Catholic Junior College
JC2 Preliminary Examinations
Higher 2

CANDIDATE NAME

CLASS 2T

PHYSICS 9749/3

Paper 3: Longer Structured Questions

12 September 2022

2 hours

Candidates answer on the Question Paper
No Additional Materials are required

READ THESE INSTRUCTIONS FIRST

Write your name and class on in the spaces at the top of this page
Write in dark blue or black pen on both sides of the paper.
You may use an HB pencil for any diagrams, graphs or rough working.
Do not use staples, paper clips, glue or correction fluid.

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

Section A
Answer **all** questions.

Section B
Answer **one** question only.

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

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

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 **30** printed pages and **4** blank pages.

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}
			$(1/(36\pi)) \times 10^{-9}$ 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}

Formulae

uniformly accelerated motion	$s = ut + ½ at^2$
	$v^2 = u^2 + 2as$
work done on / by a gas	$W = p \Delta V$
hydrostatic pressure	$p = \rho gh$
gravitational potential	$\phi = -\frac{Gm}{r}$
temperature	$T / K = T / {}^{\circ}C + 273.15$
pressure of an ideal gas	$p = \frac{1}{3}\frac{Nm}{V}\langle c^2 \rangle$
mean translational kinetic energy of an ideal gas molecule	$E = \frac{3}{2}kT$
displacement of particle in s.h.m.	$x = x_0 \sin \omega t$
velocity of particle in s.h.m.	$v = v_0 \cos \omega t$
	$= \pm \omega \sqrt{x_0^2 - x^2}$
electric current	$I = Anvq$
resistors in series	$R = R_1 + R_2 + \ldots$
resistors in parallel	$1/R = 1/R_1 + 1/R_2 + \ldots$
electric potential	$V = \frac{Q}{4\pi\varepsilon_o r}$
alternating current / voltage	$x = x_0 \sin \omega t$
magnetic flux density due to a long straight wire	$B = \frac{\mu_o I}{2\pi d}$
magnetic flux density due to a flat circular coil	$B = \frac{\mu_o N I}{2r}$
magnetic flux density due to a long solenoid	$B = \mu_o n I$
radioactive decay	$x = x_0 \exp(-\lambda t)$
decay constant	$\lambda = \frac{\ln 2}{t_{\frac{1}{2}}}$

Section A

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

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

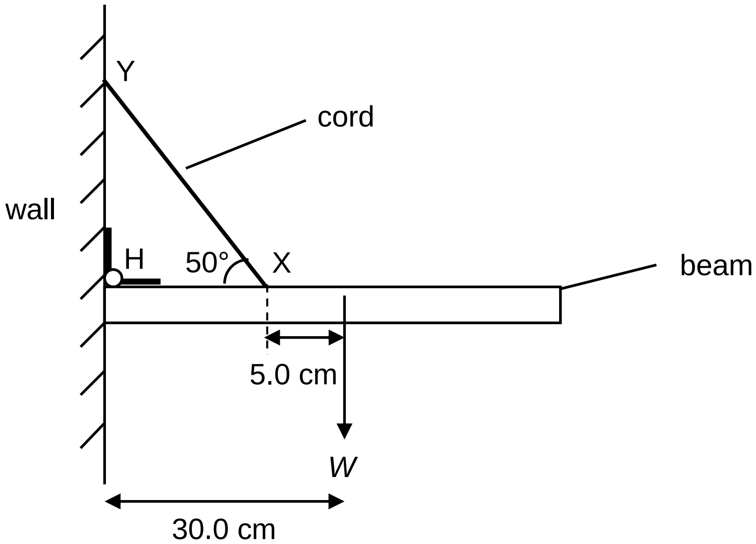

Fig. 1.1

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]

(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]

(ii) the force *R*.

R = ... N [2]

(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.

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.... [2]

[Total: 8]

2 (a) State the principle of *conservation of linear momentum*.

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.... [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]

(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]

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

....

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.... [2]

(iv) Explain why particles of similar mass to neutrons such as hydrogen nuclei are unsuitable for slowing down neutrons in the nuclear reactor.

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.... [1]

[Total: 9]

[Turn over

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

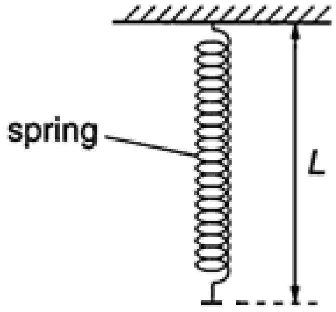

Fig. 3.1

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.

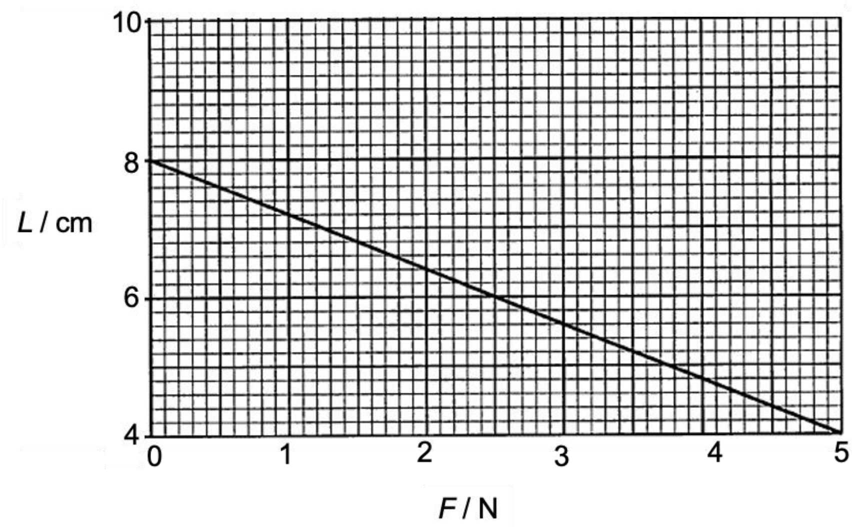

Fig. 3.2

(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.

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.... [2]

(b) Calculate the force constant of the spring.

force constant = ... N m^{-1} [3]

(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]

(d) Describe the energy changes in the spring-mass system when the mass moves from L = 8.0 cm to L = 6.0 cm.

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.... [2]

[Total: 8]

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.

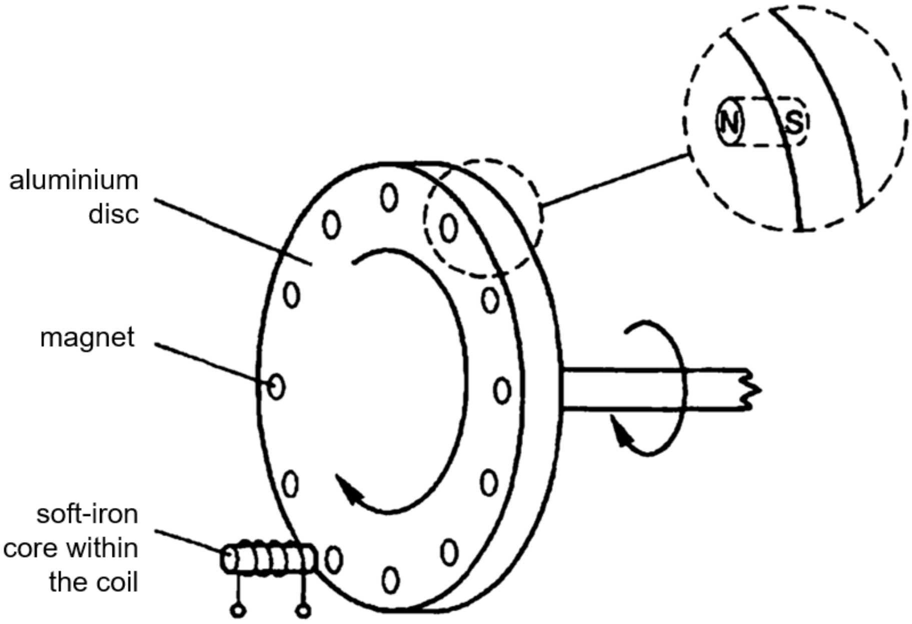

Fig. 4.1

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]

2. why there is a reversal in the direction of the induced e.m.f.

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.... [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]

(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.

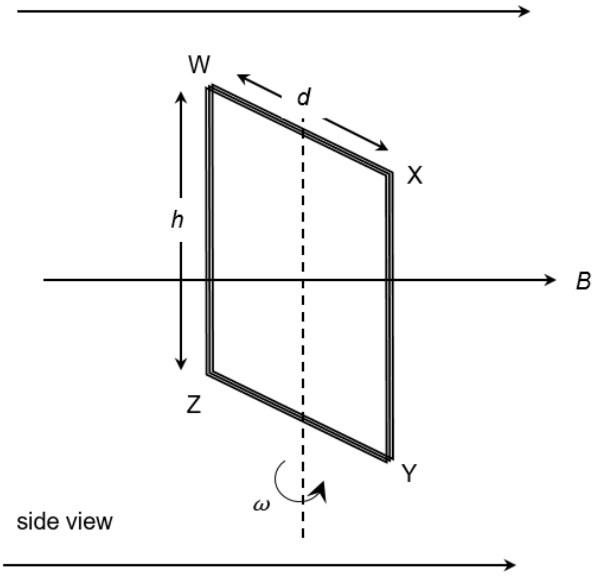

Fig. 4.3

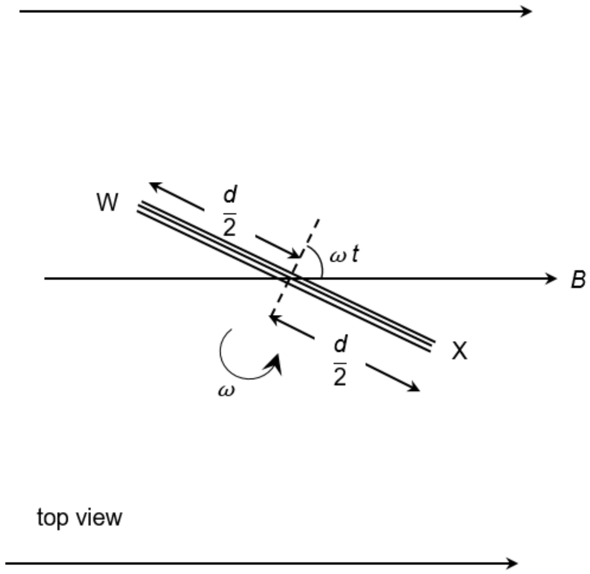

Fig. 4.4

(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]

(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 induced e.m.f.,

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

2. the root-mean-square value of the induced e.m.f.

root-mean-square e.m.f. = ... V [1]

[Total: 9]

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.

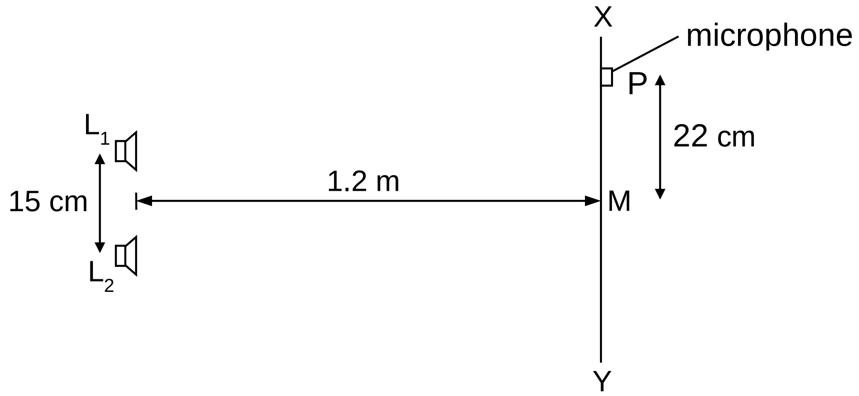

Fig. 5.1

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]

(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.

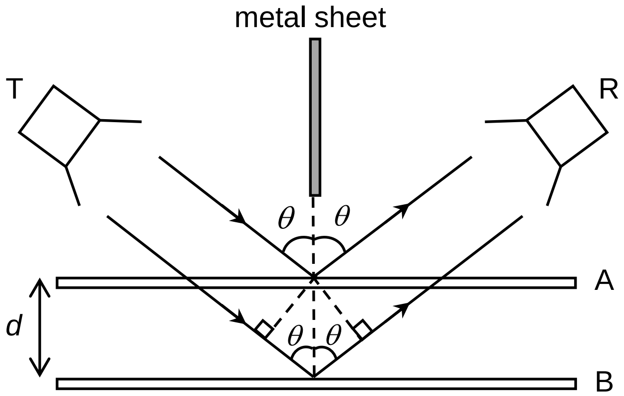

Fig. 5.2

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]

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

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.... [3]

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

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]

[Total: 9]

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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.

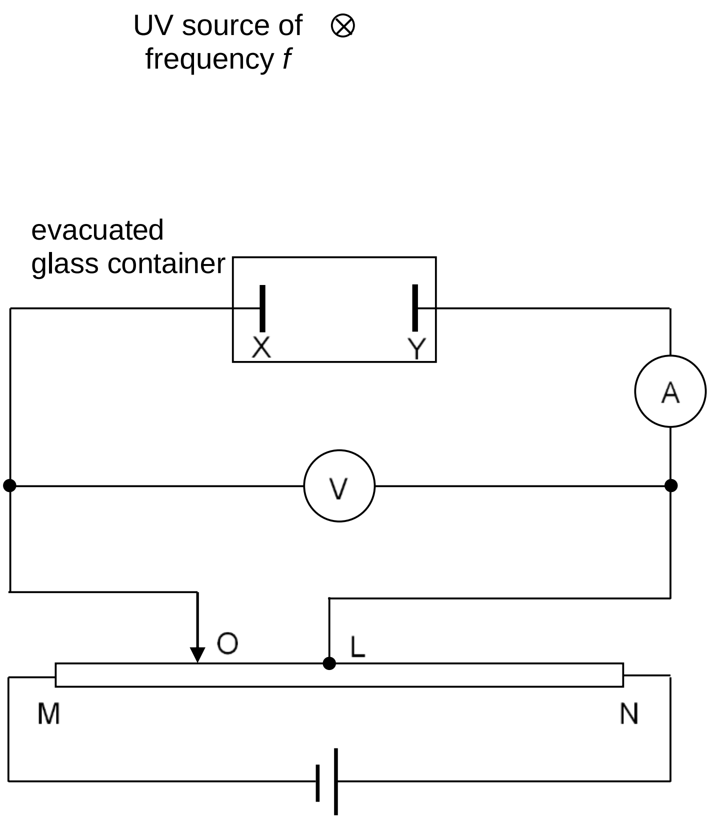

Fig. 6.1

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.

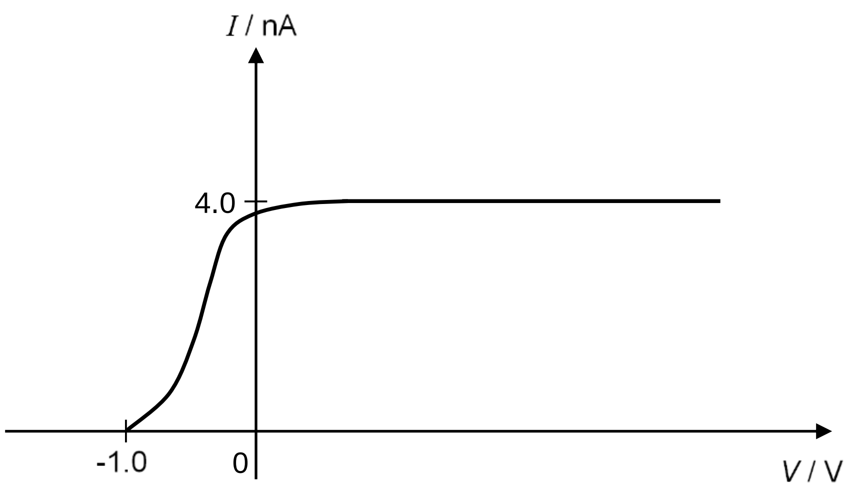

Fig. 6.2

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

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.... [3]

(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]

(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]

(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.

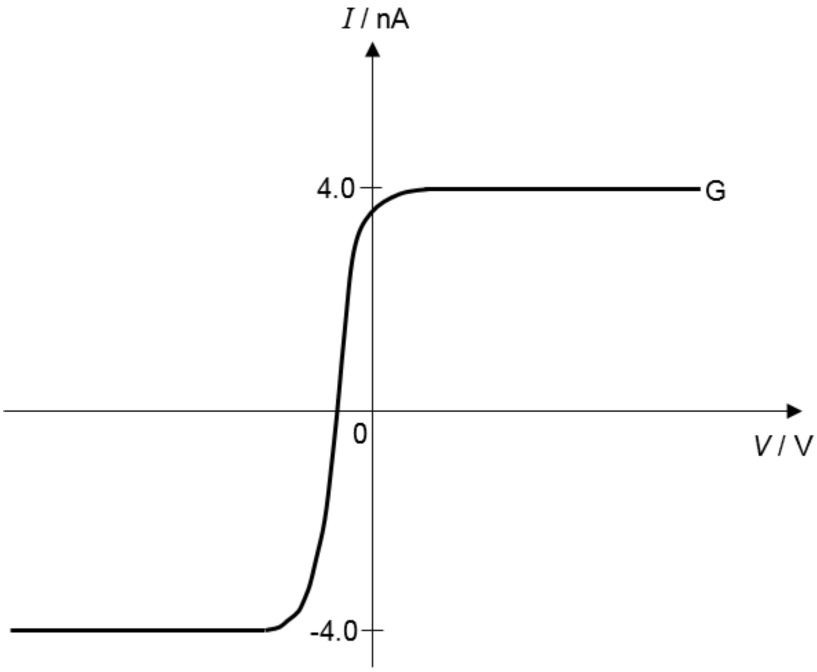

Fig. 6.3

Explain which metal plate, X or Y, has a greater work function energy.

-- [2]

[Total: 9]

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7 **(a)** State experimental evidence to suggest that the process of radioactive decay is

(i) random;

....

.... [1]

(ii) spontaneous.

....

.... [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]

(c) Technetium-99, $^{99}_{43}$Tc, decays to ruthenium-99, $^{99}_{44}$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]

(ii) On the axes of Fig. 7.1, sketch a graph to show how the ratio

$$R = \frac{\text{number of ruthenium-99 nuclei}}{\text{number of technetium-99 nuclei}}$$

will change in a sample with time t.

Take t = 0 to be the instant of creation of ruthenium-99.

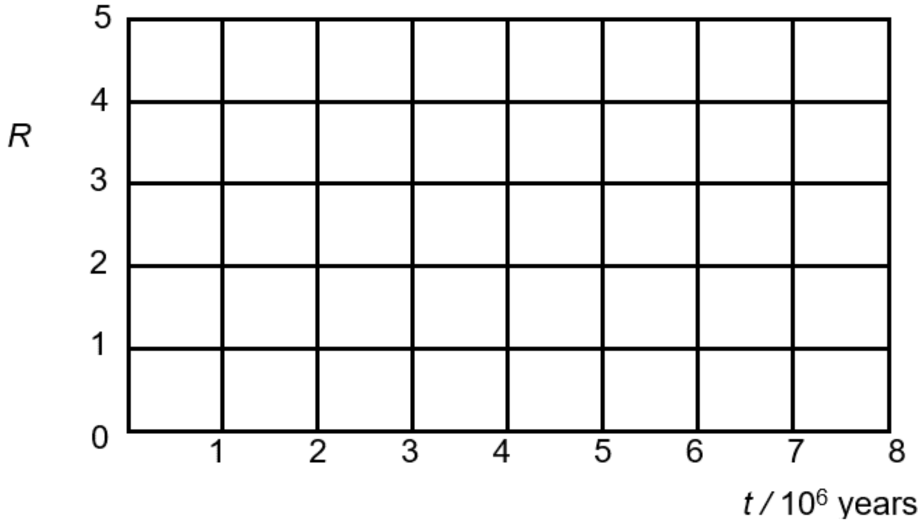

Fig. 7.1 [2]

[Total: 8]

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Section B

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

8 **(a)** Explain what is meant by an *electric field*.

[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.

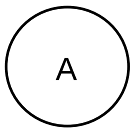

Fig. 8.1 [1]

(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]

(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.

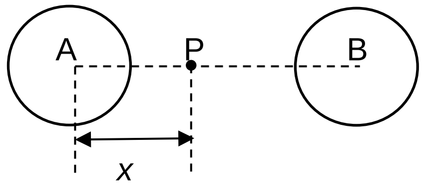

Fig. 8.3

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

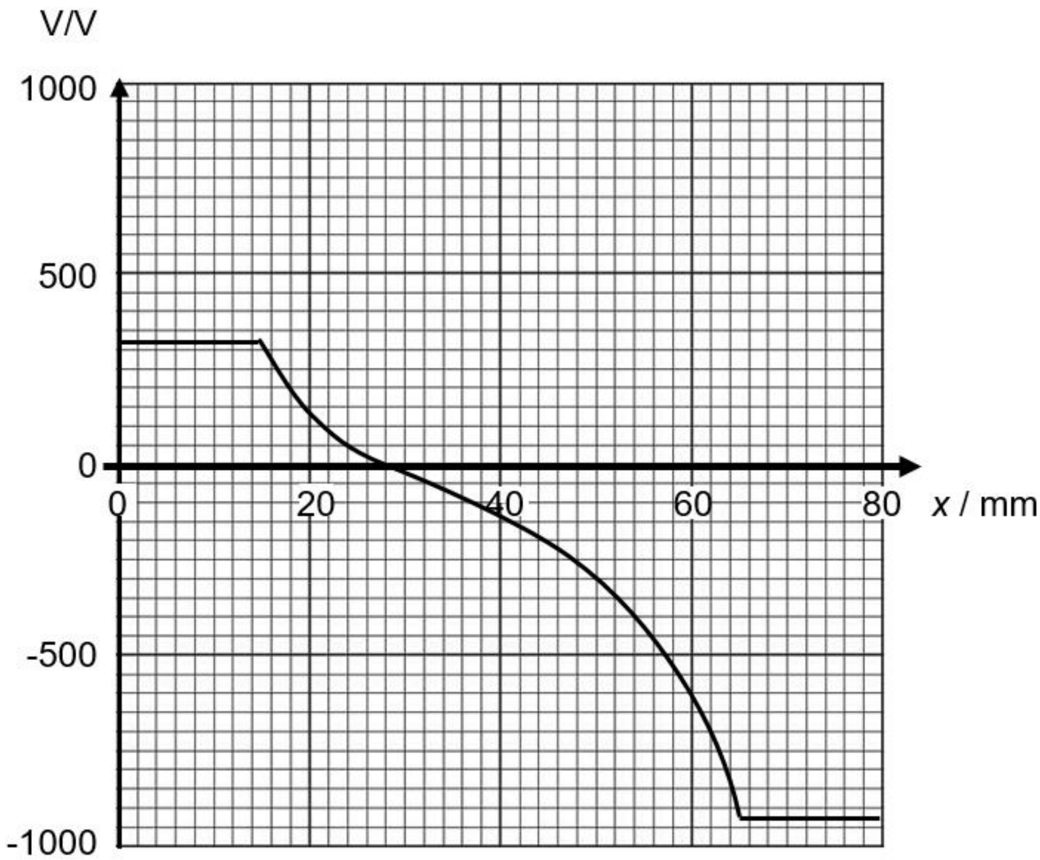

Fig. 8.4

(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]

(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]

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]

(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.

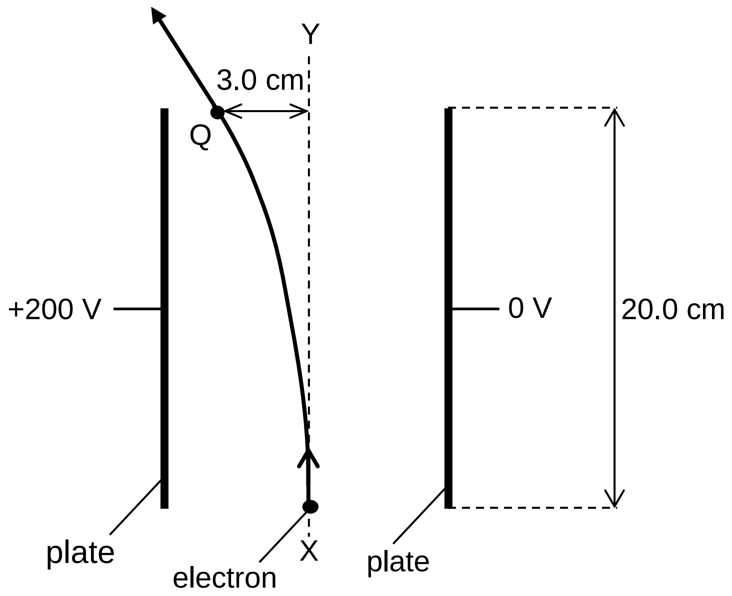

Fig. 8.5

(i) Calculate the electric field strength between the two plates.

electric field strength = ... V m^{-1} [1]

(ii) Calculate the initial speed of the electron projected into the electric field.

speed = ... $m\ s^{-1}$ [4]

(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.

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.... [2]

[Total: 20]

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]

(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]

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]

3. Hence, determine the kinetic energy of the satellite which has a mass of 1200 kg.

kinetic energy = ... 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]

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

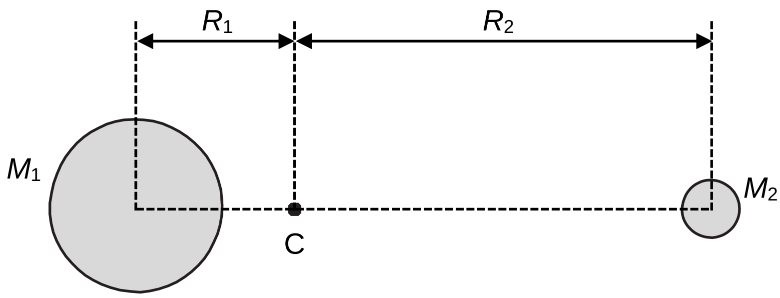

Fig. 9.2

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]

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

period = ... years [2]

(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]

(iv) Given that $\frac{M_1}{M_2} = 3.0$ and the separation between the stars is 3.2×10^{11} m, calculate the radius R_1.

R_1 = ... m [2]

(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.

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.... [2]

[Total: 20]

-- END OF PAPER 3 –

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