used to calculate the isotopic ratios. Fig. 7.2 below shows the path of the ions in a mass spectrometer.

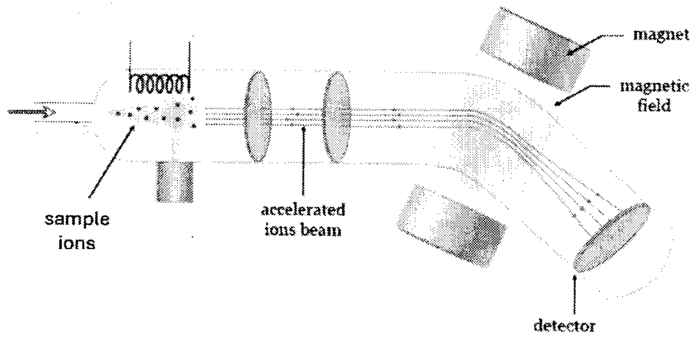


Fig 7.2

SIMS allows highly precise measurement of isotope ratios in microscopic regions within a single zircon grain. By comparing these measured ratios with those expected from known decay rates and plotting the results on the Concordia diagram, geologists can derive robust and accurate age estimates—often within a few million years—even for samples that are over 4 billion years old.

(a) Explain, using the ratio of daughter to parent nuclei, why isotopes with long half-lives are more suitable than those with short half-lives for dating very old geological samples.

....

....

.... [1]

Solution:

Isotopes with shorter half-lives would have decayed almost completely, **leaving too few parent nuclei** (or too high daughter-to-parent ratio) to **measure accurately.** B1

Note: Instruments may not be sensitive enough to detect or count such small quantities precisely. With a very large daughter-to-parent ratio, any small measurement error in the number of remaining parent atoms results in a large error in the calculated age.

[Turn over

(b) Uranium-238 decays into stable lead-206 via a series of alpha and beta decays.

(i) In the first step of the uranium-238 decay chain, a uranium-238 nucleus undergoes alpha decay to form a thorium-234 nucleus and an alpha particle.

The atomic masses of the nuclei involved are:

Mass of uranium-238 nucleus = 238.0508 u
Mass of thorium-234 nucleus = 234.0436 u
Mass of helium-4 nucleus = 4.0026 u

Calculate the energy released in this decay in MeV.

energy released = ... MeV **[4]**

Solution:

Calculating mass defect
Mass defect (Δm) is the difference between the mass of the parent nucleus and the total mass of the decay products.

Δm = mass of uranium-238 − (mass of thorium-234 + mass of helium-4)
Δm = 238.0508 u − (234.0436 u + 4.0026 u) M1
Δm = 0.0046 u = $(0.0046 \times 1.66 \times 10^{-27})$ kg
$\Delta m = 7.6385 \times 10^{-30}$ kg (correct delta m) M1

Calculating energy
$E = \Delta mc^2 = 7.6385 \times 10^{-30} \times (3.00 \times 10^8)^2$ (correct substitution and E value)
$E = 6.8746 \times 10^{-13}$ J M1

1 MeV = 1.602×10^{-13} J

$E = 6.8746 \times 10^{-13} \div 1.602 \times 10^{-13}$
E = 4.29 MeV (converted correctly) A1

(ii) Calculate the total number of alpha and beta decays in the decay chain of uranium-238 ($^{238}_{92}U$) to lead-206 ($^{206}_{82}Pb$).

number of alpha decays = ...

number of beta decays = ... [3]

Solution:

Mass number decreases from 238 to 206: decrease of 32 nucleons — M1

Since each alpha decay reduces the mass number by 4, there must be 8 alpha decays

Atomic number decreases from 92 to 82: decrease of 10 protons — M1

Each alpha decay decreases Z by 2: decrease of 16 protons Since only 10 protons were lost, 6 must have been gained via beta decay

Final solution: **8 alpha decays, 6 beta decays** — A1

(c) (i) **Using the radioactive decay equation and the information in the passage, show that the age of a sample of zircon t with a ratio of daughter to parent isotopes $\frac{D}{N}$ is given by**

$$t = \frac{1}{\lambda}\ln(\frac{D}{N}+1)$$

where λ is the decay constant of the parent isotope.

[2]

Solution:

The number of undecayed parent nuclei after time t is $N = N_0 e^{-\lambda t}$ — M1

Since $D = N_0 - N$, therefore $N_0 = D + N$

Substituting into the first equation: — M1

$N = (D + N)e^{-\lambda t}$

$e^{\lambda t} = \frac{D}{N} + 1$

$\lambda t = \ln(\frac{D}{N}+1)$

$t = \frac{1}{\lambda}\ln(\frac{D}{N}+1)$ — A0

(ii) **In a particular sample of zircon found in Western Australia, the ratio of lead-206 to uranium-238 isotope was found to be 0.978.**

Determine the age of the zircon sample t in years.

t = ... years [2]

Solution:

Decay constant

$$\lambda = \frac{\ln 2}{t_{1/2}} = \frac{0.693}{4.47\times10^{9}} = 1.55\times10^{-10}\ yr^{-1}$$

Using the equation from (c)(ii)

$t = \frac{1}{1.55\times10^{-10}}\ln(0.978+1)$ — M1

$t = 4.41\times10^{9}$ years — A1

(iii) **The ratio of lead-207 to uranium-235 ratio for the same sample was measured to be 76.0. Using the Concordia diagram (Fig 7.1), determine whether the two ratios agree on the age of this zircon sample.**

....

....

			.... [2]	
			Solution: **The point (76.0, 0.978) lies on the Concordia curve.** Therefore, **the two ratios agree** on the age of the zircon sample.	M1 A1
		(iv)	**Natural processes may change the number of lead or uranium nuclei in a sample. Suggest what changes may have occurred to the number of nuclei in a certain sample for it to have a data point that lies below the Concordia curve.** .... [1]	
			Solution: It suggests **a loss of lead isotopes** after their formation in the decay process. OR **Reintroduction of new uranium isotopes** into the zircon lattice.	B1 B1
	(d)	**(i)**	**The ions from a zircon crystal in a SIMS device are accelerated through a potential difference of *V* before entering a uniform magnetic field of magnetic flux density *B* where they move in a circular arc of radius *r*.** **Show that the mass to charge ratio of the ions $\frac{m}{q}$ is given by** $$\frac{m}{q} = \frac{B^2r^2}{2V}$$ [3]	
			Solutions: The kinetic energy gained by the ions come from the electric potential energy change due to the p.d. $qV = \frac{1}{2}mv^2$ The centripetal force of the circular arc is provided by the magnetic force:	 M1

			$\frac{mv^2}{r} = Bqv$ $v = \frac{Bqr}{m}$ Combining the two equations and rearranging for the mass to charge ratio: $qV = \frac{1}{2}m\left(\frac{Bqr}{m}\right)^2 = \frac{q^2B^2r^2}{2m}$ $\frac{m}{q} = \frac{B^2r^2}{2V}$	M1 M1 A0
		(ii)	**For the SIMS described in the passage, determine the expected arc radius *r* for a singly charged $^{206}Pb^+$ ion.** **The mass of a $^{206}Pb^+$ ion is 205.974 u.** *r* = ... m	[2]
			Solution: $r = \sqrt{\frac{2Vm}{qB^2}}$ $r = \sqrt{\frac{2 \times 1.00 \times 10^4 \times 205.974 \times 1.66 \times 10^{-27}}{1.60 \times 10^{-19} \times 0.75^2}}$ $r = 0.276$ m	 M1 A1
		(iii)	**State and explain whether the arc radius of the singly charged $^{238}U^+$ ion will be larger or smaller than that of the lead ion from (d)(ii).** .... [2]	
			[Total: 22 marks]	
			Solution: All other variables being constant, **the mass is proportionate to the square of the radius**. (must include relationship between variables) **Therefore, the radius will be larger** for the heavier uranium ion.	 M1 A1

END OF PAPER

Catholic Junior College

JC2 Preliminary Examinations
Higher 2

CANDIDATE NAME	MARK SCHEME
CLASS	2T

PHYSICS — 9749/03

Paper 3 Longer Structured Questions

September 2025
2 hours

Candidates answer on the Question Paper.

READ THESE INSTRUCTIONS FIRST

Write your name and class in the spaces at the top of this page.
Write in dark blue or black pen on both sides of the paper.
You may use an HB pencil for any diagrams, graphs or rough working.
Do not use staples, paper clips, glue or correction fluid.

The use of an approved scientific calculator is expected, where appropriate.
Answer **all** questions.

Section A
Answer **all** questions.

Section B
Answer **one** question only.

You are advised to spend one and a half hours on Section A and half an hour on Section B.

The number of marks is given in brackets [ ] at the end of each question or part question.

FOR EXAMINER'S USE	
SECTION A	
Q1	/ 8
Q2	/ 8
Q3	/ 11
Q4	/ 6
Q5	/ 10
Q6	/ 7
Q7	/ 10
SECTION B	
Q8	/ 20
Q9	/ 20
PAPER 3	/ 80
PAPER 2	/ 80
PAPER 1	/ 30
PAPER 4	/ 55
TOTAL (WEIGHTED)	%

This document consists of **32** printed pages and **0** blank page.

[Turn over

DATA

speed of light in free space	c	$= 3.00 \times 10^{8}$ m s^{-1}
permeability of free space	μ_0	$= 4\pi \times 10^{-7}$ H m^{-1}
permittivity of free space	ε_0	$= 8.85 \times 10^{-12}$ F m^{-1}
		$(1/(36\pi)) \times 10^{-9}$ F m^{-1}
elementary charge	e	$= 1.60 \times 10^{-19}$ C
the Planck constant	h	$= 6.63 \times 10^{-34}$ J s
unified atomic mass constant	u	$= 1.66 \times 10^{-27}$ kg
rest mass of electron	m_e	$= 9.11 \times 10^{-31}$ kg
rest mass of proton	m_p	$= 1.67 \times 10^{-27}$ kg
molar gas constant	R	$= 8.31$ J K^{-1} mol^{-1}
the Avogadro constant	N_A	$= 6.02 \times 10^{23}$ mol^{-1}
the Boltzmann constant	k	$= 1.38 \times 10^{-23}$ mol^{-1}
gravitational constant	G	$= 6.67 \times 10^{-11}$ N m^{2} kg^{-2}
acceleration of free fall	g	$= 9.81$ m s^{-2}

FORMULAE

uniformly accelerated motion	$s = ut + \frac{1}{2}at^2$ $v^2 = u^2 + 2as$
work done on / by a gas	$W = p\Delta V$
hydrostatic pressure	$p = \rho gh$
gravitational potential	$\phi = -\frac{Gm}{r}$
temperature	$T/K = T/^\circ C + 273.15$
pressure of an ideal gas	$p = \frac{1}{3}\frac{Nm}{V}\langle c^2\rangle$
mean translational kinetic energy of an ideal gas molecule	$E = \frac{3}{2}kT$
displacement of particle in s.h.m.	$x = x_0 \sin \omega t$
velocity of particle in s.h.m.	$v = v_0 \cos \omega t$ $= \pm\omega\sqrt{x_0^2 - x^2}$
electric current	$I = Anvq$
resistors in series	$R = R_1 + R_2 + \ldots$
resistors in parallel	$1/R = 1/R_1 + 1/R_2 + \ldots$
electric potential	$V = \frac{Q}{4\pi\varepsilon_0 r}$
alternating current / voltage	$x = x_0 \sin \omega t$
magnetic flux density due to a long straight wire	$B = \frac{\mu_0 I}{2\pi d}$
magnetic flux density due to a flat circular coil	$B = \frac{\mu_0 NI}{2r}$
magnetic flux density due to a long solenoid	$B = \mu_0 nI$
radioactive decay	$x = x_0 \exp(-\lambda t)$
decay constant	$\lambda = \frac{\ln 2}{t_{\frac{1}{2}}}$

[Turn over

Section A

Answer **all** questions in the spaces provided.

1 A solid iron sphere of density 8000 kgm^{-3} and volume 4.50 × 10^{-4} m^3 is completely submerged in a liquid of density 800 kgm^{-3}. The iron sphere is resting on a spring, as shown in Fig. 1.1. The spring is compressed by 10.2 cm.

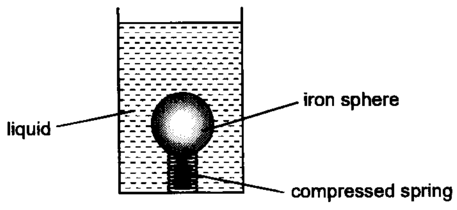


Fig. 1.1

(a) Show that the upthrust on the iron sphere is 3.53 N. **[1]**

Solution

Upthrust

$= \rho Vg$

$= 800(4.50\times10^{-4})(9.81)$ M1

$= 3.5316$ N

$= 3.53$ N (Shown) A0

(b) Hence, calculate the force constant of the spring.

force constant = ... N m^{-1} **[2]**

Solution

At equilibrium, considering forces on the iron sphere

$kx + U = mg$

$k = \frac{mg - U}{x} = \frac{8000(4.50\times10^{-4})(9.81) - 3.5316}{0.102}$ M1

$= 312$ N m^{-1} A1

(c) A string of breaking strength 32.0 N is used to lift the iron sphere vertically upwards, as shown in Fig. 1.2. The iron sphere is then lifted partially out of the liquid as shown in Fig. 1.3.

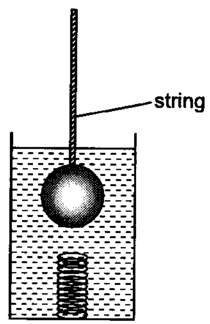


Fig. 1.2

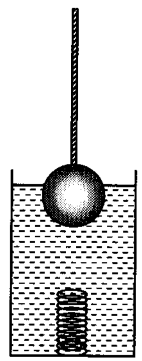


Fig. 1.3

(i) Explain why the string breaks as the sphere emerges from the liquid.

....

....

....

.... [2]

Solution
When the sphere is lifted out of the liquid, the volume of liquid displaced is reduced. This causes the upthrust acting on sphere to decrease. B1

To maintain equilibrium, the tension will increase and the string breaks when the tension exceeds the maximum allowable value. B1

(ii) Calculate the volume of the fluid displaced at the instant when the string breaks.

volume = ... m^3 [3]

Solution
At breaking point,
$T + U = mg$ C1
$32.0 + 800(V)(9.81) = 8000(4.50 \times 10^{-4})(9.81)$ M1
$V = 4.23 \times 10^{-4}$ m^3 A1

[Total: 8]

[Turn over

2 (a) A satellite S of mass m is in a stable circular orbit at an altitude of $2R$ above the surface of a planet of mass M and radius R, as shown in Fig. 2.1.

Assume the planet has no atmosphere and that all its mass is concentrated at its centre.

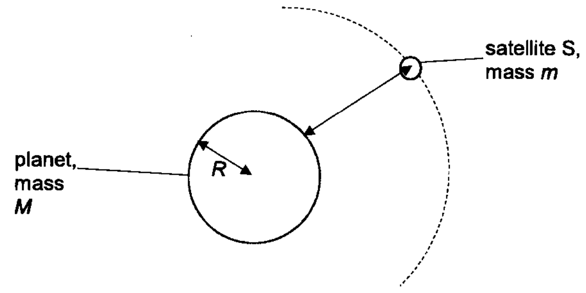


Fig. 2.1

(a) Show that the kinetic energy E_k of the satellite S in orbit is given by the expression:

$$E_k = \frac{GMm}{6R}$$

where G is the gravitational constant.

[2]

Solution:

The gravitational force provides the centripetal force.

$F_G = F_C$

$\frac{GMm}{(3R)^2} = \frac{mv^2}{3R}$ B1

$v^2 = \frac{(3R)Mm}{(3R)^2 m} = \frac{GM}{3R}$

$KE = \frac{1}{2}mv^2 = \frac{1}{2}m\frac{GM}{3R}$ B1

$= \frac{GMm}{6R}$

(b) **The planet has mass 4.5 × 10²⁴ kg and radius of 5.5 × 10³ km. The satellite has a mass of 1500 kg.**

Determine the total energy of satellite S in orbit.

total energy = ... J [2]

Solution:

Total energy = $-\frac{GMm}{2r}$ where r is the orbital radius and is equal to 3R for this Q

$= \frac{(6.67 \times 10^{-11})(4.5 \times 10^{24})1500}{2 \times 3(5.5 \times 10^{3} \times 10^{3})}$ M1

$= -1.36 \times 10^{10}$ J (negative sign to be included) A1

If students equate E_K to E_T, there must be some derivation shown to get M1 marks.

(c) **A second satellite P is launched into orbits from the surface of the same planet with an initial kinetic energy of 2.0 × 10¹⁰ J. It rises to a distance of 4R from the centre of the planet.**

On the axes provided in Fig 2.2, sketch a graph to show how the satellite's orbital kinetic energy varies with distance from the centre of the planet as it moves from R to 4R.

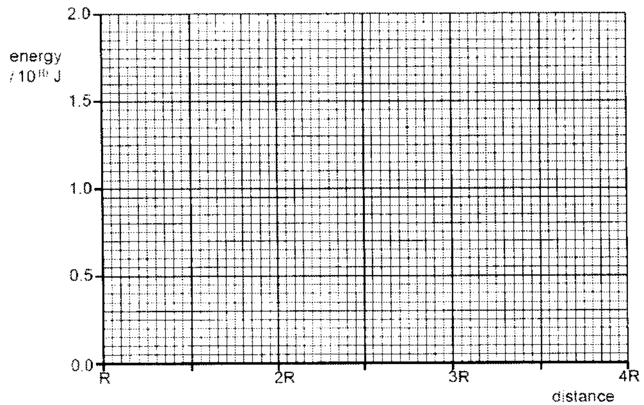
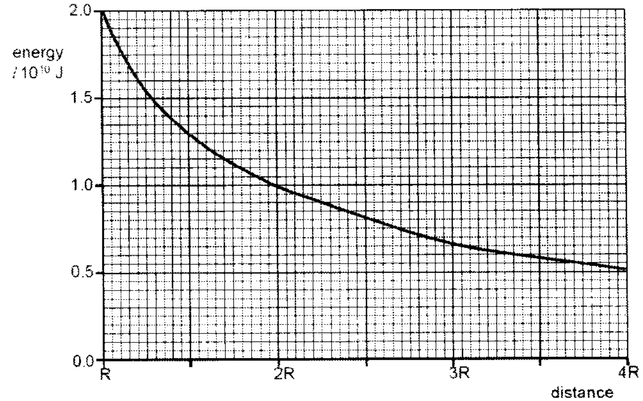


Fig 2.2

[2]

[Turn over

Solution:



B1 – Shape of graph:
- Smooth curve decreasing with increasing r (concave upwards)

1 mark – Correct key points labelled or plotted:
- Correctly labels or plots the following values:

Since $E_k \alpha \frac{1}{r}$

r	E_K / 10^{10} J
R	+2.0
2R	+1.0
3R	+0.67
4R	+0.5

(d) **A third satellite Q is to be launched vertically from the surface of the same planet. Determine the minimum speed that satellite Q must be given at the surface to escape the planet's gravitational field.**

minimum speed = ... m s⁻¹ [2]

Solution:

By conservation of energy,
Energy of satellite Q at the surface of the planet = energy of satellite Q at infinity

$$\frac{1}{2}mv^2+\left(\frac{-GMm}{r}\right)=0$$ M1

$$v=\sqrt{\frac{2GM}{r}}=\sqrt{\frac{2(6.67\times10^{-11})(4.5\times10^{24})}{5.5\times10^{3}\times10^{3}}}$$

$v = 1.04 \times 10^4$ m s^{-1} A1

[Total: 8]

[Turn over

3 **A student sets up the apparatus illustrated in Fig. 3.1 in order to observe two-source interference fringes. The double slit with slit separation 0.800 mm, situated 2.50 m from the screen, is illuminated with coherent red light of wavelength 690 nm. Fringes are observed on the screen.**

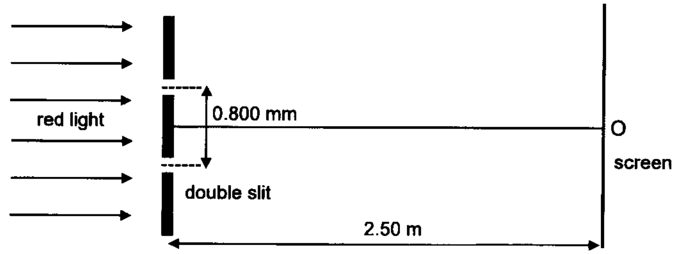


Fig. 3.1

(a) **State two conditions necessary for two source interference fringes to be observed.**

....

....

....

.... [2]

Solution
Waves must be of the same nature and must overlap. B1
Sources must be coherent, i.e. the phase difference between them remains constant. B1
Amplitudes of the two waves must be approximately equal.
For transverse waves, they must be either unpolarized or, if polarized, polarized in the same direction.

(b) **Explain why a maxima is always observed at Point O.**

....

....

....

.... [2]

Solution
The two sources are in phase and there is no path difference of the waves at Point O as it is equidistant from the two sources. B1

Therefore, constructive interference must occur as the two waves are in phase with each other at point O, giving rise to a maxima at point O. B1

(c) **Calculate the distance from O to the second minima observed on the screen.**

separation = ... m [3]

Solution

$x = \frac{\lambda D}{a}$

$= \frac{(690\times10^{-9})(2.50)}{0.800\times10^{-3}}$ M1

$= 2.15625 \times 10^{-3}$ m

Distance from O to the second minima observed on the screen

$= 1.5x$

$= 1.5 \times (2.15625 \times 10^{-3})$ M1

$= 3.23 \times 10^{-3}$ m A1

(d) **Describe the changes, if any, that occur in the separation of the fringes and the difference in the brightness between bright and dark fringes observed on the screen, when each of the following changes is made separately.**

(i) **increasing the intensity of the red light incident on the double slit,**

....

....

....

.... [2]

Solution

There is no change in the spacing. B1

The maxima is brighter and thus the difference in the brightness is higher. B1

(ii) **increasing the distance between the double slit and the screen.**

....

....

....

.... [2]

Solution

Since D is larger, x will be larger. The separation of the fringes will increase. B1

The maxima is dimmer/ less intense/ less bright due to the longer distance travelled by the waves. Thus, the difference in the brightness is lower. B1

[Total: 11]

4 A 3.00 g copper coin at 20.0 °C drops 50.0 m to the ground.

(a) **The copper is said to possess internal energy.**

Explain what is meant by the internal energy.

....

....

....

.... [2]

Solution

The internal energy of a system is the sum of its kinetic energy due to the random motion of its molecules and potential energy due to intermolecular forces of attraction. B1 B1

(b) **The coin does not undergo a change in volume after it landed on the ground.**

Determine the gain in temperature of the coin given that the specific heat capacity of copper is 385 $Jkg^{-1}K^{-1}$. Assuming that 10.0 % of the change in gravitational potential energy of the coin goes to increasing the internal energy of the coin.

gain in temperature = ... K [2]

Solution

By principle of conservation of energy, decrease in G.P.E. → increase in internal energy

$0.10mg\Delta h = mc\Delta\theta$

$\Delta\theta = \frac{0.10mg\Delta h}{mc} = \frac{0.10(9.81)(50.0)}{385}$ M1

$= 0.13$ K A1

(c) **The first law of thermodynamics for a system can be expressed as**

$$\Delta U = q + w$$

where ΔU is the increase in internal energy of the system, q is the heat supplied to the system and w is the work done on the system.

Use the words positive, negative and zero to complete Table 4.1 for the three terms in the equation for each of the processes shown. You may use each word once, more than once, or not at all.

Process	ΔU	q	w
Copper coin drops and lands on the ground			

Table 4.1

[2]

Solution
ΔU: positive
q: positive (B1 for both delta U and q) B1
w: zero – B1 one mark here B1

As the coin's temperature rises, its average molecular kinetic energy increases. Thus, the increase in internal energy of the system ΔU is positive.
As the coin does not undergo any change in volume, the work done on the system w is zero.
By the First Law, since ΔU is positive and $w = 0$, the heat supplied to the system q must be positive.

[Total: 6]

5 (a) State Faraday's law of electromagnetic induction.

....

....

.... [2]

Faraday's law of electromagnetic induction states that the magnitude of the induced e.m.f. in a conductor **[B1]** is directly proportional to the rate of change of magnetic flux linkage **[B1]** of the conductor.

(b) Two coils of insulated wire are wound on an iron bar, as shown in Fig. 5.1.

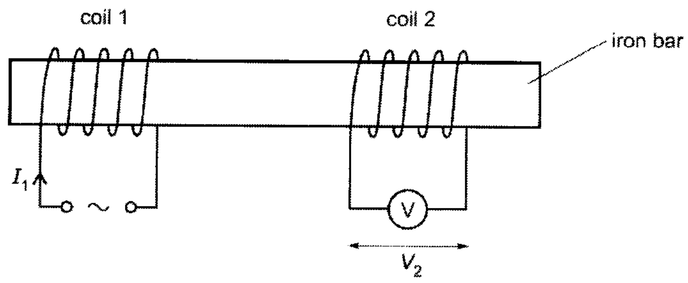


Fig. 5.1

[Turn over

There is a current I_1 in coil 1 that varies with time t as shown in Fig. 5.2.

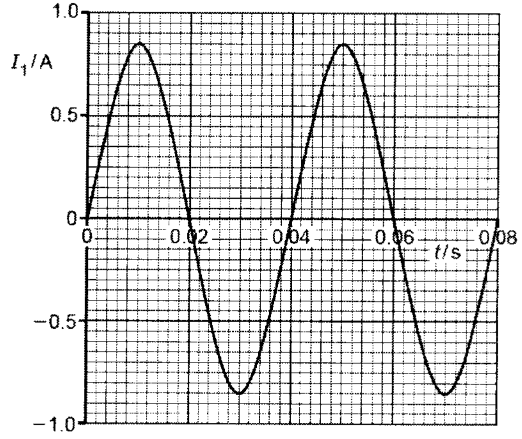


Fig. 5.2

(i) The variation with t of I_1 can be represented by the equation

$$I_1 = A \sin B(t)$$

where A and B are constants.

Use Fig. 5.2 to determine the values of A and B. Give units to your answers.

A = ... unit ....

B = ... unit .... [2]

From Fig. 5.2, $A = 0.85$ A **[A1]**

$B = 2\pi / T = 2\pi / 0.040$
$= 160$ (or 157) rad s^{-1} **[A1]**

(* Answers must include appropriate units)

(ii) **The current in coil 1 gives rise to a magnetic field with a flux density that is proportional to I_1.**

An electromotive force (e.m.f.) is induced across coil 2. The potential difference (p.d.) across coil 2 is measured using a voltmeter that gives a root-mean-square (r.m.s.) value of 4.6 V.

On Fig. 5.3, sketch a graph to show the variation with *t* of V_2 between *t* = 0 and *t* = 0.08 s.

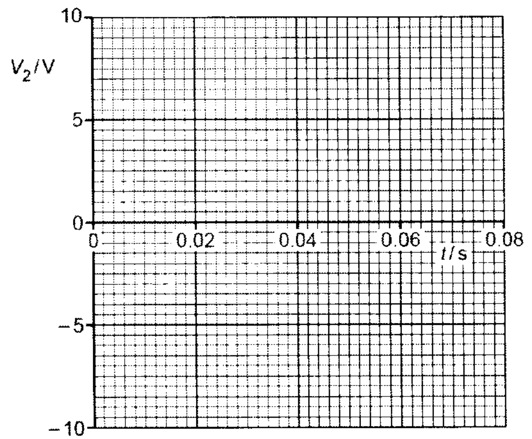


Fig. 5.3

[3]

[B1] – 2 cycles of a negative cosine graph (starting at (0, - 6.5)) with a

[B1] – Minimum e.m.f of zero at t = 0.01, 0.03, 0.05 and 0.07 s
- Maximum (magnitude) e.m.f. at t = 0, 0.02, 0.04, 0.06 and 0.08 s.
- period of 0.040 s.

[B1] - $V_0 = \sqrt{2}(4.6)$ = +/- 6.5 V at peak e.m.f. times.

(iii) **Use the laws of electromagnetic induction to explain the shape of your graph in (b)(ii).**

....

....

....

....

.... [3]

According to Faraday's law,
- Magnitude of V_2 is proportional to gradient of the $I_1 - t$ graph (Fig. 5.2)
- V_2 has maximum magnitude when gradient of the $I_1 - t$ graph is the steepest.

[Turn over

- V_2 is zero when $I_1 - t$ graph is horizontal momentarily at its peak and minimum points.

2 x [B1] – Any 2 points above, 1 mark each

According to Lenz's law,
- The induced e.m.f produces effects that opposes the magnetic flux linkage that causes it.
- Hence, V_2 changes sign when the sign of the gradient of the $I_1 - t$ graph changes.

[B1] – 2nd point above

[Total: 10]

6 A sinusoidal voltage supply of peak voltage 8 V and period of 1.2 s is connected to a circuit as shown in Fig. 6.1. The circuit consists of four resistors P, Q, R and S, which has a resistance of 10 Ω each.

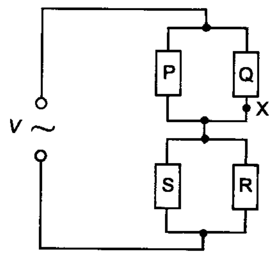


Fig. 6.1

(a) Calculate the maximum potential difference across resistor P.

potential difference = ... V [3]

Solution

Total resistance = $\left(\frac{1}{10}+\frac{1}{10}\right)^{-1}+\left(\frac{1}{10}+\frac{1}{10}\right)^{-1}=10\ \Omega$ C1

Using potential divider principle,

Maximum potential difference across P = $\frac{5}{10}(8)$ M1

= 4 V A1

(b) Determine the peak power dissipated across resistor P.

peak power = ... W [2]

Solution

Peak power = $\frac{V_o^2}{R_p}=\frac{4^2}{10}$ (ecf allowed) M1

= 1.6 W A1

[Turn over

(c) An ideal diode is connected in series with resistor Q at point X.

On Fig. 6.2, sketch the variation with t of the p.d. across resistor Q for a time of 1.2 s. Add a scale to the y-axis.

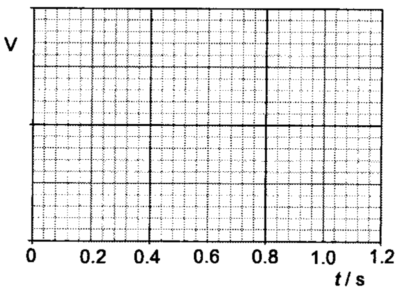
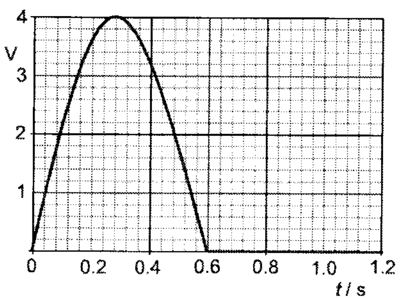


Fig. 6.2

[2]

Solution



Correct shape of graph. (accept cosine) B1
Correct labelling of graph. B1

[Total: 7]

7 (a) In the Rutherford α-particle scattering experiment, α-particles are emitted from a source and travel towards a thin gold foil.

(i) An α-particle is deflected through an angle of approximately 45° as it passes near a stationary gold nucleus. On Fig. 7.1, sketch the path of the α-particle as it passes the gold nucleus.

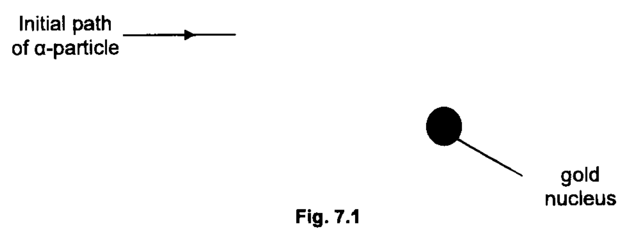
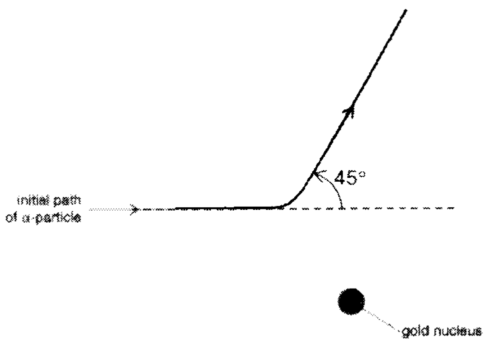


Fig. 7.1

[1]

Solution:



Marking points: (B1 - both have to be present)
- Deflect away from the nucleus, since like charges repel.
- Deviation through 45°.

(ii) Only a small proportion of the α-particles incident on the metal foil are deflected through large angle deflections greater than 90°. Explain the following phenomenon.

....

....

....

[Turn over

....

....[2]

Solution:

The atom contains a **small, positively charged nucleus** that is **very small compared to the overall size of the atom**, so only a **small proportion of alpha particles** come close enough to it. B1

These alpha particles experience **strong electrostatic repulsion**, which can cause deflections greater than 90° since **alpha particles are also positively charged**. B1

(ii) In the α-particle scattering experiment, a large number of alpha particles are directed at the metal foil.

Explain why a large number of alpha particles is necessary.

....

....

....

....[2]

Solution:

Large angle deflections are rare / occur for only a small proportion of alpha particles. B1

A large number ensures that enough deflections are observed to draw reliable conclusions / obtain statistically significant results. B1

(b) An α-particle with kinetic energy 7.7×10^{-13} J is directed at a stationary gold nucleus ($^{197}_{79}Au$). Determine the minimum separation possible between this α-particle and the gold nucleus.

separation = ... m [3]

Solution:

Given:
- Charge of α-particle: $Q_1 = 2e = 2 \times 1.60 \times 10^{-19}$ C
- Charge of gold nucleus: $Q_2 = 79e = 79 \times 1.60 \times 10^{-19}$ C

At the start of the alpha particle's motion, when it is far away from the nucleus, the electric potential energy is taken to be zero.

By conservation of energy,
Gain in EPE = loss in KE

$$\frac{Q_1Q_2}{4\pi\varepsilon_0 r} = E_k$$

$$r = \frac{Q_1Q_2}{4\pi\varepsilon_0 E_k} = \frac{(2 \times 1.60 \times 10^{-19}) \times (79 \times 1.60 \times 10^{-19})}{4\pi(8.85\times10^{-12})7.7 \times 10^{-13}}$$ B1

[correct substitution] M1

$$r = 4.7 \times 10^{-14}\ m$$ A1

(c) **The metal foil is changed from gold ($^{197}_{79}Au$) to carbon ($^{12}_{6}C$), while the α-particle energy is kept the same.**

State and explain how the number of large-angle deflections would change.

....

....

....

....[2]

Solution:

As carbon nuclei have a smaller positive charge (atomic number 6) compared to gold (atomic number 79), the electrostatic repulsion between the α-particle and the carbon nucleus is weaker. M1

As a result, fewer α-particles are deflected through large angles, so the number of large-angle deflections decreases. A1

[Total: 10]

[Turn over

Section B

Answer **one** question from this Section in the spaces provided.

8 **(a)** Define *simple harmonic motion*

....

....

.... [2]

Simple harmonic motion is a periodic motion in which the **acceleration is proportional to the displacement from the equilibrium position** B1

And **directed towards the equilibrium position** OR **in the opposite direction to the displacement.** B1

(b) **Fig. 8.1** shows the force–extension graph for a light spring.

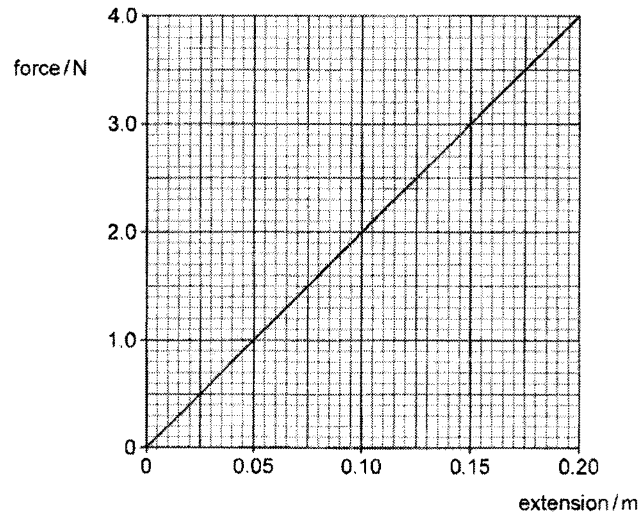


Fig 8.1

The spring described by Fig. 8.1 is attached to a fixed point on the ceiling and a mass of 2.0 N is hung on the spring.

Once the mass reaches its equilibrium position, it is displaced a further 0.15 m downward and released, such that it oscillates with simple harmonic motion.

(i) Determine the force constant *k* of the spring.

k = ... N m^{-1} [2]

Solution:

$k = \frac{F}{x} = \frac{4.0\text{N}}{0.20\text{m}}$ **M1**

$k = 20.0 \text{ N m}^{-1}$ **A1**

(ii) Show that the maximum acceleration of the mass when it is oscillating in simple harmonic motion is 14.7 m s^{-2}.

[3]

Solution:

At amplitude position

$F_{net} = kx - mg$ [*mark for setting up F_{net} correctly*]

$F_{net} = (20.0)(0.10 + 0.15) - 2.0$ **M1**

$F_{net} = 3.0\ N$ [*mark for the correct value*] **C1**

$ma = 3.0\ N$

$\frac{2.0}{9.81}a = 3.0$ [*mark for correct substitution in ma*] **M1**

$a = 14.7 m\ s^{-2}$ **A0**

(iii) Hence, determine the period of the oscillation.

[Turn over

period = ... s [3]

Solution:

using $\boldsymbol{a} = -\omega^2 x$ **M1**

$a_0 = -\omega^2 x_0$

$-14.7 = -\omega^2 (0.15)$

$\omega^2 = \frac{14.7}{0.15} = 98$

$\omega = 9.90 \text{ rad s}^{-1} = \frac{2\pi}{T}$ **M1**

$T = 0.63$ s **A1**

(c) On Fig. 8.2, sketch the variations with time of the displacement *x*, the velocity *v* and the acceleration *a* of the object for two complete oscillations, starting at *t* = 0. Take upwards as positive.

Include an appropriate scale on the axes.

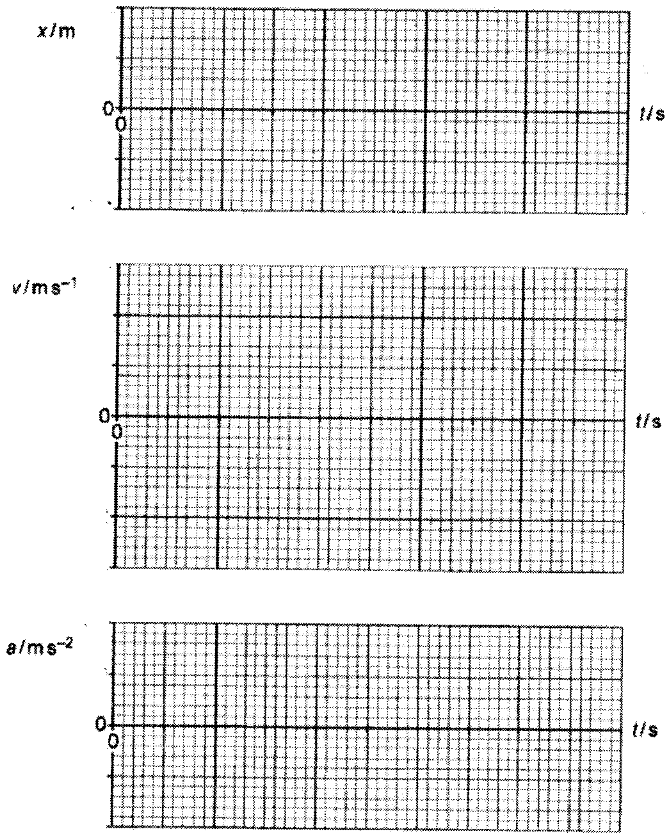
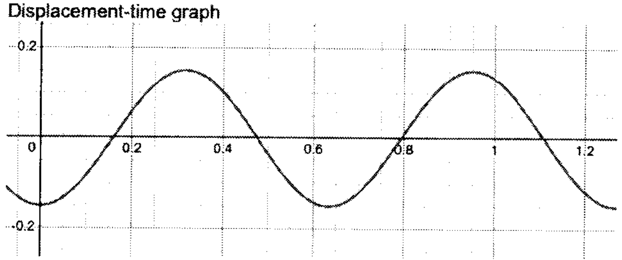


Fig. 8.2

[6]

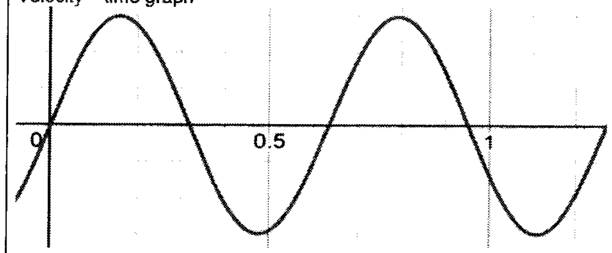
Solution:

Displacement-time graph



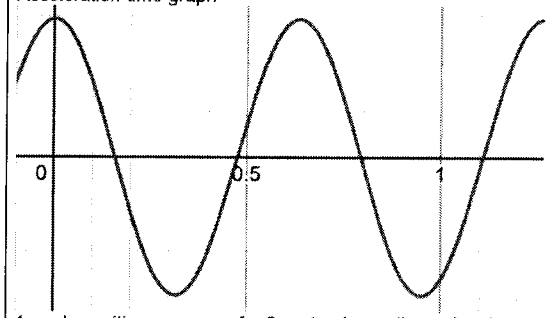
1 mark: negative cos curve for 2 cycles (regardless of period value) **B1**
1 mark: amplitude = 0.15 m (ecf), period = 0.63 s (ecf) **B1**

Velocity – time graph



1 mark: positive sin curve for 2 cycles (regardless of period value) **B1**
1 mark: max v = 1.5 m s^{-1}(from $v_0 = \omega x_0 = \frac{2\pi}{0.63} \times 0.15$), period = 0.63 s **B1**
(ecf if wrong value but same as x-t graph)

Acceleration-time graph



1 mark: positive cos curve for 2 cycles (regardless of period value) **B1**
1 mark: max a = 14.7 m s^{-2}, period = 0.63 s (ecf if wrong value but same as x-t graph) **B1**

(d) **A second, identical spring is attached in parallel to the first spring as shown in Fig. 8.3.**

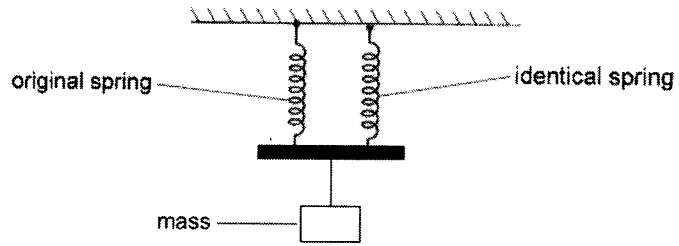


Fig. 8.3

(i) **State and explain how the extension of the spring system compares with that of the original single spring when the same 2.0 N mass is suspended from it.**

....

....

.... [2]

Solution:

Effective spring constant **doubles** for springs in parallel **M1**

Extension is **halved** **A1**

(ii) **The mass is again displaced by 0.15 m and released to oscillate.**

State and explain how the period of oscillation of the new system compares with the period found in (b)(iii).

....

....

....

....

.... [2]

Solution:

Higher k means **resultant force is higher**, **acceleration is higher** and **angular frequency is higher**. **M1**

Hence, **period decreases**. **A1**

[Total: 20]

9 (a) **Two point charges A and B are placed in a vacuum 10.0 cm apart, as illustrated in Fig. 9.1. A point P lies on the line joining the charges, at a distance *x* from charge A. The variation of electric field strength *E* with distance *x* is shown in Fig. 9.2.**

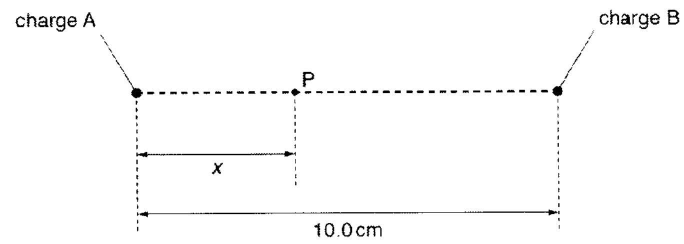


Fig. 9.1

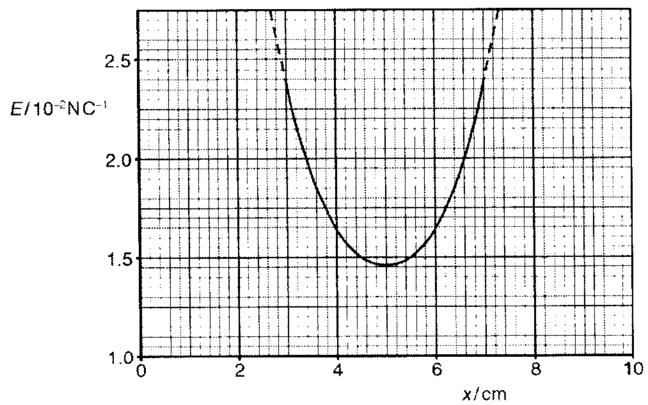


Fig. 9.2

State and explain whether the charges A and B:

(i) **have the same, or opposite, signs.**

....

....

....[2]

Solution:

The electric field **does not change direction/ always positive / field strength does not become zero** along the line between the charges. M1

The charges have **opposite signs**. A1

(ii) **State and explain whether the charges A and B have the same, or different, magnitudes.**

....

....

....[2]

Solution:

The electric field strength is **minimum at the midpoint** between the charges. (accept: graph is symmetric about the midpoint, not accepting parabola) — M1

This implies that both charges produce electric fields of **equal magnitude** at that point, so the charges must have the **same magnitude**. — A1

(b) **An electron is situated at point P.**

Without calculation, state and explain the variation in the magnitude of the acceleration of the electron as it moves from the position where *x* = 3.0 cm to the position where *x* = 7.0 cm.

....

....

....

....

....

....[4]

Solution:

Acceleration is proportional to electric field strength, (use F = qE and F = ma → a ∝ E) — B1

From x = 3.0 cm to x = 5.0 cm: Electric field strength decreases → acceleration decreases. — B1

At x = 5.0 cm: Electric field strength is minimum → acceleration is minimum — B1

From x = 5.0 cm to x = 7.0 cm: Electric field strength increases → acceleration increases. — B1

(c) **Determine the acceleration of the electron at *x* = 7.0 cm.**

acceleration = ... m s^{-2} [3]

Solution:

Read off the value of E from the graph at *x* = 7.0 cm
E = 2.4 × 10^{-2} N C^{-1} (accept 2.35) — B1

Using Newton's Second Law:
F = qE and F = ma ⇒ $a = \frac{Eq}{m}$
$a = \frac{2.4 \times 10^{-2} \times 1.60 \times 10^{-19}}{9.11 \times 10^{-31}}$ — M1

a = 4.21 × 10^{8} m s^{-2} — A1

(d) **A particle of charge +*q* and mass *m* is travelling with a constant speed of 1.6 × 10^5 m s^{-1} in a vacuum. The particle enters a uniform magnetic field of flux density 9.7 × 10^{-2} T, as shown in Fig. 9.3.**

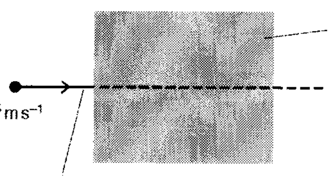


Fig. 9.3

The magnetic field direction is perpendicular to the initial velocity of the particle and perpendicular to, and out of, the plane of the paper.

A uniform electric field is applied in the same region as the magnetic field so that the particle passes undeviated through the fields.

(i) **State and explain the direction of the electric field.**

....

....

....[2]

Solution:

The **magnetic field exerts a downward force** on the positively charged particle (using Fleming's left-hand rule). To prevent deflection, the **electric field must exert an equal force in the opposite direction/ upwards.** — M1

Therefore, the electric field is directed **up the page** (same direction as electric force on a positive charge). A1

(ii) **The electric field is now removed so that the positively charged particle follows a curved path in the magnetic field. This path is an arc of a circle of radius 4.0 cm.**

Calculate, for the particle, the ratio $\frac{q}{m}$.

ratio = ...C kg^{-1} [2]

Solution

Magnetic force provides the centripetal force.

$$\frac{mv^2}{r} = Bqv$$

$$\frac{q}{m} = \frac{v}{Br}$$

$$\frac{q}{m} = \frac{(1.6 \times 10^5)}{[(9.7 \times 10^{-2})(4.0 \times 10^{-2})]}$$ M1

$$= 4.1 \times 10^7 \text{ C kg}^{-1}$$ A1

(iii) **Determine the time taken for the particle to complete one full circle.**

time taken = ... s [2]

Solution:

$$T = \frac{2\pi r}{v} = \frac{2\pi(0.040)}{1.6 \times 10^5}$$ M1

$T = 1.57 \times 10^{-6}$ s A1

[Turn over

(e) **With the electric field still switched off, a proton enters the same uniform magnetic field, but at an angle of 30° to the magnetic field lines as shown in Fig. 9.4.**

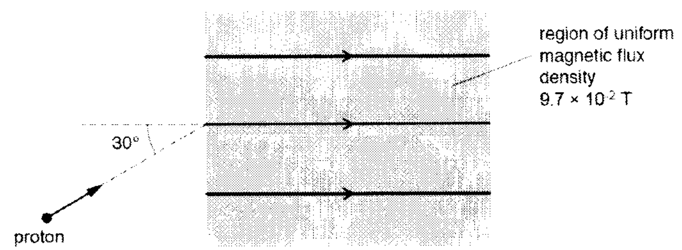


Fig. 9.4.

(i) **Describe the resultant path of the proton in the magnetic field.**

....

....[1]

Solution:

It follows a helical path. It is a helix. B1

(ii) **Determine the speed of the proton if it experiences a magnetic force of 4.7×10^{-15} N.**

speed = ... m s^{-1} [2]

Solution:

Magnetic force provides the centripetal force

$Bqv\sin\theta = 4.7 \times 10^{-15}$

$$v = \frac{F}{Bq\sin\theta} = \frac{4.7 \times 10^{-15}}{9.7 \times 10^{-2}(1.6 \times 10^{-19})\sin 30}$$ M1

$v = 6.0 \times 10^5$ m s^{-1} A1

END OF PAPER