NANYANG JUNIOR COLLEGE
JC 2 PRELIMINARY EXAMINATION
Higher 2

CANDIDATE NAME			
CLASS		TUTOR'S NAME	
CENTRE NUMBER	S	INDEX NUMBER	

PHYSICS 9749/03

Paper 3 Longer Structured Questions

19 September 2022

2 hours

Candidates answer on the Question Paper.

No Additional Materials are required.

READ THESE INSTRUCTIONS FIRST

Write your name, class, Centre number and index number 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 a 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.

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.

At the end of the examination, fasten all your work securely together.
The number of marks is given in brackets [ ] at the end of each question or part question.

For Examiner's Use	
Section A	
1	**/ 8**
2	**/ 12**
3	**/ 8**
4	**/ 9**
5	**/ 6**
6	**/ 9**
7	**/ 8**
Section B	
8	**/ 20**
9	**/ 20**
Total	**/ 80**

This document consists of **24** printed pages.

Data

speed of light in free space	$c = 3.00 \times 10^{8}$ m s^{-1}
permeability of free space	$\mu_0 = 4\pi \times 10^{-7}$ H m^{-1}
permittivity of free space	$\varepsilon_0 = 8.85 \times 10^{-12}$ 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	$k = 1.38 \times 10^{-23}$ J K^{-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	$\phi = -Gm / r$
temperature	$T / \text{K} = T / {}^\circ\text{C} + 273.15$
pressure of an ideal gas	$p = \frac{1}{3}\frac{Nm}{V} < c^2 >$
mean translational kinetic energy of an ideal 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	$\lambda = \frac{\ln 2}{t_{\frac{1}{2}}}$

Section A

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

1 Fig. 1.1 shows a man standing on a stationary sailboard floating in the sea. The sailboard consists of a surfing board, mast and sail.

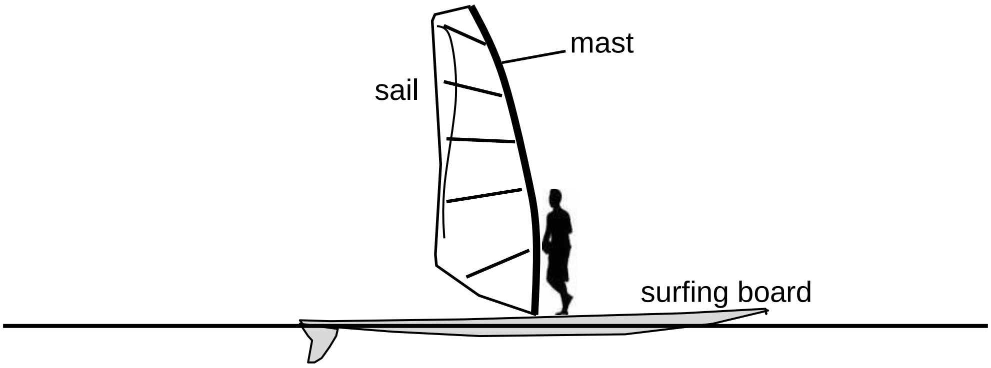


Fig. 1.1

(a) The total mass of the sailboard and the man is 90 kg. Taking the density of seawater to be 1020 kg m^{-3}, calculate the volume of seawater displaced by the sailboard.

$$\Sigma F = 0$$

$$U - mg = 0$$

$$V\rho g = mg$$

$$V = \frac{90}{(1020)} = 0.088 \text{ m}^3$$

volume of seawater displaced = ... m^3 [2]

Comments: A significant number of students did not show evidence of resultant force is zero. Hence presentation of answers is important in this question in general.

(b) The sailboard then cruises at constant speed. Fig. 1.2 shows some of the forces acting on the mast and sail of the sailboard.

The uniform mast has length 4.3 m and the base of the mast is connected to the surfing board by a smooth hinge. The wind exerts a force of 200 N on the sail, perpendicular to the mast at a distance 3.5 m away from the hinge.

The man pulls the sail with a force *T* at distance 1.5 m away from the hinge and the weight of the mast and sail is 50 N.

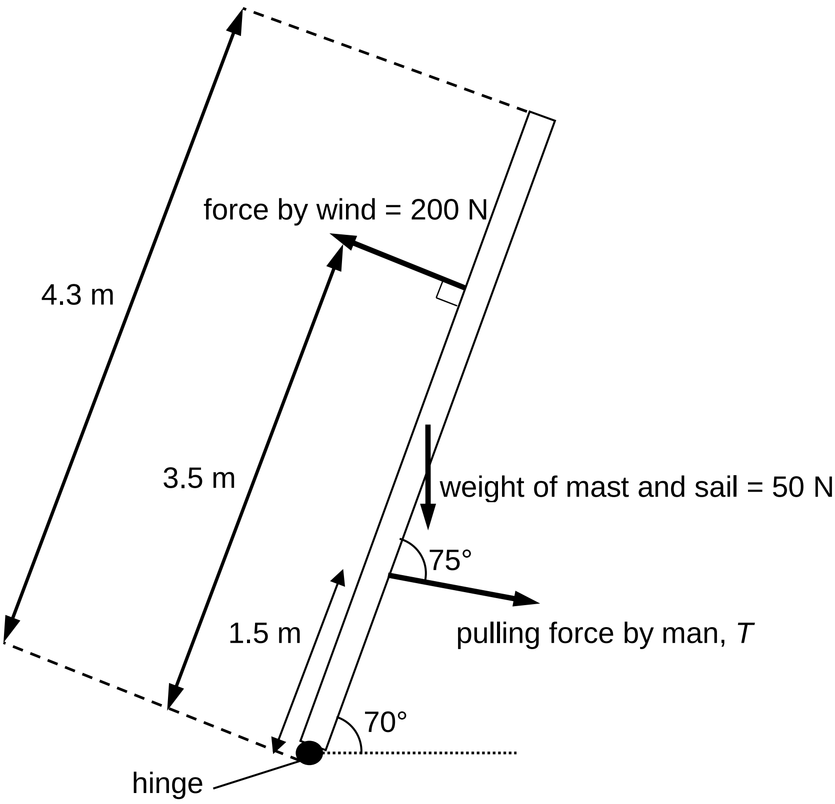


Fig. 1.2

(i) Show that pulling force *T* by the man is 460 N.

$$\sum \tau_{hinge} = 0$$

$$200(3.5) - (50)(2.15\cos 70^o) - T\sin 75^o(1.5) = 0$$

$$T = 460 \text{ N}$$

[2]

(ii) Determine the magnitude of the force, R, exerted by the hinge.

$\sum Fy = 0$

$200\cos 70^o - 50 - 460\sin 5^o + Ry = 0$

$Ry = 21.7$ N

$\sum Fx = 0$

$Rx - 200\sin 70^o + 460\cos 5^o = 0$

$Rx = -270$ N

$R = \sqrt{(270)^2 + (21.7)^2} = 271$ N

magnitude of R = ... N [3]

Comments: A significant number of students are able to get full credit for this question even though it is quite mathematically challenging.

(c) The surfing board is designed with the foot straps at the rear part of the board rather than at the centre part of the board, as shown in Fig. 1.3.

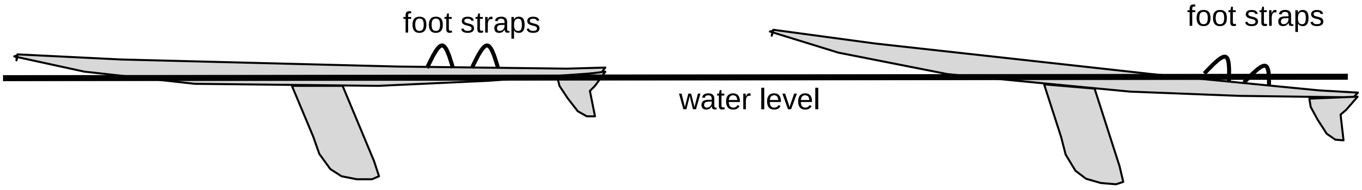


Fig. 1.3

Such a design allows the surfing board to move across the water surface while inclined at an angle to the surface.

Suggest why when the man is moving horizontally with the board at an incline, the volume of seawater displaced by the sailboard is lower than your answer in **(a).**

As the surfboard move across the water surface inclined at an angle, there will be water continuously changing direction as it come into contact with the surf board. By Newton 2nd law, there is a rate of change in momentum resulting in a force acting iin the downward direction. Hence by Newton's 3rd law, there is upwards force acting acting on the surf board. Hence the upthrust can be smaller causing water displaced to decrease. [1]

[Total: 8]

Comments: This part prove to be challenging for the large majority of students.

2 **(a)** Planets have been observed orbiting a star in another solar system. Measurements are made for the orbital radius r and the time period T of each of these planets.

The variation with r^3 of T^2 is shown in Fig. 2.1.

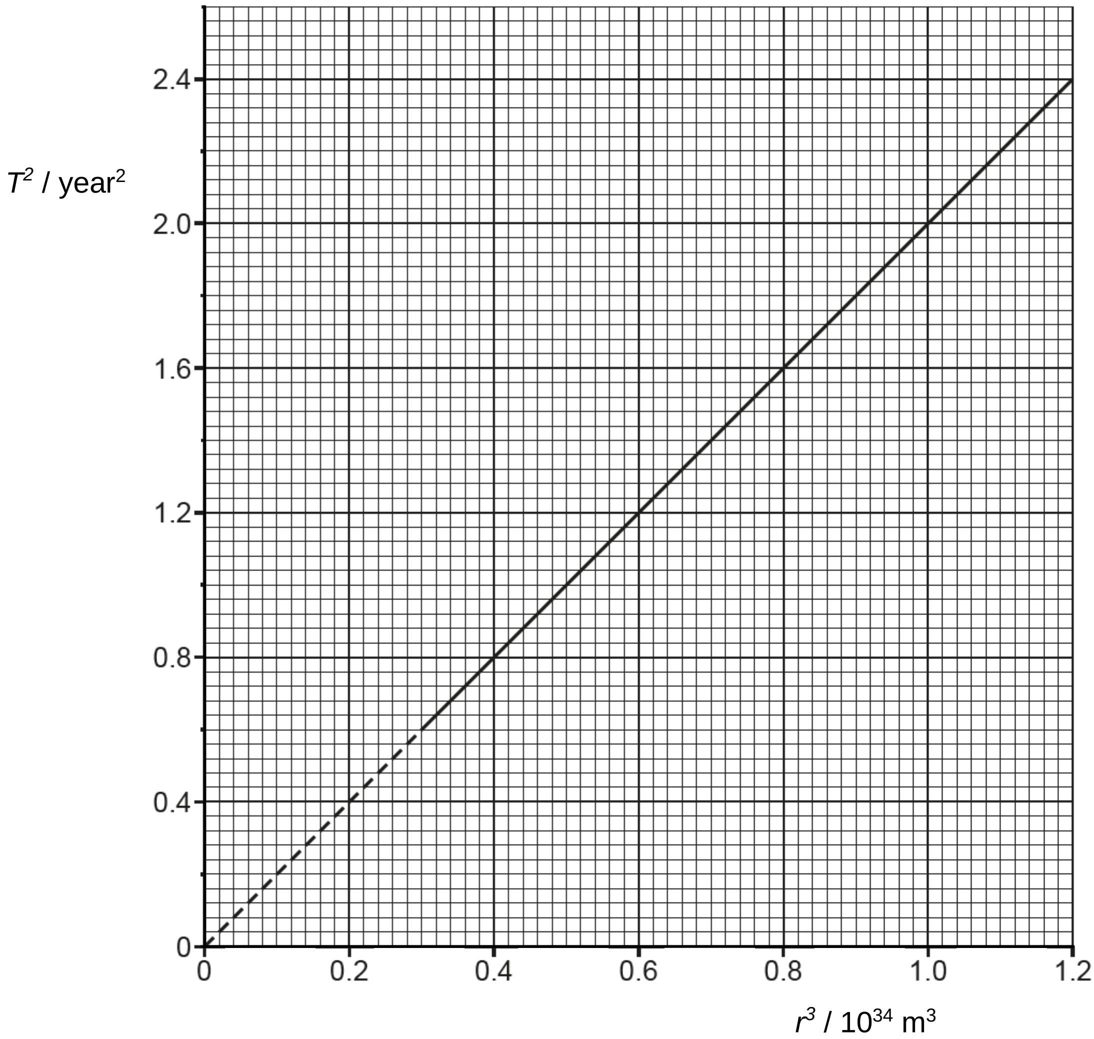


Fig. 2.1

The relationship between T and r is given by

$$T^2 = \frac{4\pi^2 r^3}{GM}$$

where G is the gravitational constant and M is the mass of the star.

(i) Determine the mass *M* of the star.

Gradient = $\dfrac{2.4-0}{(1.2-0)\times 10^{34}} = 2.0\times10^{-34}$

$\dfrac{4\pi^2}{GM} = 2.0\times10^{-34}\times(365\times24\times60\times60)^2$ [1]

M = 2.98 x 10^{30} kg or in 2 sf [1]

M = ... kg [2]

(ii) The radius of the star is 700 000 km. Determine the minimum speed with which gas particles from its surface have to be ejected to just escape from the star's pull of gravity.

By Conservation of Energy,

Initial KE + initial GPE at surface = Final KE + final GPE at infinity

½ mv_{escape}^2 + (-GMm/r) = 0

v_{escape} = $(2GM/r)^{1/2}$ = 7.53 x 10^5 m/s

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

(iii) Hydrogen gas, consisting of hydrogen-2 particles, may be assumed to be an ideal gas. If the surface temperature of the star is 6000 K, determine whether hydrogen gas

(Find speed of hydrogen-2 particles)
½ mv^2 = 3/2 kT
½ (2 x 1.66 x 10^{-27}) v^2 = 3/2 (1.38 x 10^{-23})(6000) [1]
v = 8630 ms^{-1} < v_{esc} = 7.53 x 10^5 m/s^{-1} , particles cannot escape [1]

Or
(Find initial KE required to escape)
KE required = ½ mv_{escape}^2 = ½ (2 x 1.66 x 10^{-27})(7.53 x 10^5)^2 = 9.41 x 10^{-16} J
KE of gas particles = 3/2 (1.38 x 10^{-23}) (6000) = 1.242 x 10^{-19} J [1]
Since KE of particles is less than that required, particles cannot escape. [1]

.....

[2]

(iv) Some gas particles have very large kinetic energy to be able to escape from the star.

Given that the star is rotating about an axis through its poles, suggest why the gas particles at the equator of the star are more likely to escape the surface than those at the poles.

Gas particles at the equator is furthest away from this axis of rotation/largest radius of rotation. [1]
Hence particles at the equator has the <u>largest speed of rotation</u> [1]
and may exceed the minimum speed to escape the star's surface

.... [2]

(b) A satellite of mass *m* is also in orbit around the star in **(a)**. The radius of the orbit is *r*.

(i) Show that the kinetic energy E_k of the satellite is given by

$$E_k = \frac{GMm}{2r}.$$

Gravitational force by star on satellite provides for the centripetal force on the satellite

By Newton's 2nd Law,
$\sum F = ma_c$
$GMm/r^2 = mv^2/r$
$\frac{1}{2} mv^2 = \frac{1}{2} GMm/r$

[1]

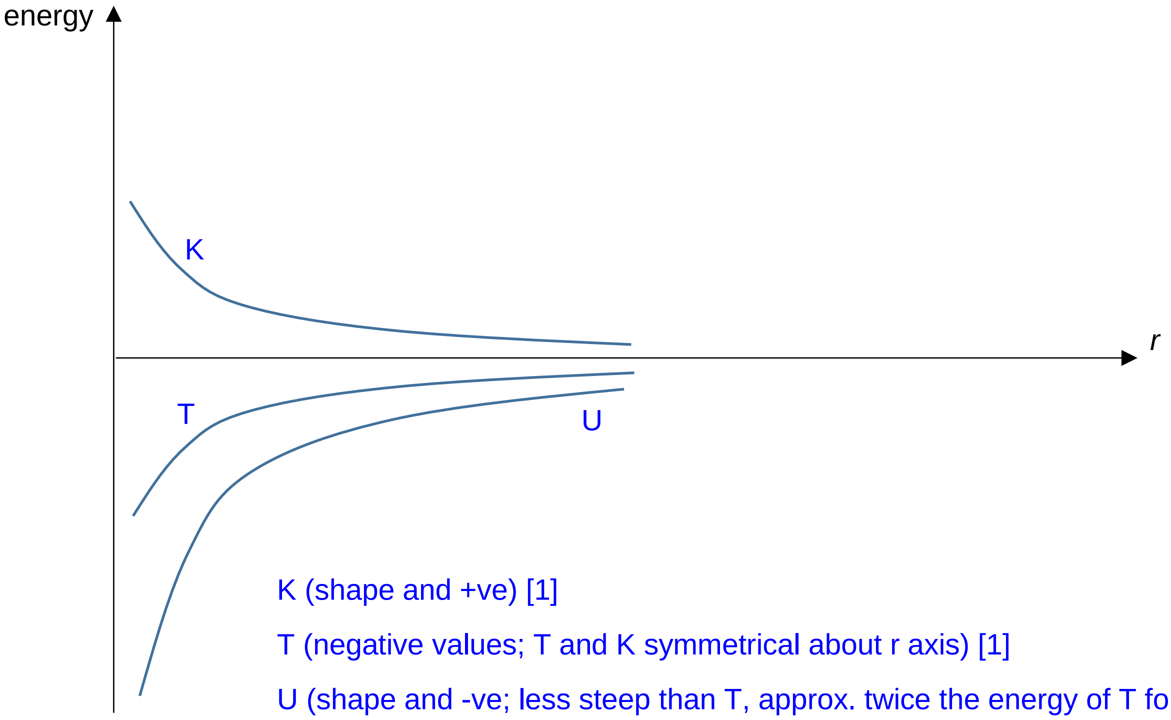
(ii) On Fig. 2.2, sketch graphs to show the variation with orbital radius *r* of the

1. gravitational potential energy of the satellite. Label the graph U.

2. kinetic energy of the satellite. Label the graph K.

3. total energy of the satellite. Label the graph T.

[3]



K (shape and +ve) [1]

T (negative values; T and K symmetrical about r axis) [1]

U (shape and -ve; less steep than T, approx. twice the energy of T for each r) [1]

Fig. 2.2

[Total: 12]

3 A roller coaster ride in an amusement park consists of an unpowered car moving freely along a smooth track. Fig. 3.1 shows the roller coaster car moving with speed v at the top of a vertical loop with radius R. Ignore any resistive forces on the car.

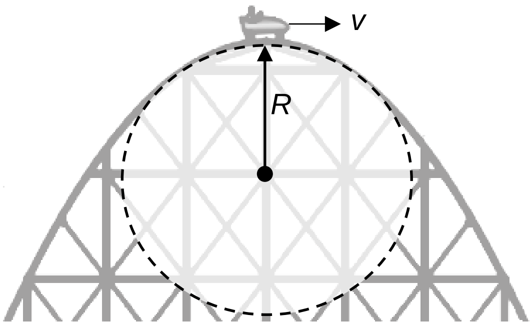


Fig. 3.1

(a) For the car to remain in contact with the track at the top of the loop, show that the maximum speed v_{max} of the car is

$$v_{max} = \sqrt{Rg}.$$

Explain your working.

At top of loop,

$mg - N = mv^2/R \rightarrow N = mg - mv^2/R$ [1] (using N2L)

For car to remain in contact, $N \geq 0$ [1]

$\rightarrow mv^2/R \leq mg$ [1]

So max speed at the top is such that $v_{max}^2/R = g$

[3]

(b) The entire roller coaster ride consists of two of such vertical loops with positions A and B as shown in Fig. 3.3. The two loops have radii R_1 and R_2 respectively.

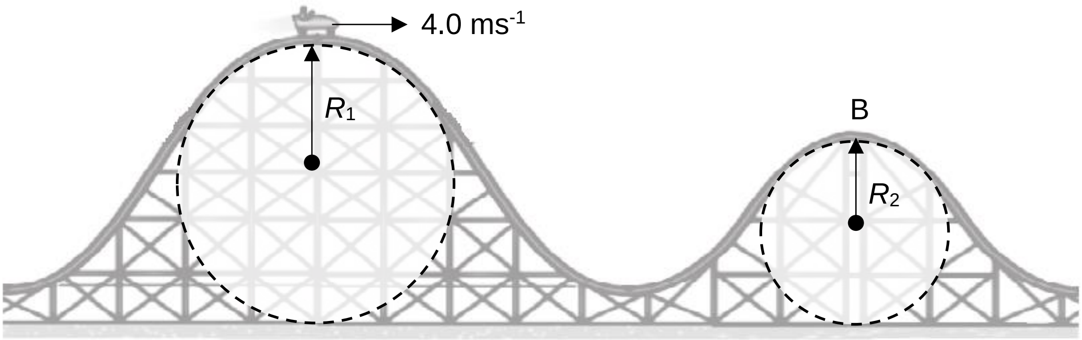


Fig. 3.3

During a test run, the car has a speed of 4.0 m s^{-1} at A where radius of the first loop R_1 is 15 m. Determine the minimum radius R_2 so that the car will remain in contact with the track throughout its journey.

To remain in contact at B,

$v_B = (R_2 g)^{1/2}$ [1]

By COE,

$\frac{1}{2} m v_B^2 = \frac{1}{2} m v_A^2 + mg(2R_1 - 2R_2)$ [1]

$\frac{1}{2} m(R_2 g) = \frac{1}{2} m v_A^2 + mg(2R_1 - 2R_2)$ $\rightarrow$ $\frac{1}{2} gR_2 + 2gR_2 = \frac{1}{2}(16) + 2g(15)$

$\rightarrow R_2 = 12$ m [1]

R_2 = ... m [3]

(c) Fig. 3.4 shows the car when it is at position C after it leaves A.

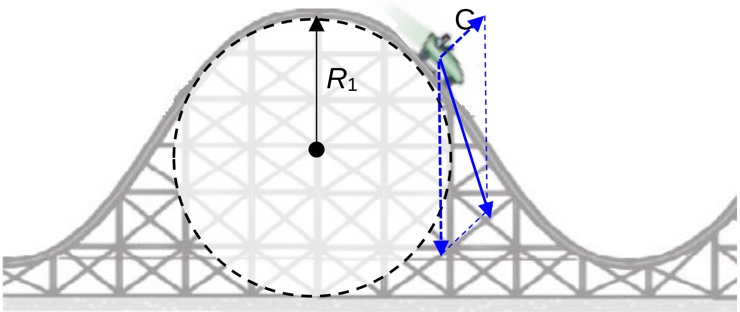


Fig. 3.4

On Fig. 3.4, draw an arrow to show the resultant force on the car at point C. Explain your answer.

The resultant of the weight and normal contact force has a radial component to produce the centripetal acceleration and a tangential component to increase the speed. [1]

Direction of arrow between direction of weight and of tangential velocity [1]

.... [2]

[Total: 8]

4 **(a)** Explain what is meant by an *ideal gas*.

It is a gas that **obeys** the equation of state $PV=nRT$ for **all values** of pressure P, volume V and temperature T for a fixed amount n of gas.

[1]

(b) A fixed mass of ideal gas has a volume of 210 cm^3 at pressure 3.0×10^5 Pa and a temperature of 35 °C.

(i) State and explain the assumption of the kinetic theory that allows a gas to maintain its temperature.

The assumption is all collisions are elastic.

If the collisions are elastic, total kinetic energy of the gas molecules will be constant Hence the average kinetic energy will also be constant resulting in the temperature remains constant.

[2]

(ii) The volume of the gas is then reduced at constant pressure to 140 cm^3 by a moving piston. Determine the final temperature of the gas.

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

$$\frac{210}{35+273} = \frac{140}{T_2}$$

$$T = 205 \text{ K}$$

temperature of gas = ... K [2]

(iii) Calculate the average kinetic energy of a gas molecule at this final temperature.

$$E_k = \frac{3}{2}kT = \frac{3}{2}(1.38\times10^{-23})(205)$$

$$= 4.24\times10^{-21} \text{ J}$$

average kinetic energy = ... J [2]

(iv) Using the first law of thermodynamics, explain whether heat is supplied to or released by the gas.

Positive work is done on the gas during compression. Since temperature of the gas decreases, its internal energy also decreases. Therefore the change in internal energy is negative. By the first law of thermodynamics, heat transfer will be negative resulting in heat released by the gas.

[2]

[Total: 9]

5 Source S_1, consisting of parallel light with wavelength 700 nm, is incident on a rectangular slit of width *b*, as shown in Fig. 5.1.

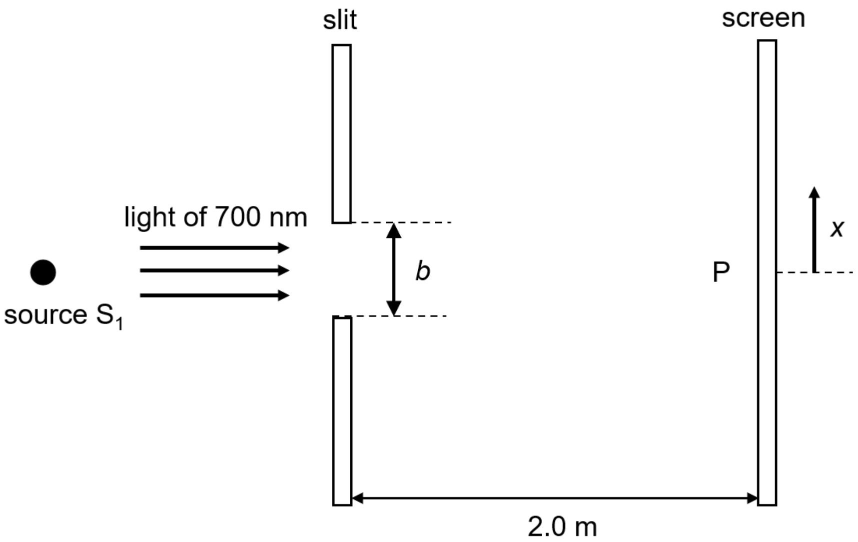


Fig. 5.1 (not to scale)

(a) A central maxima is observed on the screen and its width is found to be 4.0 mm. Calculate the width b of the single slit.

Since θ is small, $\theta = \frac{\lambda}{b} = \tan\theta = \frac{x}{D}$

$\frac{700\times10^{-9}}{b} = \frac{0.002}{2.0}$ [C1]

$b = 7.0 \times 10^{-4}\ m$ [A1]

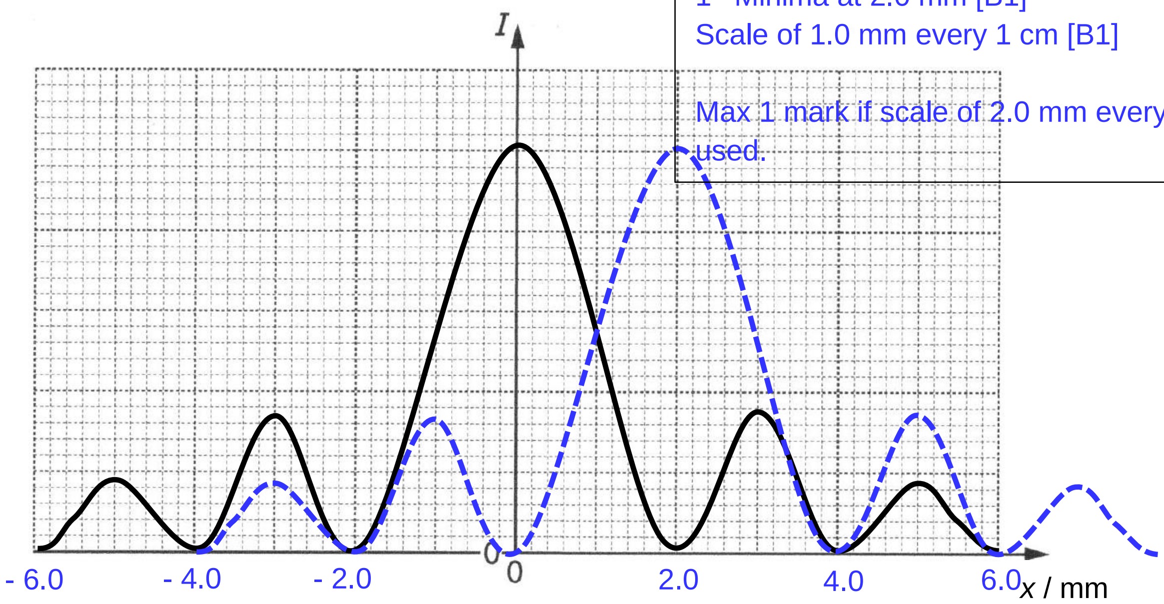
Comment
Poorly done. A number of candidates do not remember that x is half the width of the central maxima.

]

(b) Fig. 5.2 shows the variation with distance x from P of the intensity I of the red light on the screen. Label, on Fig. 5.2, the values of the six x-intercepts. [2]

1st Minima at 2.0 mm [B1]
Scale of 1.0 mm every 1 cm [B1]

Max 1 mark if scale of 2.0 mm every 1 cm is used.



Comment
Poorly done. Candidates equated slit width with width of central maxima which is conceptually wrong. Uneven scaling of x axis is observed. Many missed this question.

(c) A

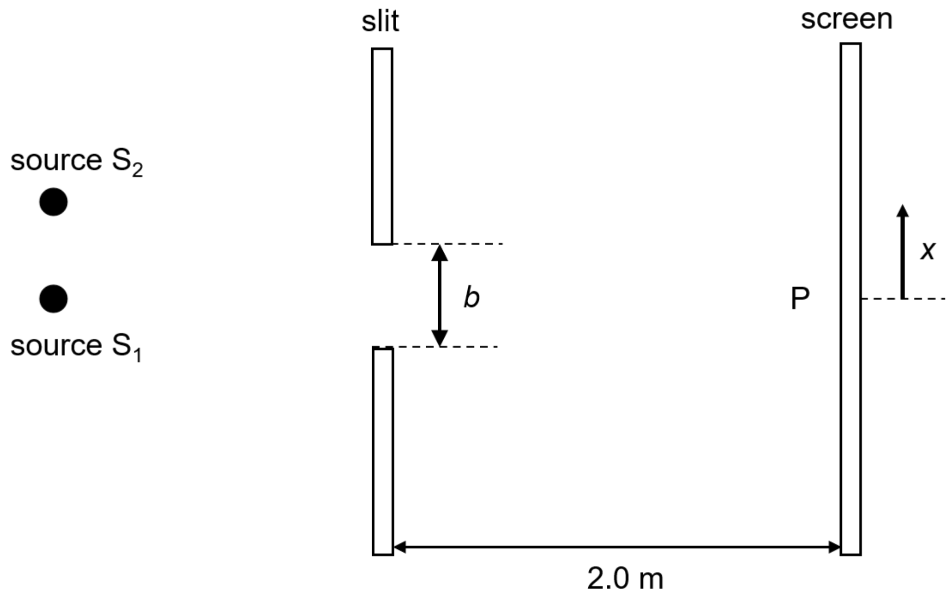


Fig. 5.3 (not to scale)

Sketch, on Fig. 5.2, the variation with distance x from P of the intensity I of the second source S_2 when Rayleigh criterion is satisfied. [2]

[Total: 9]

Central maxima of new diffraction envelop at first minima of original diffraction envelop [B1]

1st Minima of new diffraction envelop at central maxima AND 2nd minima of original diffraction envelop [B1] – rephrase using terms in Rayleigh's criterion.

Comment
Very poorly done. Candidates did not read question and drew on Fig. 5.3 instead. Curve was drawn without regards to Rayleigh Criterion. Awkwardly shaped graphs and unsymmetrical graphs are observed. Many missed this question.

Comment
Very poorly done. Confusion between magnetic flux density, magnetic flux and magnetic flux linkage is common. Magnetic field is insufficient as it describe a region and not quantify the strength.

6 **(a)** Define *magnetic flux*.

The magnetic flux through a plane surface is the product of the component of the magnetic flux density normal to the surface and the area of the surface.

....

....

.... [2]

(b) A uniform conducting bar XY is pulled horizontally across long parallel frictionless conducting guide rails by a light inextensible string. The string passes over a frictionless pulley and is attached to a hanging block. The guide rails are placed in a vertical magnetic field of uniform magnetic flux density as shown in Fig. 6.1.

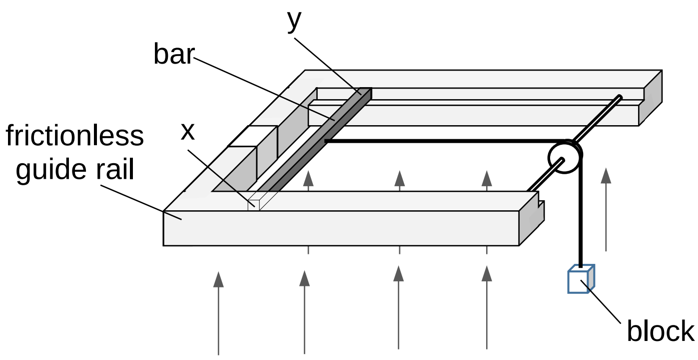


Fig. 6.1

The block is released from rest at time t = 0 s, and the bar starts to move.

(i) An e.m.f. is induced in the bar. State which end X or Y of the bar is at a higher potential.

End X of the rod is at a higher potential. .... [1]

Comment
Mainly guess work.

(ii) Use Faraday's law and Lenz's law to explain the subsequent motion of the bar.

When the bar accelerates, the velocity increases and there is a change (increase) in magnetic flux linkage through the area enclosed by the rod and the conducting rails because the area is changing (increasing) OR cutting of flux/cutting of magnetic field lines. [B1]

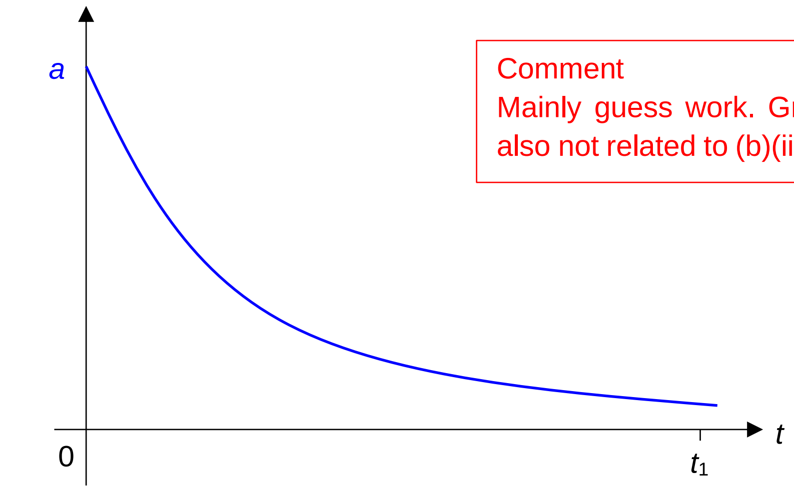
By Faradays law, there is an e.m.f induced and by Lenz's law, a current is induced in a clockwise direction viewed from above to oppose the change in the magnetic flux linkage. [B1]

Hence by Fleming's left hand rule, a magnetic force is experienced by the bar towards the left, hence decreasing its acceleration/decreasing the net force acting on it. [B1]

Hence the speed of the bar increases at a decreasing rate. [B1]

Comment
Very poorly done. Majority failed to support change in flux linkage due to change in area of loop. Magnetic flux linkage is a scalar there should not be direction associated with it which is seen in many answers. Faraday's Law and Lenz Law are just stated without linking it to context of question. Faraday's Law do not account for induced current. Lenz Law (in this context) only used to oppose increase in magnetic flux linkage, it is incorrect to say that magnetic flux linkage is reduced. It should account for induced e.m.f. only. Many answers failed to describe direction of induced current adequately. Common misconception that reduction in net force result in deceleration when in fact it only leads to smaller acceleration. Many failed to describe motion of bar adequately to score.

On Fig. 6.2, sketch a graph to show the variation with time t of the acceleration of the rod from t = 0 to time t = t_1. Label clearly the acceleration at t = 0 as a.



Comment
Mainly guess work. Graph plotted are also not related to (b)(ii) when it should.

[B1] Shape of curve.
[B1] Start from a positive value, labelled a.

[2]

[Total: 6]

7 **(a)** A beam of electrons is accelerated through a potential difference of 130 V and is then incident on a thin silicon crystal.

(i) State what is meant by *de Broglie wavelength*.

A particle/electron has a wavelength (associated with it) which is dependent on its momentum.

....

....[1]

(ii) Show that the de Broglie wavelength of the electrons is 1.08 × 10^{-10} m.

By conservation of energy, Loss in Electric PE = Gain in KE

$$q\Delta V = \frac{1}{2}mv^2 = \frac{p^2}{2m}$$

$$(1.60\times10^{-19})(130) = \frac{p^2}{2(9.11\times10^{-31})}$$

$$p = 6.1561\times10^{-24}$$

$$\lambda = \frac{h}{p}$$

$$= \frac{6.63\times10^{-34}}{6.1561\times10^{-24}}$$

$$= 1.08\times10^{-10}\text{ m}$$

[3]

(b) A fluorescent screen is positioned 12 cm away from the silicon crystal as shown in Fig. 7.1. The separation of silicon atoms in a silicon crystal is 0.235 nm.

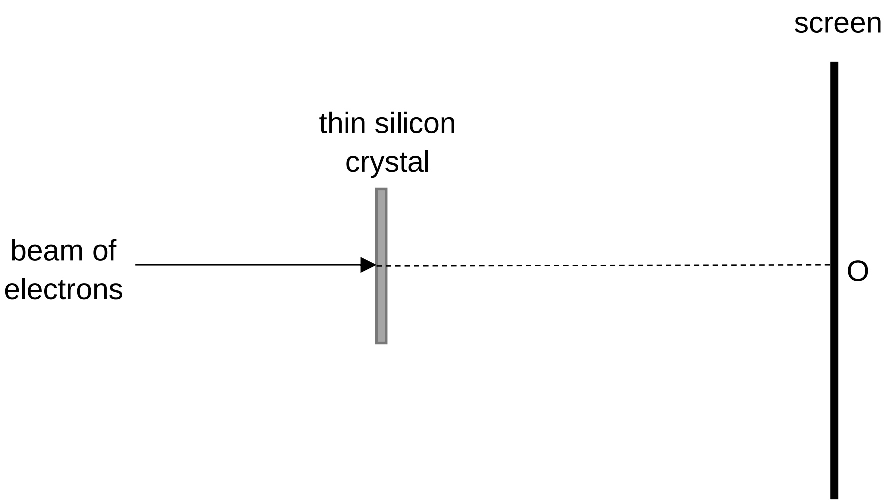


Fig. 7.1

(i) Explain why electron diffraction will be observed on the fluorescent screen.

The separation of the silicon atoms is in the same order of magnitude as the de Broglie wavelength of the electrons. Hence effect of diffraction is appreciable/significant.[1]

(ii) Electrons are observed in the straight-through direction at position O as shown in Fig. 7.1 and Fig. 7.2. Assume that the silicon crystal acts as a diffraction grating.

Draw to scale, on Fig. 7.2, the resulting diffraction pattern for the 1st order maxima. Show your working.

For electron diffraction,

$$d\sin\theta = n\lambda$$

$$(0.235\times10^{-9})(\sin\theta) = 1(1.08\times10^{-10})$$

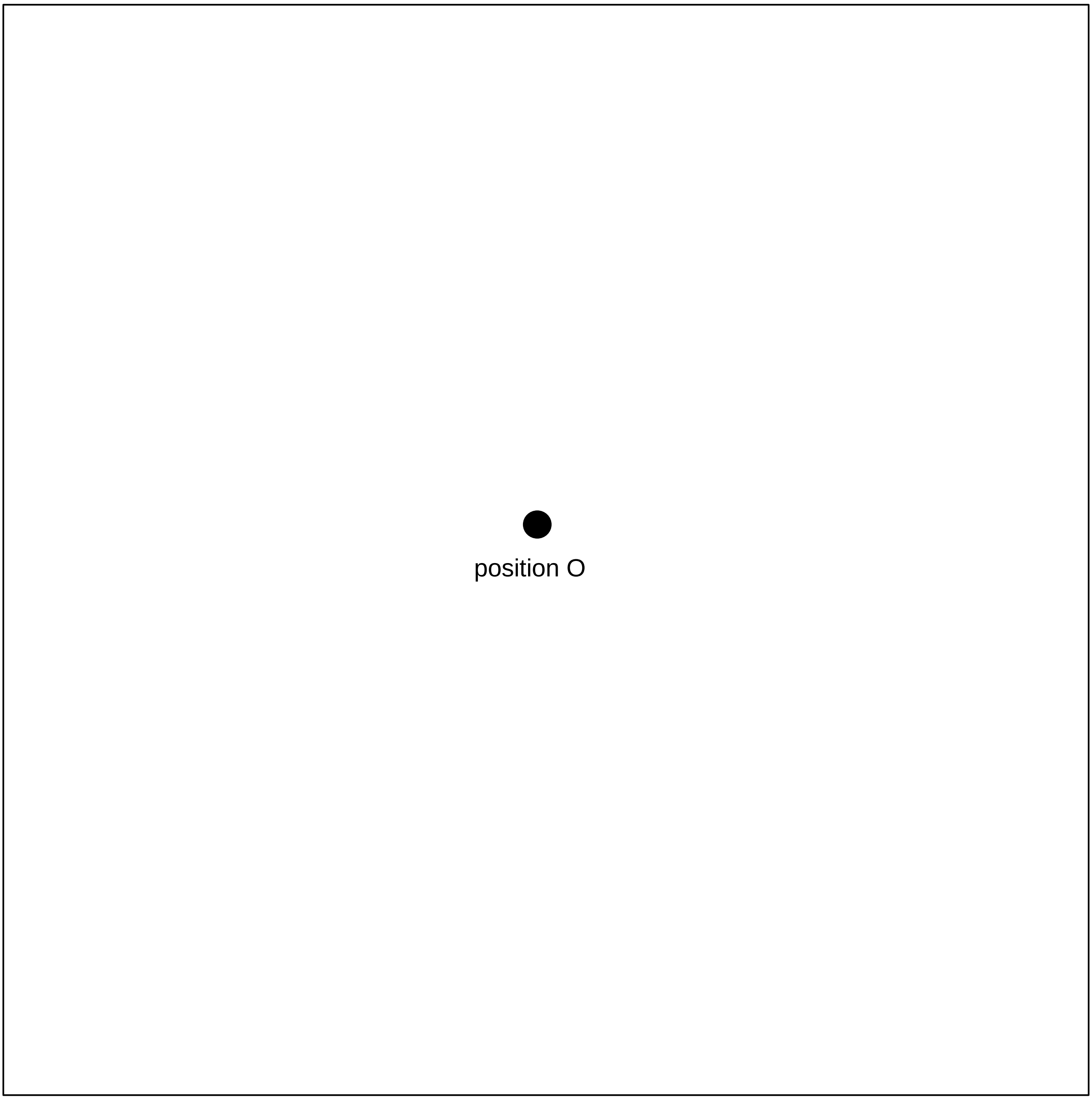


Fig. 7.2

[3]

[Total: 8]

Section B

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

8 Fig. 8.1 shows a thin iron strip of length 8.0 cm, width 2.0 cm and thickness 2.0 mm. As iron is a conductor of electricity, it contains free electrons, one of which is shown in Fig. 8.1.

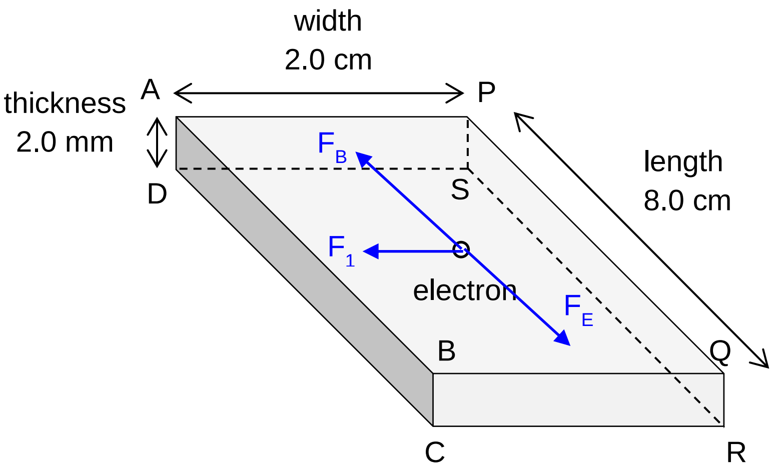


Fig. 8.1

(a) A small potential difference is applied to the iron strip such that face ABCD is at a potential 12 mV higher than face PQRS.

(i) Draw, on Fig. 8.1, an arrow to show the direction of the force on the free electron. Label as F_1. [1]

(ii) Calculate the magnitude of the force in **(a)(i)**.

$E = V / d = 12\times10^{-3} / 0.020 = 0.60 \text{ N C}^{-1}$

$F = q E = 1.6\times10^{-19} \times 0.60 = 9.6\times10^{-20} \text{ N}$

force = ... N [2]

(iii) Determine the change in the electric potential energy of the electron when it moves across the entire width of the strip.

Loss in EPE = $q V = 1.6\times10^{-19} \times 12\times10^{-3} = 1.9\times10^{-21}$ J

change in electric potential energy = ... J [2]

(b) Iron has a resistivity of $9.7 \times 10^{-8}\ \Omega$ m and an electron density of 8.8×10^{28} m^{-3}.

(i) Calculate the current in the iron strip when there is a potential difference of 12 mV across faces ABCD and PQRS.

$R = \rho L / A = 9.7\times10^{-8} \times 0.020 / (0.080 \times 0.0020) = 1.21\times10^{-5}\ \Omega$

$I = V / R = 12\times10^{-3} / 1.21\times10^{-5} = 990$ A

current = ... A [3]

(ii) Hence, show that the drift velocity of the electrons is 4.4×10^{-4} m s^{-1}.

$I = n A v e$

$990 = 8.8\times10^{28} \times (0.080 \times 0.0020) \times v \times 1.6\times10^{-19}$

$v = 4.39\times10^{-4}$ m s^{-1}

[1]

(c) A magnetic field of flux density 20 mT is now applied in the downward direction into face ABQP.

(i) Explain what is meant by a magnitude of *20 mT*.

A force per unit length of 20 mN m^{-1} is exerted by the magnetic field on a long conductor carrying 1 A of current placed perpendicular to the magnetic field.

....[1]

(ii) Draw, on Fig. 8.1, an arrow to show the direction of the force exerted by the magnetic field on the electron. Label as F_2. [1]

(iii) Calculate the magnitude of the force in **(c)(ii)**.

$F = B q v = 20\times10^{-3} \times 1.6\times10^{-19} \times 4.4\times10^{-4} = 1.41\times10^{-24}$ N

force = ... N [2]

(iii) Explain why a potential difference develops across faces APSD and BQRC.

The magnetic force on electrons is parallel to PQ, causing them to drift in the direction of the force. Due to the resulting difference in number density of electrons across the two ends, an electric field is set up across the two faces. [1]

(iv) Draw, on Fig. 8.1, an arrow to show the direction of the force due to the potential difference in **(c)(iii)** on the electron. Label as F_3. [1]

(v) The potential difference in **(c)(iii)** eventually reaches a steady value. State the magnitude of the resultant force on the electron that acts along the length of the strip.

resultant force = zero N [1]

(vi) Hence calculate the value of the potential difference in **(c)(iii)**.

$F_E = F_B$

$1.6\times10^{-19} \times V / 0.080 = 1.41\times10^{-24}$ N

$V = 7.04\times10^{-7}$ V

potential difference = ... V [2]

(vii) Briefly explain how this iron strip can be used to determine the direction of a different magnetic field in another region.

Change orientation of strip until p.d. across APSD and BQRC is maximum. (The magnetic field is normal to the face APQB.)

If APSD is at higher potential, the magnetic field is directed towards APQB. If APSD is at lower potential, the magnetic field is directed towards DSRC. [2]

[Total: 20]

9 **(a)** Radioactive decay is a random and spontaneous process.

Explain what is meant by

(i) a *random* process,

It is a process in which it cannot be predicted which nuclide will decay at a particular instant or when any particular nuclide will decay. [1]

(ii) a *spontaneous* process.

It is a process which it is not triggered or affected by external factors such as temperature and pressure. [1]

(b) An unstable nucleus of mass number A undergoes α-decay, as illustrated in Fig. 9.1.

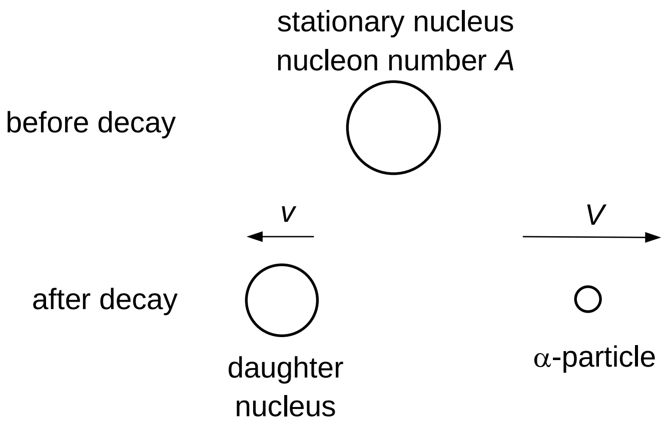


Fig. 9.1

The nucleus is stationary before the decay.

After the decay, the initial speed of the α-particle is V and that of the daughter nucleus is v.

(i) Derive an equation, in terms of A, v and V, to represent conservation of linear momentum for this decay.

[1]

$$□ \Sigma p_{\text{inital}} = □ \Sigma p_{\text{final}}$$

$$0 = 4V + (A\text{-}4)\,v$$

$$□ \frac{V}{v} = \frac{A-4}{4} \qquad [1]$$

(ii) Show that the ratio

$$\frac{\text{initial kinetic energy of } \alpha-\text{particle}}{\text{initial kinetic energy of daughter nucleus}}$$

is equal to (¼ A – 1).

$$\frac{\text{initial KE of } \alpha\text{-particle}}{\text{initial KE of daughter nucleus}} = \frac{\frac{1}{2}(4)v^2}{\frac{1}{2}(A-4)V^2}$$

[1] ratio

$$= \frac{4}{A-4}\left(\frac{v}{V}\right)^2$$

$$= \frac{4}{A-4}\left(\frac{A-4}{4}\right)^2$$

$$= \frac{A-4}{4}$$

[1] subst

$$= \frac{1}{4}A - 1$$

[2]

(c) Data for the α-decay of bismuth-212 ($^{212}_{83}\mathrm{Bi}$) to form thallium-208 ($^{208}_{81}\mathrm{Tl}$) are given in Fig. 9.2.

nucleus	mass of nucleus / u
bismuth-212	211.9459
thallium-208	207.9374
helium-4	4.0015

Fig. 9.2

(i) Use the data of Fig. 9.2 to calculate, to two places of decimals, the energy released during the decay.

total rest mass of reactants = 211.9459 u

total rest mass = 207.9374 u + 4.0015 u

mass difference = 0.007 u

energy released/J = $0.007 \times (1.66 \times 10^{-27}) \times (3.0 \times 10^{8})^2$

energy released/MeV = $0.007 \times (1.66 \times 10^{-27}) \times (3.0 \times 10^{8})^2 / (1.6 \times 10^{-19}) = 6.54$

[1] mass diff/u

[1] to kg

[1] to J

[1] to MeV

energy = ... MeV [4]

(ii) Use your answer in **(c)(i)** to show that, based on the expression in **(b)(ii)**, the energy of the α-particle is 6.42 MeV.

$$\frac{\text{initial KE of }\alpha\text{-particle}}{\text{initial KE of Tl}} = \tfrac{1}{4}(212) - 1$$

$$\frac{\text{initial KE of }\alpha\text{-particle}}{\text{total initial KE- initial KE of }\alpha\text{-particle}} = 53$$

$$\begin{aligned}\text{initial KE of }\alpha\text{-particle} &= 53\ (\text{total initial KE- initial KE of }\alpha\text{-particle})\\ &= 53\ (6.54\text{- initial KE of }\alpha\text{-particle})\\ &= 6.42\ \text{MeV}\end{aligned}$$

[2]

(d) In practice, the α-particle is found to have an energy of 6.10 MeV, rather than 6.42 MeV, as calculated in **(c)(ii)**.

Suggest

(i) an explanation for the difference in energy,

The energy released in a nuclear reaction are in the form of the kinetic energy of the product particles or energy of an emitted γ photon. Since KE of the product particles is smaller than the total energy lost in the reaction, this implies there is an emission of γ -photon(s).

....

....[1]

(ii) why it is likely that the thallium nucleus and the α-particle do not move off in opposite directions.

Since there is emission of gamma photon(s), the total momentum of zero would include the momentum of the gamma photon(s) as well as the momentum of the thallium nucleus and that of the α-particle . The thallium nucleus and particles need not move off directly in opposite, they could move in other directions such that the vector sum of momentum of the thallium nucleus, α- particle and gamma photon(s) is zero.

....

....

....

....[2]

(e) Some data for the half-lives and decay constants of bismuth-212 and thallium-208 are given in Fig. 9.3.

nucleus	half-life / s	decay constant / s^{-1}
bismuth-212	....	1.9×10^{-4}
thallium-208	190	3.7×10^{-3}

Fig. 9.3

(i) Define *half-life*.

The half life t1/2 of a quantity is defined as the time taken for the quantity to decrease to half of its initial value. [1]

(ii) Complete Fig. 9.3 by calculating the half-life of bismuth-212.

$T_{1/2}$ of bismuth 212 = 0.693/ □ = 0.693/ 1.93 x 10^{-4}

[1]

(iii) Initially, a radioactive source contains *N* nuclei of bismuth-212.

After two hours, it is found that the number of bismuth-212 nuclei has reduced to approximately ¼ *N*. However, although bismuth-212 decays to form thallium-208, the number of thallium nuclei is much less than ¾ *N*.

Suggest an explanation for these observations.

Based on the data given, the half life for bismuth 212 is 3700 s while the hale life for thallium 208 is only 190 s. Hence half life for bismuth 212 is significantly larger than half life for thallium 208.

Hence in the first 190 s of decay, the number of bismuth 212 will remains approximately the same while the number of thallium 208 will have reduced by half.

After two hours, bismuth -212 would have gone through about 2 half lives, hence the number of bismuth 212 is about N/4. But thallium 208 is not a stable nucleus, hence the number of thallium after two hours must be less than 3/4N.

Since thallium 208 only have a half life of 190 s, after 2 hours, the number of thallium would have reduced greatly and hence much less than 3/4N.

[4]

[Total: 20]

End of Paper