MINISTRY OF EDUCATION, SINGAPORE
in collaboration with
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 2020

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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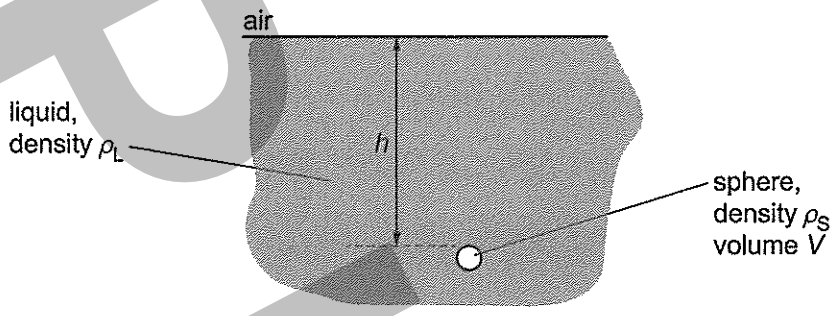
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Section A

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

1 A small sphere of volume V and density ρ_S is submerged in a liquid of density ρ_L, as shown in Fig. 1.1.



$\rho_L > \rho_S$

Fig. 1.1

floats

The liquid density ρ_L is greater than the density ρ_S of the sphere.
The top of the sphere is a distance h below the surface of the liquid.

(a) (i) Explain why the liquid exerts an upthrust on the sphere.

Pressure increases with depth. The top part of sphere experiences downward pressure which is smaller than the larger upward pressure at the bottom part of sphere, due to the greater depth. Since pressure is the product of the force and perpendicular area, there is a larger upward force acting on the bottom hemisphere and a smaller downward force acting on the top hemisphere, resulting in a net upward force, known as the upthrust. [3]

(ii) Determine, in terms of ρ_L, V and the acceleration of free fall g, the upthrust produced by the liquid on the sphere. Explain your working.

By Archimedes Principle,

$U = W_{\text{fluid displaced}} = \rho_f V_{disp} g = \rho_f V_{object} g = \rho_L V g$ *

upthrust = $\rho_L V g$ [2]

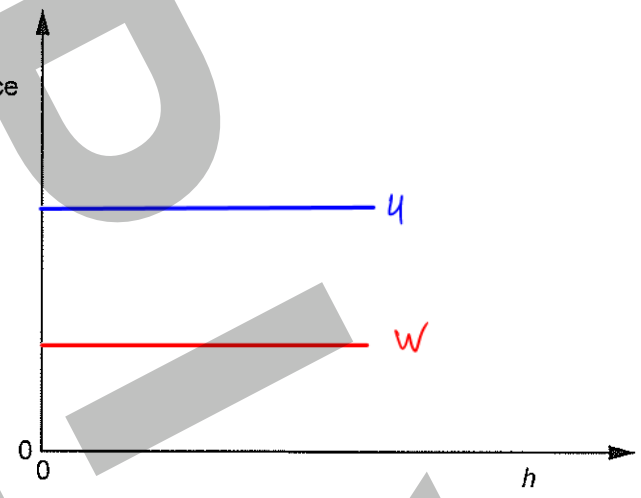
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(b) Complete Fig. 1.2 to show the variation with depth *h* of:

- the weight of the sphere (label this line W)
- the upthrust on the sphere (label this line U).

} constants



$W = \rho_S V g$

$U = \rho_L V g$

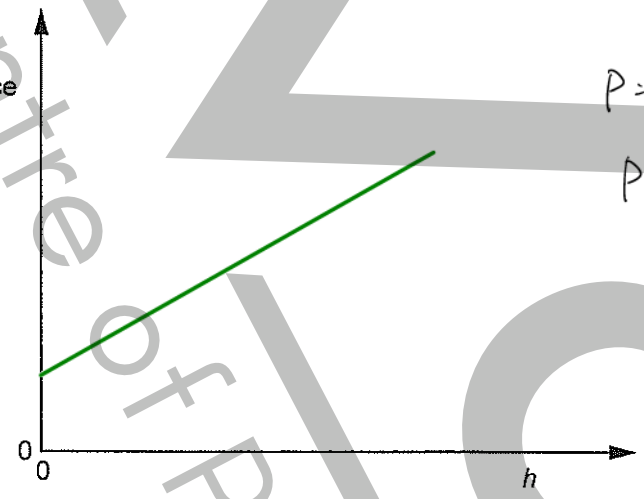
$\rho_L > \rho_S$

$\therefore U > W$

Fig. 1.2

[2]

(c) Complete Fig. 1.3 to show the variation with depth *h* of the downward force on the sphere due to both atmospheric pressure and water pressure.



$P = FA$

$P = \rho g h + P_{atm}$ (linear)

$\therefore F = \frac{P}{A} = \frac{\rho g h}{A} + \frac{P_{atm}}{A}$

const const

Fig. 1.3

[2]

[Total: 9]

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343.15K

2 A sample of an ideal monatomic gas has a volume of $4.2 \times 10^{-3}\,m^3$ at a pressure of $3.6 \times 10^5\,Pa$ and a temperature of 70 °C.

(a) Explain why the mean velocity of the atoms of the gas is zero.

The atoms move in constant random motion in all directions. Velocity is a vector quantity, where magnitude and direction needs to be considered. The mean velocity in a particular direction is always equal and opposite to the mean velocity in the exact opposite direction, thereby vectorally cancelling out to give 0 mean velocity. [2]

(b) Show that the sample of gas contains 3.2×10^{23} atoms.

°C + 273.15 = K

From $pV = NkT$

$$\therefore N = \frac{pV}{kT} = \frac{(3.6\times10^5)(4.2\times10^{-3})}{(1.38\times10^{-23})(343.15)} = 3.1929\times10^{23}$$

$= 3.2 \times 10^{23}$ atoms

∴ shown.

[3]

(c) Each atom of the gas has a diameter of approximately 2×10^{-10} m.

Estimate the volume of the gas atoms.

$$V_{gas\ atoms} = V_{1\ gas\ atom} \cdot N = \frac{4}{3}\pi r^3 \cdot N = \frac{4}{3}\pi\left(\frac{2\times10^{-10}}{2}\right)^3(3.2\times10^{23})$$

$$= 1.3404\times10^{-6}$$

$$= 1.34\times10^{-6}\ m^3$$

volume = 1.34×10^{-6} m^3 [1]

(d) Explain why your answer in **(c)** provides evidence to support the assumption that the gas is ideal.

The volume of the gas atoms ($1.34\times10^{-6}\ m^3$) is much smaller than the volume of the entire sample of gas ($4.2\times10^{-3}\ m^3$), thereby suggesting that the gas atoms are far apart, indicating that the attractive forces are negligible. [2]

[Total: 8]

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3 The piston in a cylinder of a car engine is shown in Fig. 3.1.

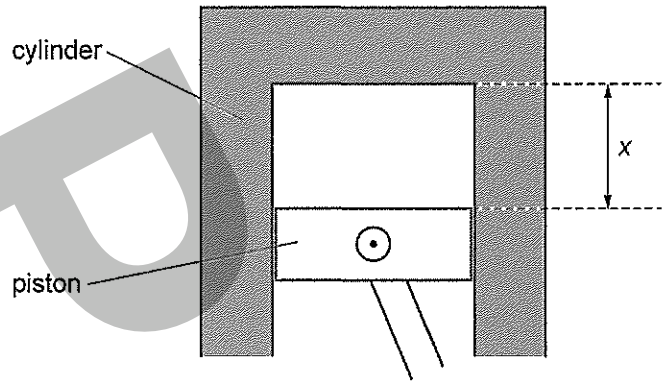


Fig. 3.1

The piston moves in the cylinder with simple harmonic motion.

The distance x between the top of the cylinder and the top of the piston varies from 1.0 cm to 6.0 cm.

At one speed of the engine, the engine completes 4200 revolutions in 1.0 minute. During one revolution of the engine, the piston moves from the position where x is minimum to where x is maximum and then back to the minimum position.

The variation with time of the distance x is shown in Fig. 3.2.

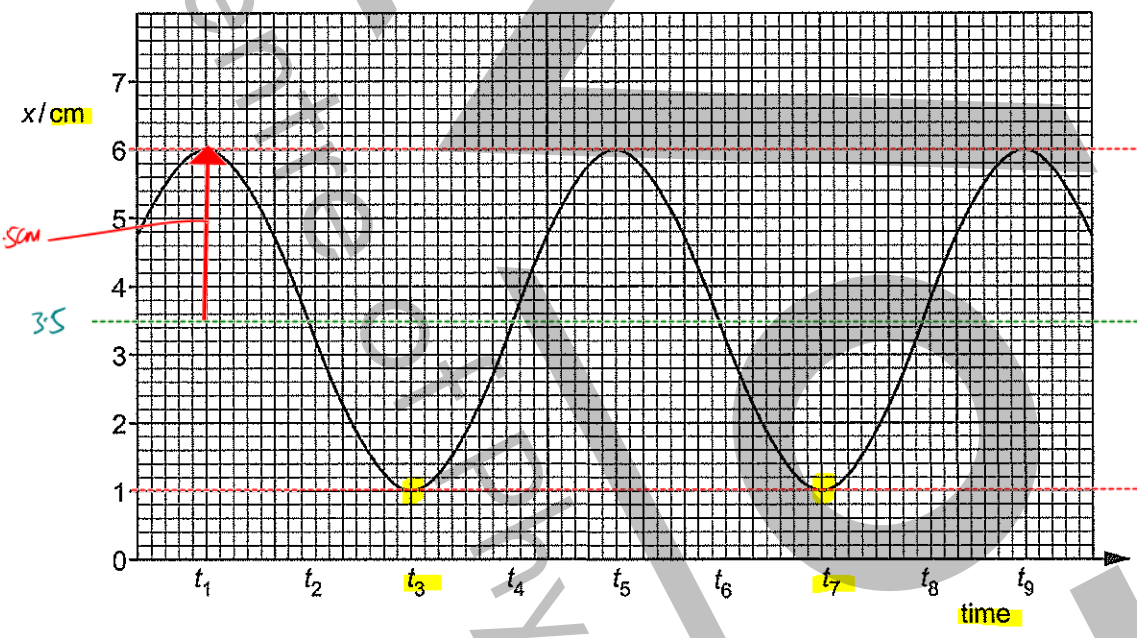


Fig. 3.2

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(a) Use Fig. 3.2 to state two times at which the piston is:

(i) at its highest point near the top of the cylinder

time ..... t_3 ..... and time ..... t_7 ..... [1]

(ii) moving away from the top of the cylinder with maximum speed.

time ..... t_4 ..... and time ..... t_8 ..... [1]

(b) Determine, for the piston:

(i) the frequency of oscillation

$f = \frac{4200}{60} = 70.0\,\text{Hz}$ (3sf)

frequency = ... 70.0 ..... Hz [1]

(ii) the maximum acceleration.

$|a_0| = |\omega^2 x_0| = |(2\pi f)^2 x_0| = \left|(2\pi)^2 (70)^2 \left(\frac{2.5}{100}\right)\right| = 4.836 \times 10^3 = 4.84 \times 10^3\ \text{m/s}^2$ (3sf)

acceleration = ... 4.84×10^3 ..... m s^{-2} [3]

(c) Use your answer to **(b)(ii)** to sketch, on the axes of Fig. 3.3, a graph to show quantitatively how the acceleration of the piston varies with the displacement from the equilibrium position.

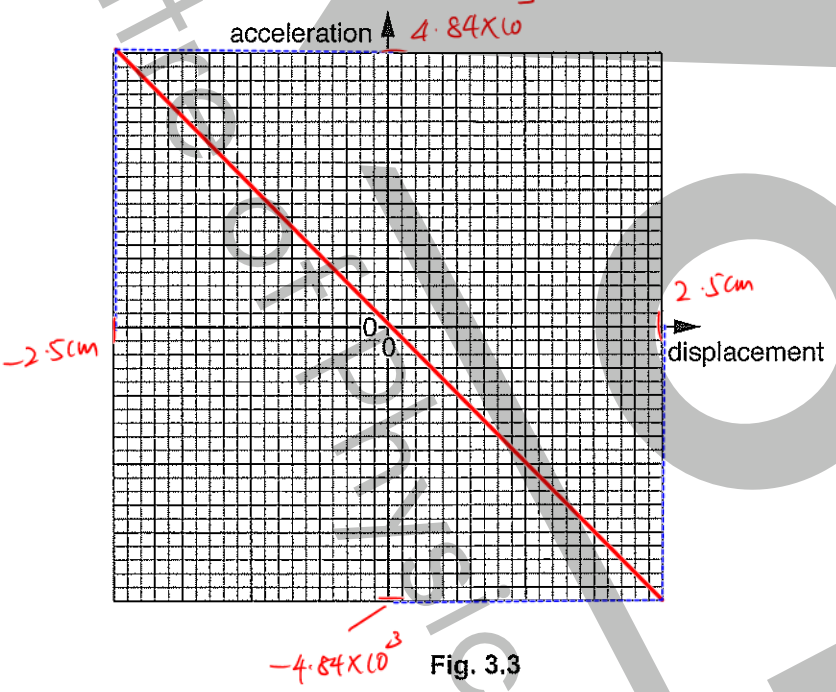


Fig. 3.3

[3]

[Total: 9]

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4 **(a)** State how a stationary wave is formed.

When 2 progressive waves, of the same amplitude, wavelength, speed, frequency and period, travelling in opposite directions, superpose, they create a stationary wave due to destructive interference, according to the Principle of Superposition. [2]

(b) A vibrating tuning fork is held above the top of a tube immersed in water, as shown in Fig. 4.1.

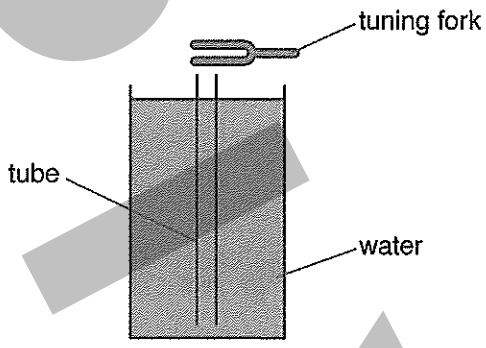
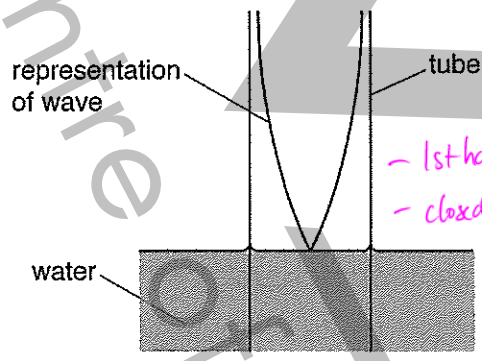


Fig. 4.1

The tube and tuning fork are gradually raised together until a loud sound (harmonic) is heard.

The loud sound indicates that a stationary wave is formed in the tube.
This longitudinal stationary wave is represented in Fig. 4.2.



- 1st harmonic
- closed pipe, only odd harmonics

Fig. 4.2

Describe how the representation in Fig. 4.2 illustrates a longitudinal wave.

Sound, a longitudinal wave, travels down parallel to the pipe, with its vibrations parallel to the pipe as well. It reflects at the water surface. The incident and reflected wave superposes to produce a stationary wave. The representation shows the magnitude of vibrational amplitude parallel to the pipe. The open end is a displacement anti-node, suggesting maximum vibrational amplitude. The closed end is a displacement node, suggesting minimum vibrational amplitude. [2]

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(c) Complete Fig. 4.3 to represent the lowest frequency of a stationary sound wave in a tube that is open at both ends.

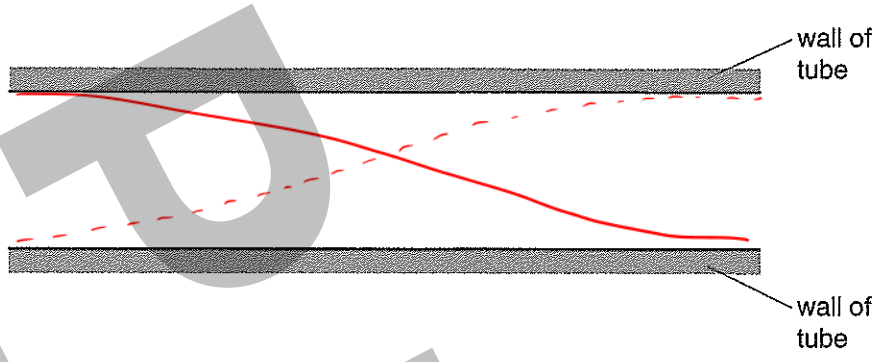


Fig. 4.3

[2]

(d) The frequency of the stationary sound wave in **(c)** is 540 Hz.

The frequency of the sound in the tube is now gradually increased until a stationary wave of the next highest frequency is formed.

Determine this frequency.

$f_1 = 540\,Hz$

$f_2 = 2f_1 = 2(540) = 1080\,Hz$

frequency = ... 1080 ..... Hz [2]

[Total: 8]

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5 The variation with potential difference (p.d.) V of the current I in a lamp is shown in Fig. 5.1.

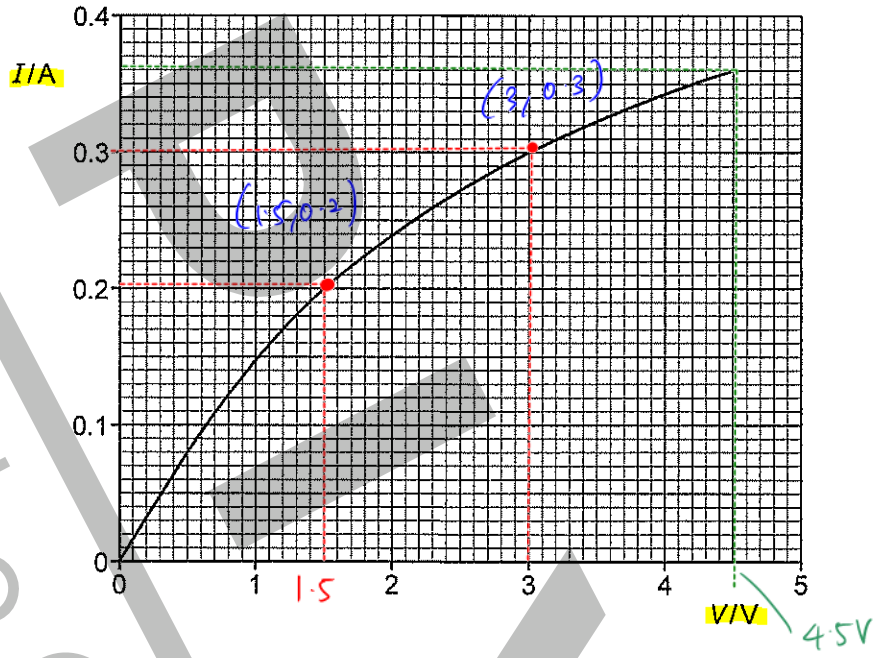


Fig. 5.1

(a) Calculate the change in resistance of the lamp for a change in p.d. from $V = 1.5\,V$ to $V = 3.0\,V$.

From ohms law, $R = \frac{V}{I}$

$\Delta R = R_f - R_i = \frac{V_f}{I_f} - \frac{V_i}{I_i} = \frac{3}{0.3} - \frac{1.5}{0.2} = 2.50\,\Omega$ (3sf)

resistance change = ... 2.50 ..... Ω [2]

(b) The lamp is connected into the circuit shown in Fig. 5.2.

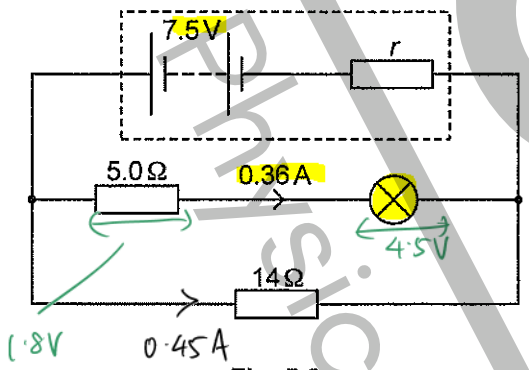


Fig. 5.2

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NOT

The battery in the circuit has an electromotive force (e.m.f.) E of 7.5 V and internal resistance r.

The current in the resistor of resistance 5.0 Ω is 0.36 A.

Determine:

(i) the current in the resistor of resistance 14 Ω

$V_{14} = V_S + V_L = (5)(0.36) + 4.5 = 6.3\,V$

$\therefore$ from ohm's law, $I_{14} = \frac{V_{14}}{R} = \frac{6.3}{14} = 0.450\,A\,(3sf)$

current = 0.450 A [2]

(ii) the internal resistance r of the battery.

$E = V_T + V_r = V_T + Ir$

$r = \frac{E - V_T}{I} = \frac{7.5 - 6.3}{0.45 + 0.36} = 1.4814 = 1.48\,\Omega\,(3sf)$

r = 1.48 Ω [2]

[Total: 6]

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6 **(a)** State Faraday's law of electromagnetic induction.

The magnitude of induced emf is directly proportional to the rate of change of magnetic flux linkage

[2]

(b) A coil is placed in a uniform magnetic field, as shown in Fig. 6.1.

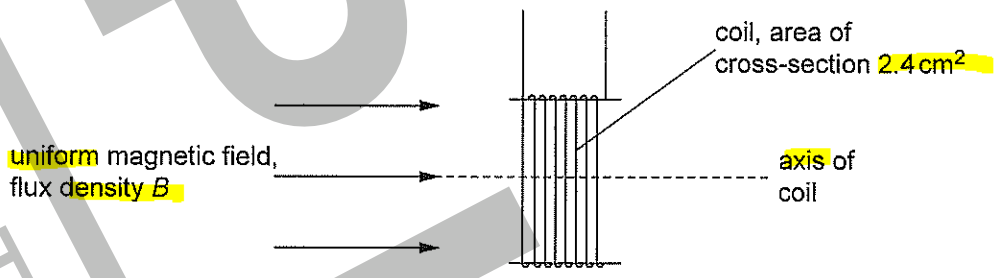


Fig. 6.1

N = 140
A = 2.4 × 10⁻⁴ m²

The coil contains 140 turns of wire and has a cross-sectional area of 2.4 cm².

The uniform magnetic field of flux density B is directed through the coil, along the axis of the coil.

The magnetic flux density B changes with time t as shown in Fig. 6.2.

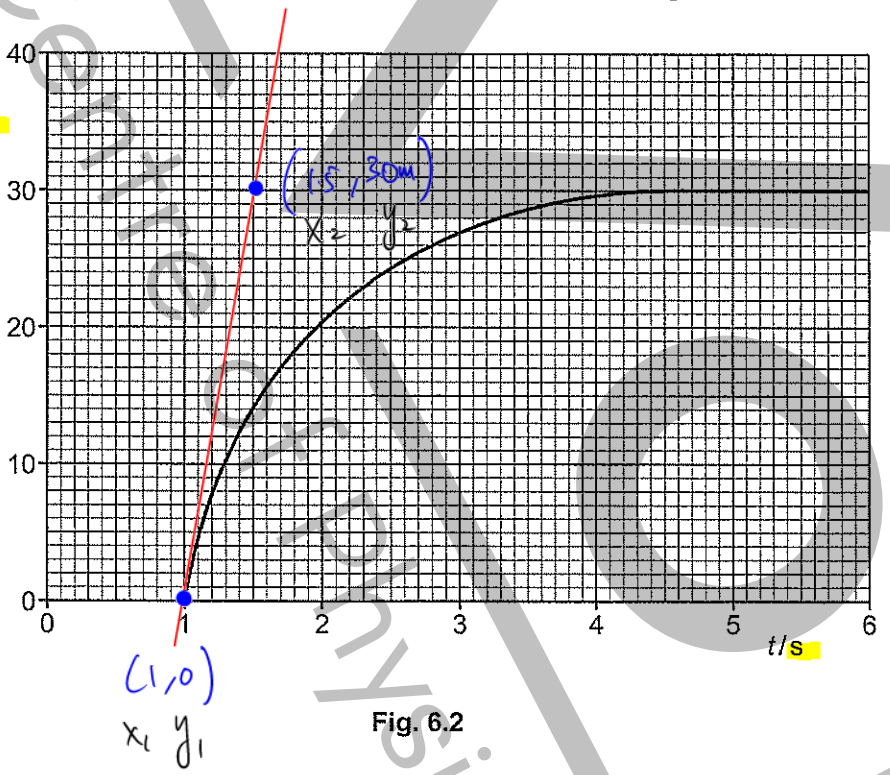


Fig. 6.2

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(i) Show that the initial rate of change of magnetic flux density at time t = 1.0 s is 6.0×10^{-2} T s^{-1}.

$\text{grad} = \frac{y_2 - y_1}{x_2 - x_1} = \frac{30 \times 10^{-3} - 0}{1.5 - 1} = 6 \times 10^{-2}$ T/s (shown)

[2]

(ii) Determine the electromotive force (e.m.f.) induced in the coil at time t = 1.0 s.

$|\varepsilon| = \left|\frac{\Delta BAN\cos\theta}{\Delta t}\right| = AN\cos\theta\left(\frac{\Delta B}{\Delta t}\right) = (2.4 \times 10^{-4})(140)(\cos 0)(6 \times 10^{-2})$

$= 2.016$ mV

$= 2.02$ mV (3sf)

e.m.f. = 2.02m ..... V [2]

(iii) On the axes of Fig. 6.3, sketch a graph to show the variation with time t of the magnitude of the e.m.f. E induced in the coil for time t = 0 to time t = 6 s.

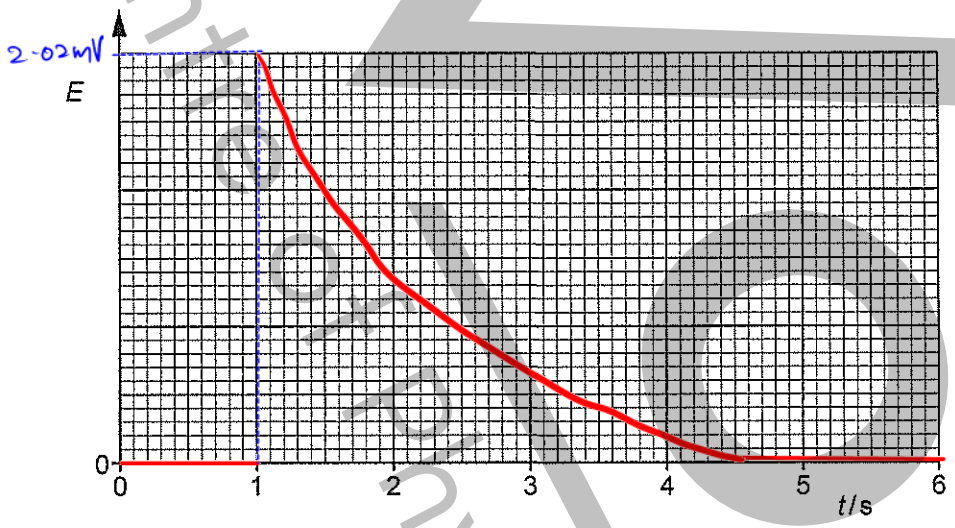


Fig. 6.3

[3]

[Total: 9]

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7 Slow-moving neutrons react with nuclei of sodium-23 to form the isotope sodium-24. The reaction is represented by the equation shown.

$$^{23}_{11}\text{Na} + {}^{1}_{0}\text{n} \longrightarrow {}^{24}_{11}\text{Na} + \gamma$$

Sodium-23 is stable.

Data for some masses are given in Fig. 7.1.

		mass / u
proton	$^{1}_{1}$p	1.00814
neutron	$^{1}_{0}$n	1.00898
sodium-23	$^{23}_{11}$Na	22.99706
sodium-24	$^{24}_{11}$Na	23.99857

Fig. 7.1

The energy equivalent to 1.000 u is 931.4 MeV.

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

The binding energy of a nucleus is the amount of energy required to completely separate a nucleus into its constituent nucleons, infinitely apart. It is the product of the mass defect and the speed of light squared

..... [2]

(ii) Use data from Fig. 7.1 to determine, to three decimal places, the binding energy per nucleon, in MeV, of sodium-23.

$^{23}_{11}\text{Na} \longrightarrow 11\,^{1}_{1}\text{p} + 12\,^{1}_{0}\text{n}$

$M_{LHS} = 22.99706$

$M_{RHS} = 11(1.00814) + 12(1.00898) = 23.1973$

$\therefore \Delta m = 0.20024\text{u}$, mass excess, BE absorbed.

$\therefore 1\text{u} = 931.4\text{MeV}$

$\therefore 0.20024\text{u} = 186.503536\text{MeV}$

$\therefore BE/nuc = \frac{186.503536}{23} = 8.10884$

$= 8.109\text{MeV}$ # (3dp)

binding energy per nucleon = ... 8.109 ..... MeV [3]

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(b) (i) For the absorption of a neutron by a sodium-23 nucleus, show that the mass change is 7.47×10^{-3} u.

$M_{LHS} = 22.99706 + 1.00898 = 24.00604\ u$

$M_{RHS} = 23.99857\ u$

$\Delta m = 7.47 \times 10^{-3}\ u$ = mass defect ∴ Energy released.

∴ Shown.

[1]

(ii) Assuming that all of the energy released in **(b)(i)** is in the form of the γ-ray photon, determine the wavelength of the γ-ray photon.

$1\ u = 931.4\ MeV$

∴ BE released $= (7.47 \times 10^{-3})(931.4)(10^6)(1.6 \times 10^{-19})$

$= 1.113209\ pJ$

from $E = \frac{hc}{\lambda}$, ∴ $\lambda = \frac{hc}{E} = \frac{(1.989 \times 10^{-25})}{(1.113209 \times 10^{-12})} = 1.7867 \times 10^{-13} = 1.79 \times 10^{-13}$ m (3sf)

∴

wavelength = 1.79×10^{-13} m [3]

(c) The isotope sodium-24 is radioactive.

A sample of sodium-24 takes 65 hours for its activity to be reduced to $\frac{1}{20}$ of its initial activity.

Determine the probability per hour of the decay of a sodium-24 nucleus.

λ

$A = A_0 e^{-\lambda t}$

$\therefore \frac{A_0}{20} = A_0 e^{-\lambda(65)}$

Take ln on both sides

$\therefore -\lambda(65) = \ln\left(\frac{1}{20}\right)$

$\therefore \lambda = 0.04608$

$= 0.0461\ hr^{-1}$ (3sf)

∴

probability = 0.0461 hour^{-1} [2]

[Total: 11]

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Section B

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

8 **(a)** State what is meant by an **inelastic** collision between two objects by reference to:

(i) the speed of the objects

The relative velocity of approach is not equal (larger) than the relative velocity of separation of the objects.

[2]

(ii) the energy of the objects.

The total kinetic energy (KE) of the objects before collision is larger than the total KE after collision.

[1]

(b) Two spheres A and B are suspended by threads from fixed points so that, when the spheres are at rest, they are touching with their centres on the same horizontal level, as shown in Fig. 8.1.

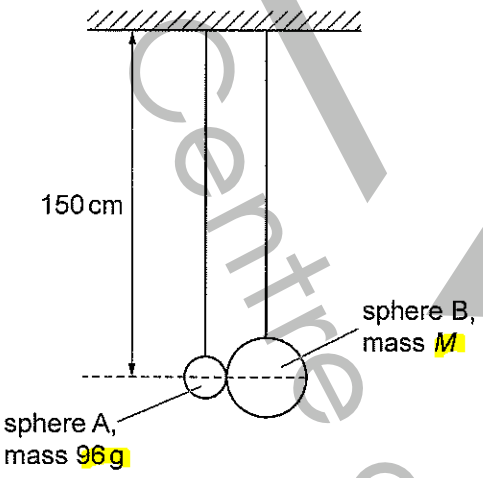


Fig. 8.1 (not to scale)

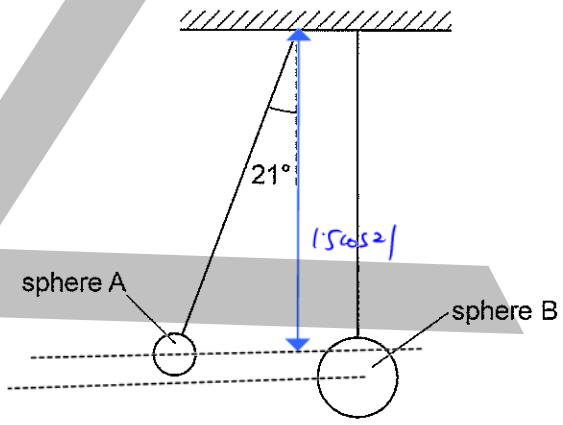


Fig. 8.2 (not to scale)

Sphere A has mass 96 g and the mass of sphere B is *M*.
The vertical distance of the support from the centre of sphere A is 150 cm.

Sphere A is displaced to one side so that the thread supporting it is at an angle of 21° to the vertical, as shown in Fig. 8.2.

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Sphere A is released. Show that the horizontal speed with which it strikes sphere B is $1.4\,m\,s^{-1}$.

By CoE, GPE loss = KE gain

$mgh = \frac{1}{2}mv^2$

$\therefore v = \sqrt{2gh} = \sqrt{(2)(9.81)(1.5)(1-\cos 21)} = 1.398$

$= 1.4\,m/s$ (2sf)

shown.

[3]

(c) The spheres in **(b)** collide.
Sphere A rebounds with a horizontal speed of $0.79\,m\,s^{-1}$. Sphere B moves off with a horizontal speed V. During the collision, 14% of the initial kinetic energy of sphere A is transferred to other forms of energy.

For sphere B immediately after the collision, determine:

(i) the magnitude p of its momentum

Tot p_i = Tot p_f

$\left(\frac{96}{1000}\right)(1.398) + 0 = \left(\frac{96}{1000}\right)(-0.79) + p_B$

$\therefore p_B = 0.2100$

$= 0.210\,kg\,ms^{-2}$ # (3sf)

p = 0.210 kg m s^{-1} [2]

(ii) its kinetic energy.

By CoE, Tot KE_i = Tot KE_f + E_{loss}

$\frac{1}{2}\left(\frac{96}{1000}\right)(1.398)^2 + 0 = \frac{1}{2}\left(\frac{96}{1000}\right)(0.79)^2 + KE_B + \frac{14}{100}\left(\frac{1}{2}\right)\left(\frac{96}{1000}\right)(1.398)^2$

$\therefore KE_B = 0.0507209$

$= 0.0507\,J$ (3sf)

kinetic energy = 0.0507 J [2]

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(d) Use your answers in **(c)** to determine, for sphere B:

(i) its initial horizontal speed

from (d)(ii) $P_B = m_B v_B$ $\therefore v_B = \frac{P_B}{m_B} = \frac{(0.210)}{0.435} = 0.48305 = 0.483 \text{ m/s}$ (3sf) #

speed = 0.483 m s^{-1} [2]

(ii) its mass *M*.

$KE = \frac{p^2}{2m}$ $\therefore m = \frac{p^2}{2(KE)} = \frac{0.210^2}{2(0.0507)} = 0.4347 = 0.435 \text{ kg}$ (3sf) #

M = 0.435 kg [1]

(e) State and explain whether, during the collision between the two spheres, both spheres are stationary at the same time.

Just before the collision, the total momentum of the system just comprises of the momentum of A only, which is 0.134 kg ms^{-1}. By the conservation of linear momentum, the total momentum of a colliding system must be constant throughout the collision, provided no net force acts on it. If both spheres are stationary at the same time, then the total momentum at that instant is 0, which is not possible, due to the violation of the conservation of linear momentum. [3]

(f) Calculate the magnitude of the impulse on sphere A during the collision.

$|I| = |p_f - p_i| = |m_A(v_f - v_i)| = \left|\left(\frac{96}{1000}\right)(-0.79 - 1.398)\right|$

$= |-0.2100|$

$= |-0.210| \text{ kg ms}^{-1}$ (3sf) #

impulse = 0.210 kg m s^{-1} [2]

(g) By reference to the direction of the impulse in **(f)**, explain why, for the initial speed of sphere B to be in a horizontal direction, the centres of the spheres are on the same horizontal level at the time of collision.

The impulse on A is to the left, horizontally. By conservation of linear momentum, the impulse on B must be to the right, suggesting that the contact force on B must lie in the same line joining the c.g. of both A and B, ie head on collision, and horizontally rightwards [2]

[Total: 20]

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

The field of force is a region of space in which an object possessing a particular property experiences a force (or acceleration) with the same property.

[2]

(ii) State the name of the field, or fields, of force that would give rise to a force on:

1. a moving uncharged particle

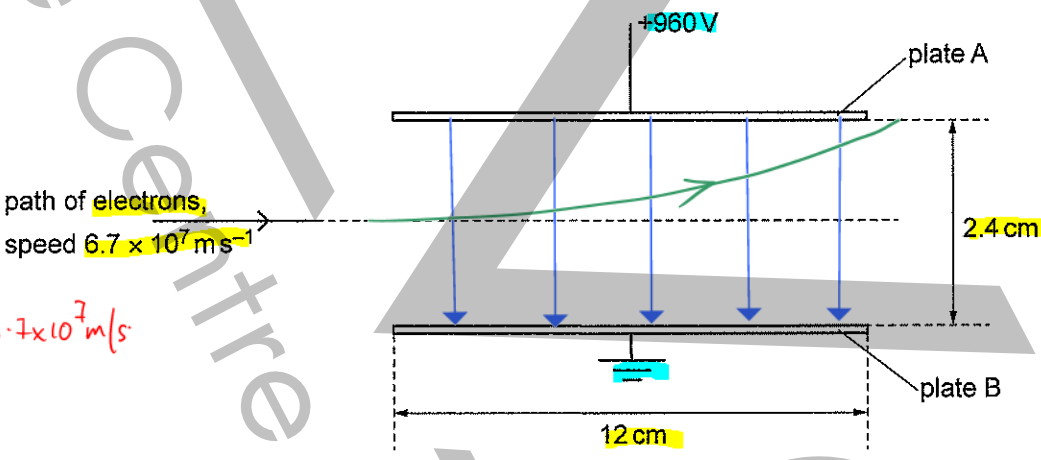
Gravitational field.

2. a stationary charged particle.

Electric field & Gravitational field.

[2]

(b) Two parallel metal plates A and B are separated by a distance of 2.4 cm in a vacuum, as shown in Fig. 9.1.



d = 2.4cm

$V_e = 6.7 \times 10^7 m/s$

Fig. 9.1

The plates have length 12 cm.

The electric field may be assumed to be uniform between the plates and zero outside the plates.

An electron with speed $6.7 \times 10^7 \text{ m s}^{-1}$ enters the region between the plates. The initial direction of the electron is along the mid-line between the plates.

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For the electron between the metal plates, calculate:

(i) the time for the electron to travel a horizontal distance equal to the length of the plates

$s = ut + \frac{1}{2}at^2$, $a_x = 0$

$\therefore t = \frac{s}{u} = \frac{\frac{12}{100}}{6.7 \times 10^7} = 1.791 \times 10^{-9}\ s = 1.79\ ns$ (3sf)

time = ... 1.79n ..... s [1]

(ii) the magnitude of its acceleration.

From N2L, $F_{net} = ma$

$\therefore a = \frac{F_{net}}{m} = \frac{F_E}{m} = \frac{qE}{m} = \frac{q}{m}\left(\frac{\Delta V}{\Delta d}\right) = \frac{q}{m}\left(\frac{V_H - V_L}{\Delta d}\right) = \frac{(1.6 \times 10^{-19})}{9.11 \times 10^{-31}} \cdot \frac{(960 - 0)}{\left(\frac{2.4}{100}\right)} = 7.025 \times 10^{15}$

$= 7.03 \times 10^{15}\ m/s^2$ (3sf)

acceleration = ... 7.03x10^15 ..... $m\,s^{-2}$ [3]

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

Vertically: $s = ut + \frac{1}{2}at^2$, $u_x = 0$

$\therefore t = \sqrt{\frac{2s}{a}} = \sqrt{\frac{2\left(\frac{1.2}{100}\right)}{7.03 \times 10^{15}}} = 1.848\ ns$

Horizontally: $s = ut + \frac{1}{2}at^2$, $a_x = 0$

$\therefore s = (6.7 \times 10^7)(1.848 \times 10^{-9}) = 0.1238\ m$

$= 12.4\ cm$ (3sf)

[3]

Since horz. range > L_{plate}, e^- won't collide with plates

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(d) Singly charged particles travelling in a vacuum at a speed of $4.6 \times 10^4\,m\,s^{-1}$ pass into a region of uniform magnetic field of flux density 0.090 T.

The direction of the magnetic field is into the page.

The charged particles enter the region of the magnetic field at right angles to the edge of the region, as shown in Fig. 9.2.

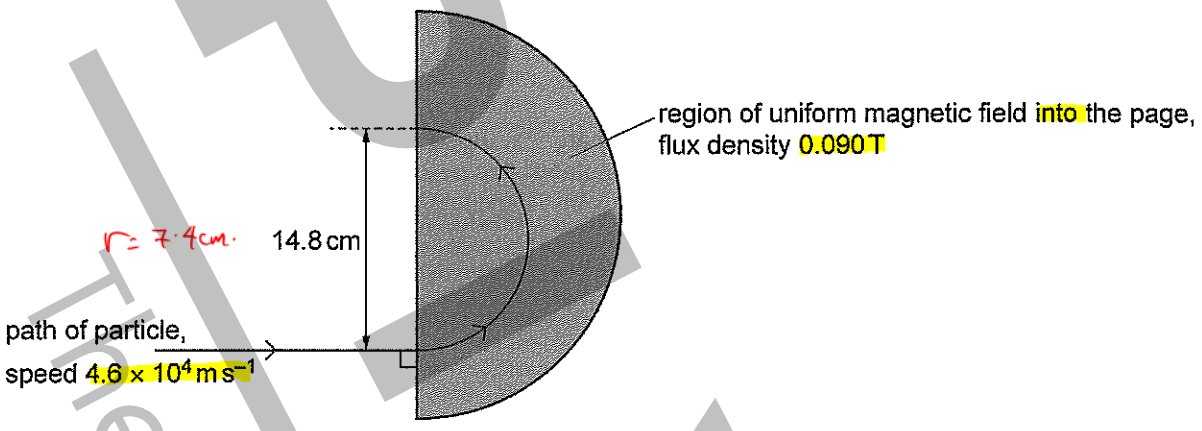


Fig. 9.2

The path of the particles in the magnetic field is a semicircle of diameter 14.8 cm.

(i) Explain why the path of a particle in the magnetic field is circular.

As the charges enter the magnetic field perpendicularly, by Fleming's left hand rule, the magnetic force is always normal to the path and always points towards a fixed point, which is the centre of the circular motion. The magnetic force provides for the centripetal force required for circular motion [2]

(ii) Determine the mass, in u, of a particle.

$F_B = F_C$

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

$\therefore m = \frac{Bqr}{v} = \frac{(0.09)(1.6\times10^{-19})(0.074)}{4.6\times10^4} = 2.3165\times10^{-26}$ kg.

$\therefore$ in u, $m = \frac{2.3165\times10^{-26}}{1.66\times10^{-27}} = 13.954\,u = 14.0\,u$ (3 sf)

mass = 14.0 u [4]

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(e) Other particles having the same speed and moving along the same initial path as those in **(d)** now enter the region of the magnetic field in **(d)**. All particles have the same sign of charge.

Suggest, by comparison with the path in **(d)**, the path followed in the magnetic field by particles that have:

$r \propto \frac{m}{q}$

(i) a smaller mass but have the same magnitude of charge as those particles in **(d)**

Smaller radius of circular motion.

..... [1]

(ii) the same mass but with double the charge as those particles in **(d)**.
Give a quantitative value for the diameter of this path.

Half the radius of circular motion, with diameter 7.4cm.

..... [2]

[Total: 20]

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H2 Physics
Paper 3