H

NATIONAL JUNIOR COLLEGE

SENIOR HIGH 2 PRELIMINARY EXAMINATION

Higher 2

CANDIDATE NAME			
SUBJECT CLASS		REGISTRATION NUMBER	

PHYSICS **9749/03**

Paper 3 Structured Questions

13 Sep 2024
2 hours

Candidate answers on the Question Paper.

No Additional Materials are required.

READ THE INSTRUCTION FIRST

Write your subject class, registration 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 a HB pencil for any diagrams or graphs.
Do not use staples, paper clips, glue or correction fluid.

The use of an approved scientific calculator is expected, where appropriate.

Section A
Answers **all** questions.

Section B
Answer one question only.

You are advised to spend one and a half hours on Section A and half an hour on Section B

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

For Examiner's Use	
Section A	
1	**/ 9**
2	**/ 7**
3	**/ 10**
4	**/ 13**
5	**/ 8**
6	**/ 6**
7	**/ 7**
Section B	
8	**/ 20**
9	**/ 20**

[Turn over

Total (80)	

This document contains **29** printed pages and **3** blank pages.

Data

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

Formulae

uniformly accelerated motion	$s = ut + \frac{1}{2}at^2$ $v^2 = u^2 + 2as$
work done on / by a gas	$W = p\Delta V$
hydrostatic pressure	$p = \rho gh$
gravitational potential	$\phi = -Gm/r$
temperature	$T/\text{K} = T/°\text{C} + 273.15$
pressure of an ideal gas	$p = \dfrac{1}{3}\dfrac{Nm}{V} < c^2 >$
mean translational kinetic energy of an ideal gas molecule	$E = \dfrac{3}{2}kT$
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	$V = \dfrac{Q}{4\pi\varepsilon_0 r}$
alternating current / voltage	$x = x_0 \sin\omega t$
magnetic flux density due to a long straight wire	$B = \dfrac{\mu_0 I}{2\pi d}$
magnetic flux density due to a flat circular coil	$B = \dfrac{\mu_0 NI}{2r}$
magnetic flux density due to a long solenoid	$B = \mu_0 nI$
radioactive decay	$x = x_0 \exp(-\lambda t)$
decay constant	$\lambda = \dfrac{\ln 2}{t_{\frac{1}{2}}}$

Section A

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

1 **(a)** Use Newton's laws of motion to explain why a body moving with uniform speed in a circle must experience a force towards the centre of the circle.

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.... [3]

(b) Fig. 1.1 shows the construction of a simple accelerometer that is used to measure the centripetal acceleration of a car turning into a corner.

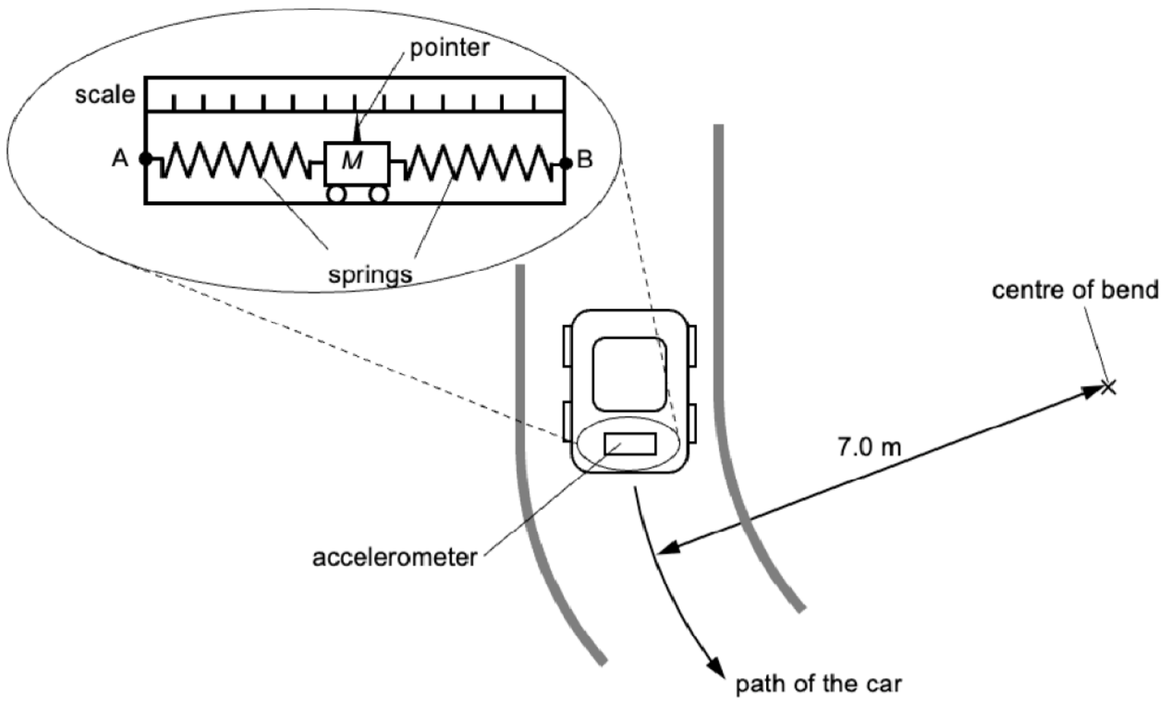

Fig. 1.1 (not to scale)

The two ends A and B of the accelerometer are fixed to the car. A mass M is connected to two identical springs and it moves between A and B with negligible friction. A pointer attached to M indicates the acceleration of the car.

The car enters the corner at a speed of 25 km h^{-1}. The radius of the path of the car is 7.0 m.

(i) Determine the centripetal acceleration of the car.

centripetal acceleration = …………………….……………. m s^{-2} [2]

(ii) The mass *M* between the springs in the accelerometer is 0.50 kg. A test shows that a force of 1.0 N moves the pointer by 5.0 mm from its equilibrium position.

Determine the displacement of the pointer from the equilibrium position when the car is turning into the corner.

displacement = ……………………….………….. mm [2]

(iii) End B is nearer to the centre of the bend compared to A. Explain, in terms of forces exerted by the springs, whether the pointer of the accelerometer moves towards end A or B.

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……………………………………………………………………………………………….. [2]

[Total: 9]

2 **(a)** Define gravitational potential at a point.

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.... [1]

(b) A satellite of mass m is in a circular orbit of radius r_1 around the Earth. It is transferred to a new circular orbit of radius r_2 as shown in Fig. 2.1 by firing its thrusters.

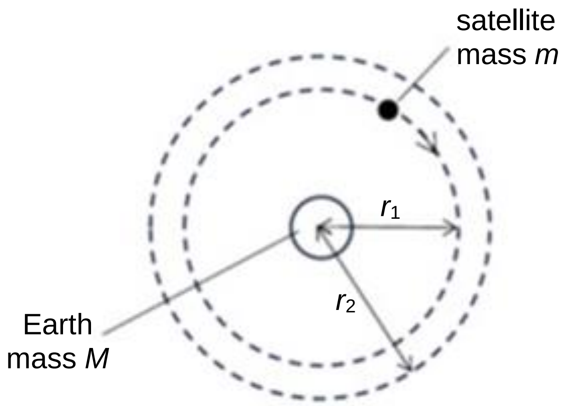

Fig. 2.1

The mass of the Earth is M and the gravitational constant is G.

(i) Show that the increase in potential energy $\otimes E_P$ of the satellite is given by

$$\Delta E_P = GMm\left(\frac{1}{r_1} - \frac{1}{r_2}\right).$$

[1]

(ii) The speed of the satellite at r_2 is smaller than at r_1. A student claims that by conservation of energy, the decrease in kinetic energy of the satellite is equal to the increase in gravitational potential energy. Explain why the student is not correct.

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………………………………………………………………………………………………….. [2]

(c) A rock of mass m_r, initially at rest at infinity, falls towards the satellite orbiting at a radius of r_2. The gravitational force between the rock and the satellite is negligible. Determine the speed v of the rock as it hits the satellite in terms of G, M, m, m_r, r_1 and r_2. [3]

[Total: 7]

3 **(a)** According to the kinetic theory of gases, the average random translational kinetic energy E_K of an ideal gas particle is given by:

$$E_K = \frac{3}{2}kT$$

where k is the Boltzmann constant and T is the thermodynamic temperature of the gas.

(i) Using the above expression, show that the root-mean-square speed $c_{r.m.s.}$ of the gas particles is given by:

$$c_{r.m.s.} = \sqrt{\frac{3RT}{M}}$$

where R is the molar gas constant and M is the molar mass.

[2]

(ii) A sealed canister contains 0.200 mol of oxygen (molar mass = 32 g). An identical canister contains 0.300 mol of nitrogen (molar mass = 28 g) at the same temperature.

Assuming ideal gas behaviour, determine the ratio

$$\frac{c_{r.m.s.} \text{ of oxygen molecules}}{c_{r.m.s.} \text{ of nitrogen molecules}}$$

ratio = ………………. [1]

(b) The root-mean-square speed of particles at the centre of the Sun is 4.85×10^5 m s^{-1} and the density of the particles in that region is 1.50×10^5 kg m^{-3}.

(i) Assuming that the particles behaved like ideal gas, calculate the pressure in that region.

pressure = ……………. Pa [2]

(ii) The actual pressure at the centre of the Sun is much higher than the value calculated above. This shows that some of the assumptions used in the kinetic theory of gases cannot be applied to the particles in that region of the Sun.

State one assumption that is no longer applicable and explain how it leads to the actual pressure being higher than the one calculated above.

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……………………………………………………………………………………………… [2]

(c) A fixed mass of ideal gas is made to undergo the processes shown in Fig 3.1 starting from state A.

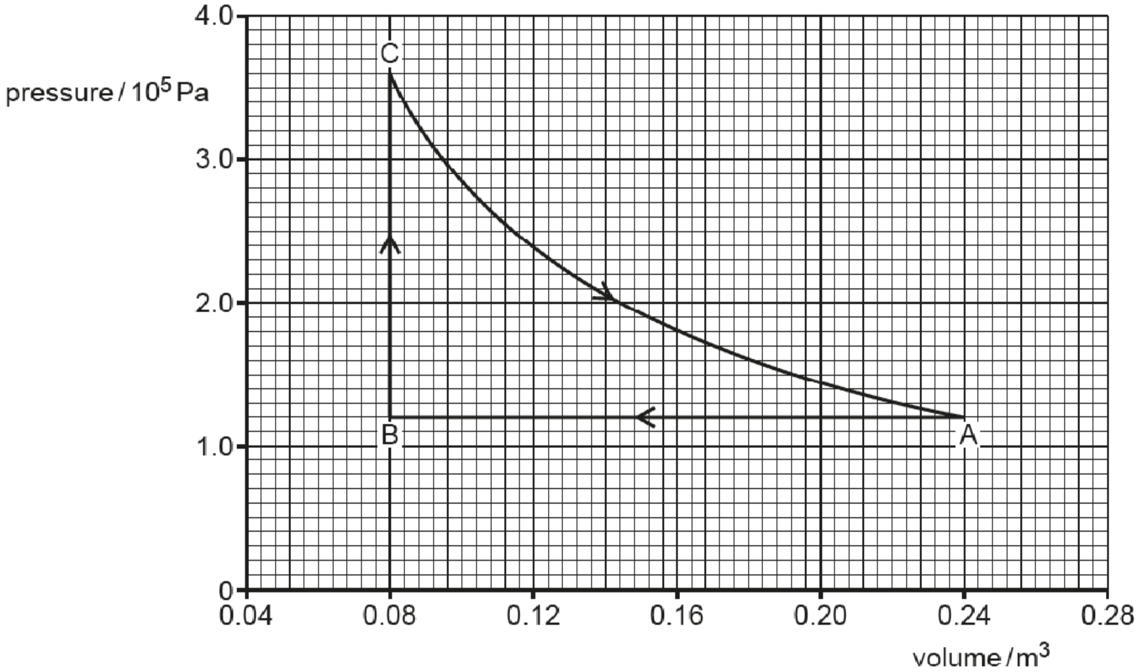

Fig. 3.1

Complete the table below for each of the processes shown in Fig. 3.1.

Process	w / kJ	q / kJ	⊗U / kJ
A to B		67.2	
B to C	0		
C to A	31.6	31.6	0

[3]

[Total: 10]

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4 A test-tube of cross-sectional area *A* is loaded with lead shots. It rests in equilibrium in a beaker of water of density *ρ* as shown in Fig. 4.1, with a length *L* submerged in the water.

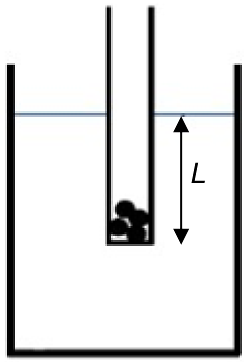

Fig. 4.1

(a) **(i)** On Fig. 4.1, draw and label the forces acting on the loaded test-tube. [2]

(ii) Derive an expression for the mass of the loaded test tube in terms of ρ, *A*, and *L*. [2]

(b) The loaded test-tube is displaced downward and released, which causes it to bob up and down in simple harmonic motion. At a particular instant in time, the loaded test-tube is at a distance x below the equilibrium position, as shown in Fig. 4.2.

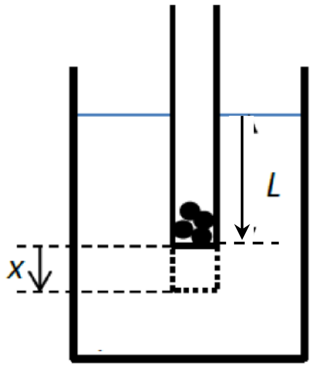

Fig. 4.2

(i) Ignoring resistive forces, show that the resultant force F acting on the loaded test-tube at this instant is given by:

$$F = -\rho A x g$$

where g is the acceleration of free fall.

[2]

(ii) Hence or otherwise, show that the angular frequency 7of oscillation of the loaded test-tube is given by:

$$\omega = \sqrt{\frac{g}{L}}$$

[3]

(iii) Given that the mass of the loaded test-tube is 50 g, L is 12.5 cm and the amplitude of oscillation is 1.5 cm.

Calculate the total energy of oscillation.

Total energy = ………………… J [2]

(iv) The loaded test-tube is at the lowest position at $t = 0$. The period of oscillation is T.

On Fig. 4.3, sketch a clearly labelled graph showing the variation with time of the kinetic energy of the loaded test-tube for two complete oscillations. Ignore resistive forces.

Indicate the maximum kinetic energy of the loaded test-tube along the vertical axis.

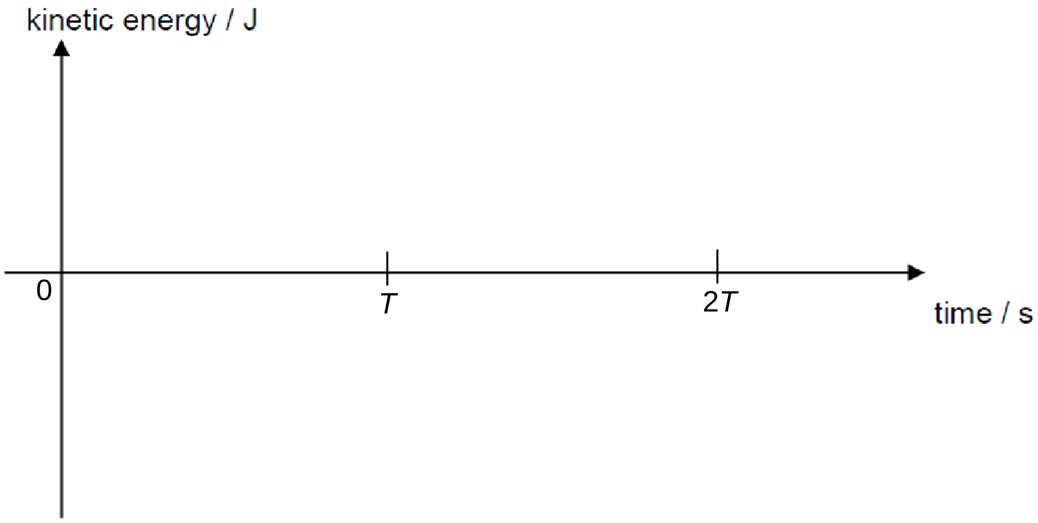

Fig. 4.3

[2]

[Total: 13]

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5 **(a)** Coherent light of wavelength 590 nm is incident normally on a double slit, as shown in Fig. 5.1.

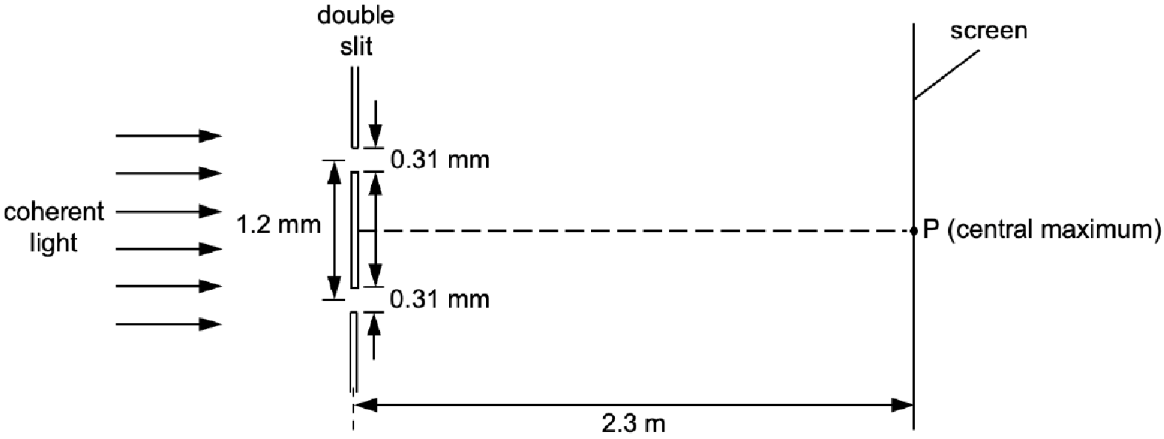

Fig. 5.1 (not to scale)

The separation of the slits is 1.2 mm and the width of each slit is 0.31 mm.

P is equidistant from the slits.

Fig. 5.2 shows the interference fringes observed near point P on a screen placed parallel to the plane of the double slit and 2.3 m from it. The central maximum is at P.

central maximum bright fringes

third order first order first order third order

second order second order

Fig. 5.2

(i) Explain why bright fringes are produced.

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………………………………………………………………………………………………… [2]

(ii) Determine the separation of the bright fringes.

separation = …………………………………………….. mm [2]

(b) The double slit in **(a)** is replaced by a single slit of width 0.31 mm, as shown in Fig. 5.3.

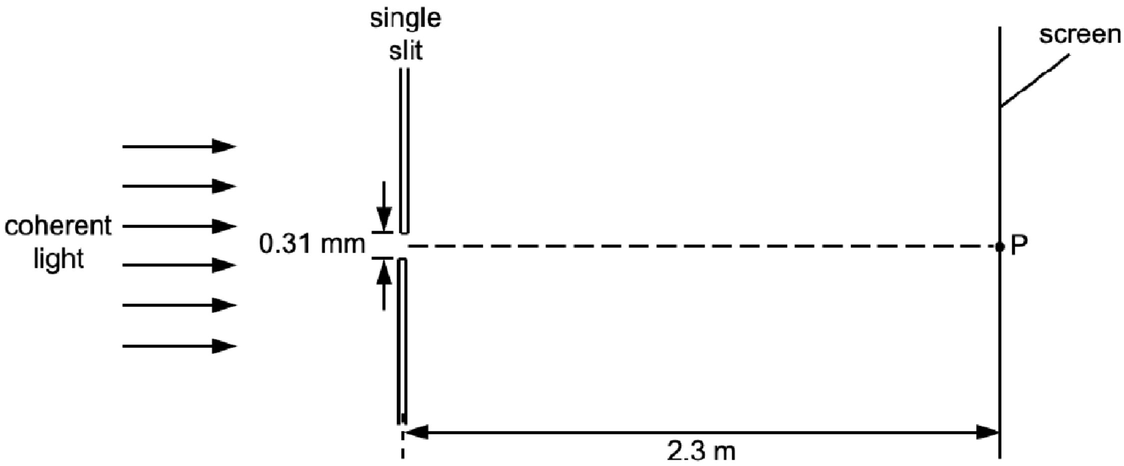

Fig. 5.3 (not to scale)

The centre of the interference pattern formed on the screen is at P.

Show that the width of the central fringe observed on the screen is 8.8 mm.

[2]

(c) The fourth order bright fringes in Fig. 5.2 are "missing".

Explain the reason for the missing fringes.

……………………………………………………………………………………………………

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………………………………………………………………………………………………….. [2]

[Total: 8]

6 A positive point charge $+Q$ is positioned at a fixed point X and an identical positive point charge is positioned at a fixed point Y, as shown in Fig. 6.1.

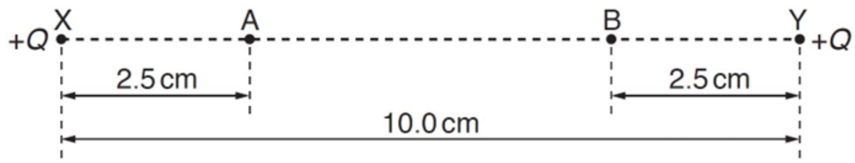

Fig. 6.1

The charges are separated in a vacuum by a distance of 10.0 cm.

Points A and B are on the line XY. Point A is a distance of 2.5 cm from X and point B is a distance of 2.5 cm from Y. The electric field strength at point A is 4.1×10^{-5} V m^{-1}.

(a) Calculate charge $+Q$.

$+Q$ = ... C [2]

(b) On Fig. 6.2, sketch the variation with distance d of the electric field strength E from A to B, along the line AB.

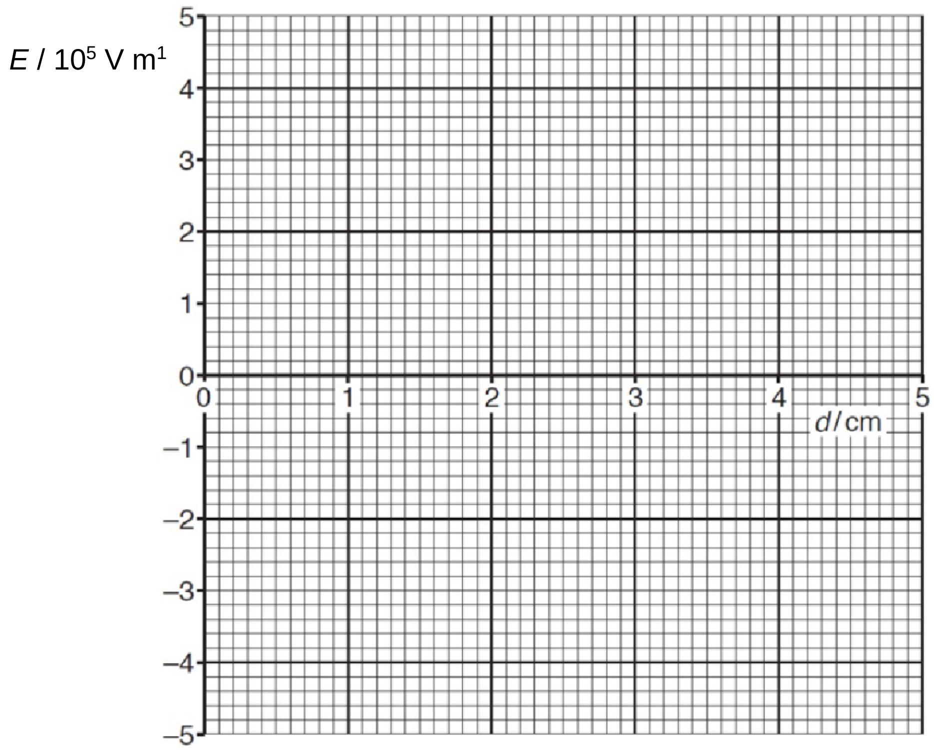

Fig 6.2

[2]

(c) A small positive charge is released at rest at d = 1.0 cm.

Using your graph in **(b)**, explain why the charge oscillates about a fixed point along the line AB.

……...

……...

……...

……...

…….. [2]

[Total: 6]

7 A d.c. converter converts direct steady voltage V into an alternating voltage of root-mean-square value V_{rms}. The output voltage V_{rms} from the d.c. converter is equal to V.

Fig. 7.1 shows a steady d.c. supply of 2.4 V connected to the d.c. converter. The output from the d.c. converter is connected to a transformer to step up the voltage so that it can power a camera flash lamp.

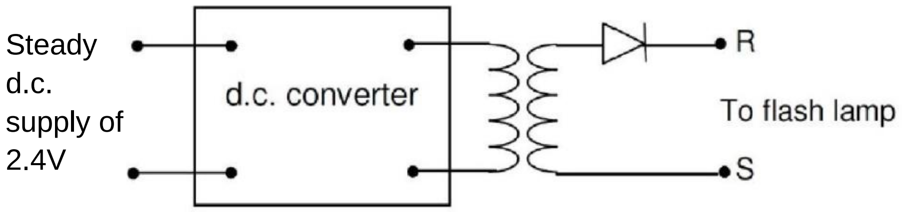

Fig. 7.1

(a) The ratio of the number of turns in the primary coil to the secondary coil is 1:50, calculate the maximum output voltage of the transformer.

maximum output voltage = ………………………………….. V [2]

(b) Fig 7.2 shows the variation with time of the output voltage across RS.

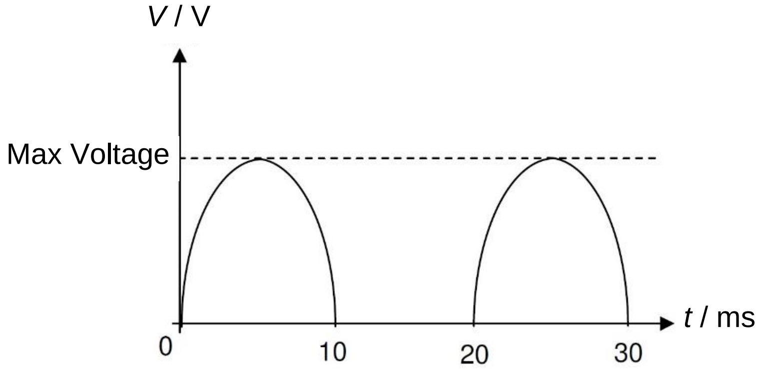

Fig. 7.2

The resistance of the flash lamp is 47 ∧. Calculate the average power supplied to the flash lamp.

average power = ………………………………….. W [2]

(c) The diode in Fig. 7.1. is replaced with a network of diodes to produce the output voltage across RS as shown in Fig. 7.3.

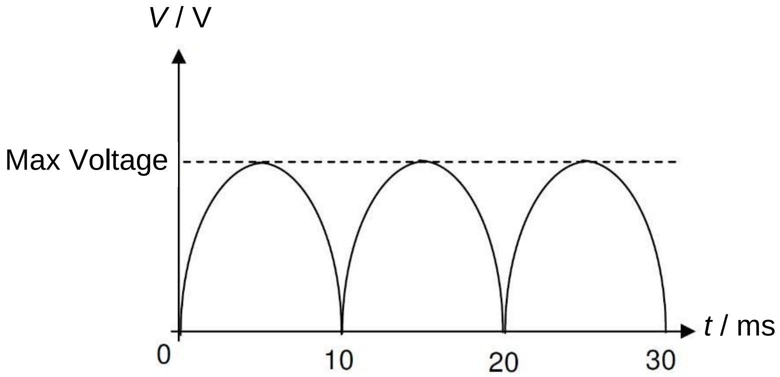

Fig. 7.3

Determine the new average power supplied to the same flash lamp.

power = …………………………………..W [1]

(d) Explain whether Fig. 7.3 represents an alternating voltage or a direct voltage.

……………………………………………………………………………………………………

…………………………………………………………………………………………………... [1]

(e) Explain why is it necessary to have a d.c. converter.

....

.... [1]

[Total: 7]

Section B

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

8 **(a)** Fig. 8.1 (top view) shows a metal ring of mass *m* and radius *r*, falling from rest within a horizontal radial magnetic field.

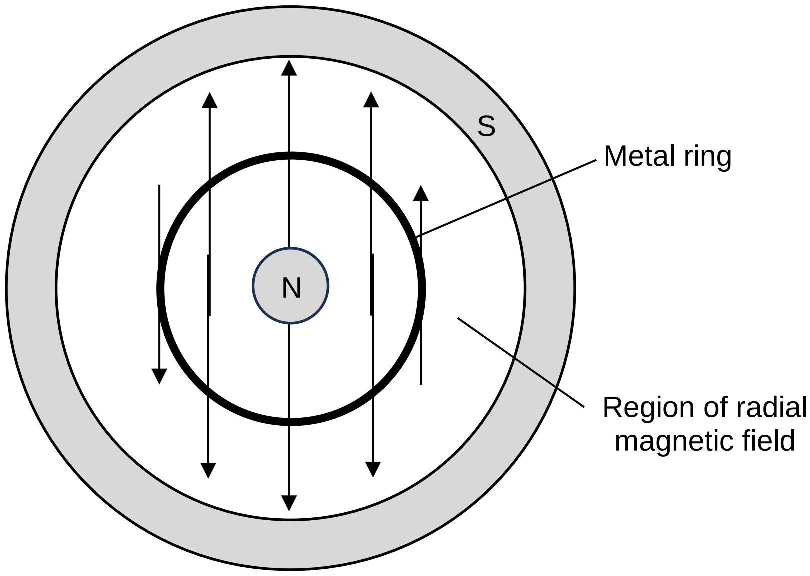

Fig. 8.1 (top view)

The centre of the ring coincides with the centre of the radial magnetic field.

The ring has a resistance *R* and the average magnetic flux density at the ring's position is *B*.

At time *t*, the ring has speed *v* and acceleration *a*.

(i) Show that the magnetic flux cut by the ring from time *t* to *t*+⊗*t*, where ⊗*t* is a short time interval is given by:

$$\Delta\Phi = 2\pi rBv\Delta t$$

[1]

(ii) Show that the current I induced in the ring is given by:

$$I = \frac{2\pi rBv}{R}$$

[2]

(iii) Air resistance is negligible. Show that the acceleration a of the ring is given by:

$$a = g - \frac{(2\pi rB)^2 v}{mR}$$

where g is the acceleration of free fall.

[2]

(iii) The average magnetic flux density B at the ring's position is 0.800 T. The ring has a resistance R = 2.30 x 10^{-4} ∧, radius r = 3.00 cm and mass m = 0.0235 kg.

Determine the maximum speed of the ring.

maximum speed = ……………… m s^{-1} [3]

(iv) On Fig. 8.2a and Fig 8.2b below, sketch the variation with time t of

1. the velocity v of the ring. [2]
2. the acceleration a of the ring. [1]

Fig. 8.2a

Fig. 8.2b

(b) Fig. 8.3 shows the ring in **(a)**, with one quadrant removed and placed in a uniform magnetic field of flux density 0.500 T.

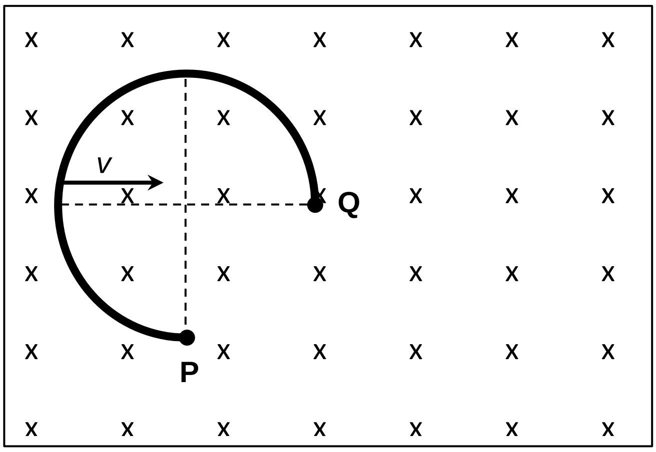

Fig. 8.3

The three-quarter ring is moved at a constant speed of 3.00 cm s^{-1} towards the right.

(i) Determine the e.m.f. induced across the two free ends P and Q.

e.m.f. = ………………… V [2]

(ii) State which end (P or Q) is at a higher potential.

higher potential at ………… [1]

(c) Fig. 8.4 shows three long straight current-carrying conductors placed parallel to one another.

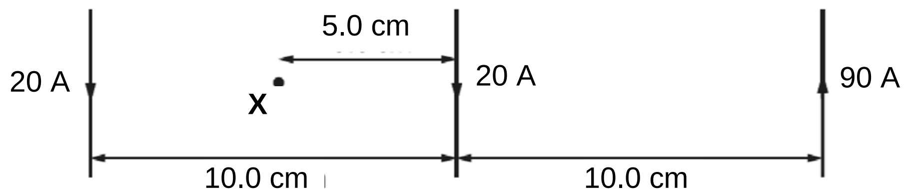

Fig. 8.4

(i) Determine the resultant magnetic flux density at X.

Flux density at X = ………………………….……… T [2]

Direction = …………………………………. [1]

(ii) The distance measured from the left-most conductor is *d*.

Curve A in Fig. 8.5 shows the variation with *d* of the magnetic flux density *B* due to the left-most conductor for the range 2.0 cm δ *d* δ 8.0 cm.

Curve C shows the magnetic flux density due to the current in the right-most conductor.

Positive values of *B* represent magnetic flux density pointing out of the page.

On the same figure, sketch the variation with *d* of

1. the magnetic flux density due to the current in the middle conductor. Label the curve B and

2. the resultant magnetic flux density due to the current in all three conductors. Label the curve R.

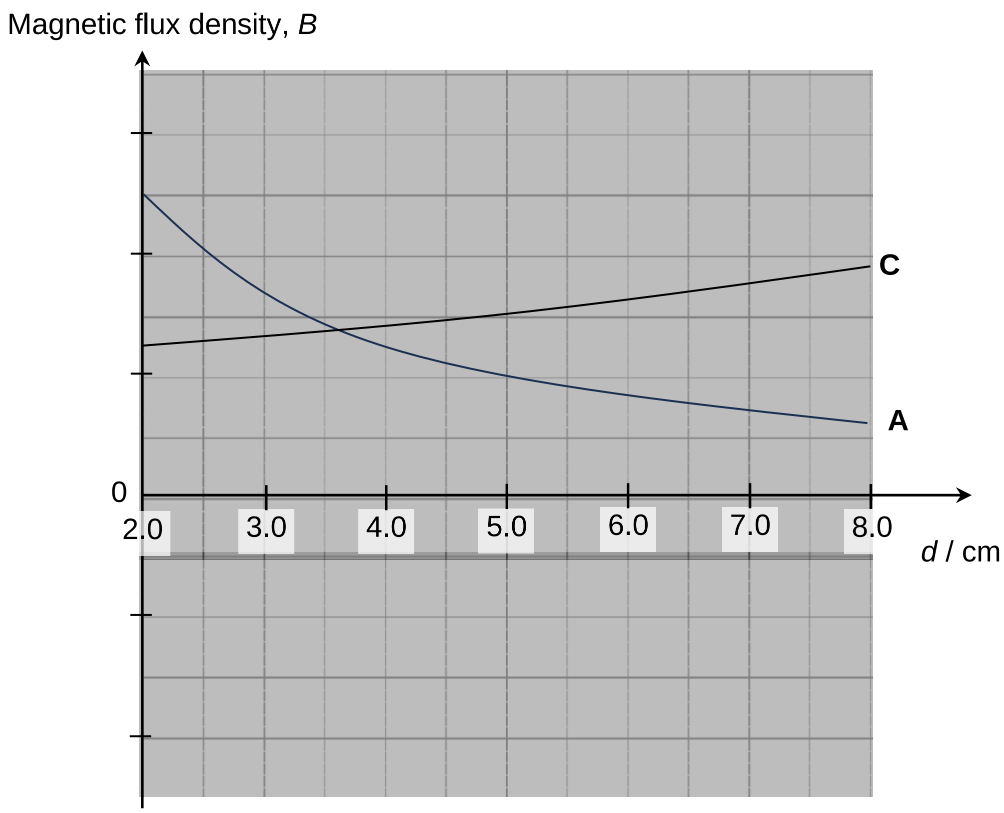

Fig. 8.5

[3]

[Total: 20]

9 **(a)** Some data for the work function energy Φ and the threshold frequency f_0 of some metal surfaces are given in Fig. 9.1.

metal	Φ / 10^{-19} J	f_0 / 10^{14} Hz
sodium	3.8	5.8
zinc	5.8	8.8
platinum	9.0	

Fig. 9.1

(i) State what is meant by the *threshold frequency*.

....

....

.... [2]

(ii) Calculate the threshold frequency for platinum.

threshold frequency = ... Hz [2]

(iii) Electromagnetic radiation having a continuous spectrum of wavelengths between 300 nm and 600 nm is incident, in turn, on each of the metals listed in Fig. 9.1. Determine which metals, if any, will give rise to the emission of electrons.

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....

....

.... [2]

(iv) Some data for the variation with frequency f of the maximum kinetic energy E_{MAX} of electrons emitted from a metal surface are shown in Fig. 9.2.

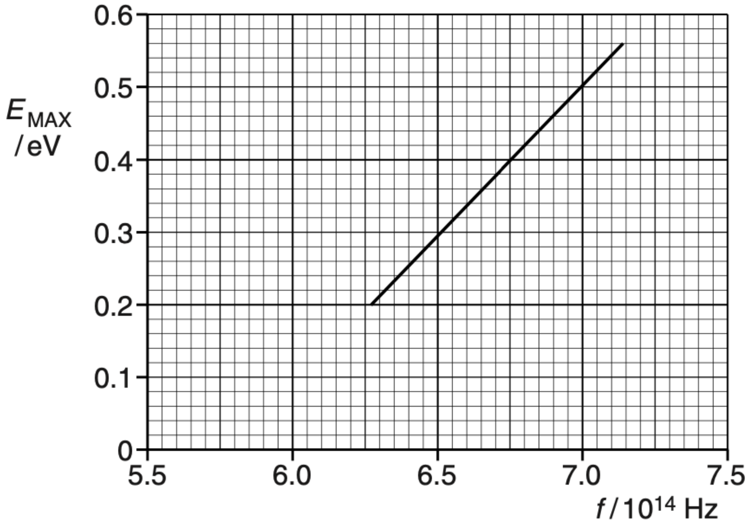

Fig. 9.2

1. Explain why emitted electrons may have kinetic energy less than the maximum at any particular frequency.

………………………………………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

……………………………………………………………………………….. [2]

2. Determine which metal listed in Fig. 9.1 is used to collect the data in Fig. 9.2.

metal is …………………………….…………….. [2]

(b) The first theory of the atom to meet with any success was put forward by Niels Bohr in 1913.

A hydrogen atom consists of a proton, of charge +*e*, and an electron, of charge –*e*. The electron of mass *m* orbits the proton at constant speed *v*. The whole system looks like the Earth orbiting around the Sun.

(i) For the electron in orbit at a distance *r* from the proton, show that

1. its kinetic energy E_K is given by:

$$E_K = \frac{e^2}{8\pi\varepsilon_0 r}$$

[2]

2. its total energy E_T is given by:

$$E_T = -\frac{e^2}{8\pi\varepsilon_0 r}$$

[1]

(ii) Show that the de Broglie wavelength of the orbiting electron is given by:

$$\lambda = \frac{h}{e}\sqrt{\frac{4\pi\varepsilon_0 r}{m}}$$

[1]

(iii) The electron wave in **(b)(ii)** forms a circular standing wave such that only an integer multiples *n* of wavelength λ could fit exactly within the orbit of radius r_n, as shown in Fig. 9.3.

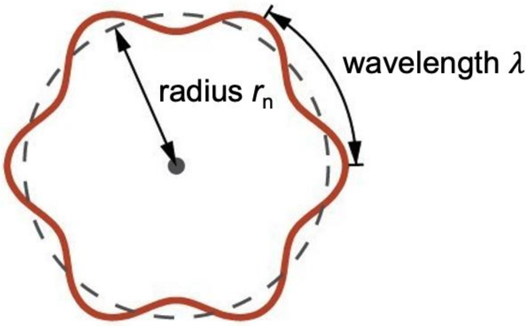

Fig. 9.3

Applying the condition in Fig. 9.3, it can be shown that the orbital radii in Bohr's atom is given by:

$$r_n = \frac{n^2 h^2 \varepsilon_0}{\pi m e^2}$$

Show that the total energy of the electron can be expressed as:

$$E_n = -\frac{k}{n^2}$$

where *k* is a constant.

Determine the value of *k*, in J.

k = ... J [3]

(iv) The expression you have derived in **(b)(iii)** is the discrete energy levels in the hydrogen atom. Transition of the electron from higher energy levels ($n > 2$) to the energy level $n = 2$ gives rise to the Balmer series line spectra.

Show that the Balmer series line spectra correspond to visible light between 350 nm and 700 nm.

[3]

[Total: 20]

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