

Surname		Other Names	
Centre Number		Candidate Number	
Candidate Signature			

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General Certificate of Education  
 June 2003  
 Advanced Level Examination



**PHYSICS (SPECIFICATION A) PHA8/W**  
**Unit 8 Nuclear Instability: Turning Points in Physics Option**

Friday 20 June 2003 Afternoon Session

**In addition to this paper you will require:**

- a calculator;
- a pencil and a ruler.

Time allowed: 1 hour 15 minutes

**Instructions**

- Use blue or black ink or ball-point pen.
- Fill in the boxes at the top of this page.
- Answer **all** questions in the spaces provided. All working must be shown.
- Do all rough work in this book. Cross through any work you do not want marked.

**Information**

- The maximum mark for this paper is 40.
- Mark allocations are shown in brackets.
- The paper carries 10% of the total marks for Physics Advanced.
- A *Data Sheet* is provided on pages 3 and 4. You may wish to detach this perforated sheet at the start of the examination.
- You are expected to use a calculator where appropriate.
- In questions requiring description and explanation you will be assessed on your ability to use an appropriate form and style of writing, to organise relevant information clearly and coherently, and to use specialist vocabulary where appropriate. The degree of legibility of your handwriting and the level of accuracy of your spelling, punctuation and grammar will also be taken into account.

For Examiner's Use			
Number	Mark	Number	Mark
1			
2			
3			
4			
5			
Total (Column 1)	→		
Total (Column 2)	→		
TOTAL			
Examiner's Initials			

**Data Sheet**

- A perforated *Data Sheet* is provided as pages 3 and 4 of this question paper.
- This sheet may be useful for answering some of the questions in the examination.
- You may wish to detach this sheet before you begin work.

**Fundamental constants and values**

Quantity	Symbol	Value	Units
speed of light in vacuo	$c$	$3.00 \times 10^8$	$\text{m s}^{-1}$
permeability of free space	$\mu_0$	$4\pi \times 10^{-7}$	$\text{H m}^{-1}$
permittivity of free space	$\epsilon_0$	$8.85 \times 10^{-12}$	$\text{F m}^{-1}$
charge of electron	$e$	$1.60 \times 10^{-19}$	C
the Planck constant	$h$	$6.63 \times 10^{-34}$	J s
gravitational constant	$G$	$6.67 \times 10^{-11}$	$\text{N m}^2 \text{kg}^{-2}$
the Avogadro constant	$N_A$	$6.02 \times 10^{23}$	$\text{mol}^{-1}$
molar gas constant	$R$	8.31	$\text{J K}^{-1} \text{mol}^{-1}$
the Boltzmann constant	$k$	$1.38 \times 10^{-23}$	$\text{J K}^{-1}$
the Stefan constant	$\sigma$	$5.67 \times 10^{-8}$	$\text{W m}^{-2} \text{K}^{-4}$
the Wien constant	$\alpha$	$2.90 \times 10^{-3}$	m K
electron rest mass	$m_e$	$9.11 \times 10^{-31}$	kg
(equivalent to $5.5 \times 10^{-4}\text{u}$ )			
electron charge/mass ratio	$e/m_e$	$1.76 \times 10^{11}$	$\text{C kg}^{-1}$
proton rest mass	$m_p$	$1.67 \times 10^{-27}$	kg
(equivalent to 1.00728u)			
proton charge/mass ratio	$e/m_p$	$9.58 \times 10^7$	$\text{C kg}^{-1}$
neutron rest mass	$m_n$	$1.67 \times 10^{-27}$	kg
(equivalent to 1.00867u)			
gravitational field strength	$g$	9.81	$\text{N kg}^{-1}$
acceleration due to gravity	$g$	9.81	$\text{m s}^{-2}$
atomic mass unit	$u$	$1.661 \times 10^{-27}$	kg
(1u is equivalent to 931.3 MeV)			

**Fundamental particles**

Class	Name	Symbol	Rest energy /MeV
photon	photon	$\gamma$	0
lepton	neutrino	$\nu_e$	0
		$\nu_\mu$	0
	electron	$e^\pm$	0.510999
	muon	$\mu^\pm$	105.659
mesons	pion	$\pi^\pm$	139.576
		$\pi^0$	134.972
	kaon	$K^\pm$	493.821
		$K^0$	497.762
baryons	proton	p	938.257
	neutron	n	939.551

**Properties of quarks**

Type	Charge	Baryon number	Strangeness
u	$+\frac{2}{3}$	$+\frac{1}{3}$	0
d	$-\frac{1}{3}$	$+\frac{1}{3}$	0
s	$-\frac{1}{3}$	$+\frac{1}{3}$	-1

**Geometrical equations**

- arc length =  $r\theta$
- circumference of circle =  $2\pi r$
- area of circle =  $\pi r^2$
- area of cylinder =  $2\pi rh$
- volume of cylinder =  $\pi r^2 h$
- area of sphere =  $4\pi r^2$
- volume of sphere =  $\frac{4}{3}\pi r^3$

**Mechanics and Applied Physics**

- $v = u + at$
- $s = \left(\frac{u+v}{2}\right)t$
- $s = ut + \frac{at^2}{2}$
- $v^2 = u^2 + 2as$
- $F = \frac{\Delta(mv)}{\Delta t}$
- $P = Fv$
- $\text{efficiency} = \frac{\text{power output}}{\text{power input}}$
- $\omega = \frac{v}{r} = 2\pi f$
- $a = \frac{v^2}{r} = r\omega^2$
- $I = \sum mr^2$
- $E_k = \frac{1}{2} I\omega^2$
- $\omega_2 = \omega_1 + \alpha t$
- $\theta = \omega_1 t + \frac{1}{2} \alpha t^2$
- $\omega_2^2 = \omega_1^2 + 2\alpha\theta$
- $\theta = \frac{1}{2} (\omega_1 + \omega_2)t$
- $T = I\alpha$
- angular momentum =  $I\omega$
- $W = T\theta$
- $P = T\omega$
- angular impulse = change of angular momentum =  $Tt$
- $\Delta Q = \Delta U + \Delta W$
- $\Delta W = p\Delta V$
- $pV^\gamma = \text{constant}$
- work done per cycle = area of loop
- input power = calorific value  $\times$  fuel flow rate
- indicated power as (area of  $p-V$  loop)  $\times$  (no. of cycles/s)  $\times$  (no. of cylinders)
- friction power = indicated power - brake power
- $\text{efficiency} = \frac{W}{Q_{in}} = \frac{Q_{in} - Q_{out}}{Q_{in}}$
- maximum possible
- $\text{efficiency} = \frac{T_H - T_C}{T_H}$

**Fields, Waves, Quantum Phenomena**

- $g = \frac{F}{m}$
- $g = -\frac{GM}{r^2}$
- $g = -\frac{\Delta V}{\Delta x}$
- $V = -\frac{GM}{r}$
- $a = -(2\pi f)^2 x$
- $v = \pm 2\pi f \sqrt{A^2 - x^2}$
- $x = A \cos 2\pi ft$
- $T = 2\pi \sqrt{\frac{m}{k}}$
- $T = 2\pi \sqrt{\frac{l}{g}}$
- $\lambda = \frac{\omega s}{D}$
- $d \sin \theta = n\lambda$
- $\theta = \frac{\lambda}{D}$
- $i_1 n_2 = \frac{\sin \theta_1}{\sin \theta_2} = \frac{c_1}{c_2}$
- $i_1 n_2 = \frac{n_2}{n_1}$
- $\sin \theta_c = \frac{1}{n}$
- $E = hf$
- $hf = \phi + E_k$
- $hf = E_1 - E_2$
- $\lambda = \frac{h}{p} = \frac{h}{mv}$
- $c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$

**Electricity**

- $\epsilon = \frac{E}{Q}$
- $\epsilon = I(R + r)$
- $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots$
- $R_T = R_1 + R_2 + R_3 + \dots$
- $P = I^2 R$
- $E = \frac{F}{Q} = \frac{V}{d}$
- $E = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2}$
- $E = \frac{1}{2} QV$
- $F = BI l$
- $F = BQv$
- $Q = Q_0 e^{-t/RC}$
- $\Phi = BA$

$$\text{magnitude of induced e.m.f.} = N \frac{\Delta\Phi}{\Delta t}$$

$$I_{\text{rms}} = \frac{I_0}{\sqrt{2}}$$

$$V_{\text{rms}} = \frac{V_0}{\sqrt{2}}$$

### Mechanical and Thermal Properties

$$\text{the Young modulus} = \frac{\text{tensile stress}}{\text{tensile strain}} = \frac{F}{A} \frac{l}{e}$$

$$\text{energy stored} = \frac{1}{2} Fe$$

$$\Delta Q = mc \Delta\theta$$

$$\Delta Q = ml$$

$$pV = \frac{1}{3} Nmc^2$$

$$\frac{1}{2} mc^2 = \frac{3}{2} kT = \frac{3RT}{2N_A}$$

### Nuclear Physics and Turning Points in Physics

$$\text{force} = \frac{eV_p}{d}$$

$$\text{force} = Bev$$

$$\text{radius of curvature} = \frac{mv}{Be}$$

$$\frac{eV}{d} = mg$$

$$\text{work done} = eV$$

$$F = 6\pi\eta rv$$

$$I = k \frac{I_0}{x^2}$$

$$\frac{\Delta N}{\Delta t} = -\lambda N$$

$$\lambda = \frac{h}{\sqrt{2meV}}$$

$$N = N_0 e^{-\lambda t}$$

$$T_{1/2} = \frac{\ln 2}{\lambda}$$

$$R = r_0 A^{1/3}$$

$$E = mc^2 = \frac{m_0 c^2}{\left(1 - \frac{v^2}{c^2}\right)^{1/2}}$$

$$l = l_0 \left(1 - \frac{v^2}{c^2}\right)^{1/2}$$

$$t = \frac{t_0}{\left(1 - \frac{v^2}{c^2}\right)^{1/2}}$$

### Astrophysics and Medical Physics

Body	Mass/kg	Mean radius/m
Sun	$2.00 \times 10^{30}$	$7.00 \times 10^8$
Earth	$6.00 \times 10^{24}$	$6.40 \times 10^6$

$$1 \text{ astronomical unit} = 1.50 \times 10^{11} \text{ m}$$

$$1 \text{ parsec} = 206265 \text{ AU} = 3.08 \times 10^{16} \text{ m} = 3.26 \text{ ly}$$

$$1 \text{ light year} = 9.45 \times 10^{15} \text{ m}$$

$$\text{Hubble constant } (H) = 65 \text{ km s}^{-1} \text{ Mpc}^{-1}$$

$$M = \frac{\text{angle subtended by image at eye}}{\text{angle subtended by object at unaided eye}}$$

$$M = \frac{f_o}{f_e}$$

$$m - M = 5 \log \frac{d}{10}$$

$$\lambda_{\text{max}} T = \text{constant} = 0.0029 \text{ m K}$$

$$v = Hd$$

$$P = \sigma AT^4$$

$$\frac{\Delta f}{f} = \frac{v}{c}$$

$$\frac{\Delta \lambda}{\lambda} = -\frac{v}{c}$$

$$R_s \approx \frac{2GM}{c^2}$$

### Medical Physics

$$\text{power} = \frac{1}{f}$$

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f} \text{ and } m = \frac{v}{u}$$

$$\text{intensity level} = 10 \log \frac{I}{I_0}$$

$$I = I_0 e^{-\mu x}$$

$$\mu_m = \frac{\mu}{\rho}$$

### Electronics

#### Resistors

Preferred values for resistors (E24)  
Series: 1.0 1.1 1.2 1.3 1.5 1.6 1.8 2.0 2.2  
2.4 2.7 3.0 3.3 3.6 3.9 4.3 4.7 5.1 5.6 6.2  
6.8 7.5 8.2 9.1 ohms  
and multiples that are ten times greater

$$Z = \frac{V_{\text{rms}}}{I_{\text{rms}}}$$

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \dots$$

$$C_T = C_1 + C_2 + C_3 + \dots$$

$$X_C = \frac{1}{2\pi f C}$$

### Alternating Currents

$$f = \frac{1}{T}$$

### Operational amplifier

$$G = \frac{V_{\text{out}}}{V_{\text{in}}} \quad \text{voltage gain}$$

$$G = -\frac{R_f}{R_1} \quad \text{inverting}$$

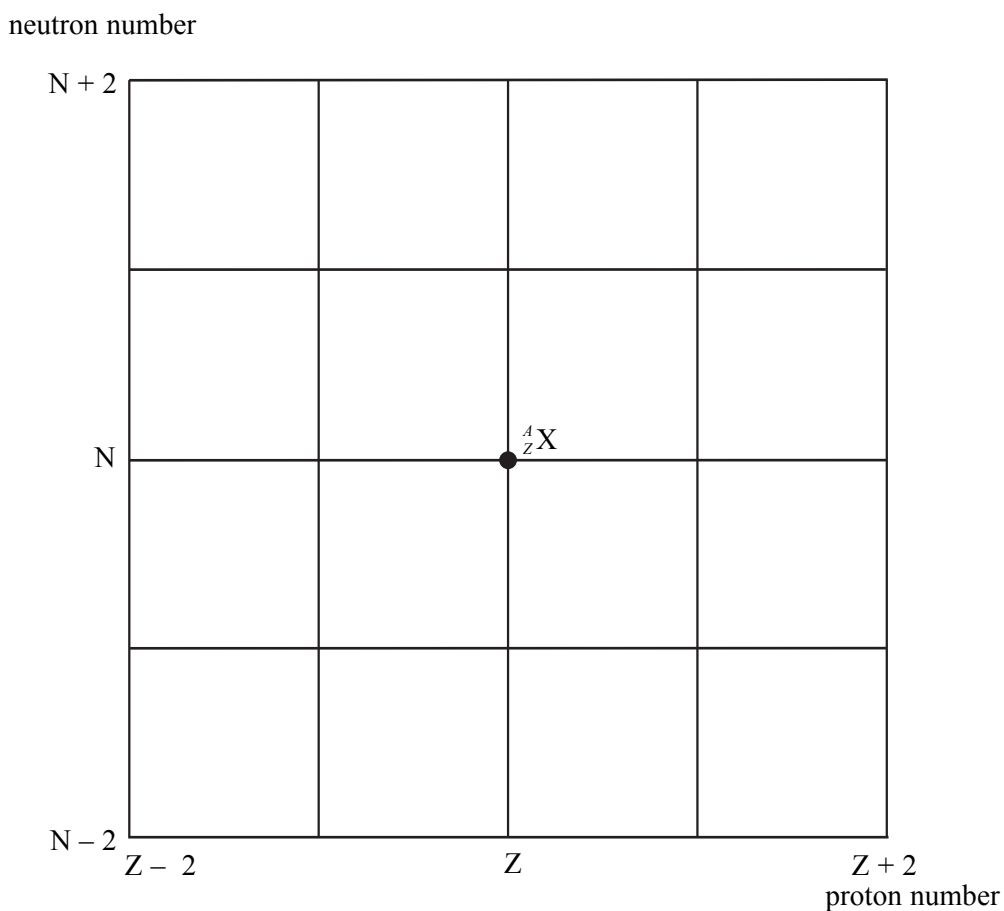
$$G = 1 + \frac{R_f}{R_1} \quad \text{non-inverting}$$

$$V_{\text{out}} = -R_f \left( \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} \right) \quad \text{summing}$$

## SECTION A: NUCLEAR INSTABILITY

Answer **all** parts of this question.

1 **Figure 1** shows a grid of neutron number against proton number. A nucleus  ${}^A_Z\text{X}$  is marked.



(a) Draw arrows on **Figure 1**, each starting on  ${}^A_Z\text{X}$  and ending on a daughter nucleus after the following transitions:

- (i)  $\beta^-$  emission (label this arrow A)  
 neutron emission (label this arrow B)  
 electron capture (label this arrow C).

(ii) Give the equation for electron capture by the nucleus  ${}^A_Z\text{X}$ .

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 (4 marks)

- (b) When  ${}_{12}^{27}\text{Mg}$  decays to  ${}_{13}^{27}\text{Al}$  by  $\beta^-$  decay, the daughter nucleus is produced in one of two possible excited states. These two states are shown in **Figure 2** together with their corresponding energies.

${}_{12}^{27}\text{Mg}$	$E/10^{-13}\text{J}$
	4.18
	1.63
	1.33
${}_{13}^{27}\text{Al}$	0.00 (ground state)

**Figure 2**

- (i) Calculate the maximum possible kinetic energy, in J, which an emitted  $\beta^-$  particle can have.
- .....
- .....
- (ii) The excited aluminium nuclei emit  $\gamma$  photons. Calculate each of the three possible  $\gamma$  photon energies in J.
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- .....
- .....
- (iii) Calculate the frequency of the most energetic  $\gamma$  photon emitted.
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(3 marks)

- (c) (i) State and explain **two** precautions that should be taken when working with a sample of  $^{27}_{12}\text{Mg}$  in a school laboratory.

You may be awarded marks for the quality of written communication in your answer.

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- (ii) Discuss which of the two types of radiation,  $\beta^-$  or  $\gamma$ , emitted from a sample of  $^{27}_{12}\text{Mg}$  would be the more hazardous.

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(3 marks)

10

**TURN OVER FOR THE NEXT QUESTION**

**SECTION B: TURNING POINTS IN PHYSICS**Answer **all** questions.

2 In an experiment to measure the charge of an oil droplet, a positively charged oil droplet was held stationary by means of a uniform electric field of strength  $4.9 \times 10^5 \text{ V m}^{-1}$ .

(a) (i) What was the direction of the electric field?

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(ii) Show that the specific charge of the oil droplet was  $2.0 \times 10^{-5} \text{ C kg}^{-1}$ .

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(3 marks)

(b) When the electric field was switched off the oil droplet fell and quickly reached constant speed. Explain why the oil droplet reached constant speed.

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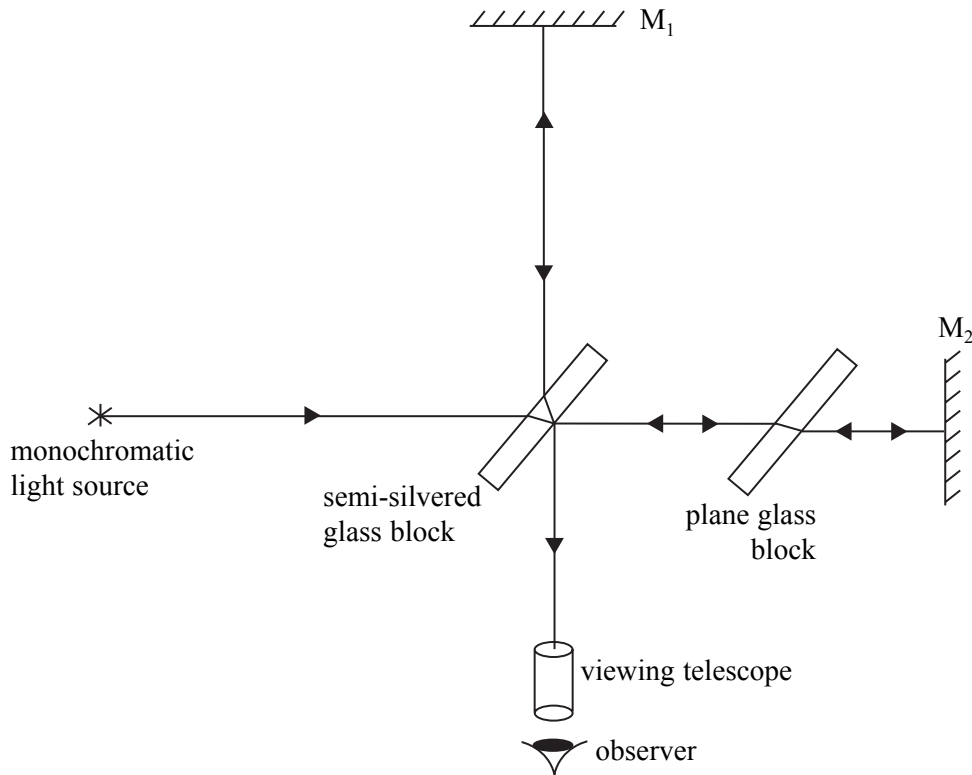
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(3 marks)

6



- 3 The Michelson-Morley experiment represented in the diagram was designed to find out if the speed of light depended on its direction relative to the Earth's motion through space. Interference fringes were seen by the observer.



- (a) (i) Explain why interference fringes were seen.

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- (ii) The interference fringe pattern did not shift when the apparatus was rotated by  $90^\circ$ . Explain the significance of this null observation.

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(5 marks)

(b) Einstein postulated that the speed of light in free space is invariant. Explain what is meant by this postulate.

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(2 marks)



4 (a) Describe **one** piece of evidence that shows that matter has

(i) a wave-like nature,

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(ii) a particle-like nature.

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(3 marks)

(b) For a proton of kinetic energy 5.0 MeV,

(i) show that its speed is  $3.1 \times 10^7 \text{ m s}^{-1}$ ,

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(ii) calculate its de Broglie wavelength.

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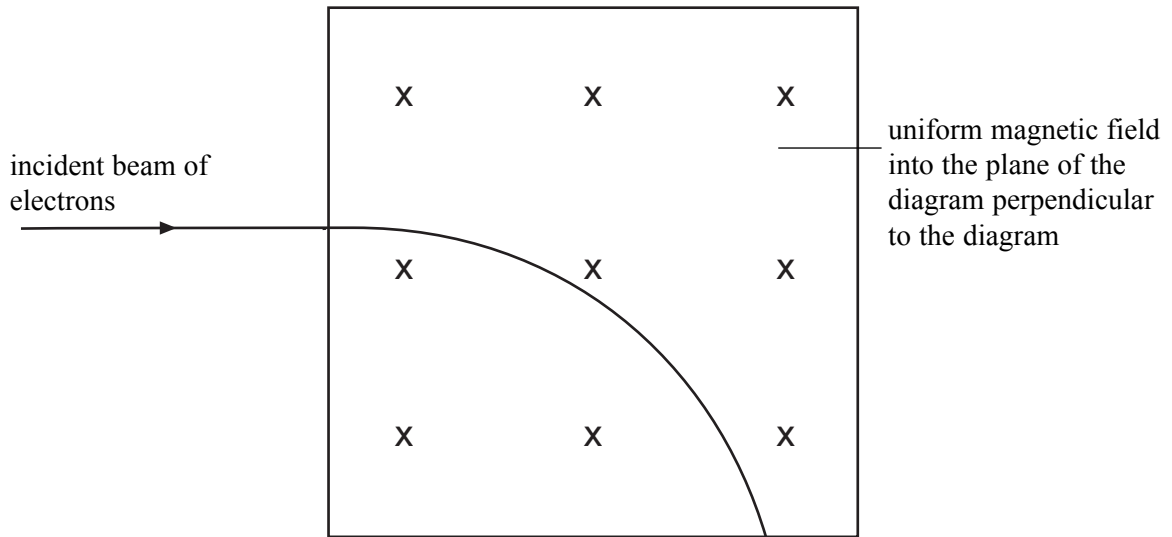
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(4 marks)

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7

**TURN OVER FOR THE NEXT QUESTION**

- 5 A narrow beam of electrons at a speed of  $3.2 \times 10^7 \text{ m s}^{-1}$  travels along a circular path in a uniform magnetic field of flux density,  $B$ , as shown in the diagram.



- (a) Explain why the path of the beam in the field is circular.

You may be awarded marks for the quality of written communication in your answer.

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(3 marks)

- (b) (i) Show that the speed,  $v$ , of the electrons in the field is given by

$$v = \frac{Ber}{m},$$

where  $r$  is the radius of the circular path of the beam in the field.

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- (ii) When the flux density was 7.3 mT, the radius of the circular path of the beam in the field was 25 mm. Use the data to calculate the specific charge of the electron.

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(5 marks)

**QUALITY OF WRITTEN COMMUNICATION** (2 marks)

**END OF QUESTIONS**

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8

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