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	$p = \dfrac{1}{3}\dfrac{Nm}{V} < c^2 >$
mean translational kinetic energy of an ideal molecule	$E = \dfrac{3}{2}kT$
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	$V = \dfrac{Q}{4\pi\varepsilon_0 r}$
alternating current/voltage	$x = x_0 \sin\omega t$
magnetic flux density due to a long straight wire	$B = \dfrac{\mu_0 I}{2\pi d}$
magnetic flux density due to a flat circular coil	$B = \dfrac{\mu_0 NI}{2r}$
magnetic flux density due to a long solenoid	$B = \mu_0 nI$
radioactive decay	$x = x_0 \exp(-\lambda t)$
decay constant	$\lambda = \dfrac{\ln 2}{t_{\frac{1}{2}}}$

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.

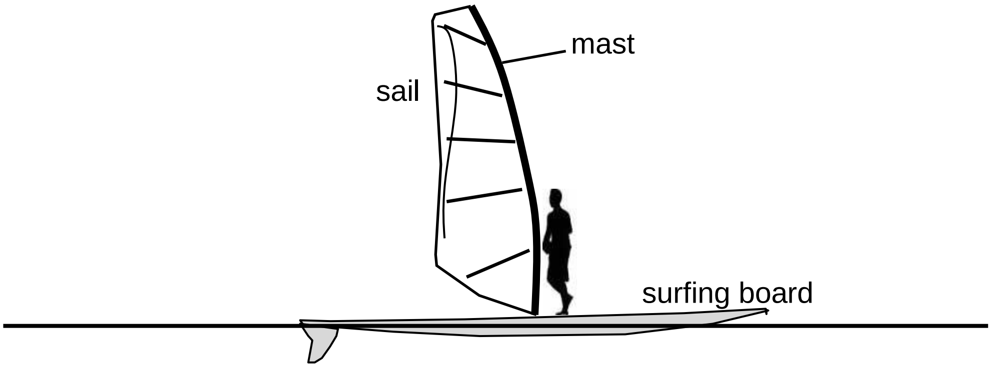


Fig. 1.1

(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.

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

(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.

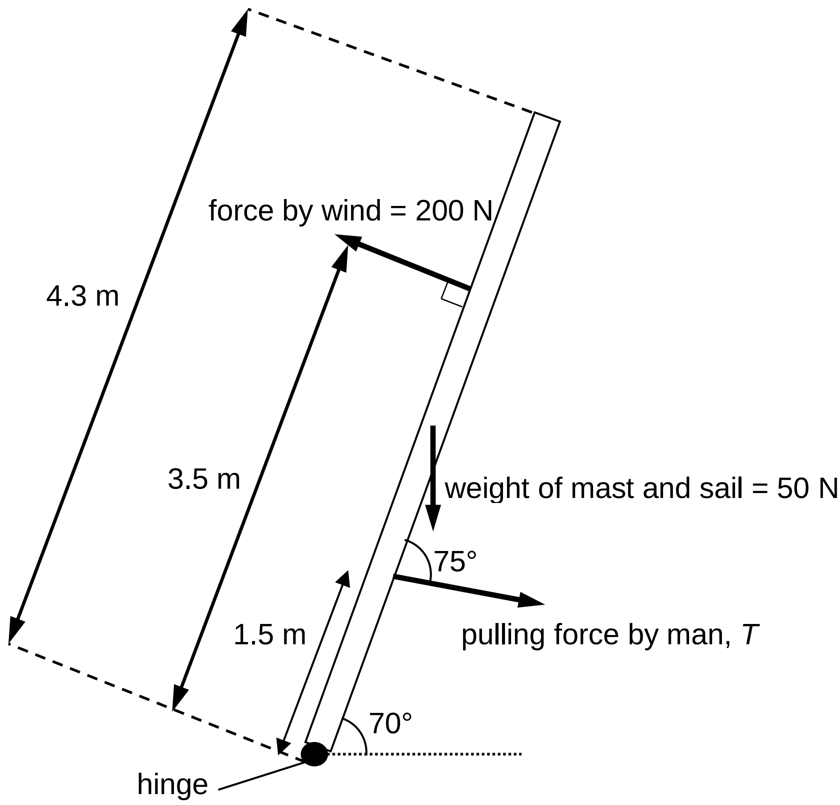


Fig. 1.2

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

[2]

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

magnitude of R = ... N [3]

(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.

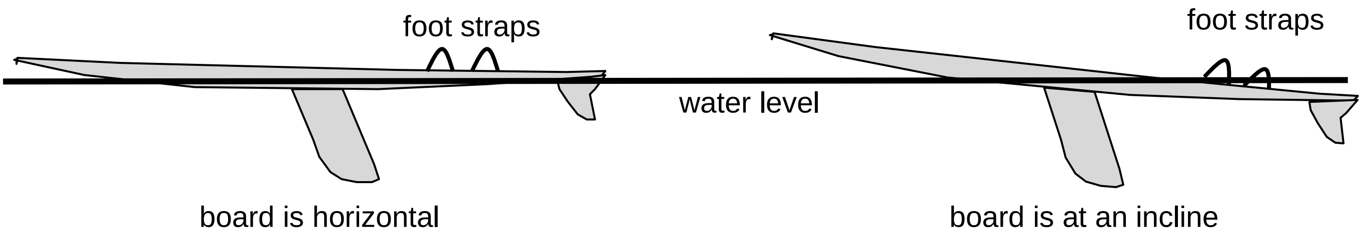


Fig. 1.3

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).**

....

....

....[1]

[Total: 8]

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.

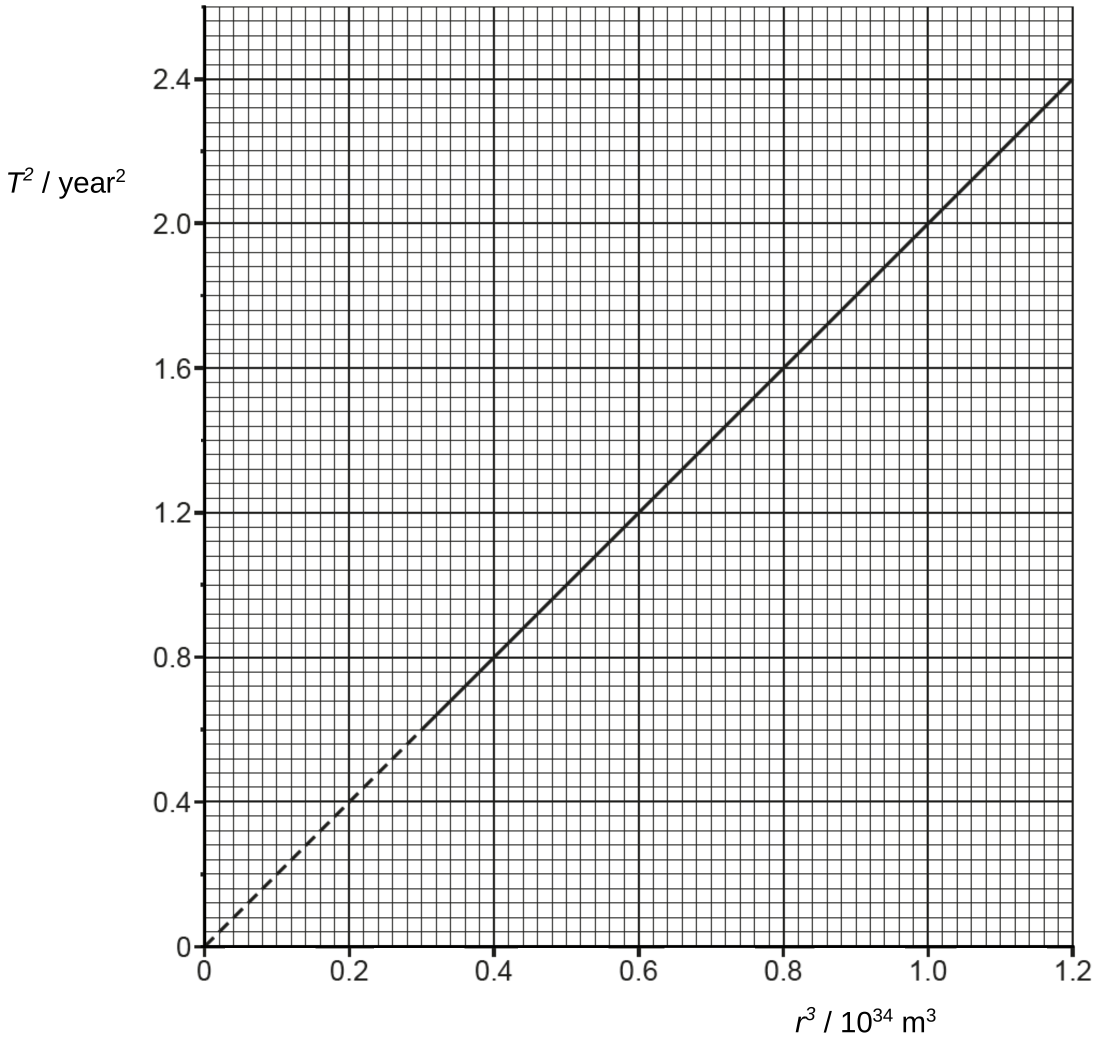


Fig. 2.1

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.

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.

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 particles are able to escape the surface.

....

....[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.

....

....

....[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

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

[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]

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.

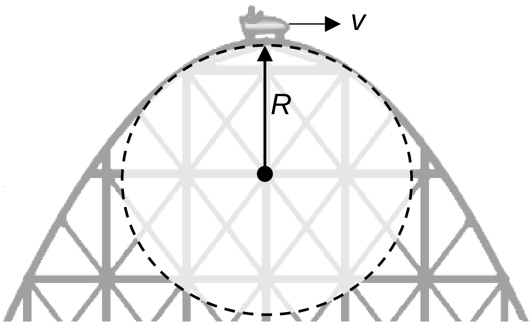


Fig. 3.1

(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.

[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.

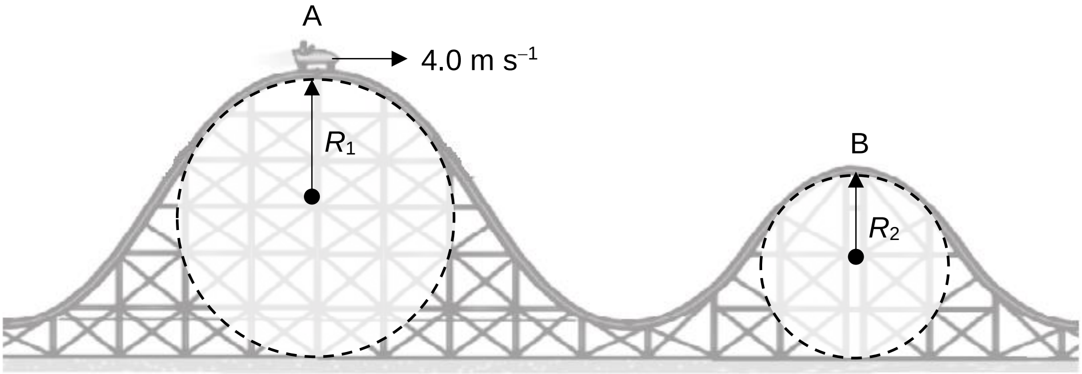


Fig. 3.3

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.

R_2 = ... m [3]

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

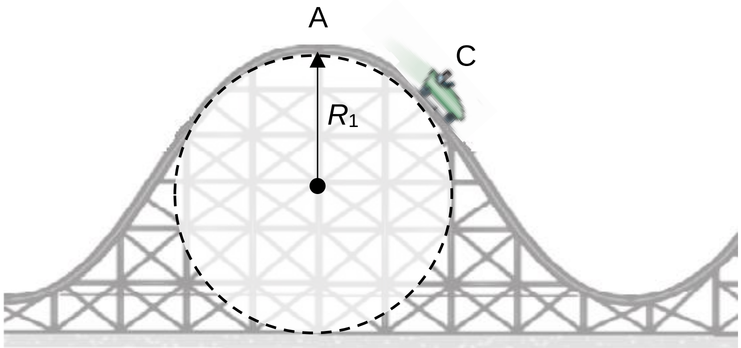


Fig. 3.4

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

....

....

....[2]

[Total: 8]

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

....

....

....[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.

temperature of gas = ... K [2]

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

average kinetic energy = ... J [2]

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

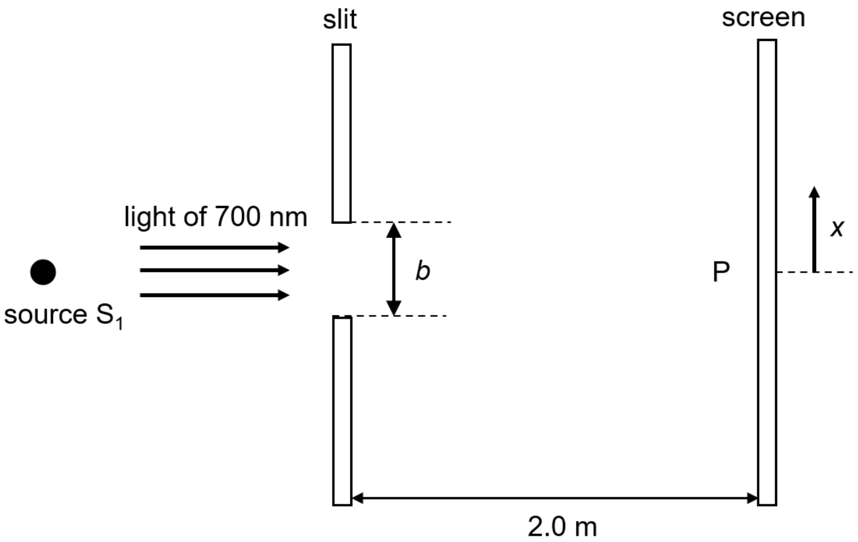


Fig. 5.1 (not to scale)

(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.

slit width b = ... m [2]

(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]

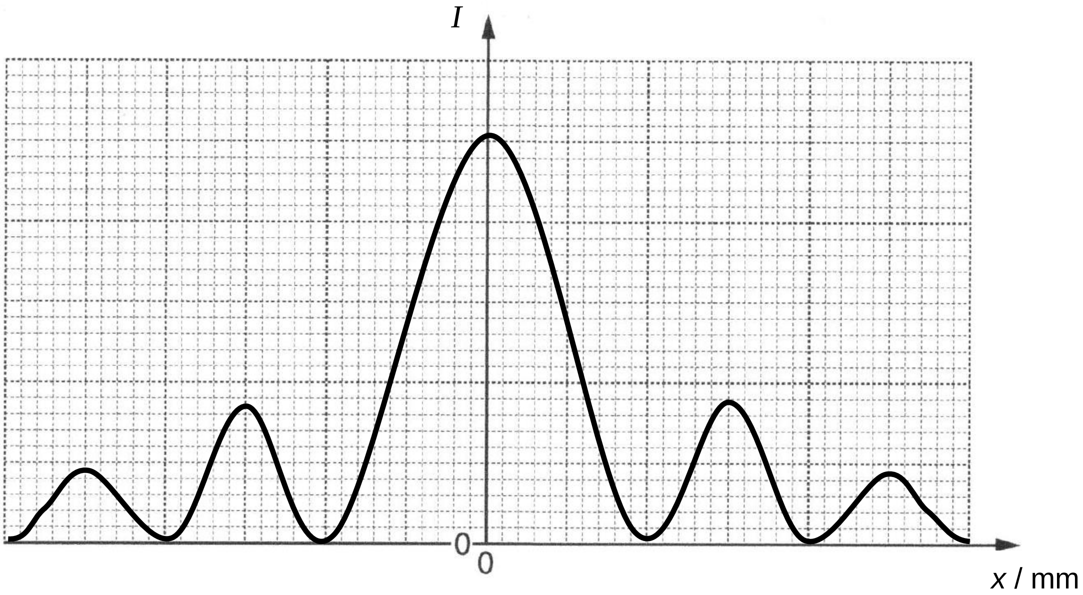


Fig. 5.2

(c) Another identical point source S_2 is placed close to S_1 as shown in Fig. 5.3.

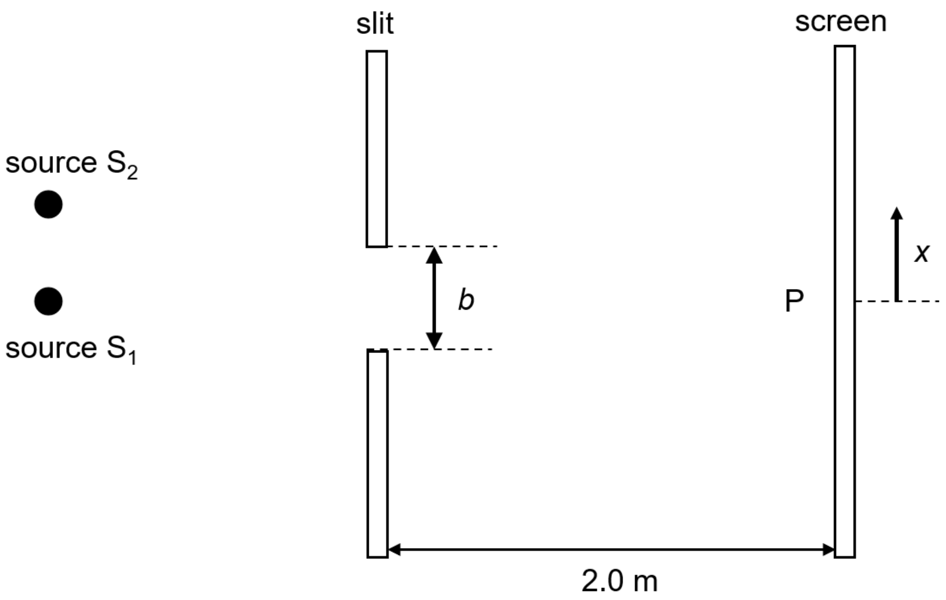


Fig. 5.3 (not to scale)

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: 6]

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

....

....

....[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.

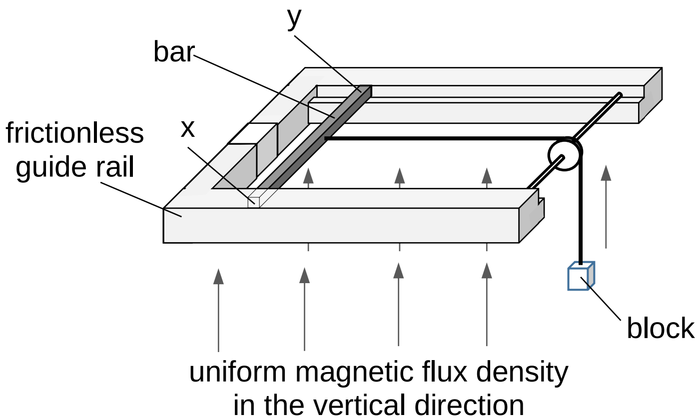


Fig. 6.1

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.

....[1]

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

....

....

....

....

....

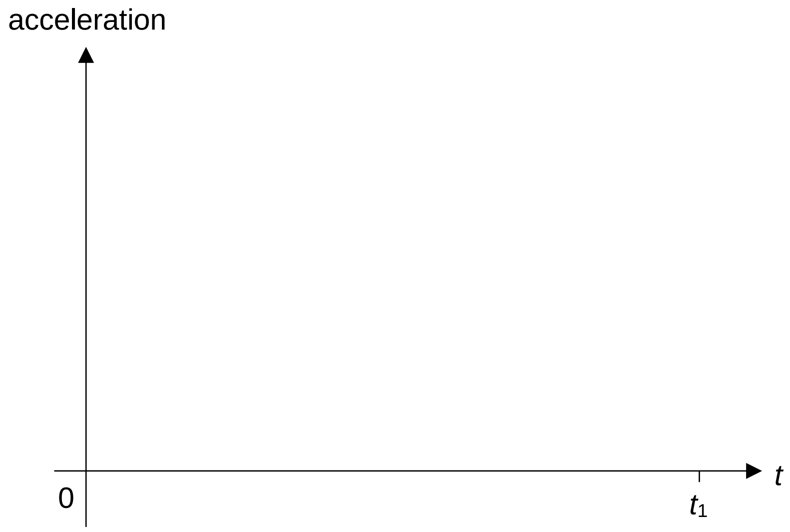
....

....

....[4]

(iii) In time t_1, the bar slides along the length of the guide rails until it reaches a position just before the pulley.

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.



[2]

[Total: 9]

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*.

....

....[1]

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

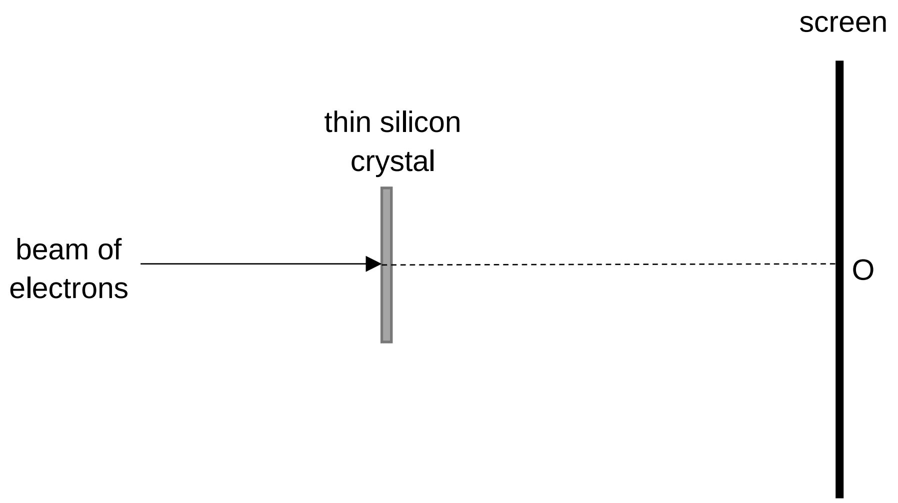


Fig. 7.1

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

....

....[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.

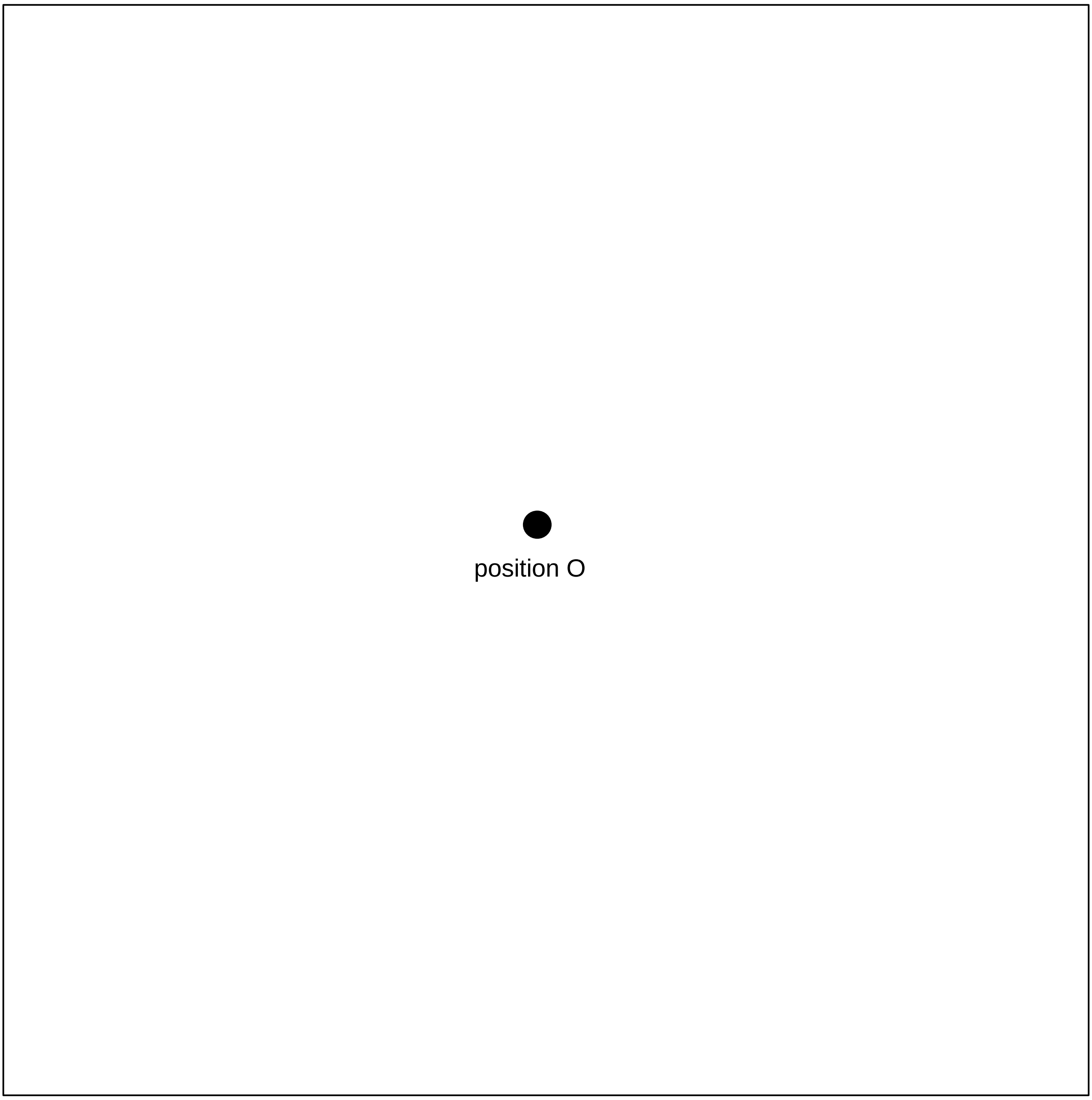


Fig. 7.2

[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.

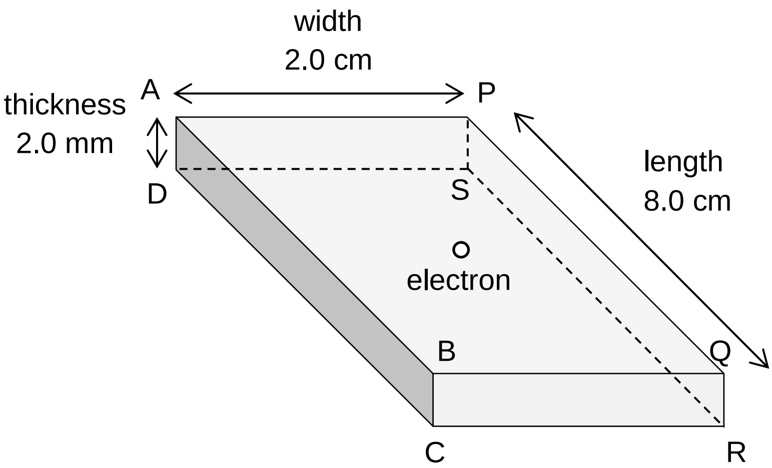


Fig. 8.1

(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)**.

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.

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.

current = ... A [3]

(ii) Hence, show that the drift velocity of the electrons is 4.4×10^{-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*.

....

....

....[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_B. [1]

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

force = ... N [2]

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

....

....

....[1]

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

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

resultant force = ... N [1]

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

potential difference = ... V [2]

(vii) This iron strip can be used in a device called the Hall probe to determine the magnitude and direction of flux density in a region of space.

Briefly explain how this iron strip can be used to determine the direction of another magnetic field.

....

....

....

....[2]

[Total: 20]

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

Explain what is meant by

(i) a *random* process,

....

....[1]

(ii) a *spontaneous* process.

....

....[1]

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

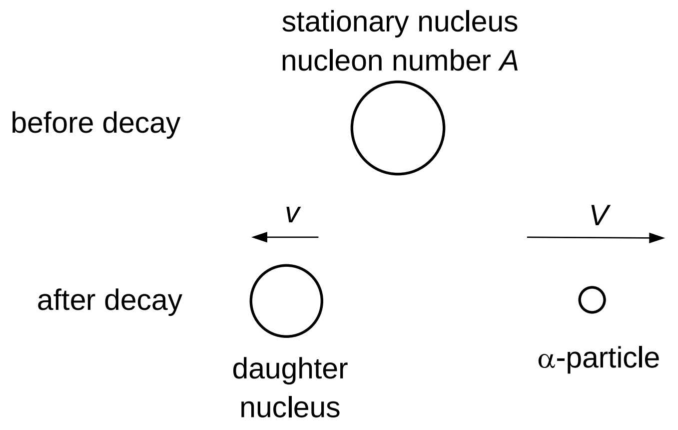


Fig. 9.1

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]

(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).

[2]

(c) Data for the α-decay of bismuth-212 ($^{212}_{83}\text{Bi}$) to form thallium-208 ($^{208}_{81}\text{Tl}$) 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.

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.

[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,

....

....[1]

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

....

....

....

....[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*.

....

....[1]

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

[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.

....

....

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....

....

....[4]

[Total: 20]

End of Paper