

H1 Prelim 2 (2016)
Paper 2 Solutions

- 1 To estimate the frictional force acting on a truck, the driver puts his truck at the neutral gear (not stepping on the accelerator nor applying any brakes) while moving on a level road. He finds that the speed slows down from 24 km h^{-1} to 18 km h^{-1} over a distance of 10.5 m . The truck is of mass 1500 kg .

- (a) (i) Show that the frictional force acting on the truck travelling on the level road is 1400 N . [1]

$$v^2 = u^2 + 2as$$

$$(18000/3600)^2 = (24000/3600)^2 + 2a(10.5)$$

$$a = -0.926$$

$$f = ma = (1500)(0.926) = 1388 = 1400 \text{ N (shown)}$$

- (ii) Hence or otherwise, determine the power developed by the truck's engine when it is travelling at a constant speed of 12 m s^{-1} on the level road. The frictional force can be assumed to be constant.

$$P = fv$$

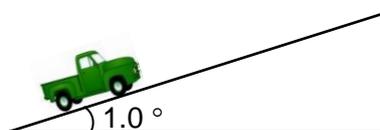
$$\text{Constant speed, driving force (from engine) = friction}$$

$$= (1400)(12)$$

$$= 16800$$

power = W [2]

- (b) The truck then moves up a gentle slope of 1.0° as shown in Fig. 1.1. The frictional force acting on the truck along the slope is 800 N .



Not to scale

Fig. 1.1

Applying the same power from the engine as (a)(ii), determine the maximum speed that the truck can attain up the slope.

$$P_{\text{engine}} = P_{\text{friction}} + WD_{\text{against gravity}} / t$$

$$16800 = 800v + mg h / t$$

$$= 800v + mg d \sin 1 / t$$

$$= 800v + mg v \sin 1$$

$$v = \dots = 15.9 = 16$$

speed = m s^{-1} [3]

- 2 An air-rifle pellet of mass 2.0 g travels horizontally towards a stationary clay block of mass 56 g. The pellet reaches the block with a speed of 140 m s⁻¹ and remains in the block after the collision.

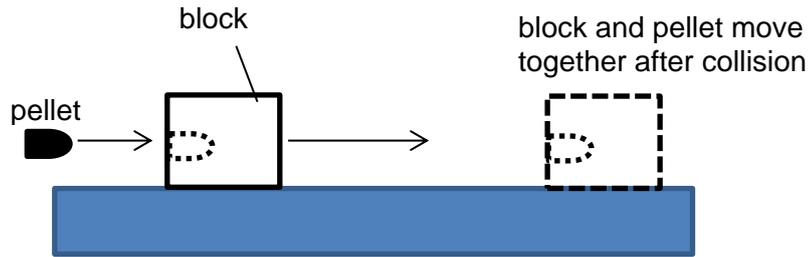


Fig. 2.1

- (a) State the principle of conservation of momentum.

Total momentum of a system of objects remains **constant** provided **no resultant external force** acts on the system.

..... [1]

- (b) Assuming that the total momentum of the pellet and the block is conserved during the collision, calculate the initial speed of the block after impact.

$$\begin{aligned}
 m_1 u_1 &= (m_1 + m_2) v \\
 (2)(140) &= (2 + 56) v \\
 v &= 4.8 \text{ m s}^{-1}
 \end{aligned}$$

speed = m s⁻¹ [2]

- (c) The variation of the momentum of the pellet p with time t is shown in Fig. 2.2. below. The duration of impact (collision) is indicated in the figure.

Sketch the variation of the momentum of the **block only** with time before, during and after the collision. Values of the momentum are not needed in the sketch.

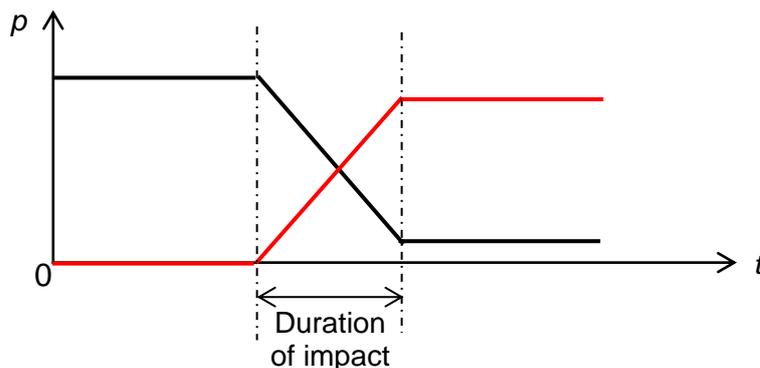


Fig.2.2

[2]

3 (a) Define *potential difference*.

energy per unit charge transferred from electrical energy to other form when the charge passes through an electrical component. [1]

(b) For the purpose of measuring the electrical resistance of shoes through the body of the wearer to a metal ground plate, the National Standards Institute (NSI) uses the circuit shown in Fig. 3.1. The potential difference ΔV across the $1.00 \text{ M}\Omega$ resistor is measured with an ideal voltmeter.

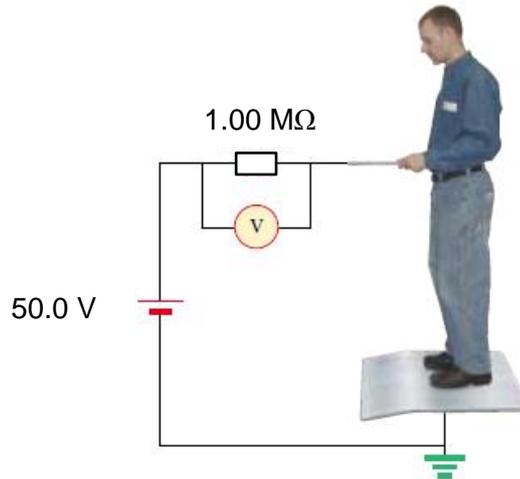


Fig. 3.1

(i) Show that the resistance of the shoes is given by

$$R_{shoes} = 1.00 \times 10^6 \left(\frac{50 - \Delta V}{\Delta V} \right).$$

$$\Delta V = \left(\frac{R_{1.00M\Omega}}{R_{1.00M\Omega} + R_{shoes}} \right) \times E$$

$$\Delta V = \left(\frac{1.00 \times 10^6}{1.00 \times 10^6 + R_{shoes}} \right) \times 50$$

$$R_{shoes} = \dots = 1.00 \times 10^6 \left(\frac{50 - \Delta V}{\Delta V} \right)$$

[1]

[Turn over

- (ii) In a medical test, a current through the human body should not exceed 150 μA .

Show with calculations, whether the current delivered by the circuit exceeds 150 μA . State any assumptions made in your calculations.

$$\text{Current through circuit} = \frac{E}{R_{tot}} = \frac{50}{1.0 \times 10^6 + R_{shoes}} < \frac{50}{1.0 \times 10^6} = 5 \times 10^{-5} \text{ A} = 50 \mu\text{A}$$

thus current is (less than 50 μA which is) less than 150 μA .

Assumption: resistance of the human body is zero.

.....

..... [2]

- (iii) State and explain how the measured value of the resistance of the shoes will change if the voltmeter is not ideal.

If the voltmeter is not ideal, the effective resistance of 1.00 $\text{M}\Omega$ resistor and voltmeter will be lower, and the potential difference across the 1.00 $\text{M}\Omega$ resistor and voltmeter will be lower.

The measured value of resistance will be higher .

[2]

4. The variation of current I with potential difference V across an electrical component X is shown below in Fig.4.1.

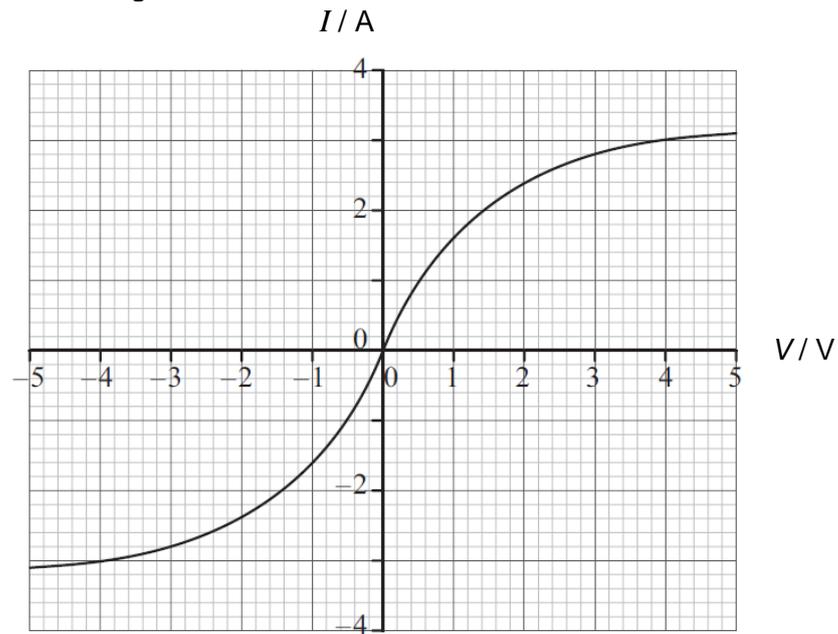


Fig. 4.1

- (a) Fig. 4.2 shows a battery, a potential divider and component X .

Complete Fig. 4.2 to show a setup that can be used to obtain readings for Fig. 4.1. Include in your diagram any other relevant components and measuring instruments.

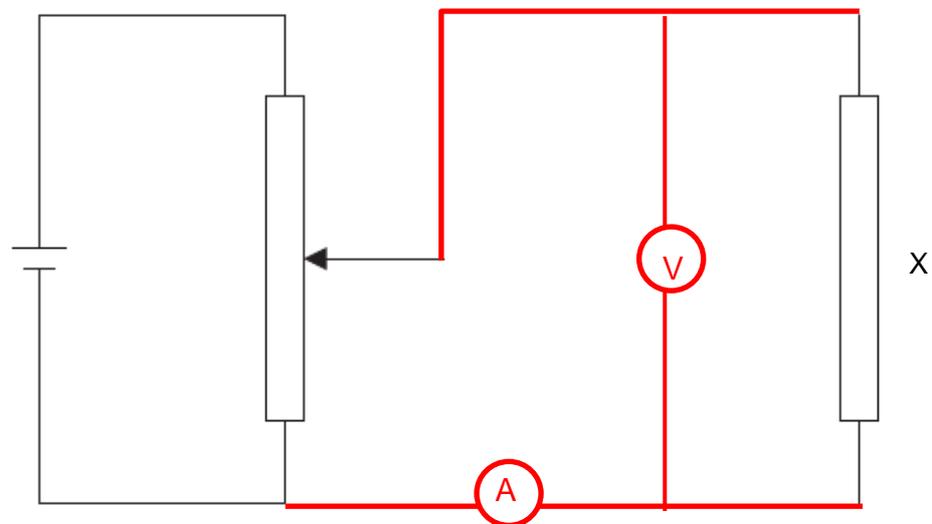


Fig. 4.2

(accept ammeter in series with X)

[2]

- (b) With reference to Fig. 4.1, describe how the resistance of X varies with the

[Turn over

potential difference across it.

As V increases, the ratio of I against V decreases, since $R = V / I$, hence the resistance increases.

..... [2]

- (c) Component X is now connected across the terminal of a cell of e.m.f. 2.0 V with negligible internal resistance.

Using Fig. 4.1, determine the resistance of X.

From Fig 4.1, when $V = 2.0$ V, $I = 2.4$ A,

$$R_x = V / I = 2 / 2.4 = 0.83 \Omega$$

Resistance of X = Ω

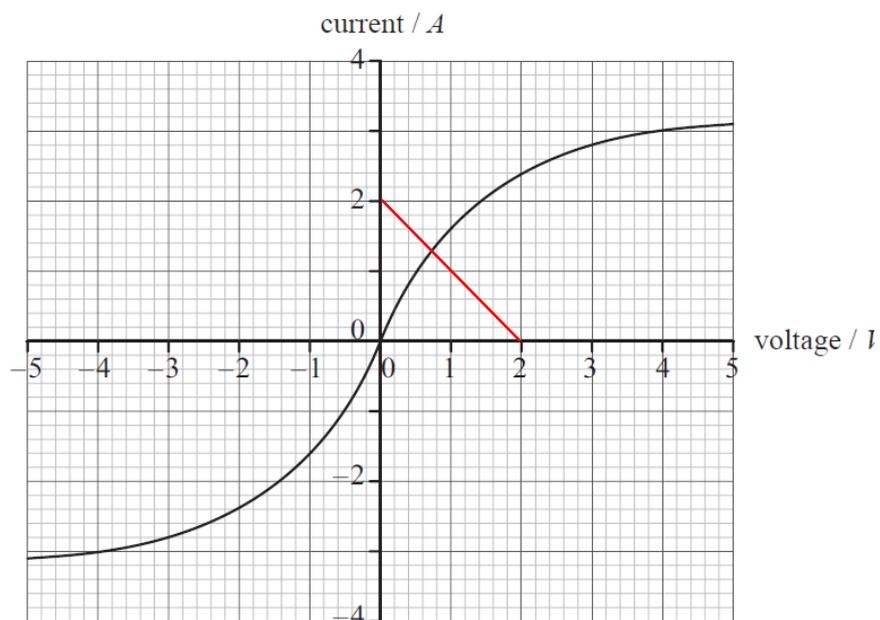
[2]

- (d) A fixed resistor of value 1.0Ω is connected in series with the cell in (c) and X. Using Fig. 4.1, or otherwise, determine the current in the circuit.

$$V_x + (1) I = 2$$

$$\text{Hence } I = 2 - V_x$$

A graph of $I = 2 - V_x$ will intercept original graph at **$I = 1.3$ A**



[3]

- 5 (a) (i) Define the *tesla*.

If a long straight conductor carrying a current of 1 amp is placed at right angles to a uniform magnetic field of flux density of 1 tesla, then the force per unit length on the conductor is 1 newton per metre.

..... [1]

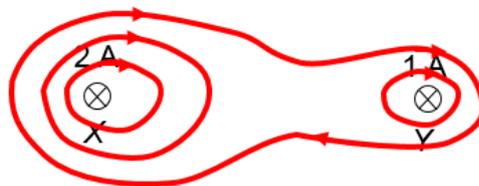
- (ii) Express the tesla in terms of the product of its base units.

$$1 \text{ T} = 1 \text{ N} / \text{A m} = \text{kg m s}^{-2} / \text{A m} = \text{kg s}^{-2} \text{ A}^{-1}$$

base units = [1]

- (b) Two long straight current-carrying conductors X and Y are placed parallel to each other. Conductor X carries a current of 2 A while conductor Y carries a current of 1 A. Both directions of currents are into the plane of the paper.

- (i) Sketch the magnetic flux pattern due to X and Y in Fig. 5.1 below. [2]



[Asymmetry field lines,
More field lines at X,
Arrows correct directions]

Fig. 5.1

- (c) A third conductor Z with a current of 1 A into the plane of the paper is placed on the right of Y.

Y is of equal distance from X and Z.

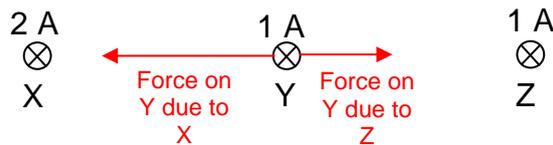


Fig. 5.2

- (i) Indicate with clear labelling on Fig. 5.2 the forces acting on Y. [1]

[left arrow double in length compared to right arrow]

[Turn over

- 6 A container used for storage of liquid is shown below in Fig. 6.1. The lower portion of the container has a uniform cross-sectional area.

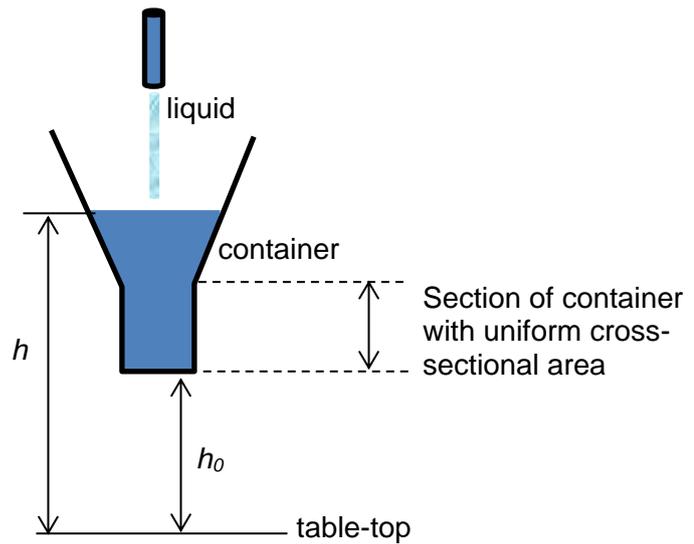


Fig. 6.1

The container, initially empty, is filled with a liquid at a constant rate from above it. The height h of the liquid surface above the table-top is measured as a function of time t . The distance between the base of the container and the table-top is h_0 .

Fig. 6.2 shows the variation of h with t .

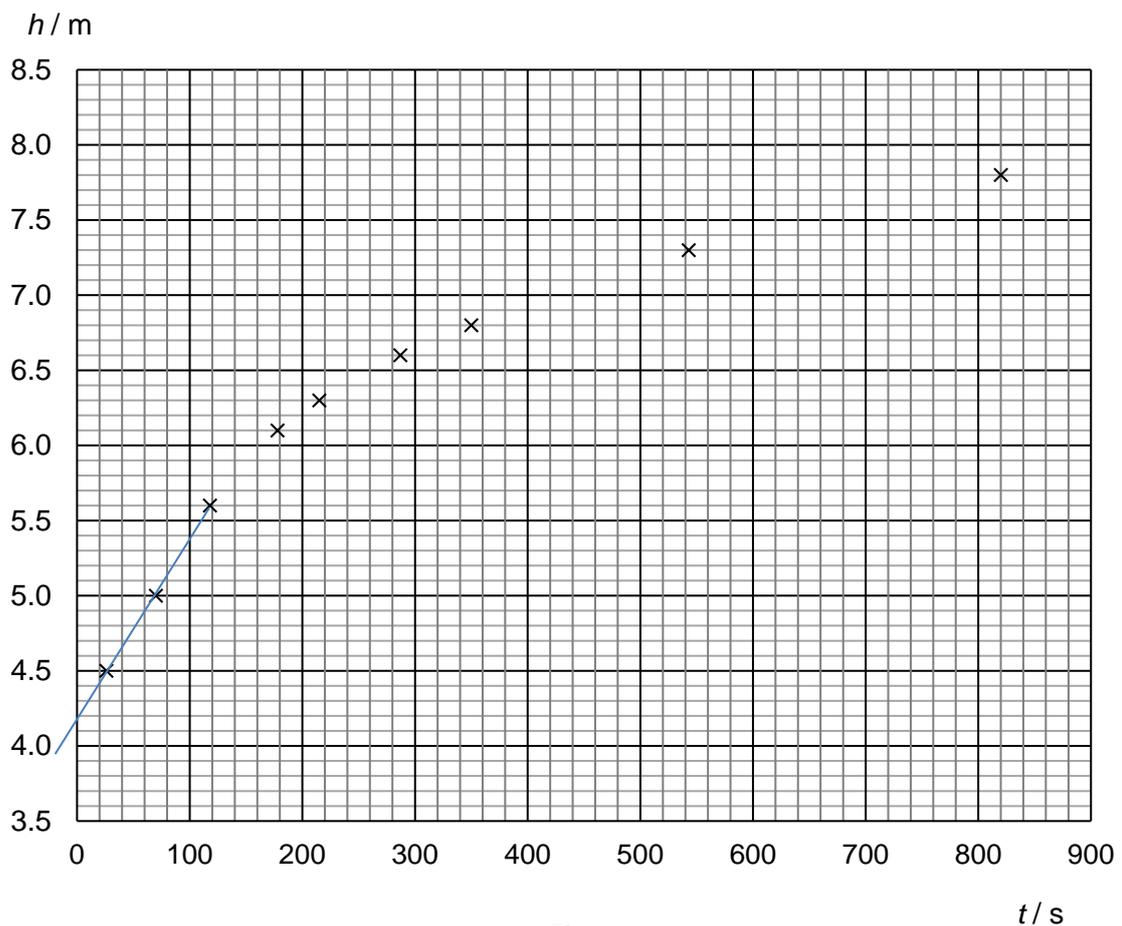


Fig. 6.2

(a) Draw a best-fit line for the graph in Fig. 6.2. [1]
 (first 3 points straight line, the next few points smooth curve)

(b) State and explain if any part of the graph shows that h is proportional to t .
 No parts of the graph shows h is proportional to t
 as no straight line passing through origin can be drawn (for any parts of the curve).

..... [2]
 (c) Determine the value of h_0 .

From graph, when $t = 0$, $h = h_0 = 4.1$ (to 4.2)m

$h_0 = \dots\dots\dots$ m [1]

(d) The base of the container has an area of 1.8 m^2 .

Show that the volume of liquid entering the container each second is approximately $0.020 \text{ m}^3 \text{ s}^{-1}$. [2]

Use first portion of graph, $\text{volume} / t = h A / t$
 Gradient of first part = $h / t = (5.6-4.2) / (120-0) = 0.01167$

Therefore $\text{volume} / t = 0.00167 \times 1.8 = 0.021 \approx 0.020 \text{ m}^3 \text{ s}^{-1}$.

(e) The container is completely filled after 850 s. Calculate the total volume of the container.

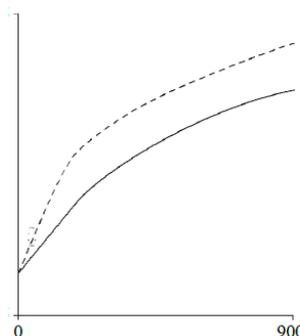
Total volume = $(0.020)(850) = 17 \text{ m}^3$

volume = m^3 [1]

(f) The container is emptied and is now filled at half the rate in (d). Sketch another graph in Fig. 6.2 to show the new variation of h with t for time = 0 to 900 s.

Label the graph as (f). [2]

Graph starts at same point but half initial gradient (judge by eye).
 line always lower than original.



[Turn over

Section B (40 marks)

Answer **two** questions from this Section in the spaces provided.

- 7 (a) (i) Define *acceleration*.

Rate of change of velocity.

[1]

- (ii) The motion of an object may be represented by the equation

$$\frac{u + v}{2} = \frac{s}{t}$$

where u : initial speed,
 v : final speed,
 s : distance travelled in time t .

State one assumption made in order for the above equation to be valid.

Acceleration is constant.

[1]

- (iii) Using (i) and (ii), derive an expression for s in terms of u , t and a , the acceleration of the object.

[1]

$a = (v - u) / t$
hence $v = u + at$ into (ii)

$$[u + (u + at)] / 2 = s / t$$

$$u + \frac{1}{2} at = s / t$$

$$s = ut + \frac{1}{2} at^2$$

- (b) The shutter speed of a camera is an indication of the amount of time that the camera film is exposed to light. In order to determine the shutter speed of a camera, a metal ball is held at rest at the zero mark of a scale, as shown in **Fig. 7.1**. The ball is then released. The shutter of a camera is opened as the ball falls.

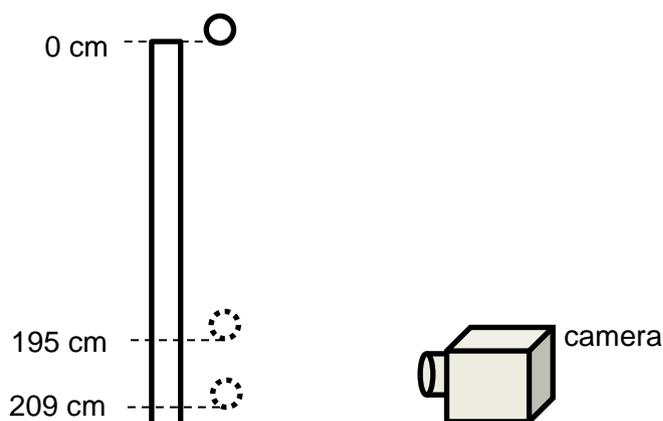


Fig. 7.1

The photograph of the ball shows that the shutter opened as the ball reached the 196 cm mark on the scale and closed as it reached the 209 cm mark.

Assume air resistance is negligible.

- (i) Calculate the time the ball falls from the zero to the 195 cm mark.

$$s = \frac{1}{2} a t^2$$

$$1.95 = \frac{1}{2} (9.81)t^2$$

$$t = 0.63 \text{ s} \quad [2]$$

- (ii) Determine the time duration for which the shutter is opened.

$$s = \frac{1}{2} a t^2$$

$$2.09 = \frac{1}{2} (9.81)t^2$$

$$t = 0.65 \text{ s}$$

hence $0.65 - 0.63 = 0.020 \text{ s}$ (or 0.022 s) [2]

- (iii) Explain why a more accurate value for the shutter speed can be obtained if the ball is allowed to fall a greater distance before the shutter is opened.

Speed is larger after falling greater distance
Hence distance moved captured by camera is greater;
so (fractional) error in measuring distance is reduced. [2]

- (iv) A student performed a similar experiment of a falling object with the help of data-loggers and obtained the following readings :

initial speed	$u = 5.0 \pm 0.1 \text{ m s}^{-1}$
duration of fall	$t = 3.50 \pm 0.01 \text{ s}$
acceleration of free fall	$g = 9.81 \text{ m s}^{-2}$ with no uncertainty

Determine the value of the distance of fall s using the equation in (a)(iii) with its associated uncertainty.

$$s = ut + \frac{1}{2} at^2$$

$$\text{max } s = (5.1)(3.51) + \frac{1}{2} (9.81)(3.51)^2 = 78.33109$$

$$\text{min } s = (4.9)(3.49) + \frac{1}{2} (9.81)(3.49)^2 = 76.84439$$

$$\Delta s = (78.33109 - 76.84439) / 2 = 1.4867 / 2 = \underline{0.743} = 0.7 \text{ (1 sf)}$$

$$s = \dots\dots = (\underline{78.77.6} \pm \underline{0.7}) \text{ m}$$

[2]

$$s = \dots\dots\dots \pm \dots\dots\dots \text{ m}$$

- (c) Another experiment is conducted with a heavier ball of mass 0.50 kg. The ball is

[Turn over

released from rest above the Earth's surface.

Fig. 7.2 shows the variation of its velocity v with time t during the fall.

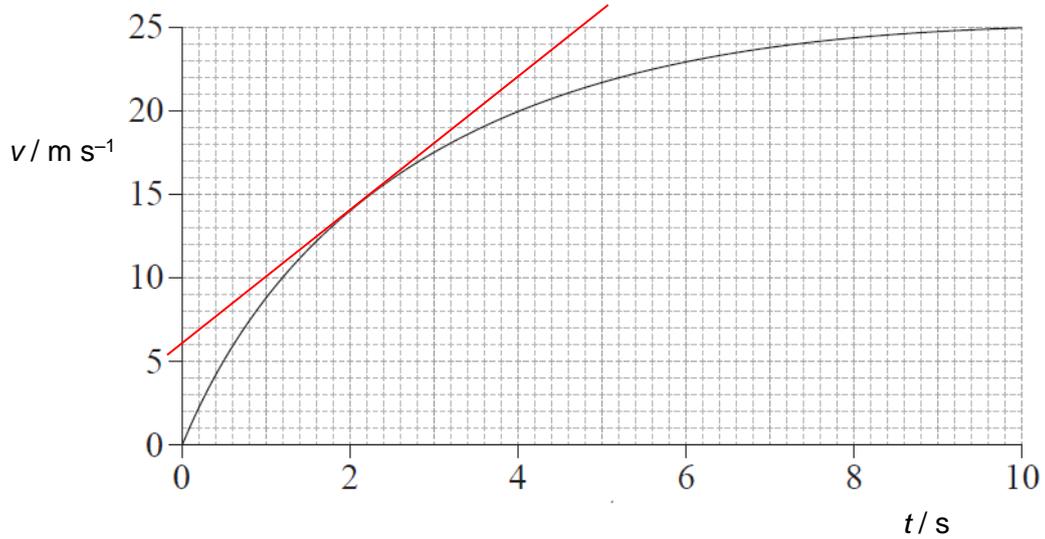


Fig. 7.2

- (i) In Fig. 7.3 below, draw and label the forces acting on the ball at time $t = 2.0$ s. [1]

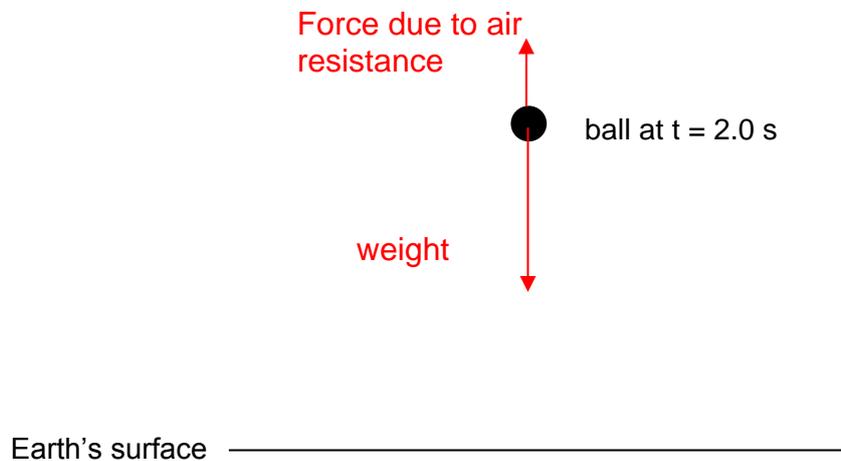


Fig. 7.3

- (ii) Use Fig. 7.2 to show that the acceleration of the ball at 2.0 s is approximately 4.0 m s^{-2} . [1]

$$\begin{aligned} \text{Gradient} &= (25 - 6) / (4.8 - 0) \\ &= 3.95 = 4.0 \end{aligned}$$

- (iii) Calculate the magnitude of the resistive force on the ball at 2.0 s.

$$mg - f = ma$$

$$(0.5)(9.81) - f = (0.5)(4)$$

$$f = 2.9 \text{ N}$$

force = N [2]

- (iv) With reference to Fig. 7.2, state and explain whether the resistive force on the ball at 5.0 s is smaller, equal or greater than that at 2.0 s.

At $t = 5.0 \text{ s}$, the gradient of graph is smaller, hence acceleration is smaller.
Since $f = mg - ma$, therefore resistive force f is larger.

[2]

- (v) Determine the total work done against resistive force after it has fallen for 10 s.

After $t = 10 \text{ s}$, $v = 25 \text{ m s}^{-1}$. Distance travelled = area under graph = 190 m [3]

$$\text{Loss in gPE} = (0.5)(9.81)(190) = 931.95$$

$$\text{Gain in KE} = \frac{1}{2} (0.5)(25^2) = 156.25$$

$$\text{Work done against resistance} = 931.95 - 156.25 = 775 = 780 \text{ J}$$

[Turn over

- 8 (a) (i) State the principle of superposition.

When two or more waves of the same kind meet at a point in space, the resultant displacement of the waves at any point is the vector sum of the displacement due to each wave acting independently.

[2]

- (ii) State two conditions necessary to produce observable interference patterns between light from two sources.

Waves must meet at a point
Coherent Sources
Equal or approximately equal amplitudes
Polarised in the same plane (or unpolarised)
(any two)

[2]

- (iii) A Young's double slits experiment is set up with a source of white light. The light is allowed to pass through a red filter before passing through a single and double slits as shown below in Fig. 8.1.

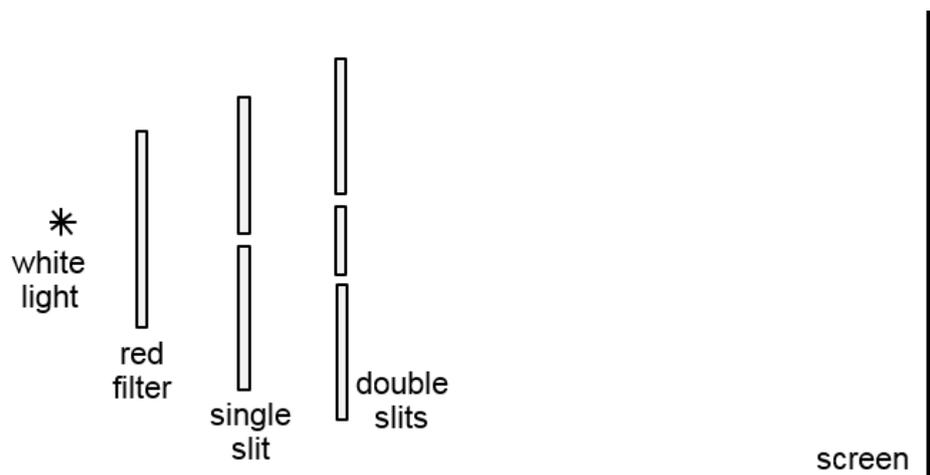


Fig. 8.1

An interference pattern of light and dark fringes is observed on the screen.

The red filter is now replaced by a blue filter.

State and explain the change in the appearance, other than the colour of the light, of the fringes on the screen.

$$x = \lambda D / a$$

blue light smaller wavelength, hence fringe separation is smaller.

[2]

- (iv) The filter in (iii) is now removed. The white light passes through the slits without any filters.

State and explain the appearance of the central maximum fringe and also of fringes that are away from this central position.

You may include a diagram to help in your explanation.

[3]

Central fringe consists of all wavelength, hence white in colour.

For the same order, larger wavelength spread out further away from central position, as fringe separation is proportional to wavelength.

The spreading of a particular order starts from blue (closer to central position) and ends with red light.

- (b) An experiment to demonstrate stationary wave formed in an open pipe is carried out. A loudspeaker is attached to the end of an open pipe. A signal generator is then connected to it. At a particular frequency, a stationary wave is formed inside the pipe.

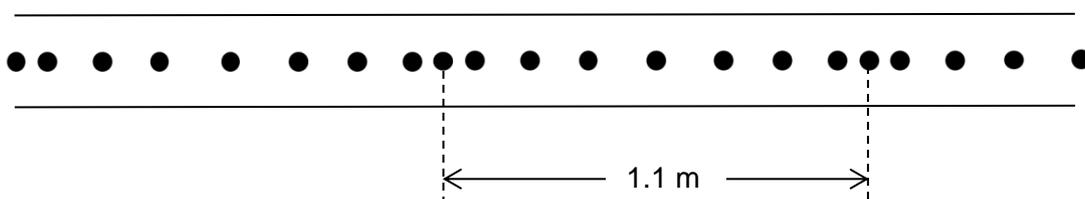


Fig. 8.2

Fig. 8.2 shows the horizontal displacement of the particles along a section of the pipe at an instant in time.

- (i) Explain the formation of the stationary wave in the pipe.

As the incident wave travels down the pipe, it will be reflected at the open end of the pipe (due to pressure differences/difference in density of medium).

[2]

As both incident and reflected waves have the similar amplitude, frequency, speed and move in opposite directions, the incident and reflected wave will superpose to form a stationary wave.

[Turn over

- (ii) Determine the node-to-node distance of the sound wave in the pipe.

$$\frac{1.1}{2} = 0.55 \text{ m}$$

distance = m [1]

- (iii) The frequency of the sound wave produced by the loudspeaker is slowly increased from a very low value. A series of loud and soft sounds is heard in the pipe.

In Fig. 8.3, show how the amplitude of the resultant wave varies from one end to the other for the **second** instance a loud sound is heard in the pipe.

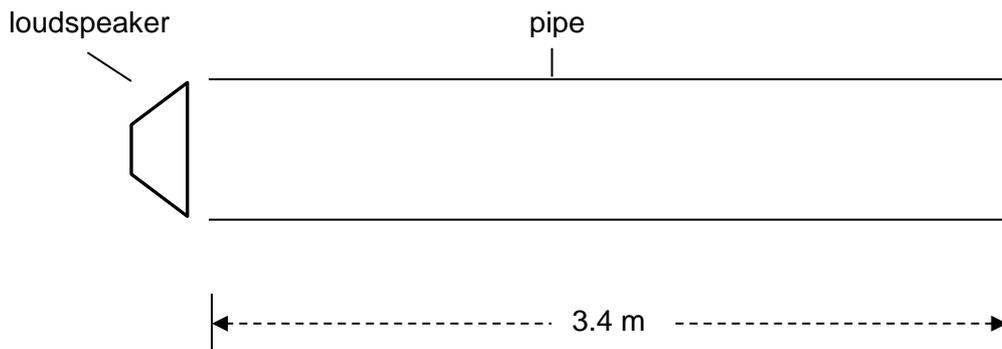
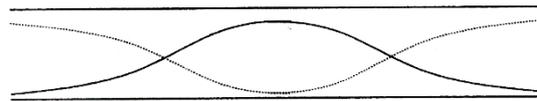


Fig. 8.3

[2]



- (iv) Given that the speed of sound is 340 m s^{-1} , calculate the **fundamental frequency** of the pipe.

$$f = \frac{v}{\lambda} = \frac{340}{2(3.4)} = 50 \text{ Hz}$$

frequency = Hz [2]

- (c) Two of the loudspeakers mentioned in (b) are driven by the same oscillator and are located on a vertical pole a distance of 8.0 m away from each other.

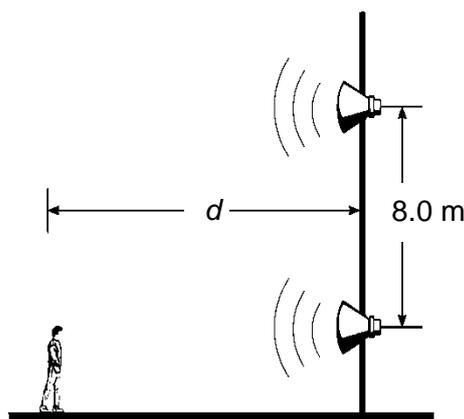


Fig. 8.4

A man walks towards the lower loudspeaker in a direction perpendicular to the pole as shown in the Fig. 8.4 while the loudspeakers are producing sound of wavelength 2.0 m. The lower speaker is at the same height as the ears of the man.

As the man walks towards the lower loudspeaker, he hears a series of maximum and minimum in sound intensities.

- (i) Show that the distance d that the man is away from the lower loudspeaker when the intensity of the sound is a minimum, can be expressed as

$$d = \frac{63 - 4n^2 - 4n}{2(2n+1)}, \text{ where } n = 0, 1, 2 \dots$$

$$\sqrt{8^2 + d^2} - d = (n + \frac{1}{2})\lambda$$

$$(8^2 + d^2) = (2n+1+d)^2$$

$$(8^2 + d^2) = 4n^2 + 4n + 4nd + 1 + 2d + d^2$$

$$d = \frac{63 - 4n^2 - 4n}{2(2n+1)}$$

[2]

- (ii) Hence or otherwise, find the number of times that the man will hear a minimum in sound intensity when he walks towards the lower loudspeaker from 50 m away.

Since $n \geq 0$, and $d > 0$, hence $63 - 4n^2 - 4n > 0$

$n = 3.5$ or -4.5 .

No of times = 4.

n	0	1	2	3	4
	31.5	9.166667	3.9	1.071429	-0.94444

[Turn over

no. of minimum = [2]

- 9 (a) According to a wave model of electromagnetic theory of light, it is assumed that an electron on the surface of a metal absorbs all the energy of an incident radiation on the surface of the metal within a distance of 5.0×10^{-11} m.

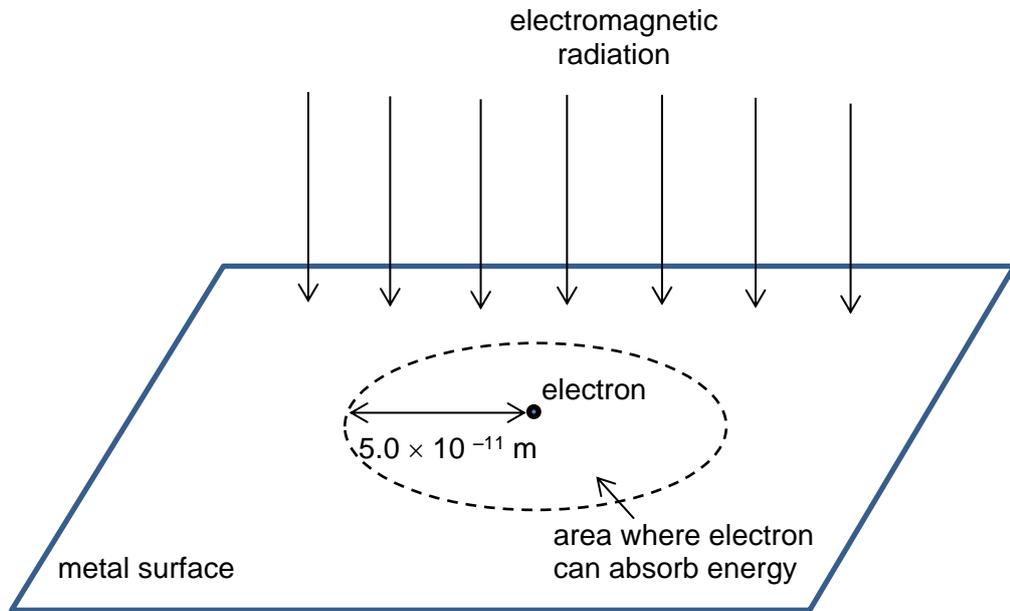


Fig. 9.1

The intensity of light incident normally on the metal surface is 1.6 W m^{-2} and the energy required to remove an electron from the surface is 1.8 eV .

- (i) Based on the above model, calculate the time needed for the electron to gain sufficient energy to leave the surface.

$$\begin{aligned} P &= E / t \\ t &= E / P \\ &= (1.8)(1.6 \times 10^{-19}) / (1.6)(\pi (5 \times 10^{-11})^2) = 23 \text{ s} \end{aligned}$$

[2]

time =s

- (ii) Experimental observations indicate that electrons are emitted from the surface in less than 10^{-9} s.
Explain how this observation is consistent with the particle theory of light.
Energy of light is carried in bundles/quanta/photons; so the electron will be ejected immediately after it absorbs one photon (of sufficient energy) [1]

- (iii) The incident light has intensity 1.6 W m^{-2} , wavelength 520 nm and 5.0% of the incident photons cause the ejection of electrons from the surface. Using the particle theory of light, determine the number of electrons ejected from 1.0 m^2 of the surface per second.

$$\text{Energy of } N \text{ photons} = N h c / \lambda$$

$$\text{Power} = E / t = \text{Intensity} \times \text{area}$$

$$\text{Hence } N h c / \lambda t = \text{Intensity} \times \text{area}$$

$$N/t = (1.6)(1) (520 \times 10^{-9}) / (6.63 \times 10^{-34})(3 \times 10^8)$$

$$= 4.18 \times 10^{18}$$

$$0.05 \times 4.18 \times 10^{18} = \underline{2.09 \times 10^{17}}$$

[3]

- (b) Fig. 9.2 shows an experimental setup used to investigate the photoelectric effect.

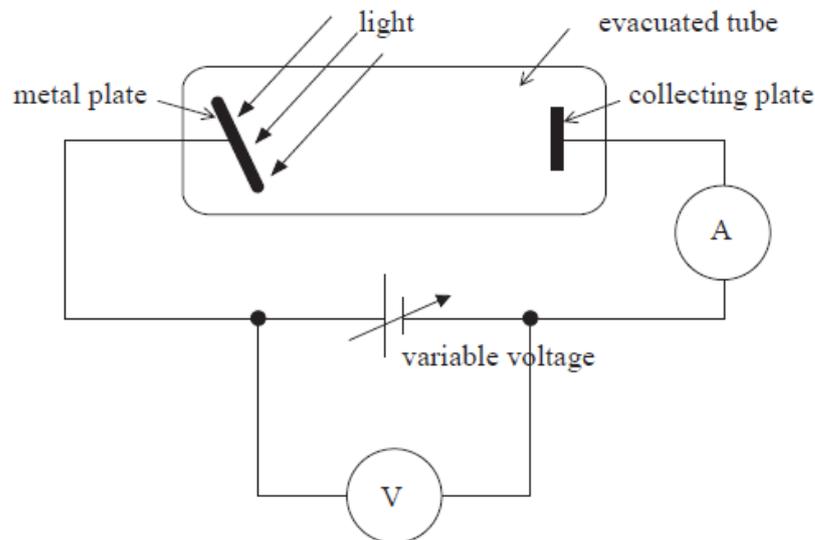


Fig. 9.2

Describe how the setup can be used to determine the maximum kinetic energy of the emitted electrons for incident light of frequency f .

Apply negative potential at collecting plate.

Slowly increase magnitude of negative potential until current just reads zero.

The potential value is stopping potential V_s .

Max KE = $e V_s$.

[3]

[Turn over

- (c) A student performed a photoelectric emission experiment. The graph of stopping potential against frequency of incident light falling on the metal surface is shown in Fig. 9.3.

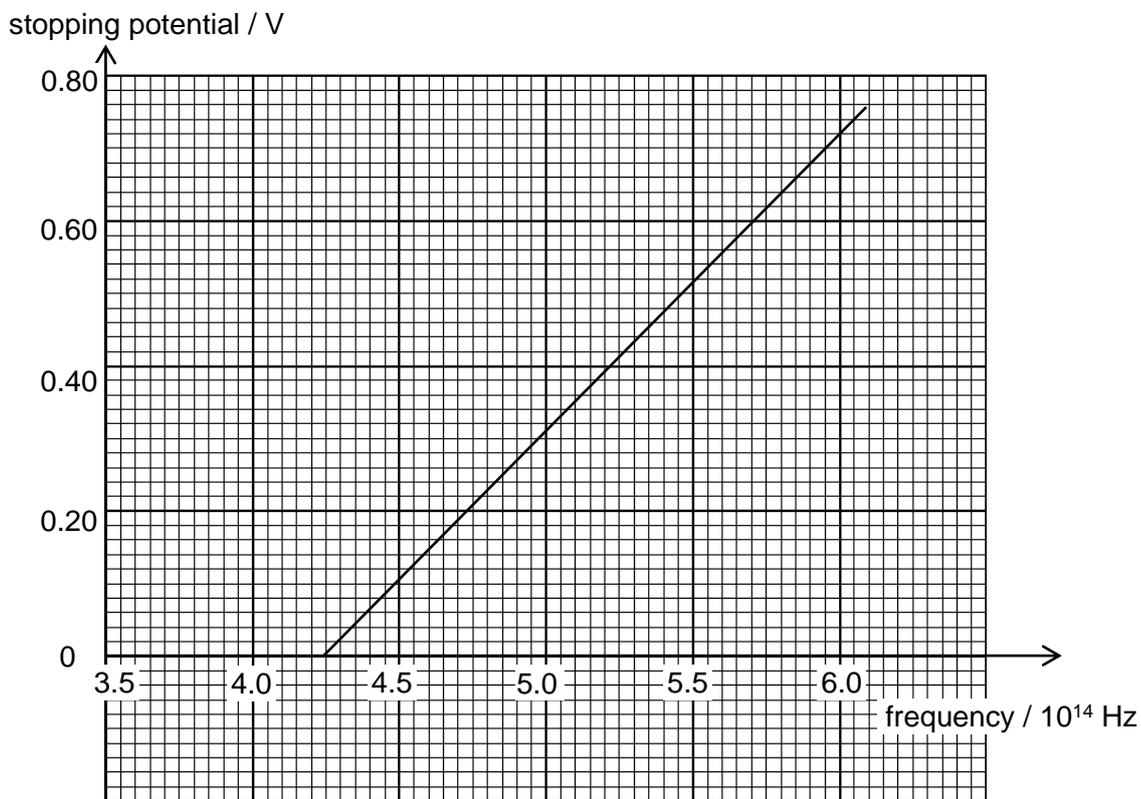


Fig. 9.3

- (i) State what is meant by *stopping potential*.

Stopping potential is the potential difference between the electrodes in a photoelectric experiment, in which the emitted electrons with the maximum kinetic energy (most energetic) from one electrode are just prevented from reaching the other electrode.

[1]

- (ii) Using Fig. 9.3, determine

1. the Planck's constant.

since $\text{gradient of graph} = \frac{h}{e}$,

$$h = \left(\frac{0.52 - 0}{(5.50 - 4.25) \times 10^{14}} \right) (1.6 \times 10^{-19}) = 6.66 \times 10^{-34}$$

Planck's constant = J s [2]

2. the work function for the metal.

work function

$$= hf_0 = (6.66 \times 10^{-34})(4.25 \times 10^{14}) / (1.6 \times 10^{-19}) \\ = 1.76 \text{ eV}$$

work function = eV [1]

(iii) Hence or otherwise, determine the stopping potential when the photons with wavelength 694×10^{-9} m are incident on the metal surface.

$$\text{Since } f = \frac{c}{\lambda} = \frac{c}{694 \times 10^{-9}} = 4.32 \times 10^{14} \text{ Hz}$$

From Fig. 8.2, when $f = 4.32 \times 10^{14}$ Hz, stopping potential = 0.030 V

OR

$$\text{Using } E_k = eV_s = h\frac{c}{\lambda} - hf_0,$$

$$\text{Since } f = \frac{c}{\lambda} = \frac{c}{694 \times 10^{-9}} = 4.32 \times 10^{14} \text{ Hz}$$

$$(1.6 \times 10^{-19})V_s = (6.66 \times 10^{-34})(4.32 \times 10^{14} - 4.25 \times 10^{14})$$

$$V_s = 0.030 \text{ V}$$

OR

Since energy of photon is 1.79 eV and the work function is 1.76 eV, the stopping potential is $= \frac{1.79 \text{ eV} - 1.76 \text{ eV}}{e} = 0.030 \text{ V}$

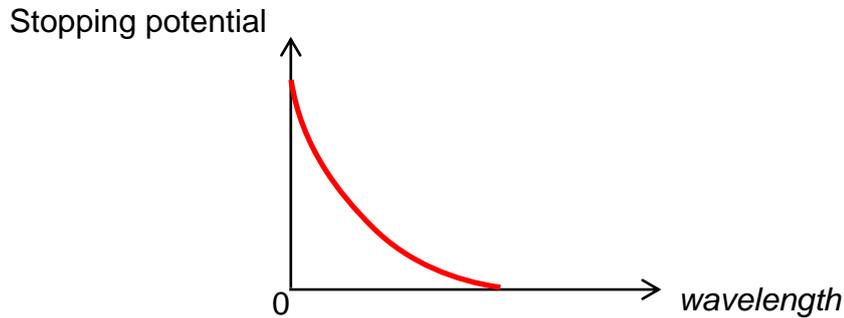
stopping potential = V [2]

(iv) Explain why the graph does not extend below the horizontal axis.

There is no photoelectric effect for frequency less than the threshold frequency. [1]

[Turn over

- (v) Sketch a graph in the axes below to show the variation of stopping potential with the wavelength of the incident light for the same photoelectric experiment.



[1]

- (d) The threshold wavelength of a photoelectric experiment is given to be λ_0 . Light of wavelength $\frac{1}{2} \lambda_0$ and intensity I is incident on the metal surface in (c). The photocurrent detected is I_p .

State and explain the effect on the current I_p for light incident on the surface

- (i) of wavelength $\frac{1}{2} \lambda_0$ and intensity $2 I$

Intensity increases, number of photons per unit time increases.
Hence current detected is $2 I_p$

[2]

- (ii) of wavelength $2\lambda_0$ and intensity I .

No photoelectric effect since it is more than threshold wavelength.

[1]

END OF PAPER