Catholic Junior College

JC2 Preliminary Examinations

Higher 2

CANDIDATE NAME	MARK SCHEME
CLASS	2T

PHYSICS

9749/03

Paper 3 Longer Structured Questions

10 September 2024

2 hours

Candidates answer on the Question Paper.

READ THESE INSTRUCTIONS FIRST

Write your name and class 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.
Answer **all** questions.

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	
SECTION A	
Q1	/ 8
Q2	/ 9
Q3	/ 8
Q4	/ 12
Q5	/ 7
Q6	/ 8
Q7	/ 8
SECTION B	
Q8	/ 20
Q9	/ 20
PAPER 3	/ 80
PAPER 2	/ 80
PAPER 1	/ 30
PAPER 4	/ 55
TOTAL (WEIGHTED)	%

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	$s = ut + \frac{1}{2}at^2$ $v^2 = u^2 + 2as$
work done on / by a gas	$W = p\,\Delta V$
hydrostatic pressure	$p = \rho gh$
gravitational potential	$\phi = -\dfrac{Gm}{r}$
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	$B = \dfrac{\mu_o NI}{2r}$
magnetic flux density due to a long solenoid	$B = \mu_o nI$
radioactive decay	$x = x_0 \exp(-\lambda t)$
decay constant	$\lambda = \dfrac{\ln 2}{t_{\frac{1}{2}}}$

Section A

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

1 **(a)** An object Q of weight 30.0 N is supported by two ropes A and B as shown in Fig. 1.1.

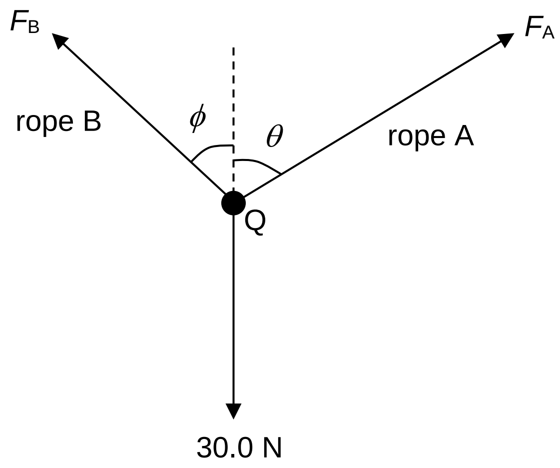


Fig. 1.1

Rope A is at an angle θ to the vertical and exerts force F_A on Q. Rope B is at an angle ϕ to the vertical and exerts a force F_B on Q.

The angle ϕ of rope B is varied from 0° to 90°. The force F_A is varied in magnitude and direction to keep Q in equilibrium.

(i) Determine the magnitude of force F_A when the angle ϕ is 35° and F_B is 20.0 N.

magnitude of F_A = ... N [3]

L2

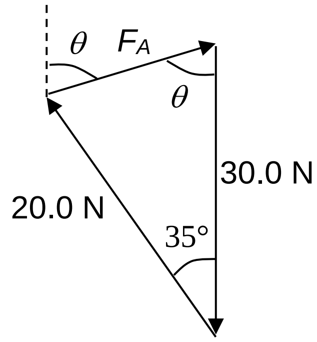
Horizontally, no net force:
$F_A \sin\theta = 20.0 \sin 35°$ -----(1) **M1**

Vertically, no net force:
$F_A \cos\theta + 20.0 \cos 35° = 30.0$ **M1**
$F_A \cos\theta = 13.617$ ------(2)

(1) / (2):
$\tan\theta = 0.84244$
$\theta = 40.112 = 40.1°$ ----- sub into (1) or (2)
F_A = 17.805 = **17.8 N** **A1**

OR

The three coplanar forces in equilibrium should form a closed vector triangle: **[M1]**



Use cosine rule (and/or sine rule) to solve,

***F**$_A$* **= 17.8 N**

(θ = 40.1°)

[M1]
[A1]

(ii) Explain why angles ϕ and θ cannot be 90° at the same time.

....

....

....

.... [2]

L2 When both angles are 90° at the same time, both F_A and F_B are horizontal and there is no vertical component of force.

There must be a **vertically upward force** that is **equal in magnitude and opposite in direction to the object Q's weight.** **B1**

to **maintain vertical equilibrium**. **B1**

(b) A uniform metal rod AB is freely pivoted at end A as illustrated in Fig. 1.2. The end B is suspended by a light spring. The other end of the spring is supported at Z.

The rod is in equilibrium.

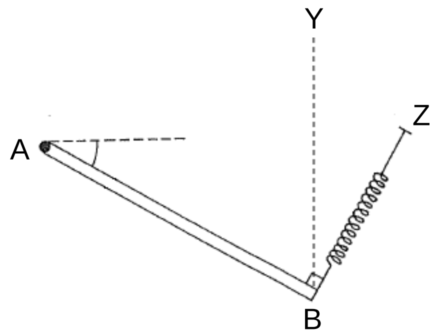


Fig. 1.2

The spring is now aligned vertically along YB so that the angle between the rod and the spring is no longer 90°. The rod remains in equilibrium in the same position.

Explain why the spring force increases.

		………	
		………	
		………	
		………	
		………	
		……	[3]
	L2	The **total clockwise moment about the pivot A due to the rod's weight** is **unchanged.**	**B1**
		If the spring is aligned vertically along YB, the **perpendicular distance of** the **line of action of the spring force from pivot A** will **decrease**.	**B1**
		Therefore, the spring force must increase to **maintain the same total anticlockwise moment about the pivot.**	**B1**

[Total: 8]

2 Two spheres A and B approach each other as illustrated in Fig. 2.1.

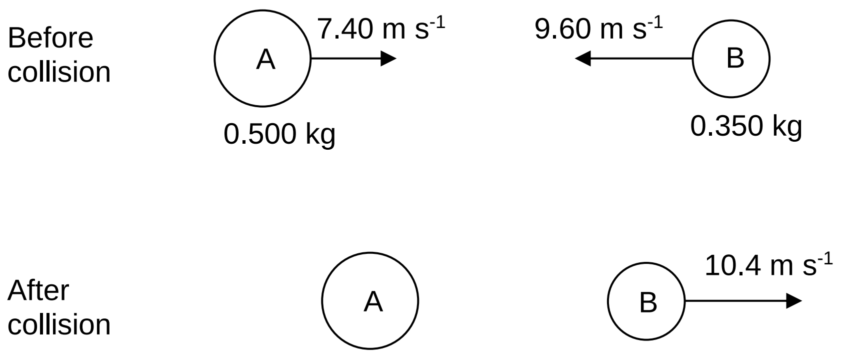


Fig. 2.1

Sphere A has a mass of 0.500 kg and moves to the right with a speed of 7.40 m s^{-1}.
Sphere B has a mass of 0.350 kg and moves to the left with a speed of 9.60 m s^{-1}.

The spheres collide and are in contact for a time of 0.400 s.

Sphere B reverses its direction of motion and moves off with a speed of 10.4 m s^{-1}.

	(a)	Using momentum consideration, explain quantitatively why spheres A and B cannot be at rest at the same instant.
		………
		………

		………	
		……	[2]
	L2	**Take right as positive direction.** **Total initial momentum of A and B** **= (0.500)(+7.40) + (0.350)(-9.60)** **= +0.34 kg m s^{-1}** **No net external force acts on system of A and B, therefore total momentum is conserved at all times and always equal to the total initial momentum.** **Total initial momentum equals 0.34 kg m s^{-1} to the right, which is non-zero.** Therefore both A and B cannot be at rest at the same time.	 **M1** **M1** **A0**
	(b)	For the time during the collision, calculate the average force between the spheres.	
		average force = ……………………………… N	[2]
	L2	Take right as positive direction. Considering sphere B's rate of change in momentum, $\text{Average force} = \frac{\Delta p}{\Delta t} = \frac{0.350(10.4-(-9.60))}{0.400}$ $= \mathbf{17.5\ N}$ (i.e. to the right) **Mark for magnitude only.*	 **M1** **A1**
	(c)	Use your answer in **(b)** to determine the magnitude of the velocity of sphere A after the collision. Explain your working.	
		magnitude of velocity = ………………………… m s^{-1}	[3]
	L2	**Take right as positive direction.** **By Newton's 3rd Law, the** force experienced by A is **equal in magnitude and opposite in direction** to the force experienced by B: **Average force on A = -17.5 N** $\text{Average force} = \frac{\Delta p}{\Delta t}$ $(\textbf{Average force on A}) \times \Delta t = \Delta p\ of\ A$ $(-17.5) \times 0.400 = 0.500(V_A - 7.40)$ $V_A = -6.60\ m\ s^{-1}$ (i.e. to the left) **B1 mark: Explanation of working (sign convention is clearly defined; application of Newton's 3rd law)** **M1 mark: Calculation (equation used and substitution of values are clear and correct)** **A1 mark: Correct answer for magnitude of velocity of A.**	 **B1** **M1** **A1**

	(d)	By considering quantitatively the relative speeds of approach and of separation of the two spheres, deduce whether the collision is elastic or inelastic.	
		………………………………………………………………………………………………	
		………………………………………………………………………………………………	
		………………………………………………………………………………………………	[2]
	L2	Take right as positive direction. Relative speed of **approach** = $U_A - U_B$ = 7.40 – (-9.60) = 17.0 m s^{-1} Relative speed of **separation** = $V_B - V_A$ = 10.4 – (-6.60) = 17.0 m s^{-1} **Since the relative speed of approach is equal to the relative speed of separation, it implies that total kinetic energy before and after the collision is unchanged, hence it is an elastic collision.** ***Allow ECF from previous part.*** • ***Calculation of relative speeds considered positive & negative directions of velocities.*** • ***Conclusion based on comparison of calculated relative speeds.***	**M1** **A1**

[Total: 9]

3	(a)	Copper has one conduction electron per atom. The density of copper is 8960 kg m^{-3}. The mass of one mole of copper is 63.5 g. Show that the number density of charge carriers in copper is 8.49 x 10^{28} m^{-3}.	
			[3]
	L2	Volume of **per mole** of copper = mass **per mole** / density = (63.5 x 10^{-3}) / 8960 = 7.0871 x 10^{-6} m^3 Number of conduction (mobile) electrons **per mole** of copper = 1 electron per atom x number of atoms per mole = 1 electron per atom x Avogadro's constant = 1 x (6.02 x 10^{23}) = 6.02 x 10^{23} Number density of charge carriers = 6.02 x 10^{23} / 7.0871 x 10^{-6} = 8.49 x 10^{28} m^{-3} (shown)	**M1** **M1** **M1** **A0**

(b) A composite wire XYZ is made by connecting in series two uniform wires, each of length *L* and made of copper but having different diameters as shown in Fig. 3.1. One wire has diameter *d* and the other wire has diameter 2*d*.

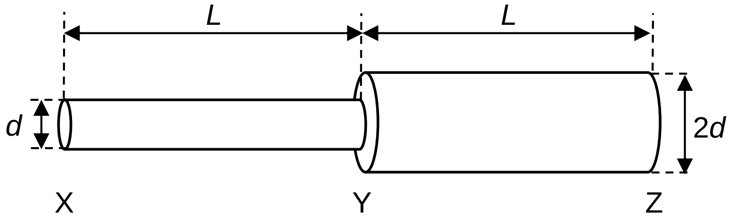


Fig. 3.1

A potential difference is then applied across X and Z of the wire and a current flows through the wire.

On Fig. 3.2, sketch a graph to show how the drift velocity v_d of electrons through the composite wire varies with distance along the wire from end X to end Z.

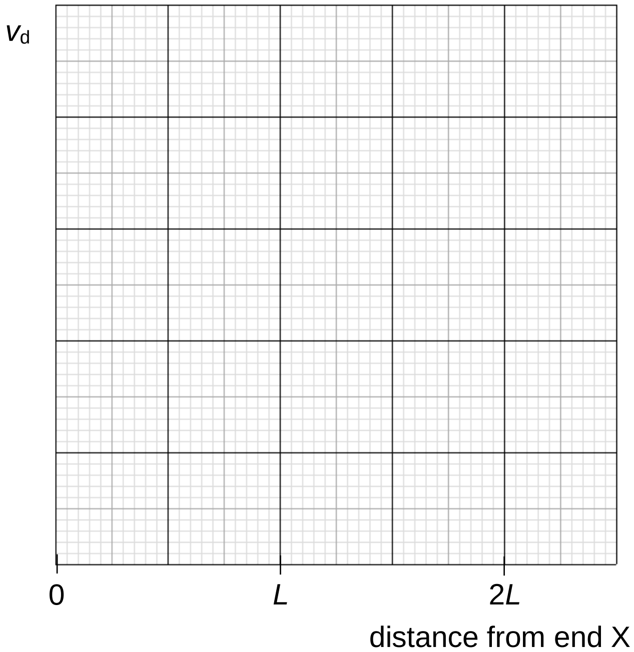


Fig. 3.2 [3]

L2

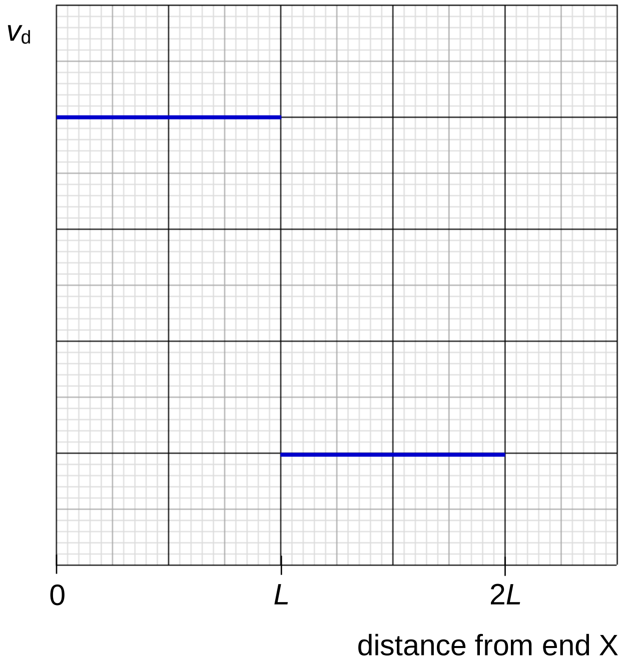
$$I = neAv_d$$

$$v_d = \frac{I}{neA} = \frac{I}{ne\left(\frac{\pi D^2}{4}\right)} = \frac{4I}{\pi neD^2}$$

Since current *I* is constant along the two wires connected in series, and, since *n* and *e* are the same for the same material,

$$v_d \propto \frac{1}{D^2}$$

Therefore,
in the wire where diameter *D* is twice are as large, the drift velocity v_d is one-quartered.
In the same wire where diameter is constant, v_d is constant.



B1
B1
B1

Marks scheme:

- ***v_d is constant in each wire.***
- ***v_d in the wire XY is 4 times greater than v_d in wire YZ.***
- ***Graph only drawn in the range of distance 0 to 2L, and, graph should be big enough, i.e. span at least half the graph grid in both horizontal and vertical directions.***

(c) The mean speed of a conduction electron in the wire is very much greater than the drift velocity of the conduction electrons in the wire.

Explain this observation.

....

....

....

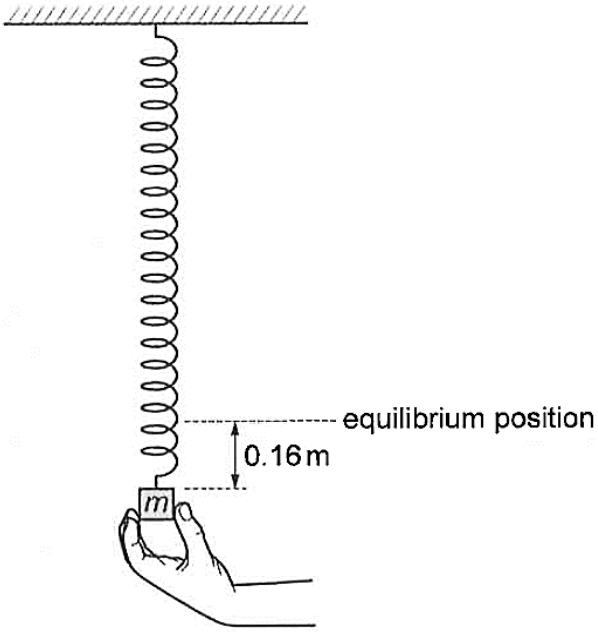
....

.... [2]

L3 **The conduction electrons experience electric forces/accelerations in all directions as a result of collisions with the lattice ions.** Thus the individual conduction electrons have a **range of velocities** of different magnitudes as well as directions, and the electron paths are rather random/erratic. **B1**

The mean speed, regardless of direction, is large. Whereas drift velocity is a vector quantity and an average velocity, which is quite small since there is a large number of conduction electrons and their individual velocities are rather random in direction and magnitude. **B1**

[Total: 8]

4	A mass m is suspended from a vertical spring of spring constant k attached to a fixed support. The mass is pulled down and held at a vertical displacement of 0.16 m from its equilibrium position, as shown in Fig. 4.1.  **Fig. 4.1** The mass is released.		
	(a)	Show that the mass's acceleration a is related to its displacement x from the equilibrium position by the equation: $$a = -\frac{k}{m}x.$$ Explain your working.	
			[3]
	L3	**Presentation 1:** **At Equilibrium position, no net force.** **upward spring force = downward weight** **At displacement x (downwards) below the Equilibrium position,** **increase in spring extension by x increases the upward spring force by kx,** **while the downward weight is unchanged.** **Thus,** **Net force is kx upwards.** **Take direction downwards as positive. Then displacement (x) is positive** **while net force (kx) is negative.** **By Newton's 2nd law of motion,**	

Net force = ma
-kx = ma
$a = -\frac{k}{m}x$ **[Shown]**

Presentation 2:

At Equilibrium position, no net force.
Spring force = Weight
$kx_o = mg$ where x_o: spring extension at Equilibrium position —(1)

Take direction downwards as positive.
At displacement x (downwards) below the Equilibrium position, spring extension is now ($x_o + x$), and net force is non-zero.
Net force = - (New Spring force) + Weight
$= -k(x_o + x) + mg$ —(2)

Sub (1) into (2): Net force = $-k(x_o + x) + kx_o = -kx$

By Newton's 2nd law of motion,
Net force = ma
-kx = ma
$a = -\frac{k}{m}x$ **[Shown]**

Marks scheme:
1 mark: use of Hooke's Law, F = kx — **M1**
1 mark: how Negative sign arise is clear from sign convention — **M1**
1 mark: use of Newton's 2nd law — **M1**
A0

(b) The mass undergoes simple harmonic oscillations described by the equation in **(a)**.

Show that the period T of the oscillations of the mass is given by:

$$T = 2\pi\sqrt{\frac{m}{k}}$$

[2]

L2

Compare with the SHM equation: $a = -\omega^2 x$ — **M1**

$\omega^2 = \frac{k}{m}$

$\left(\frac{2\pi}{T}\right)^2 = \frac{k}{m}$ — **M1**

$T = 2\pi\sqrt{\frac{m}{k}}$ **[Shown]** — **A0**

(c) Ten oscillations are timed using a stopwatch. The data for the mass and the time, together with their uncertainties, are shown in Table 4.1.

Table 4.1

time for 10 oscillations / s	7.2 ± 0.2
m / g	$120 \pm 1\%$

		Determine the value of *k* together with its actual uncertainty. Give your answer to an appropriate number of significant figures.	
		k = ... ± .... N m^{-1}	[3]
	L2	$T = \frac{t}{10}$ $T = \frac{7.2\ s}{10} = 0.72$ s $\frac{\Delta T}{T} = \frac{\Delta t}{t} = \frac{0.2}{7.2}$ Making k the subject in the equation from (b), $k = \frac{4\pi^2 m}{T^2} = \frac{4\pi^2(0.120\ kg)}{(0.72\ s)^2}$ = **9.1385 N m^{-1}** $\frac{\Delta k}{k} = \frac{\Delta m}{m} + 2\frac{\Delta T}{T} = \frac{1}{100} + 2\left(\frac{0.2}{7.2}\right) = 0.065556$ Δk = 0.065556 k = 0.065556 (9.1385) = **0.6 N m^{-1}** **(1 sig. fig.)** **(k ± Δk) = (9.1 ± 0.6) N m^{-1}** **(Round off k to the same precision as Δk)**	 **M1** **M1** **A1**
	(d)	Calculate the total energy of oscillations of the spring-mass system.	
		total energy = ... J	[2]
	L2	**Total energy of oscillations = Maximum KE** $= \frac{1}{2} m v_o^2 = \frac{1}{2} m (\omega x_o)^2 = \frac{1}{2} m\omega^2 x_o^2$ $= \frac{1}{2}(0.120\ kg)\left(\frac{2\pi}{0.72\ s}\right)^2 (0.16\ m)^2$ = 0.11697 = **0.12 J**	 **C1** **A1**
	(e)	On Fig. 4.2, sketch a graph to show the variation with time of the kinetic energy of the mass for one complete oscillation, starting from the time of release. Label the axes with values obtained from **(c)** and **(d)**.	

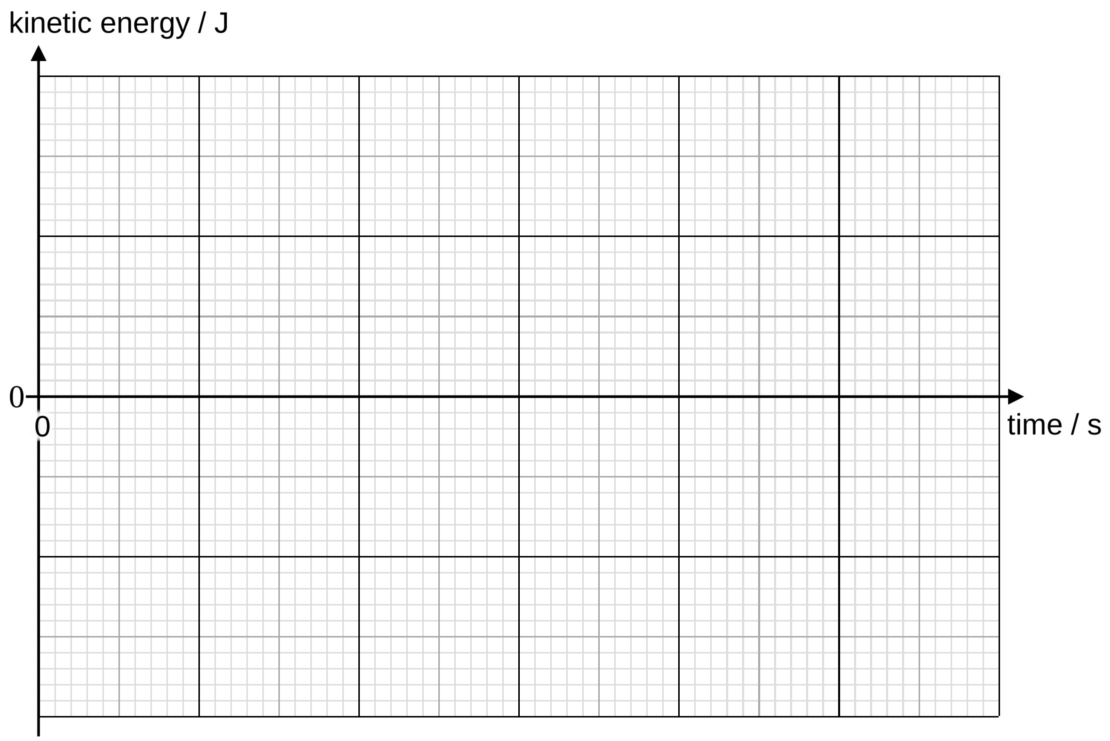
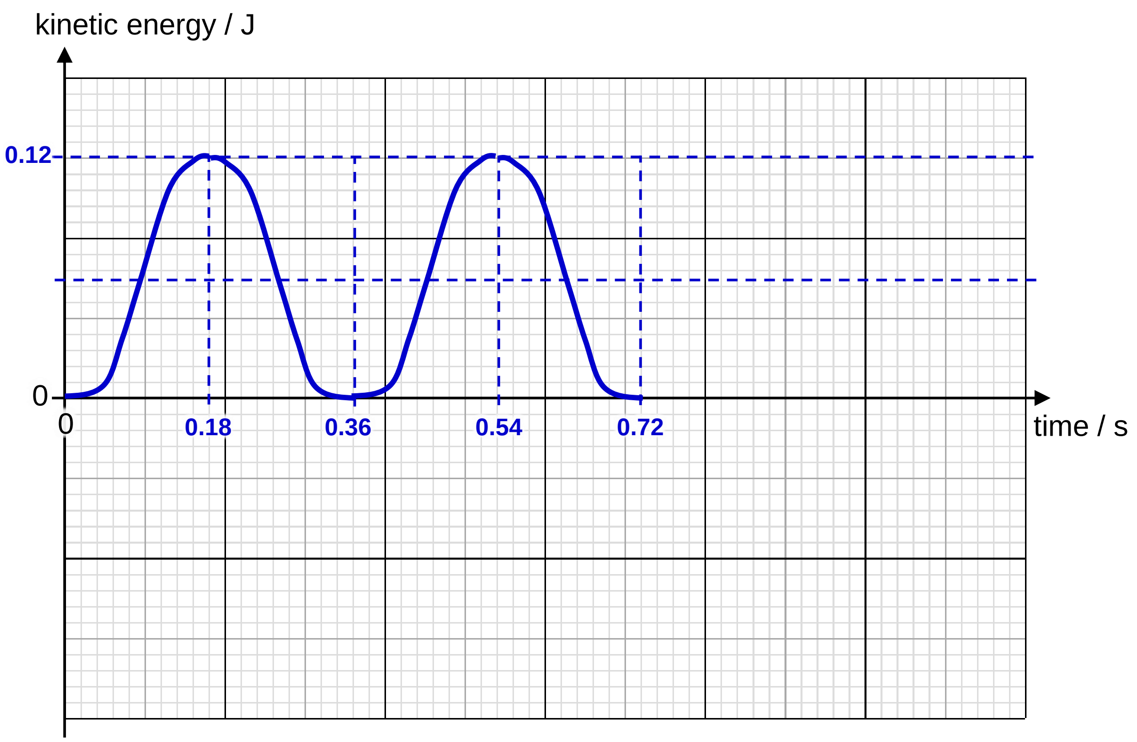


Fig. 4.2 [2]

L2



1 mark for: • Initial conditon: start from (0, 0) since at time = 0, KE = 0. • Shape: sine-squared graph; symmetrical.	**B1**
1 mark for: • Axes labelled with values found earlier. • Drawn for one complete oscillation.	**B1**

[Total: 12]

5 Coherent light is incident normally on a double slit, as shown in Fig. 5.1.

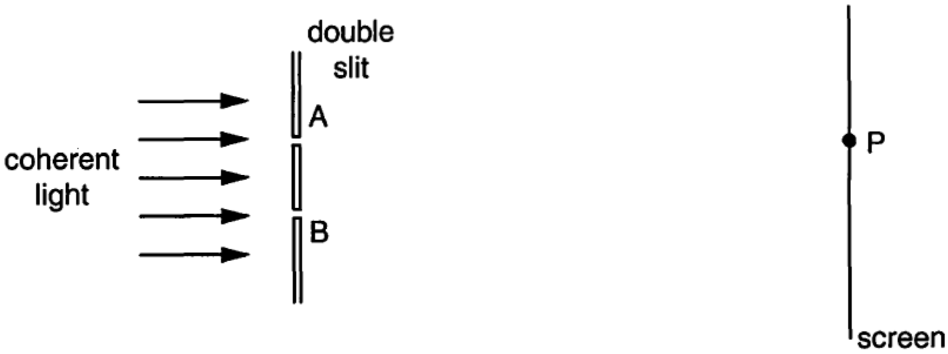


Fig. 5.1 (not to scale)

Light passes through the two slits A and B and is incident on a screen.

The variation with time t of the displacement x of the light arriving at point P on the screen is shown in Fig. 5.2.

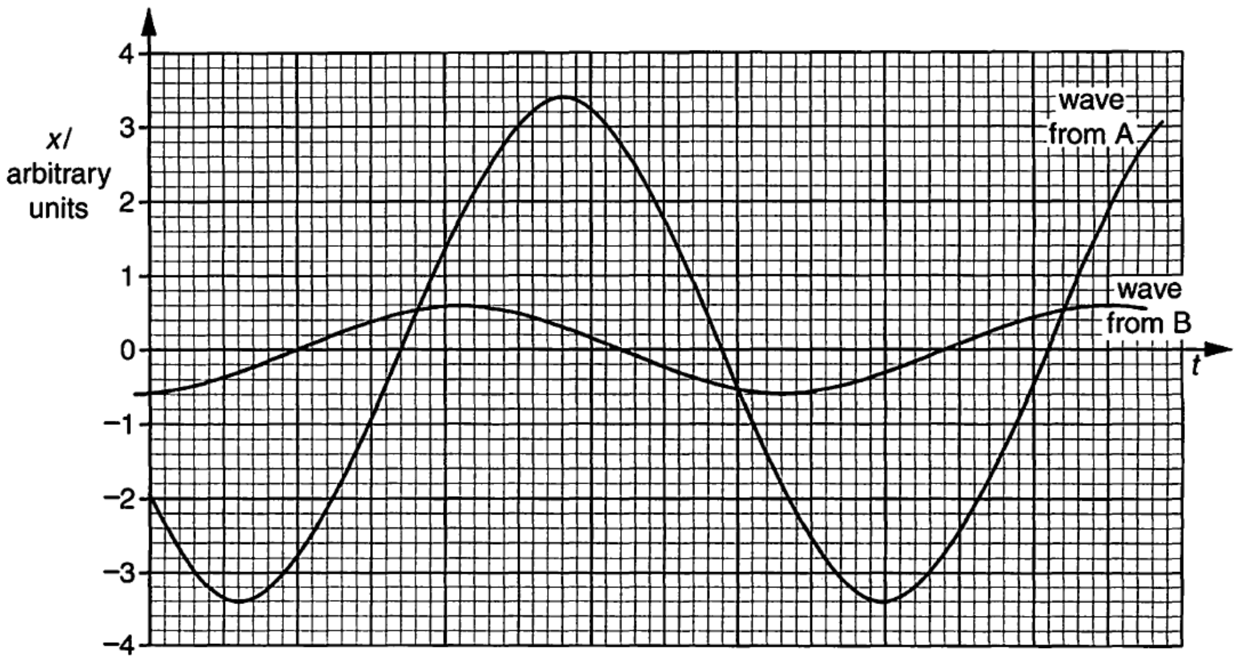
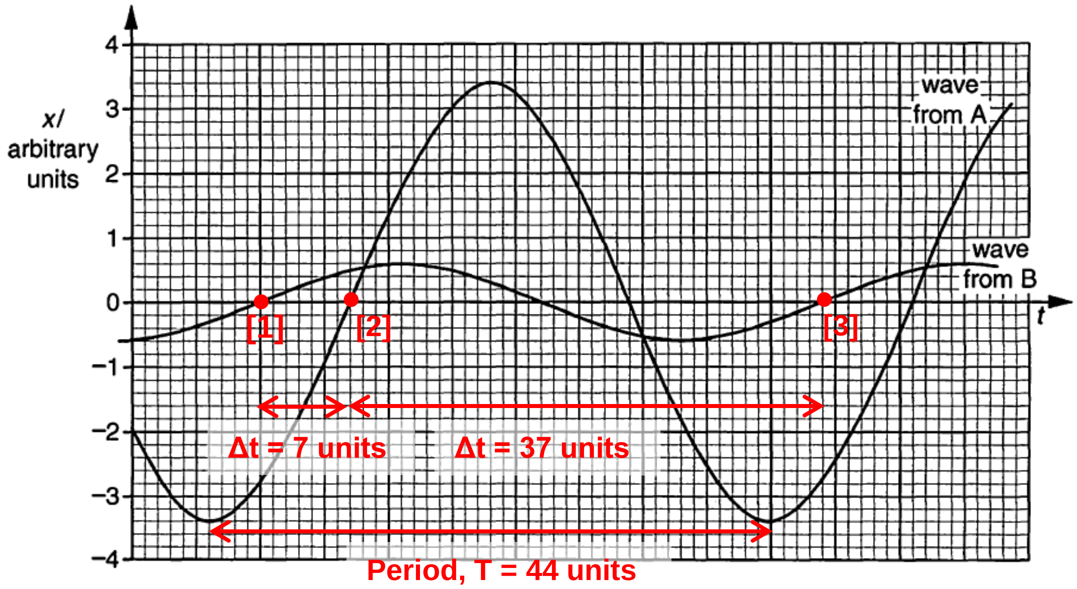


Fig. 5.2

(a) Use Fig. 5.2 to determine the phase difference between the waves from slit A and from slit B that arrive at point P.

phase difference = ...° [2]

L2 Determine the time difference Δt from between points [1] and [2], or, between [2] and [3].



$$\frac{\Delta\varphi}{360^\circ} = \frac{\Delta t}{T}$$ **M1**

$$\frac{\Delta\varphi}{360^\circ} = \frac{37}{44}$$

$$\Delta\varphi = \frac{37}{44}x360^\circ = 302.73^\circ$$ **A1**

Phase difference = **303° (or 300°).**

OR

$$\frac{\Delta\varphi}{360^\circ} = \frac{7}{44}$$

$$\Delta\varphi = \frac{7}{44}x360^\circ = 57.3^\circ$$

Phase difference = **57.3° (or 57°)**

(b) Dark fringes and bright fringes are both formed on the screen.

Use Fig. 5.2 to determine, for the bright fringe and the dark fringe closest to point P, the ratio

$$\frac{\text{intensity of light at the bright fringe}}{\text{intensity of light at the dark fringe}}.$$

ratio = ... [3]

L2 At a **bright** fringe, the waves arrive **in phase**, undergoing **constructive interference**. Thus the resultant amplitude
= 3.4 + 0.6 = 4.0 units

At a **dark** fringe, the waves arrive **in antiphase (180° out of phase)**, undergoing **destructive interference**. Thus the resultant amplitude
= 3.4 – 0.6 = 2.8 units **C1**

		(Since we are considering the dark and bright fringes **closest** to P, assume that the amplitudes of the waves from A and B do not differ significantly from those arriving at P) *[Recall that when slits are not infinitely small, single slit diffraction effects causes the double slit bright fringes to be non-uniform in intensity. If the bright fringes are close, the difference in intensity is less.]* The intensity of a wave I is directly proportional to the square of its amplitude A. $\frac{I_{bright}}{I_{dark}} = \left(\frac{A_{bright}}{A_{dark}}\right)^2 = \left(\frac{4.0}{2.8}\right)^2$ $\frac{I_{bright}}{I_{dark}} = 2.0408 = 2.0$	M1 A1
	(c)	In an attempt to produce brighter fringes, the student widens each of the two slits, keeping their separation constant. Fringes are no longer observed. Suggest why the fringes are no longer observed.	
		....	
		....	
		....	
		....	[2]
	L3	When the two slits are widened, the **light waves passing through each slit will diffract less.** A smaller degree of diffraction causes the region in which the two waves overlap and interfere to become smaller. **If the widths of the slits are too wide, the two waves do not overlap at all and hence no interference occurs**. Hence, the fringes are no longer observed. ***Note: As a coherent light beam is used (e.g. laser beam), widening the slits do not cause the waves to be incoherent. Citing incoherence as the reason is not acceptable.***	B1 B1

[Total: 7]

6	Two metal plates X and Y are contained in an evacuated container and are connected as shown in Fig. 6.1. Metal plate X is then illuminated with monochromatic light.

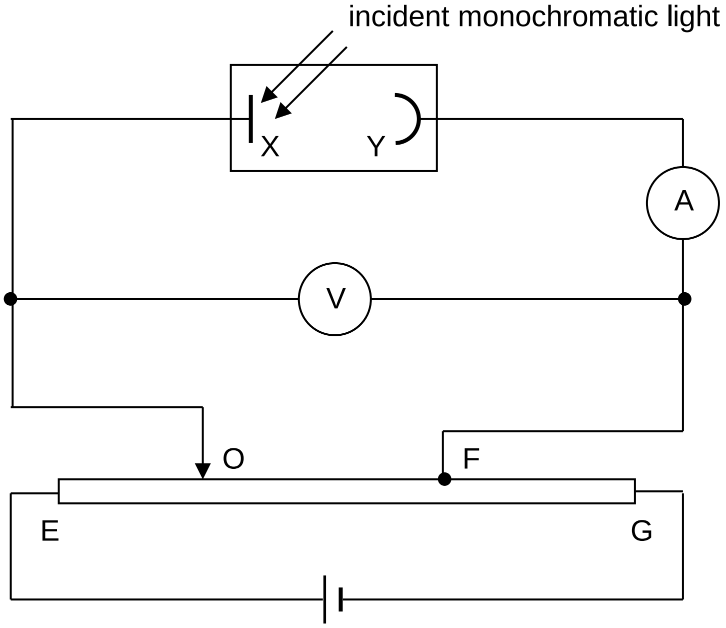


Fig. 6.1

The graph shown in Fig. 6.2 depicts the relationship between the voltmeter reading V and the ammeter reading I.

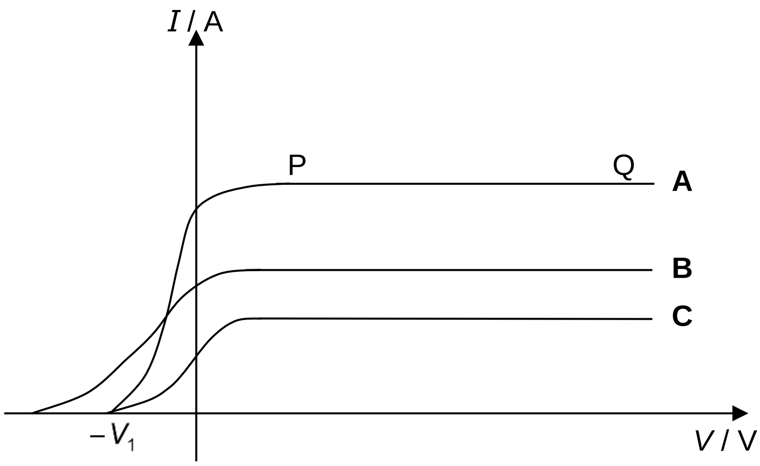


Fig. 6.2 (not to scale)

(a) A student obtained the part PQ on graph A by shifting the sliding contact O.

State and explain where the position of O along EG should be shifted to for the student to obtain part PQ of graph A.

………

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		………………………………………………………………………………………………	
		………………………………………………………………………………………………	
		………………………………………………………………………………………………	[4]
	L2	Part PQ represents the saturation/maximum current. **At the current position of O, the potential of X is higher than Y which will create an electric field between them directed towards plate Y.**	B1
		Photoelectrons/electrons are negatively charged and thus will experience an electric force towards plate X which *retards* their motion. Depending on where O is between E and F, ***only some or none* of the photoelectrons have sufficient kinetic energy to reach plate Y. Hence current measured in the circuit will *not* be maximum in value**.	B1
		Therefore, **for saturation/maximum current to be measured, O would need to be shifted in the region FG / between F and G / to the right of F.**	B1
		This allows for Y to be at higher potential than X. The **electric force experienced by the photoelectrons would then act towards Y** and **accelerate *all* of the photoelectrons towards Y.**	B1
	(b)	Given that the work function energy of X is 1.3 eV and the wavelength of the light is 550 nm, calculate the value of the stopping potential V_1.	
		V_1 = …………………………… V	[2]
	L1	$hf = \Phi + KE_{MAX}$ $\frac{hc}{\lambda} = \Phi + eV_S$ $\frac{(6.63 \; x \; 10^{-34})(3.00 \; x \; 10^{8})}{550 \; x \; 10^{-9}} = (1.3)(1.60 \; x \; 10^{-19}) + (1.60 \; x \; 10^{-19})V_s$ $V_1 = V_s = 0.96023 = \mathbf{0.96\ V}$	M1 A1
	(c)	Describe the changes, if any, to the intensity and frequency of the incident monochromatic light that the student made to obtain graphs B and C if the same metal plate X is used.	
		graph B: ………………………………………………………………………………	
		………………………………………………………………………………………………	
		………………………………………………………………………………………………	
		graph C: ………………………………………………………………………………	
		………………………………………………………………………………………………	

		……………………………………………………………………………………………	[2]
	L2	**Graph B** has a smaller maximum current and a larger stopping potential than graph A. The larger stopping potential indicates that an **<u>incident light of higher frequency (or shorter wavelength)</u> is used.** Intensity of the light is unchanged or lesser or greater (but increase in Intensity not as much as increase in frequency). **Graph C** has a smaller maximum current but has the same stopping potential as graph A. Since stopping potential is the same, the **<u>frequency (or wavelength) of the incident light must be unchanged</u>.** The smaller maximum current is due to a **<u>lower intensity</u> of light used.**	B1 B1

[Total: 8]

7	**(a)**	The decay of radioactive nuclei is said to be *random* and *spontaneous*. Explain what is meant by the radioactive decay is *random* and *spontaneous*.	
		random: ………………………………………………………………………………………………	
		………………………………………………………………………………………………………	
		………………………………………………………………………………………………………	
		spontaneous: …………………………………………………………………………………………	
		………………………………………………………………………………………………………	
		……………………………………………………………………………………………………	[2]
	L1	**Random:** It is **impossible to predict which particular <u>radioactive</u> <u>nucleus</u> in a given sample will decay next and when it will decay,** **even though <u>any nucleus</u> has a constant probability of decay per unit time.** ** Reference to 'nucleus' is required.* ** Full definition, including mention that any nucleus has a constant probability of decay per unit time, is necessary for full credit.* **Spontaneous:** The decay **occurs without external stimuli and the rate of decay is unaffected by environmental factors such as temperature and pressure.**	B1 B1
	(b)	A Geiger-Müller counter was used to measure the count rate *C* of a radioactive source over several years. The readings were recorded and used to obtain the graph in Fig. 7.1.	

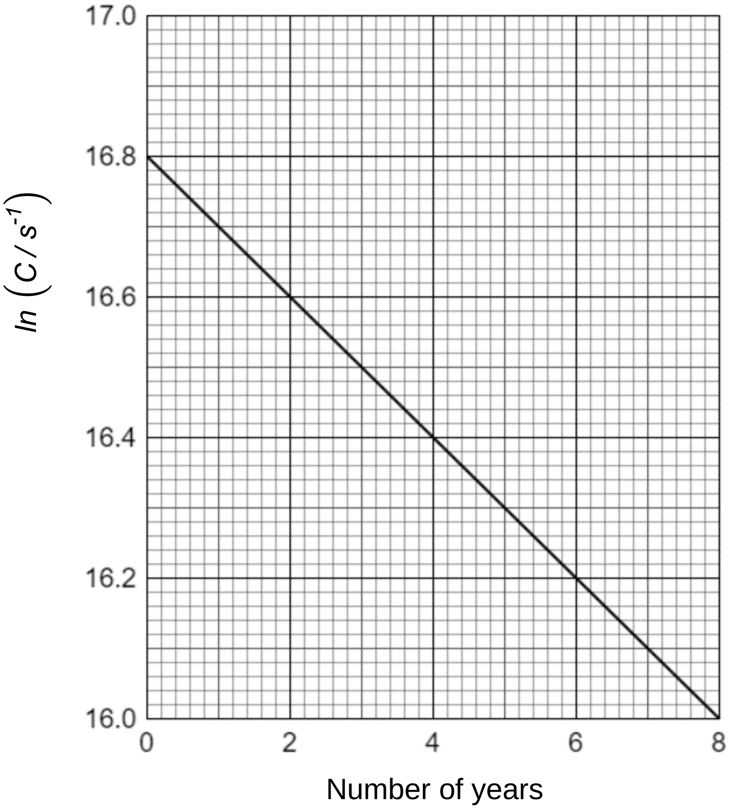

Fig. 7.1

(i) Using Fig. 7.1, determine the decay constant.

decay constant = ……………..………………… s^{-1} [3]

L2

$C = C_0 e^{-\lambda t}$

Linearise:

$\ln C = \ln C_0 - \lambda t$

$\ln C = (-\lambda)t + \ln C_0$

The gradient of Fig. 7.1 is $-\lambda$. **B1**

$$-\lambda = \frac{\mathbf{16.8 - 16.2}}{\mathbf{0 - 6}} = -\,\mathbf{0.1}\ \boldsymbol{year^{-1}}$$ **M1**

$$\lambda = 0.1\ year^{-1} = \frac{0.1}{365\ x\ 24\ x\ 3600} = 3.1710\ x\ 10^{-9} = \mathbf{3.17\ x\ 10^{-9}}\ \boldsymbol{s^{-1}}$$ **A1**

(ii) Determine the half-life of the radioactive isotope.

half-life = ………………………………..… s [1]

L1

$$t_{1/2} = \frac{\ln 2}{\lambda} = \frac{\ln 2}{3.1710\ x\ 10^{-9}} = \mathbf{2.19\ x\ 10^{8}}\ \boldsymbol{s}$$ **A1**

(c) Describe what an experimenter would do in the measurement of the half-life of the sample to reduce the effect of

(i) the random nature of the radioactivity decay process,

			………………………………………………………………………………………………………	
			………………………………………………………………………………………………………	
			……………………………………………………………………………………………………	[1]
		L3	**Measure the count rate for a longer period of time**, in the process, **averaging out the random fluctuations**. OR Use a **sample with greater number of radioactive nuclei to increase the measured count rate,** thereby reducing the percentage error in the counting.	**B1**
		(ii)	the background radiation.	
			………………………………………………………………………………………………………	
			………………………………………………………………………………………………………	
			……………………………………………………………………………………………………	[1]
		L2	First **measure the background radiation count rate <u>in the absence of</u> the sample**. Then **subtract the background radiation count rate from the measured count rate <u>in the presence of</u> the sample**.	**B1**

[Total: 8]

Section B

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

8 A mass spectrometer separates charge particles based on mass-to-charge ratio so that the composition of the charge particles can be identified.

The schematic diagram of a type of mass spectrometer is shown in Fig. 8.1. There are three sections to this mass spectrometer – the accelerator, the velocity selector and the mass separator.

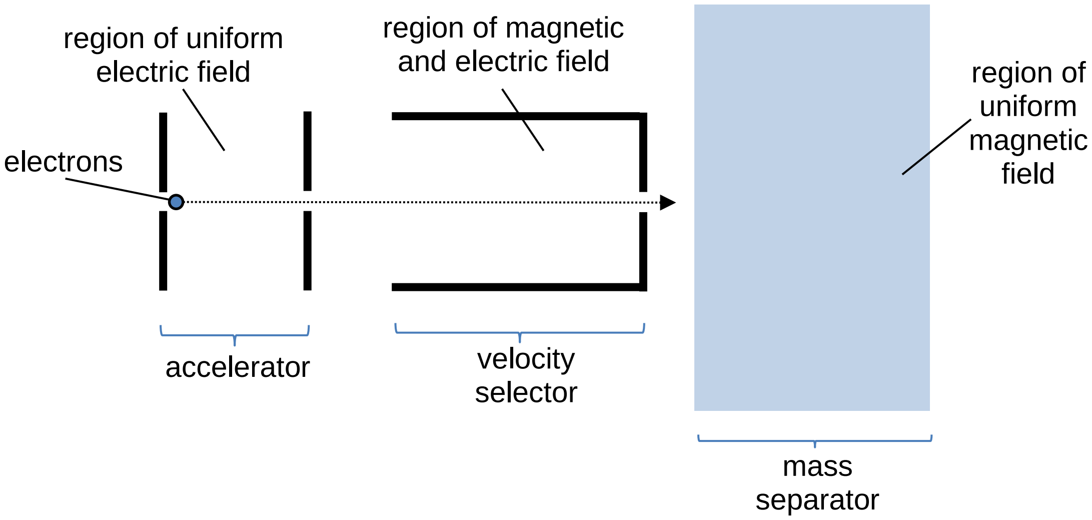

Fig. 8.1

Electrons are ejected into the mass spectrometer to demonstrate the working principle of the mass spectrometer.

(a) **(i)** Electrons enter the mass spectrometer at the accelerator near to the negatively charged plate so that they accelerate towards the positively charged plate as shown in Fig. 8.2.

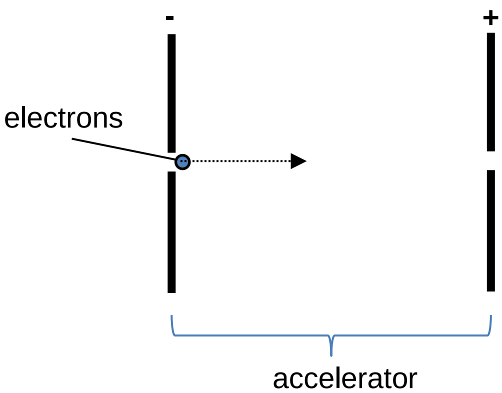

Fig. 8.2

The kinetic energy of the electrons increases by 2.50×10^{-16} J between leaving the negatively charged plate and reaching the positively charged plate.

Calculate the accelerating potential difference (p.d.).

accelerating p.d. = ……………….……………………V [2]

[Turn over

		L1	By conservation of energy, the electric potential energy is equal to the gain in kinetic energy of the electron, $q\Delta V = \Delta E_k$ $\Delta V = \frac{\Delta E_k}{q} = \frac{2.50\times10^{-16}}{1.60\times10^{-19}}$ $\Delta V = 1562.5 \approx 1560\ \text{V}$	C1 A1
		(ii)	Suggest a reason why the electrons reaching the positively charged plate have a range of speeds.	
			....	
			....	
			....	[1]
		L2	**When electrons are first introduced into the accelerator, electrons may be moving with different speeds randomly**. As the **gain in** kinetic energy for all electrons moving between the negative and positive plates is the **same**, they will reach the positively charged plate with different **final** speeds.	B1
	(b)	At the velocity selector, the electrons enter a region in between two horizontal parallel charged plates placed 16 mm apart with a potential difference of 1500 V across them.		

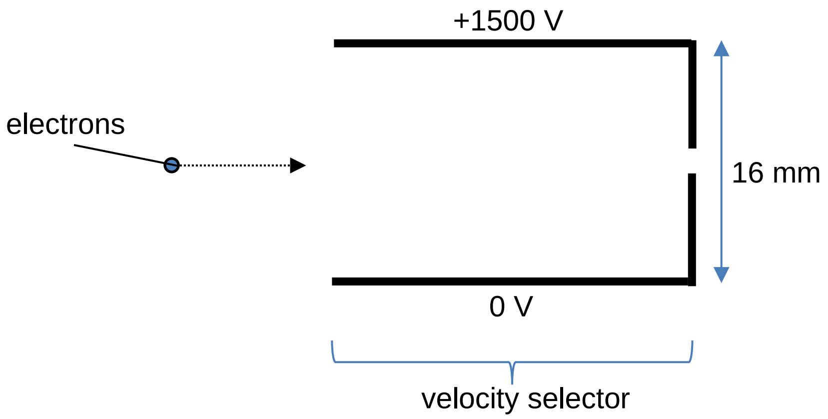

Fig. 8.3

Describe and explain the path of the electrons due to only the uniform electric field set up in between the parallel charged plates.

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		……………………………………………………………………………………………………		[3]
L2		The electrons will move in a **parabolic path**. **Electrons** in a uniform electric field will **experience a constant electric force upwards** towards the positively charged plates **throughout its motion**. Therefore, the electrons will **accelerate uniformly upwards**. As there is **no horizontal force** on the electrons, the **horizontal velocity will remain unchanged**.		B1 B1 B1
(c)		A uniform magnetic field is subsequently applied to the region in between the parallel charged plates such that only electrons with specific velocity pass through the velocity selector undeflected.		
	(i)	State the direction of the magnetic field.		
		……………………………………………………………………………………		[1]
L1		(Perpendicular and) **into the page.**		B1
	(ii)	Calculate the magnetic flux density in the velocity selector if the electrons that are undeflected have a speed of 3.25×10^6 m s^{-1} after passing through the fields.		
		magnetic flux density = ……………………………………… T		[3]
L2		The electric field in between the two parallel plates, $E = \frac{\Delta V}{d} = \frac{1500}{16 \times 10^{-3}} = 93750 \text{ N C}^{-1}$ By Newton's second law, as the magnetic force is equal in magnitude to the electric force on the undeflected electrons, $Bqv = qE$ $B = \frac{E}{v} = \frac{93750}{3.25 \times 10^6} = 0.028846$ $B = 2.88 \times 10^{-2}$ T		C1 M1 A1
(d)		At the mass separator, the electrons then enter a region of uniform magnetic field set up by a large solenoid. The solenoid has 120 turns for every 15 cm of the solenoid. The current in the solenoid is 3.5 A.		
	(i)	Calculate the magnitude of the magnetic flux density B at the centre of the solenoid due to the current of 3.5 A.		
		B = ……………………………………… T		[2]
L1		The magnetic flux density at the centre of the solenoid, $B = \mu_0 nI = 4\pi \times 10^{-7} \left(\frac{120}{15 \times 10^{-2}}\right) 3.5$ $B = 3.5186 \times 10^{-3} = 3.52 \times 10^{-3}$ T		M1 A1
	(ii)	Inside the dashed region on Fig. 8.4, sketch the magnetic field pattern due to the current in the solenoid.		

[Turn over

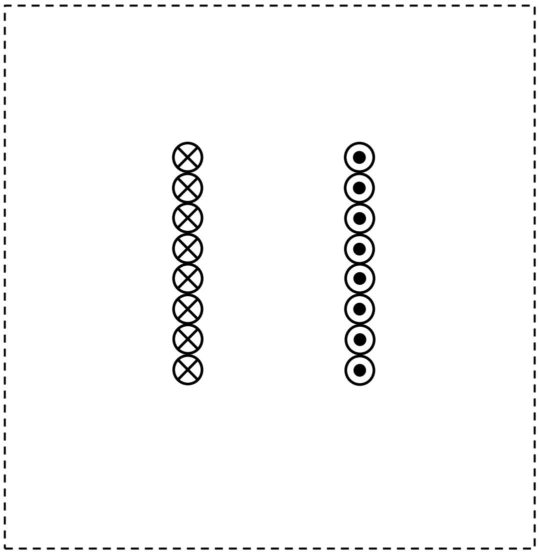
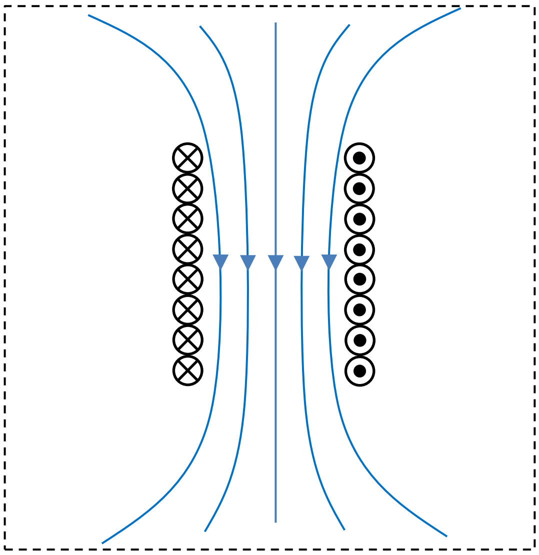


Fig. 8.4 [3]

L2

Solution:



1 mark – illustrate uniform strength of field through spacing between lines – equal spacing at the centre of the solenoid and **B1**

1 mark – illustrate weaker strength of field – large spacing at the ends **B1**

1 mark – direction of all field lines – arrows downwards **B1**

(iii) The electrons enter the region of the uniform magnetic field perpendicularly.

Explain why the path of the electrons in the magnetic field is circular.

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			....	
			....	
			....	[3]
	L2		As the **electrons are charged** and **enters the uniform magnetic field perpendicularly**, there is a **magnetic force that is *always* perpendicular to both the electrons' velocity and the field.**	B1
			As the magnetic force is always perpendicular to the electrons' velocity, the force **continuously changes the electrons' velocity direction but not the velocity magnitude**.	B1
			The **magnetic force will be constant at constant speed**, and provides for the centripetal force of the electrons, causing the electrons to travel in **a circular path of constant radius.**	B1
		(iv)	In usual application, charged particles of different masses enter the mass separator instead of just electrons. Suggest how the uniform magnetic field can separate the charged particles by mass.	
			....	
			....	
			....	
			....	
			....	[2]
	L3		As the magnetic force provides for the centripetal force, $Bqv = \frac{mv^2}{r}$ $r = \frac{mv}{Bq}$ thus, when the charged particles of the **same speed *v*** (after passing through the velocity selector all the particles have same speed) move in the **same uniform magnetic flux density B**, the **radius r of the circular path of the charged particles is proportional to the mass m but inversely proportional to the charge q (proportional to the mass-to-charge) ratio.**	B1
			Different charged particles have different mass-to-charge ratio, thus separated by moving in circular path with various respective radius.	B1

[Total: 20]

9	The variation with distance *r* of the electric potential *V* of a charged object is shown in Fig. 9.1.		

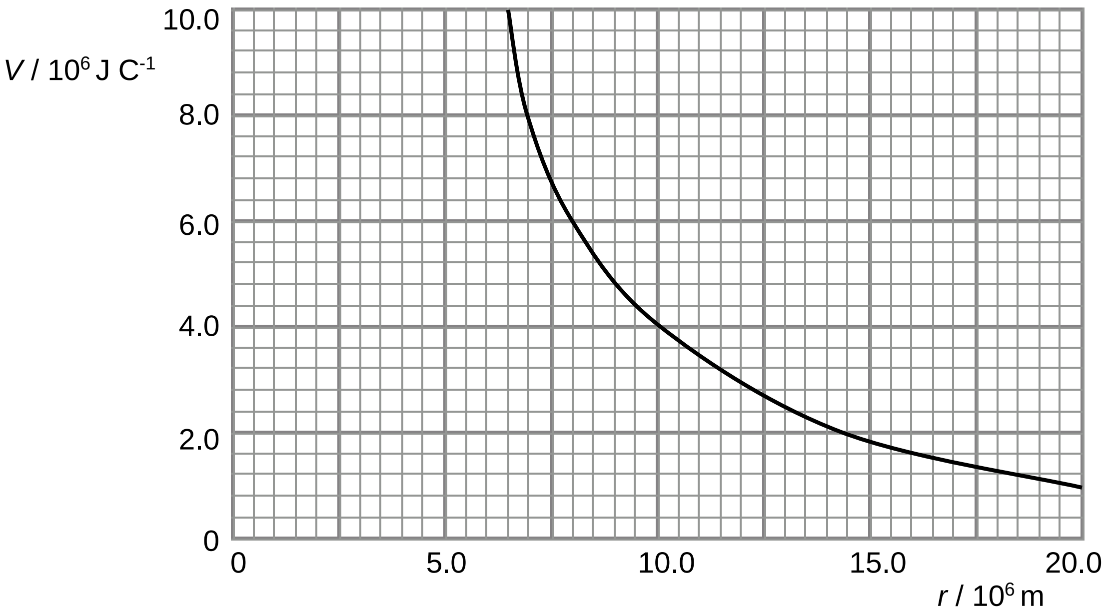


Fig. 9.1

	(a)	The charged object is fixed in its position. A proton is initially at rest at 7.5×10^6 m from the centre of the charged object. Determine its kinetic energy when it has moved a distance of 7.0×10^6 m away from the charged object.	
		kinetic energy =................................... J	[3]
	L3	The **proton would accelerate from 7.5×10^6 m to 14.5×10^6 m from** the centre of the charged object. **Electric potential at 7.5×10^6 m = 6.8×10^6 J** **Electric potential at 14.5×10^6 m = 2.0×10^6 J** **Gain in kinetic energy = Loss in electric potential energy** Final kinetic energy – 0 = q ΔV **Final kinetic energy = (1.60×10^{-19}) $(6.8 \times 10^6 - 2.0 \times 10^6)$** **= 7.68×10^{-13} J**	**C1** **M1** **A1**
	(b)	On Fig. 9.2, draw a graph to show the variation with distance *r* of the electric field strength *E* for values of *r* from 7.5×10^6 m to 17.5×10^6 m.	

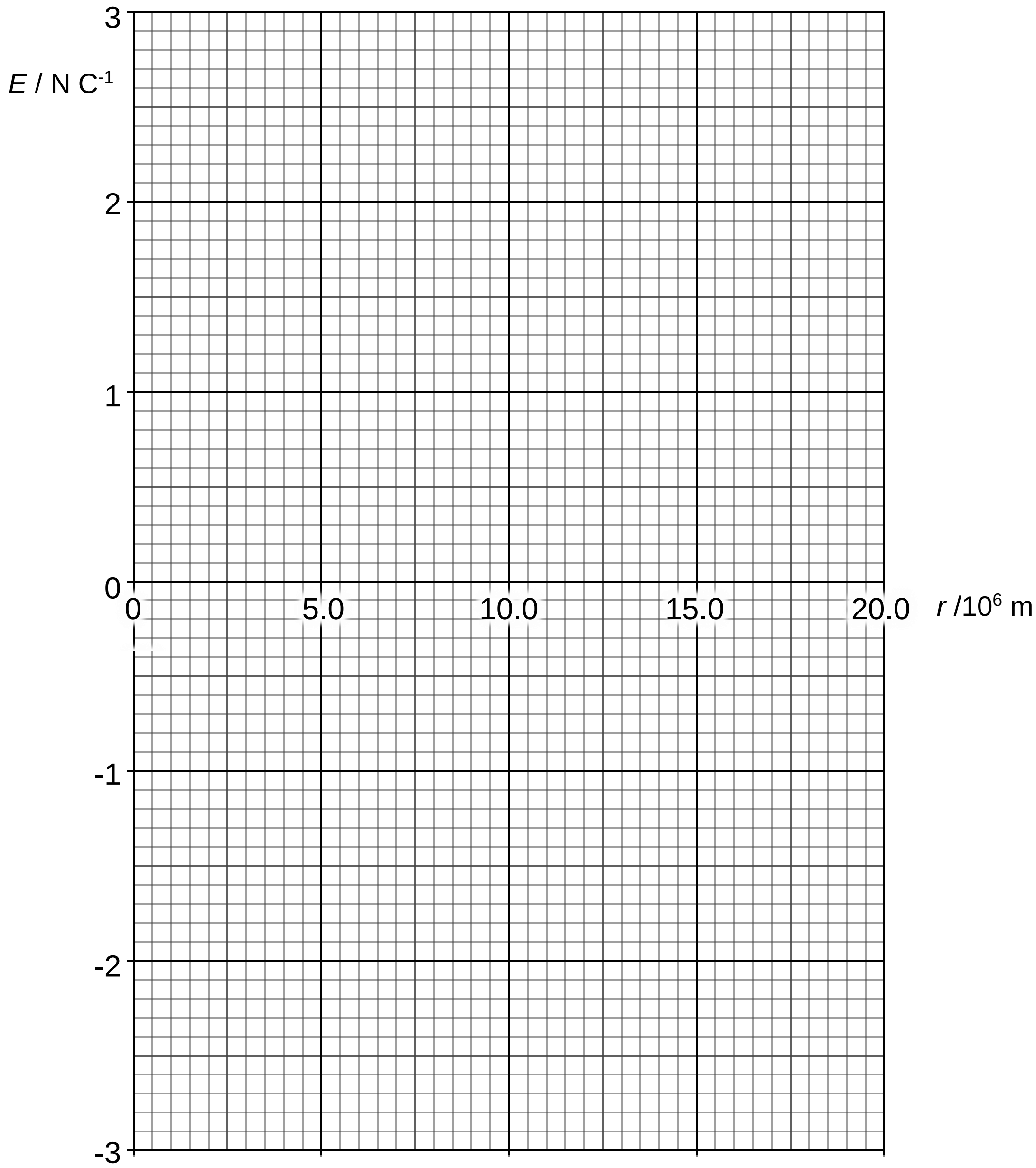


Fig. 9.2

[3]

L2 Electric field strength E = - dV/dr

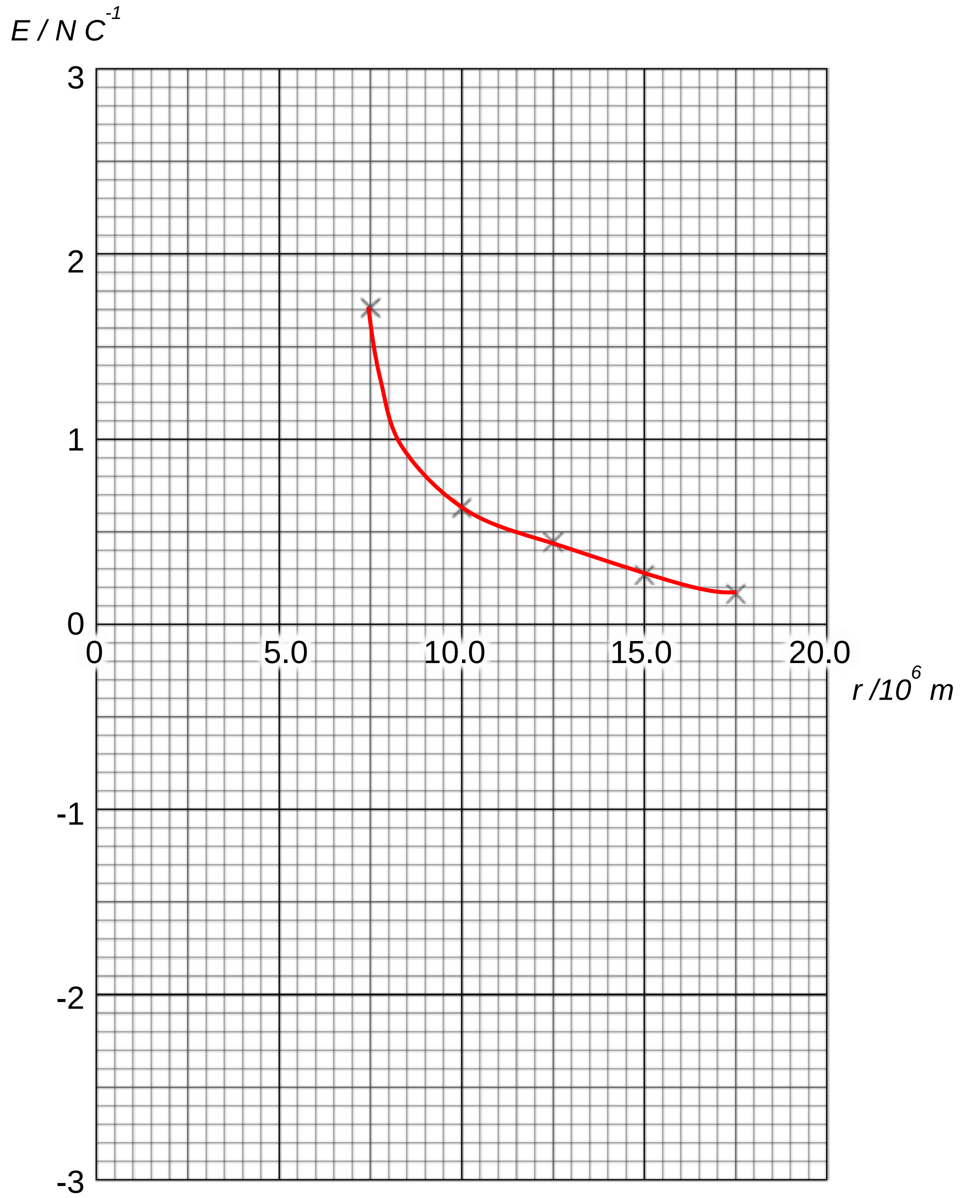
At r = 7.5 x 10^6 m,
dV/dr = gradient of V-r graph = (2.4 – 8.4)/(10 – 6.5) = - 1.71 V m^{-1}
E = +1.71 V m^{-1}

At r = 10.0 x 10^6 m,
dV/dr = gradient of V-r graph = (0 – 8.8)/(16.5 – 2.5) = - 0.629 V m^{-1}
E = +0.629 V m^{-1}

At r = 12.5 x 10^6 m,
dV/dr = gradient of V-r graph = (1.2 – 7.2)/(16 – 2.5) = - 0.444 V m^{-1}
E = +0.444 V m^{-1}

At r = 15.0 x 10^6 m,
dV/dr = gradient of V-r graph = (0.8 – 5.6)/(19 - 1) = - 0.267 V m^{-1}
E = +0.267 V m^{-1}

At $r = 17.5 \times 10^6$ m,
dV/dr = gradient of V-r graph = (1.2 – 4)/(18.5 – 1.5) = - 0.165 V m^{-1}
E = +0.165 V m^{-1}



1 mark: <u>at least 1 coordinate</u> <u>calculated correctly</u>, showing understanding of $E = - dV/dx$. **B1**

1 mark: <u>at least 3 coordinates plotted to draw a curve</u> in the <u>positive</u> region of the graph grid and <u>in the required range of 7.5×10^6 m to 17.5×10^6 m</u>. (Allow for computation errors. However, <u>the 3 coordinates should be well spread out over the correct range, e.g. at the 2 boundaries plus 1 coordinate midway between these 2 boundary coordinates.)</u> **B1**

1 mark: <u>smooth curve and line of best fit drawn</u> across the required range of 7.5×10^6 m to 17.5×10^6 m. **B1**

(c) A certain planet has a radius of 1150 km. Fig. 9.3 below shows the variation with the distance x from the centre of this planet, of the gravitational potential ϕ near it. The planet may be assumed to be isolated in space.

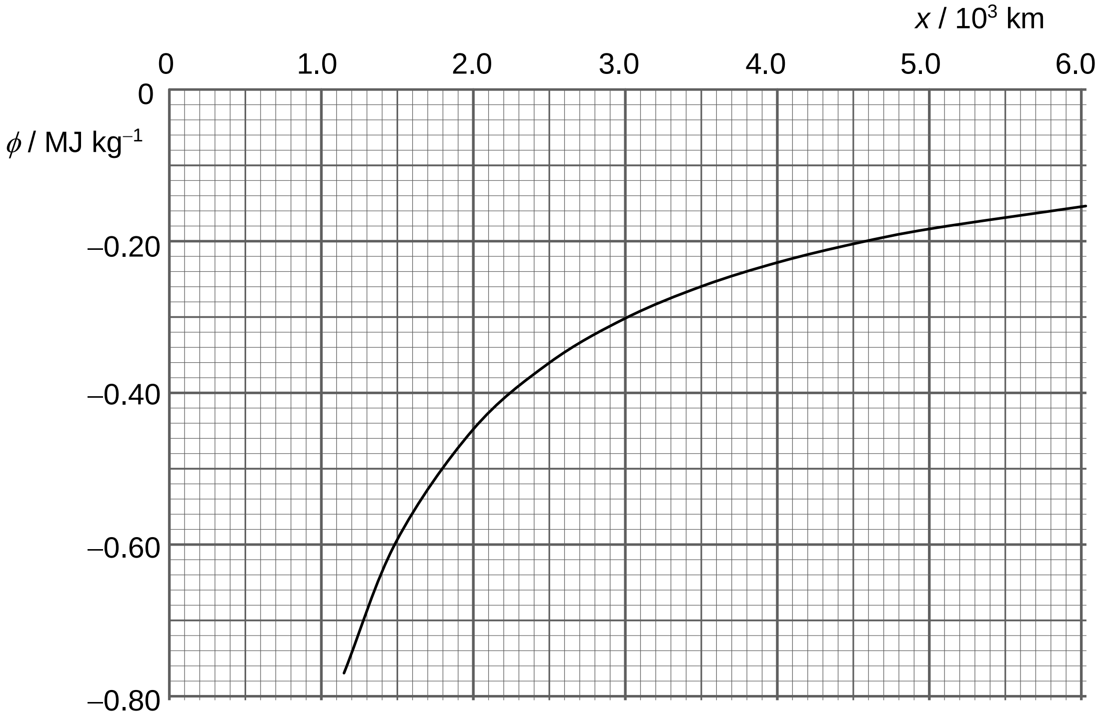


Fig. 9.3

(i) Explain why gravitational potential has a negative value.

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

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

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

L1 Gravitational potential is <u>defined</u> to be **<u>zero at infinity</u>**. **B1**

Also, due to the **<u>attractive</u>** <u>nature of gravitational force,</u> to move a <u>point mass</u> **<u>from infinity towards</u>** <u>another mass</u> **<u>without a change in kinetic energy</u>**, an **<u>external agent</u>** would need to **<u>exert a force</u>** that acts **<u>opposite direction to</u>** the **<u>change in displacement of the mass being moved</u>**, thus **<u>work done</u>** ***<u>per unit mass</u>*** **<u>by the external agent is negative</u>**. **B1**

Thus gravitational potential at any point other than at infinity is negative.

- *Relate back to definition of gravitational potential: Gravitational potential at a point is the work done per unit mass by an external agent in bringing a point mass from infinity to that point (without a change in kinetic energy).*
- *potential' is a 'per unit mass' quantity, hence reference is made to work done 'per unit mass' in the explanation.*

		(ii)	Use Fig. 9.3 to determine the mass of the planet.	
			mass = ………………………………… kg	[2]
		L2	Using $x = 3.0 \times 10^3$ km with its corresponding potential $\phi = -0.30 \times 10^6$ J (or any other coordinates), $\phi = -\frac{GM}{x}$ $-0.30 \times 10^6 = -\frac{(6.67 \times 10^{-11})(M)}{3.0 \times 10^3 \times 10^3}$ $M = 1.3493 \times 10^{22} = 1.35 \times 10^{22}$ kg	M1 A1
		(iii)	A moon of the planet has a circular orbit of radius 3.0×10^3 km. The period of its orbit is 3.44×10^4 s. Calculate the centripetal acceleration of the moon.	
			centripetal acceleration = ………………………………… m s^{-2}	[2]
		L2	$a = r\omega^2 = r(\frac{2\pi}{T})^2 = 3.0 \times 10^3 \times 10^3 (\frac{2\pi}{3.44 \times 10^4})^2$ $a = 0.10008 = 0.100$ m s^{-2}	M1 A1
		(iv)	Explain why the gravitational field strength at the position of the moon has the same magnitude and same direction as the centripetal acceleration of the moon.	
			…………………………………………………………………………………………	
			…………………………………………………………………………………………	
			…………………………………………………………………………………………	
			…………………………………………………………………………………………	
			…………………………………………………………………………………………	
			…………………………………………………………………………………………	
			…………………………………………………………………………………………	[3]
		L2	**Gravitational field strength *g* is defined as the gravitational force F_g per unit mass, hence F_g = mass of moon x *g*.** **By Newton's second law of motion, centripetal force F_c = mass of moon x centripetal acceleration a_c.** As **gravitational force F_g provides the centripetal force F_c for the moon to orbit the planet,** *g* is of the same magnitude and same direction as a_c.	B1 B1 B1
		(v)	The mass of the moon is 1.52×10^{21} kg. Calculate the total energy of the moon.	

			total energy = ... J	[3]
		L2	Gravitational potential energy $= -\frac{GMm}{r}$ $= -\frac{(6.67\,x\,10^{-11})(1.3493\,x\,10^{22})(1.52\,x\,10^{21})}{3.0\,x\,10^{3}\,x\,10^{3}}$ $= -4.5599\,x\,10^{26}\,J$ Kinetic energy $= \frac{1}{2}mv^2 = \frac{1}{2}(1.52\,x\,10^{21})(r\omega)^2$ $= \frac{1}{2}(1.52\,x\,10^{21})\left((3.0\,x\,10^3\,x\,10^3)(\frac{2\pi}{3.44\,x\,10^4})\right)^2$ $= 2.28191\,x\,10^{26}\,J$ Total energy = Gravitational potential energy + Kinetic energy $= -4.5599\,x\,10^{26} + 2.28191\,x\,10^{26} = -2.28\,x\,10^{26}\,J$ OR **Derive** to show that KE $= \frac{1}{2}\frac{GMm}{r}$ Total energy = KE + GPE $= \frac{1}{2}\frac{GMm}{r} + \left(-\frac{GMm}{r}\right)$ $= -\frac{1}{2}\frac{GMm}{r}$ $= -\frac{1}{2}\frac{(6.67\,x\,10^{-11})(1.3493\,x\,10^{22})(1.52\,x\,10^{21})}{3.0\,x\,10^{3}\,x\,10^{3}}$ $= -2.27995\,x\,10^{26}\,J$ $= -2.28\,x\,10^{26}\,J$	M1 M1 A1
	(d)	State and explain one similarity and one difference in the variations in the electric potential and gravitational potential shown in Fig. 9.1 and Fig. 9.3 respectively.		
		similarity:		
		....		
		....		
		difference:		
		....		
		....		[2]
	L1	Similarity: **The magnitudes of both electric potential and gravitational potential are inversely proportional to the distance from the centre of the object.** Difference: **Gravitational potential is always negative for any mass, whereas electric potential is positive for a positive charge (and negative for a negative charge).**		B1 B1

[Total: 20]

END OF PAPER

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