MINISTRY OF EDUCATION, SINGAPORE
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CAMBRIDGE ASSESSMENT INTERNATIONAL EDUCATION
General Certificate of Education Advanced Level
Higher 2

CANDIDATE NAME

CENTRE NUMBER	S					INDEX NUMBER				

PHYSICS 9749/03

Paper 3 Longer Structured Questions

October/November 2021

2 hours

Candidates answer on the Question Paper.

No Additional Materials are required.

READ THESE INSTRUCTIONS FIRST

Write your Centre number, index number and 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 an HB pencil for any diagrams, graphs or rough working.
Do not use staples, paper clips, glue or correction fluid.
DO **NOT** WRITE ON ANY BARCODES.

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.

[Turn over

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Section A

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

1 In a child's toy, a small ball moves along a smooth track. The ball moves down a straight slope and then travels around a vertical circular loop, as shown in Fig. 1.1.

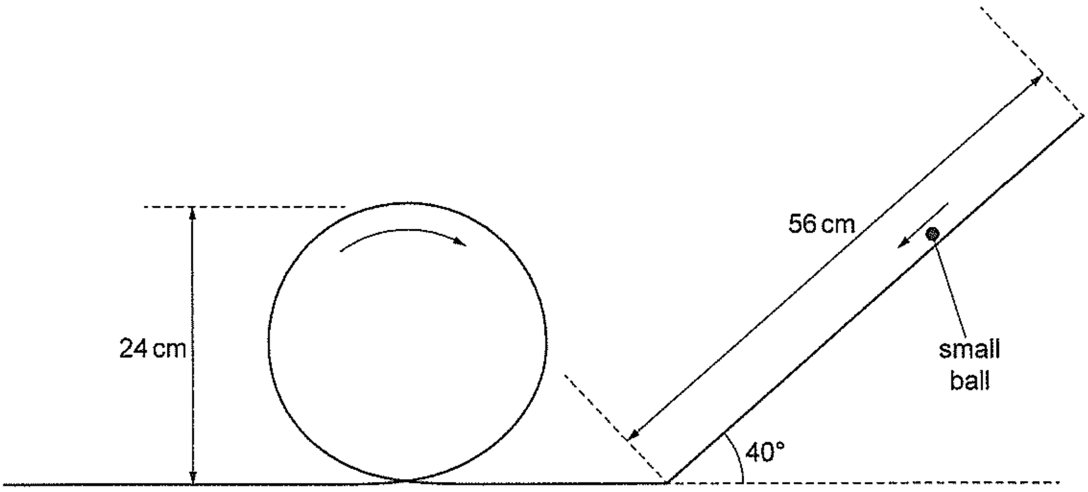

Fig. 1.1

The loop has a diameter of 24 cm.
The slope has a length of 56 cm and is inclined at an angle of 40° to the horizontal.
Initially, the ball is at rest at the top of the slope.

(a) For the ball moving down the slope:

(i) calculate the acceleration of the ball

$a = g\sin\theta = (9.81)\sin 40° = 6.3057$ ✓ [M1]

✓ [A1]

acceleration = 6.3 OR 6.31 m s^{-2} [2]

(ii) use your answer in **(a)(i)** to determine the speed of the ball at the bottom of the slope.

$v^2 = u^2 + 2as$

$v = \sqrt{0^2 + 2(6.3057)(0.56)}$ ✓ [M1]

$= 2.6575$

speed = 2.7 OR 2.66 ✓ [A1] m s^{-1} [2]

(b) The speed of the ball at the top of the loop is $1.5\,m\,s^{-1}$, as shown in Fig. 1.2.

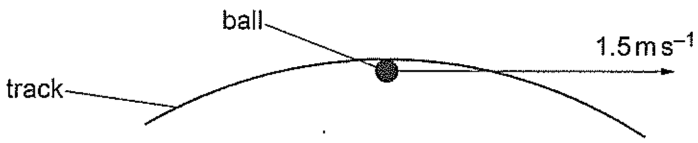

Fig. 1.2

The ball has a mass of 72 g.

Determine, for the ball at the top of the loop:

(i) the magnitude of the centripetal force acting on the ball

$$F_c = ma_c = \left(\frac{72}{1000}\right)\left(\frac{1.5^2}{0.12}\right) = 1.35\text{ N}$$ ✓ [M1]

force = 1.4 OR 1.35 N [2] ✓ [A1]

(ii) the magnitude and direction of the force due to the track acting on the ball.

$$N + mg = ma_c$$ ✓ [M1]

$$N = m(a_c - g) = \frac{72}{1000}\left(\frac{1.5^2}{0.12} - 9.81\right) = 0.6368\text{ N}$$

force = 0.64 OR 0.637 N ✓ [A1]

direction downwards ✓ [A1]

[3]

[Total: 9]

2 **(a)** The gravitational potential ϕ at a distance x from a point mass M is given by the expression

$$\phi = -\frac{GM}{x}$$

where G is the gravitational constant.

Explain why gravitational potential is a negative quantity. (Refer Physics Compendium)

Since infinity is denoted as zero ✓ [B1]

and gravitational force is attractive, ✓ [B1]

negative work is done when moving a unit ✓ [B1]

mass from infinity. [3]

(b) A planet of diameter 6.8×10^3 km has a mass of 6.2×10^{23} kg. The planet has no atmosphere and it may be assumed to be isolated in space.
The mass of the planet may be considered to be a point mass at its centre.

A meteorite collides with the planet. This causes a rock of mass 2.8 kg to be thrown up from the surface of the planet with a speed of $3.8 \times 10^3\,\text{m s}^{-1}$.

(i) Calculate the gravitational potential at the surface of the planet.

$$\phi = -\frac{GM}{r} = \frac{-(6.67\times10^{-11})(6.2\times10^{23})}{3.4\times10^{6}} = -1.216\times10^{7}$$

gravitational potential = -1.22×10^{7} OR -1.2×10^{7} J kg^{-1} [1] ✓ [A1]

$$\frac{GMm}{2r} = \frac{1}{2}mv^2$$

$$v = \sqrt{\frac{2GM}{r}}$$

$$= \sqrt{2\phi}$$

(ii) Use energy considerations, and your answer in **(b)(i)**, to determine whether the rock returns to the surface of the planet or travels out into space.

Escape speed $v_s = \sqrt{\dfrac{2\times6.67\times10^{-11}\times6.2\times10^{23}}{3.4\times10^{6}}}$ ✓ [B1]

$= 4932$ m/s $> 3.8\times10^{3}$ m/s ✓ [M1]

∴ rock returns to surface since its speed is less than escape speed of the planet. ✓ [A1] [3]

[Total: 7]

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3 **(a)** State what is meant by the *internal energy* of an ideal gas. (Refer Physics Compendium)

[M1] ✓ sum of microscopic kinetic energies

[A1] ✓ due to random motion of all the gas molecules in the system. (no PE for ideal gas) [2]

(b) A fixed mass of an ideal gas has a volume of $3.2 \times 10^{-3}\,m^3$ at a pressure of $1.0 \times 10^5\,Pa$ and a temperature of 12 °C.
The gas is heated at constant pressure so that its volume increases to $3.6 \times 10^{-3}\,m^3$ at temperature θ, as shown in Fig. 3.1.

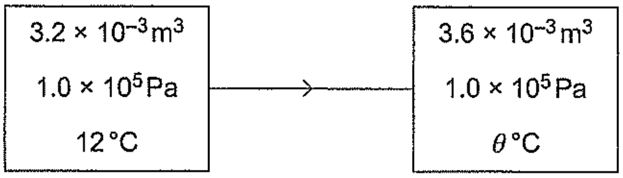

Fig. 3.1

(i) Calculate the final temperature θ, in degrees Celsius, of the gas.

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \quad \text{if } P = \text{constant}$$

$$\frac{3.2 \times 10^{-3}}{12 + 273.15} = \frac{3.6 \times 10^{-3}}{T + 273.15}$$ ✓ [M1]

$\theta = 47.64\,°C$ ✓ [A1]

θ = 48 OR 47.6 °C [2]

(ii) Determine the work done against the atmosphere during the expansion of the gas.

$$W = P\Delta V = (1.0 \times 10^5)(3.6 - 3.2) \times 10^{-3}$$ ✓ [M1]

$$= 40$$

✓ [A1]

work done = 40 J [2]

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(c) During the heating process in **(b)**, 101 J of thermal energy is supplied to the gas. For this heating process:

(i) use your answer in **(b)(ii)** to determine the increase in internal energy of the gas

$\Delta U = Q + W = 101 - 40 = 61 J$

increase = 61 J [1] ✓ [A1]

(ii) calculate the average increase in kinetic energy of a molecule of the gas.

$\Delta T = 47.64 - 12 = 35.64$ ✓ [C1]

$\Delta U = \frac{3}{2} k \Delta T$

$= \frac{3}{2}(1.38 \times 10^{-23})(35.64)$ ✓ [M1]

$= 7.377 \times 10^{-22}$

increase = 7.4×10^{-22} OR 7.38×10^{-22} OR 7.5×10^{-22} J [3] ✓ [A1]

[Total: 10]

Alternative :

$PV = NkT$

$N = \frac{PV}{kT} = \frac{(1.0 \times 10^5)(3.2 \times 10^{-3})}{(1.38 \times 10^{-23})(12 + 273.15)} = 8.132 \times 10^{22}$

$\therefore \frac{\Delta U}{N} = \frac{61}{8.132 \times 10^{22}} = 7.5 \times 10^{-22}$

4 A strip of steel is clamped at one end so that the strip is horizontal.
A mass M is attached to the other end, causing the strip to bend, as illustrated in Fig. 4.1.

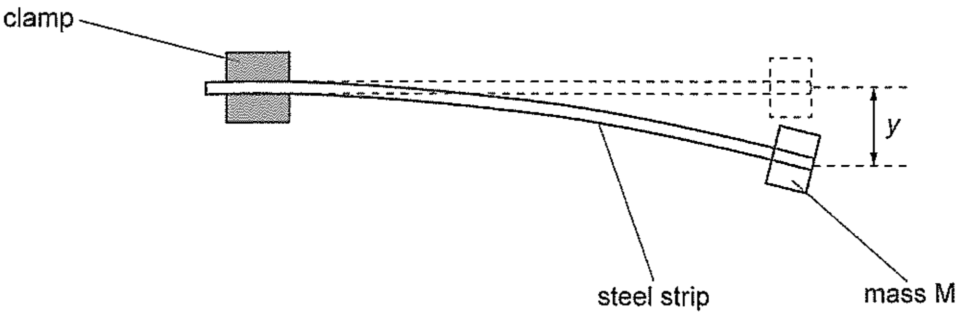
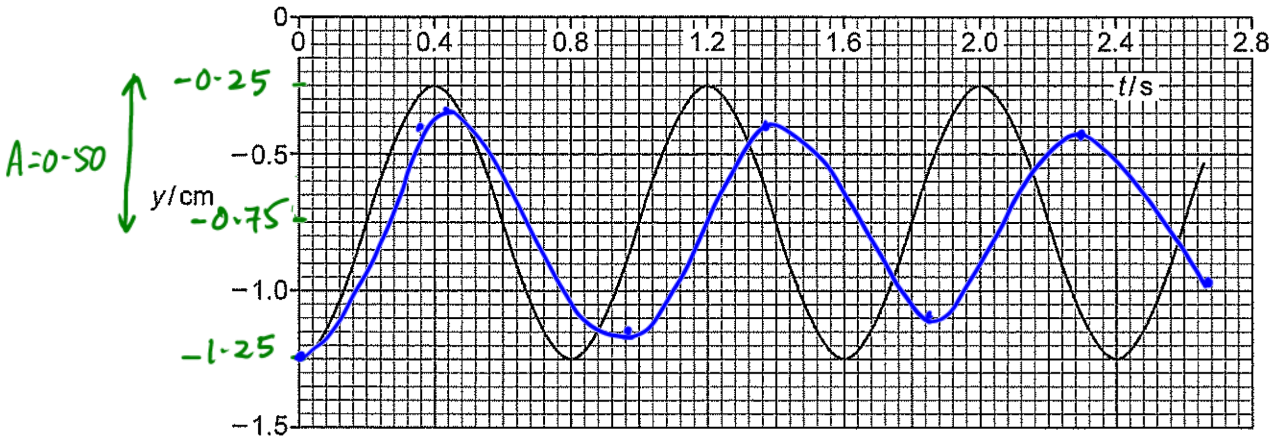


Fig. 4.1

The mass M is given a further vertical displacement and is then released. The subsequent motion of the mass on the end of the steel strip is simple harmonic.

The variation with time t of the total vertical displacement y of the mass M is shown in Fig. 4.2.



✓ decreasing amplitude [B1]

✓ increasing period [B1]

✓ 3 complete cycles. [B1]

Fig. 4.2

(a) Use Fig. 4.2 to determine, for the oscillations of the mass M:

(i) the amplitude x_0

x_0 = 0.50 OR 0.500 cm [1] ✓ [A1]

(ii) the angular frequency ω

$$\omega = \frac{2\pi}{T} = \frac{2\pi}{0.8} = 7.85398$$ ✓ [M1]

ω = 7.9 OR 7.85 rad s^{-1} [2] ✓ [A1]

(iii) the maximum speed v_0 of the mass.

$V_0 = \omega x_0 = (7.85398)(0.50) = 3.927$ ✓ [M1]

✓ [A1]

v_0 = 3.9 OR 3.93 cm s^{-1} [2]

(b) A light piece of card is now fixed to the mass M, as shown in Fig. 4.3.

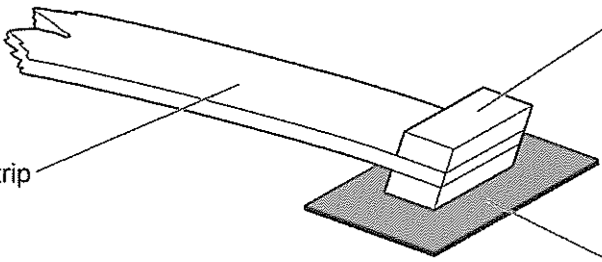


Fig. 4.3

The mass of the card is negligible when compared to the mass of M.

The mass M is again displaced and then released. Its initial displacement is the same as that shown in Fig. 4.2.

On Fig. 4.2, sketch the variation with time *t* of the total vertical displacement *y* of mass M for **three** complete, lightly damped oscillations of the mass. [3]

[Total: 8]

5 **(a)** State what is meant by the *diffraction* of a wave. (Refer Physics Compendium)

Spreading of waves into its geometrical shadow ✓ [M1]

after passing through a slit or obstacle. ✓ [A1]

[2]

(b) A double slit consists of two parallel slits, each of width 0.100 mm. The separation of the slits is 1.40 mm, as illustrated in Fig. 5.1.

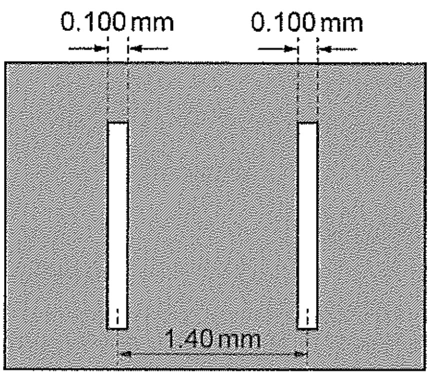


Fig. 5.1 (not to scale)

Parallel light of wavelength 590 nm is incident normally on the double slit. A screen is placed parallel to the plane of the double slit at a distance of 2.60 m from the slits, as illustrated in Fig. 5.2.

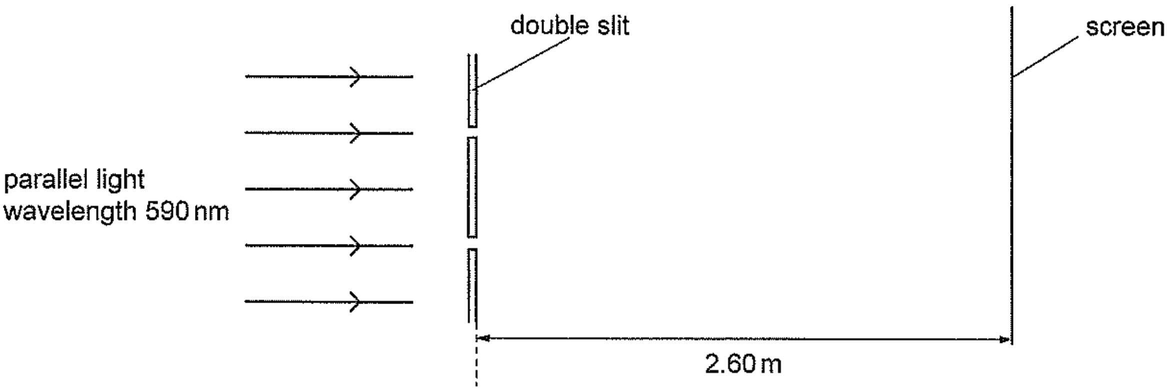


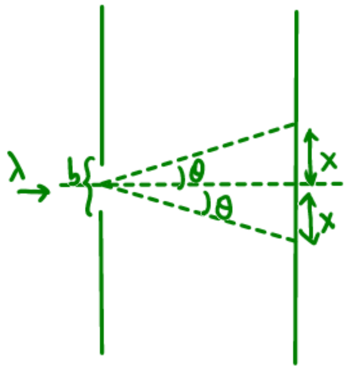
Fig. 5.2 (not to scale)

(i) Initially, one of the two slits is covered.

Calculate the width of the central fringe of the single-slit diffraction pattern seen on the screen.
Give your answer to three significant figures.

$\sin\theta = \dfrac{\lambda}{b}$

$\tan\theta = \dfrac{x}{D}$



$\sin\theta = \dfrac{590\times10^{-9}}{0.100\times10^{-3}} \Rightarrow \theta = 0.338^\circ$ ✓ [C1]

$\tan 0.338^\circ = \dfrac{x}{2.60} \Rightarrow x = 0.01534$

width $= 2x = 0.03068$ m ✓ [M1]

fringe width = ...0.0307...... m [3] ✓ [A1]

(ii) Both slits are now uncovered.

Estimate the number of fringes resulting from double-slit interference that are seen within the central maximum produced by single-slit diffraction.

$x = \dfrac{\lambda D}{a} = \dfrac{(590\times10^{-9})(2.60)}{1.40\times10^{-3}} = 1.0957\times10^{-3}$ m ✓ [B1]

Fringes $= \dfrac{0.0307}{1.0957\times10^{-3}} = 28.01$ ✓ [M1]

number = ...28...... [3] ✓ [A1]

[Total: 8]

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6 A solar cell generates an electromotive force (e.m.f.) when solar radiation is incident on its surface.

A variable resistor R is connected across the terminals of the cell, as shown in Fig. 6.1.

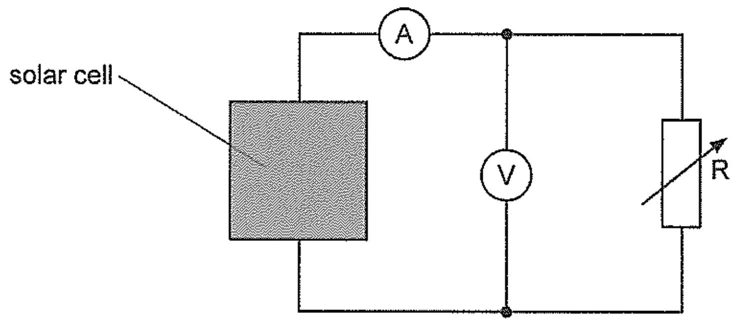
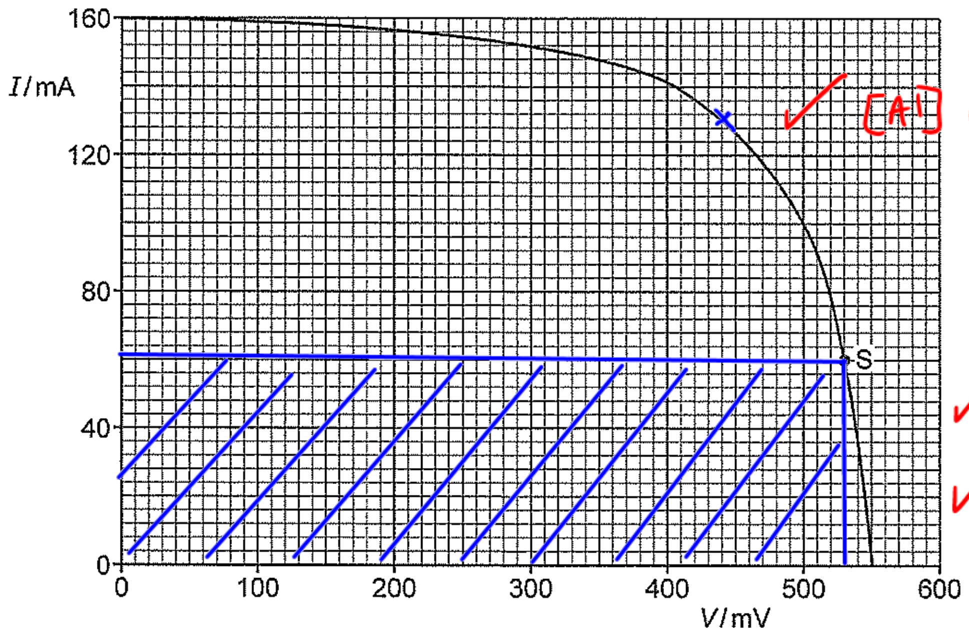


Fig. 6.1

For one particular intensity of solar radiation incident on the cell, the resistance of the resistor R is varied.
The variation with potential difference V of the current I is shown in Fig. 6.2.



✓ [A1] (440, 130)

✓ [B1] correct rectangle

✓ [B1] correct shading

Fig. 6.2

(a) **(i)** At one value of resistance, the current and potential difference are given at point S on the graph of Fig. 6.2.

On Fig. 6.2, shade the area that represents the power dissipated in the resistor for point S. [2]

(ii) On Fig. 6.2, mark with the letter M the point on the curve that would give rise to maximum power in the resistor. [1]

(b) For this light intensity incident on the solar cell, the current in the resistor R is 100 mA.

Use data from Fig. 6.2 to determine, for the current of 100 mA:

(i) the resistance of resistor R

$V = 500\,mV$ ✓ [M1]

$R = \frac{V}{I} = \frac{500 \times 10^{-3}}{100 \times 10^{-3}}$ ✓ [A1]

resistance = 5.0 OR 5.00 Ω [2]

(ii) the power dissipation in resistor R

$P = I^2R = (100 \times 10^{-3})^2(5.0) = 0.05\,W$ ✓ [M1]

power = 0.050 OR 0.0500 W [2] ✓ [A1]

(iii) the internal resistance of the solar cell.

At max power dissipation, $R = r$

$\therefore r = R = \frac{P}{I^2} = \frac{(440 \times 130 \times 10^{-6})}{(130 \times 10^{-3})^2} = 3.3846$ ✓ [M1]

internal resistance = 3.4 OR 3.38 Ω [2] ✓ [A1]

[Total: 9]

Caution: Do not use $\mathcal{E} = 550\,mV$ because the value of e.m.f. is non-constant due to varying intensity.

TYs answer is INCORRECT !!

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7 **(a)** State **one** similarity and **one** difference between the electric potential produced by a point electric charge and the gravitational potential produced by a point mass.

similarity ..... both inversely proportional to distance ✓ [B1]

(refer Physics Compendium for other possible answers)

difference ..... always negative for gravitational potential & could be negative or positive for electric potential. ✓ [B1]

[2]

(b) Two point charges, A and B, are separated in a vacuum by a distance of 12 cm, as shown in Fig. 7.1.

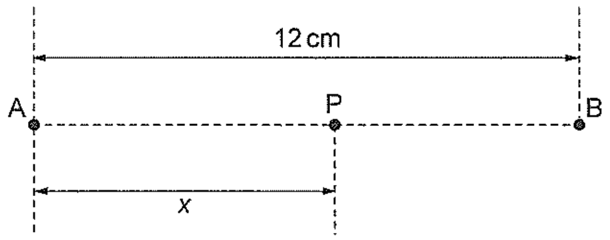

Fig. 7.1

A point P is on the line joining the two charges and is a distance x from charge A.

The variation with distance x of the electric potential V_x at point P is shown in Fig. 7.2.

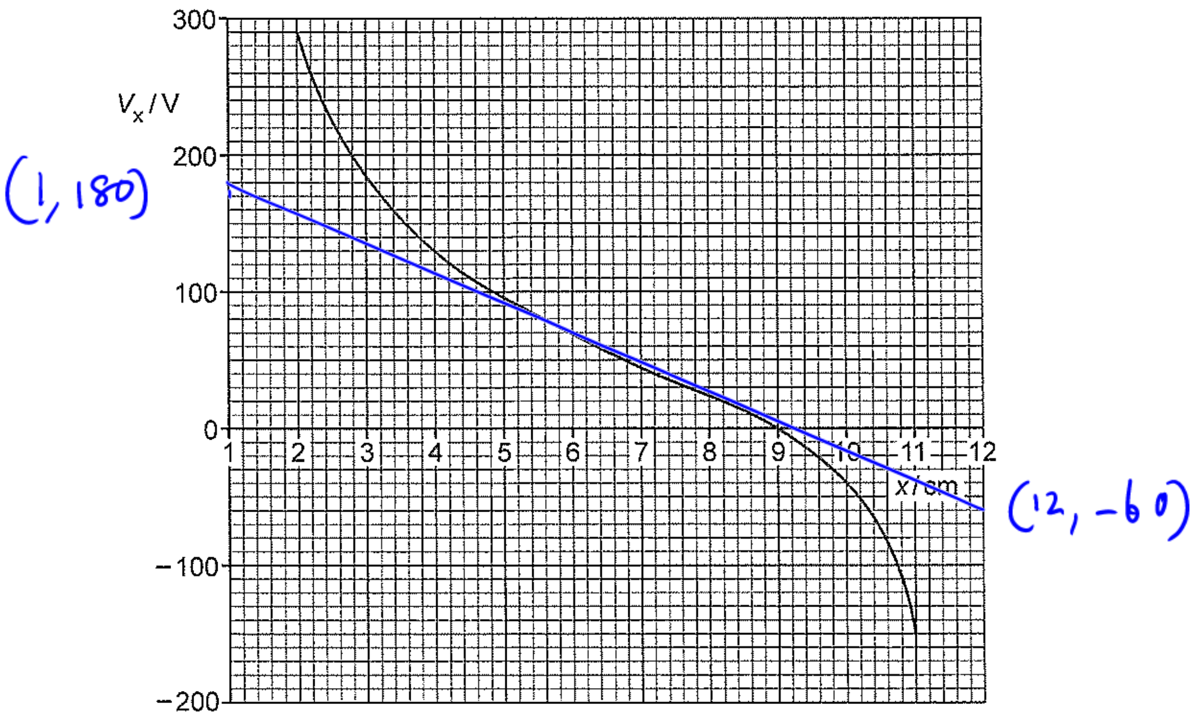

Fig. 7.2

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(i) Explain whether the charges have the same, or opposite, signs.

opposite sign as it has positive & negative potentials. [1] ✓ [A1]

(ii) Determine the ratio

$$\frac{\text{magnitude of charge A}}{\text{magnitude of charge B}}.$$

Explain your working.

$$\frac{Q_A}{4\pi\varepsilon_0(9)} = \frac{Q_B}{4\pi\varepsilon_0(3)}$$ ✓ [B1]

$$\frac{Q_A}{Q_B} = \frac{9}{3} = 3:1$$ ✓ [M1]

ratio = 3 : 1 OR 3.0 OR 3.00 [3] ✓ [A1]

(iii) Calculate the magnitude of the electric field strength at point P where x = 7.0 cm.

$$E = -\frac{dV}{dr} = \frac{180-(-60)}{(12-1)\times 10^{-2}} = 2182\ NC^{-1}$$

✓ correct gradient [B1]

✓ correct substitution [M1]

✓ [A1]

electric field strength = 2180 OR 2200 NC^{-1} [3]

[Total: 9]

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Section B

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

8 (a) Define *magnetic flux density*. (Refer Physics Compendium)

Force per unit length ✓ [B1]

acting on a straight conductor carrying unit current ✓ [M1]

placed normal to the magnetic field. ✓ [A1]

Greater density of lines implies greater strength. [3]

(b) A proton is travelling in a vacuum in a straight line with a speed of $6.2 \times 10^5\,m\,s^{-1}$. It enters a region of uniform magnetic field of flux density B, as shown in Fig. 8.1.

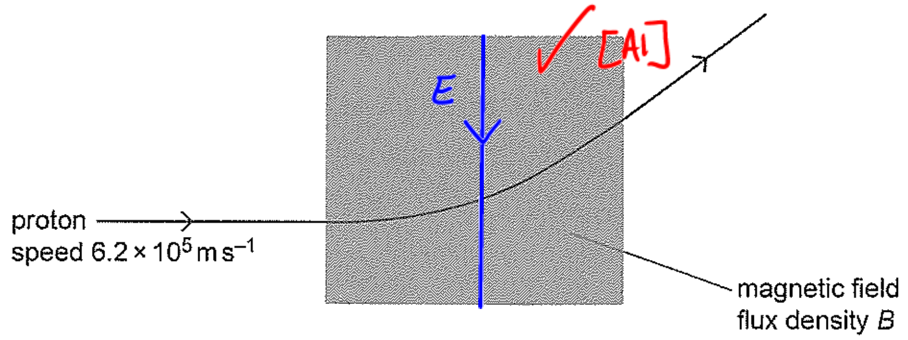

Fig. 8.1 (not to scale)

Initially, the proton is travelling in a direction normal to the magnetic field.
The proton follows a circular path in the magnetic field of radius 7.6 cm.

(i) Explain why the path in the magnetic field is an arc of a circle.

magnetic force provides centripetal force. ✓ [B1]

Constant magnitude of force acts

perpendicular to the speed at every point. [2] ✓ [B1]

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(ii) Calculate the magnetic flux density B.

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

$B = \frac{mv}{qr} = \frac{(1.67\times10^{-27})(6.2\times10^{5})}{(1.6\times10^{-19})(\frac{7.6}{100})} = 0.0851$ ✓ [M1]

✓ [A1]

$B =$ 0.085 OR 0.0851 T [2]

(c) A uniform electric field is now switched on in the same region as the magnetic field in **(b)**. The magnitude of the electric field is adjusted so that the proton moves undeviated through the two fields.

(i) On Fig. 8.1, draw an arrow to show the direction of the electric field. [1]

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

$Bqv = qE$

$E = Bv = (0.0851)(6.2\times10^{5}) = 52762$ $\mathrm{V\,m^{-1}}$ ✓ [M1]

$E =$ 52800 OR 53000 $\mathrm{V\,m^{-1}}$ [2] ✓ [A1]

(d) Two coils, P and S, are wound onto an iron core, as shown in Fig. 8.2.

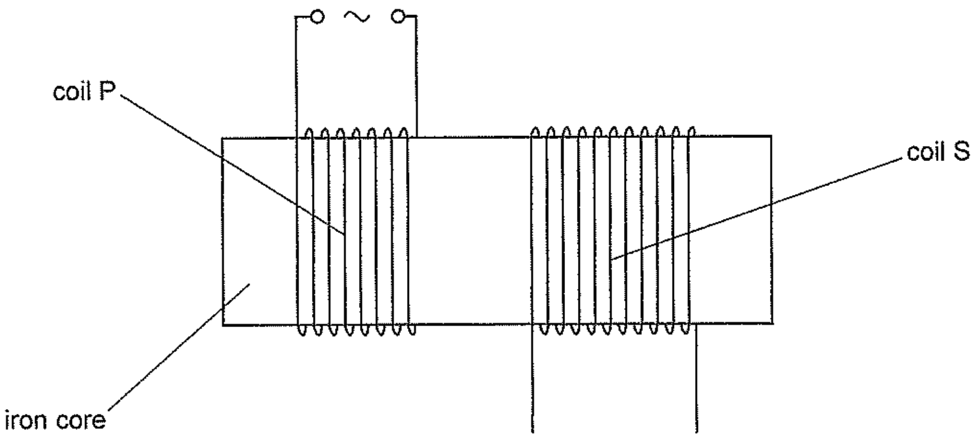

Fig. 8.2

A sinusoidal alternating current in coil P gives rise to an alternating magnetic flux in coil S. The magnetic flux density is uniform throughout coil S.
The variation with time t of the uniform magnetic flux density B in coil S is shown in Fig. 8.3.

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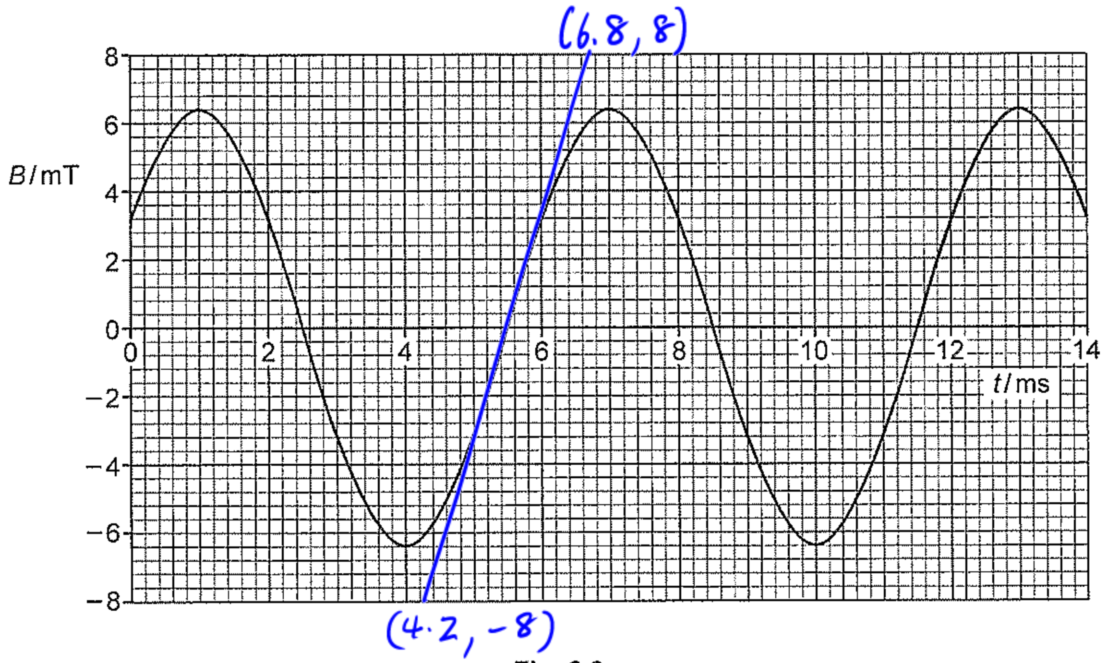

Fig. 8.3

(i) Calculate the root-mean-square (r.m.s.) value of the magnetic flux density in coil S.

$$B_{rms} = \frac{B_0}{\sqrt{2}} = \frac{6.4 \times 10^{-3}}{\sqrt{2}} = 4.525 \times 10^{-3}$$

r.m.s. value = 4.52 OR 4.5 mT [1] ✓ [A1]

(ii) State **two** times at which the electromotive force (e.m.f.) induced in coil S is zero.

time 1.0 ms and time 4.0 ms [1] ✓ [A1]

OR 7.0 ms, 10.0 ms OR 13.0 ms

(e) The coil S in **(d)** contains 270 turns of wire. Each turn of wire has a diameter of 2.4 cm.

Use data from Fig. 8.3 to determine the maximum e.m.f. induced in coil S.

$$\frac{dB}{dt} = \frac{8-(-8)}{6.8-4.2} = 6.1538$$ ✓ [B1]

$$\mathcal{E} = NA\frac{dB}{dt} = (270)\left[\underbrace{\pi \times (1.2\times10^{-2})^2}_{✓ [B1]}\right](6.1538) = 0.7516$$ ✓ [M1]

e.m.f. = 0.75 OR 0.752 V [4] ✓ [A1]

[Acept: 0.74 to 0.90]

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(f) The alternating current in coil P in **(d)** is now replaced by a direct current that is reversed at regular time intervals.
The variation with time t of the magnetic flux ϕ in coil S is shown in Fig. 8.4.

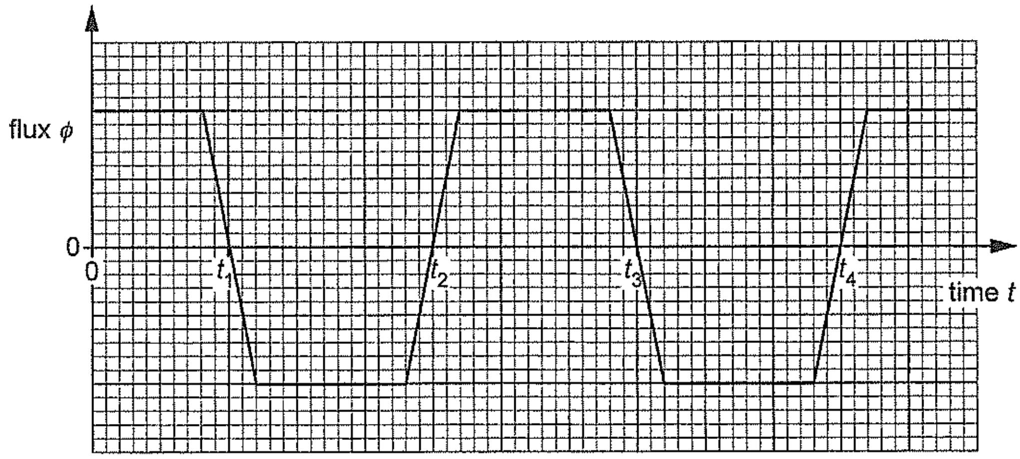

Fig. 8.4

Use data from Fig. 8.4 to sketch, on Fig. 8.5, the variation with time t of the e.m.f. induced in coil S.

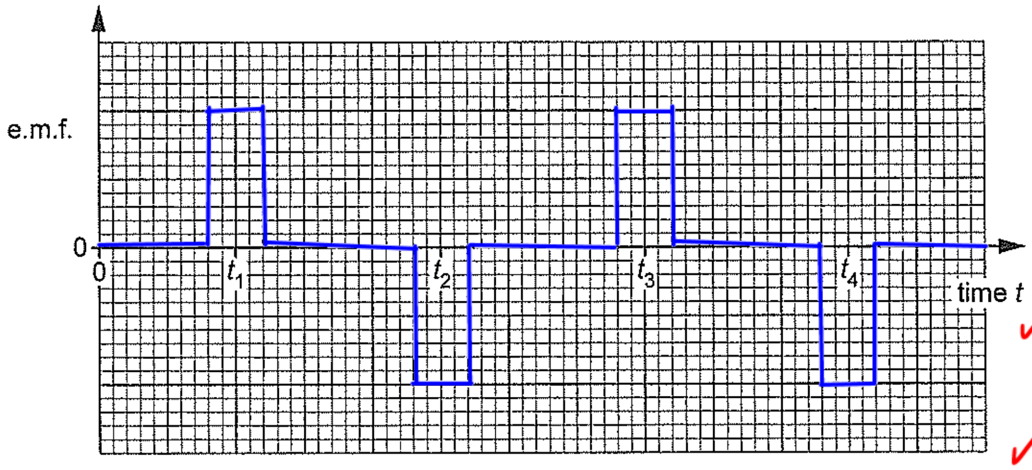

Fig. 8.5

✓ [correct shape]
✓ [same sign]
✓ [same magnitude]
✓ [same frequency]

[4]

[Total: 20]

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9 (a) State:

(i) **two** pieces of evidence provided by the photoelectric effect for the particulate nature of electromagnetic radiation

1. refer to Physics Compendium page 94 Q7 (choose any 2)

2.

[2]

(ii) how a line emission spectrum may be explained on the basis of the existence of discrete electron energy levels in atoms.

Refer Physics Compendium Page 107 Q37.

[3]

(b) Some electron energy levels in an isolated atom are shown in Fig. 9.1.

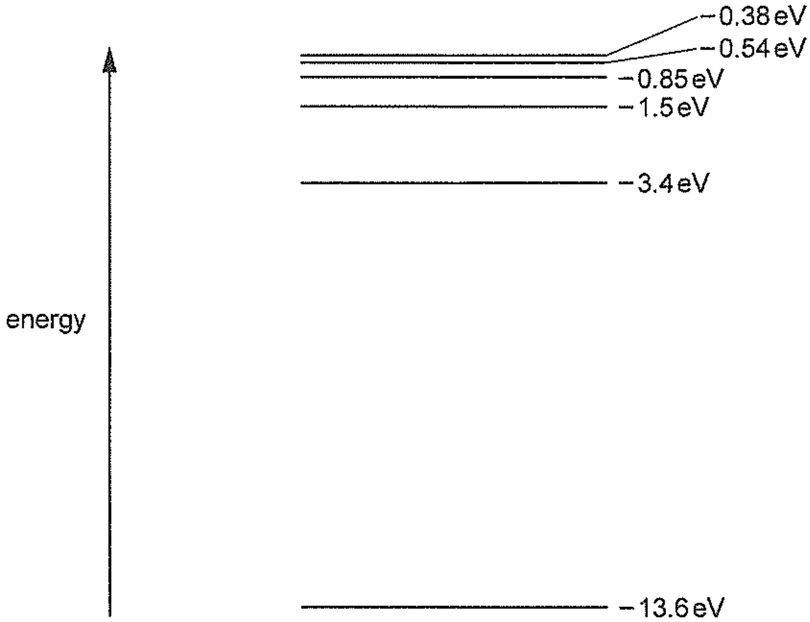

Fig. 9.1

In the visible section of the spectrum of electromagnetic radiation, purple light has the shortest wavelength.

(i) Calculate the energy, in eV, of a photon of purple light of wavelength 340 × 10^{-9} m.

$$E = \frac{hc}{\lambda} = \frac{6.63\times10^{-34} \times 3\times10^{8}}{340\times10^{-9}} = 5.85\times10^{-19}\ J$$ ✓ [M1]

$$= \frac{5.85\times10^{-19}}{1.6\times10^{-19}}$$ ✓ [C1]

$$= 3.65625\ eV$$

energy = 3.66 OR 3.7 eV [3] ✓ [A1]

(ii) By reference to your answer in **(b)(i)**, explain why a visible line spectrum does **not** result from electrons de-exciting to the −13.6 eV energy level.

Smallest energy transition $= 13.6 - 3.4 = 10.2\ eV$ that ✓ [M1]

produces $\lambda = 1.21\times10^{-7}$ m ⇒ UV spectrum. ✓ [A1]

[2]

Electrons de-excite to −13.6 eV results in UV spectrum.

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(c) The isotope beryllium-7 ($^{7}_{4}Be$) is radioactive with a half-life of 53 days. A beryllium-7 nucleus decays by the emission of a γ-ray photon of energy 0.48 MeV.
Initially, the total mass of undecayed beryllium-7 in a radioactive sample is 5.7×10^{-12} kg.

(i) Determine the probability of decay of a beryllium-7 nucleus in a time of 1.0 day.

$$\lambda = \frac{\ln 2}{53} = 0.013078$$

probability = 0.013 OR 0.0131 day^{-1} [1] ✓ [A1]

(ii) Calculate the number of undecayed beryllium-7 nuclei in the sample after 120 days.

$$n = \frac{N_0}{N_A} = \frac{m}{M_r} = \frac{5.7\times10^{-12}\times10^{3}}{7}$$

$$N_0 = \frac{5.7\times10^{-12}\times10^{3}}{7}(6.02\times10^{23}) = 4.902\times10^{14}$$ ✓ [B1]

$$N = N_0\left(\frac{1}{2}\right)^{t/t_{\frac{1}{2}}} = (4.902\times10^{14})\left(\frac{1}{2}\right)^{120/53} = 1.02\times10^{14}$$ ✓ [M1]

number = 1.02×10^{14} OR 1.0×10^{14} [3] ✓ [A1]

(iii) State why, although the beryllium-7 is radioactive, the number of beryllium-7 nuclei in the sample does **not** change.

Beryllium nuclei merely loses energy to γ ray ✓ [B1]
which does not carry any nucleons. [2] ✓ [B1]

(d) The beryllium-7 nuclei in **(c)** may be considered to be stationary before the emission of the γ-ray photons.

Determine the recoil speed of a beryllium-7 nucleus due to the emission of a γ-ray photon.

$$E = \frac{hc}{\lambda} = 0.48\ MeV$$

$$\lambda = \frac{6.63\times10^{-34}\times3\times10^{8}}{0.48\times10^{6}\times1.6\times10^{-19}} = 2.5898\times10^{-12}$$ ✓ [C1]

By COM: $mv = \frac{h}{\lambda}$ ✓ [C1]

speed = 2.2×10^{4} ms^{-1} [4] ✓ [A1]

$$v = \frac{h}{m\lambda} = \frac{6.63\times10^{-34}}{(7)(1.66\times10^{-27})(2.5898\times10^{-12})}$$ ✓ [M1]

$$= 2.2\times10^{4}\ m/s$$

[Total: 20]

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