



Oxford Cambridge and RSA

Wednesday 24 May 2023 – Afternoon

AS Level Physics A

H156/02 Depth in physics

Time allowed: 1 hours 30 minutes



You must have:

- the Data, Formulae and Relationships Booklet

You can use:

- a scientific or graphical calculator
- a ruler (cm/mm)



Please write clearly in black ink. **Do not write in the barcodes.**

Centre number

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Candidate number

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First name(s)

Last name

StemUp Model Solution

INSTRUCTIONS

- Use black ink. You can use an HB pencil, but only for graphs and diagrams.
- Write your answer to each question in the space provided. If you need extra space use the lined pages at the end of this booklet. The question numbers must be clearly shown.
- Answer **all** the questions.
- Where appropriate, your answer should be supported with working. Marks might be given for using a correct method, even if your answer is wrong.

INFORMATION

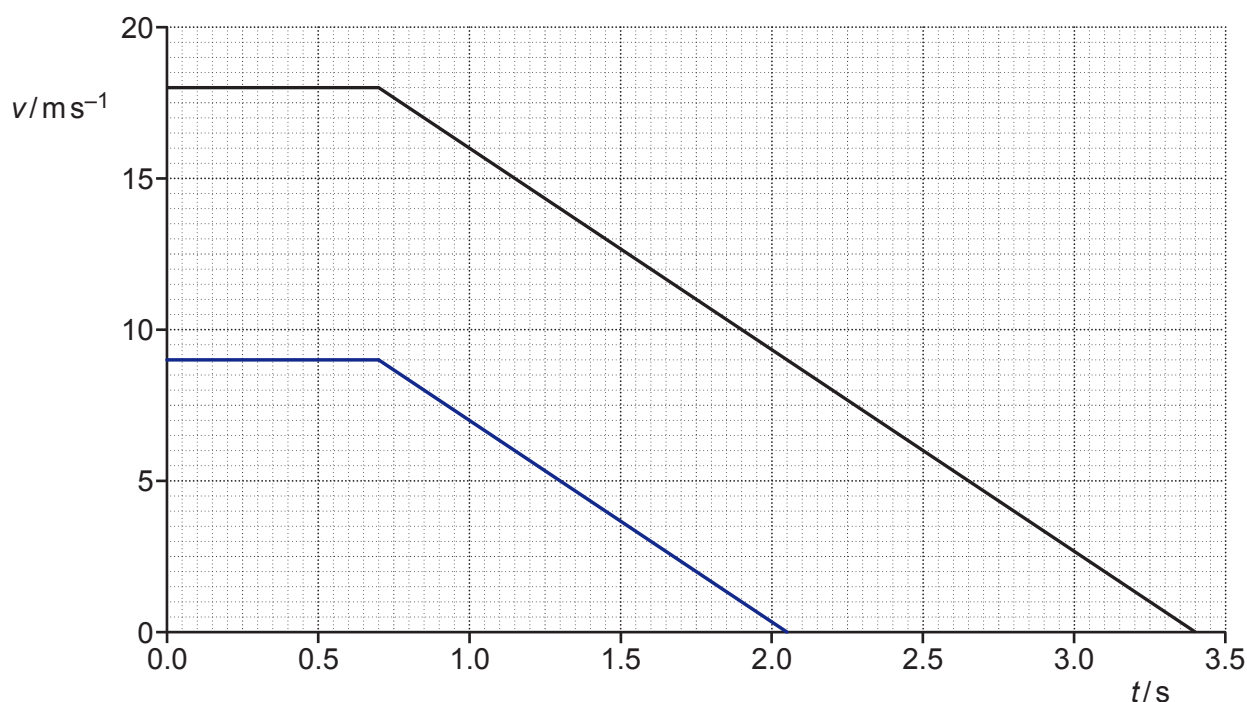
- The total mark for this paper is **70**.
- The marks for each question are shown in brackets [].
- Quality of extended response will be assessed in questions marked with an asterisk (*).
- This document has **24** pages.

ADVICE

- Read each question carefully before you start your answer.

- 1 The brakes of a car of mass 1200 kg are being tested on a track. The driver sees a hazard and applies the brakes.

The graph shows the variation of the velocity v of the car with time t from when the driver sees the hazard to when the car stops.



- (a) (i) Calculate the acceleration a of the car while the brakes are applied.

$$a = \Delta v \div \Delta t = (0 - 18) \div (3.4 - 0.7)$$

$$a = -18 \div 2.7 = -6.7 \text{ m s}^{-2}$$

$$a = \dots -6.7 \dots \text{ m s}^{-2} \text{ [1]}$$

- (ii) Calculate the average braking force F while the brakes are applied.

$$F = ma = 1200 \times 6.7$$

$$F = 8000 \text{ N (8040 N)}$$

$$F = \dots 8000 \dots \text{ N [1]}$$

- (iii) Calculate the total stopping distance d of the car.

$$d = \text{thinking distance} + \text{braking distance}$$

$$d = 18 \times 0.7 + \frac{1}{2} \times 18 \times 2.7 = 12.6 + 24.3$$

$$d = 36.9 \text{ m}$$

$$d = \dots 37 \dots \text{ m [2]}$$

- (iv) Calculate the work W done by the brakes to stop the car.

$$W = \text{loss in kinetic energy} = \frac{1}{2}mv^2$$

$$W = \frac{1}{2} \times 1200 \times 18^2 (= 8000 \times 24.3)$$

$$W = 1.9 \times 10^5 \text{ J (194 000 J)}$$

$$W = \dots 1.9 \times 10^5 \dots \text{ J [2]}$$

- (b) The same driver in the same car repeats the test at half the initial velocity. The braking force is constant.

On the graph, draw the variation of velocity of the car from the time the driver sees the hazard to the time the car stops.

[2]

- (c) Explain how your graph in (b) would change if:

- (i) the driver was tired

The horizontal section would be longer (longer reaction time); the sloping line would have the same gradient.

[1]

- (ii) the surface of the track was more resistive.

The sloping section would be steeper (greater deceleration); the horizontal section would be unchanged.

[1]

- 2* A student is investigating the motion of small metal balls falling from rest vertically through a liquid.

The student drops a ball of diameter d from rest at the surface of the liquid. The student determines the terminal velocity v of the ball in the liquid.

It is suggested that the relationship between the terminal velocity v and the diameter d is

$$v = \frac{(\rho - \sigma)gd^2}{18K}$$

where

ρ is the density of the metal

σ is the density of the liquid

g is the acceleration of free fall = 9.81 ms^{-2} and

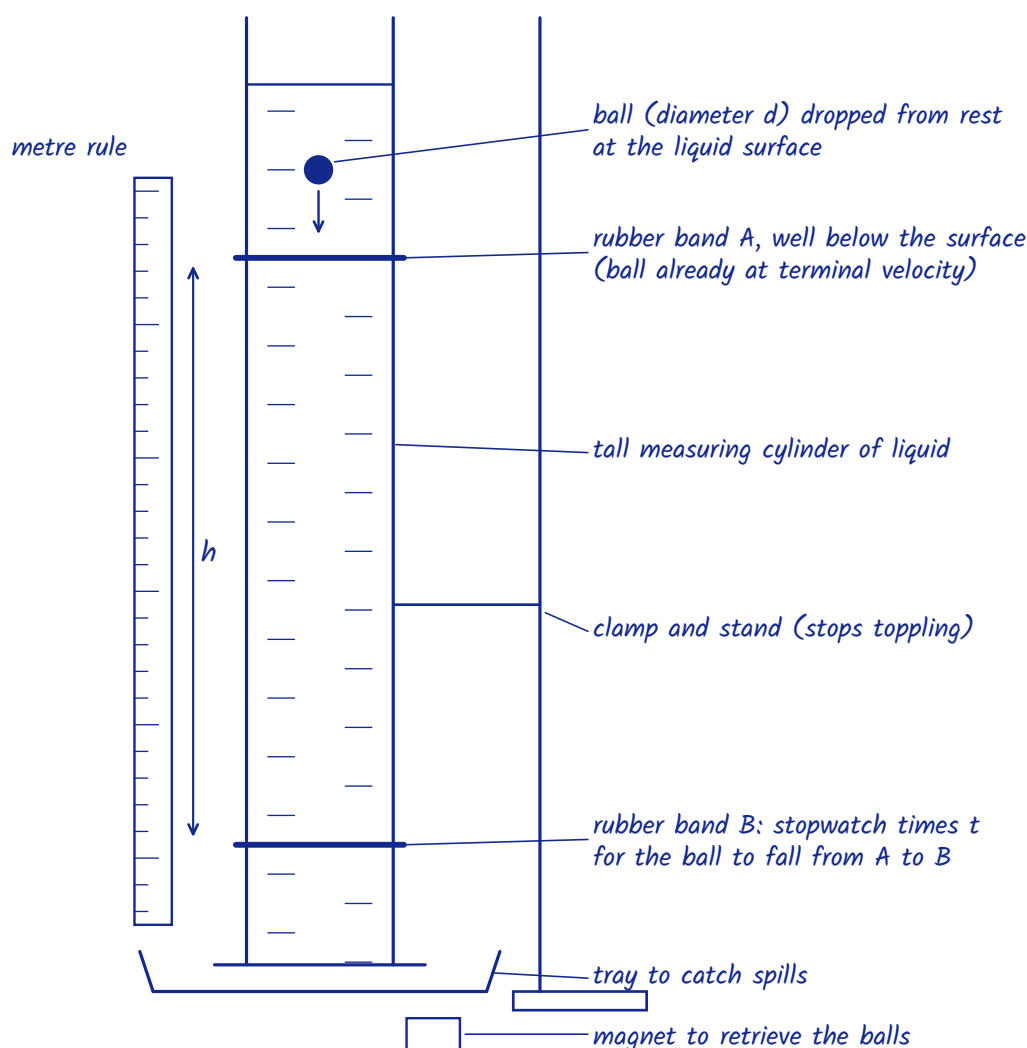
K is a constant.

Describe, with the aid of a suitable diagram:

- how an experiment can be safely conducted to test this relationship between v and d , and
- how the data can be analysed to determine K .

[6]

Diagram



Set up as in the diagram. Clamp a tall measuring cylinder of the liquid upright in a tray. Put two rubber bands round it, the upper band A well below the surface so the ball has reached terminal velocity, and measure the distance h between the bands with a metre rule.

Measure d with a micrometer, taking readings in different directions on the ball, and find the mean. Find $\rho = \text{mass} \div \text{volume}$, using a balance for the mass and volume = $\frac{4}{3} \pi (d/2)^3$; find σ from the mass of a known volume of liquid in a measuring cylinder.

Drop the ball from rest at the surface and use a stopwatch to time t from A to B, viewing at eye level to avoid parallax. Check v is terminal: two equal distances lower down give the same time. Repeat three times and find the mean t ; $v = h/t$. Repeat for at least six different diameters of the same metal.

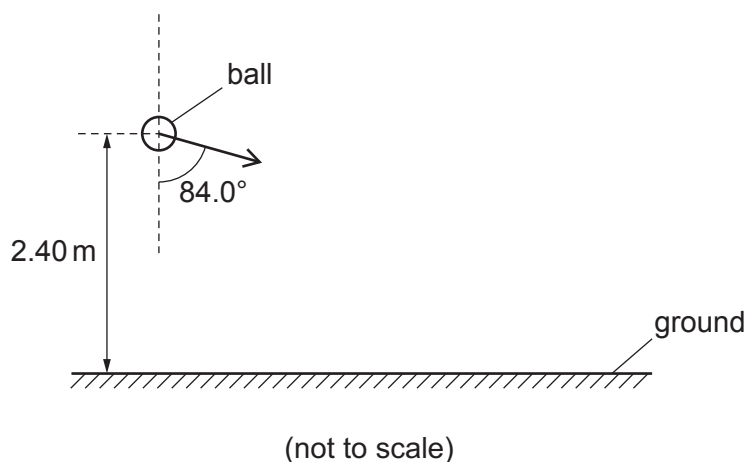
Safety: the tray catches spills and the clamp stops the cylinder toppling; wipe up spills so no one slips; remove balls with a magnet, not hands.

Analysis: plot a graph of v (y-axis) against d^2 (x-axis). If the relationship is correct

Additional answer space if required

the graph is a straight line through the origin. Gradient = $(\rho - \sigma)g/18K$, so $K = (\rho - \sigma)g \div (18 \times \text{gradient})$.

- 3 A student throws a ball of mass 0.210 kg. The hand of the student is a vertical distance of 2.40 m above the ground. The ball leaves the student's hand with a velocity of 22.3 m s^{-1} at an angle of 84.0° to the vertical as shown in the diagram.



Assume that air resistance is negligible.

- (a) Show that the vertical component u_v of the velocity of the ball as it leaves the student's hand is about 2.33 m s^{-1} .

$$u_v = 22.3 \cos 84.0^\circ = 2.33 \text{ m s}^{-1}$$

[1]

- (b) Show that the vertical component v_v of the velocity of the ball as it hits the ground is about 7.25 m s^{-1} .

$$v^2 = u^2 + 2as = 2.33^2 + 2 \times 9.81 \times 2.40$$

$$v_v^2 = 52.5, \text{ so } v_v = \sqrt{52.517} = 7.247$$

$$v_v = 7.25 \text{ m s}^{-1}$$

[2]

- (c) Calculate the kinetic energy E_k of the ball as it hits the ground.

$$\text{horizontal component } u_h = 22.3 \sin 84.0^\circ = 22.2 \text{ m s}^{-1} \text{ (constant)}$$

$$v = \sqrt{(22.2^2 + 7.25^2)} = \sqrt{545} = 23.35 \text{ m s}^{-1}$$

$$E_k = \frac{1}{2}mv^2 = \frac{1}{2} \times 0.210 \times 23.35^2$$

$$E_k = 57.2 \text{ J}$$

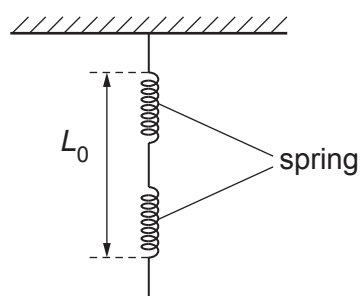
$$E_k = 57.2 \text{ J [3]}$$

- (d) Explain why the momentum of the ball changes as the ball travels from the hand to the ground.

Momentum = mass $\times$ velocity, and momentum is a vector. Gravitational force (weight) acts on the ball and force = rate of change of momentum, so as the ball falls its velocity increases (and changes direction), so the momentum changes (increases). [2]

- 4 (a) Two identical springs each have a force constant of 36 N m^{-1} . In an experiment, the two springs are suspended from a fixed support as shown in Fig. 4.1.

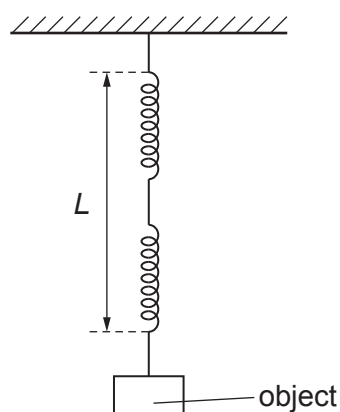
Fig. 4.1



The initial length of the spring arrangement is L_0 .

An object of mass M is added to the spring arrangement as shown in Fig. 4.2.

Fig. 4.2



The new length of the spring arrangement is L .

A student measures L_0 and L and records the results in a table.

Quantity	Measurement/mm
L_0	(22.2 ± 0.1)
L	(54.9 ± 0.1)

- (i) State the name of the instrument the student used to measure L_0 and L .

Vernier callipers [1]

- (ii) Determine the extension x of the spring arrangement. Include the absolute uncertainty in your answer.

$$x = 54.9 - 22.2 = 32.7 \text{ mm}; \text{ uncertainty} = 0.1 + 0.1 = 0.2 \text{ mm}$$

$$x = 32.7 \pm 0.2 \text{ mm} \quad [1]$$

- (iii) Calculate the mass M of the object. Write your answer to **2** significant figures.

$$\text{springs in series: } k = 36 \div 2 = 18 \text{ N m}^{-1}$$

$$Mg = kx = 18 \times 0.0327 = 0.589 \text{ N}$$

$$M = 0.589 \div 9.81 = 0.060 \text{ kg}$$

$$M = \dots 0.060 \dots \text{ kg [2]}$$

- (iv) Calculate the total energy W stored by the springs when the object is suspended.

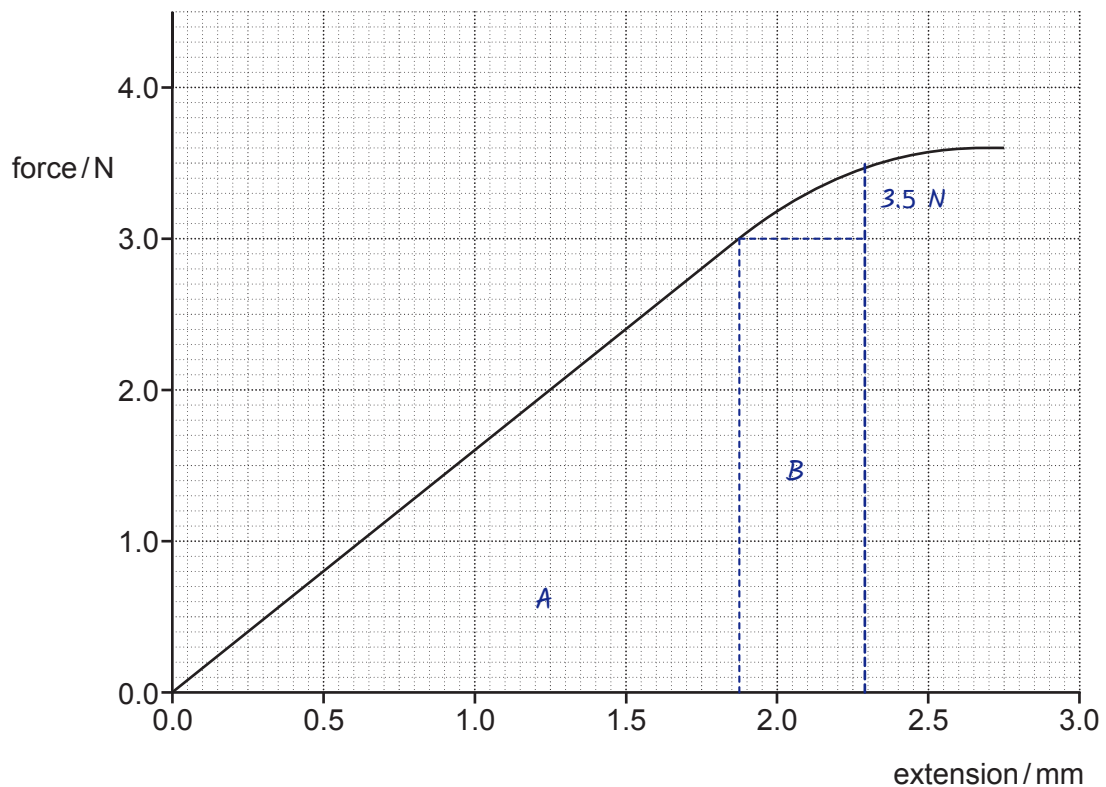
$$W = \frac{1}{2}kx^2 = \frac{1}{2} \times 18 \times 0.0327^2$$

$$W = 9.6 \times 10^{-3} \text{ J}$$

$$W = \dots 9.6 \times 10^{-3} \dots \text{ J [2]}$$

- (b) A metal wire has a length of 4.4 m. The Young modulus of the metal is 120 GPa.

In an experiment force is applied to the wire and the extension is measured.
The graph shows the variation of the extension of the wire with the force applied.



- (i) The gradient of the linear section of the graph is 1.6 N mm^{-1} .

Determine the cross-sectional area A of the wire.

$$E = FL/Ax, \text{ so } F = (EA/L) x \text{ and gradient} = EA/L$$

$$\text{gradient} = 1.6 \text{ N mm}^{-1} = 1600 \text{ N m}^{-1}$$

$$A = \text{gradient} \times L \div E = 1600 \times 4.4 \div 120 \times 10^9$$

$$A = 5.9 \times 10^{-8} \text{ m}^2$$

$$A = \dots 5.9 \times 10^{-8} \dots \text{m}^2 \text{ [3]}$$

- (ii) Use the graph to determine an estimate of the work done E_w in stretching the wire when a 3.5 N force is applied.

work done = area under graph up to 3.5 N (at 2.29 mm)

triangle A (linear part) = $\frac{1}{2} \times 3.0 \times 1.875 \times 10^{-3} = 2.8 \times 10^{-3} \text{ J}$

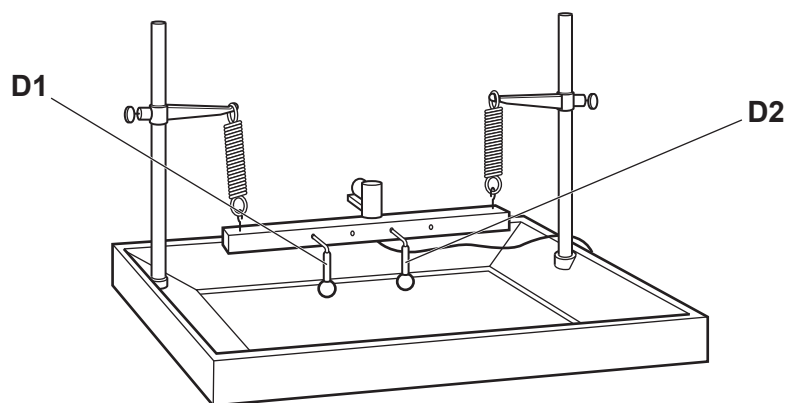
curved strip B $\approx$ average force $3.3 \text{ N} \times 0.42 \times 10^{-3} \text{ m} = 1.4 \times 10^{-3} \text{ J}$

$E_w = 2.8 \times 10^{-3} + 1.4 \times 10^{-3} = 4.2 \times 10^{-3} \text{ J}$

$E_w = \dots 4.2 \times 10^{-3} \dots \text{ J [3]}$

- 5 Two spherical dippers, **D1** and **D2** oscillate on a ripple tank as shown in **Fig. 5.1**.

Fig. 5.1



Waves on the surface of the water are produced from each dipper. These waves are in phase with each other.

The water waves have a speed of 8.0 cm s^{-1} and a wavelength of 3.2 cm .

- (a) (i) State and explain whether these waves are transverse or longitudinal waves.

Transverse, because the water surface oscillates vertically, at right angles (perpendicular) to the direction of travel of the wave (energy transfer). [1]

- (ii) State and explain whether these waves are plane polarised.

Yes, they are plane polarised, because the oscillations are all in one plane only (the vertical plane). [1]

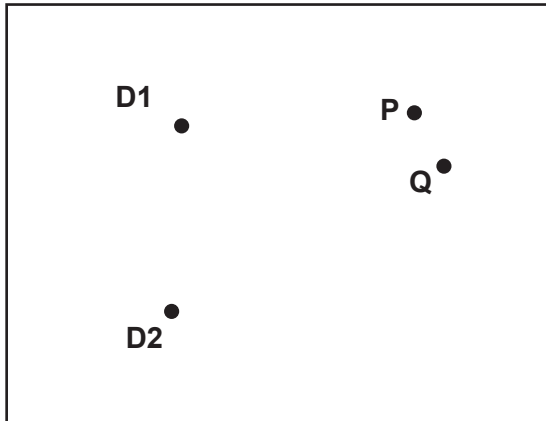
- (b) Calculate the frequency f of the dippers.

$$f = v/\lambda = 8.0 \div 3.2 = 2.5 \text{ Hz}$$

$$f = 2.5 \text{ Hz} \quad [1]$$

- (c) Fig. 5.2 shows the positions **D1** and **D2** of the two dippers in the ripple tank.

Fig. 5.2



P and **Q** are two points on the water.

- (i) The distance between **P** and **D1** is 12.2 cm.
The distance between **P** and **D2** is 20.2 cm.

Explain whether constructive or destructive interference occurs at **P**.

$$\text{path difference} = 20.2 - 12.2 = 8.0 \text{ cm}; 8.0 \div 3.2 = 2.5, \text{ so } 2.5\lambda$$

The path difference is an odd number of half wavelengths (2.5λ), so
the waves from **D1** and **D2** arrive at **P** in antiphase (180° out of
phase): destructive interference occurs. [3]

- (ii) The distance between **Q** and **D1** is 12.5 cm.
The distance between **Q** and **D2** is 19.7 cm.

Calculate the phase difference ϕ , in rad, between the waves arriving at point **Q** from **D1** and the waves arriving at **Q** from **D2**.

$$\text{path difference} = 19.7 - 12.5 = 7.2 \text{ cm}$$

$$7.2 \div 3.2 = 2.25, \text{ so path difference} = 2.25\lambda$$

$$\phi = 0.25 \times 2\pi = \pi/2 \text{ rad} = 1.6 \text{ rad}$$

$$\phi = \pi/2 \text{ (1.6)} \text{ rad [3]}$$

- 6 A switch, resistor of resistance R and a component Z are connected to a battery of electromotive force (e.m.f.) E and internal resistance r . An ammeter and voltmeter are also connected to the circuit as shown in Fig. 6.1.

Fig. 6.1

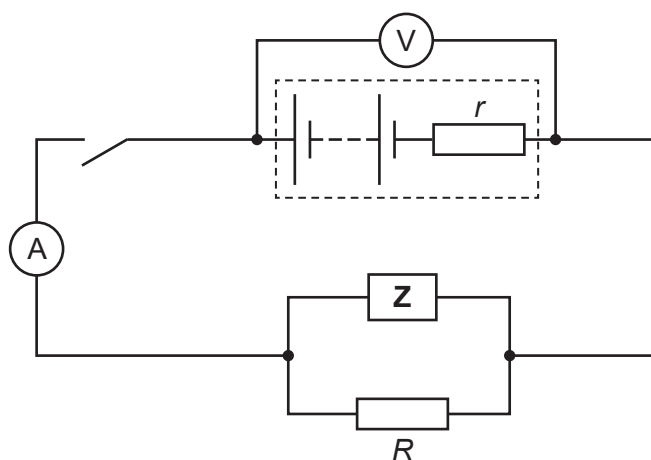
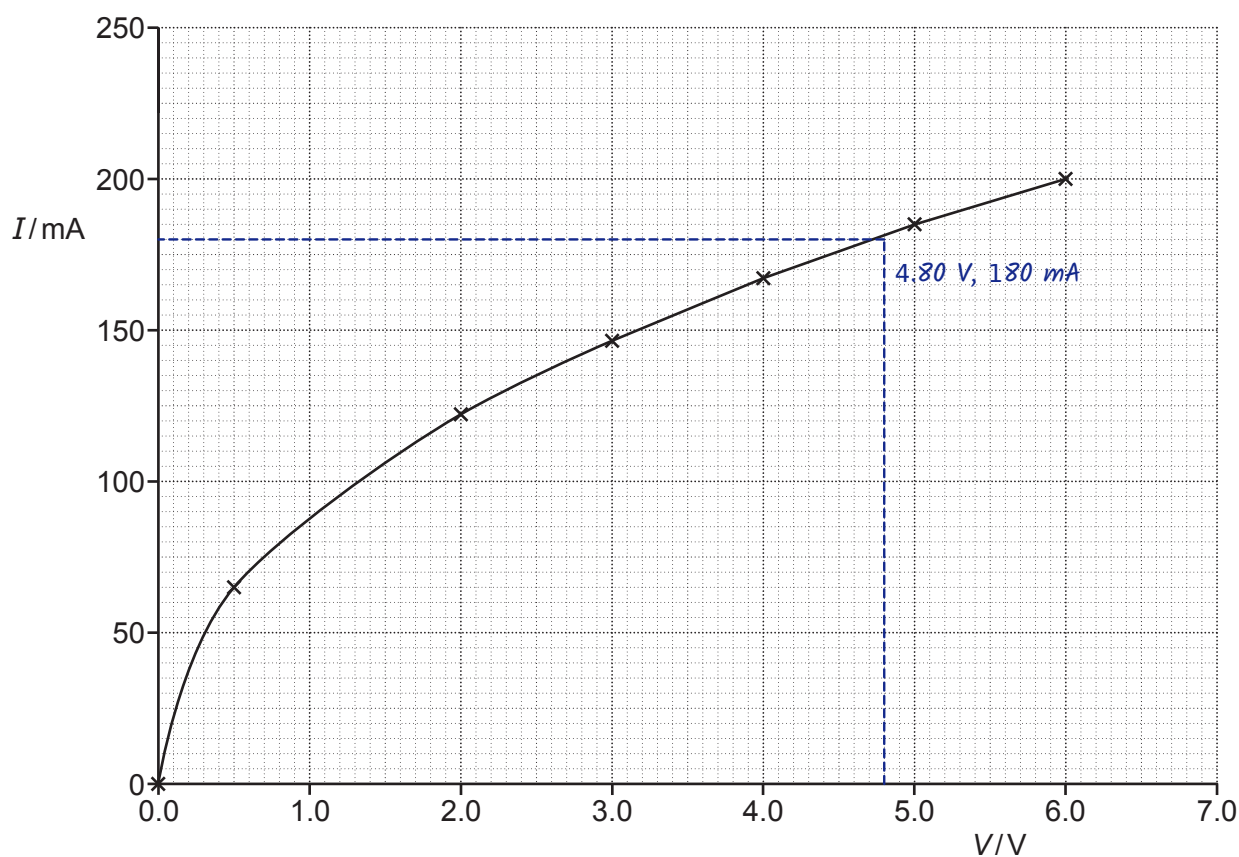


Fig. 6.2 shows the current I and potential difference V characteristic for the electrical component Z .

Fig. 6.2



- (a) State the name of component **Z**.

(Filament) lamp [1]

- (b) The switch is initially open.

The voltmeter reading is 5.72 V

The following voltmeters are available:

A: 0–2 V, ± 0.001 V **B:** 0–2 V, ± 0.01 V **C:** 0–2 V, ± 0.1 V

D: 0–20 V, ± 0.001 V **E:** 0–20 V, ± 0.01 V **F:** 0–20 V, ± 0.1 V

State the voltmeter, **A** to **F**, that has been used in this experiment.

Voltmeter ... *E* [1]

- (c) The switch is now closed.

The ammeter and voltmeter readings are:

Ammeter reading = 220 mA

Voltmeter reading = 4.80 V

- (i) Show that the resistance of *R* is 120 Ω .

From Fig. 6.2, at 4.80 V current in Z = 180 mA

current in R = 220 – 180 = 40 mA

$R = V/I = 4.80 \div 0.040 = 120 \Omega$

[2]

- (ii) Determine values for *E* and *r*.

Switch open, no current: $E = \text{voltmeter reading} = 5.72 \text{ V}$

$E = V + Ir$, so $r = (E - V)/I = (5.72 - 4.80) \div 0.220$

$r = 0.92 \div 0.220 = 4.18 \Omega$

$E = 5.72$ V

$r = 4.2$ Ω

[3]

Turn over

- (d) The resistor R is changed to a lower value.

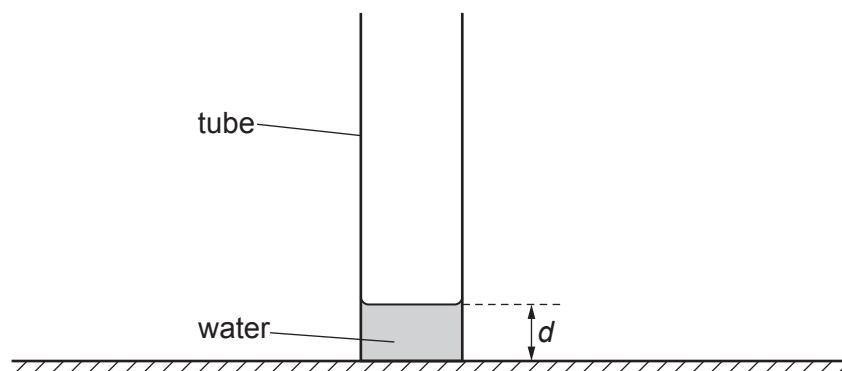
State and explain the change, if any, in the ammeter and voltmeter readings when the switch is closed.

The ammeter reading increases, because the total resistance of the circuit decreases (the parallel combination of R and Z has less resistance), so the current is larger.

The larger current means the lost volts Ir across the internal resistance are greater (a greater proportion of E is across r), so the voltmeter reading (terminal p.d. $V = E - Ir$) decreases. [4]

- 7* A student carries out an experiment to determine the speed v of sound in air. The student forms stationary sound waves in a resonance tube with water at the bottom as shown in Fig. 7.1.

Fig. 7.1



The depth of the water is d .

Sound is produced by a signal generator connected to a loudspeaker. The sound is detected by a microphone connected to an oscilloscope.

The signal generator is adjusted. The frequency f of the fundamental mode of vibration of the sound in air is determined.

The experiment is repeated for different values of d .

The table shows the results. Values of $\frac{1}{f}$ have been included.

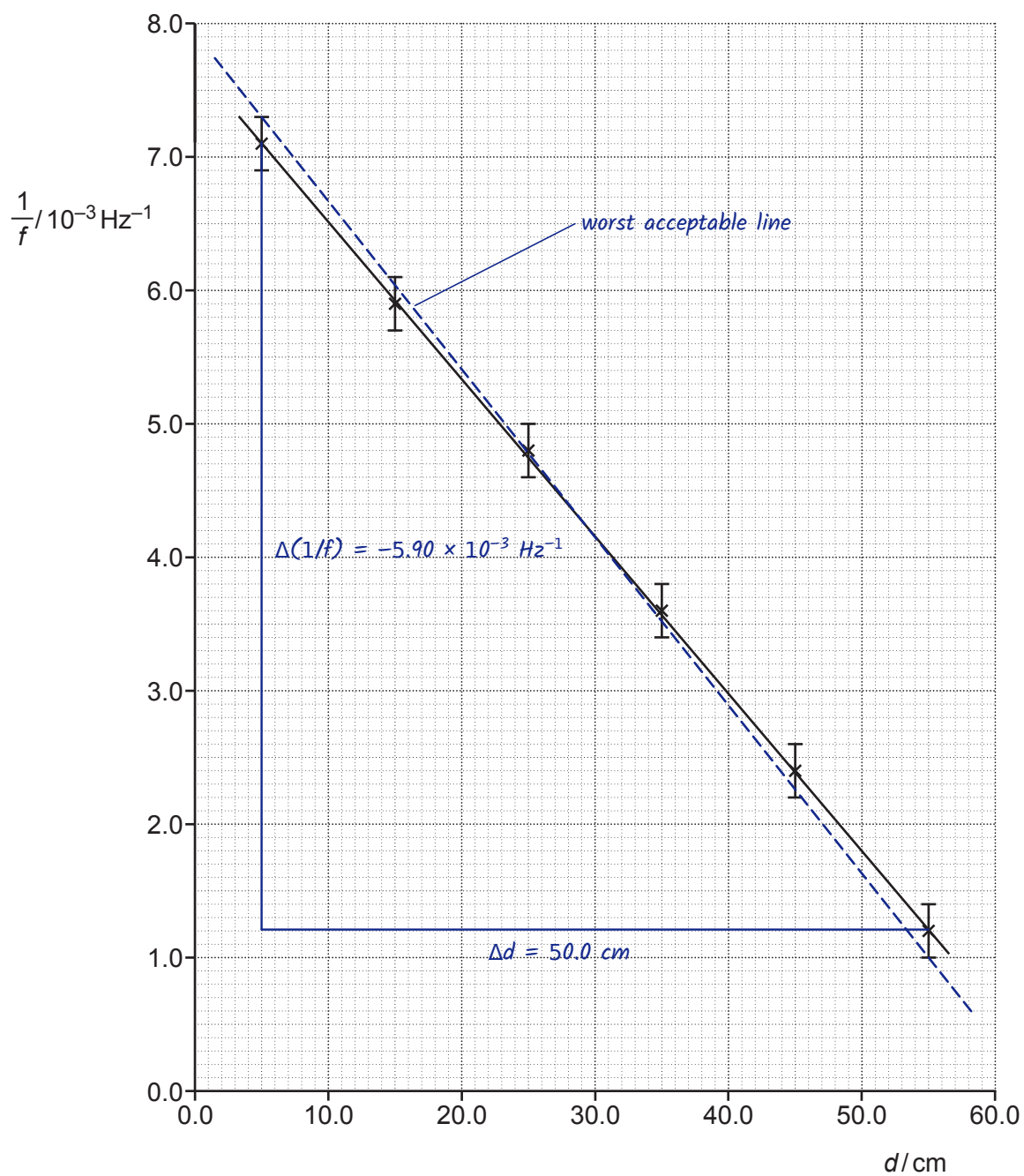
d/cm	f/Hz	$\frac{1}{f}/10^{-3}\text{Hz}^{-1}$
5.0	140	7.1 ± 0.2
15.0	170	5.9 ± 0.2
25.0	210	4.8 ± 0.2
35.0	280	3.6 ± 0.2
45.0	420	2.4 ± 0.2
55.0	840	1.2 ± 0.2

It is suggested that the relationship between f and d is

$$\frac{1}{f} = -\frac{4d}{v} + c$$

where v is the speed of sound in air and c is a constant.

A graph of $\frac{1}{f}/10^{-3} \text{ Hz}^{-1}$ on the y-axis against d/cm on the x-axis is plotted as shown below.



Explain how the apparatus is used to determine f **and** use the graph to determine v . Include the percentage uncertainty in your value of v . [6]

The loudspeaker is held just above the open end of the tube with the microphone near it. Starting from a low frequency, slowly increase the frequency on the signal generator until the trace on the oscilloscope has maximum amplitude (loudest sound): resonance. The first (lowest) resonance is the fundamental mode. Measure the period T on the oscilloscope: $T = \text{number of horizontal divisions} \times \text{timebase setting}$, and $f = 1/T$ (check with the signal generator reading). Repeat and average f for each d .

Comparing $1/f = -(4/v)d + c$ with $y = mx + c$, the gradient $= -4/v$.

Best-fit line gradient (triangle) $= (1.21 - 7.11) \times 10^{-3} \div (55.0 - 5.0) \times 10^{-2} = -0.0118 \text{ s m}^{-1}$

$v = -4 \div \text{gradient} = 4 \div 0.0118 = 339 \text{ m s}^{-1}$

Worst acceptable line (top of first error bar to bottom of last): gradient $= (1.0 - 7.3) \times 10^{-3} \div 0.500 = -0.0126 \text{ s m}^{-1}$

Absolute uncertainty in gradient $= 0.0126 - 0.0118 = 0.0008 \text{ s m}^{-1}$

% uncertainty in gradient $= 0.0008 \div 0.0118 \times 100 = 7\%$, so % uncertainty in $v = 7\%$.

Additional answer space if required

$v = 340 \text{ m s}^{-1} \pm 7\% (\pm 20 \text{ m s}^{-1})$

8 Electromagnetic radiation is incident on a metal plate. Photoelectrons are emitted.

(a) (i) State why electrons are emitted.

Each photon transfers all its energy to a single electron; the photon energy is greater than the work function, so the electron can escape the surface.

..... [1]

(ii) The metal plate has a threshold frequency of 990 THz.

State what is meant by the term **threshold frequency**.

The minimum frequency of the incident electromagnetic radiation needed to emit (photo)electrons from the metal surface.

..... [1]

(b) The maximum kinetic energy of the emitted photoelectrons is 1.9 eV.

(i) Show that the maximum kinetic energy of the emitted photoelectrons, is about 3.0×10^{-19} J.

$$E_k = 1.9 \times 1.60 \times 10^{-19} = 3.04 \times 10^{-19} \text{ J} \approx 3.0 \times 10^{-19} \text{ J}$$

[1]

(ii) Determine the wavelength λ of the incident electromagnetic radiation.

$$hf = hf_0 + KE_{\max}$$

$$f = 990 \times 10^{12} + 3.0 \times 10^{-19} \div 6.63 \times 10^{-34}$$

$$f = 9.90 \times 10^{14} + 4.52 \times 10^{14} = 1.44 \times 10^{15} \text{ Hz}$$

$$\lambda = c/f = 3.00 \times 10^8 \div 1.44 \times 10^{15}$$

$$\lambda = 2.1 \times 10^{-7} \text{ m}$$

$$\lambda = 2.1 \times 10^{-7} \text{ m} \quad [3]$$

- (c) The intensity of the incident radiation is doubled.

State the change, if any, on

- (i) the maximum kinetic energy of the photoelectrons emitted from the surface of the metal plate

No change (stays the same) [1]

- (ii) the rate of emission of the photoelectrons.

It doubles [1]

END OF QUESTION PAPER

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