Centre Number	Index Number	Name	Class
S3016			

RAFFLES INSTITUTION
2024 Preliminary Examination

PHYSICS
Higher 2

9749/03

Paper 3 Longer Structured Questions

18 September 2024
2 hours

Candidates answer on the Question Paper.
No Additional Materials are required.

READ THESE INSTRUCTIONS FIRST

Write your index number, name and class in the spaces at the top of this page.
Write in dark blue or black pen in the spaces provided in this booklet.
You may use 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
Answer **all** questions.

Section B
Answer **one** question only and **circle the question number** on the cover pages.

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.

***This booklet only contains Section A.**

For Examiner's Use		
Section A	1	/ 10
	2	/ 11
	3	/ 12
	4	/ 10
	5	/ 6
	6	/ 5
	7	/ 6
Section B (circle 1 question)	8	/ 20
	9	/ 20
Deduction		
Total		/ 80

This document consists of **20** printed pages.

[Turn over

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 $g = 9.81\ \text{m s}^{-2}$

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 $p = \rho g h$

gravitational potential $\phi = -Gm/r$

temperature $T/\text{K} = T/{}^\circ\text{C} + 273.15$

pressure of an ideal gas $p = \dfrac{1}{3}\dfrac{Nm}{V}\langle c^2 \rangle$

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 $B = \dfrac{\mu_0 N I}{2r}$

magnetic flux density due to a long solenoid $B = \mu_0 n I$

radioactive decay $x = x_0 \exp(-\lambda t)$

decay constant $\lambda = \ln 2 / t_{1/2}$

Section A

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

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

....

....

....

....

.... [2]

(b) A fixed mass of an ideal monatomic gas has a volume of 2.0×10^{-2} m^3 at a pressure 1.0×10^5 Pa.

(i) To determine the specific heat capacity of the gas at constant volume, the gas is heated so that its pressure increases to 1.5×10^5 Pa without any change in volume.

1. Show that the heat supplied to the gas is 1500 J.

[1]

2. Determine the increase in temperature of the gas if the average translational kinetic energy of a gas molecule is 6.2×10^{-21} J just before the gas is heated.

increase in temperature = ... °C [3]

(ii) To determine the specific heat capacity of the gas at constant pressure, the gas is heated from its initial state without any change in pressure.

State the first law of thermodynamics and use it to explain why the specific heat capacity of the ideal gas determined at constant volume is different to the specific heat capacity when determined at constant pressure.

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.... [4]

[Total: 10]

2 A light spring of force constant k hangs vertically from a fixed point. A block of mass m is attached to the free end of the spring, as shown in Fig. 2.1.

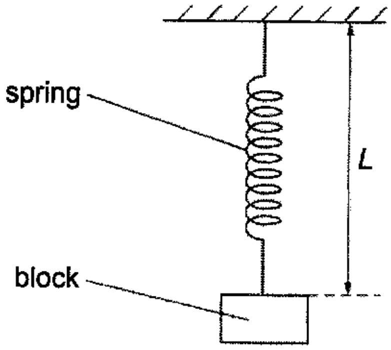

Fig. 2.1

The block is displaced downwards from its equilibrium position and then released at time $t = 0$ s.

(a) The acceleration a of the block is related to its displacement x from the equilibrium position by the equation

$$a = -\frac{k}{m}x.$$

Explain why the equation leads to the conclusion that the block is performing simple harmonic motion.

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.... [2]

(b) The variation with time *t* of the length *L* of the spring is shown in Fig. 2.2.

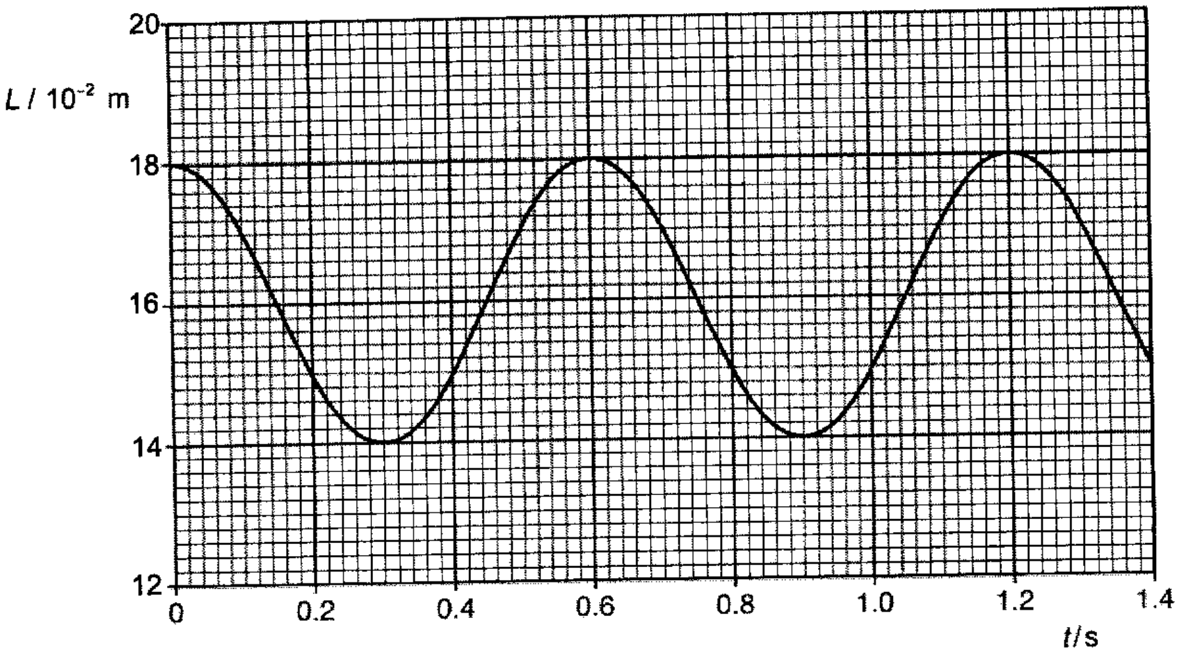

Fig. 2.2

(i) Determine the maximum speed of the block.

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

(ii) On Fig. 2.3, show the variation with time t of the velocity v of the block from $t = 0$ s to $t = 1.4$ s.

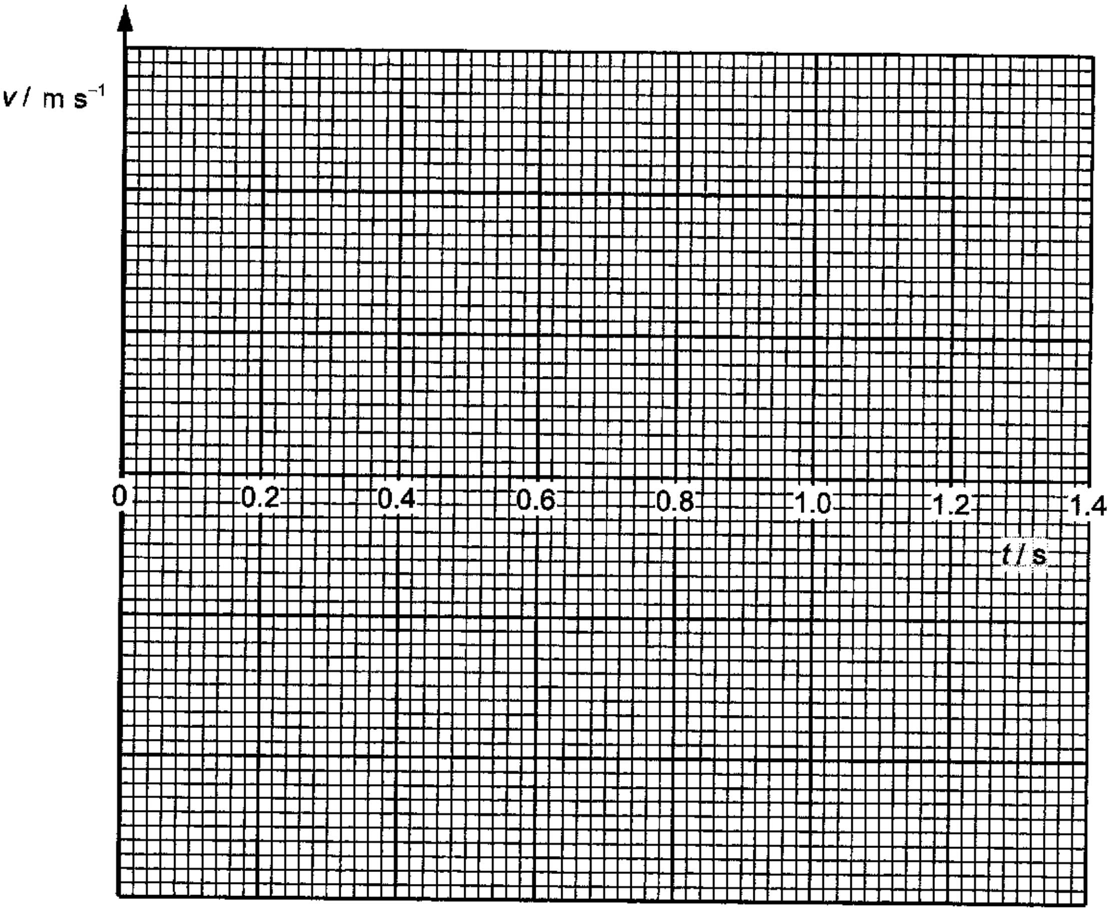

Fig. 2.3

[2]

(iii) Determine a value of L at which the potential energy and kinetic energy of the oscillating system are equal.

The total potential energy of the oscillating system at equilibrium is taken to be zero.

L = ... cm [2]

(c) The same block is suspended from two springs as shown in Fig. 2.4. Both springs are identical to that used in Fig. 2.1.

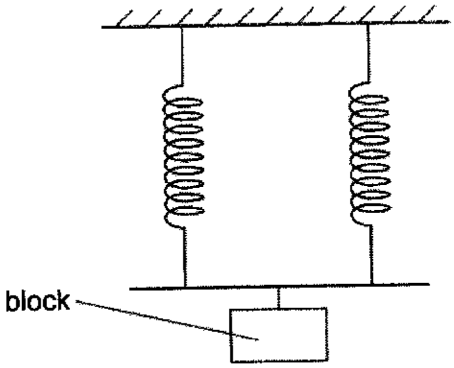

Fig. 2.4

The block is pulled down a small distance and released so that it oscillates.

By considering the extension at equilibrium of the spring combination in Fig. 2.4, state and explain how the period of these oscillations compares with the period of oscillations in **(a)**.

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.... [3]

[Total: 11]

3 Fig. 3.1 shows, at time t_0, the positions x of the air particles where a progressive sound wave passes through the air towards a reflector.

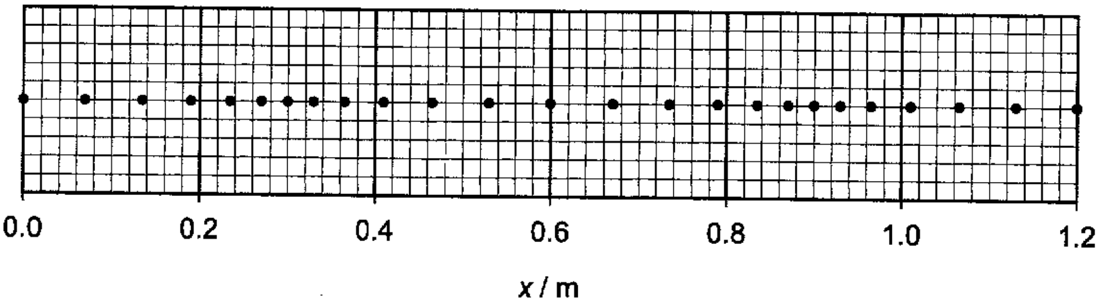

Fig. 3.1

Fig. 3.2 shows, at a later time t_1, the positions x of the same air particles when the reflected sound wave is superposed with the original sound wave to form a stationary wave.

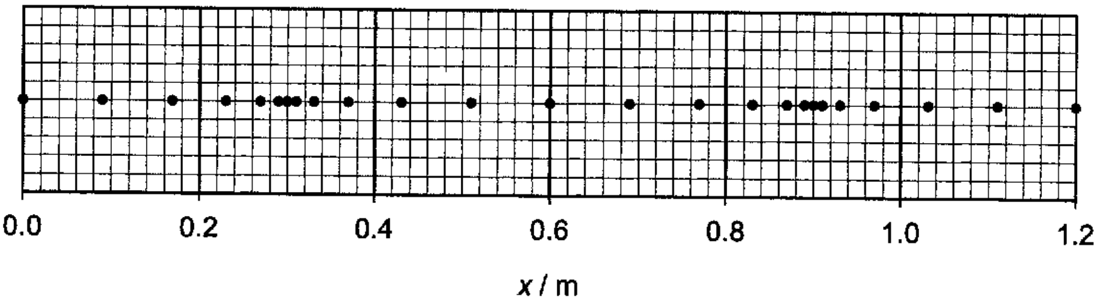

Fig. 3.2

(a) Distinguish between progressive and stationary waves in terms of the amplitudes and the phases of oscillations of the particles.

amplitudes: ....

....

....

....

phases: ....

....

....

.... [2]

(b) Use Fig. 3.1 to deduce, with an explanation,

(i) the wavelength of the sound wave,

wavelength = ... m

....

....

.... [1]

(ii) the amplitude of the oscillations of the particles.

amplitude = ... m

....

....

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.... [2]

(c) **(i)** On Fig. 3.2, indicate all the positions of the displacement nodes (label as N) and displacement antinodes (label as A). [1]

(ii) By considering the positions of the particles in Fig. 3.2, draw on Fig. 3.3, the variation with position x of the pressure p of the air when a stationary wave is set up

1. at time t_1 (label as Y), [1]

2. at time $t_1 + \frac{T}{8}$ (label as Z), where T is the period of the wave. [1]

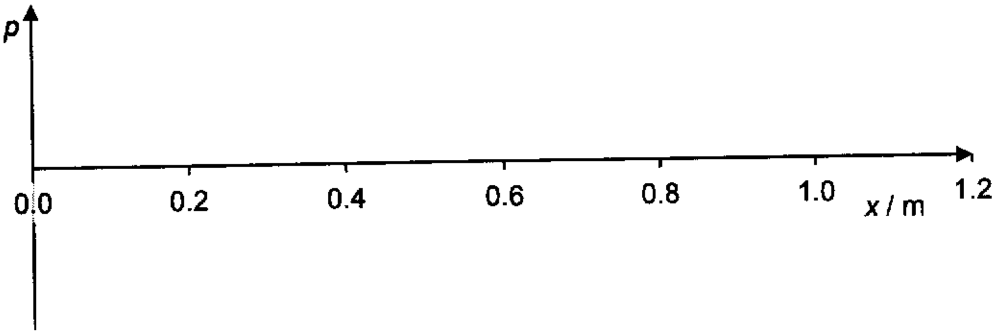

Fig. 3.3

(d) The sound wave represented in Fig. 3.1 is now continuously projected along a vertical tube that is initially fully immersed in water.

As the tube is raised vertically, it was found that the first loud note was heard when the air column has a length of 14.4 cm.

Determine

(i) the end correction of the tube,

end correction = ... m [2]

(ii) the length of the air column when the next loud note is heard.

length = ... m [2]

[Total: 12]

4 **(a)** Two charged particles, A and B, are isolated in space and separated by a distance x, as shown in Fig. 4.1.

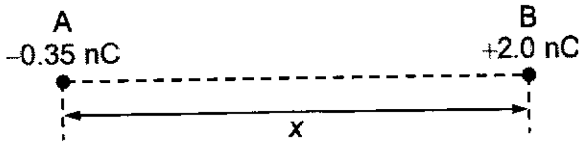

Fig. 4.1

Particle A has a charge of −0.35 nC and particle B has a charge of +2.0 nC.

(i) Explain whether the electric field strength is zero at any point along the straight line between the two charged particles.

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.... [1]

(ii) Explain whether the electric potential is zero at any point along the straight line between the two charged particles.

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....

.... [1]

(b) Two long parallel metal plates, X and Y, are separated by a distance 3.6 cm in a vacuum. Plate X is at potential *V* and plate Y is earthed. The potential difference between the plates gives rise to a uniform electric field in the region between the plates.

A particle of charge -3.2×10^{-19} C and mass 6.6×10^{-27} kg is projected into the uniform electric field midway between plates. It enters the electric field with speed 4.1×10^{5} m s^{-1} at an angle 32° from the vertical and hits plate Y at point P with speed 6.5×10^{5} m s^{-1}. Point P is a vertical distance *d* from the top of the plate.

Fig. 4.2 shows the path of the particle. Ignore gravitational effects.

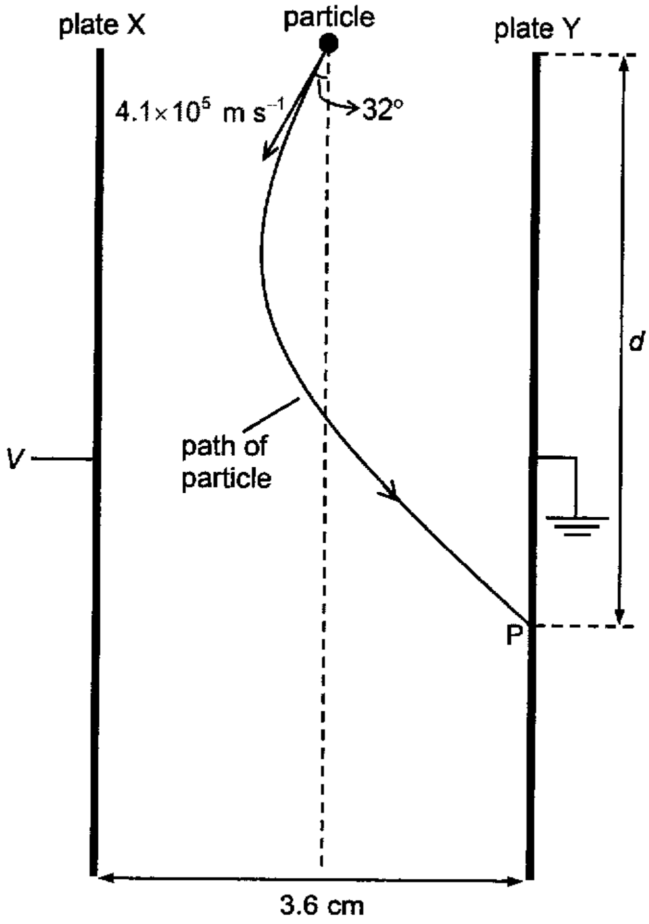

Fig. 4.2

Determine

(i) the potential V,

V = ... V [3]

(ii) the magnitude of the acceleration a of the particle,

a = ... m s^{-2} [2]

(iii) the distance d.

d = ... m [3]

[Total: 10]

5 A model for a braking system is shown in Fig. 5.1. A large thin horizontal aluminium disc spinning about a vertical axle through its centre slows down as the poles of two magnets are brought near to it.

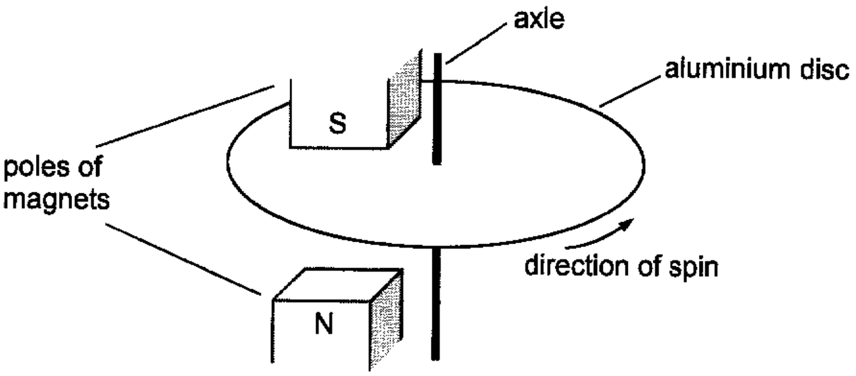

Fig. 5.1

(a) Explain how the model of the braking system shows that Lenz's law is an example of the law of conservation of energy.

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.... [2]

(b) Fig. 5.2 shows the top view of the disc.

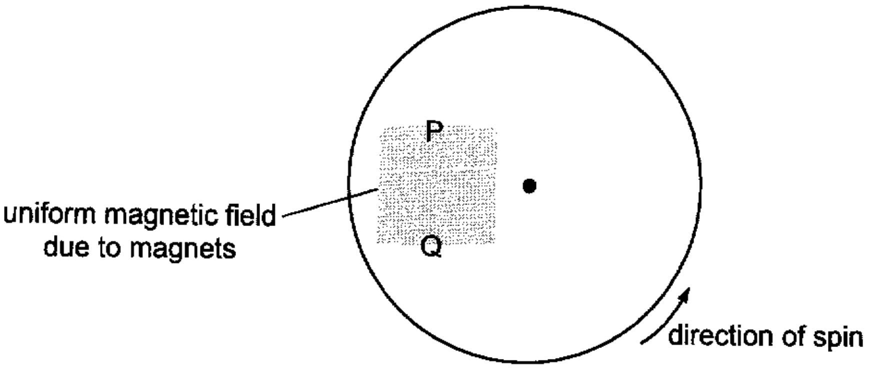

Fig. 5.2

On Fig. 5.2, draw the directions of the eddy currents induced at regions P and Q of the disc.

[1]

(c) Explain why the angular velocity of the disc does not decrease linearly with time.

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....

....

....

....

.... [3]

[Total: 6]

6 **(a)** By reference to heating effect, state what is meant by the *root-mean-square* value of an alternating current.

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.... [1]

(b) An alternating power supply is connected to a switch S, an ideal diode and two identical resistors R_1 and R_2, as shown in Fig. 6.1. Each resistor has a resistance of 18 Ω.

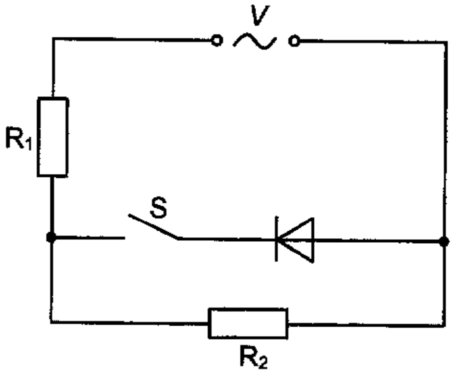

Fig. 6.1

The variation with time *t* of the potential difference *V* of the alternating supply is given by the expression

$$V = 24 \sin 314\, t$$

where *V* is in volts and *t* is in seconds.

(i) Switch S is closed.

On Fig. 6.2, show the variation with time t of the potential difference V_1 across R_1 for two periods of the alternating voltage.

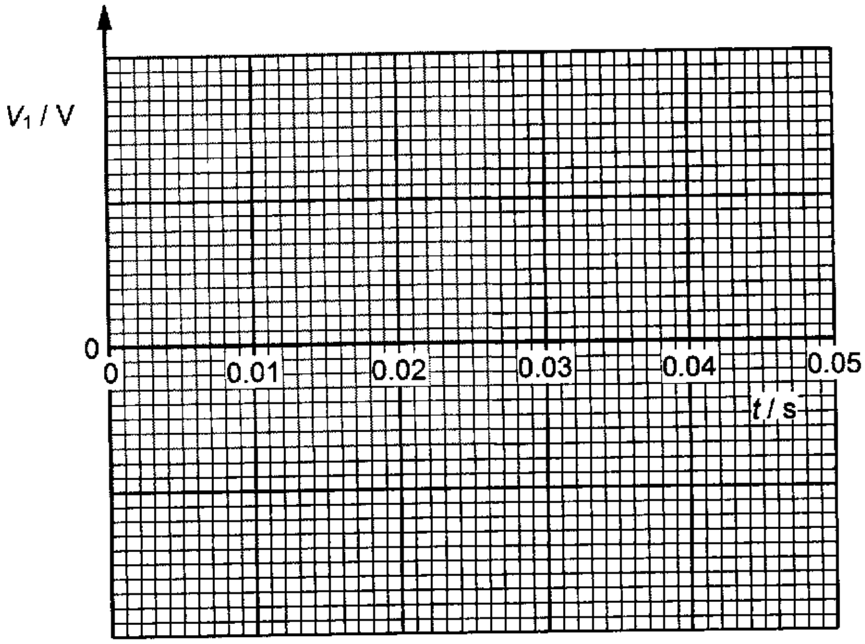

Fig. 6.2

[2]

(ii) Switch S is opened.

On Fig. 6.3, draw the variation with time t of the power P_1 transferred in R_1 for two periods of the alternating voltage.

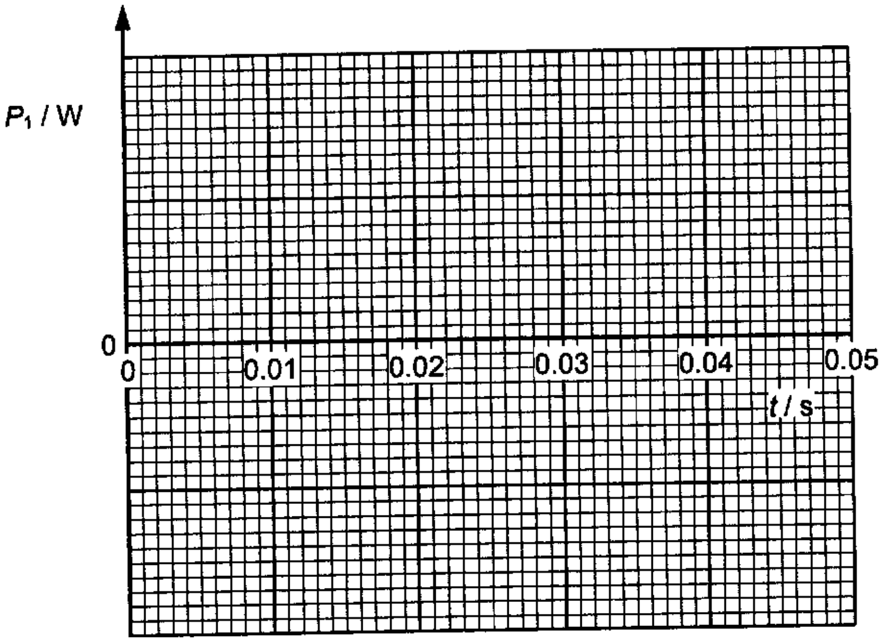

Fig. 6.3

[2]

[Total: 5]

7 **(a)** Explain how emission line spectra provide evidence for discrete electron energy levels in isolated atoms.

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.... [2]

(b) X-rays are produced when high speed electrons collide with a metal target.

Fig. 7.1 shows how the intensity of the X-rays varies with their wavelength.

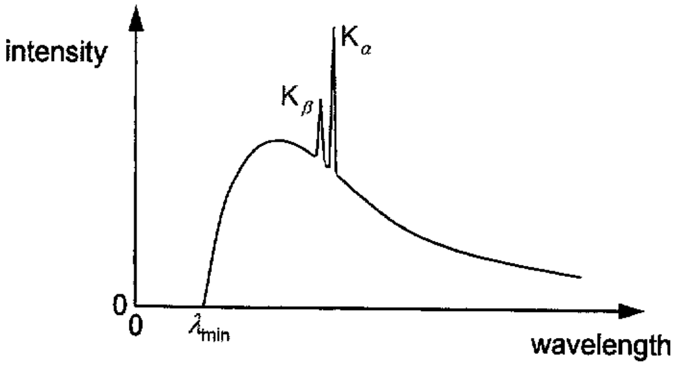

Fig. 7.1

Explain the origins of the following features in Fig. 7.1:

(i) The wavelength of the characteristic line K_α is greater than the wavelength of K_β.

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.... [2]

(ii) There is a minimum wavelength λ_{min} for the X-rays.

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.... [2]

[Total: 6]

End of Paper 3 Section A

Centre Number	Index Number	Name	Class
S3016			

RAFFLES INSTITUTION
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Paper 3 Longer Structured Questions

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For Examiner's Use		
Section B **(circle 1 question)**	**8**	/ 20
	9	/ 20
Deduction		

This document consists of **12** printed pages.

Section B

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

8 A research facility located in the northern hemisphere is used to study the effects of the solar wind from the Sun. At its location, the Earth's magnetic field is found to have a magnetic flux density of 5.2×10^{-5} T at an angle of 70° below the horizontal.

(a) A vertical window at the research facility has an aluminium frame ABCD with length 80 cm and width 55 cm, as shown in Fig. 8.1.

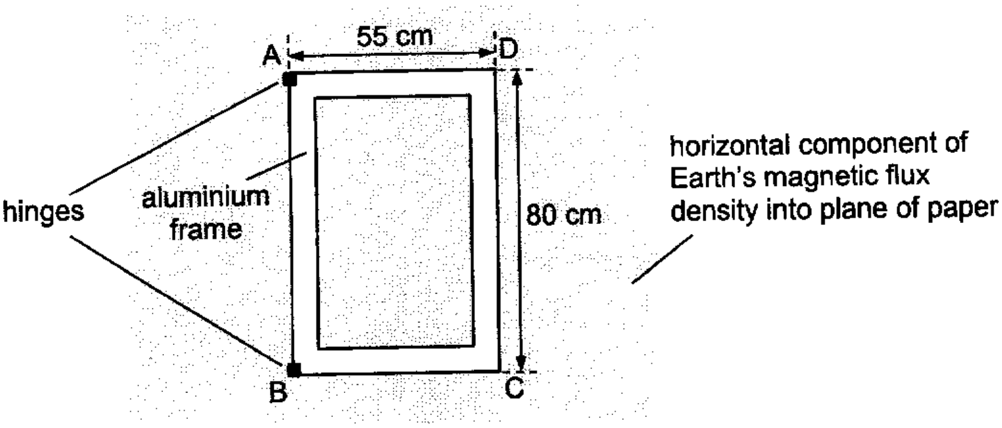

Fig. 8.1

The window is hinged along the side AB. When the window is closed as in Fig. 8.1, the horizontal component of the Earth's magnetic flux density is directed normally into the plane of the window.

(i) Calculate the magnetic flux through the window when it is closed.

magnetic flux = ... Wb [2]

(ii) The window is opened by pushing it into the plane of the paper in a time of 0.30 s. When fully opened, the plane of the window is parallel to the horizontal component of the Earth's magnetic flux density.

During the opening of the window,

1. use the laws of electromagnetic induction to explain why there is a current induced in the aluminium frame,

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.... [3]

2. determine the change in the magnetic flux through the window,

magnetic flux = ... Wb [1]

3. calculate the magnitude of the average e.m.f. induced in side CD of the frame.

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

(b) An electron and an alpha particle from the solar wind enter a region of uniform magnetic field. Both particles are travelling along the same path with the same speed just before they enter the uniform magnetic field, as shown in Fig. 8.2.

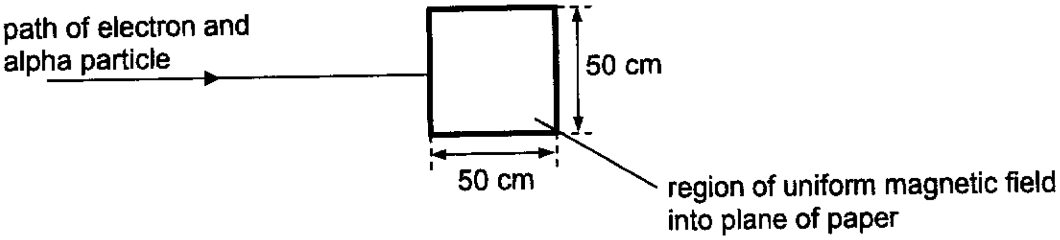

Fig. 8.2

The direction of the magnetic field is into the plane of the paper.

The particles enter the region of the magnetic field at right angles to the edge of the region. Both particles follow circular paths in the magnetic field.

(i) Explain why the charged particles follow circular paths in the magnetic field.

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.... [2]

(ii) Show that the radius r_α of the circular path of the alpha particle is related to the radius r_e of the circular path of the electron by the equation

$$r_\alpha = 3.6 \times 10^3 r_e.$$

Explain your working.

[2]

(iii) The radius of the circular path of the electron is observed to be about 7 mm.

On Fig. 8.2, draw a possible path for the alpha particle as it passes through and beyond the region of the magnetic field.

[1]

(iv) The uniform magnetic field in Fig. 8.2 is now replaced with a varying magnetic field. The variation with time t of the magnetic flux density B of this new magnetic field is shown in Fig. 8.3.

Positive values of B indicate that the magnetic field is directed into the plane of the paper.

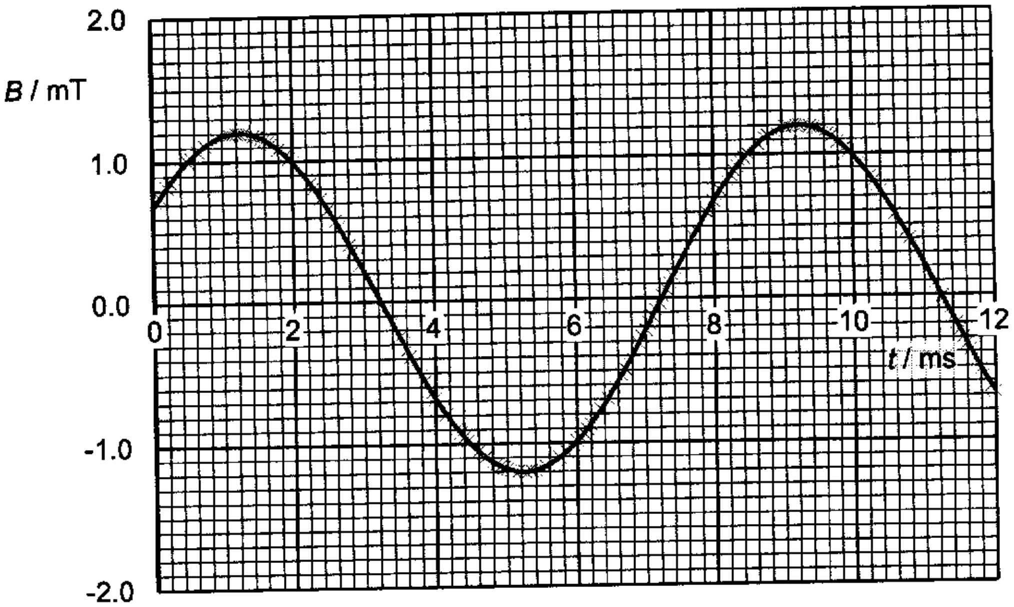

Fig. 8.3

Another electron travelling perpendicularly to the magnetic field and at a speed of 1.2×10^6 m s^{-1} enters the centre of the magnetic field at time $t = 0$ ms.

From Fig. 8.3, at $t = 0$ ms, $B = 0.70$ mT.

1. Show that the radius of curvature of the electron's path is 9.8 mm at $B = 0.70$ mT.

[1]

2. Calculate the period of the electron's motion at $B = 0.70\ \text{mT}$.

$T =$ .... s [2]

3. Describe the path of the electron in the magnetic field for the first 4.0 ms, assuming it stays in the magnetic field for the whole of this duration.

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.... [3]

4. In reality, the electron leaves the magnetic field before 4.0 ms.

Without any calculations, state a possible time when this occurs.

Explain your answer.

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.... [1]

[Total: 20]

9 **(a)** Photoelectrons are emitted with insignificant time lag when electromagnetic radiation of a certain frequency is incident on a metal plate.

State and explain one other observation from the photoelectric effect that provides evidence for the particulate nature of electromagnetic radiation.

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.... [4]

(b) Two parallel zinc plates placed a distance *d* apart are used to investigate the photoelectric effect, as shown in Fig. 9.1. Zinc has a work function of 4.33 eV.

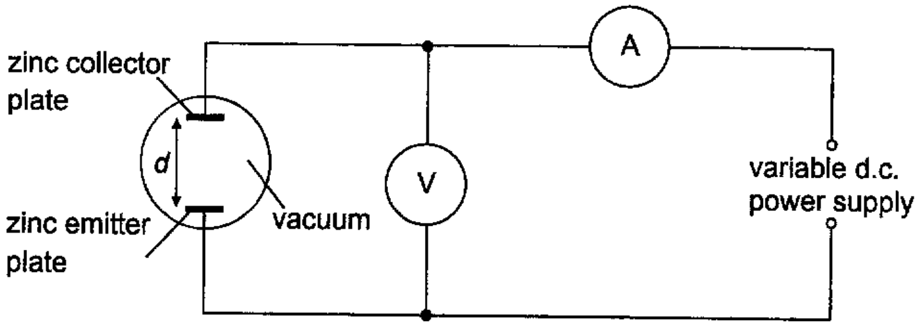

Fig. 9.1

Electromagnetic radiation of wavelength 210 nm is incident on the zinc emitter plate. The potential of the zinc collector plate is varied from –3.0 V to +3.0 V with respect to the zinc emitter plate.

The variation of the current *I* with the potential difference *V* is shown in Fig. 9.2.

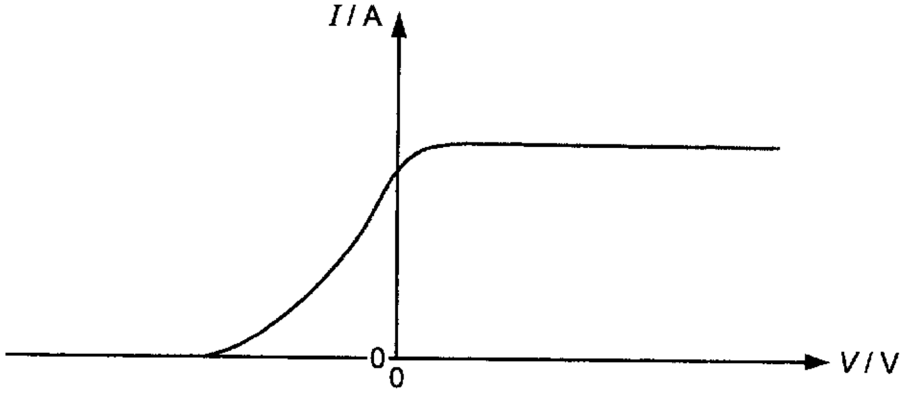

Fig. 9.2

(i) Calculate the threshold wavelength for the zinc plate.

wavelength = ... nm [2]

(ii) Calculate the maximum speed of the emitted photoelectrons.

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

(iii) Photoelectrons in **(b)** are emitted perpendicularly to the zinc emitter plate.

Explain why the subsequent motion of the emitted photoelectrons is different when $V = 0$ V and $V = +3.0$ V.

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.... [3]

(iv) On Fig 9.2, draw the variation of I with V if the zinc emitter plate is now illuminated with radiation of a shorter wavelength but the same intensity as in **(b)**. [2]

(c) Electrons are accelerated in a vacuum before passing through a graphite film, as shown in Fig. 9.3. The electrons are then incident on a fluorescent screen.

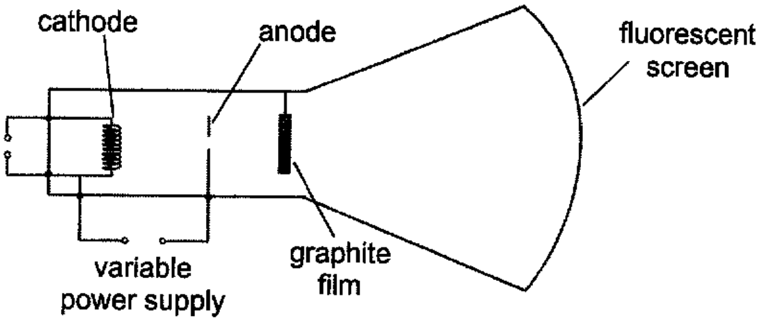

Fig 9.3

Concentric rings of light are observed on the screen.

(i) Explain how the observation of the concentric rings of light provides evidence for the wave nature of electrons.

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.... [2]

(ii) The electrons are accelerated from rest through a potential difference of 5.0 kV.

Calculate the de Broglie wavelength of the accelerated electrons.

wavelength = ... m [3]

(iii) Optical and electron microscopy techniques are widely utilised for imaging and analysing microscopic structures.

With reference to **(c)(ii)**, state and explain an advantage of an electron microscope compared to an optical microscope.

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....

.... [2]

[Total: 20]

End of Paper 3 Section B

Raffles Institution
Year 5-6 Physics Department

2024 H2 Physics Preliminary Examination Solution

Paper 3

1 **(a)** The internal energy of an ideal gas is just the <u>sum of the microscopic kinetic energy</u>, due to the <u>random motion</u> of its molecules since the microscopic potential energy of an ideal gas is zero.

Its internal energy <u>depends only on its state</u> (pressure, volume, temperature) and amount of gas.

(b) **(i)** **1.** $\Delta U = Q + W$

Since volume is constant, $W = 0$.

$$\begin{aligned} Q &= \Delta U \\ &= \frac{3}{2}p_2V - \frac{3}{2}p_1V \\ &= \frac{3}{2}V(p_2 - p_1) \\ &= \frac{3}{2}\left(2.0\times10^{-2}\right)\left(1.5\times10^{5} - 1.0\times10^{5}\right) \\ &= 1500.0 = 1500 \text{ J (shown)} \end{aligned}$$

2. Since

$$E_k = \frac{3}{2}kT_1 = 6.2\times10^{-21}\ \text{J}$$

$$T_1 = \frac{2}{3}\left(\frac{6.2\times10^{-21}}{1.38\times10^{-23}}\right) = 299.52\ \text{K}$$

From $p = \frac{nR}{V}T$, since volume is constant,

$$\Delta p = \frac{nR}{V}\Delta T = \frac{p_1}{T_1}\Delta T$$

$$\begin{aligned} \Delta T &= \frac{\Delta p}{p_1}T_1 \\ &= \frac{0.5\times10^{5}}{1.0\times10^{5}}(299.52) \\ &= 149.76 = 150\ \text{K} \end{aligned}$$

OR

$$E_k = \frac{3}{2}kT_1$$
$$T_1 = \frac{2}{3}\frac{E_k}{k}$$

Since volume is constant,

$$\frac{p_1}{T_1} = \frac{p_2}{T_2}$$
$$T_2 = \frac{p_2}{p_1}T_1 = \frac{p_2}{p_1}\left(\frac{2}{3}\frac{E_k}{k}\right)$$

$$\begin{aligned} T_2 - T_1 &= \frac{p_2}{p_1}\left(\frac{2}{3}\frac{E_k}{k}\right) - \frac{2}{3}\frac{E_k}{k} \\ &= \frac{2}{3}\frac{E_k}{k}\left(\frac{p_2}{p_1} - 1\right) \\ &= \frac{2}{3}\left(\frac{6.2\times10^{-21}}{1.38\times10^{-23}}\right)\left(\frac{1.5\times10^{5}}{1.0\times10^{5}} - 1\right) \\ &= 149.76 = 150\text{ K} = 150\text{ °C} \end{aligned}$$

OR

$U_1 = NE_k$ where N is the number of gas molecules

$$N = \frac{U_1}{E_k}$$

$$\begin{aligned} \Delta U &= U_2 - U_1 \\ &= \frac{3}{2}NkT_2 - \frac{3}{2}NkT_1 \\ &= \frac{3}{2}Nk\left(T_2 - T_1\right) \end{aligned}$$

$$\begin{aligned} T_2 - T_1 &= \frac{2}{3}\frac{\Delta U}{Nk} \\ &= \frac{2}{3}\frac{\Delta U}{\left(U_1/E_k\right)k} \\ &= \frac{2}{3}\frac{E_k\Delta U}{\left(\frac{3}{2}p_1V\right)k} \\ &= \frac{4}{9}\frac{\left(6.2\times10^{-21}\right)(1500)}{\left(1.0\times10^{5}\right)\left(2.0\times10^{-2}\right)\left(1.38\times10^{-23}\right)} \\ &= 149.76 = 150\text{ K} = 150\text{ °C} \end{aligned}$$

(ii) The first law of thermodynamics states that the increase in internal energy ΔU is equal to the sum of the work done on the system W and the heat supplied to the system Q, i.e. $\Delta U = Q + W$. Hence $Q = \Delta U - W$.

When a unit mass of the gas, heated under constant volume or under constant pressure, experiences a unit rise in temperature, ΔU will be the same since $\Delta U \propto \Delta T$.

When the gas is heated at constant volume, there is no work done. W is zero and $Q_V = \Delta U$.

When the gas is heated at constant pressure, work is done by the gas as it expands. W is negative and $Q_p > \Delta U$.

The specific heat capacity of a gas is the heat supplied to a unit mass of the gas to cause a unit rise in its temperature i.e. $c = \dfrac{Q}{m(\Delta T)}$. Since $Q_p > Q_V$ the specific heat capacity at constant pressure is higher than that at constant volume.

2 **(a)** Since <u>k and m are constant</u>, $a \propto -x$.
This implies that the block's <u>acceleration is proportional to its displacement from</u> the <u>equilibrium position</u>.

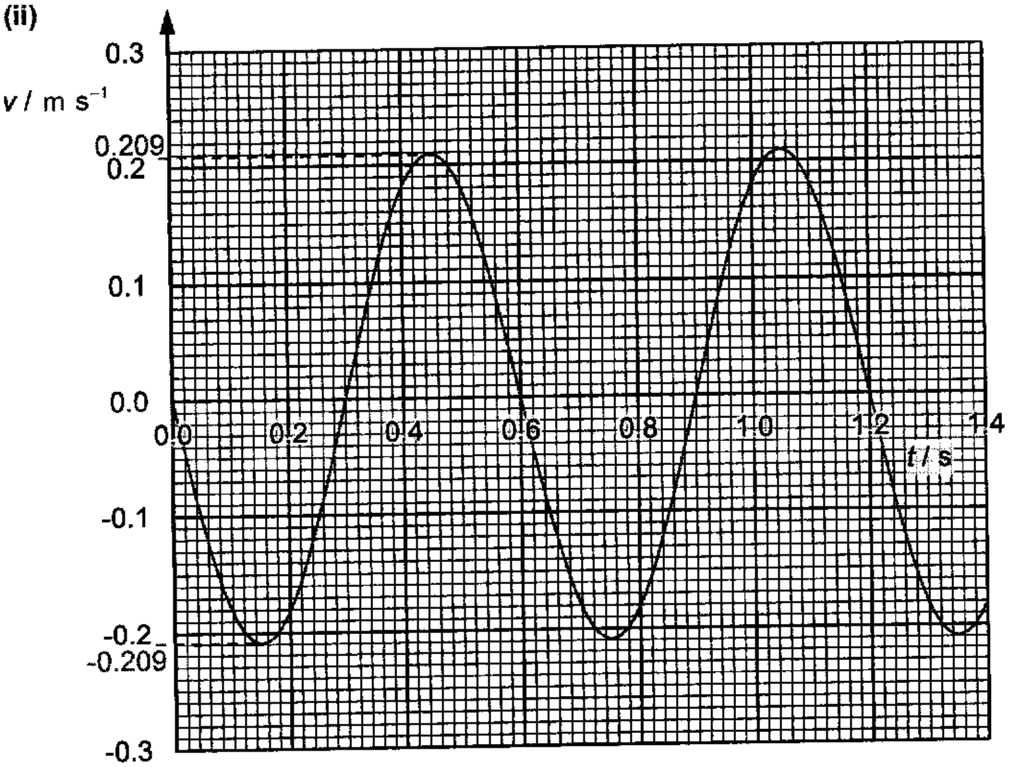
The <u>negative sign</u> implies that the <u>direction of its acceleration is always opposite to its displacement</u>, pointing towards the equilibrium position.

This satisfies the definition for simple harmonic motion.

(b) **(i)** From the graph, $T = 0.60$ s, $x_0 = 2.0 \times 10^{-2}$ m

$$\begin{aligned} v_0 &= \omega x_0 \\ &= \frac{2\pi}{T} x_0 \\ &= \frac{2\pi}{0.60}\left(2.0 \times 10^{-2}\right) \\ &= 0.20944 = 0.209 \text{ m s}^{-1} \end{aligned}$$

(ii)



(iii) $E_K = \frac{1}{2}mv^2 = \frac{1}{2}m\left(\pm\omega\sqrt{x_0^{\,2} - x^2}\right)^2 = \frac{1}{2}m\omega^2\left(x_0^{\,2} - x^2\right)$

$E_P = E_T - E_K = \frac{1}{2}m\omega^2 x_0^{\,2} - \frac{1}{2}m\omega^2\left(x_0^{\,2} - x^2\right) = \frac{1}{2}m\omega^2 x^2$

$$E_P = E_K$$

$$\frac{1}{2}m\omega^2 x^2 = \frac{1}{2}m\omega^2\left(x_0^{\,2} - x^2\right)$$

$$2x^2 = x_0^{\,2}$$

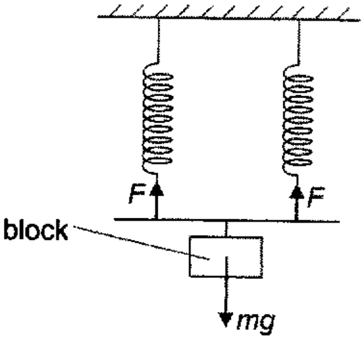
$$x = \pm\frac{x_0}{\sqrt{2}} = \pm\frac{2.0\times10^{-2}}{\sqrt{2}} = \pm0.014142 \text{ m} = \pm1.4142 \text{ cm}$$

At equilibrium, $L = 16.0$ cm.
When $E_P = E_K$,
$L = 16.0 + 1.4142 = 17.4142 = 17.4$ cm (block is below equilibrium)
OR
$L = 16.0 - 1.4142 = 14.5858 = 14.6$ cm (block is above equilibrium)

(c) $F_{eff} = 2F = mg$

$k_{eff}e = 2ke = mg$

$k_{eff} = 2k$



The <u>same mass results in half the extension</u> in each spring at equilibrium compared to a single spring in Fig. 2.1. Hence the <u>effective force constant is twice</u> the force constant of one spring ($k_{eff} = 2k$).

From $a = -\frac{k}{m}x$, angular frequency $\omega = \frac{2\pi}{T} = \sqrt{\frac{k}{m}}$. Hence period $\underline{T = 2\pi\sqrt{\frac{m}{k}}}$.

When the force constant is twice that in (a), the <u>period decreases to $\frac{1}{\sqrt{2}}$ the period in (a)</u>.

Raffles Institution
Year 5-6 Physics Department

3 (a) amplitudes:

Particles in a progressive wave have the same amplitude.
Particles in a stationary wave have amplitudes ranging from zero at the nodes to maximum amplitude at the antinodes.

phases:

Particles within a wavelength in a progressive wave have different phases.
Particles in a stationary wave between adjacent nodes oscillate with the same phase and particles between adjacent segments oscillate π rad out-of-phase.
Particles at the node do not oscillate.

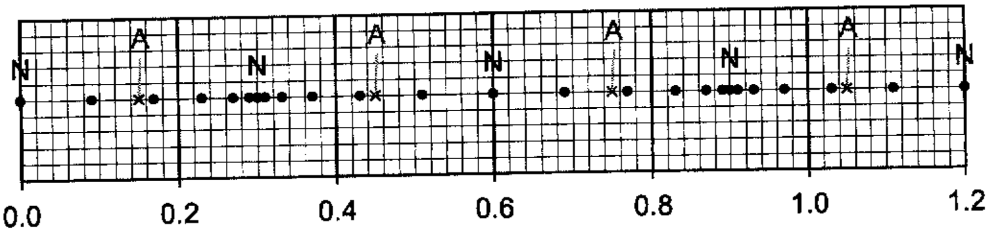
(b) (i) Wavelength is the distance between two adjacent particles that oscillate in phase.

$2\lambda = 1.20$ m (2 d.p.)
$\lambda = 0.600$ m (3 s.f.)

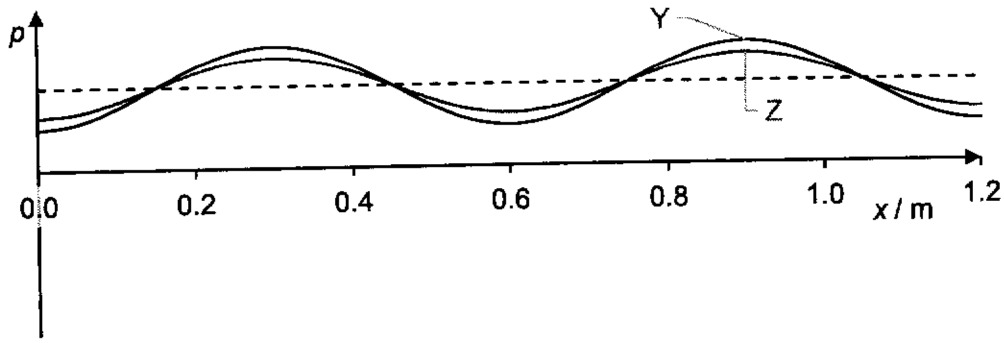
(ii) There are 6 intervals between 0.00 m and 0.30 m (1/2 wavelength) indicating that the separation between particles when they are at equilibrium is 0.05 m. The particle with equilibrium position at 0.15 m is at the amplitude position of 0.19 m at t_0.

$x_0 = 0.19 - 0.15 = 0.04$ m (2 d.p.)

(c) (i)



(ii)



1. Pressure at the nodes is highest or lowest compared to the initial atmospheric pressure.
*Correct high and low pressure positions.

2. For stationary waves, energy is not transferred and the waveform does not progress forward. Positions of nodes and antinodes remain unchanged. Only the displacement of the particles between the nodes changes.
*Graph of smaller amplitude at $t_1 + \frac{T}{8}$ compared to at t_1.

(d) **(i)** Stationary wave is formed in the air column in the tube when an anitnode is at the mouth of the tube and a node is at the water surface.

When first loud note is heard,

$$L_1 + c = \tfrac{1}{4}\lambda$$

$$\begin{aligned} c &= \frac{1}{4}\lambda - L_1 \\ &= \frac{1}{4}(0.600) - 0.144 \\ &= 0.150 - 0.144 \\ &= 0.006 \text{ m} \quad \text{(3 d.p.)} \end{aligned}$$

(ii) When the next loud note is heard,

$$L_2 + c = \tfrac{3}{4}\lambda$$

$$\begin{aligned} L_2 &= \frac{3}{4}\lambda - c \\ &= \frac{3}{4}(0.600) - 0.006 \\ &= 0.444 \text{ m} \quad \text{(3 d.p.)} \end{aligned}$$

4 (a) (i) The electric field strength due to each particle is directed towards the left. As the resultant electric field strength at any point is the vector addition of the individual electric field strengths of A and B, it is always towards the left. Hence there will be no point where the electric field strength is zero.

(ii) The electric potential due to A is negative while that due to B is positive. The total electric potential at any point is the scalar addition of the individual electric potentials of A and B. Hence, there will be a point in between the charges where electric potential is zero.

(b) (i) By the principle of conservation of energy, considering energy changes of particle from the point it enters the electric field to the point it hits point P,

increase in kinetic energy = decrease in electric potential energy

$$\frac{1}{2}m\left(v_f^2 - v_i^2\right) = q\left(\frac{1}{2}\Delta V\right)$$

$$\Delta V = \frac{m}{q}\left(v_f^2 - v_i^2\right)$$

$$= \frac{\left(6.6\times10^{-27}\right)}{\left(3.2\times10^{-19}\right)}\left[\left(6.5\times10^5\right)^2 - \left(4.1\times10^5\right)^2\right]$$

$$= 5247 = 5250 \text{ V}$$

Since the negatively charged particle accelerates towards plate Y which is at 0 V, plate X must be at a lower potential with respect to plate Y.

$V = -5250$ V

(ii)

$$F_E = ma$$

$$q\left(\frac{\Delta V}{d}\right) = ma$$

$$a = \frac{q\Delta V}{md}$$

$$= \frac{\left(3.2\times10^{-19}\right)(5250)}{\left(6.6\times10^{-27}\right)\left(3.6\times10^{-2}\right)}$$

$$= 7.0707\times10^{12} = 7.07\times10^{12} \text{ ms}^{-2}$$

(iii) Take direction to the right and downwards as positive.
consider horizontal motion,

$$s = -(u\sin\theta)t + \frac{1}{2}at^2$$

$$0.5\times3.6\times10^{-2} = -\left(4.1\times10^5\sin32^\circ\right)t + \frac{1}{2}\left(7.07\times10^{12}\right)t^2$$

$$t = 1.0842\times10^{-7} \text{ s} \quad \text{or} \quad -4.6963\times10^{-8} \text{ s (NA)}$$

consider vertical motion,

$$d = (u\cos\theta)t$$

$$= \left(4.1\times10^5\cos32^\circ\right)\left(1.0842\times10^{-7}\right)$$

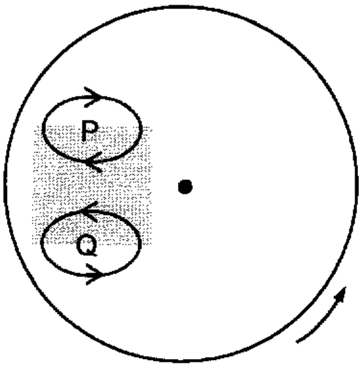
$$= 0.037698 = 0.0377 \text{ m}$$

5 **(a)** The sections of the disc moving towards or away from the magnets experience a change in magnetic flux linkage. There will be induced e.m.f. and induced currents in the conducting disc.

By Lenz's law, the direction of the induced currents in the disc will oppose the change in the magnetic flux linkage. This produces a force that opposes the direction of the spin of the disc, causing it to slow down.

In slowing down, the mechanical / kinetic energy of the disc is converted to electrical energy as induced currents and eventually converted to thermal energy which is dissipated to the surroundings. This obeys the law of conservation of energy.

(b)



*At least one closed loop drawn at each region P and Q.
*Correct direction of eddy current for each loop.
*For each loop, part of loop in the magnetic field, part of it outside the magnetic field.

(c) As the disc is slowing down, its angular velocity is decreasing. This leads to a rate of change of magnetic flux linkage that is decreasing which produces a decreasing induced e.m.f.

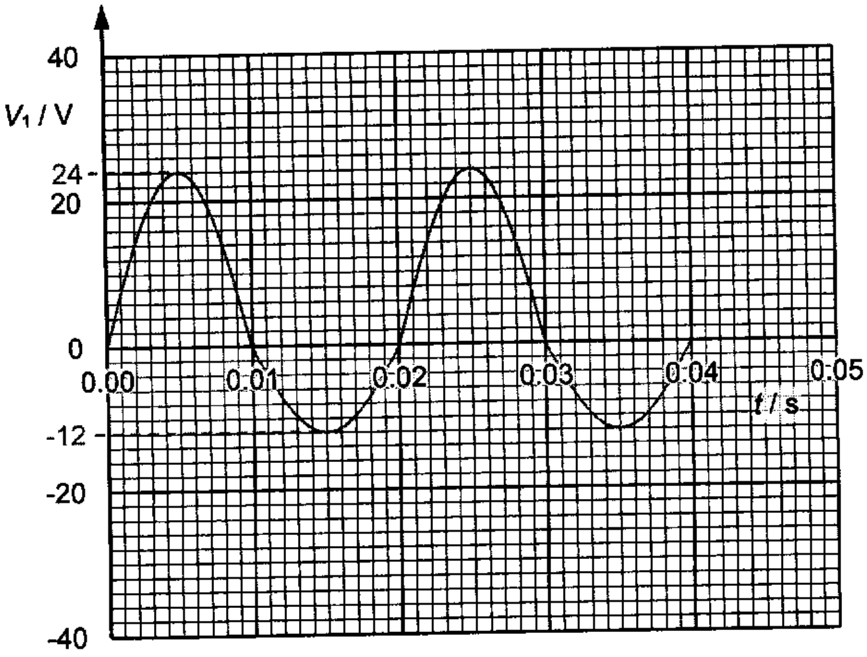
The decreasing induced current produces an opposing / decelerating force that is decreasing in magnitude.

This causes the angular velocity of the disc to decrease at a decreasing rate. Hence its decrease is not linear (does not decrease at a constant rate).

(Angular deceleration is decreasing in magnitude.)

6 (a) The root-mean-square value of an alternating current is that value of the direct current that would produce thermal energy at the same rate in the same resistor.

(b) (i)

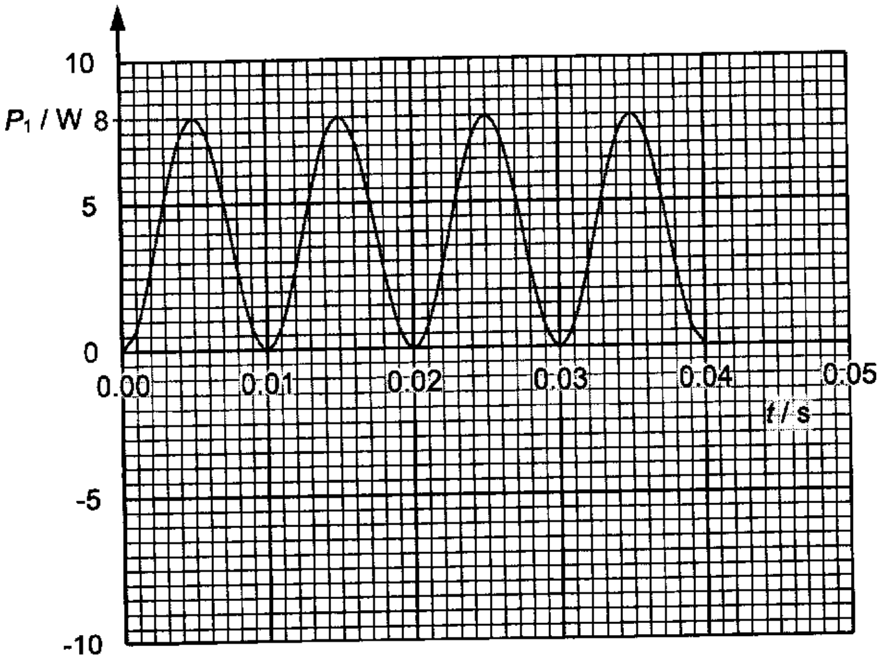


With S closed, current passes through the diode and R_1 in the forward bias direction. In the reverse bias direction, current passes through R_1 and R_2.

Forward bias: peak V_1 = peak $V = 24$ V
Reverse bias: peak $V_1 = 12$ V
period $T = \frac{2\pi}{\omega} = \frac{2\pi}{314} = 0.02$ s

*Sine graph with correct period.

(ii)



With S opened, current passes through R_1 and R_2 all the time and does not pass through the diode.
Since V and I of the alternating supply is sinusoidal, power graph will be a sine^2 graph.

$$\text{peak } P_1 = \frac{(\text{peak } V_1)^2}{R_1} = \frac{(24/2)^2}{18} = 8 \text{ W}$$

*Correct shape (smooth curve, sine squared) with correct period.

7 **(a)** The emission line spectrum consists of a series of distinct lines of specific colours/ wavelengths/ frequencies on a dark background.

Each line is produced by the emission of photons of a specific quantum of energy. Since the photons have specific energy, they must be emitted when electrons in the atoms de-excites between discrete energy levels.

(b) (i) The characteristic K_α and K_β lines are due to X-ray photons produced from electron transitions from shell L to K and shell M to K, respectively (or from energy level n = 2 to n = 1 and n = 3 to n = 1, respectively).

Since shell L is nearer to shell K than shell M to shell K, K_α photons have smaller energy E than K_β photons. As energy E is inversely proportional to the wavelength λ, K_α photons have a longer wavelength than K_β photons.

(ii) X-ray photons are emitted when high speed electrons collide with the target atom and undergo many rapid decelerations. The kinetic energy lost by an incident electron is converted into the energy of an X-ray photon. The amount of energy lost varies since an electron can undergo multiple collisions resulting in X-ray photons of varying energies.

The most energetic X-ray photon is produced when an incident electron loses all its kinetic energy in one collision. Since the energy of a photon is given by $E = \frac{hc}{\lambda}$, this most energetic X-ray photon has the shortest wavelength.

8 **(a)** **(i)** $\phi = B_H A$

$= \left(5.2\times10^{-5}\cos70^\circ\right)(0.80\times0.55)$

$= 7.8254\times10^{-6} = 7.83\times10^{-6}$ Wb

(ii) **1.** When the window is opening, the aluminium frame cuts the Earth's magnetic field lines and the magnetic flux through the window decreases. This causes a rate of change of magnetic flux linkage in the frame.

By Faraday's law, there will be an induced e.m.f. in the frame.

Since the frame is a closed loop, this induced e.m.f. produces an induced current in the frame.

By Lenz's law, the direction of the induced current is such as to produce an effect to oppose the decrease in the magnetic flux. Current will flow from ADCB to increase the magnetic flux.

2. $\Delta\phi = \phi_f - \phi_i$

$= 0 - 7.83\times10^{-6}$

$= -7.83\times10^{-6}\,\text{Wb}$

3. $|E| = \left|-\dfrac{\Delta\phi}{\Delta t}\right|$

$= \left|-\dfrac{-7.83\times10^{-6}}{0.30}\right|$

$= 2.61\times10^{-5}$ V

(b) **(i)** Since the velocity of the charged particles is perpendicular to the magnetic field, the magnetic force acting on the charged particles is always perpendicular to their velocity. The magnetic force only changes the direction of the velocity while the speed remains constant.

As the magnitude of the magnetic force is constant, it points towards a fixed point, causing the particles to move in a circular motion about the fixed point with a constant radius.

(ii) The magnetic force acting on the particle provides the centripetal force.

$$Bqv = m\frac{v^2}{r}$$

$$r = \frac{mv}{Bq}$$

Since the particles travel at the same speed in the field of the same magnetic flux density,

$$\frac{r_\alpha}{r_e} = \frac{m_\alpha}{m_e}\frac{q_e}{q_\alpha}$$

$$= \frac{\left(4\times1.66\times10^{-27}\right)}{9.11\times10^{-31}}\times\frac{1}{2}$$

$$= 3644.3$$

$r_\alpha = 3.6\times10^{3} r_e$ (shown)

(iii)

*Slight curve (due to large radius) in B field.
*Straight path after it exits B field from the right edge of the field.

(iv) **1.**

$$R=\frac{mv}{Bq}$$
$$=\frac{(9.11\times10^{-31})(1.2\times10^{6})}{(0.70\times10^{-3})(1.60\times10^{-19})}$$
$$=9.7607\times10^{-3}=9.8\text{ mm}\quad\text{(shown)}$$

2.

$$T=\frac{2\pi R}{v}$$
$$=\frac{2\pi(9.8\times10^{-3})}{1.2\times10^{6}}$$
$$=5.131\times10^{-8}=5.13\times10^{-8}\text{ s}$$

3. The electron moves in a circular path in a clockwise direction (viewed from top).

From 0 ms to 1.2 ms, the radius of curvature of its path decreases and increases from 1.2 ms to 3.2 ms.

After 3.2 ms, the direction of its circular path will change to an anti-clockwise direction.

From 3.2 ms to 4.0 ms, the radius of curvature of its path decreases.

4. State any time from 2.4 ms to just before 3.2 ms (from $B=0.70$ mT and decreasing to zero).

As the magnetic flux density of the field decreases, the radius of curvature of the electron's path increases and leaves the magnetic field due to the high speed of the electron.

9 (a) The maximum kinetic energy of the photoelectrons is dependent only on the frequency, but not on the intensity of the incident radiation.

In the particulate theory of light, electromagnetic radiation is made up of discrete quanta of energy known as photons. Each photon has energy $E_{photon} = hf$ where h is the Planck constant and f is the frequency. Emission of a photoelectron is only possible when a single photon is absorbed by an electron on the surface of the metal in a one-to-one interaction.

The maximum kinetic energy of the photoelectron is given by $\text{K.E.}_{\max} = hf - \Phi$ where Φ is the work function of the metal. The equation shows that the maximum kinetic energy is a function of the photon's energy and hence frequency for the same metal with constant Φ.

Increasing the intensity of light only increases the rate of incident photons on the metal and has no effect on E_{photon} which is dependent only on frequency. Therefore, there is no effect of intensity on the maximum kinetic energy which provides evidence for the particulate nature of electromagnetic radiation.

OR

There is a threshold frequency below which there is no emission of photoelectrons regardless of the intensity of the incident radiation.

In the particulate theory of light, electromagnetic radiation is made up of discrete quanta of energy known as photons. Each photon has energy $E_{photon} = hf$ where h is the Planck constant and f is the frequency. Emission of a photoelectron is only possible when a single photon is absorbed by an electron on the surface of the metal in a one-to-one interaction.

The maximum kinetic energy of the photoelectron is given by $\text{K.E.}_{\max} = hf - \Phi$ where Φ is the work function of the metal. The emission of a photoelectron is only possible if the maximum kinetic energy is greater than zero hence $hf \geq \Phi$. If the photon energy is less than Φ i.e. $f < f_0$ where $f_0 = \frac{\Phi}{h}$ is the threshold frequency, there will be no emission of photoelectrons.

Increasing the intensity of light only increases the rate of incident photons on the metal and has no effect on E_{photon} which is dependent only on frequency. Therefore, there is no effect of intensity on the threshold frequency which provides evidence for the particulate nature of electromagnetic radiation.

(b) (i)

$$\Phi = \frac{hc}{\lambda_0}$$

$$\lambda_0 = \frac{(6.63\times10^{-34})(3.00\times10^{8})}{(4.33)(1.60\times10^{-19})}$$

$$= 2.8709\times10^{-7} = 287 \text{ nm}$$

(ii) $E_{K,\max}=\frac{1}{2}mv_{\max}^2=\frac{hc}{\lambda}-\Phi$

$$v_{\max}=\sqrt{\frac{2}{m}\left(\frac{hc}{\lambda}-\Phi\right)}$$

$$=\sqrt{\frac{2}{9.11\times10^{-31}}\left(\frac{(6.63\times10^{-34})(3.00\times10^{8})}{210\times10^{-9}}-(4.33)(1.60\times10^{-19})\right)}$$

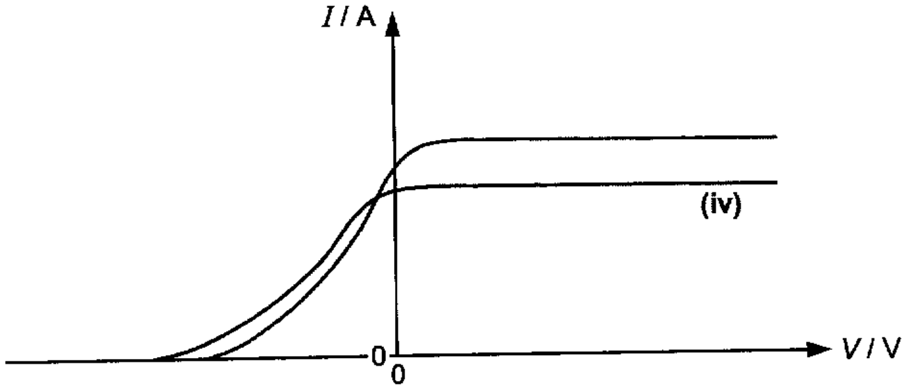
$$=7.4725\times10^{5}=7.47\times10^{5}\text{ m s}^{-1}$$

(iii) When $V=0$ V, there is no electric force on the emitted photoelectrons and they travel at a constant speed along a straight line perpendicular to the collector plate.

When $V=+3.0$ V, the electric force, $F_e=eE=\frac{eV}{d}=\frac{3e}{d}$, is the resultant force on the photoelectron and it acts in the same direction as its velocity.

Since the resultant electric force is constant, acceleration, $a=\frac{3e}{m_e d}$, is constant, and the speed of the emitted photoelectron increases at a constant rate as it moves along a straight line perpendicular to the collector plate.

(iv)



Shorter wavelength, higher photon energy, higher maximum kinetic energy, hence larger stopping potential.

Since intensity $I=\frac{hc}{\lambda A}\left(\frac{dN_p}{dt}\right)$ remains the same, the rate of incident photons $\frac{dN_p}{dt}$ decreases with a decrease in wavelength or an increase in photon energy. Hence the saturated photocurrent decreases.

(c) **(i)** The electrons behave as waves with de Broglie's wavelength λ which is related to its momentum p by $\lambda=\frac{h}{p}$. The graphite film, having atoms that are regularly spaced at distances comparable to the wavelength of the electrons, acts as a diffraction grating resulting in a diffraction pattern of concentric rings when the electrons pass through the graphite film.

The maximum and minimum intensities of the concentric rings are a result of electron waves undergoing constructive and destructive interference similar to how light waves interfere.

(ii)

$$E_k = \frac{1}{2}mv^2 = \frac{1}{2}\frac{(mv)^2}{m} = \frac{p^2}{2m} = \frac{(h/\lambda)^2}{2m} = \frac{h^2}{2m\lambda^2}$$

increase in kinetic energy = decrease in electric potential energy

$$\frac{h^2}{2m\lambda^2} - 0 = q\Delta V$$

$$\lambda = \frac{h}{\sqrt{2mq\Delta V}}$$

$$= \frac{6.63\times10^{-34}}{\sqrt{2(9.11\times10^{-31})(1.60\times10^{-19})(5.0\times10^{3})}}$$

$$= 1.7366\times10^{-11} = 1.74\times10^{-11}\ \text{m}$$

(iii) According to Rayleigh criterion, the limiting angle of resolution $\theta_{\min} \approx \frac{\lambda}{b}$ where b is the size of the aperture. For the electrons, $\theta_{\min}$ is approximately four orders of magnitude smaller ($\theta_{\min} \propto \lambda$) than for visible light.

Hence, an electron microscope has a much higher resolving power compared to an optical microscope allowing it to resolve structures at the atomic scale which the optical microscope is unable to.