Catholic Junior College
JC2 Preliminary Examinations
Higher 2

CANDIDATE NAME

CLASS 2T

PHYSICS
Paper 3: Longer Structured Questions

9749/3
12 September 2022
2 hours

READ THESE INSTRUCTIONS FIRST
Write your name and class on all the work you hand in.
Write in dark blue or black pen in the space provided. **[PILOT FRIXION ERASABLE PENS ARE NOT ALLOWED]**
You may use a soft pencil for any diagrams, graphs or rough working.
Do not use highlighters, glue or correction fluid.

Answer **ALL** questions in **Section A**.

Answer **ONE** out of two questions in **Section B**.
Circle on the cover page the question number attempted in Section B.

Suggested Solutions

FOR EXAMINER'S USE		DIFFICULTY		
		L1	L2	L3
SECTION A				
Q1	/ 8			
Q2	/ 9			
Q3	/ 8			
Q4	/ 9			
Q5	/ 9			
Q6	/ 9			
Q7	/ 8			
SECTION B				
Q8	/ 20			
Q9	/ 20			
PAPER 3	/ 80			
PAPER 2	/ 80			
PAPER 1	/ 30			
PAPER 4	/ 55			
TOTAL (WEIGHTED)	%			

This document consists of **32** printed pages and **zero** blank page.

[Turn over

PHYSICS DATA:

speed of light in free space	c	=	3.00×10^{8} m s^{-1}
permeability of free space	μ_0	=	$4\pi \times 10^{-7}$ H m^{-1}
permittivity of free space	ε_0	=	8.85×10^{-12} F m^{-1}
			$\approx (1/(36\pi)) \times 10^{-9}$ F m^{-1}
elementary charge	e	=	1.60×10^{-19} C
the Planck constant	h	=	6.63×10^{-34} J s
unified atomic mass constant	u	=	1.66×10^{-27} kg
rest mass of electron	m_e	=	9.11×10^{-31} kg
rest mass of proton	m_P	=	1.67×10^{-27} kg
molar gas constant	R	=	8.31 J K^{-1} mol^{-1}
the Avogadro constant	N_A	=	6.02×10^{23} mol^{-1}
the Boltzmann constant	k	=	1.38×10^{-23} mol^{-1}
gravitational constant	G	=	6.67×10^{-11} N m^{2} kg^{-2}
acceleration of free fall	g	=	9.81 m s^{-2}

PHYSICS FORMULAE:

uniformly accelerated motion	s	=	$u t + \frac{1}{2} a t^2$
	v^2	=	$u^2 + 2 a s$
work done on / by a gas	W	=	$p \Delta V$
hydrostatic pressure	P	=	$\rho g h$
gravitational potential	ϕ	=	$-\dfrac{Gm}{r}$
temperature	T / K	=	$T / {}^{\circ}C + 273.15$
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	=	$\dfrac{Q}{4\pi\varepsilon_o r}$
alternating current / voltage	x	=	$x_0 \sin \omega t$
magnetic flux density due to a long straight wire	B	=	$\dfrac{\mu_o I}{2\pi d}$
magnetic flux density due to a flat circular coil	B	=	$\dfrac{\mu_o N I}{2r}$
magnetic flux density due to a long solenoid	B	=	$\mu_o n I$
radioactive decay	x	=	$x_0 \exp(-\lambda t)$
decay constant	λ	=	$\dfrac{\ln 2}{t_{\frac{1}{2}}}$

Section A

Answer **all** questions from this section.

1 Fig. 1.1 shows a hinged beam of length 60.0 cm held horizontally against a wall by a cord XY.

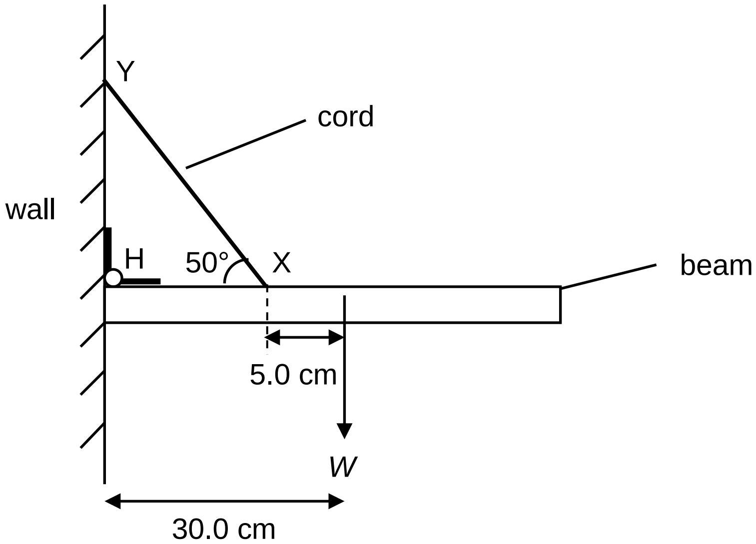


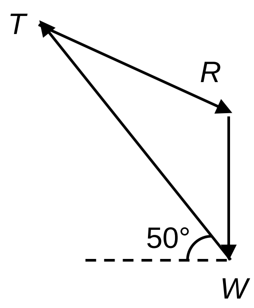
Fig. 1.1

The forces acting on the beam are its weight W, the force T exerted by the cord, and the force R exerted by the hinge H.

(a) In the space provided below, sketch a labelled vector triangle of the forces acting on the beam.

[2]

Solution:



- Correct labelling of forces and arrows point in the same direction (closed polygon). **1**
- R must be diagonally down not up, i.e. must have both a rightward & downward component. **1**

	(b)	The weight of the uniform beam is 40.0 N and the mass of the cord is negligible Calculate the magnitude of		
		(i)	the tension *T*,	
			T = ... N	[2]
			By principle of moments, taking moments about the hinge H, Sum of clockwise moment = sum of anti-clockwise moment $40.0 \times 0.300 = T \sin 50^0 \times 0.250$ *T* = 62.7 N	**1** **1**
		(ii)	the force *R*.	
			R = ... N	[2]
			Applying the cosine rule for the vector triangle, $R^2 = T^2 + W^2 - 2TW\cos 40^0$ $R^2 = 62.7^2 + 40.0^2 - \left(2 \times 62.7 \times 40.0 \times \cos 40^0\right)$ *R* = 41.1 N Method 2: Setting up 2 equations for Vertical & Horizontal Equilibrium, and then solving these 2 equations simultaneously.	**1** **1**
	(c)	A brick is placed on the beam at X without the cord snapping. Subsequently, when the brick is shifted further away from the hinge along the beam, the cord snaps. Explain why the cord snaps.		
		....		
		....		
		....		
		....		[2]
		The total clockwise moments about the hinge H is larger than the total anti-clockwise moment that can be provided by the tension in the cord. Hence the cord snaps as the tension *T* has exceeded its breaking strength.		**1** **1**

2	**(a)**	State the principle of *conservation of linear momentum*.	
			[1]
		The total linear momentum of a system will remain constant if no net external force acts on it.	**1**

(b)	In a nuclear reactor, carbon atoms are used to slow down neutrons. A fast neutron collides head-on with a stationary carbon atom.		
	(i)	Show that the impulse acted on the neutron is proportional to the final velocity of the carbon atom in such a collision.	[2]

By conservation of momentum,

$$m_n u_n + m_C u_C = m_n v_n + m_C v_C$$
$$m_n v_n - m_n u_n = m_C u_C - m_C v_C$$
$$\text{impulse on neutron}, \Delta p_n = 0 - m_C v_C \qquad \textbf{1}$$

Since the mass of the carbon atom is constant, **1**

$$\Delta p_n \propto v_C$$

OR

By conservation of momentum,
Total initial momentum of neutron and carbon atom
= Total final momentum of neutron and carbon atom
Change in momentum of the neutron
= - Change in momentum of the carbon atom

From definition of impulse,
Impulse on the neutron = Change in momentum of the neutron

Thus,
Impulse on the neutron = - Change in momentum of the carbon atom
= - (mass of carbon atom) x (final velocity of carbon atom – initial velocity of carbon atom)
= - (mass of carbon atom) x (final velocity of carbon atom) , since carbon atom was initially stationary

Since the mass of the carbon atom remains constant,

Impulse on the neutron is proportional to the final velocity of the carbon atom.

(ii)	In the collision between a neutron and a carbon atom, a neutron of mass 1.0*m* with initial velocity *u* collides elastically head-on with a stationary carbon atom of mass 12*m*. The final velocities of the neutron and the carbon atom are *v* and *V* respectively. By considering the relative speeds between the neutron and carbon atom before and after their collision, show that the fraction of the kinetic energy that is retained by the neutron after such a collision is 0.72.	[3]

$$\frac{KE\ retained}{initial\ KE} = \frac{KE_{f,n}}{KE_{i,n}}$$
$$= \frac{\frac{1}{2}mv^2}{\frac{1}{2}mu^2}$$
$$= \frac{v^2}{u^2} \quad ---(1) \qquad \textbf{1}$$

Using Relative speed of approach = Relative speed of separation **1**

$$u - 0 = V - v$$
$$V = v + u$$

And Conservation of momentum,

$$m_n u_n + m_C u_C = m_n v_n + m_C v_C$$
$$mu + 0 = mv + 12mV$$
$$u = v + 12V$$

Therefore,

$$u = v + 12(v + u)$$ **1**
$$v = -\frac{11}{13}u \quad --- (2)$$

Sub (2) into (1):

$$\frac{KE\ retained}{initial\ KE} = \frac{\left(-\frac{11}{13}u\right)^2}{u^2}$$
$$= 0.72$$

(c) **(i)** Explain why nuclei which are much more massive than carbon atoms are ineffective in slowing down neutrons in the nuclear reactor.

....

....

.... [2]

Method 1: **From working in (b)**

$$\frac{KE\ retained}{initial\ KE} = \frac{m_{particle} - m_n}{m_{particle} + m_n}$$

When $m_{particle} \gg m_n$, ratio $\frac{KE\ retained}{initial\ KE} \approx \frac{m_{particle}}{m_{particle}} = 1$ which is the maximum. **1**

Thus, when very massive particles are used ($m_{particle} \gg m_n$), the **kinetic energy retained by the neutron will be very large**. **1**

Derivation in detail (optional):

Using Relative speed of approach = Relative speed of separation [1]

$$V = v + u$$

And Conservation of momentum, [1]

$$m_n u + 0 = m_n v + m_{particle} V$$
$$u = v + \frac{m_{particle}}{m_n} V$$

Therefore,

$$u = v + \frac{m_{particle}}{m_n}(v + u)$$
$$v = -\frac{m_{particle} - m_n}{m_{particle} + m_n} u \quad --- (2)$$

Sub (2) into (1):

$$\frac{KE\ retained}{initial\ KE} = \frac{\left(-\frac{m_{particle} - m_n}{m_{particle} + m_n}u\right)^2}{u^2} = \frac{m_{particle} - m_n}{m_{particle} + m_n}$$

Method 2: **From conservation of momentum**

When very massive particles are used, **by the principle of conservation of momentum, the neutrons will retain most of the magnitude of its initial momentum after collision**,

traveling in the opposite direction to its initial momentum.

(ii) Explain why particles of similar mass to neutrons such as hydrogen nuclei are not suitable for slowing down neutrons in the nuclear reactor.

…………………………………………………………………………………………………..

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

Method 1: From working in (b)

$$\frac{KE\ retained}{initial\ KE} = \frac{m_{particle} - m_n}{m_{particle} + m_n}$$

When $m_{particle} = m_n$, ratio $\frac{KE\ retained}{initial\ KE} = 0$.

Thus, when particles of similar mass to neutrons are used ($m_{particle} = m_n$), the **neutrons will stop moving completely which is not the aim** (we want the neutrons to move more slowly but not to stop moving otherwise they cannot collide with the fissile isotope). **1**

Method 2: From conservation of momentum

By the principle of conservation of momentum, when a neutron collides with an initially stationary particle of similar mass (e.g. hydrogen atom), **the neutrons will stop moving completely after the collision which is not the aim** (we want the neutrons to move more slowly but not to stop moving otherwise they cannot collide with the fissile isotope).

3 A light helical spring is suspended vertically from a fixed point as shown in Fig. 3.1.

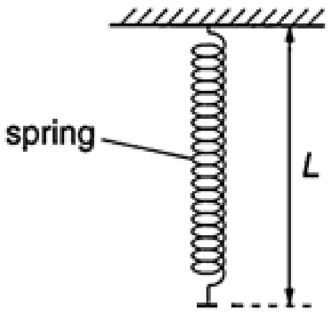


Fig. 3.1

A mass of weight 5.0 N is suspended from the spring of unstretched length 4.0 cm and then released from rest. The mass oscillates vertically.

The variation with resultant force *F* on the mass when *L* is between 4.0 cm and 8.0 cm is shown in Fig. 3.2 below.

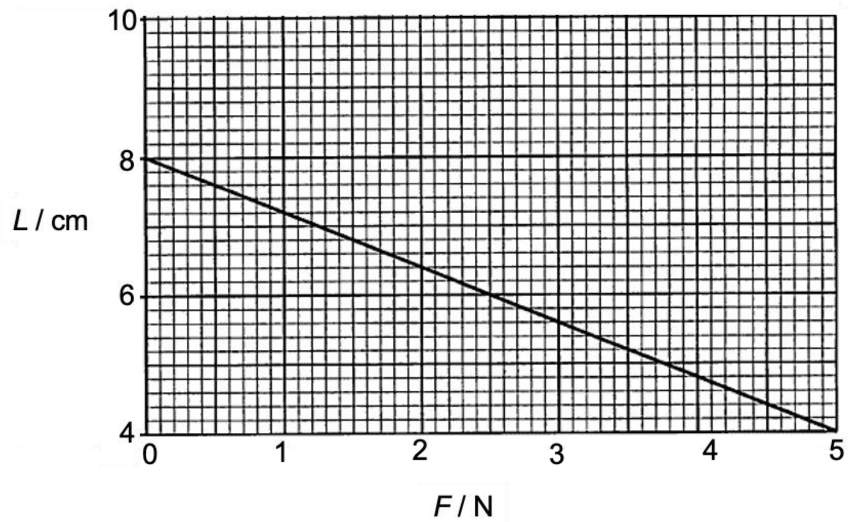


Fig. 3.2

(a) Explain why, as shown in Fig. 3.2, the resultant force on the mass increases as the length of the spring decreases from L = 8.0 cm to L = 4.0 cm.

....

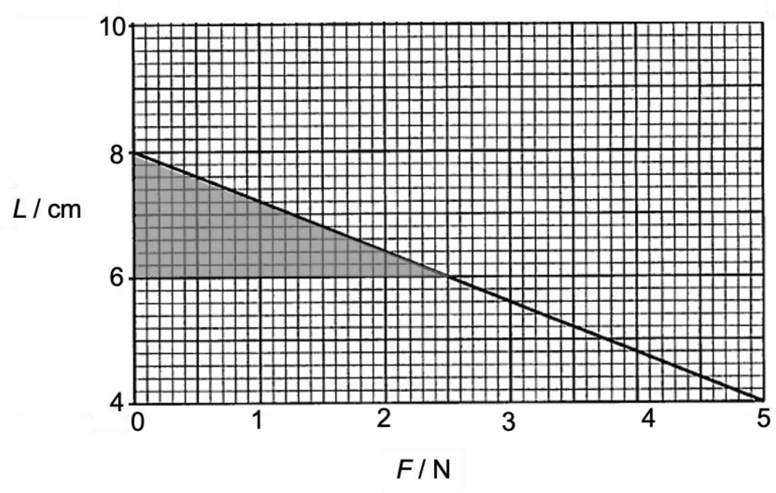
.... [2]

Fig. 3.2 shows the part of the motion when the mass is **at and above** the equilibrium position.
Also, for the mass to **oscillate,** the upward spring force F_s must be **lesser than** the weight W when the mass is above the equilibrium position.

As spring length *L* decreases, the extension *x* of the spring decreases, hence spring force F_s decreases. **1**

Since weight *W* remains constant throughout the motion, the **magnitude of the resultant force *F* acting downwards increases (since F = W – F_s)**. **1**

(Hence Fig. 3.2 has a negative gradient.)

	(b)	Calculate the force constant of the spring.	
		force constant = ………………………. N m^{-1}	[3]
		At equilibrium position (where resultant force F = 0), From Fig. 3.2 → L = 8.0 cm Since the unstretched spring length = 4.0 cm, **Extension x of the spring at the equilibrium position = 8.0 – 4.0 cm = 4.0 cm** **Consider equilibrium of forces:** $F_s = W$ $kx = W$ $k = \frac{W}{x}$ $= \frac{5.0}{4.0 \times 10^{-2}}$ $= 125\ N\ m^{-1}$	**1** **1** **1**
	(c)	On Fig. 3.2, shade clearly the area of the graph that represents net work done on the mass when the mass has travelled from L = 8.0 cm to L = 6.0 cm.	[1]
		Solution:  *For info:* $WD_{net} = Area\ bounded\ by\ the\ graph\ and\ the\ L - axis$ Net work done on the mass = $\int F\ ds$ where s is the displacement moved/change in displacement, hence corresponds to the **change in** L.	**1**
	(d)	Describe the energy changes in the spring-mass system when the mass moves from L = 8.0 cm to L = 6.0 cm.	
		………………………………………………………………………………………………..	[2]
		The **kinetic energy of the mass decreases and the elastic potential energy of the spring also decreases**, **these energies convert into the increase in the gravitational potential energy of the mass**.	**1** **1**

4 **(a)** A revolving aluminium disc has small magnets equally spaced around its rim as shown in Fig. 4.1. The magnets are all aligned in the same direction with the north poles on the same side of the disc. The disc rotates at a constant angular velocity.

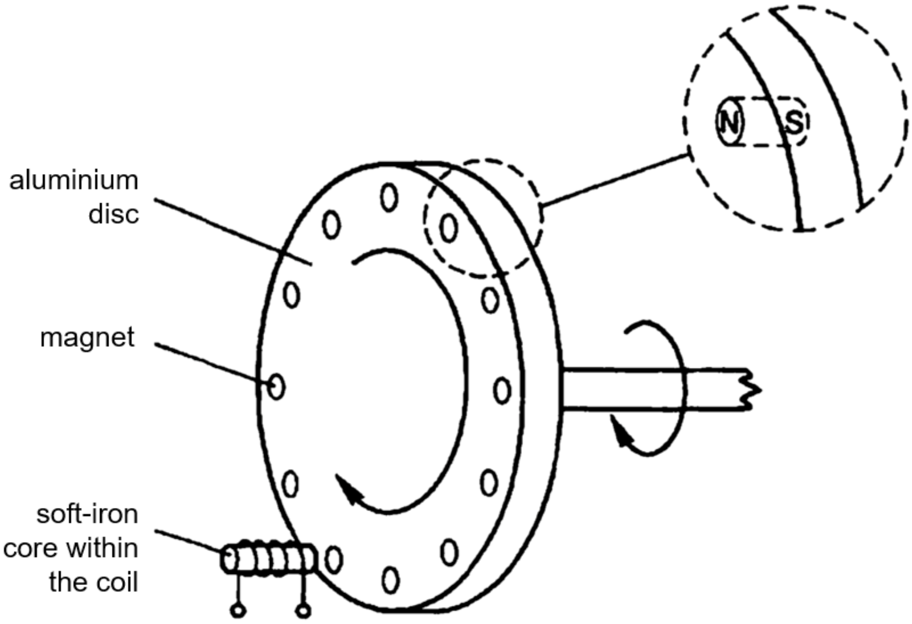


Fig. 4.1

A coil, wound on a soft-iron core, is fixed such that the north poles of the magnets pass close by the end of the coil without touching it. The terminals of the coil are connected to a detector which monitors the e.m.f. induced in the coil.

(i) As one magnet passes the coil, use the laws of electromagnetic induction to explain

1. why there is an induced e.m.f. in the coil.

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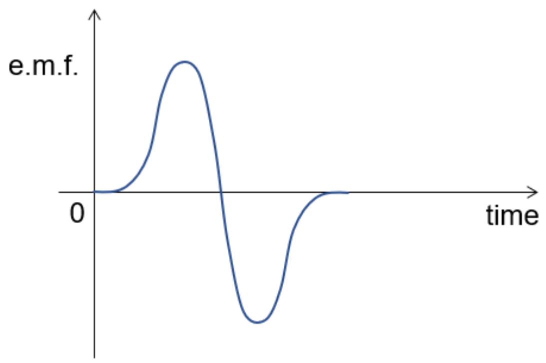
…………………………………………………………………………………………… [2]

The **magnetic flux density experienced by the coil increases and decreases when one magnet approaches and leaves the coil respectively.** **1**

There is a rate of change of magnetic flux linkage experienced by the coil, and by Faraday's Law, there is an induced e.m.f. in the coil. **1**

			2.	why there is a reversal in the direction of the induced e.m.f.	
				………………………………………………………………………………………………	
				………………………………………………………………………………………………	
				………………………………………………………………………………………………	
				………………………………………………………………………………………………	[1]
			By Lenz's law, the **direction of the induced e.m.f in the time interval when the magnetic flux linkage increases will be negative to that in the time interval when the magnetic flux linkage decreases**.		**1**
		(ii)	On Fig. 4.2, sketch a graph to show the variation with time of the e.m.f. induced in the coil as one magnet passes the coil. 		
			Fig. 4.2		[1]
			Solution:  1 mark for • General shape (accept other similar variation but not linear e.g. do not accept saw-tooth, do not accept plateau) • Start from e.m.f. = 0 (accept if graph did not start from t = 0)		**1**

(b) Fig. 4.3 and Fig. 4.4 show two views of a rectangular coil of height *h* and width *d* rotating with an angular speed ω about a vertical axis in a horizontal magnetic field of flux density *B*. At a certain instance of time *t*, the normal to the plane of the coil makes an angle of ωt with the magnetic field.

There are *N* turns in the coil.

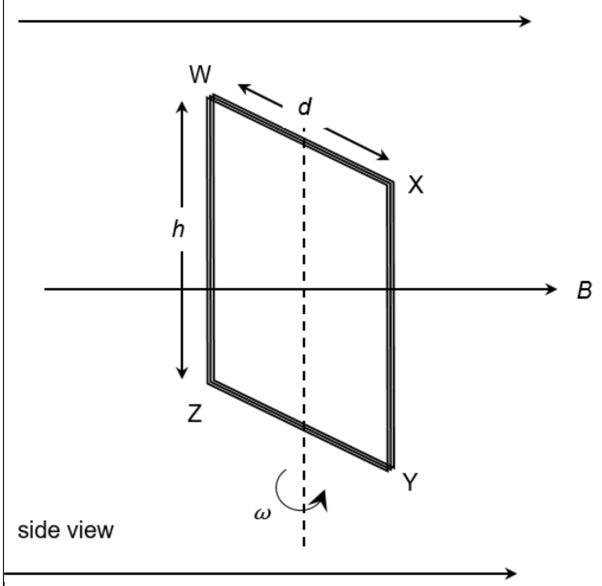


Fig. 4.3

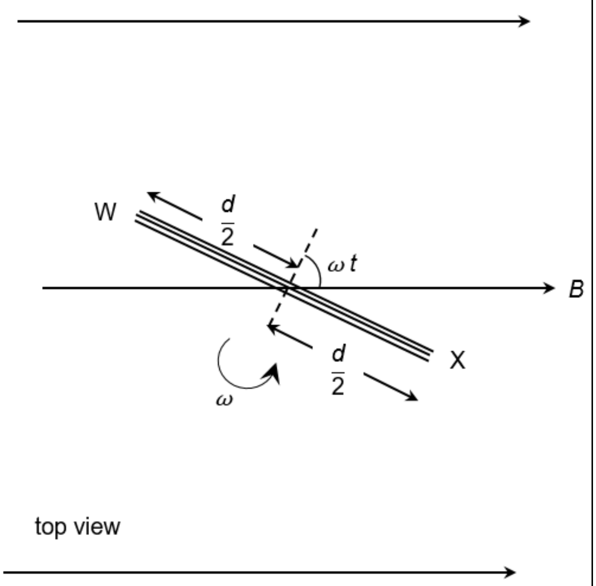


Fig. 4.4

(i) At time *t* = 0, the plane of the coil is perpendicular to the magnetic field.

Show that the magnitude of the induced e.m.f. *E* in the coil is given by

$$E = NBdh\omega \sin(\omega t)$$

[2]

Method 1

$$E = -\frac{d\Phi}{dt}$$ **1**

$$= -\frac{d(N\phi)}{dt}$$

$$= -N\frac{d(BA\cos\ \omega t)}{dt}$$

$$= -NBA\frac{d(\cos\omega t)}{dt}$$ **1**

$$= NBdh\omega\sin\omega t$$

Method 2

The linear speed *v* of the sides XY and ZW as they execute circular motion about the vertical axis is given by

$$v = r\omega = \left(\frac{d}{2}\right)\omega$$

Hence, the e.m.f. induced in each of the sides XY and ZW is given by

$$E = NB_{\perp v}lv = N(B\sin\omega t)lv = NBlv\sin\omega t$$ **[1]**

			$= NBh\left(\frac{d}{2}\right)\omega\sin\omega t$ Since the orientation of the induced e.m.f in XY and ZW are such that they are in the same direction, $E = E_{XY} + E_{ZW}$ $= 2\left[NBh\left(\frac{d}{2}\right)\omega\sin\omega t\right]$ $= NBdh\omega\sin\omega t$	**[1]** **[0]**
		(ii)	The coil has dimension 30 cm by 24 cm and has 15 turns and the uniform magnetic field has flux density of 0.018 T. The coil rotates with a frequency of 25 Hz. Determine, for the coil,	
			1. the maximum e.m.f. induced,	
			maximum e.m.f. induced = ……………………… V	[2]
			Max . e.m.f. induced, E_0 = $NBdh\omega$ = $NBdh(2\pi f)$ = $15(0.018)(24\times10^{-2})(30\times10^{-2})(2\pi(25))$ = 3.053628 = 3.1 V	**1** **1**
			2. the root-mean-square value of the e.m.f. induced.	
			root-mean-square e.m.f. induced = ……………………… V	[1]
			$E_{RMS} = \frac{E_0}{\sqrt{2}}$ $= \frac{3.053628}{\sqrt{2}}$ $= 2.1592 = 2.2\ V$	**1**

5 (a) Fig. 5.1 shows two small loudspeakers, L_1 and L_2, separated by 15 cm. A microphone is moved along a line XY parallel to the line joining the two loudspeakers and at a perpendicular distance of 1.2 m away.

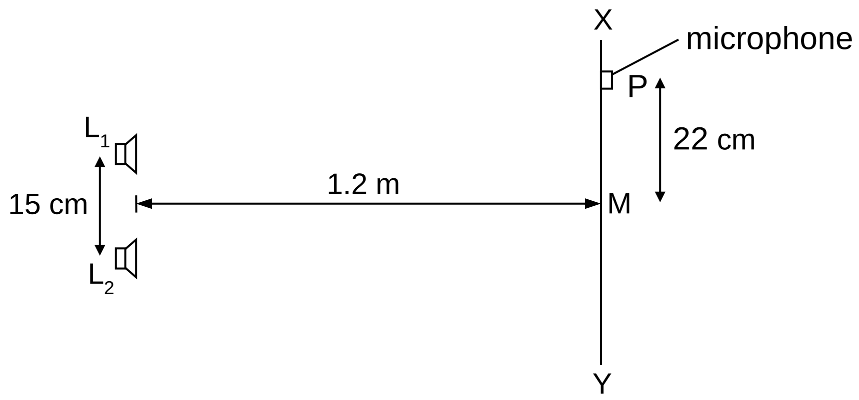


Fig. 5.1

The centre of the interference pattern formed along XY is at point M. When the microphone is moved from M to P by a distance of 22 cm, it detects three intensity maxima including the ones at M and P.

Given that the speed of sound in air is 330 m s^{-1}, determine the approximate frequency at which the speakers were driven. Express your answer to 2 significant figures.

frequency = ………………………….. Hz [3]

Method 1

three intensity maxima detected from M to P including the ones at M and P **1**

- ➔ 2 fringe separations = 22 cm
- ➔ fringe separation, x = 11 cm

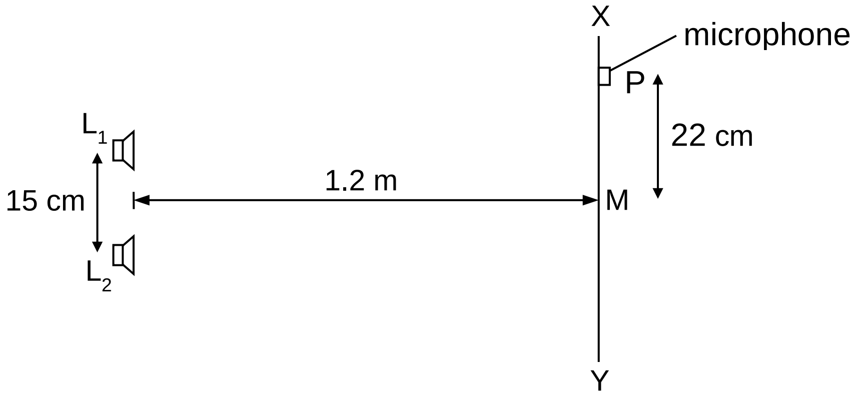
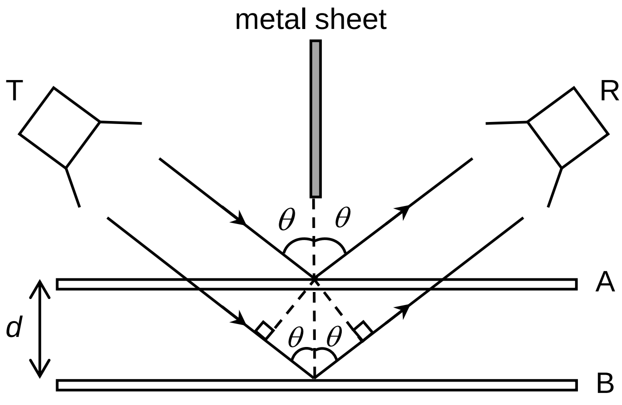
Two-source interference fringe separation,

$$x = \frac{\lambda D}{a}$$

$$11x10^{-2} = \frac{\lambda(1.2)}{15x10^{-2}}$$ **1**

$$\therefore \ \lambda = 0.01375 \text{ m}$$

$$\therefore \ f = \frac{v}{\lambda} = \frac{330}{0.01375} = 2.4 \times 10^{4} \text{ Hz}$$ **1**

		Method 2  **Finding the path difference,** **Path of L_1P =** $\sqrt{1.2^2 + (0.22 - 0.075)^2} = 1.209$ **m** **Path of L_2P =** $\sqrt{1.2^2 + (0.22 + 0.075)^2} = 1.236$ **m** **Path difference = 1.236 – 1.209 = 0.027 m = 2*λ*** $\therefore\ \lambda = 0.0135$ m (Note that it is a different outcome from the Young Double Slit experiment. It is expected as the Young's Double Slit equation is an approximation to the fringe separation. $\therefore\ f = \frac{v}{\lambda} = \frac{330}{0.0135} = 2.4 \times 10^4$ Hz	
	(b)	Fig. 5.2 shows a microwave transmitter T and a microwave receiver R placed at the same angle θ to the normal of a horizontal board A, which partially reflects and transmits microwaves. A similar horizontal board B is placed a distance *d* below board A, such that a high intensity signal is detected by receiver R. A metal sheet is placed between T and R to prevent microwaves from reaching R directly from T.  **Fig. 5.2** The path difference between the two waves reflected off boards A and B is given by $2d \cos \theta$ When a high intensity signal is detected by R,	

$$2d \cos \theta = m\lambda$$

where m is a positive integer and refers to the order of constructive interference (m = 1, 2, 3, …) and λ is the wavelength of the microwaves.

(i) State the phase difference, in radians, between the reflected microwaves from A and B at a point where a high intensity signal is detected.

phase difference = ………………………….. rad [1]

0 rad (or 2π rad, 4π rad, etc.), as a high intensity signal or constructive interference is detected. **1**

(ii) When distance d is increased by lowering board B, alternating low and high intensity signals are detected by receiver R. Explain these observations.

………………………………………………………………………………………………

………………………………………………………………………………………………

……………………………………………………………………………………….. [3]

As board B is lowered, the **path difference** between the two reflected waves **continuously increases**. **1**

This causes the **phase difference** between the **two waves at R** to **continuously alternate between being in phase and antiphase**. **1**

The **high intensity signals are due to constructive interference** between the reflected waves **whenever they meet in phase at R**. **1**
The **low intensity signals are due to destructive interference** between the reflected waves **whenever they meet in antiphase at R**.

(iii) Transmitter T and receiver R are now placed side-by-side and facing the boards normally, meaning that θ = 0°.

As board B is moved 140 mm downwards at a constant speed, receiver R goes from the initial high intensity signal through nine high intensity signals and then to a final high intensity signal.

Determine the wavelength of these microwaves.

wavelength = ………………………….. m [2]

Since θ = 0°, the expression for path difference in terms of d now becomes:
$2d \cos 0° = 2d$

Distance moved by board B (d) x 2 = Change in path difference = 10 λ **1**
Thus,
$2d$ = 10 λ
140 mm x 2 = 10 λ
λ = 28 mm
= 0.028 m **1**

6 In a photoelectric experiment, an ultraviolet (UV) light source of constant intensity and single frequency is used. Two metal plates X and Y are contained in an evacuated glass container and are connected to a circuit as shown in Fig. 6.1. The UV source is placed at a distance away from X and Y.

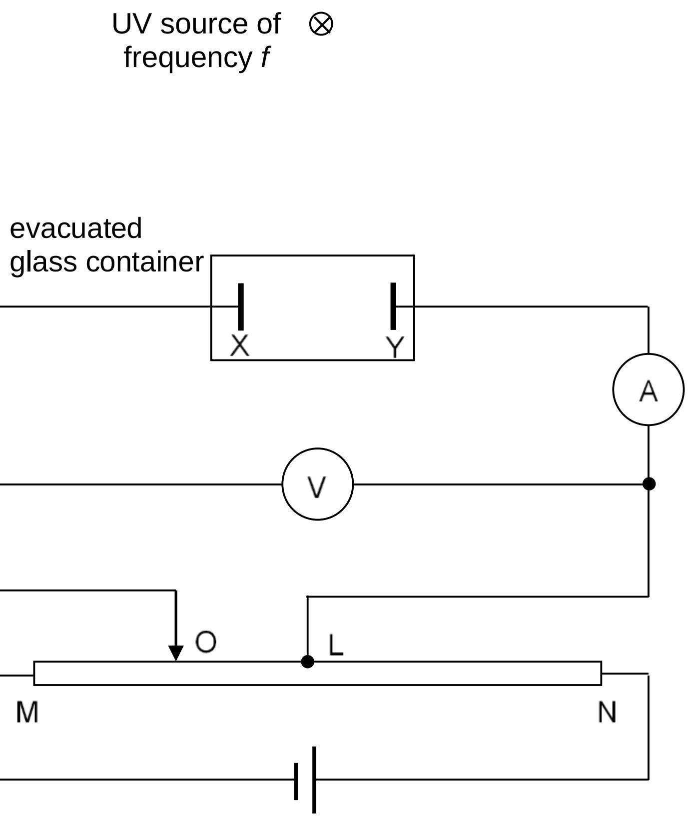


Fig. 6.1

The graph shown in Fig. 6.2 depicts the relationship between the voltmeter reading and the ammeter reading when metal plate X is the photoelectric emitter. No photoelectrons are emitted from Y.

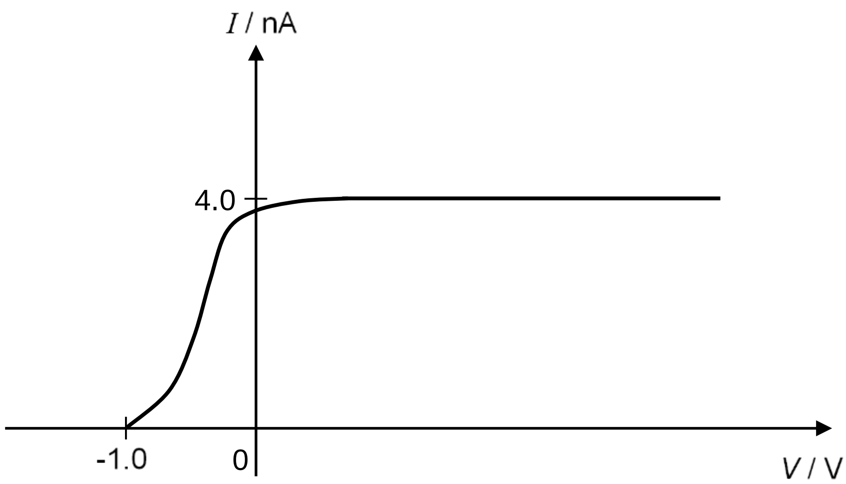


Fig. 6.2

(a) Explain why the current remains constant for positive values of *V*.

....

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

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

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

…………………………………………………………………………………………………… [3]

The **current measured is proportional to the rate of electrons reaching Y.** **1**

The rate of <u>electron</u> ejection from X arriving at Y is fixed because it is proportional to the rate of <u>photon</u> incidence on X which is fixed when electromagnetic radiation is at a fixed intensity and fixed frequency. **1**

For positive values of *V*, the electrons experience an accelerating force towards Y. Thus, ALL the electrons ejected from X will be collected at Y regardless of the applied potential difference. Therefore, the current will also be constant at a maximum value. **1**

(b) Metal plate X is made of zinc with a work function of 3.8 eV. Using information from Fig. 6.2, determine the wavelength of the UV source.

wavelength = ………………………….. m [2]

Applying the photoelectric equation,
Photon Energy = Work function of metal surface + Maximum K.E. of emitted electrons

$$\frac{hc}{\lambda} = \phi + eV_s$$

$$\lambda = \frac{hc}{\phi + eV_s}$$ **1**

$$= \frac{6.63\times10^{-34}(3.00\times10^{8})}{3.8(1.60\times10^{-19})+1.60\times10^{-19}(1.0)}$$

$$= 2.59\times10^{-7}\ \text{m}$$ **1**

(c) Sketch, on Fig. 6.2, the graph when the experiment was repeated with UV light source of the same frequency but with intensity one-quartered. [2]

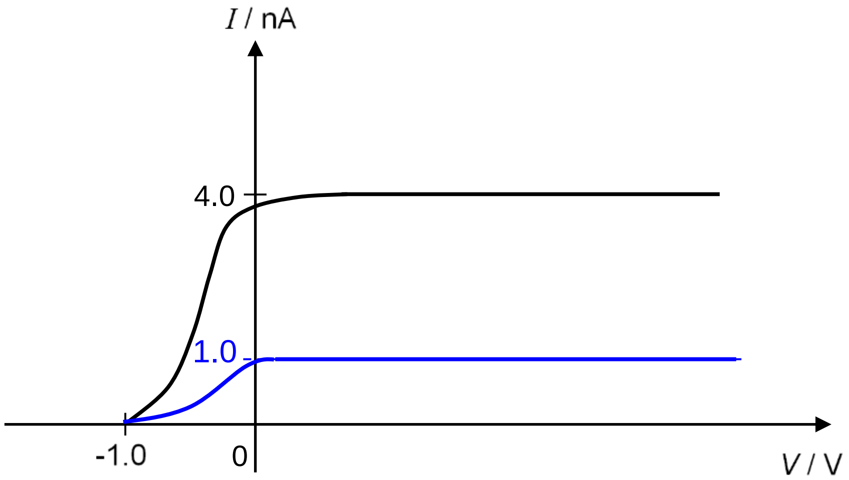
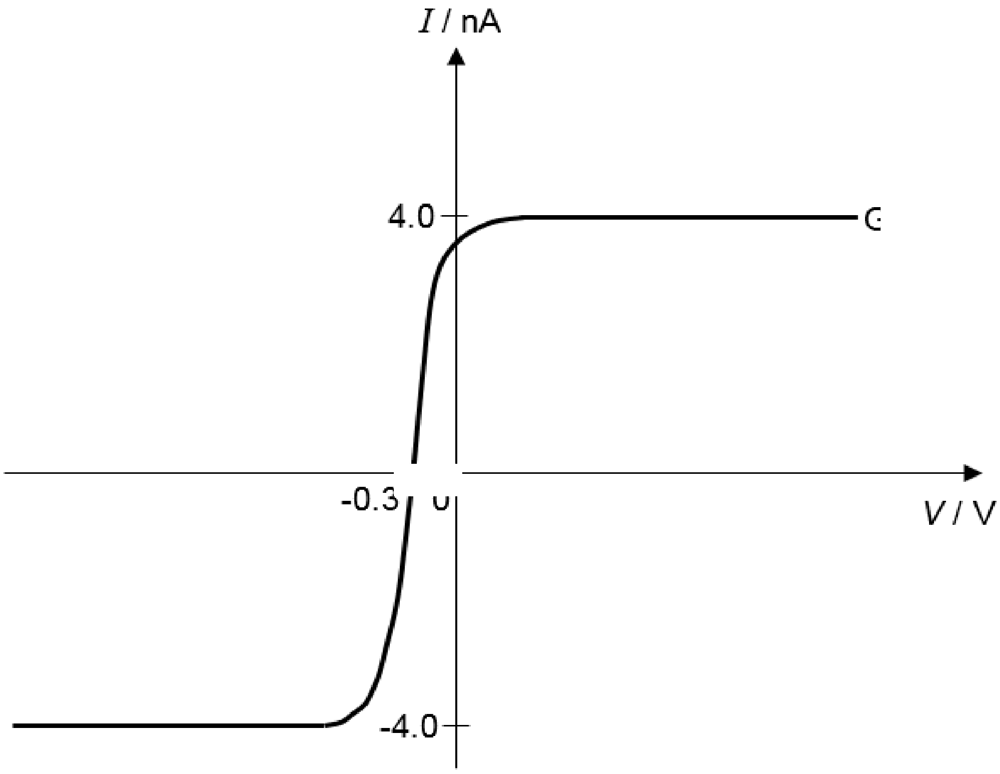
LHS of graph:
Same frequency photons incident and same work function energy of the metal
- ➔ Maximum K.E. of electrons ejected unchanged
- ➔ **Stopping potential unchanged**

RHS of graph:

$$Intensity\ of\ radiation = \frac{P}{A} = \frac{E}{tA} = \frac{Nhf}{tA}$$

$$\frac{N}{t} = Intensity\ of\ radiation\ x\ \frac{A}{hf}$$

Same frequency f and Intensity one-quartered
- ➔ No. of photons incident per unit time, $\frac{N}{t}$ will be one-quarter the original.
- ➔ Since each electron ejected is the result of absorbing one photon, the photoelectric current is proportional to $\frac{N}{t}$. Thus, **maximum photoelectric current will be <u>one-quarter</u> the original**.

			1 1
	(d)	The UV light source was replaced with another light source of higher frequency. The graph in Fig. 6.3 was obtained when the experiment was conducted using the higher frequency light source.  **Fig. 6.3**	
		Explain which metal plate, X or Y, has a greater work function energy.	
		…………………………………………………………………………………………	
		…………………………………………………………………………………………	[2]
		Fig. 6.3 shows that photoelectron emission occurs in <u>both</u> metal plates X and Y when light source of higher frequency is used. Energy per photon is proportional to its frequency, and for an electron to be ejected from a metal surface the photon energy must be greater or equal to the work function energy of the metal surface.	**1**

		Since Y emits electrons only with the higher frequency light source but X emits electrons with both the lower and higher frequency light source, Y must have the greater work function energy.	**1**

7	**(a)**	State experimental evidence to suggest that the process of radioactive decay is		
		(i)	random;	
			……………………………………………………………………………………………	
			……………………………………………………………………………………………	[1]
			The **points on a count rate against time graph scatter about the (exponential) line of best fit.** **OR** **Measured count rate fluctuates** from instant to instant in time**.**	**1**
		(ii)	spontaneous.	
			……………………………………………………………………………………………	
			……………………………………………………………………………………………	[1]
			The rate of decrease of the measured count rate is unaffected by external stimuli and changes in physical conditions. **OR** **Repeated experiments under different physical conditions result in no change in the rate of decrease of the measured count rate.**	**1**
	(b)	Uranium-238 decays into lead-206 by several stages. Lead-206 is a stable isotope. The overall decay can be represented by the following equation: $^{238}_{92}\text{U} \rightarrow {}^{206}_{82}\text{Pb} + \text{decay products}$ It is suggested that **all** of the decay products are alpha particles. Use the equation to show that this cannot be correct.		
				[2]
		Proof by Contradiction: Suppose all the decay products are alpha particles and total number of alpha particles produced is x. $^{238}_{92}\text{U} \rightarrow {}^{206}_{82}\text{Pb} + x\,{}^{4}_{2}\text{He}$ **For nucleon number to be conserved**: $238 = 206 - 4x \Rightarrow x = 8$ **For proton number to be conserved:** $92 = 82 - 2x \Rightarrow x = 5$ Need 8 alpha particles to balance the total number of nucleons, but 5 alpha particles to balance the total number of protons in the equation. Hence, it is not possible for all		**1**

		decay products to be alpha particles. OR alpha-particle: ${}^{4}_{2}\mathrm{He} \Longrightarrow$ ratio of nucleon no. to proton no. = 2:1 Total number of nucleons in the decay products, A = 236 – 206 = 32 Total number of protons in the decay products, B = 92 – 82 = 10 ratio A:B = 32:10 $\neq$ 2:1 Therefore not all the decay products are alpha particles. OR alpha-particle: ${}^{4}_{2}\mathrm{He} \Longrightarrow$ 2 protons and 2 neutrons Total number of protons in the decay products = 92 – 82 = 10 Total number of neutrons in the decay products = (238-92) – (206-82) = 22 Since an alpha-particle has equal number of protons and neutrons, but the total number of protons and neutrons are different in the decay products, hence not all the decay products are alpha-particles.	**1**
	(c)	Technetium-99, ${}^{99}_{43}\mathrm{Tc}$, decays to ruthenium-99, ${}^{99}_{44}\mathrm{Ru}$. The half-life of technetium-99 is 4.00 x 10^{6} years. Ruthenium-99 is a stable nuclide.	
		(i) Write down the nuclear equation representing this decay. State also the name(s) of the products other than ruthenium-99 that is/are formed.	
		Equation:	
		Name(s) of additional product(s):	[2]
		${}^{99}_{43}\mathrm{Tc} \rightarrow {}^{99}_{44}Ru + {}^{0}_{-1}\mathrm{e}$ **Beta-particle <u>AND</u> antineutrino/neutrino.**	**1** **1**
		•	
		(ii) On the axes of Fig. 7.1, sketch a graph to show how the ratio $R = \dfrac{\text{number of ruthenium-99 nuclei}}{\text{number of technetium-99 nuclei}}$ will change in a sample with time t. Take t = 0 to be the instant of creation of ruthenium-99.	

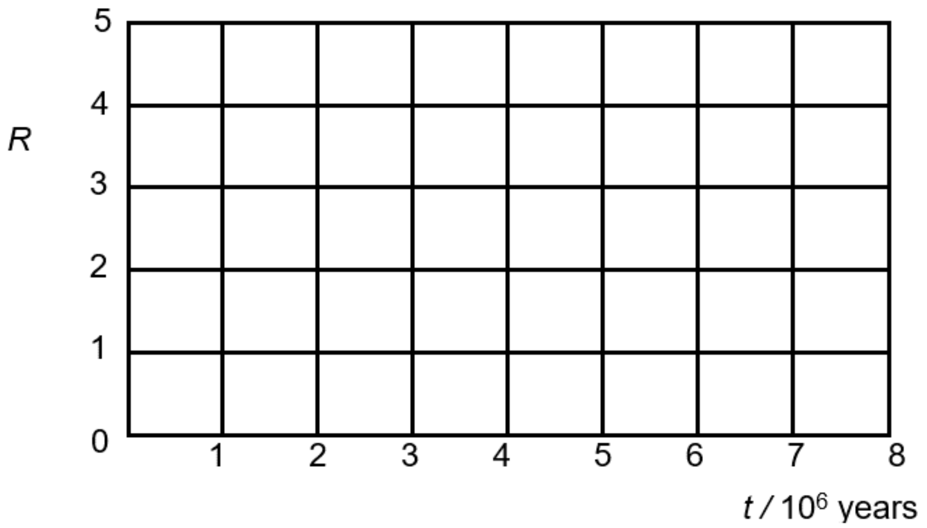
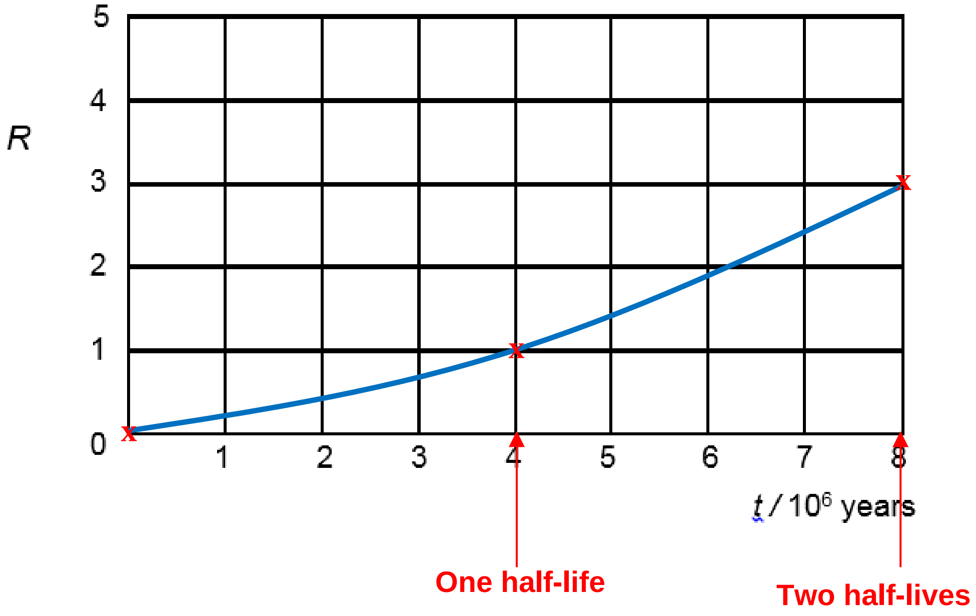


Fig. 7.1 [2]

Ru should be increasing, Tc decreasing with time.
Ru:Tc
0 : N at t=0
N/2 : N/2 after one half-life
3N/4 : N/4 after two half-lives
7N/8 : N/8 after three half-lives
etc…

Therefore,
R = 0 at t=0 → plot (0,0)
R = 1 at t=4x10^6 years → plot (4,1)
R = 3 at t=8x10^6 years → plot (8,3)

Since N is an exponential function with time, the ratio R will also be an exponential function. So graph of R is an exponential curve.



1
1

Section B

Answer **one** question from this section.

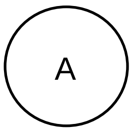
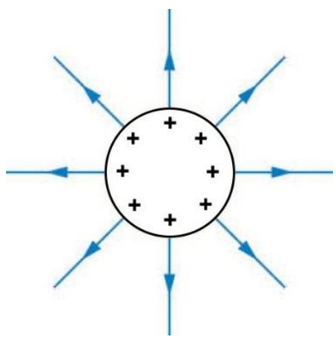
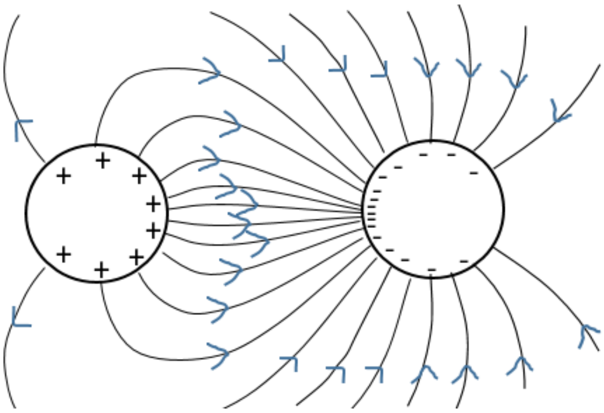
8	**(a)**	Explain what is meant by an *electric field*.	
		…………………………………………………………………………………………..	[1]
		It is the **region of space** where a **charged particle experiences an electric force**.	**1**
	(b)	The charges on an isolated metal sphere are uniformly distributed on its surface. Fig.8.1 shows a positively charged metal sphere A. On Fig.8.1, draw the charge distribution on the sphere and the electric field around it.	
		 	
		Fig. 8.1	[1]
		Solution:  • equal spacing of charge on the surface of sphere, **and,** • radial field acting outwards • field lines drawn perpendicular to the surface of the metal sphere	**1**
	(c)	A negatively charged metal sphere B is brought close to the positively charged metal sphere A as shown in Fig.8.2. The charge on metal sphere B is twice that of the charge on metal sphere A. On Fig. 8.2, draw the charge distribution on the spheres and the electric field around the spheres.	

		Fig. 8.2	[3]
		Solution: 	
		Mark scheme: • Distribution of charges: correct distribution, charges drawn on the surfaces, twice the number of '-' on B compared to the number of '+' on A. • Field pattern: correct shape & variation of density of field lines, number of field lines around B twice that around A. • Direction of field lines, including field lines drawn perpendicular to the surface of each metal sphere. OR • Distribution of charges: correct distribution, charges drawn on the surfaces, twice the number of '-' on B compared to the number of '+' on A. • Field pattern & Direction of field lines • Details: number of line around each sphere, lines drawn perpendicular to the surface of the spheres.	**1** **1** **1** **[1]** **[1]** **[1]**

(d) Point P is at a distance *x* from the centre of sphere A along the line joining the centres of the two spheres as shown in Fig.8.3. The radius of A and B is 15 mm and the distance between the centres of the spheres is 80 mm.

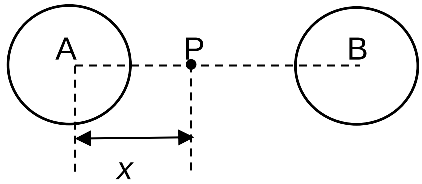


Fig. 8.3

The variation with *x* of the electric potential *V* at P is shown in Fig. 8.4.

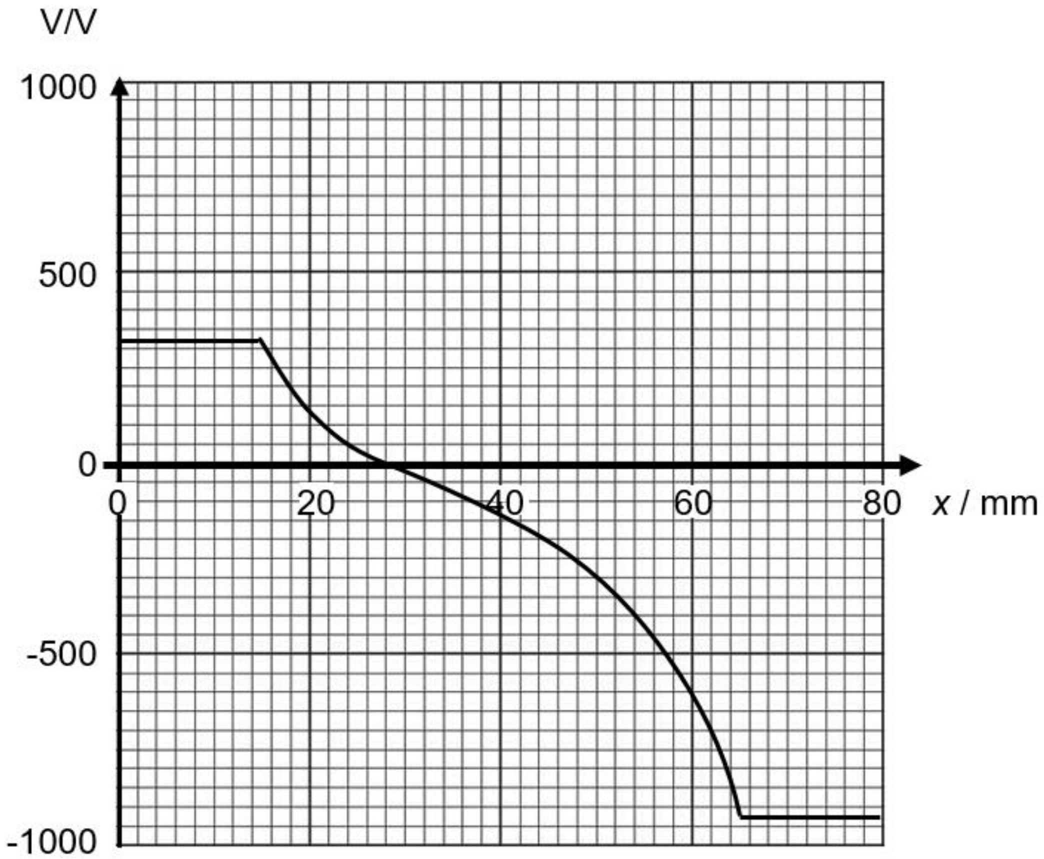


Fig. 8.4

(i) Determine the magnitude of the electric field strength at P where x = 40 mm.

magnitude of the electric field strength = …………..…..…………….. V m^{-1} [2]

$|E| = |dV / dx|$ **1**
= gradient of V-x graph at x = 40 mm
= $350 - (-600) / 80 \times 10^{-3}$
= 1.19×10^4 V m^{-1} **1**

(ii) An electron is initially at rest at point P where x = 40 mm.

1. Describe and explain the motion of the electron as it travels 20 mm along the line joining the centres of the spheres.

………………………………………………………………………………………………

…………………………………………………………………………………………… [3]

$a = \frac{F_{net}}{m} = \frac{F_E}{m} = \frac{eE}{m}$

where $E = -\frac{dV}{dx}$

Gradient of the V-x graph is proportional to the electric field strength which is proportional to acceleration. 1

When gradient decreases from 40 mm to 28 mm, acceleration decreases. 1

- ➔ **The electron moves to the left towards A, speeds up at a decreasing rate.**

When gradient increases from 28 mm to 20 mm, acceleration increases. 1

- ➔ **The electron continues moving to the left towards A, speeds up at an increasing rate.**

2. Determine the speed of the electron when it has travelled 20 mm along the line joining the centres of the spheres.

speed of electron = ……………..……………m s^{-1} [3]

moving 20 mm towards A, the electron moves from x = 40 mm to x = 20 mm,

increase in potential, Δ**V** = 125 –(-150) = 275 V

[Also accept V_{40mm} between -125 V to -150 V; V_{20mm} between 125 V to 150 V] 1

decrease in potential **energy**, Δ**U** = **q.**Δ**V** = 1.60 x 10^{-19} x 275 = 4.40 x 10^{-17} J

By conservation of energy,

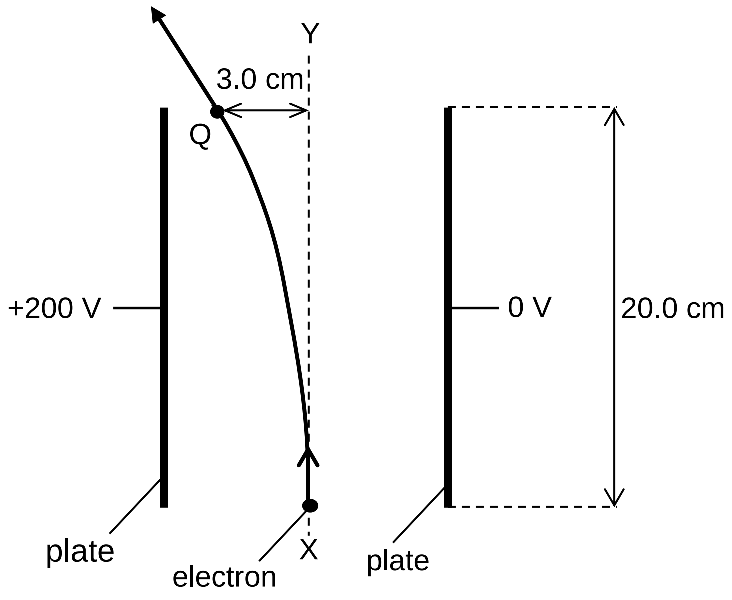
increase in KE = decrease in electric potential energy

final KE – initial KE = ΔU 1

½ m v^2 – 0 = 4.40 x 10^{-17}

½ (9.11 x 10^{-31}) v^2 = 4.40 x 10^{-17}

v = 9.83 x 10^6 m s^{-1} 1

	(e)	An electron is projected along the line XY into a region of uniform electric field between two charged parallel plates of length 20.0 cm separated by 8.0 cm, as shown in the Fig 8.5. The potential difference between the two plates is 200 V. Between the plates, the electron travels along a curved path and exit the region between the plates at point Q which is 3.0 cm from the line XY.		
		 **Fig. 8.5**		
		(i)	Calculate the electric field strength between the two plates.	
			electric field strength = ……………………………… V m^{-1}	[1]
			E = V /d = 200 / 0.080 = 2500 V m^{-1}	**1**
		(ii)	Calculate the initial speed of the electron projected into the electric field.	
			speed = ………………………….. m s^{-1}	[4]
			consider motion perpendicular to XY Electic force F = qE = 1.60 x 10^{-19} x 2500 accleration = F / m = 1.60 x 10^{-19} x 2500 / 9.11 x 10^{-31} = 4.396 x 10^{14} Using s = ut + ½ a t^2 0.030 = 0 + ½ (4.396 x 10^{14})t^2 ……………..(2) t = 1.168 x 10^{-8} s consider motion along XY Using s = ut + ½ a t^2 0.200 = u(1.168 x 10^{-8}) +0 u = 1.712 x 10^7= 1.7x 10^7 m s^{-1}	**1** **1** **1** **1**
		(iii)	A proton is now projected into the same electric field and with the same velocity as that of the electron. Explain why the deflection of the proton is much lesser compared to the deflection of the electron.	
			………………………………………………………………………………………………..	

			....	[2]
			A proton has the same magnitude of charge as the electron, hence it will experience the same magnitude of electric force as that on the electron. **A proton has a mass about <u>1800 times</u> that of the electron (or <u>much more massive than</u> that of the electron), hence it will experience an acceleration <u>1800 times less than</u> that on the electron (or <u>much smaller</u> acceleration).** **Time spent between the plates is the same for both the proton and electron,** hence the deflection will be much lesser and the path is much less curved.	1 1

9	**(a)**	A satellite orbits the Earth of mass M in a circular path of radius r.		
		(i)	Show that the period T of the satellite is given by the expression $$T^2 = \frac{4\pi^2}{GM}r^3$$	
				[3]
			Gravitational force F_G provides the centripetal force F_C. $F_C = F_G$ $mr\omega^2 = \frac{GMm}{r^2}$ $mr\left(\frac{2\pi}{T}\right)^2 = \frac{GMm}{r^2}$ $T^2 = \frac{4\pi^2}{GM}r^3$	1 1 1
		(ii)	A satellite is orbiting the Earth above the equator with a period of 28 hours. The mass of the Earth is 5.98×10^{24} kg.	
			1. Calculate the radius of the satellite's orbit.	
			radius = ... m	[2]
			Using $T^2 = \frac{4\pi^2}{GM}r^3$ $r = \sqrt[3]{\frac{GM}{4\pi^2}\left(T^2\right)}$ $= \sqrt[3]{\frac{\left(6.67\times10^{-11}\right)\left(5.98\times10^{24}\right)}{4\pi^2}\left(28\times60\times60\right)^2}$ $= 4.68 \times 10^7$ m	 1 1

			2. The mass of the satellite is m. For the satellite in orbit, show that its kinetic energy E_K is given by $$E_K = \frac{GMm}{2r}$$	
				[2]
			$\frac{mv^2}{r} = \frac{GMm}{r^2}$ $E_K = \frac{1}{2}mv^2$ $= \frac{GMm}{2r}$	**1** **1**
			3. Hence, determine the kinetic energy of the satellite if it has a mass of 1200 kg.	
			kinetic energy = ... J	[1]
			$E_K = \frac{GMm}{2r} = \frac{(6.67\times10^{-11})(5.98\times10^{24})(1200)}{2(4.68\times10^{7})}$ $= 5.11 \times 10^9$ J	**1**
			4. The satellite is then moved into a new orbit, gaining 1.14×10^9 J of gravitational potential energy in the process. Calculate the satellite's loss in kinetic energy.	
			loss in kinetic energy = ... J	[3]
			Given: Gain in gravitational potential energy $= -\frac{GMm}{r_2} - \left(-\frac{GMm}{r_1}\right) = 1.14\times10^9$ J where r_1 and r_2 are the radii of the old and new orbit respectively. Loss in kinetic energy = KE_i - KE_f $= \frac{GMm}{2r_1} - \left(\frac{GMm}{2r_2}\right)$ $= \frac{1}{2}\left(\frac{GMm}{r_1} - \frac{GMm}{r_2}\right)$ $= \frac{1}{2}(1.14\times10^9)$ $= 5.70 \times 10^8$ J.	**1** **1** **1**

(b) A binary star consists of two stars that orbit about a fixed point C, as shown in Fig. 9.2.

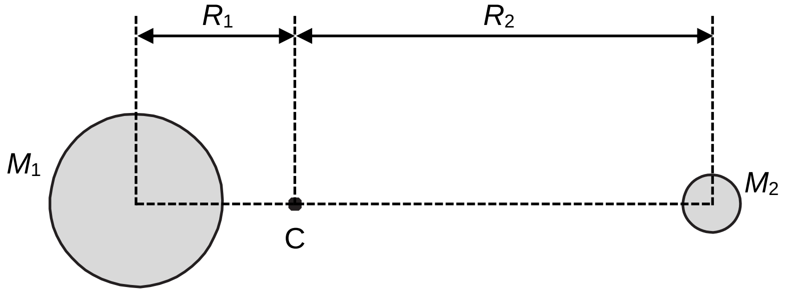


Fig. 9.2

The star of mass M_1 has a circular orbit of radius R_1, and the star of mass M_2 has a circular orbit of radius R_2. Rotating about point C, both stars have the same angular speed of 4.98×10^{-8} rad s^{-1}.

(i) Explain why the centripetal force acting on the two stars are equal in magnitude.

....

....

....

.... [2]

The **gravitational force on each star exerted by the other star provides the centripetal force required** for each star's circular motion. **1**

By Newton's 3rd law, the gravitational force that each star exerts on the other star are equal in magnitude and opposite in direction. **1**

(ii) Calculate the period of orbit of each star.

period = ...years [2]

$$\omega = \frac{2\pi}{T}$$

$$T = \frac{2\pi}{\omega} = \frac{2\pi}{4.98 \times 10^{-8}}$$ **1**

$= 1.2617 \times 10^{8}$ s

$= 4.00$ years **1**

(iii) Show that the ratio of the masses of the stars is given by the expression

$$\frac{M_1}{M_2} = \frac{R_2}{R_1}$$

[1]

			Centripetal force experienced by both stars are equal, hence $M_1R_1\omega^2 = M_2R_2\omega^2$ Hence, $\dfrac{M_1}{M_2} = \dfrac{R_2}{R_1}$	1
		(iv)	Given that $\dfrac{M_1}{M_2} = 3.0$ and the separation between the stars is 3.2×10^{11} m, calculate the radius R_1.	
			R_1 = ... m	[2]
			$\dfrac{M_1}{M_2} = \dfrac{R_2}{R_1} = 3.0$ $R_1 = \dfrac{1}{3.0}(R_2)$ Therefore, $R_1 = \dfrac{1}{4} \times (3.2 \times 10^{11})$ $= 8.0 \times 10^{10}$ m	1 1
		(v)	A planet orbits around the star of mass M_1 in the binary star system. Suggest why the orbit of the planet is not circular.	
			....	
			....	
			....	
			....	[2]
			When the planet and star of mass M_2 are on opposite sides of star of mass M_1, resultant force acting on the planet is large. **When the planet and star of mass M_2 are on the same side of star of mass M_1, resultant force acting on the planet can be possibly be lower in magnitude.** Hence, the orbit of the planet will not be a perfect circle. e.g. The star M_2 also exerts a gravitational force on the planet. **As the planet orbits the star M_1, the resultant gravitational force due to both stars M_1 and M_2 will not remain constant as the relative positions between the stars and planet change during orbit. It will be the least when the planet is in between the two stars and greatest when M_1 is in between the planet and M_2.**	1 1

			Since the resultant gravitational force on the planet provides the centripetal force for its orbit, the centripetal force is not constant and thus the orbit will not be circular.	

-- END OF PAPER 3 --

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