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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 | | | | |

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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.

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This document consists of **23** printed pages and **5** blank pages.

Singapore Examinations and Assessment Board

Cambridge Assessment International Education

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Data

speed of light in free space	$c = 3.00 \times 10^{8}\,\text{m s}^{-1}$
permeability of free space	$\mu_0 = 4\pi \times 10^{-7}\,\text{H m}^{-1}$
permittivity of free space	$\varepsilon_0 = 8.85 \times 10^{-12}\,\text{F m}^{-1}$
	$(1/(36\pi)) \times 10^{-9}\,\text{F m}^{-1}$
elementary charge	$e = 1.60 \times 10^{-19}\,\text{C}$
the Planck constant	$h = 6.63 \times 10^{-34}\,\text{J s}$
unified atomic mass constant	$u = 1.66 \times 10^{-27}\,\text{kg}$
rest mass of electron	$m_e = 9.11 \times 10^{-31}\,\text{kg}$
rest mass of proton	$m_p = 1.67 \times 10^{-27}\,\text{kg}$
molar gas constant	$R = 8.31\,\text{J K}^{-1}\,\text{mol}^{-1}$
the Avogadro constant	$N_A = 6.02 \times 10^{23}\,\text{mol}^{-1}$
the Boltzmann constant	$k = 1.38 \times 10^{-23}\,\text{J K}^{-1}$
gravitational constant	$G = 6.67 \times 10^{-11}\,\text{N m}^2\,\text{kg}^{-2}$
acceleration of free fall	$g = 9.81\,\text{m s}^{-2}$

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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	$\phi = -\frac{Gm}{r}$
temperature	$T/\text{K} = T/^\circ\text{C} + 273.15$
pressure of an ideal gas	$p = \frac{1}{3}\frac{Nm}{V}\langle c^2 \rangle$
mean translational kinetic energy of an ideal gas 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	$\lambda = \frac{\ln 2}{t_{\frac{1}{2}}}$

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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.

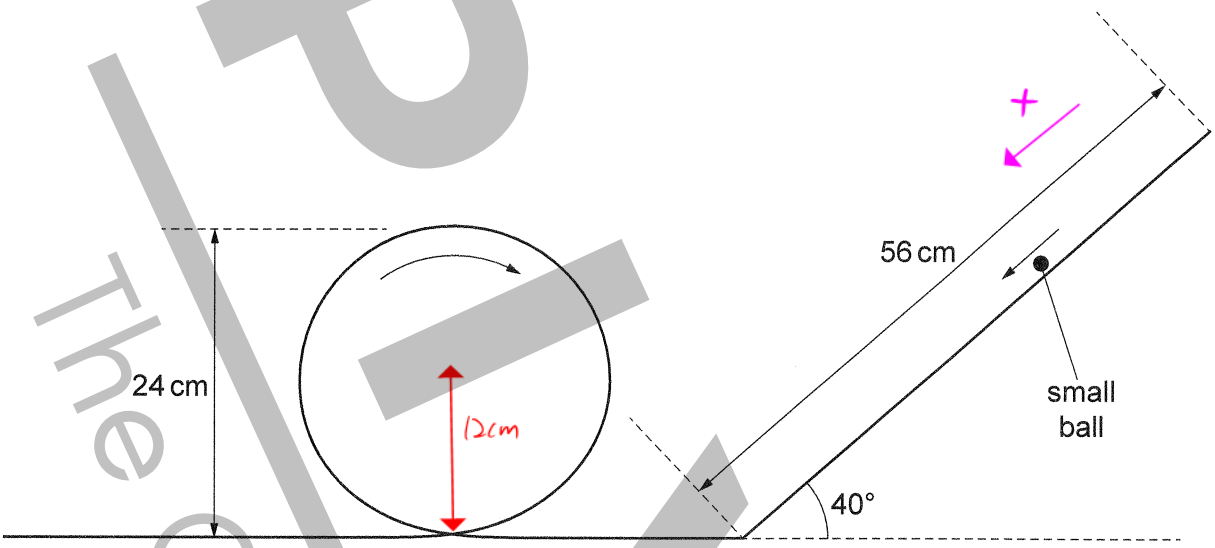


Fig. 1.1

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

$a_{\parallel\text{-slope}} = g\sin\theta = (9.81)(\sin 40)$
$= 6.3057$
$= 6.31\ \text{ms}^{-2}$ (3sf)
#

acceleration = 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.

$v^2 = u^2 + 2as$
$v^2 = 0^2 + 2(6.3057)\left(\frac{56}{100}\right)$
Hence $v = 2.6575 = 2.66\ \text{ms}^{-1}$ (3sf)
#

speed = 2.66 m s^{-1} [2]

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

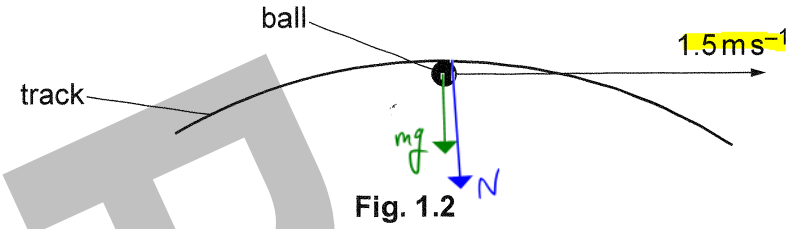


Fig. 1.2

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

$F_c = \frac{mv^2}{r} = \frac{\left(\frac{72}{1000}\right)(1.5)^2}{\frac{12}{100}} = 1.35\,N\,(3sf)$ #

force = 1.35 N [2]

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

$F_{net} = F_c = mg + N$

$\therefore N = F_c - mg = 1.35 - \left(\frac{72}{1000}\right)(9.81) = 0.64368 = 0.644\,N\,(3sf)$

force = 0.644 N

direction Vertically downwards.

[3]

[Total: 9]

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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.

Gravitational potential is defined as the work done by an external agent to bring unit mass from infinity to a point without acceleration. By convention, potential at infinity is taken to be 0. Moreover, gravitational force is attractive. Therefore, negative work is done by the external agent in moving unit mass from infinity to that point. Hence, potential is a negative quantity. [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 3.8×10^3 m s^{-1}.

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

$r_p = 3.4 \times 10^6$ m
$M_p = 6.2 \times 10^{23}$ kg

$\phi_s = \frac{-GM}{r} = -\frac{(6.67 \times 10^{-11})(6.2 \times 10^{23})}{(3.4 \times 10^6)} = -1.216 \times 10^7$
$= -1.22 \times 10^7$ J kg^{-1} (3sf) #1

gravitational potential = -1.22×10^7 ..... J kg^{-1} [1]

(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.

By CoE, $KE_s + PE_s = KE_\infty + PE_\infty$ ($KE_\infty \geq 0$, $PE_\infty = 0$)

$\therefore \frac{1}{2} m_r v_e^2 + m_r \phi_s \geq 0$

$\therefore \frac{1}{2} m_r v_e^2 \geq -m_r \phi = -(-1.216 \times 10^7)$

$v_e \geq \sqrt{2(1.216 \times 10^7)}$

[3]

$\therefore v_{e_min} = 4932.12 \text{ m s}^{-1}$

But $v_r = 3800 \text{ m s}^{-1} < v_{e-min}$. Hence, rock returns to surface #1.

[Total: 7]

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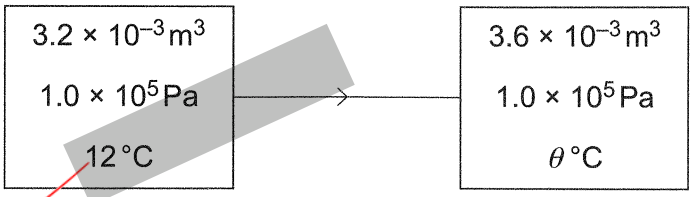
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3 **(a)** State what is meant by the *internal energy* of an ideal gas.

The internal energy of an ideal gas is only the microscopic molecular kinetic energies due to the random motion of its particles. The internal energy of an ideal gas depends only on its state, ie, its pressure, temperature, volume and amount. [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.

°C + 273.15 = K



285.15 K

Fig. 3.1

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

From $pV = nRT$, $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$

$\therefore T_2 = \frac{P_2V_2}{P_1V_1} \cdot T_1 = \frac{(3.6\times10^{-3})}{(3.2\times10^{-3})} \cdot (285.15\,K) = 320.793\,K$

$\therefore$ in °C : 47.643
$= 47.6\,°C$ # (3sf)

θ = 47.6 °C [2]

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

WD by

W_{by} +ve W_{on} −ve

$|WD| = p\Delta V$
$= p(V_f - V_i)$
$= (1\times10^5)(3.6-3.2)(10^{-3})$
$= 40.0\,J$ (3sf)
#

work done = 40.0 J [2]

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$Q_{to} = 101\,J$

(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

From 1st law of thermodynamics, $\Delta U = Q_{to} + W_{on}$

$= 101 + (-40)$

$= 61.0\,J\ (3\,sf)$ #

increase = 61.0 J [1]

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

From ideal gas equation, $n = \frac{PV}{RT} = \frac{(1\times10^5)(3.2\times10^{-3})}{(8.31)(285.15)} = 0.135044\ mol$

$\therefore N = nN_A = (0.135044)(6.023\times10^{23}) = 8.133705\times10^{22}$ molecules

Since ideal gas, $\Delta U = \Delta KE = 61\,J$

$\therefore \langle KE \rangle$ of 1 molecule $= \frac{61}{8.133705\times10^{22}}$

$= 7.4996\times10^{-22}\,J$

$= 7.50\times10^{-22}\,J\ (3\,sf)$ #

increase = 7.50×10^{-22} J [3]

[Total: 10]

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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.

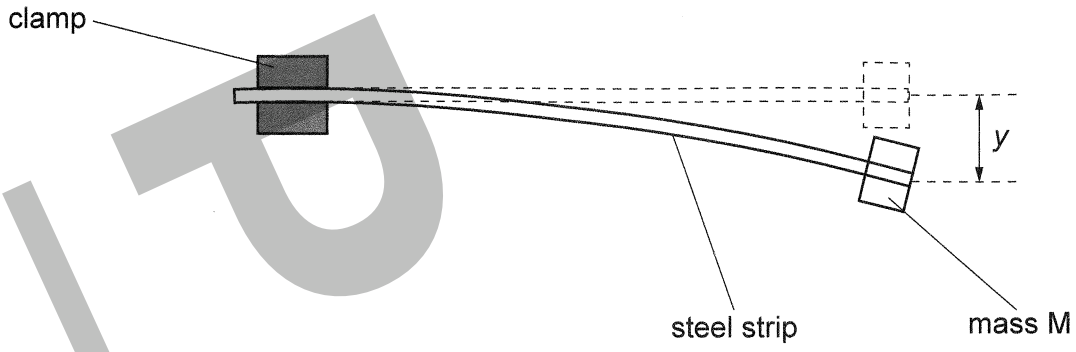


Fig. 4.1

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.

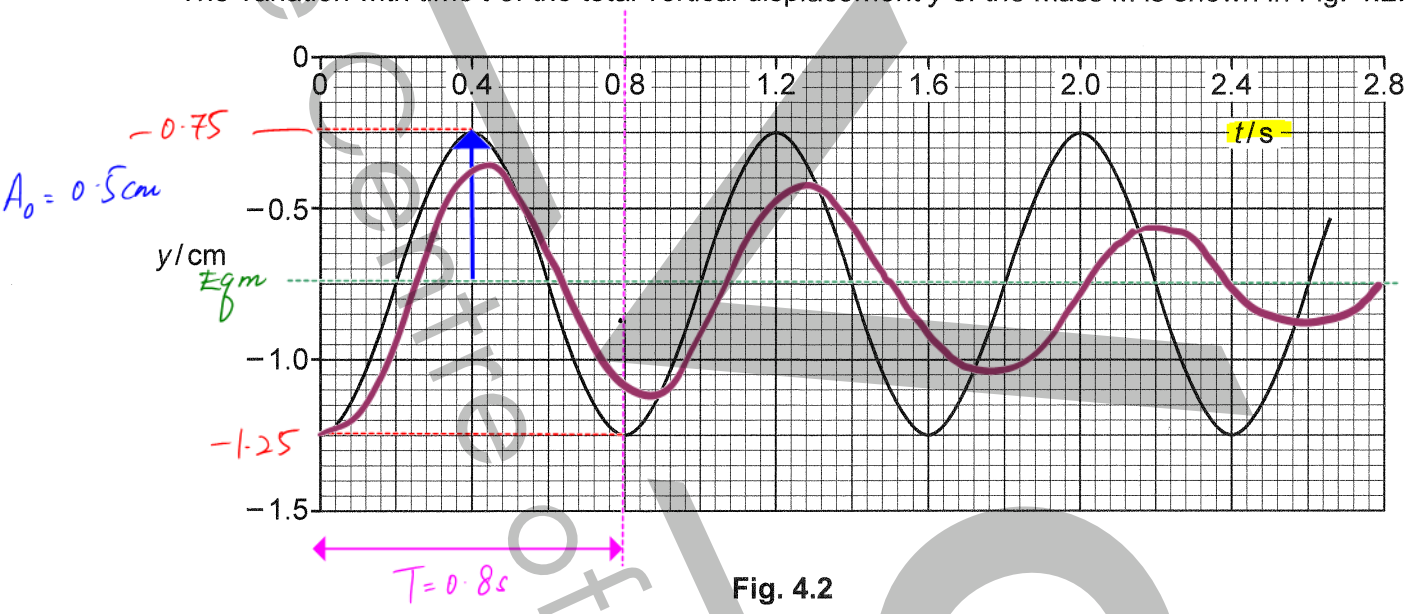


Fig. 4.2

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

(i) the amplitude x_0

x_0 = 0.500 (3sf) # ..... cm [1]

(ii) the angular frequency ω

$\omega = \frac{2\pi}{T} = \frac{2\pi}{0.8} = 7.8539 = 7.86 \text{ rads}^{-1}$ (3sf) #

ω = 7.86 ..... rad s^{-1} [2]

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(iii) the maximum speed v_0 of the mass.

$V_0 = \omega X_0 = (7.8539)(0.5) = 3.9269 = 3.93 \text{ cm s}^{-1}$ (3sf)

v_0 = 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.

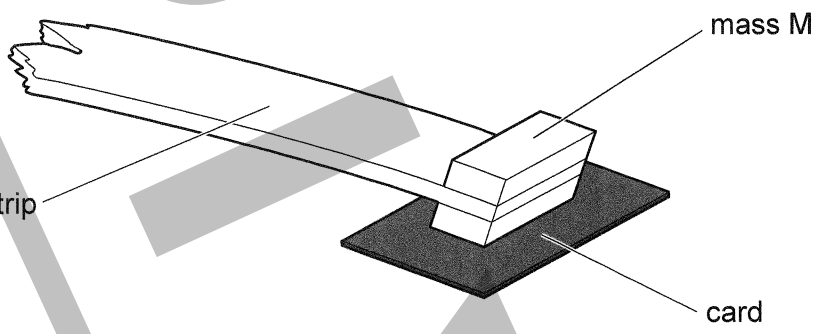


Fig. 4.3

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]

① Amp ↓
② T ↑

[Total: 8]

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

Diffraction refers to the spreading of wavefronts through an aperture (slit) or around an obstacle. It is observable when the wavelength is approximately of the same order of magnitude as the slit or obstacle size. [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.

$a = 0.1\,mm$
$d = 1.4\,mm$
$\lambda = 590\,nm$
$D = 2.6\,m$

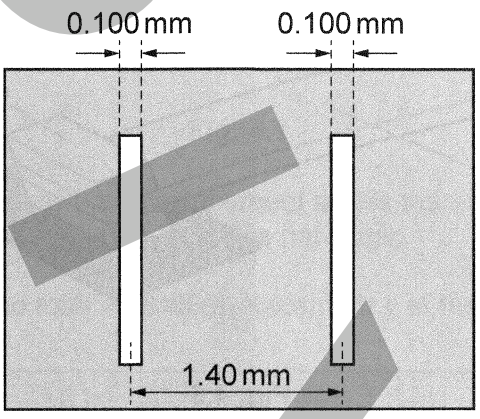


Fig. 5.1 (not to scale)

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.

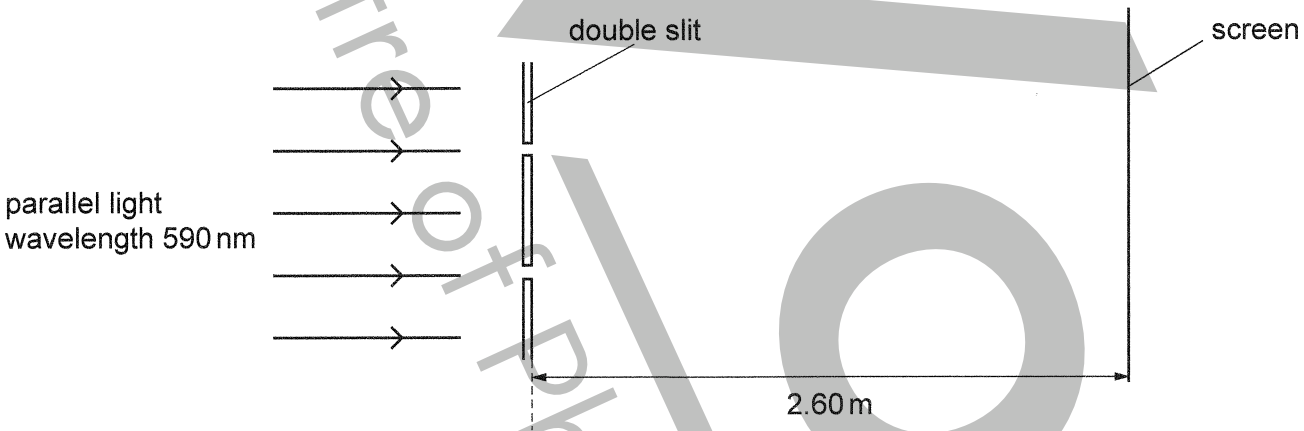


Fig. 5.2 (not to scale)

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

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

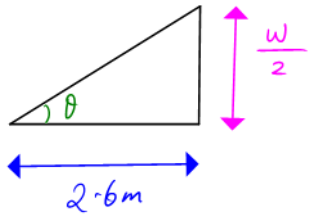
$a\sin\theta = n\lambda$

$\therefore \sin\theta = \frac{n\lambda}{a} = \frac{(1)(590\times10^{-9})}{(0.1\times10^{-3})} = 5.9\times10^{-3}$

Since $\sin\theta$ is small, by small angle approx,

$\therefore \sin\theta \simeq \theta = 5.9\times10^{-3}$ rad.

and $\tan\theta \simeq \theta$



$\therefore \tan\theta = 5.9\times10^{-3} = \frac{\frac{w}{2}}{2.6}$

and $w = 0.03068$

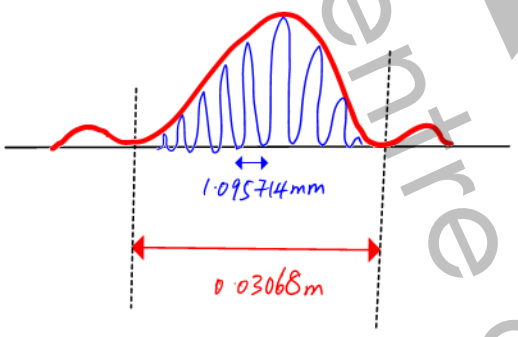
$= 0.0307\text{m}$ (3sf) #

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

(ii) Both slits are now uncovered. YDSE

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

For YDSE, $w = \frac{\lambda D}{d} = \frac{(590\times10^{-9})(2.6)}{(1.4\times10^{-3})} = 1.095714\times10^{-3}\text{m}$



$\therefore N = \frac{w_{SS}}{w_{DS}} = \frac{0.03068\text{m}}{1.095714\text{mm}} = 28$

number = ... 27. ..... [3]

[Total: 8]

Checking 14th Bright Fringe for YDSE

$d\sin\theta = n\lambda$

$\sin\theta = \frac{n\lambda}{d} = \frac{(14)(590\times10^{-9})}{(1.4\times10^{-3})} = 5.9\times10^{-3}$ rad.

This means that the 14th order bright fringe coincides with the 1st order minima of the single slit diffraction

$\therefore$ Central bright fringe of single slit diffraction only contains 0 – 13 bright fringes of YDSE.

$\therefore$ No. of YDSE bright fringes = $13 + 1 + 13 = 27$ #

(Central max of YDSE.)

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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.

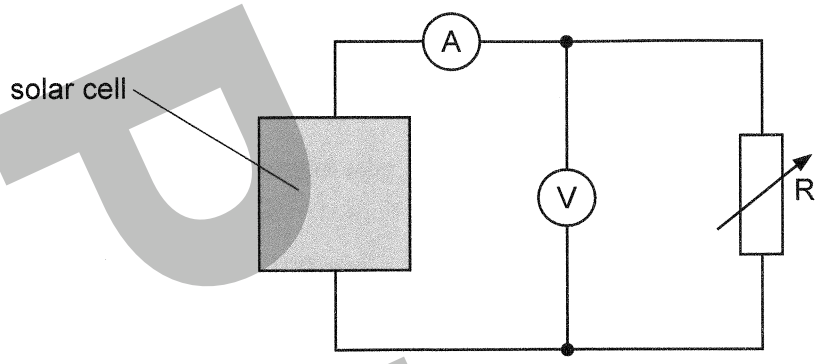


Fig. 6.1

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.

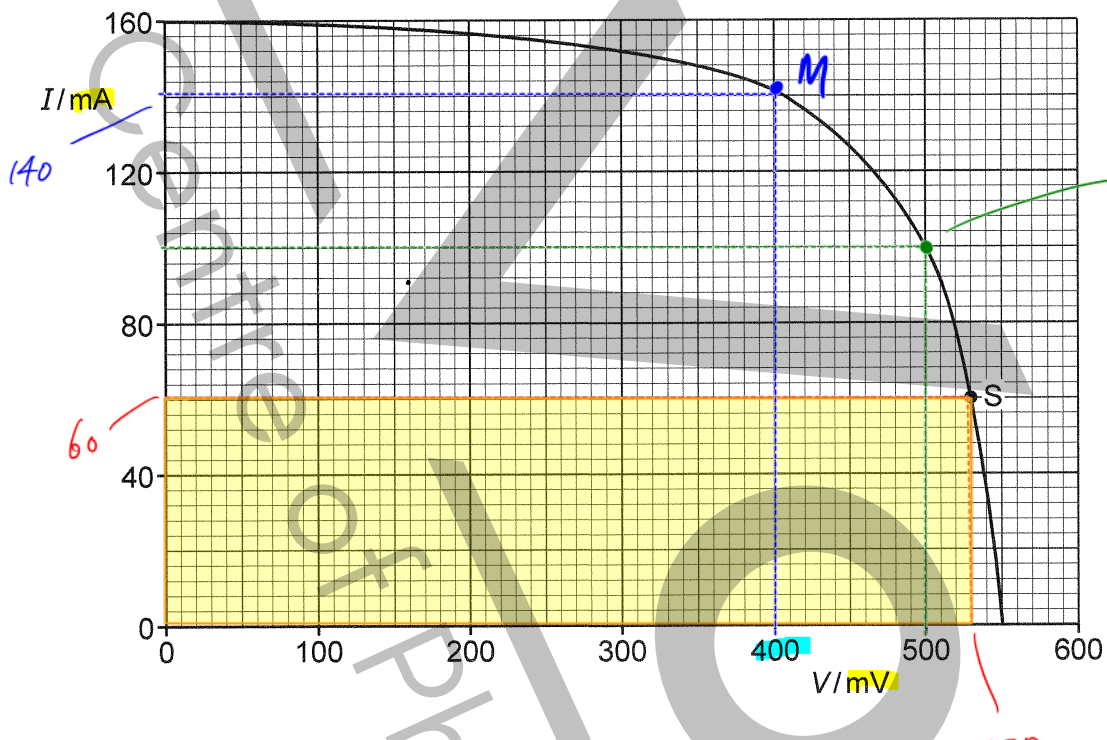


Fig. 6.2

(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]

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(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

$\therefore$ from ohm's law, $R = \frac{V}{I} = \frac{500m}{100m} = 5.00\,\Omega\ (3sf)$

resistance = 5.00 Ω [2]

(ii) the power dissipation in resistor R

$P = I^2R = (100 \times 10^{-3})^2(5) = 0.0500\ W\ (3sf)$ #

power = 0.0500 W [2]

(iii) the internal resistance of the solar cell.

when $I = 0$, $V = 550\,mV$ = Emf of solar cell.

$\mathcal{E} = V_T + V_r = I(R + r)$

$\therefore r = \frac{\mathcal{E}}{I} - R = \frac{550 \times 10^{-3}}{100 \times 10^{-3}} - 5 = 0.500\,\Omega\ (3sf)$ #

internal resistance = 0.500 Ω [2]

[Total: 9]

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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 Electric and gravitational potential are both inversely proportional to the distance from the point charge and point mass respectively.

difference Electric potential can be either negative or positive depending on the signs of the charges, but gravitational potential is always negative.

[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.

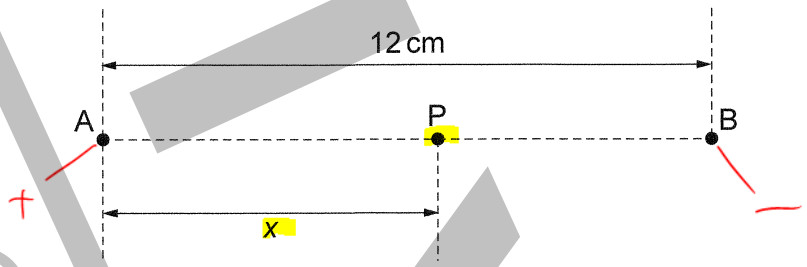
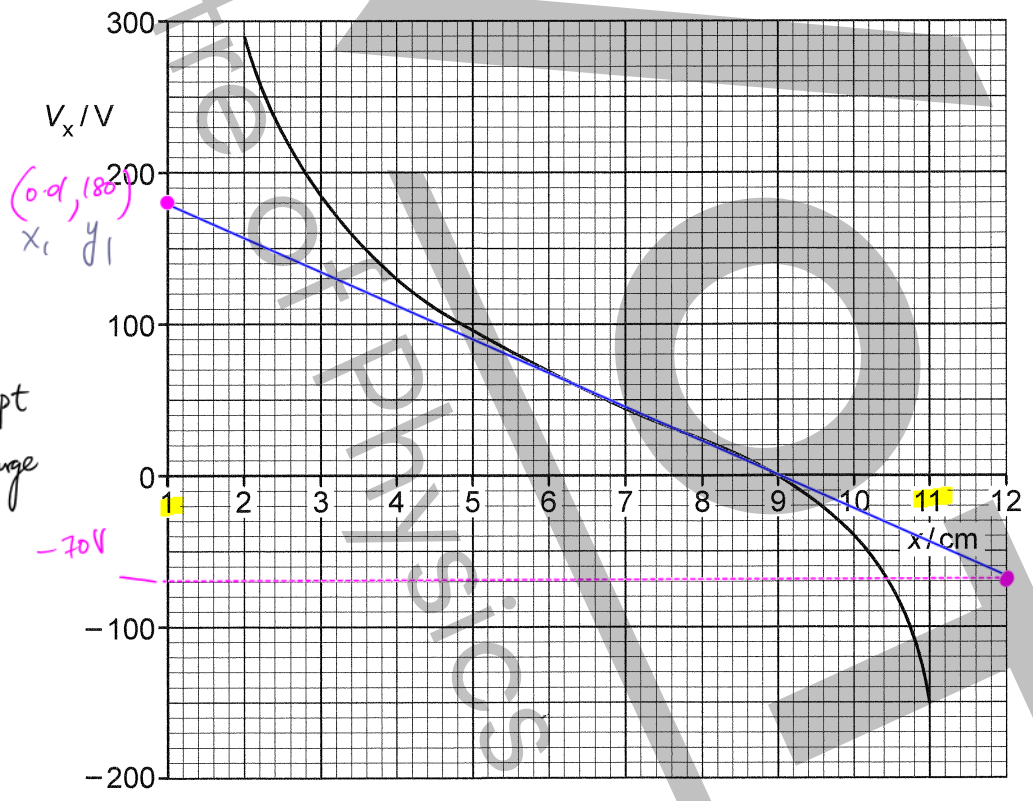


Fig. 7.1

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.



① x = 9 cm, null pt

② B is smaller charge as null pt closer to smaller charge.

Fig. 7.2

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

Opposite signs. At any point along AB, the electric potential is the sum of the individual electric potentials due to charges A and B. When x = 9cm, the net potential is 0V, suggesting that the 2 individual potentials due to A and B sum up to 0V, implying that the charges must be opposite in signs. [1]

(ii) Determine the ratio

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

Explain your working.

① A is + charge
② B is − charge

$V = \frac{Q}{4\pi\varepsilon_0 r}$

when $x = 9\text{cm}$, $V_{net} = V_A + V_B = \frac{Q_A}{4\pi\varepsilon_0(0.09)} + \frac{Q_B}{4\pi\varepsilon_0(0.03)} = 0$

$\therefore \frac{Q_A}{4\pi\varepsilon_0(0.09)} = -\frac{Q_B}{4\pi\varepsilon_0(0.03)}$

$\therefore \frac{Q_A}{Q_B} = \left| -\frac{0.09}{0.03} \right| = 3.00\ (3\text{sf})$ #

ratio = 3.00 [3]

(iii) Calculate the magnitude of the electric field strength at point P where $x = 7.0\,\text{cm}$.

$E = -\frac{dV}{dr} = -\frac{\Delta V}{\Delta r} = -\frac{(y_2 - y_1)}{(x_2 - x_1)} = -\frac{(-70 - 180)}{(0.12 - 0.01)} = 2272.727$

$= 2270\ \text{Vm}^{-1}\ (3\text{sf})$ #

electric field strength = 2270 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*.

The magnetic force acting per unit electric constant current per unit length on a long conductor wire placed at right angles to a uniform magnetic field. The SI unit for magnetic flux density is the Tesla, T.

[3]

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

$m_p = 1.67 \times 10^{-27}\,\text{kg}$
$v_p = 6.2 \times 10^5\,\text{m/s}$
$r = 7.6\,\text{cm}$

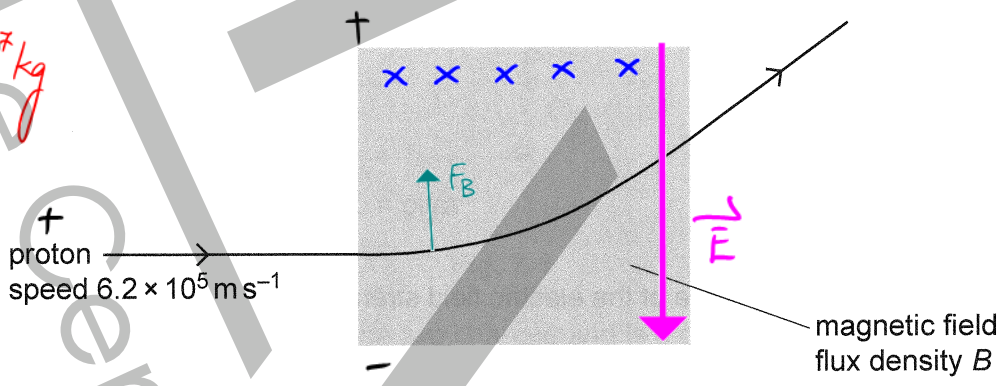


Fig. 8.1 (not to scale)

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.

When the proton travels in the field, the magnetic force, F_B, is always normal to the path of the proton, according to Flemings Left Hand Rule. This F_B always points to a fixed pt, which is the centre of the circular motion, and provides for the centripetal force required for circular motion.

[2]

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(ii) Calculate the magnetic flux density B.

$F_B = F_C$

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

$\therefore B = \frac{mv}{qr} = \frac{(1.67\times10^{-27})(6.2\times10^{5})}{(1.6\times10^{-19})(0.076)} = 0.085148 = 0.0851\ \text{T (3sf)}$ #

$B =$ 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. vel. selector, $v = \frac{E}{B}$

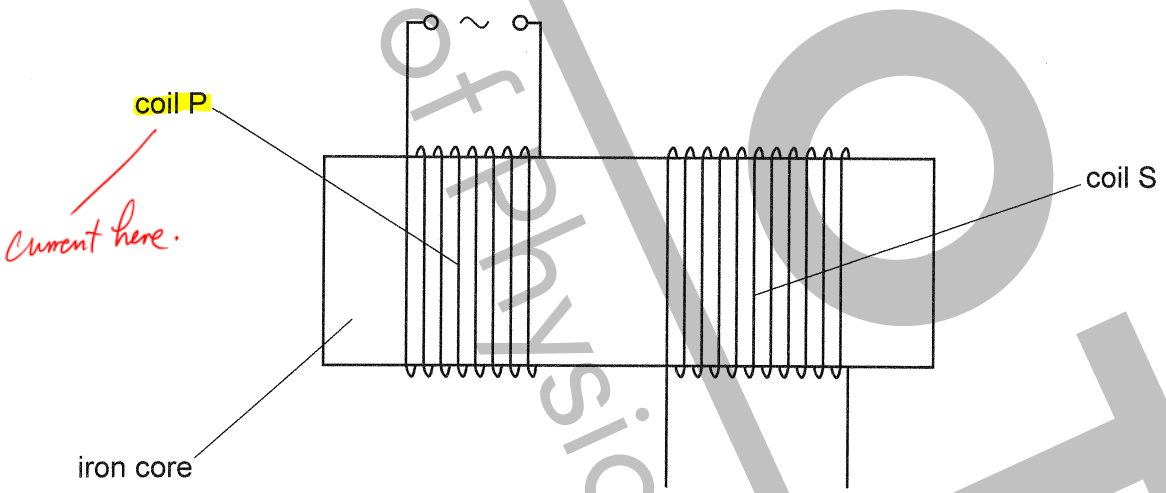
(i) On Fig. 8.1, draw an arrow to show the direction of the electric field. [1]

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

$\therefore E = vB = (6.2\times10^{5})(0.085148) = 52791.76 = 52.8\text{k NC}^{-1}\ (3sf)$ #

$E =$ 52.8 k V m^{-1} [2]

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



current here.

$B_{sol} = \frac{\mu_0 I \cdot N}{L} = \mu_0 I n$

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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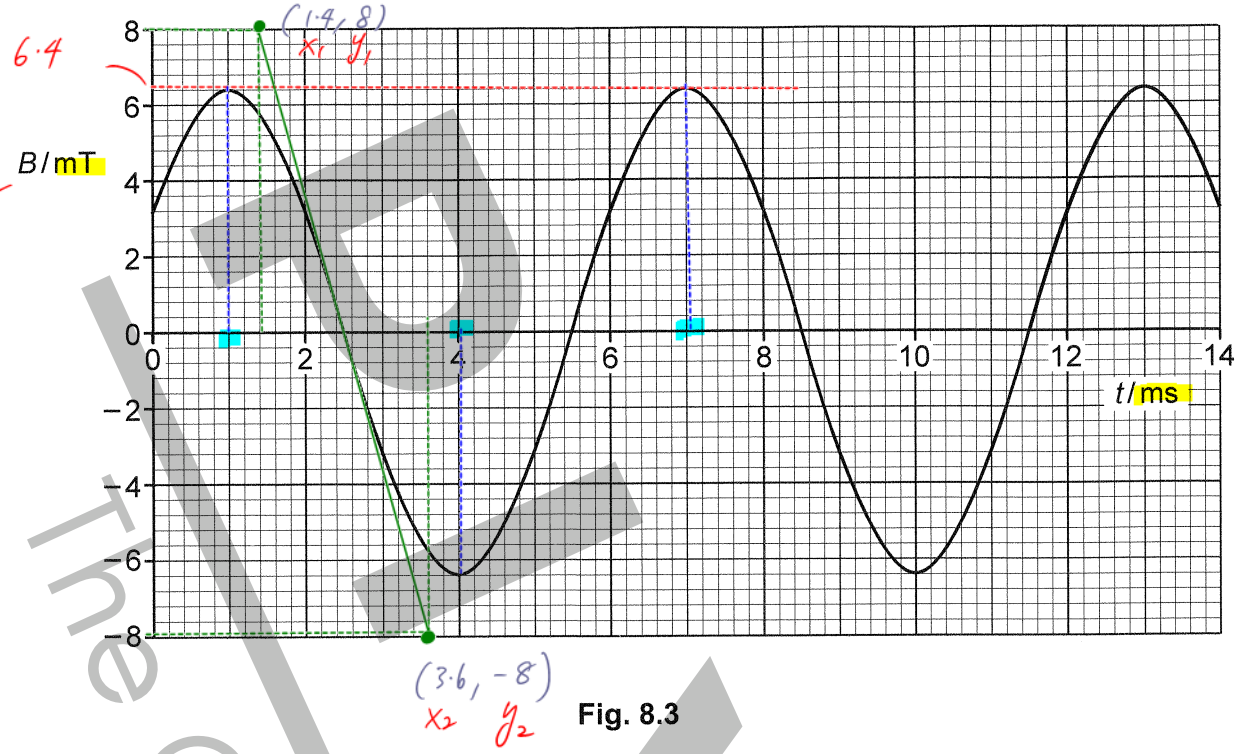


Fig. 8.3

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

r.m.s. value = ... mT [1]

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

time ..... ms and time ..... ms [1]

(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.

e.m.f. = ... V [4]

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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.

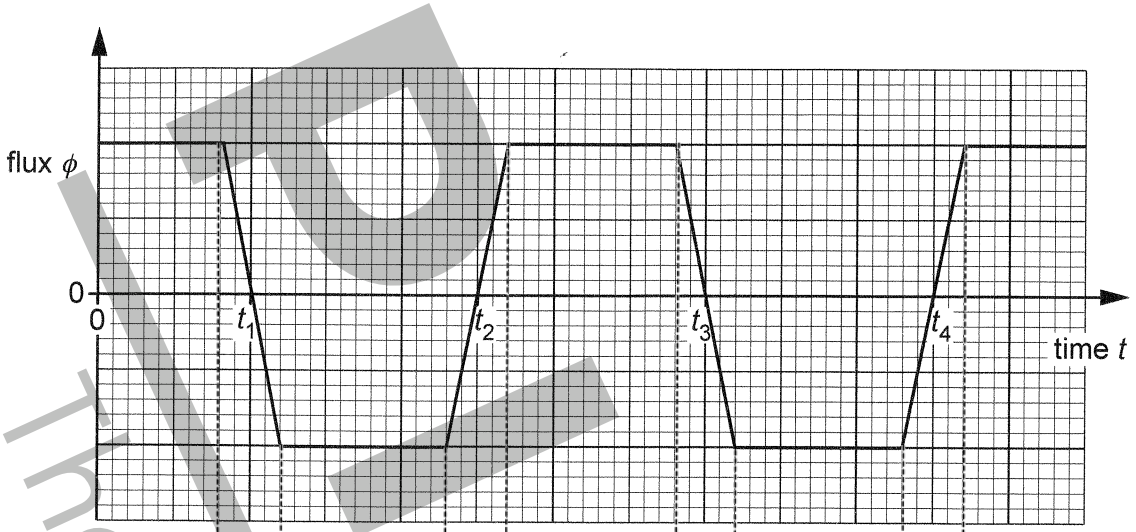


Fig. 8.4

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.

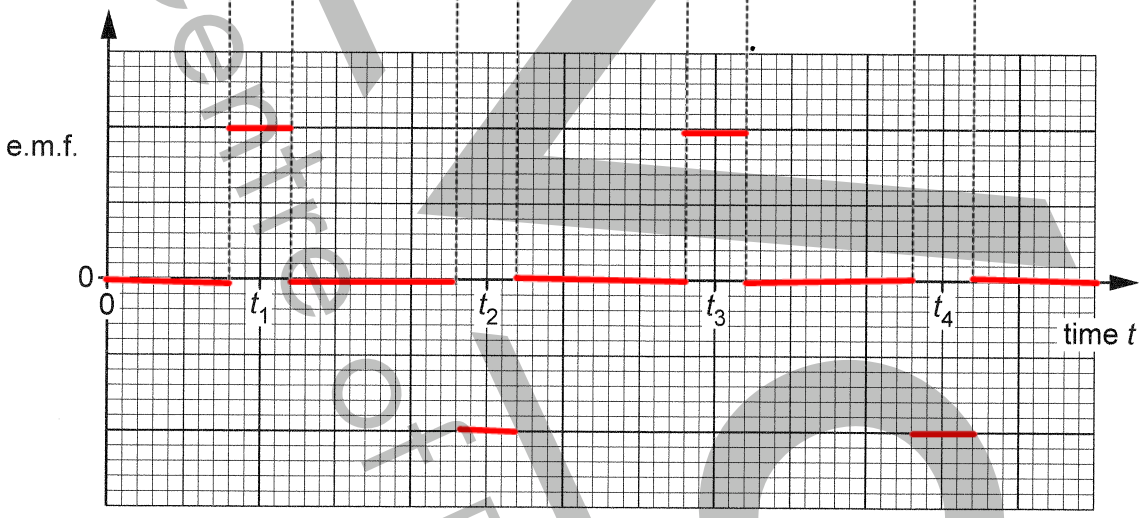


Fig. 8.5

[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. Only Electromagnetic (EM) radiation of frequency larger than or equal to the threshold frequency of the metal is able to cause emission of photoelectrons from metal, regardless of radiation intensity

2. The almost instantaneousness of photoelectron emission, when energy of EM radiation is larger than or equal to the workfunction of the metal [2]

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

Emission line spectra provides evidence for electron transitions within an atom when electrons emit photons of specific energies (energy difference between any 2 energy levels) and transit to a more stable, quantised energy level. The well-defined separation of emission lines is experimental proof for the quantised energy levels in an atom, thereby suggesting that electrons cannot have energies between any 2 energy levels, thus proving the discrete nature of electron energy levels. [3]

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

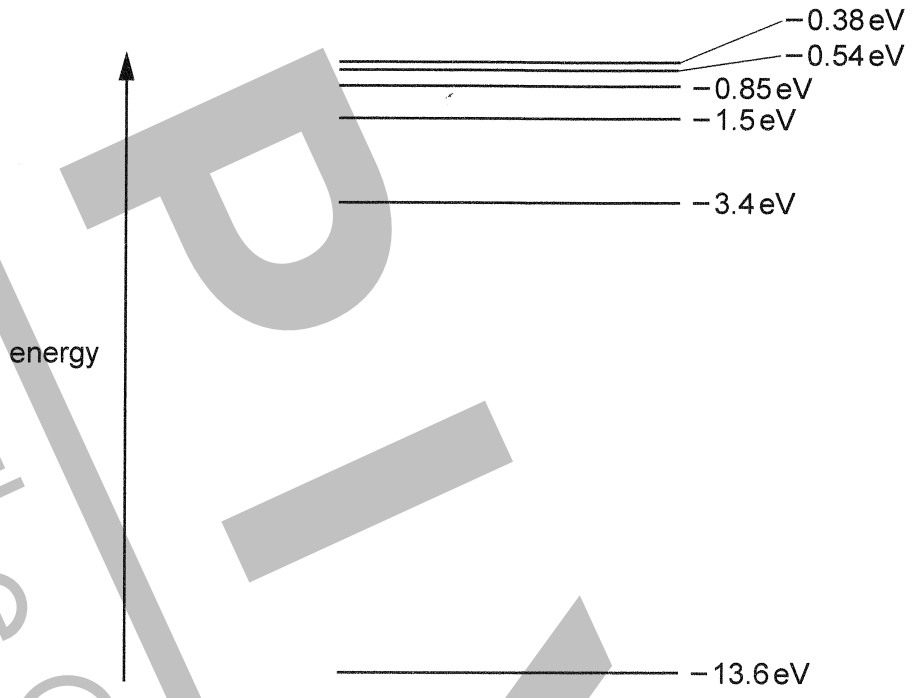


Fig. 9.1

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.

$E = \frac{hc}{\lambda} = \frac{(1.989 \times 10^{-25})}{340 \times 10^{-9}} = 5.85 \times 10^{-19}$ J

$\therefore$ in eV, $E_{purple} = \frac{5.85 \times 10^{-19}}{1.6 \times 10^{-19}} = 3.6562 = 3.66$ eV (3sf) *

energy = 3.66 eV [3]

(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.

If electrons de-excite from −3.4eV energy level to −13.6eV energy level, it must release 10.2 eV of photon energy, which is much larger than the energy of violet light (3.66eV). So, if electrons de-excite from higher energy levels to −13.6eV energy level, from Planck's law, since the energy is inversely proportional to the wavelength, photons having smaller wavelength than purple light would be emitted, thereby showing that visible light spectrum does not result. [2]

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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.

$t_{\frac{1}{2}} = 53$ days.

$E_\gamma = 0.48$ MeV

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

λ

$\lambda = \frac{\ln 2}{t_{\frac{1}{2}}} = \frac{\ln 2}{53} = 0.013078 = 0.0131$ (3sf) #

probability = 0.0131 [1]

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

$M = M_0 e^{-\lambda t} = (5.7 \times 10^{-12}) e^{-(0.0131\ \text{day}^{-1})(120\ \text{days})} = 1.18348 \times 10^{-12}$ kg (Mass of undecayed nuclei)

from $n = \frac{m}{A_r}$ and $n = \frac{N}{N_A}$, $\therefore N = \frac{M \cdot N_A}{A_r} = \frac{(1.18348 \times 10^{-12})(1000)(6.023 \times 10^{23})}{7}$

$= 1.0183 \times 10^{14}$

$= 1.02 \times 10^{14}$ # (3sf)

number = 1.02×10^{14} [3]

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

Beryllium-7 decays by emitting γ-photons, which are massless and chargeless.

This does not alter Beryllium-7. [2]

(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.

By COM, $P_i = P_f$, and $E = pc$

$\therefore 0 = \frac{E}{c} - m_{Be} v_{Be}$, $m_{Be} = 7u$

$\therefore v_{BE} = \frac{E}{c} \cdot \frac{1}{m_{Be}} = \frac{(0.48 \times 10^6 \times 1.6 \times 10^{-19})}{3 \times 10^8} \times \frac{1}{7(1.66 \times 10^{-27})} = 22030.9$

$= 2.20 \times 10^4\ \text{ms}^{-1}$ (3sf) #

speed = 2.20×10^4 m s^{-1} [4]

[Total: 20]

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