H

NANYANG JUNIOR COLLEGE
JC 2 PRELIMINARY EXAMINATION
Higher 2

CANDIDATE NAME	Solution
CLASS	
TUTOR'S NAME	
CENTRE NUMBER	S
INDEX NUMBER	

PHYSICS 9749/03

Paper 3 Longer Structured Questions

19 September 2025

2 hours

Candidates answer on the Question Paper.

No Additional Materials are required.

READ THESE INSTRUCTIONS FIRST

Write your name, class, Centre number and index number in the spaces at the top of this page.
Write in dark blue or black pen on both sides of the paper.
You may use a HB pencil for any diagrams, 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.

At the end of the examination, fasten all your work securely together.
The number of marks is given in brackets [ ] at the end of each question or part question.

For Examiner's Use	
Section A	
1	**/ 6**
2	**/ 8**
3	**/ 12**
4	**/ 10**
5	**/ 9**
6	**/ 8**
7	**/ 7**
Section B	
8	**/ 20**
9	**/ 20**
Total	**/ 80**

This document consists of **24** printed pages.

Data

speed of light in free space	$c = 3.00 \times 10^{8}$ m s^{-1}
permeability of free space	$\mu_0 = 4\pi \times 10^{-7}$ H m^{-1}
permittivity of free space	$\varepsilon_0 = 8.85 \times 10^{-12}$ F m^{-1}
	$(1 / (36\pi)) \times 10^{-9}$ F m^{-1}
elementary charge	$e = 1.60 \times 10^{-19}$ C
the Planck constant	$h = 6.63 \times 10^{-34}$ J s
unified atomic mass constant	$u = 1.66 \times 10^{-27}$ kg
rest mass of electron	$m_e = 9.11 \times 10^{-31}$ kg
rest mass of proton	$m_p = 1.67 \times 10^{-27}$ kg
molar gas constant	$R = 8.31$ J K^{-1} mol^{-1}
the Avogadro constant	$N_A = 6.02 \times 10^{23}$ mol^{-1}
the Boltzmann constant	$k = 1.38 \times 10^{-23}$ J K^{-1}
gravitational constant	$G = 6.67 \times 10^{-11}$ 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	$\phi = -Gm / r$
temperature	$T / \text{K} = T / {}^\circ\text{C} + 273.15$
pressure of an ideal gas	$p = \frac{1}{3}\frac{Nm}{V} < c^2 >$
mean translational kinetic energy of an ideal 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	$V = \frac{Q}{4\pi\varepsilon_0 r}$
alternating current/voltage	$x = x_0 \sin\omega t$
magnetic flux density due to a long straight wire	$B = \frac{\mu_0 I}{2\pi d}$
magnetic flux density due to a flat circular coil	$B = \frac{\mu_0 NI}{2r}$
magnetic flux density due to a long solenoid	$B = \mu_0 nI$
radioactive decay	$x = x_0 \exp(-\lambda t)$
decay constant	$\lambda = \frac{\ln 2}{t_{\frac{1}{2}}}$

Section A

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

1 A projectile is fired from ground level with initial velocity u at an angle θ to the horizontal as shown in Fig. 1.1. The projectile strikes a target which is at a horizontal displacement x from the point of projection and a vertical height y above ground level.

Fig. 1.1

(a) Neglecting the effect of air resistance, show that the vertical height y is given by the expression

$$y = x\tan\theta - 4.91\left(\frac{x}{u\cos\theta}\right)^2$$

$s_x = u_x t$

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

$t = \frac{x}{u\cos\theta}$ [M1]

$s_y = u_y t + \frac{1}{2}a_y t^2$

$y = (u\sin\theta)t + \frac{1}{2}(-9.81)t^2$ [C1]

$y = u\sin\theta \times \frac{x}{u\cos\theta} - 4.91(\frac{x}{u\cos\theta})^2$ [M1]

$y = x\tan\theta - 4.91\left(\frac{x}{u\cos\theta}\right)^2$ [A0]

[3]

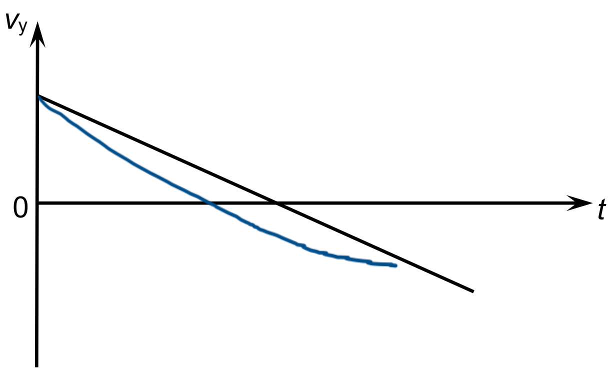
(b) Given that the angle θ is 60°, the horizontal displacement x is 115 m and the vertical height y is 23 m, calculate the speed u.

$23 = 115\tan 60 - 4.91\left(\frac{115}{u\cos 60}\right)^2$

$u = 38\ \text{m s}^{-1}$

u = ... m s^{-1} [1]

(c) Fig. 1.2 shows the variation with time t of the vertical velocity v_y of the projectile when air resistance is negligible. On the same axes, sketch a graph to show the variation with time t of the vertical velocity v_y of the projectile when air resistance is not negligible. [2]



The curve must decrease at a decreasing rate throughout, with following details:

1. Positive area larger than negative area
2. a larger initial gradient
3. a smaller t-intercept
4. at v_y = 0, gradient parallel

Fig. 1.2

[Total: 6]

2 **(a)** State the **two** conditions necessary for a body to be in equilibrium.

1\. The net force is zero. [B1]

2\. The net torque is zero./ The net moment about any point is zero. [B1]

[2]

(b) Fig. 2.1 shows a uniform beam AB of length 6.0 m and weight 2700 N suspended by two ropes AC and BC, each of length 6.0 m. The tensions in ropes AC and BC are T_1 and T_2 respectively.

A worker of weight 900 N is holding onto the beam at point D, where AD = 4.0 m and DB = 2.0 m.

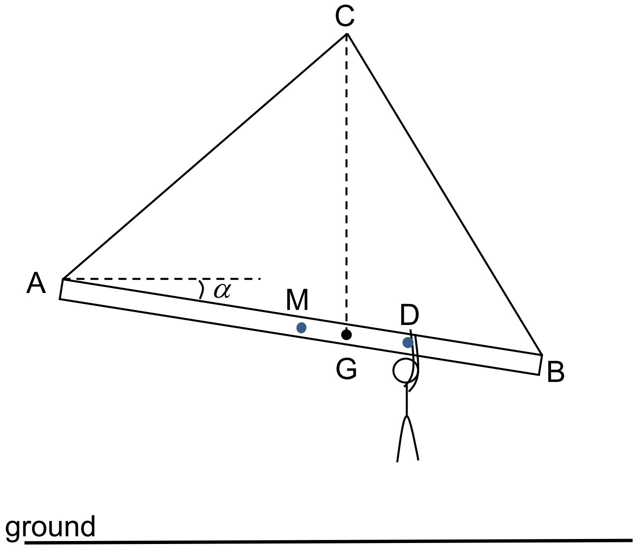


Fig. 2.1

The beam makes an angle α to the horizontal. The point M is the mid-point of the beam and the point G on the beam is the position of the centre of gravity of the beam and the worker.

(i) Explain in terms of forces acting on the beam, why the point G must lie directly below C.

The combined weight of the beam and the worker can be considered to be acting at G. Considering moments about C, moments due to T_1 and T_2 about C is zero as their lines of action pass through C. Hence for the resultant moments about C to be zero, the line of action of the combined weight of the beam and worker must pass through C as well so that the moment of the combined weight about C is zero. Hence the vertical line through G must pass through C.

[2]

(ii) Calculate the distances MG and DG.

Considering moments due to the weight of beam, W_b, and that of the worker, W_w, about C,
Let distance MG be x and distance DG be y
$W_b \cdot x = W_w \cdot y$
(2700) x = (900) y
y = 3 x
MD = AD – AM = 4.0 – 3.0 = 1.0 m
MD = MG + GD = x + 3 x = 1.0 m, 4x = 1.0 m, x = 0.25 m.
MG = 0.25 m
DG = 0.75 m

distance MG = ... m

distance DG = ... m
[2]

(iii) If the angle α is 2.8°, determine the magnitude of the tension T_2.

For horizontal equilibrium,
$T_1 \cos(60.0° - 2.8°) = T_2 \cos(60.0° + 2.8°)$

$$T_1 = \left(\frac{\cos 62.8°}{\cos 57.2°}\right) T_2$$

$$T_1 = 0.8438\, T_2 \quad \cdots(1)$$

For vertical equilibrium,
$T_1 \sin 57.2° + T_2 \sin 62.8° = 2700 + 900 \quad \cdots(2)$
Substituting equation (1) into equation (2) and solving for T_2,
T_2 = 2250 N (3 s.f.)

tension T_2 = ... N [2]

[Total: 8]

3 **(a)** Explain why gravitational potential is a negative value for an isolated mass.

Gravitational potential at infinity is defined to be zero [B1]

Since, gravitational forces are attractive, [B1]

the force exerted by external agent to bring the test mass from infinity to that point (without a change in KE) is opposite in direction to the test mass's displacement. The work done by the external agent is negative and by definition of gravitational potential it will take on a negative value. [B1]

....

....[3]

(b) A satellite can orbit the Earth along an east-to-west direction (known as a retrograde orbit) as well as along the west-to-east direction (known as a prograde orbit).

(i) A satellite is launched in the west-to-east direction from a launch pad on the Equator to the geostationary orbit.

Explain why this launch direction is preferred.

same direction as Earth's rotation about its own axis so satellite begins launch with some speed in correct direction [B1]

satellite already has some kinetic energy so less fuel needed to raise the gravitational potential energy [B1]

....[2]

(ii) The Earth may be considered to be a uniform sphere of radius 6400 km with its mass of 6.0×10^{24} kg concentrated at its centre.

Show that the geostationary satellite is 3.59×10^{7} m above the Earth's surface.

gravitational force provides centripetal force [M1]

$$\frac{GMm}{r^2} = mr\omega^2$$

$$GM = r^3\omega^2$$

$$r = \sqrt[3]{\frac{GM}{\omega^2}} = \sqrt[3]{\frac{GM}{\left(\frac{2\pi}{T}\right)^2}}$$

$$= \sqrt[3]{\frac{(6.67 \times 10^{-11})(6.0 \times 10^{24})}{\left(\frac{2\pi}{24 \times 60 \times 60}\right)^2}}$$

$\left[= 4.23 \times 10^{7} \text{ m} \quad (4.2298 \times 10^{7} \text{ m})\right]$ [M1]

$h = r - R_E = r - 6400 \times 10^3$

$= 3.59 \times 10^{7}$ m [A0]

[2]

(iii) A satellite of mass 1000 kg is in geostationary orbit. Find its total energy.

$$E_{total} = E_K + E_P$$
$$= \frac{1}{2}mv^2 + \left(-\frac{GMm}{r}\right) = \frac{1}{2}r\left(\frac{mv^2}{r}\right) + \left(-\frac{GMm}{r}\right)$$
$$= \frac{1}{2}r\left(\frac{GMm}{r^2}\right) + \left(-\frac{GMm}{r}\right) = \left(\frac{GMm}{2r}\right) + \left(-\frac{GMm}{r}\right) \quad \text{[M1]}$$
$$= -\frac{GMm}{2r}$$
$$= -\frac{(6.67\times10^{-11})(6.0\times10^{24})(1000)}{2(4.2298\times10^{2})}$$
$$= -4.73\times10^{9} \text{ J} \quad \text{[A1]}$$

total energy = ... J [2]

(iv) Atmospheric drag is very low but nonetheless present at the height where geostationary satellites orbit.

Explain, in terms of energy, the impact of atmospheric drag on the subsequent trajectory of geostationary satellites.

Work done against drag so total energy decreases [B1]

GPE decrease so satellite lowers in height
KE increase so linear speed increase } [B1]

satellite spirals towards Earth with increasing speed [B1]

....

....

....[3]

[Total: 12]

4 Fig. 4.1 shows a ball of mass 37 g on a smooth surface. It is held between two fixed points A and B by two identical stretched helical springs, of spring constant 3.5 N m^{-1}.

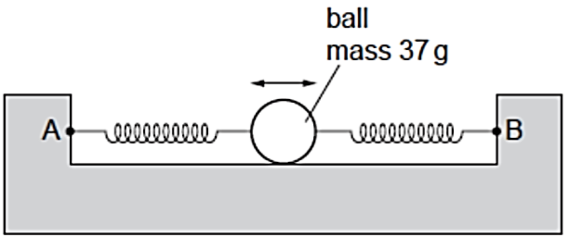


Fig. 4.1

The extension of each spring is 3.2 cm when the ball is at the equilibrium position. The ball oscillates along the line AB with simple harmonic motion of frequency 2.19 Hz and amplitude 3.0 cm.

(a) **(i)** State the extension of the springs when the ball is at the amplitude position closest to point B.

Extension in spring B = 3.2 – 3.0 = 0.2 cm
Extension in spring A = 3.2 + 3.0 = 6.2 cm

extension of spring A = ... cm

extension of spring B = ... cm
[1]

(ii) Show that the total energy of the system is 6.7 × 10^{-3} J.

Total energy of the system = maximum PE at the amplitude position [B1]

$$= \frac{1}{2}kx_A^{\ 2} + \frac{1}{2}kx_B^{\ 2}$$

$$= \frac{1}{2}(3.5)(0.062)^2 + \frac{1}{2}(3.5)(0.002)^2 \quad \text{[B1]}$$

$$= 6.734 \times 10^{-3}\ \text{J} \approx 6.7 \times 10^{-3}\ \text{J}$$

[2]

(b) On the axes of Fig. 4.2 and using your answers to **(a)**, sketch a graph to show the variation with displacement *x* of

(i) the total energy of the system (label this line T), [1]

(ii) the kinetic energy of the ball (label this line K), [2]

(iii) the potential energy stored in the springs (label this line P). [2]

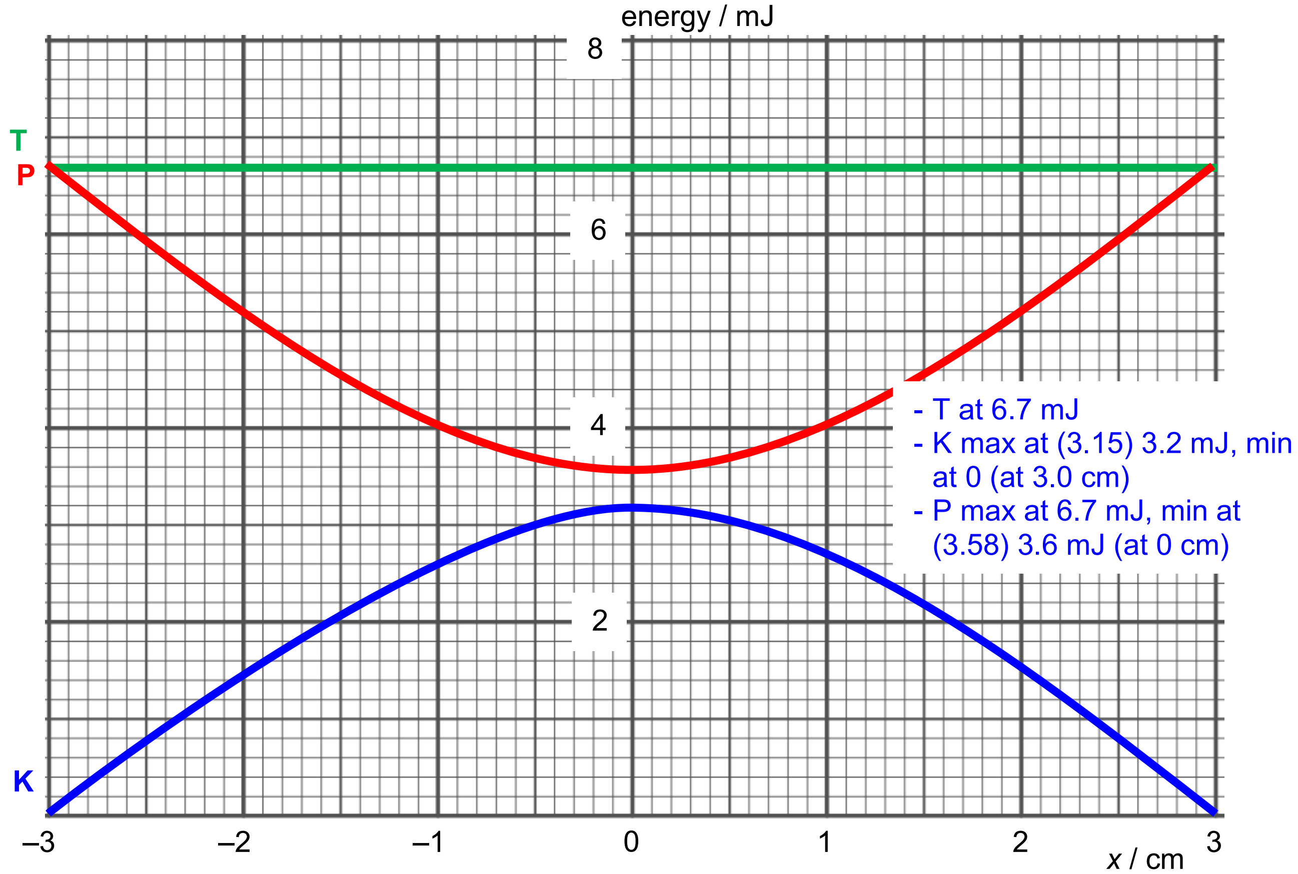


Fig. 4.2

(c) The ball in Fig. 4.1 is replaced with a heavier ball of the same size. State and explain the change, if any, to the maximum speed of the ball during the oscillation, if the amplitude remains unchanged.

The maximum energy of the oscillation remains constant [B1], hence considering energy conservation, the maximum KE (at equilibrium position) remains unchanged. However, with a larger mass, the maximum speed is therefore reduced [B1].

[2]

[Total: 10]

5 **(a)** Two light sources that produce light with the same wavelength are placed at position A and B respectively as shown in Fig. 5.1.

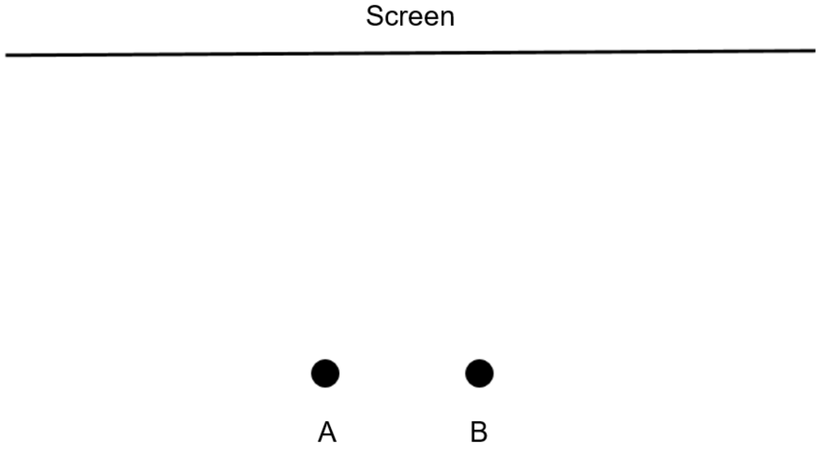


Fig. 5.1

The light from the light sources meet on the screen and a steady interference pattern is formed on the screen.

State two other conditions required for the interference pattern to be observable.

1. Any two of the following:
- Polarised along the same plane or not polarized [B1]
- (Roughly) same amplitude/ Intensity [B1] ....[1]
- Light source must be coherent [B1]

2. ....

.... [1]

(b) When a distant streetlight, which is behaving as a point source of light of wavelength 4.5×10^{-7} m, is viewed through a nylon net curtain, the diffraction pattern of the light projected on a screen is shown in Fig. 5.2. The screen is 3.0 m away from the nylon net curtain.

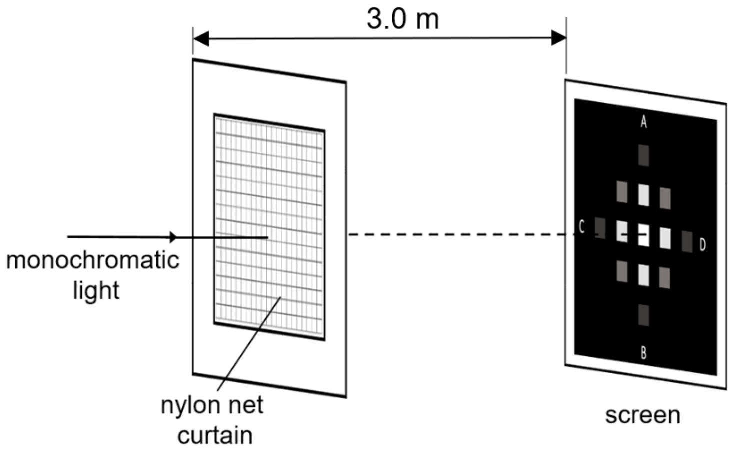


Fig. 5.2

The full-scale diagram of the diffraction pattern is shown in Fig. 5.3.

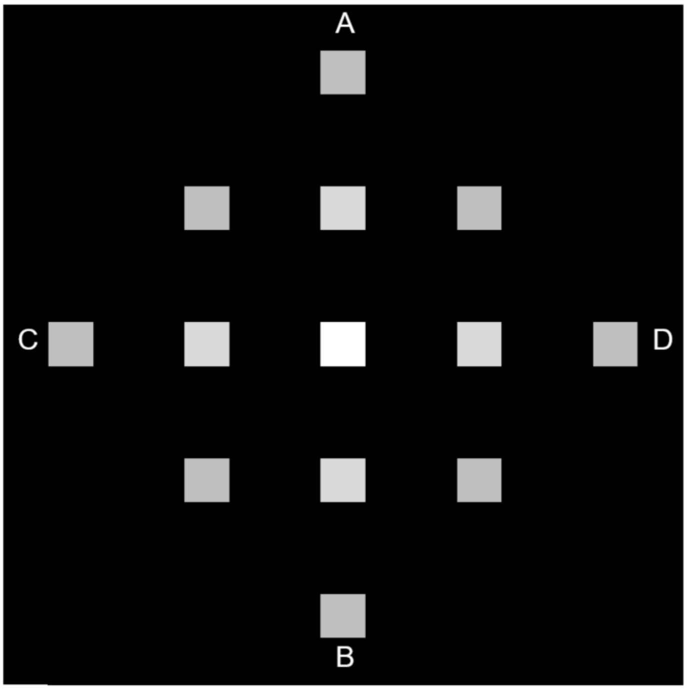


Fig. 5.3

The main feature of this pattern is two lines (AB and CD) of bright images.

(i) Calculate the angle, in radians, between the orders of the diffracted light.

Distance between orders = 1.8 cm [C1]

$\tan\theta = \dfrac{0.018}{3.0}$

θ = 0.0060 rad [A1]

angle = ... rad [2]

(ii) Using your answer to **(b)(i)**, determine the number of nylon threads per millimetre of the mesh.

$d \sin \theta = n \lambda$

$d \sin (0.0060) = 1\ (4.5 \times 10^{-7})$ [C1]

$d = 7.5 \times 10^{-5}$ m

number per mm = $\dfrac{1}{7.5\times10^{-5}}\times10^{-3}$ = 13 [A1]

number = ... mm^{-1} [2]

(c) A long horizontal tube, containing fine powder, is closed at one end. A loudspeaker, connected to a signal generator, is positioned at the other end as shown in Fig. 5.4.

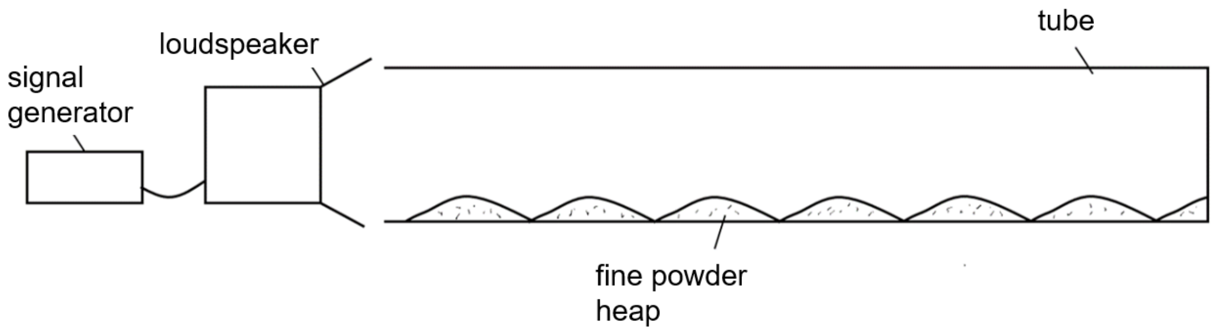


Fig. 5.4

At a particular frequency, a stationary wave is set up inside the tube and the powder forms heaps as shown. The speed of sound is 330 m s^{-1}.

(i) On Fig. 5.4, mark out 2 points where displacement nodes are and label them as N. [1]

Any 2 points directly above the heap. [B1]

(ii) Determine the distance between adjacent heaps if the signal generator is producing a signal with frequency of 3.5 kHz.

$v = f\lambda$

$\lambda = \frac{330}{3.5 \times 10^3} = 0.09429 \text{ m}$ [M1]

Distance betwen adjacent heaps is 0.5λ

$0.5 \times 0.09429 = 0.047\text{m}$ [A1]

spacing = ... m [2]

[Total: 9]

6 An electric guitar uses electromagnetic pickups to detect the vibration of its strings, which are made from steel. Each pickup consists of a coil of wire wrapped around a permanent magnet as shown in Fig. 6.1. When the string vibrates near the pickup, an alternating electromotive force (e.m.f.) is induced in the coil (which is channelled to an output amplifier and speaker)

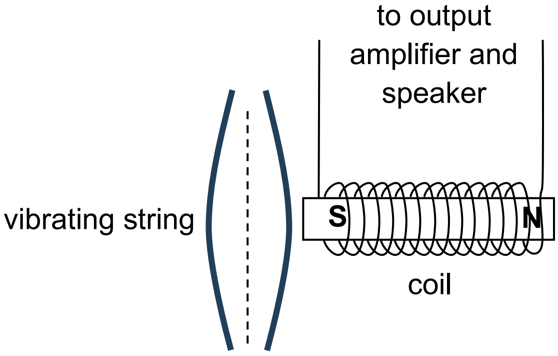


Fig. 6.1

(a) Explain how the vibration of the steel string leads to the generation of an alternating e.m.f. in the coil of the pickup.

The steel string is made of magnetic material, and so it causes changes in the magnetic field from the permanent magnet that the coil is situated in.
As the string vibrates, the magnetic field near the (pickup) coil changes over time. [B1]
A changing (periodically increasing and decreasing) magnetic flux linkage through the coil [B1] induces an electromotive force in the coil proportional to the rate of change of magnetic flux [B1]
Because the vibration is periodic, the magnetic flux linkage also changes periodically and thus the e.m.f. induced is alternating [B1]

....

....[4]

(b) A guitarist plucks a string more strongly, causing it to vibrate with the same frequency but larger amplitude. Explain how this affects the e.m.f. induced in the coil.

Larger amplitude of vibration with the same frequency causes greater change in magnetic field around the magnet and coil, so there will be a greater change in magnetic flux linkage in coil in the **same period**, hence greater magnitude of induced voltage.

....[2]

(c) A guitar string vibrates in a magnetic field, where the field strength at the coil fluctuates between maximum and minimum with a difference of field strength of 5.0 × 10^{-2} T at a frequency of 880 Hz. The coil has a cross-sectional area of 1.0 × 10^{-6} m^2. It is desired that the average e.m.f. of the pickup coil is about 0.20 V.

Estimate the number of turns the coil must have.

$$|E| = \frac{d\Phi}{dt} = NA\frac{dB}{dt} = NA\frac{\Delta B}{\Delta t} \qquad \frac{\Delta B}{\Delta t} = \frac{\Delta B_{\text{max to min}}}{T/2} = 2(\Delta B)f$$

$$N = \frac{|E|}{A\left(\frac{\Delta B}{\Delta t}\right)} = \frac{0.20}{(1.0\times10^{-6})(5.0\times10^{-2})(2\times880)} [M1]$$

$$= 2272 \ turns \approx 2\times10^{3} [A1]$$

number of turns = ... [2]

[Total: 8]

7 **(a)** Define *electric field strength* at a point.

The electric field strength at a point is defined as the electric force exerted per unit positive charge acting on a test charge placed at that point. ......

....[1]

(b) Electrons are emitted from a cathode C and are accelerated towards an anode A, as illustrated in Fig. 7.1.

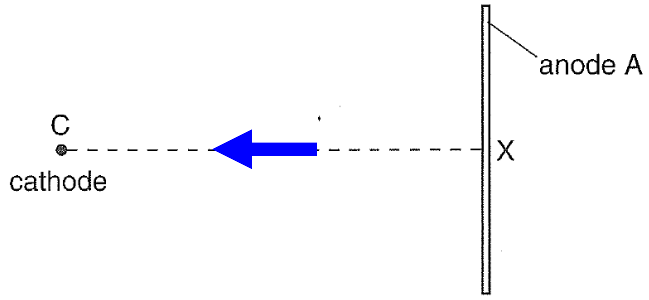
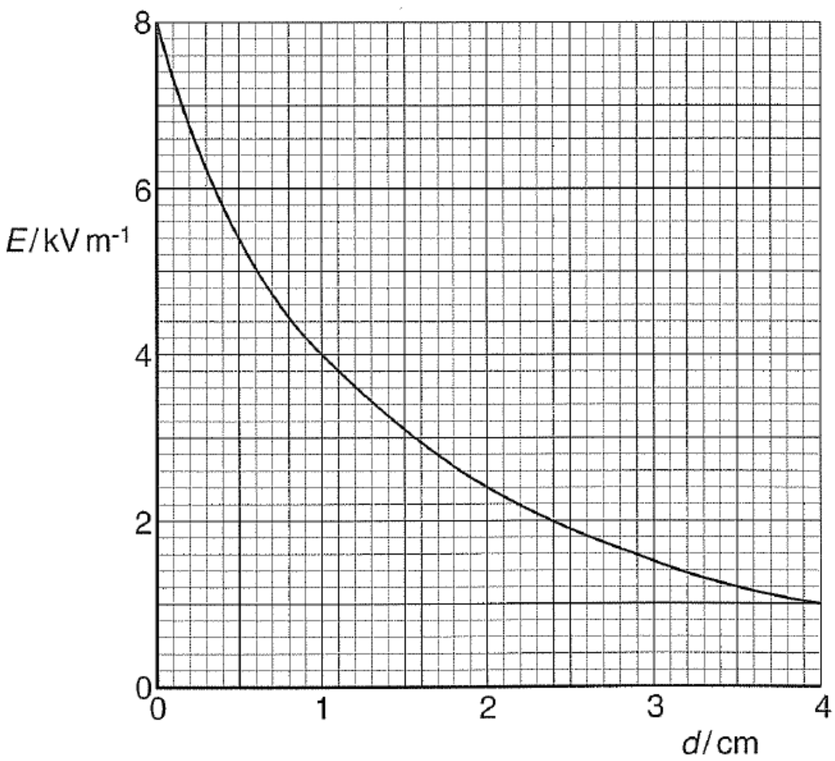


Fig. 7.1

The anode is earthed. CX is a line drawn from C normal to the anode A. The distance CX is 4.0 cm.

The variation with distance *d* from C along CX of the magnitude of the electric field strength *E* is shown in Fig. 7.2.



(i) On Fig. 7.1, mark with an arrow the direction of the electric field along CX. [1]

(ii) Use Fig. 7.2 to determine the force F on an electron at a point mid-way between C and X.

At $d = 2$ cm, $E = 2.4$ kV m^{-1} [C1]

$F = qE$

$= (1.60 \times 10^{-19})(2.4 \times 10^{3})$

$= 3.84 \times 10^{-16}$ N [A1]

F = ... N [2]

(c) (i) A student assumes that the force F on the electron remains constant as the electron moves from C to X.

Use the value of F calculated in **(b)(ii)** to estimate, on the basis of this assumption, the potential difference between C and X.

Work done on charge $= Fd$

$q\Delta V = Fd$

$\Delta V = \frac{Fd}{q}$

$= \frac{(3.84 \times 10^{-16})(4.0 \times 10^{-2})}{1.60 \times 10^{-19}}$ [M1: must use (b)(ii) answer]

$= 96$ V [A1]

potential difference = ... V [2]

(ii) Suggest, with a reason, whether the magnitude of the potential difference calculated in **(i)** will be an over-estimate or an under-estimate of the actual potential difference.

Under-estimate because (by observation) the area under graph is greater than 96 V or answer in (c)(i). ....

....[1]

[Total: 7]

Section B

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

8 **(a)** By reference to energy transfers, distinguish between electromotive force (e.m.f.) and potential difference (p.d.).

p.d. refers to the electrical energy per unit charge converted to other forms of energy [B1] whereas e.m.f. refers to the electrical energy per unit charge converted from other forms of energy. [B1]

....

....[2]

(b) A circuit is set up as shown in Fig. 8.1.

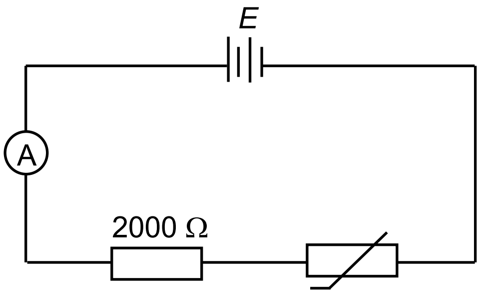


Fig. 8.1

The source of negligible internal resistance is found to provide 2.4×10^5 J of electrical energy to the 2000 Ω resistor and thermistor when a charge of 2.2×10^4 C passes through the ammeter. At room temperature, the thermistor has a resistance of 1800 Ω.

(i) Sketch on Fig. 8.2 the variation with temperature θ of resistance R in a thermistor.

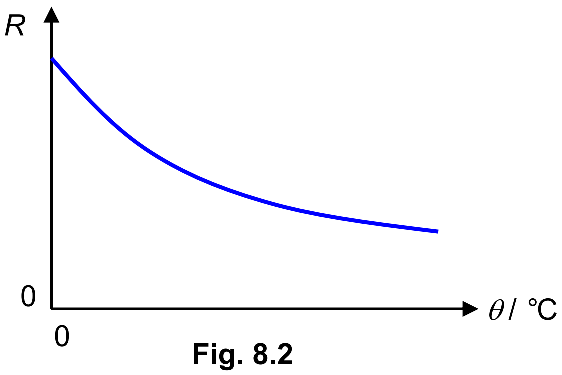


Fig. 8.2

Correctly drawn curve (straight lines not accepted)

cuts R-axis at 0°C.

[1]

(ii) For the thermistor at room temperature,

1. show that the e.m.f. of the source is 11 V.

$$E = \frac{W}{Q} = \frac{2.4 \times 10^5}{2.2 \times 10^4} \quad \text{[M1]}$$
$$= 11 \text{ V} \quad \text{[A0]}$$

[1]

2. determine the time taken for the charge of 2.2 × 10^4 C to pass through the ammeter.

$$Q = It = \left(\frac{E}{R}\right)t$$
$$t = \frac{QR}{E} = \frac{(2.2 \times 10^4)(2000 + 1800)}{11} \quad \text{[C1]}$$
$$= 7.6 \times 10^6 \text{ s} \quad \text{[A1]}$$

time = ... s [2]

3. determine the ratio

$$\frac{\text{power dissipated in thermistor}}{\text{total power supplied by the cell}}$$

$$\frac{P_{therm}}{P_{total}} = \frac{I^2 R_{therm}}{I^2 (R_{therm} + R_{2000})}$$
$$= \frac{1800}{1800 + 2000} \quad \text{[C1]}$$
$$= 0.47 \quad \text{[A1]}$$

ratio = ... [2]

(c) A uniform resistance wire PQ of length 1.2 m is subsequently connected across the resistor and thermistor, as shown in Fig. 8.3. An ideal voltmeter is connected between point Y and a moveable contact M on the wire.

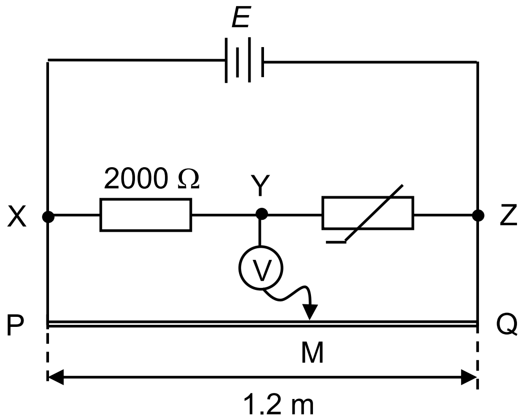


Fig. 8.3

(i) At room temperature, the contact M is moved along PQ until the voltmeter shows zero reading.

Calculate the length of wire between M and Q

$V_{MQ} = V_{YZ}$ when voltmeter has zero reading

$\frac{L}{1.2} = \frac{1800}{2000 + 1800}$ [C1]

$L = 0.57$ m [A1]

length of wire = ... m [2]

(ii) State and explain the effect, if any, on the length of the wire between M and Q for the voltmeter to remain at zero deflection if each of the following changes takes place independently.

1. The thermistor is warmed slightly.

With a rise in temperature, resistance of thermistor decreases. The ratio of p.d. across thermistor to the fixed resistor decreases, [M1] thus ratio of length MQ to PQ decreases too. Length MQ decreases. [A1]

....[2]

2. A uniform wire of the same material but with a larger cross sectional area is used for PQ.

Since the total potential difference and total length remains the same, the potential gradient remains the same. [M1] Therefore length MQ remains the same. [A1]

....[2]

(d) The heating element of an electric heater is made of nichrome wire. Nichrome has a resistivity of 1.0 × 10^{-6} Ω m at the operating temperature of the heater. The heater is rated at 240 V, 1200 W.

(i) Determine the resistance of the nichrome wire when the heater is operating normally.

$$P = \frac{V^2}{R}$$

$$R = \frac{240^2}{1200} \quad \text{[C1]}$$

$$= 48\ \Omega \quad \text{[A1]}$$

resistance = ... Ω [2]

(ii) Calculate the length of nichrome wire of diameter 0.40 mm required for the heater.

$$R = \frac{\rho L}{A}$$

$$L = \frac{(48)(\pi(\frac{0.40\times10^{-3}}{2})^2)}{1.0\times10^{-6}} \quad \text{[C1]}$$

$$= 6.0\ \text{m} \quad \text{[A1]}$$

length of wire = ... m [2]

(iii) The potential difference across the heater is then reduced to 180 V. Assuming the resistance of the nichrome wire remains constant, state and explain how this change affects the time taken to dissipate the same amount of thermal energy.

Since $P = \frac{V^2}{R}$, <u>a decrease in potential difference will result in a decrease in power,</u> [M1] Hence, the <u>time taken to dissipate the same amount of heat would increase</u>. [A1]

....[2]

[Total: 20]

9 **(a)** An electron is travelling in a vacuum towards an electrode with kinetic energy of 8.55×10^{-19} J.

Calculate the stopping potential V_s required to stop the electron.

Loss in KE = Gain in EPE

$8.55 \times 10^{-19} - 0 = e(V_s - 0)$ [C1]

$$V_s = \frac{8.55 \times 10^{-19}}{1.60 \times 10^{-19}} = 5.344 \text{ V} = 5.34 \text{ V}$$ [A1]

V_s = ... V [2]

(b) **(i)** The electron in **(a)** is emitted from a material whose work function is 2.80 eV. Calculate the wavelength of the radiation responsible for causing the emission of the electron.

$$\frac{hc}{\lambda} = \phi + KE_{max}$$

$$\frac{(6.63 \times 10^{-34})(3.00 \times 10^{8})}{\lambda} = (2.80 \times 1.60 \times 10^{-19}) + 8.55 \times 10^{-19}$$ [C1]

$$\lambda = 1.53 \times 10^{-7} \text{ m}$$ [A1]

wavelength = ... m [2]

(ii) Suggest the type of radiation which has the wavelength in **(b)(i)**.

type of radiation = ...ultraviolet.......... [1]

(c) **(i)** Calculate the de Broglie wavelength of an electron travelling with speed 1.85×10^{7} m s^{-1}.

$$\lambda = \frac{h}{p} = \frac{h}{mv}$$

$$\lambda = \frac{6.63 \times 10^{-34}}{(9.11 \times 10^{-31})(1.85 \times 10^{7})}$$ [C1]

$$= 3.93 \times 10^{-11} \text{ m}$$ [A1]

wavelength = ... m [2]

(ii) Graphite, with its layered structure as shown in Fig. 9.1, acts as a natural diffraction grating when used in electron diffraction experiments. The distance between each layer of graphite is 0.335 nm.

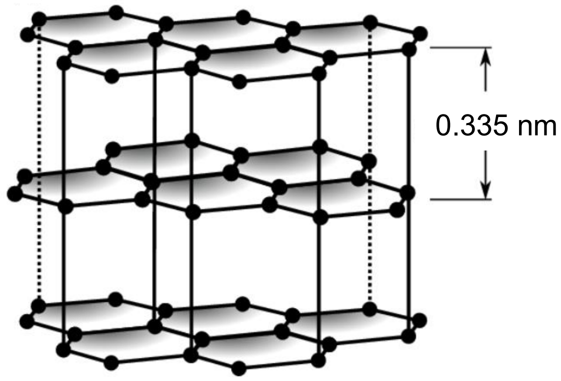


Fig. 9.1

Explain whether electrons having the speed of 1.85×10^7 m s^{-1} can be used to demonstrate electron diffraction.

The atomic lattice spacing (distance between layers of 3.35×10^{-10} m) is much larger than the de Broglie's wavelength (of 3.93×10^{-11} m), [M1] hence there is negligible/little spreading of electrons. [A1] It is not suitable to demonstrate electron diffraction.

....[2]

(d) Tungsten, a transition metal, is commonly used as a target metal to produce X-rays. The energy levels of the K- to M-shells for tungsten are shown in Fig. 9.2 below.

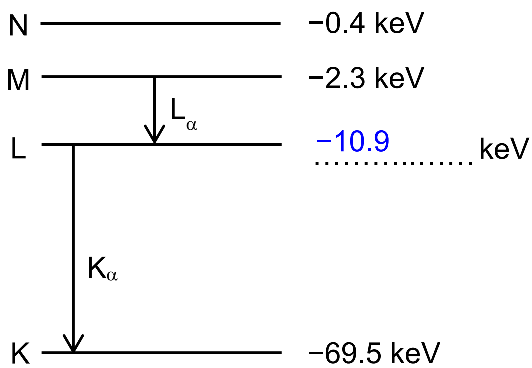


Fig. 9.2 (not to scale)

The wavelength of the photon produced by the K_α transition is 21.2 pm.

(i) Complete Fig. 9.2 by filling in the energy level of the L-shell for tungsten. Show your working clearly.

$$E = \frac{hc}{\lambda} = \frac{(6.63 \times 10^{-34})(3.00 \times 10^{8})}{21.2 \times 10^{-12}}$$ [C1]

$$= 9.382 \times 10^{-15} \text{ J} = 58.64 \text{ keV}$$ [A1]

$$E_2 = -69.5 + 58.64 = -10.9 \text{ keV}$$ [A1]

[3]

(ii) The intensity of various photon wavelengths from electron bombardment of a tungsten target metal is shown in Fig. 9.3. The peak representing K_α transition is labelled.

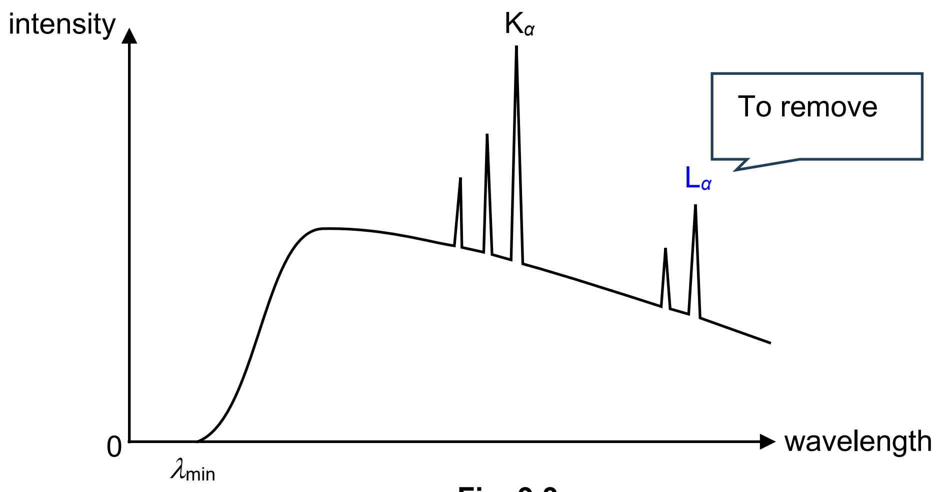


Fig. 9.3

1. On Fig. 9.3, label the peak for L_α transitions. [1]

2. Explain the existence of a minimum wavelength λ_{min}.

The minimum wavelength corresponds to the most energetic X-ray photon produced. [B1]
This happens when a bombarding electron is completely stopped by the target metal and loses all its KE in a single interaction. [B1]

....

....[2]

(iii) With reference to Fig. 9.2, state the minimum energy of the bombarding electrons to produce the characteristic X-rays lines shown in Fig. 9.3.

minimum energy = ... 69.5 .... keV [1]

(iv) Explain your answer in **(d)(iii)**.

The bombarding electrons must have sufficient energy to knock out / remove K-shell electron so that orbital electrons from higher level can de-excite to emit photons resulting in characteristic x-ray lines.

....[1]

(e) Fig. 9.4 below shows a typical setup for producing such X-ray beams.

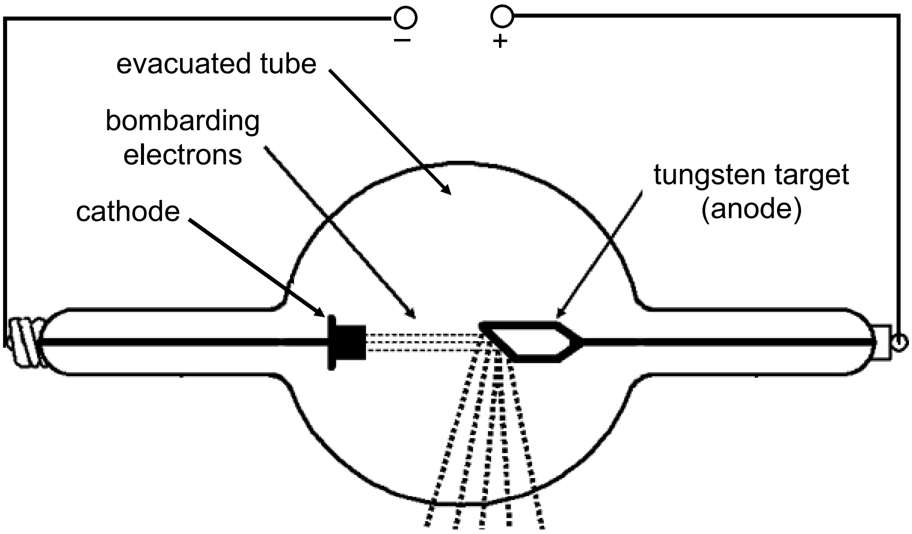


Fig. 9.4

(i) For safety reasons, the wavelength of radiation used for medical X-rays should not be shorter than 50 pm.

Suggest why the wavelength of X-rays radiation should not be shorter than 50 pm.

A shorter wavelength in X-rays translates to higher energy photons, which can be harmful as they can damage living tissue and increase the risk of cancer.

[1]

(ii) Determine the minimum applied potential difference for medical X-rays.

Loss in energy of electron = Maximum photon energy

$q\Delta V = hc / \lambda$

$$\Delta V = \frac{hc}{\lambda q} = \frac{(6.63\times10^{-34})(3.00\times10^{8})}{(50\times10^{-12})(1.60\times10^{-19})}$$ [M1]

$= 24862.5 \text{ V} = 2.5\times10^{4} \text{ V}$ [A1]

minimum potential difference = ... V [2]

[Total: 20]

End of Paper