



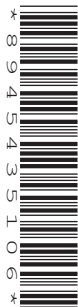
Oxford Cambridge and RSA

Monday 6 June 2022 – Morning

AS Level Physics A

H156/02 Depth in physics

Time allowed: 1 hour 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 **20** pages.

ADVICE

- Read each question carefully before you start your answer.

PLEASE DO NOT WRITE ON THIS PAGE

Answer **all** the questions.

- 1 A student investigates the motion of a steel ball in oil in a laboratory.

The radius r of the ball is 8.1 mm.

- (a) Describe how the student can determine r accurately in the laboratory.

Measure the diameter with a micrometer (or vernier caliper).

Repeat in different directions on the ball and find the mean diameter;

$r = \text{mean diameter} \div 2$

[3]

- (b) The student uses a measuring cylinder and a digital balance to determine the density of the oil.

The student records the following measurements:

- mass of empty measuring cylinder = 96 g
- volume of oil added to measuring cylinder = 87 cm³
- total mass of measuring cylinder and oil = 169 g

Show that the density of the oil is about 840 kg m⁻³.

$$\text{mass of oil} = 169 - 96 = 73 \text{ g} = 0.073 \text{ kg}$$

$$\text{volume} = 87 \text{ cm}^3 = 87 \times 10^{-6} \text{ m}^3$$

$$\rho = m/V = 0.073 \div 87 \times 10^{-6}$$

$$\rho = 839 \text{ kg m}^{-3} \approx 840 \text{ kg m}^{-3}$$

[2]

- (c) The steel ball is submerged in the oil.

Show that the upthrust acting on the steel ball is 1.8×10^{-2} N.

$$V = \frac{4}{3} \pi r^3 = \frac{4}{3} \times \pi \times (8.1 \times 10^{-3})^3 = 2.226 \times 10^{-6} \text{ m}^3$$

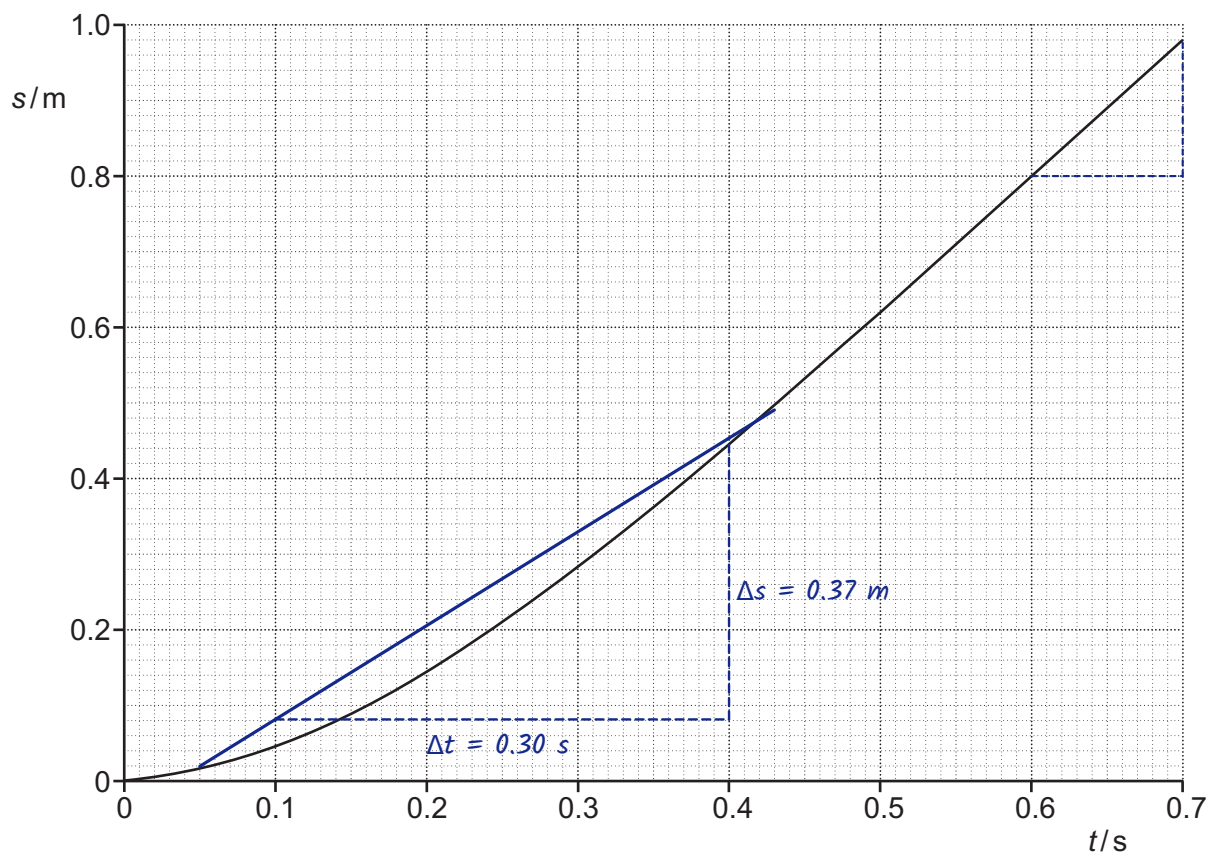
$$\text{upthrust} = \rho V g = 840 \times 2.226 \times 10^{-6} \times 9.81$$

$$\text{upthrust} = 0.0183 \text{ N} \approx 1.8 \times 10^{-2} \text{ N}$$

[2]

- (d) The student fills a long tube with the oil.
The student drops the steel ball from rest at the surface of the oil at time $t = 0$.
The displacement s of the ball is measured from the surface of the oil.

The graph shows the displacement s against time t for the steel ball from the instant it enters the oil.



- (i) The terminal velocity v of the steel ball is 1.8 m s^{-1} .

Describe and explain how this can be determined from the graph.

Terminal velocity is when velocity is constant (acceleration zero): the graph becomes a straight line (constant gradient).
 $v = \text{gradient of straight part} = (0.98 - 0.80) \div (0.70 - 0.60) = 1.8$
 m s^{-1} [3]

- (ii) Use the graph to calculate the velocity u of the steel ball at time $t = 0.20$ s.

Tangent drawn to the curve at $t = 0.20$ s:

$$u = \text{gradient} = (0.45 - 0.08) \div (0.40 - 0.10)$$

$$u = 0.37 \div 0.30 = 1.2 \text{ m s}^{-1}$$

$$u = \dots\dots\dots 1.2 \dots\dots\dots \text{ m s}^{-1} \text{ [2]}$$

- (e) The mass of the steel ball is 17 g.

The drag F acting on the steel ball falling through the oil is given by the equation

$$F = 6\pi\eta rv$$

where η is a constant for the oil, r is the radius of the steel ball and v is the speed of the steel ball through the oil.

At $v = 1.8 \text{ m s}^{-1}$, the force F is equal to the **difference** between the weight of the steel ball and the upthrust acting on the steel ball.

Calculate η .

Include an appropriate unit.

$$W - \text{upthrust} = 0.017 \times 9.81 - 0.018 = 0.149 \text{ N}$$

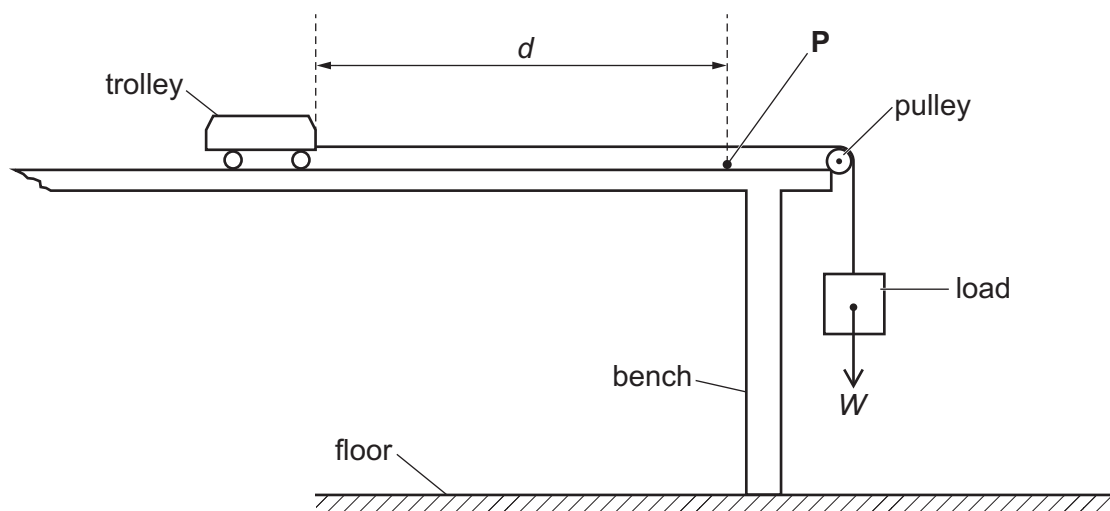
$$F = 6\pi\eta rv, \text{ so } \eta = F \div 6\pi rv$$

$$\eta = 0.149 \div (6\pi \times 8.1 \times 10^{-3} \times 1.8)$$

$$\eta = 0.54$$

$$\eta = \dots\dots\dots 0.54 \dots\dots\dots \text{ unit } \dots\dots\dots Pa \cdot s \dots\dots\dots \text{ [3]}$$

- 2* A student is investigating the motion of a trolley as it accelerates from rest along a horizontal surface.
The diagram shows the trolley on a horizontal surface. A load of weight W accelerates the trolley.



Point P is a distance d from the initial position of the trolley.
A light gate connected to a timer is used to determine the velocity v of the trolley at point P .

It is suggested that the relationship between v and the mass M of the trolley is

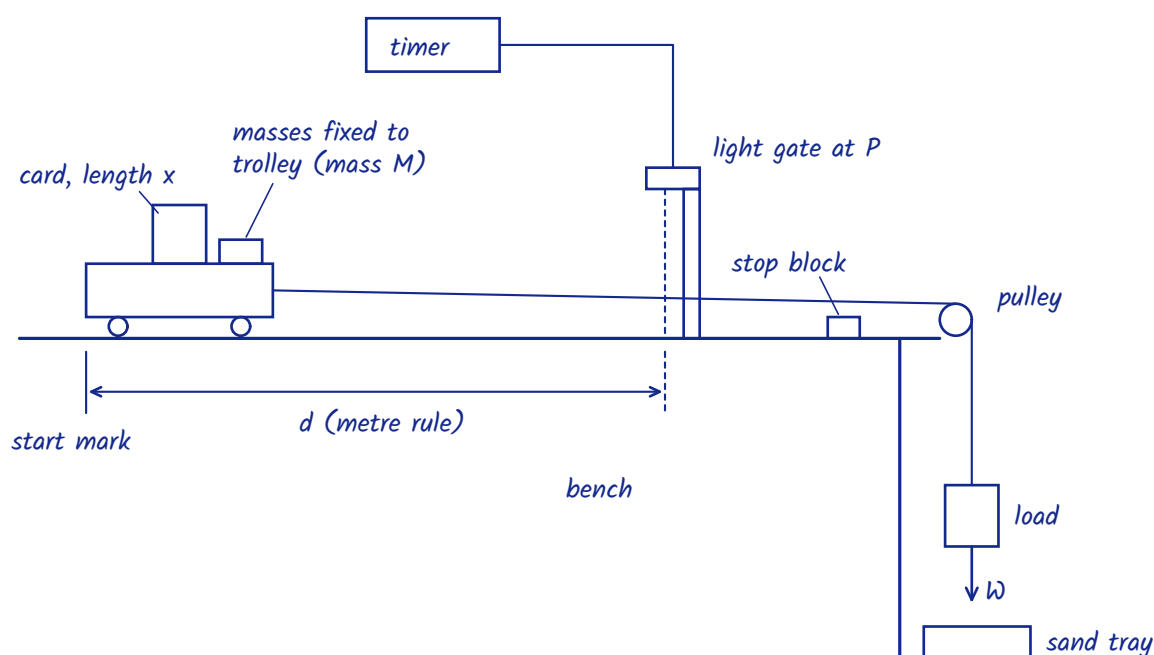
$$\frac{1}{v^2} = \frac{M}{2dW - Q} + R$$

where Q and R are constants.

Describe, with the aid of a suitable diagram,

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

[6]



Set up as in the diagram. Measure the mass M of the trolley (and any masses fixed to it) with a digital balance. Find $W = mg$ by measuring the mass m of the load on a balance. Measure the length x of the card with a ruler (or vernier caliper).

Mark the start position on the bench and use a metre rule to place the light gate at P a distance d from it. Keep d and W constant. Release the trolley from rest at the mark each time (use a release mechanism, no push). The timer records the time t for the card to cut the beam, so $v = x/t$.

Repeat three times for each M and find the mean t . Increase M by taping extra masses securely to the trolley; use at least six values of M .

Safety: a sand tray (cushion) under the load so it does not land on the floor or feet, and a stop block so the trolley does not hit the pulley.

Analysis: calculate $1/v^2$ and plot $1/v^2$ (y-axis) against M (x-axis). The relationship is correct if the graph is a straight line. Comparing with $y = mx + c$: gradient = $1/(2dW - Q)$, so $Q = 2dW - 1/\text{gradient}$, and the y-intercept = R .

Additional answer space if required

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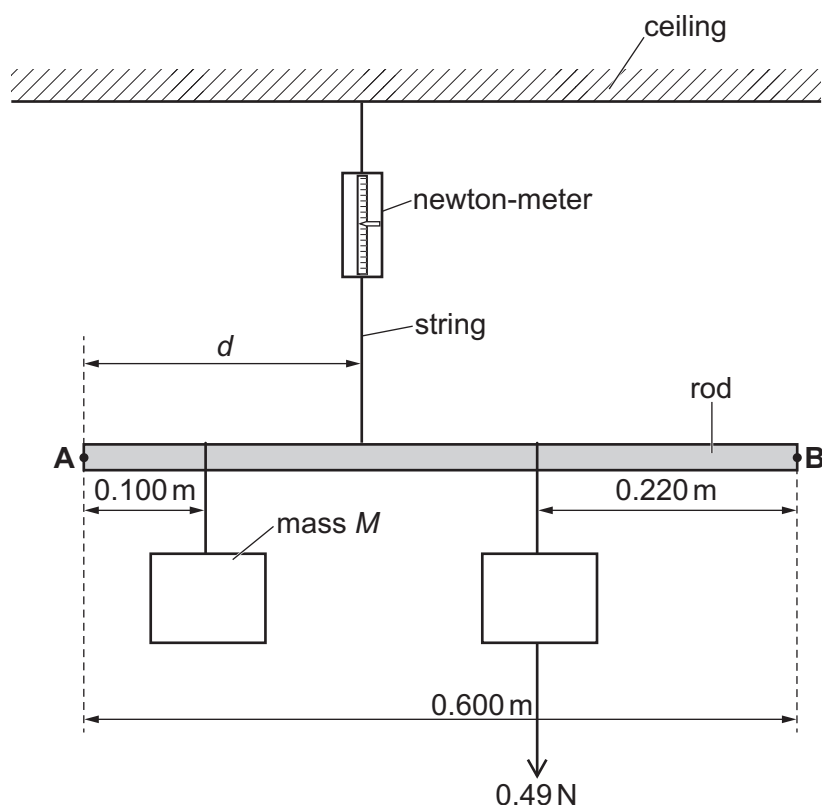
- 3 (a) State the **two** conditions for an object to be in equilibrium.

1. *The resultant (net) force on the object in any direction is zero.*

2. *The resultant (net) moment about any point is zero (clockwise moments = anticlockwise moments).*

[3]

- (b) The diagram shows a uniform rod which is in equilibrium. The rod has a circular cross-section and has length 0.600 m and weight 2.1 N.



Mass M is suspended at a distance of 0.100 m from point **A**.
 A weight of 0.49 N is suspended at a distance of 0.220 m from point **B**.
 A string is attached to the rod at a distance d from point **A**.
 The tension in the string, measured by the newton-meter (force meter), is 3.9 N.

- (i) Show that M is about 0.13 kg.

$$\text{up} = \text{down}: 3.9 = 2.1 + 0.49 + \text{weight of } M$$

$$\text{weight of } M = 3.9 - 2.59 = 1.31 \text{ N}$$

$$M = 1.31 \div 9.81 = 0.134 \text{ kg} \approx 0.13 \text{ kg}$$

[2]

- (ii) By taking moments about point **A**, determine d .

Moments about A (rod centre of mass at 0.300 m;

0.49 N weight at 0.600 – 0.220 = 0.380 m from A):

$$3.9 \times d = 1.31 \times 0.100 + 2.1 \times 0.300 + 0.49 \times 0.380$$

$$3.9d = 0.131 + 0.630 + 0.186 = 0.947$$

$$d = 0.947 \div 3.9 = 0.24 \text{ m}$$

$$d = \dots\dots\dots 0.24 \dots\dots\dots \text{ m [3]}$$

- 4 (a) A ball of mass 0.16 kg is dropped from rest from a height of 2.5 m above the ground.

Assume air resistance is negligible.

Calculate

- (i) the change in gravitational energy E_p

$$E_p = mgh = 0.16 \times 9.81 \times 2.5 = 3.9 \text{ J}$$

$$E_p = \dots 3.9 \dots \text{ J [1]}$$

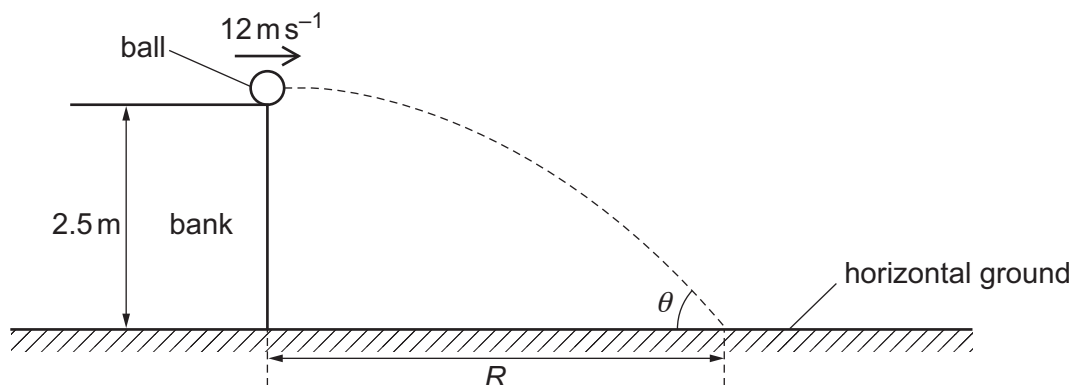
- (ii) the velocity v of the ball as it reaches the ground.

$$\frac{1}{2}mv^2 = 3.9, \text{ so } v^2 = 2 \times 3.924 \div 0.16 = 49.05$$

$$v = 7.0 \text{ m s}^{-1}$$

$$v = \dots 7.0 \dots \text{ m s}^{-1} \text{ [2]}$$

- (b) The ball from (a) is now fired horizontally with a speed of 12 m s^{-1} from a bank. The height of the bank is 2.5 m. The time for the ball to travel from the edge of the bank to the horizontal ground is 0.71 s. The path of the ball is shown in the diagram. The ball hits the horizontal ground a distance R from the bottom of the bank. Assume air resistance is negligible.



Calculate

(i) R

$$R = 12 \times 0.71 = 8.5 \text{ m}$$

$$R = \dots\dots\dots 8.5 \dots\dots\dots \text{ m [1]}$$

(ii) the kinetic energy E_k of the ball as it reaches the ground

$$\text{initial } E_k = \frac{1}{2} \times 0.16 \times 12^2 = 11.5 \text{ J}$$

$$E_k = 11.5 + E_p = 11.5 + 3.9 = 15.4 \text{ J}$$

$$E_k = \dots\dots\dots 15 \dots\dots\dots \text{ J [2]}$$

(iii) the angle θ between the ground and the direction of the ball as it reaches the ground.

$$\text{vertical velocity} = 7.0 \text{ m s}^{-1}, \text{ horizontal} = 12 \text{ m s}^{-1}$$

$$\theta = \tan^{-1}(7.0 \div 12) = 30^\circ$$

$$\theta = \dots\dots\dots 30 \dots\dots\dots ^\circ \text{ [1]}$$

- 5 The table shows the refractive index of air, glass and oil for red light. It also shows the speed v of red light in air.

	air	glass	oil
refractive index n	1.00	1.52	1.46
speed of light $v/\text{m s}^{-1}$	3.00×10^8	1.97×10^8	2.05×10^8

- (a) Complete the table by determining the missing values for v for glass and oil. Write your answers to 3 significant figures.

[1]

- (b) Show that the critical angle for a ray of red light at the boundary between glass and air is less than 45° .

$$\sin C = 1/n = 1 \div 1.52 = 0.658$$

$$C = 41^\circ \text{ which is less than } 45^\circ$$

[2]

- (c) Fig. 5.1 shows a glass block inside a beaker.

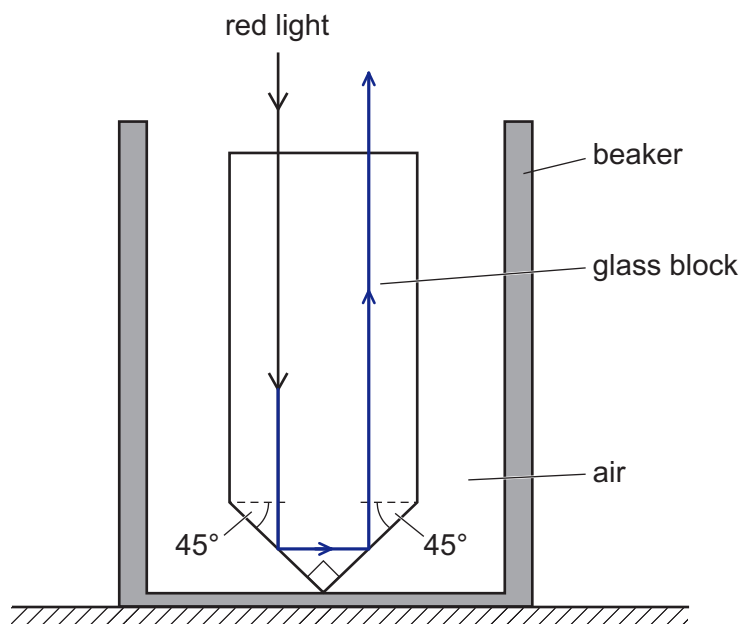


Fig. 5.1

The path of a ray of red light is shown entering the glass block.

Complete Fig. 5.1 to show the path of the ray through the block until it leaves the block. [2]

- (d) Oil is now added to the beaker as shown in **Fig. 5.2**.

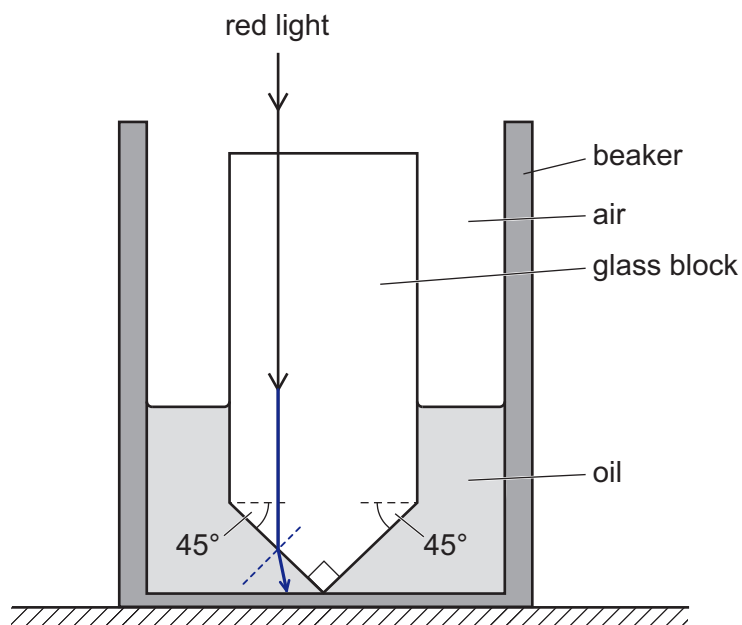


Fig. 5.2

The path of a ray of red light is shown entering the glass block.

- (i) Calculate the critical angle C for a ray of red light at the boundary between glass and oil.

$$\sin C = n_{oil} \div n_{glass} = 1.46 \div 1.52 = 0.961$$

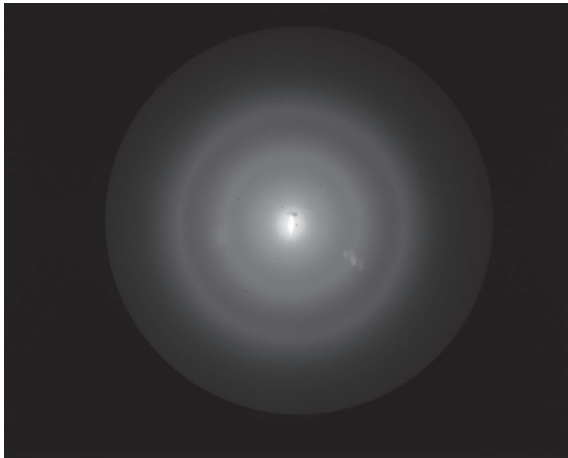
$$C = 74^\circ$$

$$C = \dots\dots\dots 74 \dots\dots\dots^\circ \quad [2]$$

- (ii) Complete **Fig. 5.2** to show the path of the ray through the block until it leaves the block. [1]

- 6 A student is investigating electron diffraction. A beam of electrons is directed towards a thin slice of graphite in an evacuated tube.

The electrons are accelerated by a potential difference of 1800 V. The diagram below shows the pattern formed on the fluorescent screen of the evacuated tube.



- (a) Explain why this pattern is formed.

Electrons have wave properties; each has a de Broglie wavelength $\lambda = h/p$.
 This wavelength is comparable to the spacing (gaps) between atoms in the
 graphite, so the electrons diffract.
 The graphite is polycrystalline (layers at random orientations), so rings are formed.
 Bright rings are maxima, dark rings minima; the electrons' kinetic energy is
 transferred to light at the screen. [3]

- (b) The relationship between the de Broglie wavelength λ and the accelerating potential difference V is

$$\lambda = \frac{h}{\sqrt{2meV}}$$

where m is the mass of the electron and e is the elementary charge.

Calculate the momentum p of an electron.

$$p = h/\lambda = \sqrt{2meV}$$

$$p = \sqrt{(2 \times 9.11 \times 10^{-31} \times 1.60 \times 10^{-19} \times 1800)}$$

$$p = \sqrt{(5.25 \times 10^{-46})} = 2.3 \times 10^{-23} \text{ kg m s}^{-1}$$

$$p = 2.3 \times 10^{-23} \text{ kg m s}^{-1} [2]$$

- 7 An electric cooker has two independent heating rings **A** and **B** as shown in **Fig. 7.1**.

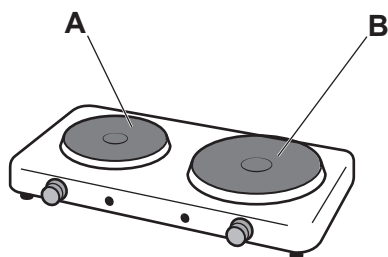


Fig. 7.1

The cooker rings **A** and **B** are connected in parallel to a 230 V power supply. At maximum power, ring **A** has a power of 1100 W and ring **B** has a power of 1700 W.

- (a) (i) Show that the maximum current in the cooker is less than 13 A.

$$I = P/V = (1100 + 1700) \div 230 = 2800 \div 230$$

$$I = 12.2 \text{ A, which is less than } 13 \text{ A}$$

[2]

- (ii) The cost of 1 kWh of energy is 18p.
Calculate the cost of using the cooker at maximum power for 30 minutes.

$$\text{energy} = 2.8 \text{ kW} \times 0.5 \text{ h} = 1.4 \text{ kW h}$$

$$\text{cost} = 1.4 \times 18 = 25.2\text{p}$$

cost = ...25..... p [1]

- (b) The filament in ring **A** is a metallic wire of length 11.8 m.
At maximum power the wire has resistance $31\ \Omega$ and the metal has resistivity $4.8 \times 10^{-7}\ \Omega\text{m}$.

Calculate the diameter d of the wire.

$$A = \rho L/R = 4.8 \times 10^{-7} \times 11.8 \div 31 = 1.827 \times 10^{-7}\ \text{m}^2$$

$$A = \pi d^2/4, \text{ so } d^2 = 4 \times 1.827 \times 10^{-7} \div \pi = 2.326 \times 10^{-7}$$

$$d = 4.8 \times 10^{-4}\ \text{m}$$

$$d = \dots 4.8 \times 10^{-4} \dots \text{ m [3]}$$

- (c) **Fig. 7.2** shows the circuit symbol for ring **A**.

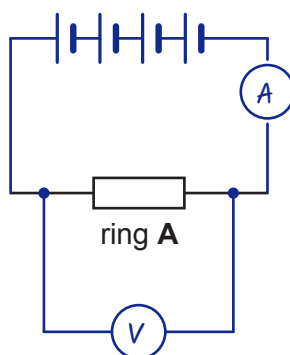


Fig. 7.2

A student uses a battery of four cells, an ammeter and a voltmeter to determine the resistance of the wire in ring **A** experimentally.

- (i) Complete **Fig. 7.2** to show how the student should connect the circuit to determine the resistance. [2]

- (ii) The current in the wire is $0.34 \pm 0.02\text{A}$ and the potential difference across the wire is $6.2 \pm 0.2\text{V}$.
Calculate the resistance R of the wire.

$$R = V/I = 6.2 \div 0.34 = 18.2 \Omega$$

$$R = \dots\dots\dots 18 \dots\dots\dots \Omega \text{ [1]}$$

- (iii) Calculate the percentage uncertainty in R .

$$\% \text{ uncertainty in } I = 0.02 \div 0.34 \times 100 = 5.9\%$$

$$\% \text{ uncertainty in } V = 0.2 \div 6.2 \times 100 = 3.2\%$$

$$\% \text{ uncertainty in } R = 5.9 + 3.2 = 9.1\%$$

$$\text{percentage uncertainty} = \dots\dots\dots 9.1 \dots\dots\dots \% \text{ [2]}$$

- (iv) Suggest why R from (c)(ii) is less than 31Ω .

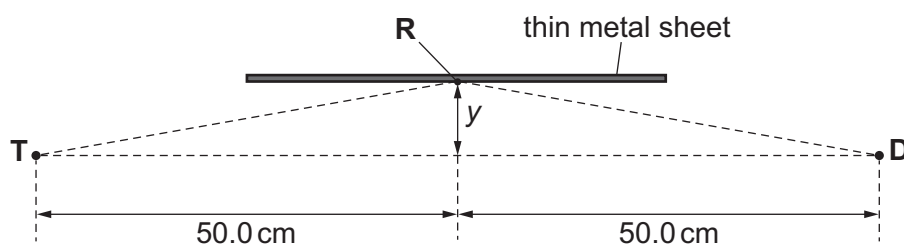
*With the battery of four cells the current in the wire is much lower
than when connected to the 230 V mains at maximum power,
so the heating effect is smaller and the wire is at a lower temperature,
giving a lower resistance.* [2]

- (v) Suggest **two** improvements to the student's experiment to determine R experimentally.

1. *Use a variable resistor (or a different number of cells) to take several
pairs of V and I readings and plot a graph of V against I ; $R =$
gradient.*
2. *Use more sensitive meters (that read to a greater resolution, e.g. 0.01
 V and $0.001 A$) to reduce the percentage uncertainties.*

[2]

- 8* In an experiment to investigate microwaves, a microwave detector **D** is placed 100.0 cm from a microwave transmitter **T**.



A thin metal sheet is placed parallel to the line joining **T** and **D**. Point **R** is at the bottom of the metal sheet. The perpendicular distance between this line and point **R** is y . The diagram shows the path of microwaves travelling directly from **T** to **D** and the path of microwaves from **T** reflected from **R** to **D**. There is a 180° phase change when microwaves are reflected at **R**.

The metal sheet is moved away from the line joining **T** and **D** so that y increases. The metal sheet remains parallel to the line from **T** and **D**. A series of maximum and minimum intensities are observed.

The table shows the values of y for successive maximum and minimum intensities.

Intensity	y/cm
maximum	8.4
minimum	11.9
maximum	14.6
minimum	17.0

Explain the presence of the regions of maximum and minimum intensities **and** determine the wavelength of the microwaves.

[6]

Microwaves reach D by two paths: directly from T, and by reflection at R. Both come from the same source so they are coherent (constant phase difference). The waves superpose at D and their displacements add.

Path difference = $TR + RD - TD = 2\sqrt{(50.0^2 + y^2)} - 100.0$ (Pythagoras). As y increases the path difference increases, so the phase difference at D changes.

Because of the 180° phase change at R, a maximum occurs when the path difference = $(n + \frac{1}{2})\lambda$: the waves arrive in phase and interfere constructively. A minimum occurs when the path difference = $n\lambda$: the waves arrive in antiphase (180° out of phase) and interfere destructively. When the path difference changes by $\lambda/2$, a maximum changes to a minimum or vice versa.

$$y = 8.4 \text{ cm: } 2\sqrt{(2500 + 70.6)} - 100.0 = 1.4 \text{ cm (maximum, } \lambda/2)$$

$$y = 11.9 \text{ cm: } 2\sqrt{(2500 + 141.6)} - 100.0 = 2.8 \text{ cm (minimum, } \lambda)$$

$$y = 14.6 \text{ cm: } 2\sqrt{(2500 + 213.2)} - 100.0 = 4.2 \text{ cm (maximum, } 3\lambda/2)$$

$$y = 17.0 \text{ cm: } 2\sqrt{(2500 + 289.0)} - 100.0 = 5.6 \text{ cm (minimum, } 2\lambda)$$

The path difference increases by $1.4 \text{ cm} = \lambda/2$ each time, so $\lambda = 2 \times 1.4 = 2.8$
cm.

The minima are not zero intensity because the reflected wave travels further (and
loses some energy at R), so its amplitude at D is smaller than that of the direct
wave.

Additional answer space if required

END OF QUESTION PAPER

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