VICTORIA JUNIOR COLLEGE
JC 2 PRELIMINARY EXAMINATION
Higher 2

CANDIDATE NAME	SOLUTION		
CLASS		TUTOR NAME	

PHYSICS 9749/03

Paper 3 Longer Structured Questions **18 September 2025**

2 hour

Candidates answer on the Question Paper.

No Additional Materials are required.

READ THESE INSTRUCTIONS FIRST

Write your name, class and tutor name 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.
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.

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

For Examiner's Use	
1	/ 7
2	/ 10
3	/ 8
4	/ 9
5	/ 7
6	/ 9
7	/ 10
8	/ 20
9	/ 20
Total	/ 83

This document consists of **23** 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	$R = R_1 + R_2 + \ ...$
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	$\lambda = \frac{\ln 2}{t_{\frac{1}{2}}}$

1 Fig. 1.1 shows a 1000 N uniform thin rod being towed by a force T and moving at constant horizontal velocity.

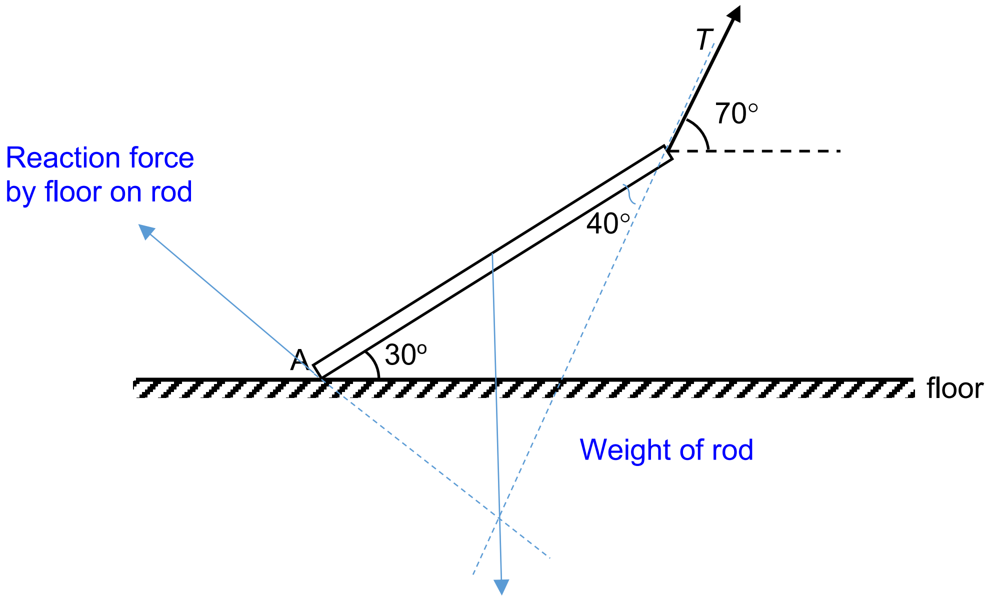


Fig. 1.1

(a) State the conditions required for a body to be in *equilibrium*.

A body is in equilibrium if the net force in any direction on the body is zero and the net torque about any axis on the body is zero.

[2]

(b) On Fig. 1.1, draw and label the **two** other forces acting on the rod. [2]

(c) Given angle θ is 70°, determine force T.

Let L be the length of the rod.
Taking moment about A,

clockwise moment due to weight = $1000(\frac{L}{2}\cos 30°)$ [1]

anticlockwise moment due to force T = $T(L\sin 40°)$ [1]

At equilibrium net moment is zero,

$1000(\frac{L}{2}\cos 30°) = T(L\sin 40°)$

$T = 670$ N [1]

force T = ... N [3]

[Total: 7]

2 The International Space Station (ISS) orbits the Earth at a height of 4.1×10^5 m above the Earth's surface. The radius of the Earth is 6.37×10^6 m.

(a) Both the ISS and the astronauts inside it are in free fall. Explain why this makes the astronauts feel weightless

There is no contact force between the astronaut and the floor of the space station.

....[1]

(b) **(i)** Calculate the value of the gravitational field strength g at the height of the ISS above the Earth.

$g_0 = \frac{GM}{R^2}$, $g_0 R^2 = GM$ [1]

$g = \frac{GM}{(R+h)^2}$, $g = \frac{g_0 R^2}{(R+h)^2} = \frac{9.81 \times (6.37 \times 10^6)^2}{(6.37 \times 10^6 + 4.1 \times 10^5)^2} = 8.66\ \text{N kg}^{-1}$ [1]

g = ... N kg^{-1} [2]

(ii) State the value of the centripetal acceleration of ISS at this height.

a_C = ... 8.66 .... m s^{-2} [1]

(iii) The speed of the ISS in its orbit is 7.7 km s^{-1}. Show that the period of the ISS in its orbit is 92 minutes.

$vT = 2\pi(R+h)$ [1]

$7700T = 2\pi(6.37 \times 10^6 + 4.1 \times 10^5)$

$T = 92.2 = 92$ min [1]

[2]

(iv) The ISS is in a low Earth orbit. Suggest an advantage of this orbit as compared to higher orbits.

It requires less fuel to launch, and hence it is less expensive.

It is easier to access for maintenance and repair.

....[1]

Higher resolution of images captured by ISS of features on the surface of the Earth.

(c) The ISS has arrays of solar cells on its wings. These solar cells charge batteries which power the ISS. The wings always face the Sun.

7% of the energy of the sunlight incident on the cells is stored in the batteries. The total area of the cells facing the solar radiation is 2500 m^2. The intensity of solar radiation at the orbit of the ISS is 1.4 kW m^{-2} outside of the Earth's shadow and zero inside it. The ISS passes through the Earth's shadow for 35 minutes during each orbit.

By reference to **(b)(iii)**, calculate the average power delivered to the batteries during one orbit.

Power stored in batteries
= 0.07×Intensity×Area = $0.07 \times 1.4 \times 10^3 \times 2500 = 2.45 \times 10^5$ W [1]

Cells are in the Sun for 92 – 35 = 57 min [1]

Average power = $\frac{57}{92} \times 2.45 \times 10^5 = 1.5 \times 10^5$ W [1]

average power = ... W [3]

[Total: 10]

3 (a) Define the term *angular velocity*.

Angular velocity is the rate of change of angular displacement.

.... [1]

(b) A 10 kg baggage is left on a rotating baggage carousel at an airport as shown in Fig. 3.1.

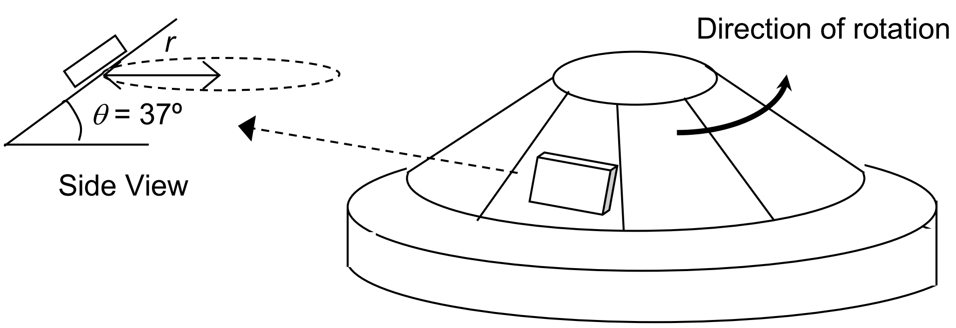


Fig. 3.1

The baggage stays at a fixed position on the slope of the carousel and rotates about in a circle of radius 10 m. The angle θ that the slanted surface makes with the horizontal is 37°. The frictional force acting on the baggage is 60 N. The baggage is moving in uniform circular motion.

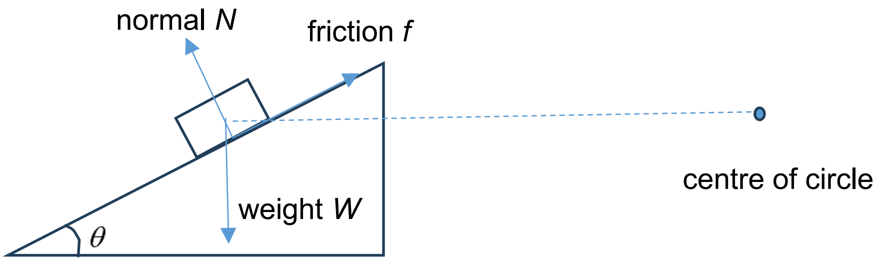
(i) Explain, using Newton's law(s) of motion, why the baggage will experience a net force towards the centre of the circle.

As the baggage is rotating at constant speed, according to Newton's First Law, a net force is needed to change the direction of motion. [1]

This change in direction of motion results in a rate of change of velocity (acceleration) directed towards the centre of rotation. By Newton's Second Law, the net force acts towards the centre of circle. [1]

[2]

(ii) Considering the forces acting on the baggage, show that the normal contact force is 78 N.



Consider forces perpendicular to slant surface,

$N = W\cos\theta$ [1]

$= (10 \times 9.81)\cos 37°$

$= 78.346$ [1]

$= 78$ N (to 2 s.f.)

[2]

(iii) Calculate the time required for the baggage to complete one full rotation.

Net force on baggage = $f\cos\theta - N\sin\theta$ [1]

$mr\omega^2 = f\cos\theta - N\sin\theta$

$mr\left(\frac{2\pi}{T}\right)^2 = f\cos\theta - N\sin\theta$ [1]

$T = 2\pi\sqrt{\frac{mr}{f\cos\theta - N\sin\theta}}$

$= 2\pi\sqrt{\frac{(10)(10)}{(60)\cos 37° - (78)\sin 37°}}$

$= 64$ s [1]

time = ... s [3]

[Total: 8]

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

An ideal gas is a theoretical gas that obeys the equation of state $pV = nRT$ at all pressures p, volumes V and thermodynamic temperatures T for a fixed mass of gas. R is the molar gas constant and n is the amount of gas in moles. [1]

....[1]

(b) Two vessels X and Y of volumes 10.0×10^{-4} m^3 and 3.0×10^{-4} m^3 are connected by a tube of negligible volume and kept at temperatures 200 K and 100 K respectively. Assume both vessels contain the same monatomic ideal gas.

Calculate the ratio of $\dfrac{\text{number of moles of gas in X}}{\text{number of moles of gas in Y}}$.

At steady state,
Pressure in X = Pressure in Y
Since $PV = nRT$ [1m for ideal gas equation and showing P are the same]

$$\frac{PV_X}{PV_Y} = \frac{n_X RT_X}{n_Y RT_Y}$$

$$\frac{n_X}{n_Y} = \frac{V_X T_Y}{V_Y T_X}$$

$$\frac{n_X}{n_Y} = \frac{10.0 \times 10^{-4}}{3.0 \times 10^{-4}} \times \frac{100}{200} = \frac{5}{3} = 1.67 \quad [1]$$

ratio = ... [2]

(c) An ideal gas in a container with a movable piston is heated. At the same time, the volume is increased such that the temperature of the gas always remains constant. By considering the First Law of Thermodynamics, explain why the temperature of the gas remains constant even though it is heated.

The First Law of Thermodynamics states that the increase in internal energy ΔU is the sum of heat provided to the system Q and the work done on the system W. [1]

If heat supplied Q is equal work done by gas (W = -Q), ΔU is zero. Since temperature of gas is proportional to internal energy, $T \propto U$, the temperature remains constant. [1] [2]

Also accept $\Delta T \propto \Delta U$

(d) Fig. 4.1 below shows how the pressure *p* of the gas varies with its volume *V* in part **(c)**. The volumes of the gas at initial and final states are V_A and V_B respectively. The pressures of the gas at initial and final are p_A and p_B respectively.

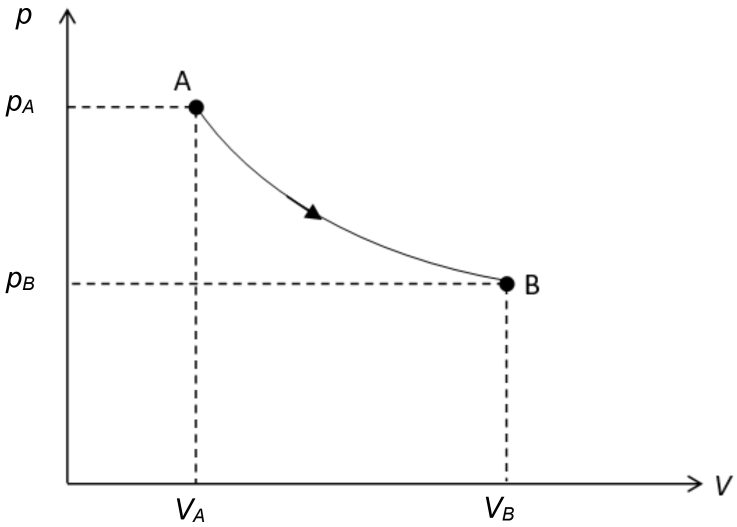


Fig. 4.1

The container in **(c)** is now insulated. The volume of the gas is increased to V_B again.

(i) Use the First law of Thermodynamics to explain whether the final pressure is higher or lower than p_B.

The piston is insulated, thus it is an adiabatic expansion, Q = 0. [1]

Since it is an expansion, *W* is negative. By First Law of Thermodynamics, $\Delta U = Q + W$, *W* is negative, Q = 0, thus ΔU is negative. Hence temperature falls. [1]

By ideal gas equation $PV = nRT$ [1], for the same final volume but at a lower temperature, the pressure must be lower than p_B. [1]

[3]

(ii) Sketch, on Fig. 4.1, a graph to show the variation with volume of pressure of the gas as its volume increases in the insulated container. [1]

Pressure drops below p_B, with correct shape and direction of arrow clearly indicated.

[Total: 9]

5 **(a)** The variation with time t of the potential difference V_1 across a resistor is shown in Fig. 5.1.

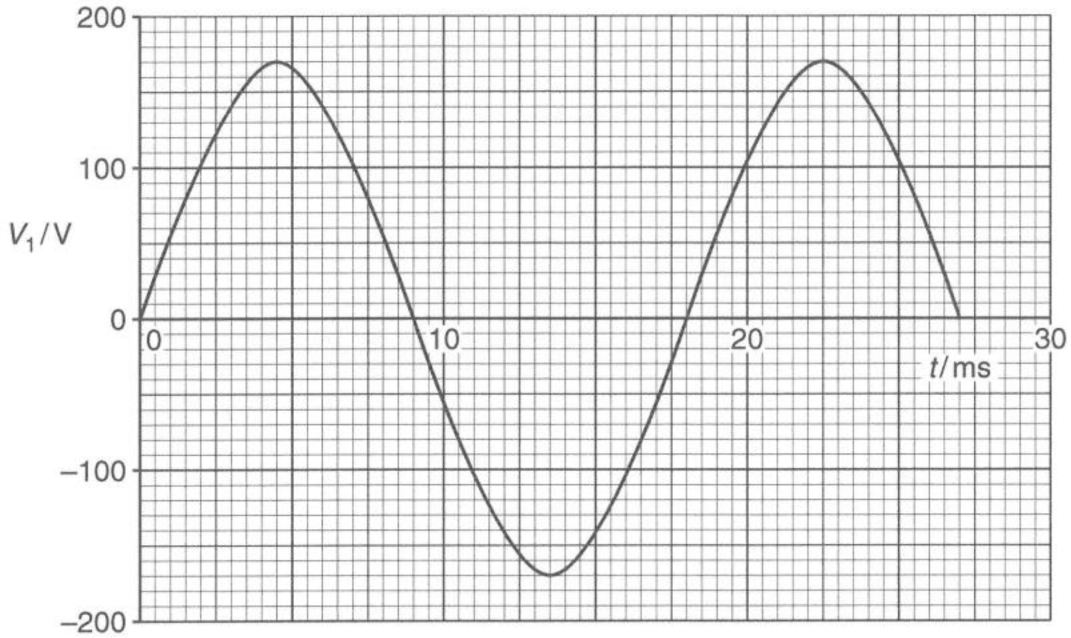


Fig. 5.1

The relation between V_1 and t is given by

$$V_1 = V_0 \sin \omega t .$$

Use Fig. 5.1 to determine the root-mean-square voltage of V_1.

Mean-square voltage = $\langle V^2 \rangle = \frac{1}{2} V_0^{\ 2} = \frac{1}{2} \times 170^2 = 14450$

Root-mean-square voltage = $\sqrt{\langle V^2 \rangle} = \sqrt{14450}$ = 120 V

root-mean-square voltage = ... V [1]

(b) The potential difference V_1 shown in Fig. 5.1 is connected to an ideal transformer, as shown in Fig. 5.2. The primary coil has 500 turns and the secondary coil has 20 turns. The secondary coil is connected to an open switch and a 15 Ω resistor.

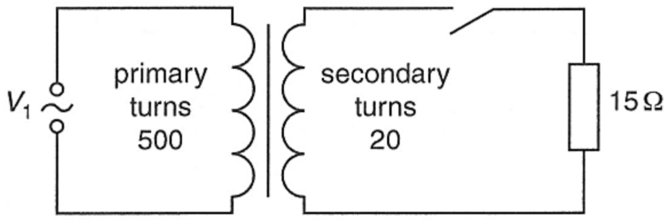


Fig. 5.2

The switch in the secondary circuit is now closed.

Determine

(i) the peak current in the 15 Ω resistor,

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

Comparing peak voltages,

$$\frac{V_s}{170} = \frac{20}{500}$$

Peak secondary voltage = V_s = 6.8 V

Peak current = $I = \frac{V}{R} = \frac{6.8}{15}$ = 0.45 A

peak current = ... A [2]

(ii) the mean power dissipated in the 15 Ω resistor.

r.m.s. secondary voltage = $V_{rms} = \frac{V_0}{\sqrt{(2)}} = \frac{6.8}{\sqrt{(2)}}$ = 4.8 V

Mean power dissipated in resistor = $\langle P \rangle = \left\langle \frac{V^2}{R} \right\rangle = \frac{{V_{rms}}^2}{R} = \frac{4.8^2}{15}$ = 1.5 W

mean power dissipated = ... W [2]

(c) For a non-ideal transformer, suggest why thermal energy is generated in the soft iron core when the transformer is in use.

The magnetic flux generated by the primary coil changes with time continuously. [1] By Faraday's Law, this means that there is an induced e.m.f. within the soft iron core. This induced e.m.f. results in eddy currents in the core that produce heat due to joule heating. [1]

[2]

[Total:7]

6 A single-turn copper square frame of length L is rotated with constant angular speed ω by an external torque in a constant magnetic field of flux density B. The frame rotates counter-clockwise about the axis of rotation as shown in Fig. 6.1.

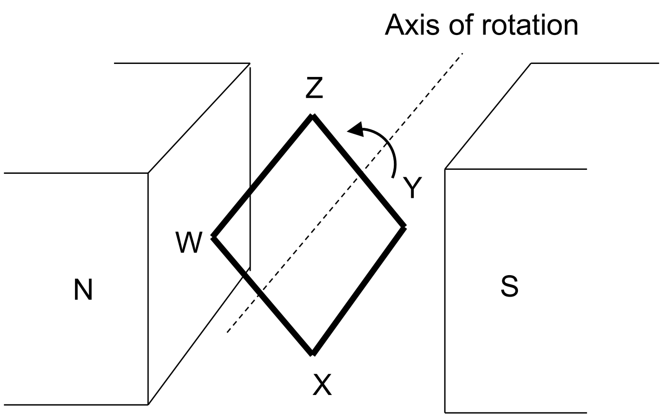


Fig. 6.1

Fig. 6.2 shows the side view of the coil when WX is at an angle θ above the horizontal.

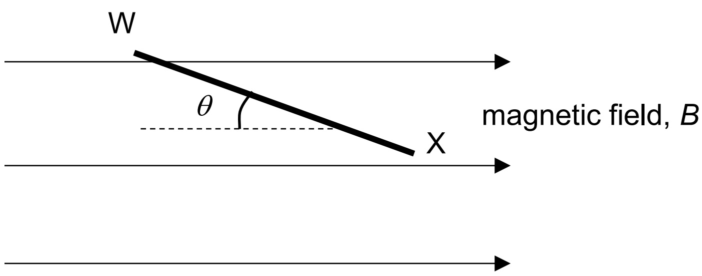


Fig. 6.2

(a) State the direction of the induced current in the frame.

In the direction WXYZW. [1] (accept WX)

....[1]

(b) Explain why an external torque is required to maintain the rotation of the frame at a constant angular speed.

The changing magnetic flux linkage produces an induced emf, and hence current due to Faraday's law. [1]

The force due to this induced current opposes the motion by Lenz' law. [1]

....[2]

(c) **(i)** At the instant shown in Fig. 6.2, write down an expression for the flux linkage in the coil in terms of B, θ and L.

The flux through the frame is $\phi = (B\sin\theta)L^2$

[1]

(ii) Hence show that the magnitude of the induced e.m.f. in the coil at this instant is $|\varepsilon| = BL^2\omega\cos\theta$.

$\phi = BL^2 \sin\omega t$ [1]

By Faraday's Law,

$$|\varepsilon| = \left|\frac{d\phi}{dt}\right| = BL^2\omega\cos\omega t = BL^2\omega\cos\theta$$ [1]

[2]

(d) The resistance of the frame is 5.0 Ω and the length L of the square frame is 0.20 m. The frame is rotated in the magnetic field of flux density 1.0 T at an angular frequency of 10 rad s^{-1}. Using your expression in **(c)(ii)**, calculate the average power dissipated in the frame.

$$P = \frac{\varepsilon^2}{R}$$

$$P = \frac{B^2L^4\omega^2\cos^2\theta}{R} = \frac{B^2L^4\omega^2\cos^2\omega t}{R} = P_0\cos^2\omega t$$ [1]

$$\langle P \rangle = \frac{P_0}{2}$$ [1]

$$\langle P \rangle = \frac{B^2L^4\omega^2}{2R} = \frac{1.0^2 \times 0.20^4 \times 10^2}{2 \times 5.0} = 16 \text{ mW}$$ [1]

average power dissipated = ... W [3]

[Total: 9]

7 **(a)** **(i)** Describe the *photoelectric effect* in terms of energy.

When electromagnetic radiation is incident upon the surface of a material, if its frequency exceeds the threshold frequency of the material, then it is able to eject electrons from the surface. [1] Part of the energy of the incident photon is used to remove an electron and the remaining energy appears as the kinetic energy of the ejected electron. [1]

....[2]

(ii) Explain one way in which the photoelectric effect provides evidence for the particulate nature, and not wave nature, of electromagnetic radiation.

Experimental observations show that no electrons are emitted unless the frequency of the monochromatic incident light is greater than a minimum (threshold) value regardless of the light intensity. On the contrary, wave theory predicts that the photoelectric effect should occur for any frequency of the incident light, and that its intensity can be increased to cause photoelectron emission If the light frequency is too low. [1] This observation suggests that the energy of the incident light has a particulate nature in that each photon has a fixed amount of energy. If frequency of the incident photon is less than the threshold frequency of the target metal, energy of the incident photon is insufficient to overcome the work function of the metal. Increasing the intensity would only increase the number of photons arriving per unit time, but the energy of each photon remains insufficient to cause photoelectric effect. [1]

(b) The graph drawn in Fig. 7.1 shows how the maximum kinetic energy E_k of a photoelectron from a particular material varies with the frequency *f* of the electromagnetic radiation that causes the emission of photoelectrons.

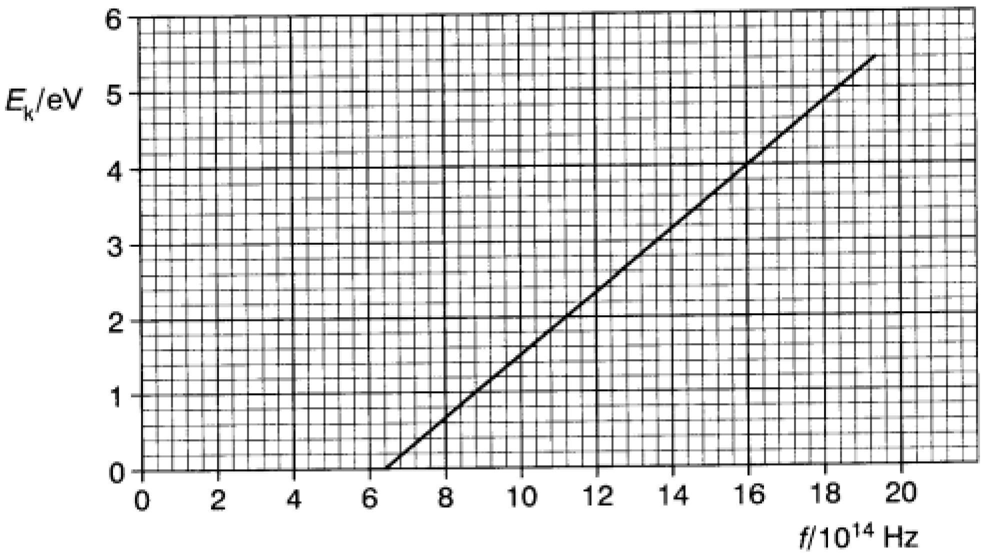


Fig. 7.1

(i) Use the graph to determine

1. the threshold frequency for this material,

At the threshold frequency, electrons are emitted with near-zero KE.
So, threshold frequency = 6.4×10^{14} Hz

threshold frequency = ... Hz [1]

2. the maximum kinetic energy of photoelectrons from this material when it is illuminated with electromagnetic radiation of frequency 18.0×10^{14} Hz.

From graph, when f = 18.0×10^{14} Hz,
Max KE = 4.8 eV [1]
= $4.8 \times 1.6 \times 10^{-19}$ J
= 7.68×10^{-19} J [1]

OR
Using the photoelectric equation,
Photon energy = Work function + max. KE of electrons
$hf = \phi + KE_{max}$
At threshold frequency,
work function = photon energy
$\phi = hf_0$
$hf = hf_0 + KE_{max}$
$6.63 \times 10^{-34} \times 18.0 \times 10^{14} = 6.63 \times 10^{-34} \times 6.4 \times 10^{14} + KE_{max}$
KE_{max} = <u>7.7×10^{-19} J</u>

maximum kinetic energy = ... J [2]

(ii) Determine the minimum potential difference between the electrodes in the photoelectric experiment that is needed to reduce the photocurrent to zero.

Loss in KE = Gain in electric PE
$\Delta KE = q\Delta V$
$7.7 \times 10^{-19} = 1.6 \times 10^{-19} \times \Delta V$
ΔV = <u>4.8 V</u>

minimum potential difference = ... V [2]

(c) Electromagnetic waves have a wave nature as well as a particulate nature. This is known as the wave-particle duality. Describe an experiment in which particles exhibit wave nature.

<u>Possible answers</u>:
- When a beam of electrons passes through a thin film of graphite, concentric rings are seen on a fluorescent screen, revealing the occurrence of interference of electron matter waves.
- When a beam of electrons is reflected from a surface of atoms arranged in a regular pattern, constructive interference is observed in certain directions, showing that the electrons are behaving as waves as they interact with the atoms.

[1]

[Total: 10]

Section B

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

8 **(a)** State what is meant by the *binding energy* of a nucleus and how it is related to the mass defect.

Binding energy is the energy required to separate to infinity all the constituent nucleons in the nucleus.

It is (the energy equivalent of mass defect and) related to mass defect in the equation Binding energy = (mass defect) $\times$ c^2

[2]

(b) The binding energy graph on Fig. 8.1 shows the variation with nucleon number *A* of the binding energy per nucleon. Some common nuclides are plotted on the graph, with a few of them labelled as shown.

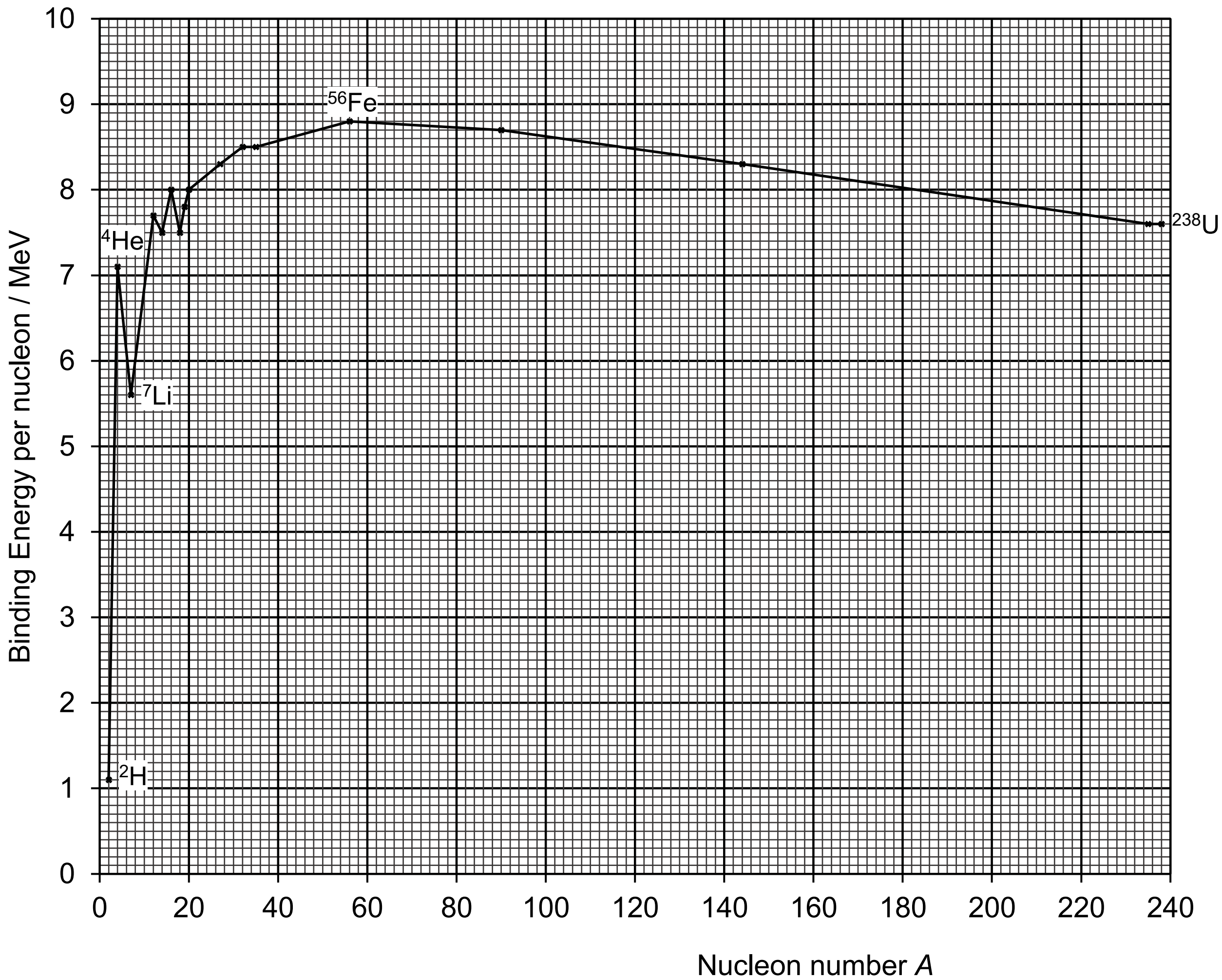


Fig. 8.1

(i) Explain why hydrogen-1 is not typically included in a binding energy graph.

H-1 is a proton which is a nucleon/constituent particle of the nucleus. Hence it has no binding energy or there is no meaning to binding energy of a proton. (identify & reasoning) [1]

[1]

(ii) A nuclear power station uses uranium-235 as fuel in fission reactions. One possible fission reaction is

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{144}_{54}Xe + ^{90}_{38}Sr + 2^{1}_{0}n\,.$$

1. Use data from Fig. 8.1 to show that energy released in the reaction is about 190 MeV.

Energy released
= total final BE – total initial BE
= (144 x 8.3) + (90 x 8.7) – (235 x 7.6) [1]
= 192.2 MeV [1]
= 190 MeV

[2]

2. Hence, calculate the energy released in the fission of 1 kg of uranium-235.

Energy released
= no of reactions x 190 MeV
= (1/235u) x 190 MeV [1]
= 4.9 x 10^{26} MeV [1]

energy released = ... MeV [2]

(c) A small sample of waste produced by the reactor in **(b)(ii)** contains strontium-90 ($^{90}_{38}Sr$). Strontium-90 is radioactive and undergoes beta decay into a daughter nuclide Yttrium- 90 (Y).

(i) In beta decay, it was discovered that an antineutrino ($\bar{\nu}$) must be emitted in order that two conservation laws are not violated. State the two conservation laws.

Conservation of momentum and Conservation of energy/mass-energy.
....

....[1]

(ii) Complete the beta decay equation, including all the decay products.

$$^{90}_{38}Sr \rightarrow \boxed{^{90}_{39}Y + ^{0}_{-1}\beta + \bar{\nu}}$$ [1]

(Optional to include antineutrino)

(iii) A radiation detector is placed close to the sample to measure the count rate for strontium-90 found in the sample. Fig. 8.2 below shows the variation with time t of the count rate.

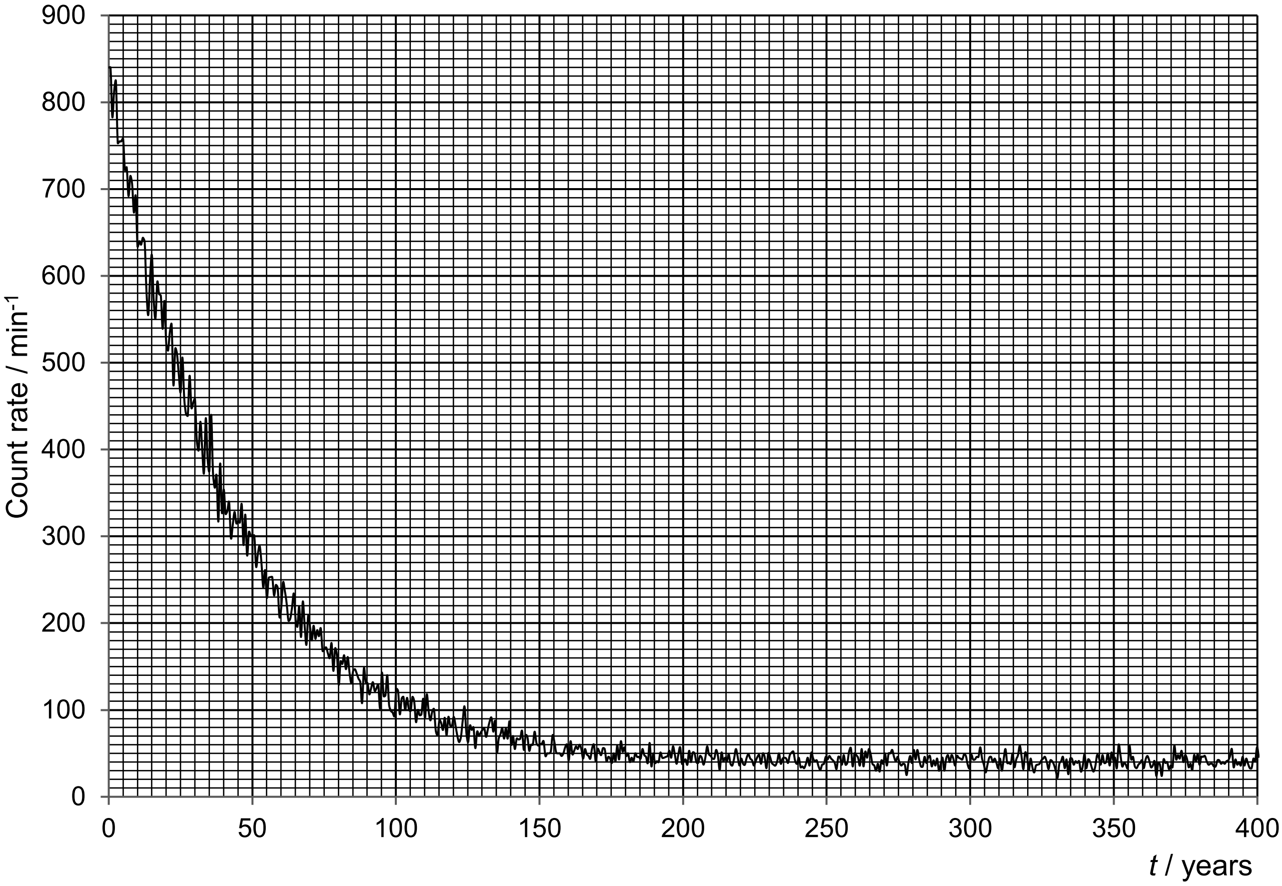


Fig. 8.2

1. State the feature of Fig. 8.2 that indicates the random nature of radioactive decay.

   Fluctuations on the curve / curve is not smooth

   ....[1]

2. Use Fig. 8.2 to determine the half-life of strontium-90.

Background count rate = 40 min^{-1} considered backgrd in calculation of $t_{1/2}$ (allow 30-50) [1]

$t_{1/2,\,1}$
Actual count rate at t=0 = 840 – 40 = 800 min^{-1}
After 1 $t_{1/2}$, actual count rate = 400 min^{-1}
measured count rate = 400 + 40 = 440 min^{-1}
From graph, $t_{1/2}$ = 35 – 0 = 35 yrs method to determine $t_{1/2}$ [1]

$t_{1/2,\,2}$
Actual count rate at t=50 yr = 300 – 40 = 260 min^{-1}
After 1 $t_{1/2}$, actual count rate = 130 min^{-1}
measured count rate = 130 +40 = 170 min^{-1}
From graph, $t_{1/2}$ = 75 – 50 = 25 yrs

Average $t_{1/2}$ = (35 + 25)/2 = 30 years
determined half-life at least twice and find $<t_{1/2}>$, range within 26 – 32 yrs [1]

half-life = ... years [4]

3. Hence, determine the probability that a nuclide of strontium-90 will undergo decay in 1 year.

Probability of decay in 1 yr = Probability of decay per unit time × 1 yr
= λ × 1 yr
= (ln 2 / $t_{1/2}$) × 1 yr
= (ln 2) / (30 yr) × 1 yr [1]
= 0.023 or 2.3%

probability = ...[1]

(d) Nuclear fusion occurs in the core of stars composed of ionised gas. A possible fusion reaction is

$$^1_1H + ^1_1H \rightarrow ^2_1H + ^0_1e \ .$$

Each ^1_1H nuclide can be considered to be a sphere of radius 0.0010 pm. Fusion occurs when the two nuclides are able to overcome the force of repulsion between them and collide.

(i) Show that the minimum total kinetic energy required of the two ^1_1H nuclides for fusion to occur is 1.2×10^{-13} J.

By cons. of energy,
Total initial KE = Total final EPE
= $(+e)(+e) / (4\pi\varepsilon_o d)$
= $(1.6 \times 10^{-19})^2 / (4\pi\varepsilon_o \times 2 \times 0.0010 \times 10^{-12})$ [1]
= 1.15×10^{-13} J [1]
= 1.2×10^{-13} J

[2]

(ii) If the ionised gas is assumed to be ideal, determine the temperature of the gas required for fusion to occur.

Average KE of nuclide = 3/2 kT
$(1.2 \times 10^{-13}) / 2$ = 3/2 kT [1]
T = 2.9×10^9 K [1] (if used intermediate K, T = 2.8×10^9 K)

temperature = ... K [2]

(iii) The temperature of the core of the Sun is known to be about 1.5×10^7 K. With reference to **(d)(i)** and **(d)(ii)**, comment on the actual kinetic energy of the nuclei in the Sun's core.

Actual temperature of Sun is much cooler than temp calculated in (ii)
So Sun's core must involve nuclei with actual KE far above the average KE calculated in (i) (since fusion must occur). [1]
....[1]

[Total: 20]

9 **(a)** State what is meant by a *field of force*.

A field of force (or force field) is a region of space in which a particle experiences a force due to a physical property that it possesses. [1]

(b) Two parallel metal plates are separated by a distance of 6.0 cm in a vacuum, as shown in Fig. 9.1. The plates have length 16 cm and potential difference of 2400 V.

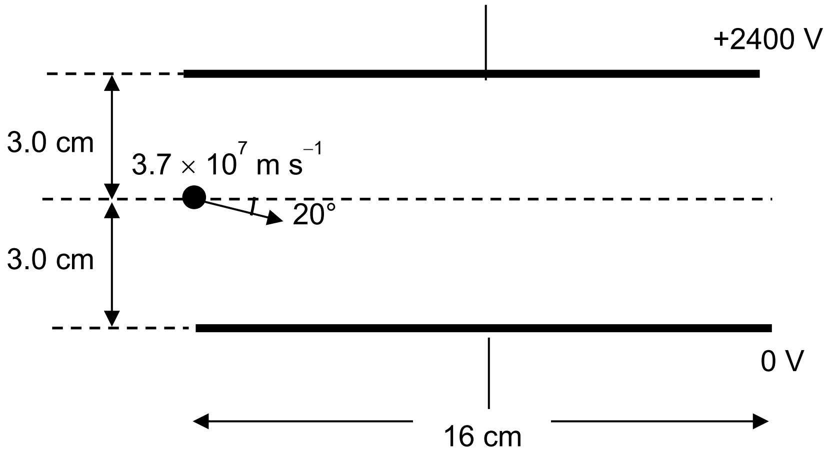


Fig. 9.1

An electron with speed 3.7×10^7 m s^{-1} enters the region between the plates. The initial direction of the electron is 20° below the midline between the plates.

(i) Calculate the acceleration of the electron and state its direction.

$$F = qE = q\frac{\Delta V}{d}$$
$$= \left(1.60 \times 10^{-19}\right)\frac{2400}{0.06}$$
$$= 6.40 \times 10^{-15} \text{ [1]}$$
$$a = \frac{F}{m}$$
$$= \frac{6.40 \times 10^{-15}}{9.11 \times 10^{-31}}$$
$$= 7.0252 \times 10^{15} \text{ upwards [2]}$$

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

direction = ...

[3]

(ii) Calculate the time taken for the electron to reach the other end of the plate.

$$t = \frac{s_x}{u_x}$$
$$= \frac{0.16}{3.7 \times 10^7 \cos 20°}$$
$$= 4.6018 \times 10^{-9} \text{ s}$$
$$= 4.60 \times 10^{-9} \text{ s}$$

time = ... s [1]

(iii) Use your answers in **(b)(i)** and **(ii)** to determine whether the electron will collide with any metal plate as it passes through the region between the plates.

Considering whether electron collides with top plate:

$$s_y = u_y t + \frac{1}{2} a_y t^2$$
$$= \left(3.7 \times 10^7 \sin 20°\right)\left(4.6018 \times 10^{-9}\right) + \frac{1}{2}\left(-7.0252 \times 10^{15}\right)\left(4.6018 \times 10^{-9}\right)^2$$
$$= -0.0162 \text{ m}$$ [1] which is less than -0.030 m

Considering whether electron collides with bottom plate:

when $v_y = 0$:

$$0 = u_y + a_y t$$
$$t = \frac{-\left(3.7 \times 10^7 \sin 20°\right)}{-7.0252 \times 10^{15}}$$
$$= 1.8013 \times 10^{-9}$$ [1]

$$s_y = u_y t + \frac{1}{2} a_y t^2$$
$$= \left(3.7 \times 10^7 \sin 20°\right)\left(1.8013 \times 10^{-9}\right) + \frac{1}{2}\left(-7.0252 \times 10^{15}\right)\left(1.8013 \times 10^{-9}\right)^2$$
$$= 0.0114 \text{ m}$$ [1] which is less than 0.030 m

Therefore, the electron will not collide with neither the top nor bottom plate. [1]

[3]

(iv) Hence, sketch, on Fig. 9.1, the path of the electron. [1]

(iv) Describe the path of the electron in the field.

For an electron in a uniform electric field, it is a parabolic path.
....[1]

(c) Another electron of the same speed now enters a region of uniform magnetic field of flux density 4.5 mT as shown in Fig. 9.2.

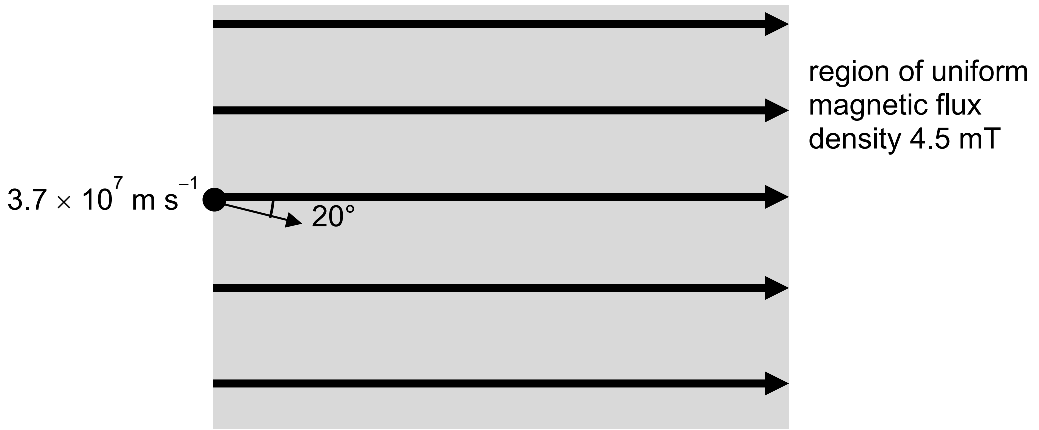


Fig. 9.2

The initial direction of the electron is at an angle of 20° to the direction of magnetic field.

(i) When the electron enters the magnetic field, the component of its velocity $v_\perp$ normal to the direction of the magnetic field causes the electron to begin to follow a circular path. Explain why.

When the velocity of the electron is perpendicular to the magnetic field, it gives rise to a magnetic force which is always perpendicular to its velocity [1]. This magnetic force on the moving charge provides a centripetal force [1] for it to move in a uniform circular motion. ....[2]

(ii) Calculate the radius of this circular path.

By Newton's Second Law, $\sum F = ma_c$

$$Bqv_\perp = \frac{mv_\perp^2}{r} \quad [1]$$

$$\left(4.5\times10^{-3}\right)\left(1.60\times10^{-19}\right) = \frac{\left(9.11\times10^{-31}\right)\left(3.7\times10^{7}\sin 20°\right)}{r}$$

$$r = 0.0160 \text{ m} \quad [1]$$

Correct component of velocity [1]

radius = ... m [3]

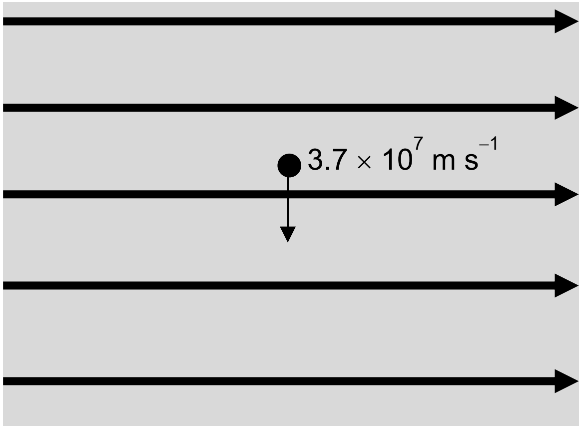
(iii) State the magnitude of the force on the electron due to the component of its velocity along the direction of the field.

Zero. ....[1]

(iv) Use your answers in **(c)(ii)** and **(iii)** to describe the resultant path of the electron in the field.

For an electron moving at an angle to a uniform magnetic field, it is a helical path. [1]

(d) Another electron of the same speed is projected downwards in the magnetic field as shown in Fig. 9.3. A uniform electric field is now switched on in the same region as the magnetic field. The magnitude of the electric field is adjusted so that the electron moves undeviated through the two fields.



Magnetic force is into the page, so electric force on the electron must be out of the page. Therefore electric field must be into the page. Draw crosses [1]

Fig. 9.3

(i) On Fig. 9.3, draw the direction of the electric field. [1]

(ii) Determine the magnitude *E* of the electric field strength.

By Newton's First Law, $\sum F = 0$

$Bqv = qE$ [1]

$(4.5 \times 10^{-3})(3.7 \times 10^{7}) = E$

$E = 1.67 \times 10^{5}$ V/m [1]

E = ... V m^{-1} [2]

[Total: 20]