



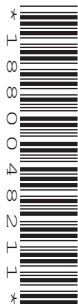
Oxford Cambridge and RSA

Wednesday 21 May 2025 – Afternoon

AS Level Physics B (Advancing Physics)

H157/02 Physics in depth

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)

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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 page 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.

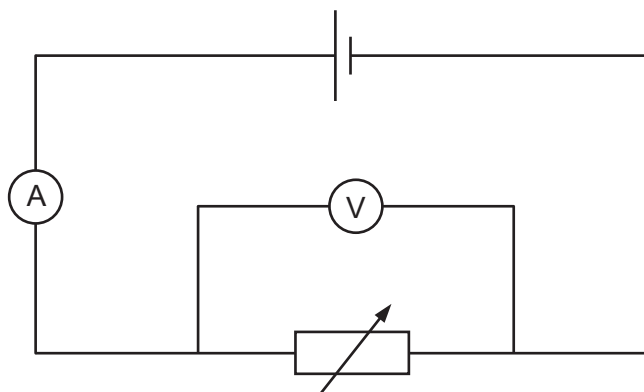
ADVICE

- Read each question carefully before you start your answer.

Section A

- 1 A student carries out an experiment to determine the electromotive force (e.m.f.) and the internal resistance of a cell. **Fig. 1.1** shows the circuit the student uses.

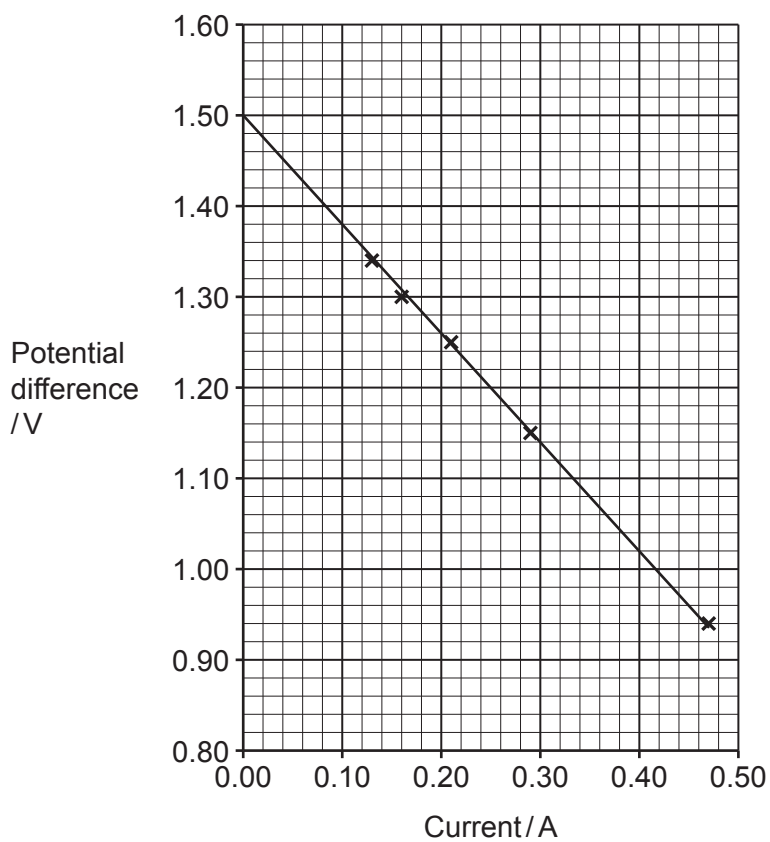
Fig. 1.1



The student changes the resistance of the variable resistor and measures corresponding values of current through and potential difference across the variable resistor.

The graph in **Fig. 1.2** shows the student's results.

Fig. 1.2



- (a) The student concludes that the e.m.f. of the cell is 1.5 V and that its internal resistance is $1.2\ \Omega$. Explain how the student reaches these conclusions. Include any relevant calculations.

Compare $V = \mathcal{E} - Ir$ with $y = mx + c$, so a graph of V against I is a straight line with gradient $-r$ and intercept $\mathcal{E}$.

The intercept on the V axis (where $I = 0$) is 1.50 V, so e.m.f. $\mathcal{E} = 1.5\ \text{V}$.

Gradient from two points on the line: $(0, 1.50)$ and $(0.40, 1.02)$: gradient = $(1.02 - 1.50) \div (0.40 - 0) = -0.48 \div 0.40 = -1.2\ \Omega$

$r = -\text{gradient}$, so internal resistance $r = 1.2\ \Omega$.

[4]

(b)

- (i) Show that when the current is 0.40 A the number of electrons passing through the variable resistor each second is 2.5×10^{18} .

$$I = Q/t = Ne/t, \text{ so } N/t = I/e$$

$$N \text{ per second} = 0.40 \div 1.6 \times 10^{-19} = 2.5 \times 10^{18}$$

[2]

- (ii) Calculate the energy transferred by one electron as it travels from one end of the variable resistor to the other when the current is 0.40 A.

$$\text{from the graph at } I = 0.40\ \text{A}, V = 1.02\ \text{V}$$

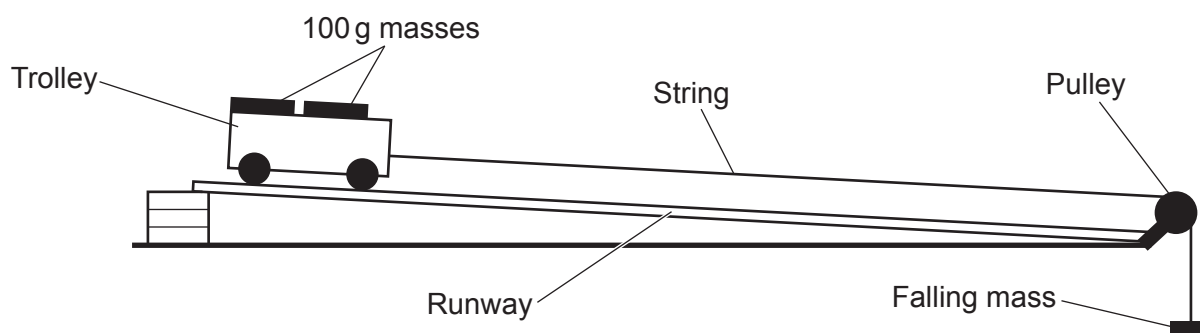
$$\text{energy per electron } W = eV = 1.6 \times 10^{-19} \times 1.02$$

$$W = 1.63 \times 10^{-19}\ \text{J}$$

$$\text{Energy transferred} = 1.63 \times 10^{-19}\ \text{J} \quad [3]$$

- 2 A student carries out an experiment to verify Newton's 2nd law of motion. **Fig. 2.1** shows equipment used by the student.

Fig. 2.1



The student follows these instructions:

- Measure the mass of the trolley.
- Place the trolley on the runway without the falling mass and compensate for the friction of the wheels.
- Connect the falling mass to the trolley, and with no masses on the trolley release it from rest at the top of the runway and time how long it takes to travel 1 m with a stopwatch.
- Repeat the experiment two more times and calculate the mean time.
- Repeat the experiment with different numbers of 100 g masses on the trolley.

- (a) Explain how the student compensates for the friction of the wheels.

Raise one end of the runway (tilt it, e.g. with blocks) and adjust the slope until the trolley on its own, given a small push, moves down at constant speed.

[2]

- (b) The mass of the trolley is 750 g. With 200 g placed on top of it, the mean time taken for the trolley to travel 1.00 m from rest is 2.2 s. Show that the acceleration of the trolley is about 0.41 m s^{-2} .

$$s = ut + \frac{1}{2}at^2 \text{ with } u = 0, \text{ so } a = 2s/t^2$$

$$a = 2 \times 1.00 \div 2.2^2 = 0.413 \text{ m s}^{-2} \text{ (about } 0.41 \text{ m s}^{-2}\text{)}$$

[1]

(c) The table shows the student's results.

Total mass of trolley / kg	Acceleration / ms^{-2}
0.750	0.53
0.850	0.45
0.950	0.41
1.050	0.38
1.150	0.33

(i) Perform an arithmetical test to find if these results support Newton's 2nd law of motion. Explain your conclusion.

Newton's 2nd law $F = ma$: F is constant (same falling mass), so $m \times a$ should be constant.

$$0.750 \times 0.53 = 0.398 \quad 0.850 \times 0.45 = 0.383 \quad 0.950 \times 0.41 = 0.390$$

$$1.050 \times 0.38 = 0.399 \quad 1.150 \times 0.33 = 0.380 \quad (\text{all in N})$$

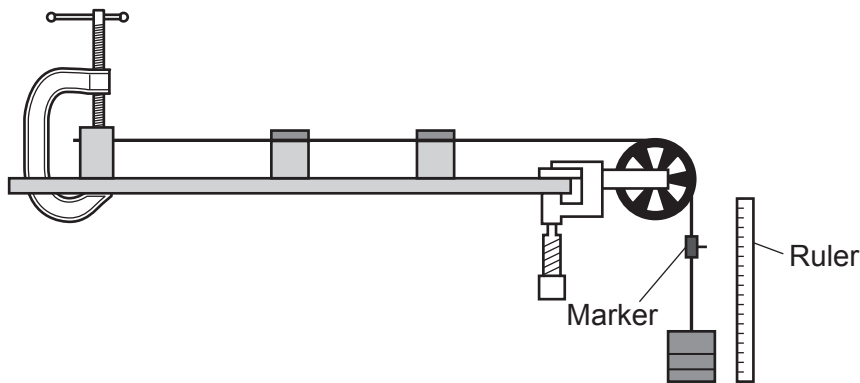
All the values of ma are very similar (0.38 to 0.40 N), so the results do support Newton's 2nd law. [2]

(ii) Describe a graph that the student could draw with these results and explain how the graph would show if the results agreed with Newton's 2nd law of motion.

Plot a graph of acceleration a against $1/m$ ($1/\text{total mass}$). If the results agree with Newton's 2nd law ($a = F/m$ with F constant), the graph is a straight line through the origin, with gradient F . [2]

- 3 A student carries out an experiment to determine the Young modulus of copper. The student stretches a long copper wire using the apparatus shown in Fig. 3.1.

Fig. 3.1



The student uses a micrometer to measure the diameter of the wire, and finds the mean diameter of the wire to be 0.38 mm.

- (a) Describe how the student makes the measurements to calculate the mean diameter.

Check the micrometer for a zero error first (close it and read it, then correct readings).

Measure the diameter at several different points along the length of the wire, and at each point take two readings at 90° to each other (rotating the micrometer), then calculate the mean.

[2]

- (b) The student obtains the following results:

Mean diameter of wire = 0.38 mm

Initial length of wire = 1.500 m

Mass suspended from wire = 2.000 kg

Extension of wire = 2.2 mm

Use these results to find the Young modulus of copper.

$$A = \pi r^2 = \pi \times (0.19 \times 10^{-3})^2 = 1.13 \times 10^{-7} \text{ m}^2$$

$$F = mg = 2.000 \times 9.81 = 19.6 \text{ N}$$

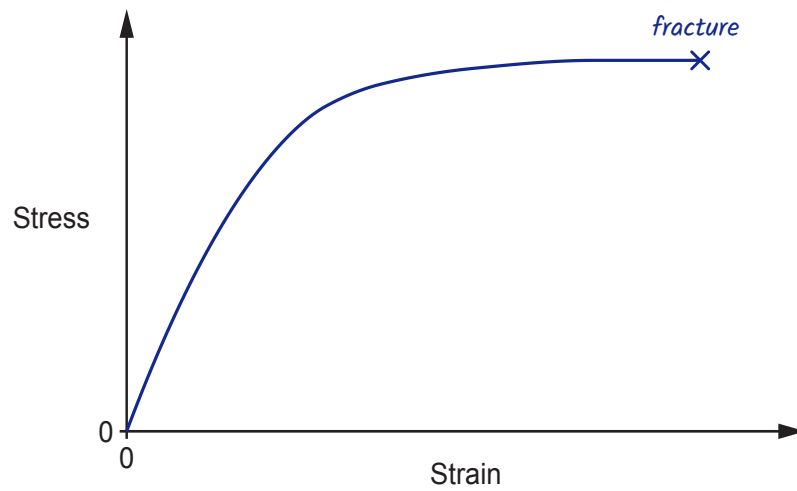
$$E = FL/Ax = (19.6 \times 1.500) \div (1.13 \times 10^{-7} \times 2.2 \times 10^{-3})$$

$$E = 1.18 \times 10^{11} \text{ Pa}$$

Young modulus = *1.18 × 10¹¹* Pa [3]

- (c) The student adds masses to the wire until it fractures. Copper is a ductile material. Sketch a graph of stress against strain for the copper wire on **Fig. 3.2**.

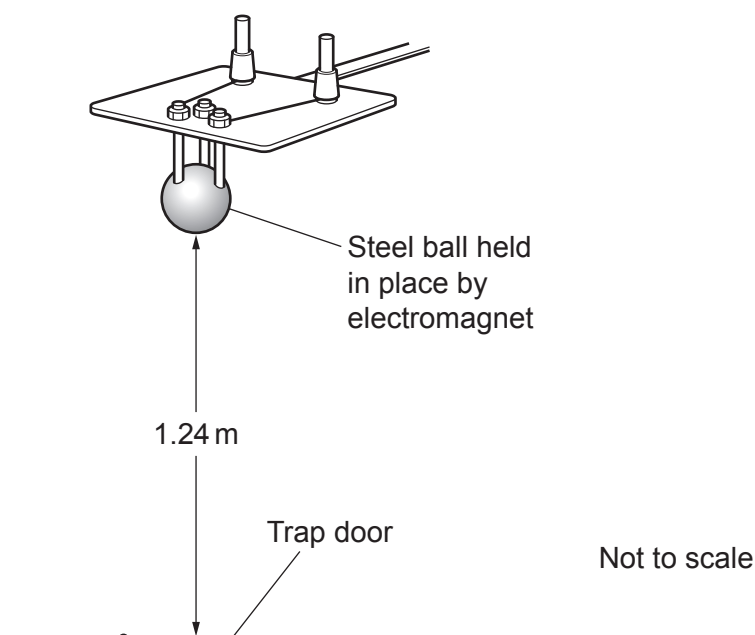
Fig. 3.2



[1]

- 4 Fig. 4.1 shows apparatus used to determine the acceleration of free fall. A millisecond timer begins timing when the steel ball is released from the electromagnet. The timing stops when the ball breaks open the metal trap door.

Fig. 4.1



A student makes five measurements and collects the following data:

Drop number	Time/s
1	0.493
2	0.490
3	0.487
4	0.498
5	0.495

The student suggests that the results show a systematic error as well as random uncertainty. Explain this reasoning and identify a likely cause for a systematic error in this experiment. Include calculations in your answer.

$$g = 2s/t^2 = 2 \times 1.24 \div t^2;$$

$$t = 0.493 \text{ s}; g = 10.2; \quad 0.490 \text{ s}; g = 10.3; \quad 0.487 \text{ s}; g = 10.5$$

$$0.498 \text{ s}; g = 10.0; \quad 0.495 \text{ s}; g = 10.1 \text{ m s}^{-2} \quad (\text{mean } t = 0.493 \text{ s}, g = 10.2 \text{ m s}^{-2})$$

$$\text{Expected } t \text{ for } g = 9.81: t = \sqrt{(2 \times 1.24 \div 9.81)} = 0.503 \text{ s}; \text{ every measured } t \text{ is shorter.}$$

All values of g are greater than the accepted 9.81 m s^{-2} , beyond the spread of the data.

So a systematic error (all g too big) plus random uncertainty (times scatter, 0.487 to 0.498.....

s). Likely cause: drop height measured wrongly (ruler position) or the delay of the.....

electromagnet / trap door..... [4]

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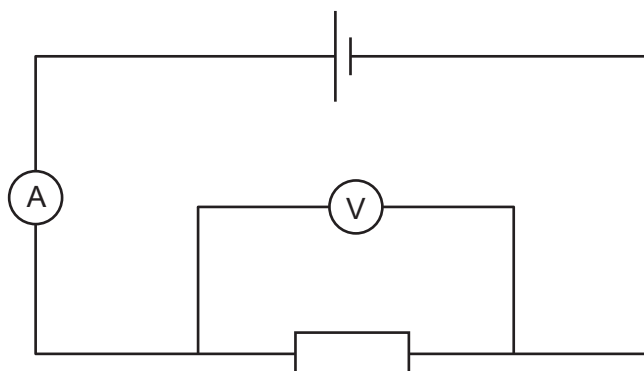
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Section B continues on page 10

Section B

5

- (a) A manufacturer produces fixed resistors, which it sells in boxes of ten. A technician checks the values of ten resistors in a box using the circuit shown in **Fig. 5.1**.

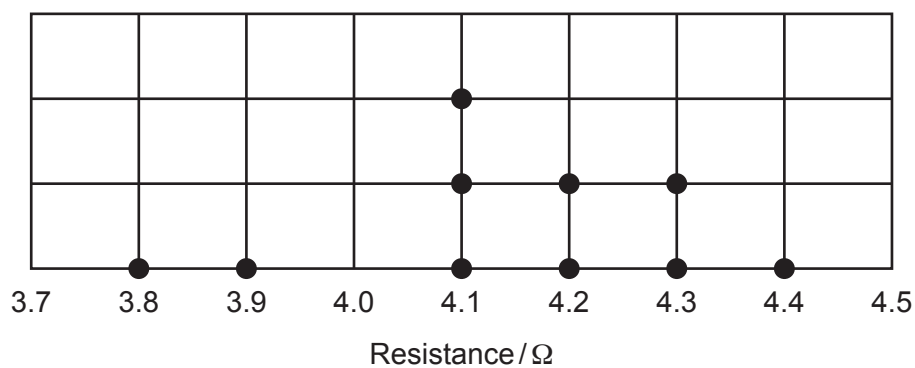
Fig. 5.1

The values of potential difference and current for one resistor are:

$$V = 1.10 \pm 0.01 \text{ V}$$

$$I = 0.26 \pm 0.01 \text{ A}$$

All ten resistors in the box are tested in this way. The dot plot in **Fig. 5.2** shows the results.

Fig. 5.2

Discuss how the value of the resistors in the box should be presented on the label on the box. Perform suitable calculations to support your answer.

From the dot plot, mean $R = (3.8 + 3.9 + 3 \times 4.1 + 2 \times 4.2 + 2 \times 4.3 + 4.4) \div 10 = 41.4 \div 10 = 4.14 \, \Omega$

Range = $4.4 - 3.8 = 0.6 \, \Omega$, so uncertainty = half range = $\pm 0.3 \, \Omega$ ($\pm 7 \%$).

One resistor: $R = 1.10/0.26 = 4.23 \, \Omega \pm (0.9 \% + 3.8 \%) = \pm 0.2 \, \Omega$, which is less than the spread.

So the label should be $4.1 \pm 0.3 \, \Omega$, as this shows the true variation of the values in the box.

[4]

- (b) Nichrome is an alloy containing nickel and chromium that is used to make resistors. Nichrome wire of cross-sectional area $5.9 \times 10^{-8} \text{ m}^2$ is used to make a $4.2 \, \Omega$ resistor. The resistivity of nichrome is $1.4 \times 10^{-6} \, \Omega \text{ m}$.

- (i) Show that the length of wire needed is about 18 cm.

$$R = \rho L/A \text{ so } L = RA/\rho = 4.2 \times 5.9 \times 10^{-8} \div 1.4 \times 10^{-6}$$

$$L = 0.177 \text{ m} = 17.7 \text{ cm (about 18 cm)}$$

[2]

- (ii) The density of a substance is given by the equation

density (ρ) = mass (m) $\div$ volume (V).

The density of nichrome is 8400 kg m^{-3} .

The specific thermal capacity of nichrome is $450 \text{ J kg}^{-1} \text{ K}^{-1}$.

The resistor is connected into a circuit so that the potential difference across it is 1.5 V.

Calculate the maximum temperature rise, $\Delta\theta$ in the resistor when the circuit is switched on for one second.

$$m = \rho V = \rho AL = 8400 \times 5.9 \times 10^{-8} \times 0.177 = 8.77 \times 10^{-5} \text{ kg}$$

$$E = V^2 t/R = 1.5^2 \times 1 \div 4.2 = 0.536 \text{ J } (I = 0.36 \text{ A})$$

$$E = mc\Delta\theta: 0.536 = 8.77 \times 10^{-5} \times 450 \times \Delta\theta$$

$$\Delta\theta = 0.536 \div 0.0395 = 13.6 \, ^\circ\text{C}$$

$$\Delta\theta = \underline{13.6} \, ^\circ\text{C} \quad [4]$$

Turn over

- (iii) A resistor of the same value can be made using a thicker wire of the same nichrome alloy. Explain the advantages and disadvantages of using thicker wire to make the resistor.

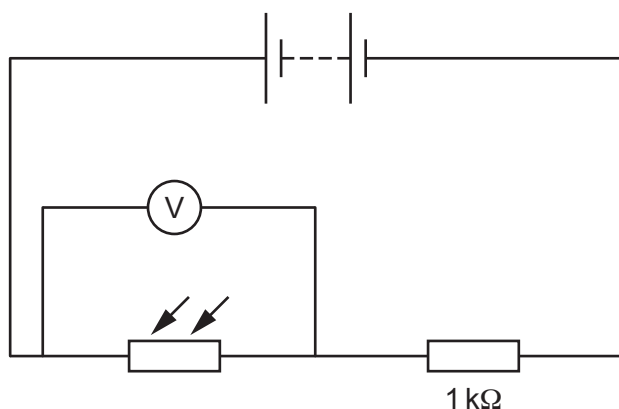
A thicker wire has a larger cross-sectional area, so a lower resistance per metre; it must be longer to give the same $4.2\ \Omega$.

Advantage: the greater diameter (mass) means a lower temperature rise $\Delta\theta$ for the same energy, so the resistor is less likely to burn out / overheat; it can store more thermal energy.

Disadvantages: smaller surface area to volume ratio, so heat is dissipated to the surroundings more slowly; and it is physically larger, so takes up more room in a circuit. [4]

- 6 A student investigates how the resistance of a light dependent resistor (LDR) varies with light level. The student uses the apparatus shown in **Fig. 6.1**.

Fig. 6.1



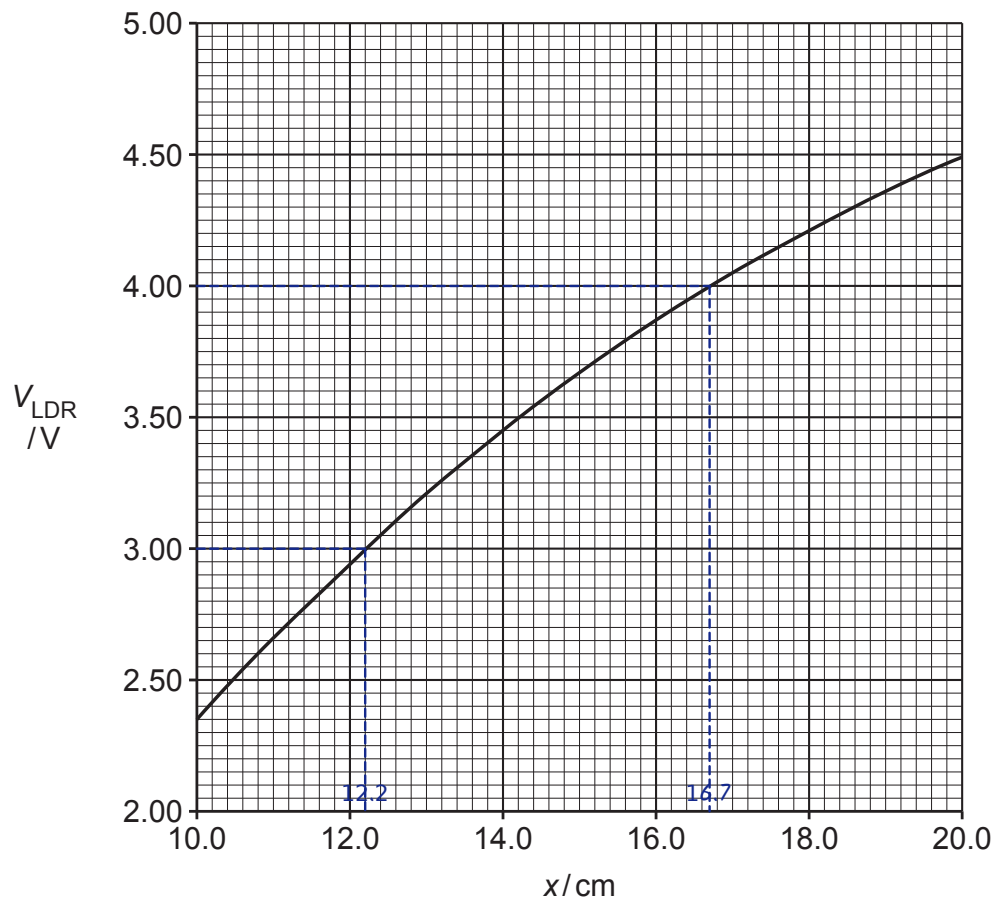
The battery has an e.m.f. of 6.0 V and negligible internal resistance. The voltmeter has a very high resistance compared to the LDR at any light level.

The student varies the light level incident on the LDR by varying the distance between the LDR and a lamp between 0.10 and 0.20 metres. The student measures and records the potential difference across the LDR, V_{LDR} , at different distances.

The light level L provided by the lamp varies with the distance x from the lamp according to the equation $L = \frac{0.80}{x^2}$ where L is in lux and x is in metres.

Fig. 6.2 shows the student's results.

Fig. 6.2



- (a)* Explain how the student can find the relationship between the resistance of the LDR and the light level using data from **Fig. 6.2**. Use values when the voltage is 3.00 V and 4.00 V as examples. Sketch a graph of the resistance of the LDR against light level on the grid in **Fig. 6.3**.

Find R_{LDR} with the potential divider rule ($\mathcal{E} = 6.0 \text{ V}$, I same in both): $V_{\text{LDR}}/6.0 = R/(R + 1000)$, so $R = 1000 \cdot V/(6.0 - V)$.

$V = 3.00 \text{ V}$: $R = 1000 \times 3.00/3.00 = 1000 \Omega$. $V = 4.00 \text{ V}$: $R = 1000 \times 4.00/2.00 = 2000 \Omega$.

Read x from Fig. 6.2 and use $L = 0.80/x^2$: 3.00 V at $x = 12.2 \text{ cm}$, $L = 0.80/0.122^2 = 54 \text{ lux}$.

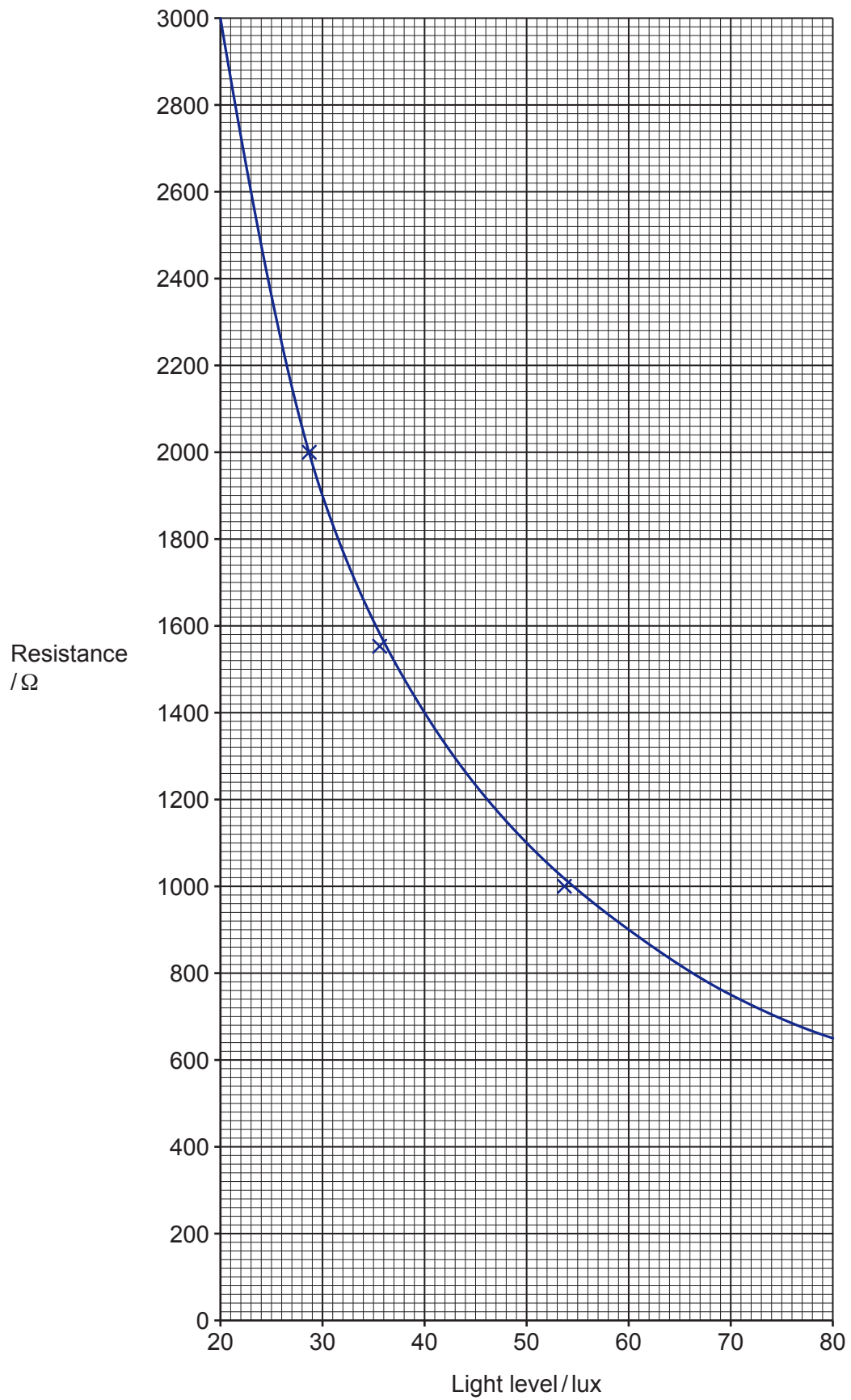
4.00 V at $x = 16.7 \text{ cm}$, $L = 0.80/0.167^2 = 29 \text{ lux}$.

Another point: $x = 15.0 \text{ cm}$, $V = 3.65 \text{ V}$, $R = 3650/2.35 = 1550 \Omega$, $L = 0.80/0.15^2 = 36 \text{ lux}$.

Repeat for more x values and plot R against L on Fig. 6.3.

R decreases as L increases with a decreasing gradient: $R \times L$ is roughly constant. ($54 \cdot 000$, $58 \cdot 000$), so R is approximately inversely proportional to L .

Fig. 6.3



[6]

- (b) Explain why the voltmeter used in the experiment should have a very high resistance.

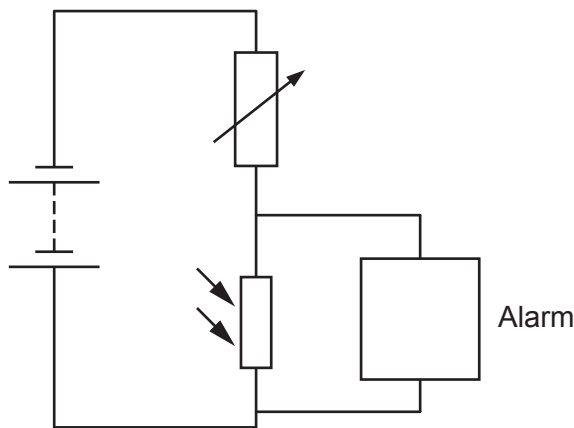
So that (almost) no current is diverted through the voltmeter, which is in parallel with the LDR.

This means the current through the LDR (and the $1\text{ k}\Omega$ resistor) does not change, as the parallel resistance stays equal to R_{LDR} .

So the p.d. across the LDR is the same whether the voltmeter is present or not, and the voltmeter records the correct reading. [3]

- (c) Fig. 6.4 shows how the circuit in Fig. 6.1 can be adapted and used as part of a burglar alarm.

Fig. 6.4



The alarm switches on when the burglar's torch shines on the LDR.

If the alarm is too sensitive it can be switched on by small increases in the ambient light level.

Explain how the sensitivity of the alarm is adjusted and state the factors that need to be considered when setting the sensitivity.

Sensitivity is adjusted by changing the resistance of the variable resistor; this alters the light intensity at which the p.d. across the LDR reaches the level that switches the alarm on (or off).

Factors: whether it is used during the day or at night (ambient light level), how bright / powerful the burglar's torch is and how far away it is, and whether it could be set off by a door opening or car headlights. [3]

Section C

- 7 A model rocket is propelled vertically upwards by a solid fuel rocket engine. Before it is launched the total mass of the rocket and the fuel is 0.500 kg. When it is ignited the fuel burns at a rate 0.020 kg s^{-1} , producing exhaust gases at the same rate. The thrust produced by the rocket engine remains constant at 7.00 N for three seconds. At this time the fuel runs out.

(a)

- (i) Calculate the speed of the exhaust gases from the rocket.

$$F = \Delta(mv)/\Delta t, \text{ so } F = v \times (\text{mass per second})$$

$$7.00 = v \times 0.020$$

$$v = 7.00 \div 0.020 = 350 \text{ m s}^{-1}$$

$$\text{speed} = \dots 350 \dots \text{ m s}^{-1} \quad [3]$$

- (ii) Show that the acceleration immediately after the ignition of the fuel is about 4.2 m s^{-2} .

$$\text{resultant force } F = \text{thrust} - \text{weight} = 7.00 - 0.500 \times 9.81 = 2.095 \text{ N}$$

$$a = F/m = 2.095 \div 0.500 = 4.19 \text{ m s}^{-2} \text{ (about } 4.2 \text{ m s}^{-2}\text{)}$$

[2]

- (iii) Explain why the acceleration of the rocket increases during the first three seconds after it is launched.

The fuel burns, so the mass (and weight) of the rocket decreases while the thrust stays at 7.00 N.
So the resultant force increases and acts on a smaller mass, so $a = F/m$ increases. [2]

- (b) An iterative model can be used to analyse the motion of the rocket and determine approximate values of velocity at different times. The process used is to calculate each value of v from the one before. In this model it is assumed that the resultant force acting on the rocket remains constant at 2.00 N in order to simplify the calculations.

The table shows the values of the mass, m , the resultant force, F , the acceleration, a , and the velocity, v , at 0.50 second intervals, Δt , after the fuel is ignited.

In row 1, time, $t = 0$ s, and all the other variables have their starting values.

In row 2, $t = 0.50$ s and new $v = \text{previous } v + \text{previous } a \times \Delta t = 0 + 4.00 \times 0.50 = 2.00 \text{ m s}^{-1}$.

In the other rows the values of v are calculated in the same way as in row 2.

t/s	m/kg	F/N	$a/\text{m s}^{-2}$	$v/\text{m s}^{-1}$
0.00	0.500	2.00	4.00	0.00
0.50	0.490	2.00	4.08	2.00
1.00	0.480	2.00	4.17	4.04
1.50	0.470	2.00	4.26	6.13
2.00	0.460	2.00	4.35	8.26
2.50	0.450	2.00	4.44	10.44
3.00	0.440	2.00	4.55	12.66

- (i) Use the m and F values to calculate the missing values of a and write them in the table. [1]

$$a = F/m: 2.00 \div 0.460 = 4.35, 2.00 \div 0.450 = 4.44, 2.00 \div 0.440 = 4.55 \text{ m s}^{-2}$$

- (ii) Calculate the missing values of v using the time and previous value of a and write them in the table. [2]

$$v(2.50) = 8.26 + 4.35 \times 0.50 = 10.44 \text{ m s}^{-1}$$

$$v(3.00) = 10.44 + 4.44 \times 0.50 = 12.66 \text{ m s}^{-1}$$

- (iii) State and explain the effect of making the time intervals between iterations shorter on the calculated velocity at 3.00 s.

..The calculated final velocity at 3.00 s increases, because the acceleration.....
 ..(which is increasing) is updated more often, closer to continuously.....
 ..So the accuracy of the model increases.....

[2]

- (c)* Space engineers are planning a mission to send a spacecraft into interstellar space. The engineers are considering two propulsion systems for the spacecraft. A conventional chemical rocket engine uses 50 kg fuel to produce 400 N thrust for 300 s. An ion thruster uses 50 kg xenon propellant to produce 0.050 N thrust for 200 days.

Compare the advantages and disadvantages of a conventional chemical rocket and an ion thruster and comment on the suitability of each one for the interstellar mission.

You should include calculations in your answer.

Momentum change $p = Ft$. Chemical: $p = 400 \times 300 = 1.2 \times 10^5 \text{ N s}$. Ion: $p = 0.050 \times 200 \times 24 \times 3600 = 8.64 \times 10^5 \text{ N s}$. Per kg of propellant: chemical $1.2 \times 10^5 / 50 = 2400 \text{ N s kg}^{-1}$; ion $8.64 \times 10^5 / 50 = 17280 \text{ N s kg}^{-1}$, so the ion thruster is about 7 times more efficient, giving a final velocity about 7 times greater for the same 50 kg. But the chemical thrust is $400/0.050 = 8000$ times greater; the ion thruster takes $1.2 \times 10^5 / 0.050 = 2.4 \times 10^6 \text{ s}$ (about 27 days) to reach the chemical rocket's momentum. High thrust is needed for take-off and to escape planets' gravity; the small ion thrust allows subtle manoeuvres. Conclusion: interstellar distances are huge, so journey time (compared with a human lifespan) is critical. With no air resistance the craft then coasts at constant velocity, so the ion thruster's much greater final speed makes it more suitable for the interstellar cruise, with a chemical rocket to leave Earth. [6]

END OF QUESTION PAPER

This image shows a blank sheet of white paper designed for handwriting practice. It features a series of evenly spaced horizontal blue lines across its entire width. A single vertical red line runs down the left side, creating a narrow margin. The paper is otherwise empty, with no text or markings.

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