



Oxford Cambridge and RSA

Tuesday 17 June 2025 – Morning

A Level Physics B (Advancing Physics)

H557/03 Practical skills 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)

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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 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 **60**.
- 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

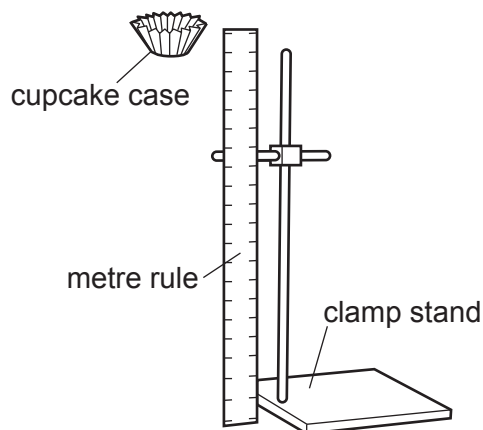
- Read each question carefully before you start your answer.

2
Section A

1 This question is about terminal velocity and drag for falling cupcake cases.

- (a) A student times how long a cupcake case takes to fall through a height of 2.000 ± 0.005 m using the equipment as shown in **Fig. 1.1**.

Fig. 1.1



A light-gate timer (not shown) is used, and the measurement repeated five times. The times are shown in **Table 1.1**.

Table 1.1

Time / s
1.68
1.69
1.71
1.70
1.73

- (i) Determine the absolute uncertainty in the measurement of time.

$$\text{half range} = (1.73 - 1.68) \div 2 = 0.025 \text{ s} \approx 0.03 \text{ s}$$

Absolute uncertainty = $\pm$ 0.03 s [1]

- (ii) Calculate the average velocity of the cupcake case.

Include the uncertainty in your answer.

Give your answer to an appropriate number of significant figures.

$$\text{mean } t = (1.68 + 1.69 + 1.71 + 1.70 + 1.73) \div 5 = 1.702 \text{ s}$$

$$v = 2.000 \div 1.702 = 1.175 \text{ m s}^{-1}$$

$$\%U = 0.005/2.000 + 0.03/1.70 = 0.25 \% + 1.76 \% = 2.0 \%$$

$$\Delta v = 0.020 \times 1.175 = 0.02 \text{ m s}^{-1}$$

$$\text{Average velocity} = \dots\dots\dots 1.18 \dots\dots\dots \pm \dots\dots\dots 0.02 \dots\dots\dots \text{ms}^{-1} \quad [3]$$

- (b) The cupcake case will accelerate from rest to reach terminal velocity at some point during its fall. The student is calculating the average velocity.

Comment on how the average velocity relates to the terminal velocity.

v_{ave} is smaller than v_t, because the calculation of v_{ave} includes the period of (non-constant) acceleration from rest up to v_t. If the drop is long enough, the case falls at v_t for most of the time, so v_{ave} will be close to v_t. A large v_t gives a large v_{ave}; both are in the same direction. [3]

- (c) The experiment is repeated with an increasing number of stacked cupcake cases, as shown in Fig. 1.2.

Fig. 1.2



The average times are recorded in Table 1.2.

Table 1.2

Number of cup cases	Average time t/s
1	1.70
2	1.27
3	0.97
4	0.81
5	0.70

Explain the trend in the relative percentage uncertainty in the calculated values of average velocity as the number of cupcake cases increases.

..The percentage uncertainty in v increases as the number of cases increases.....
 ..The stack falls faster so t decreases, but the absolute uncertainty in t stays the
 ..same, so it is a larger proportion of t : the percentage uncertainty in t (and so in
 .. v) increases.....

[2]

- (d) Drag force = $\frac{1}{2}\rho A v_t^2$ where v_t is the terminal velocity. A is the cross-sectional area of the falling object.
- (i) Show that v_t^2 is proportional to the number of cupcake cases.

At terminal velocity: drag force = weight = Nmg

(N cases each of mass m ; the stack has the same shape so A is the same)

$$\frac{1}{2}\rho A v_t^2 = Nmg$$

$$v_t^2 = 2Nmg \div \rho A$$

$2mg \div \rho A$ is constant, so $v_t^2 \propto N$

[2]

(ii)* Calculate the values of average velocity squared in **Table 1.3**.

Determine whether the average velocity calculated in this experiment is close enough to the terminal velocity to be used in the relationship: Drag force = $\frac{1}{2}\rho A v_t^2$.

Describe how the experiment can be improved so that the average velocity is as close as possible to the terminal velocity.

Table 1.3

Number of cupcake cases	Average time t/s	Average velocity $v_{ave}/m\ s^{-1}$	Average velocity squared $v_{ave}^2/m^2\ s^{-2}$
1	1.70	1.18	1.38
2	1.27	1.57	2.48
3	0.97	2.06	4.25
4	0.81	2.47	6.10
5	0.70	2.86	8.16

$v_{ave} = 2.000 \div t$, e.g. $2.000 \div 1.27 = 1.57\ m\ s^{-1}$, so $v_{ave}^2 = 2.48\ m^2\ s^{-2}$ (all values in Table 1.3).

If v_{ave} were close to v_t , then $v^2 \propto N$, so v^2/N would be constant.

$v^2/N = 1.38/1 = 1.38$, $2.48/2 = 1.24$, $4.25/3 = 1.42$, $6.10/4 = 1.53$, $8.16/5 = 1.63\ m^2\ s^{-2}$.

These vary by about 30 % (1.24 to 1.63) and rise steadily with N , far more than the uncertainty in v^2 (about 4 %), so v^2 is not proportional to N .

Conclusion: v_{ave} is not close enough to v_t to be used in $drag = \frac{1}{2}\rho A v_t^2$. Much of the 2 m fall is spent accelerating from rest, and this is included in v_{ave} , so v_{ave} is less than v_t .

Improvement 1: use a much longer drop (e.g. 4 m down a stairwell). The case then travels at terminal velocity for more of the fall, and the larger time to fall also gives a smaller percentage uncertainty in t .

Improvement 2: release the case well above the timed region and only start timing a short distance below the release point, using two light gates a measured distance apart (e.g. 1.000 m) lower down, so only the constant-speed part is timed.

Check that v_t has been reached by moving both gates further down: the time between them should stay the same.

Alternatively, film the fall against a metre rule and use frame-by-frame analysis to see where the distance moved per frame becomes constant, then calculate v_t from that part only.

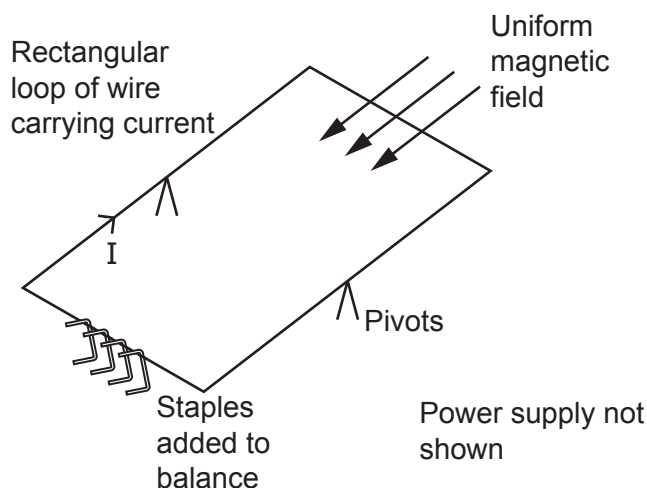
[6]

- 2 A simple current balance can be used to find the magnetic field strength of a magnetic field.

The current balance shown in **Fig. 2.1** is made from a single rectangular loop of stiff wire connected to a power supply.

The length of wire within the magnetic field is 5.0 cm. The pivots are in the centre of the long edges of the rectangle.

Fig. 2.1



The current is varied, and staples are added to restore the rectangular loop to a horizontal balanced position.

- (a) The mean mass of a staple is found to be 0.0325 g.
- (i) Describe how the mass of one staple could be found using a standard laboratory balance with a precision of 0.1 g and a maximum of 2000.0 g.

Count out 200 staples, weigh them together on the laboratory balance (about 6.5 g) and divide the total mass by 200.
Reason: 0.0325 g implies an uncertainty of ± 0.0005 g, so $0.1 \text{ g} \div n \leq 0.0005 \text{ g}$ needs about 200 staples. [2]

- (ii) Estimate the absolute uncertainty in the value of mass of one staple obtained by your method in part (a)(i).

$$\begin{aligned} \text{uncertainty in one staple} &= 0.1 \text{ g} \div \text{number of staples} \\ &= 0.1 \div 200 = 5 \times 10^{-4} \text{ g} \end{aligned}$$

Uncertainty = $\pm 5 \times 10^{-4}$ g [2]

- (b) The experiment is repeated several times for each value of current.

With a current of 1.5A, the number of staples needed to balance the wire horizontally was found four times. The results are shown in **Table 2.1**.

Table 2.1

Number of staples needed to balance when current = 1.5A
4
5
4
5

Calculate the mean magnetic force exerted on the wire when the current is 1.5A.

$$\text{mean number of staples} = (4 + 5 + 4 + 5) \div 4 = 4.5$$

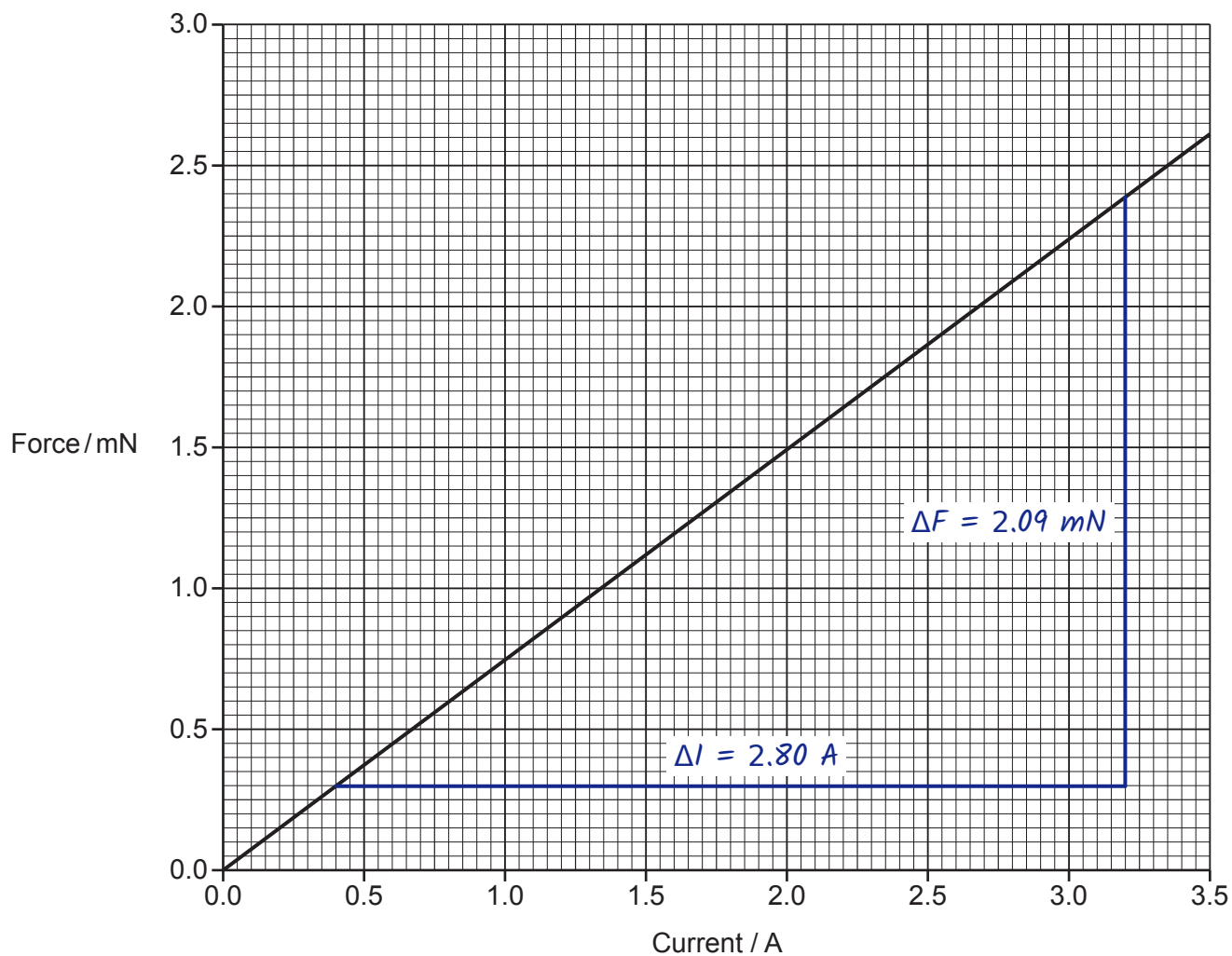
$$\text{mass} = 4.5 \times 0.0325 = 0.146 \text{ g} = 1.46 \times 10^{-4} \text{ kg}$$

$$F = mg = 1.46 \times 10^{-4} \times 9.81 = 1.43 \times 10^{-3} \text{ N}$$

Force = ... 1.43×10^{-3} N [2]

(c) Further data were collected for other values of current. **Fig. 2.2** shows the graph of the data.

Fig. 2.2



(i) Calculate the gradient of the line.

Triangle on graph from (0.40 A, 0.30 mN) to (3.20 A, 2.39 mN)

$$\text{gradient} = \Delta F / \Delta I = (2.39 - 0.30) \div (3.20 - 0.40)$$

$$= 2.09 \div 2.80 = 0.746 \approx 0.75 \text{ mN A}^{-1}$$

Gradient = ...0.75 mN A⁻¹..... [2]

- (ii) Use the value of gradient to calculate the value of magnetic field strength.

$$F = BIL, \text{ so } F/I = BL \text{ and gradient} = BL$$

$$B = \text{gradient} \div L = 0.746 \times 10^{-3} \div 5.0 \times 10^{-2}$$

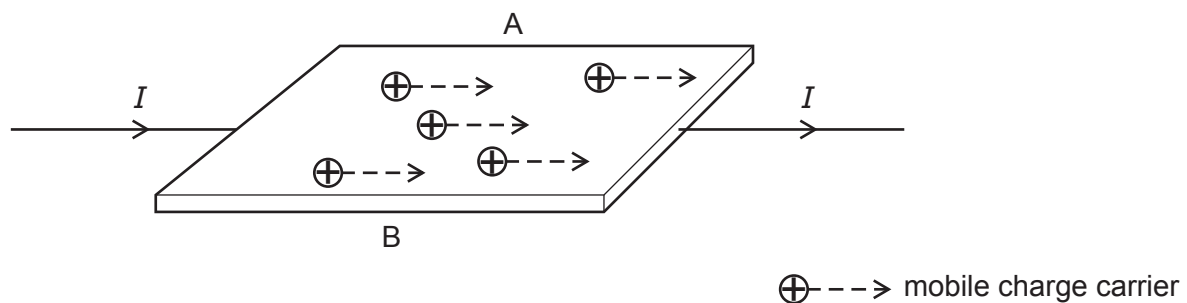
$$B = 1.49 \times 10^{-2} \text{ T}$$

Magnetic field strength = ...0.0149..... T [3]

- (d) Another method to measure magnetic field strength is to use a Hall probe.

A small current passes through a slice of semiconductor material as represented in **Fig. 2.3**.

Fig. 2.3



The probe is placed in a magnetic field. The large face of the semiconductor is at right angles to the field.

Explain why a small potential difference is detected across sides A and B of the semiconductor.

The mobile charge carriers move through the semiconductor in the magnetic field, so there is a force on each moving carrier ($F = Bqv$). The force is at right angles to the motion of the carriers and at right angles to the magnetic field (Fleming's left-hand rule), so the carriers are pushed sideways towards side A (or B). Charge builds up on side A (or B), with the opposite charge on the other side, which gives a potential difference across A and B. [3]

3 This question is about diffraction gratings.

A teacher has a box of 20 unlabelled diffraction gratings. The students are asked to find the number of lines per mm for each grating in the box.

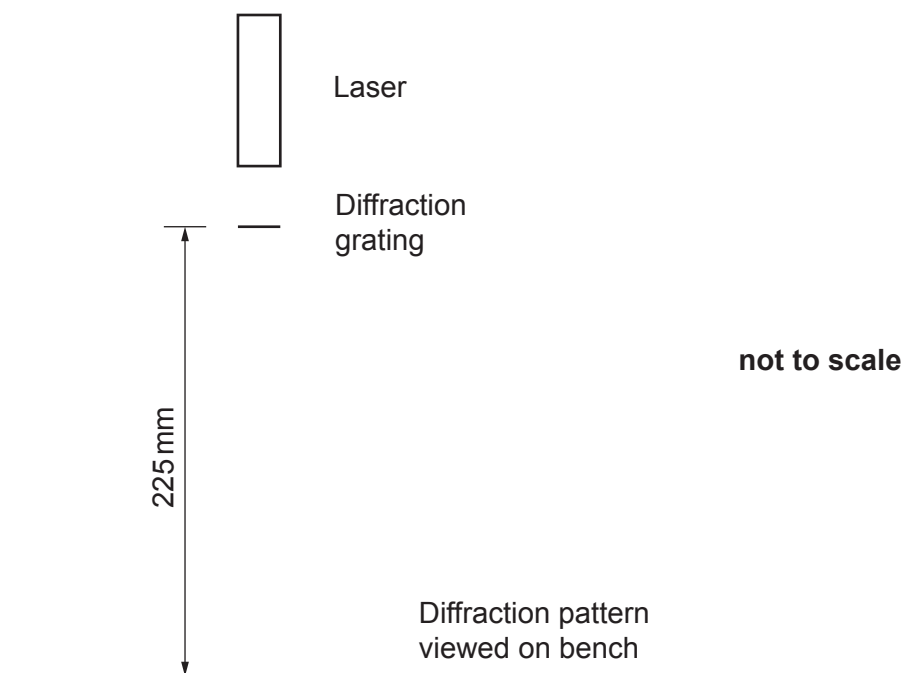
A laser beam is directed downwards at one diffraction grating, as shown in **Fig. 3.1**.

The laser light is red, wavelength 650 nm.

The distance between the grating and the bench is 225 mm.

The diffraction pattern is visible on the surface of the bench.

Fig. 3.1



- (a) The distance between the two first order maxima is measured as 191 mm.
- (i) Calculate the angle between the straight-through direction and the first order maximum.

$$\text{distance from centre to one first order maximum} = 191 \div 2 = 95.5 \text{ mm}$$

$$\tan \theta = 95.5 \div 225 = 0.424$$

$$\theta = \tan^{-1} 0.424 = 23.0^\circ$$

Angle = ...23.0..... ° [2]

- (ii) Calculate the number of lines per mm on the diffraction grating.

$$d = \lambda \div \sin \theta = 650 \times 10^{-9} \div \sin 23.0^\circ = 650 \times 10^{-9} \div 0.391$$

$$d = 1.66 \times 10^{-6} \text{ m} = 1.66 \times 10^{-3} \text{ mm}$$

$$\text{lines per mm} = 1 \div 1.66 \times 10^{-3} = 601$$

Number of lines per mm = ...601..... mm⁻¹ [2]

- (b) Describe how you could determine a more accurate value for the number of lines per mm on the diffraction grating.

.....Increase the distance between the grating and the bench, to increase the.....

.....separation of the maxima (smaller % uncertainty).....

.....Measure between higher order maxima instead of the first order..... [2]

- (c) Table 3.1 shows the values obtained from all 20 diffraction gratings.

Table 3.1

Number of lines per mm				
144	320	590	594	603
156	567	591	599	605
299	588	592	600	605
310	590	593	602	610

Standard values for school diffraction gratings are usually 80 lines/mm, 150 lines/mm, 300 lines/mm and 600 lines/mm.

Explain which set the majority of these gratings are from.

Suggest a value for the **absolute** uncertainty in the published value for the number of lines per mm.

15 of the 20 values are close to 600 lines/mm, so the majority are from the 600 lines per mm set.

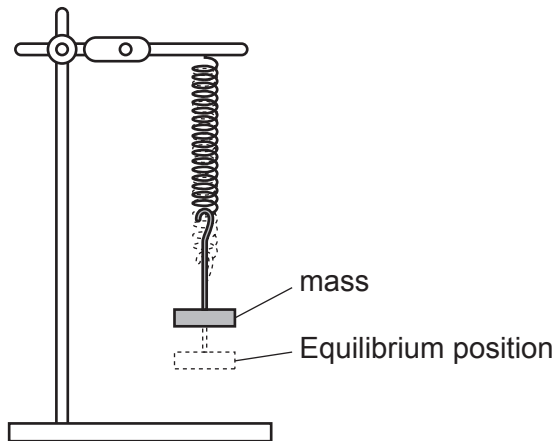
.....567 is an outlier, so use only values from 588 to 610: uncertainty = $\frac{1}{2}(610 -$
588) = $\pm 11 \text{ mm}^{-1}$, i.e. $600 \pm 11 \text{ lines per mm}$

..... [3]

Section B

- 4 A student carries out an experiment investigating how the period of oscillation of a mass on a spring varies as the mass is increased. The experimental setup is shown in **Fig. 4.1**.

Fig. 4.1



The teacher tells the student that measuring the time for ten oscillations rather than the time for one oscillation will provide more reliable data.

- (a) State why measuring ten oscillations provides a more reliable measurement of the time period.

It reduces the (percentage) uncertainty in T , as the timing uncertainty is a smaller fraction of the time measured. [1]

- (b) One pair of data points is shown below.

Time for ten oscillations = $10.4 \text{ s} \pm 0.5 \text{ s}$

Mass = $0.50 \text{ kg} \pm 0.01 \text{ kg}$

The student decides to ignore the uncertainty in the mass and the teacher agrees.

Explain whether this is a reasonable decision. Use calculations in your answer.

$$\% \text{ uncertainty in } t = 0.5 \div 10.4 \times 100 = 4.8 \%$$

$$\% \text{ uncertainty in } m = 0.01 \div 0.50 \times 100 = 2 \%$$

Reasonable: the uncertainty in T is more than double that in m (and 9.6 % in T^2), so the mass uncertainty is small in comparison.

[2]

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Question 4 continues on page 16

The student gathers the data in **Table 4.1**.

Table 4.1

Mass / kg	Time for ten oscillations (± 0.5) / s	Time for one oscillation, T / s	T^2 / s ²
0.10	4.9	0.49	0.240
0.20	5.9	0.59	0.348
0.30	7.9	0.79	0.624
0.40	9.2	0.92	0.846
0.50	10.4	1.04	1.082
0.60	10.9	1.09	1.188
0.70	12.0	1.20	1.440

- (c) The student plots the data as a graph as shown in **Fig. 4.2** and includes uncertainty bars for T^2 values based on the uncertainty value given in part (b).

- (i) Complete **Table 4.1** and plot the remaining point on **Fig. 4.2**. [2]

- (ii) Calculate the uncertainty in the value of T^2 for the final data point and add these uncertainty bars to the graph.

$$\% \text{ uncertainty in } T = 0.5 \div 12.0 \times 100 = 4.17 \%$$

$$\% \text{ uncertainty in } T^2 = 2 \times 4.17 = 8.34 \%$$

$$\Delta T^2 = 0.0834 \times 1.44 = 0.12 \text{ s}^2$$

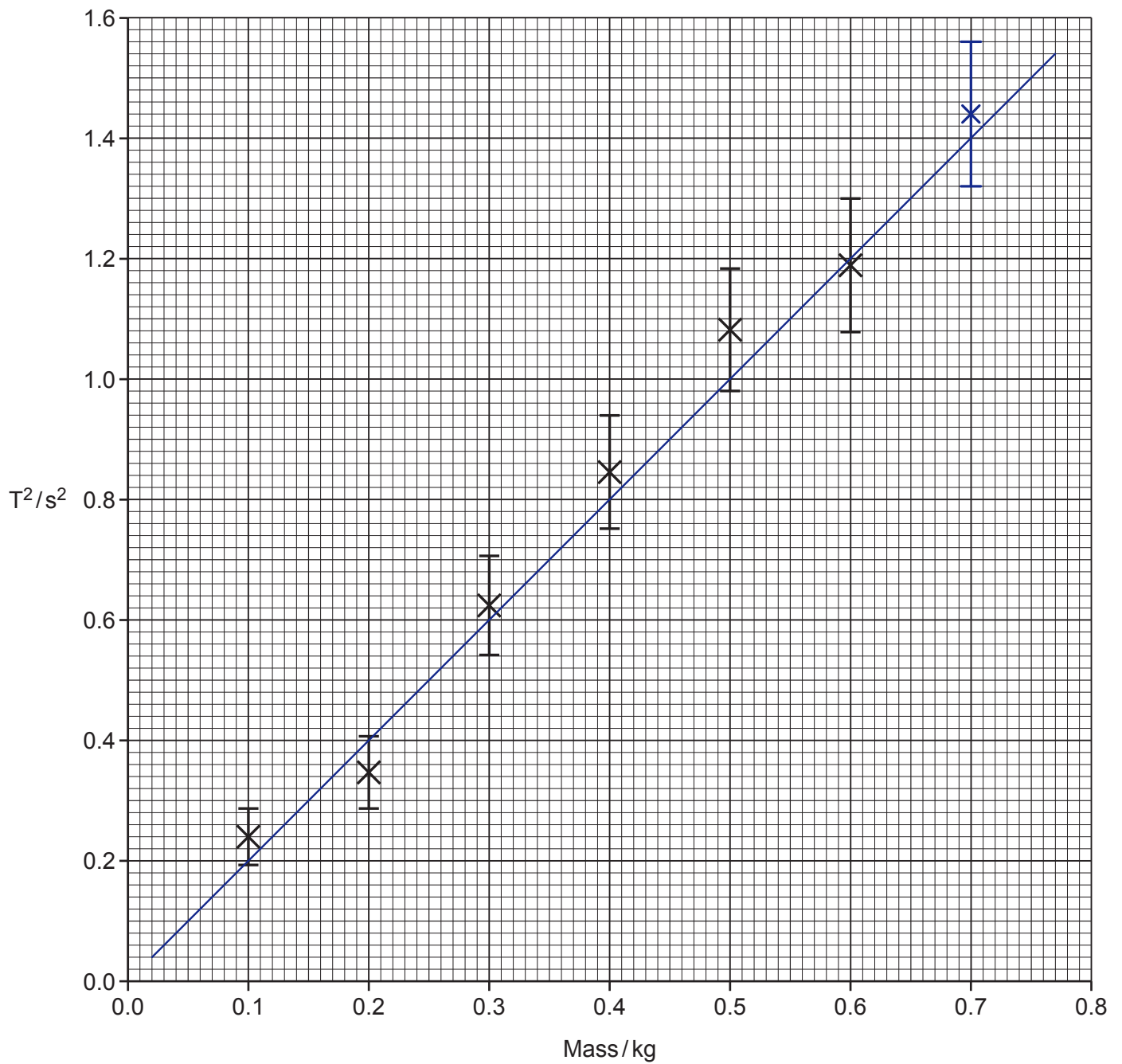
$$\text{bars from } 1.44 - 0.12 = 1.32 \text{ to } 1.44 + 0.12 = 1.56 \text{ s}^2$$

[3]

- (iii) Draw a line of best fit on **Fig. 4.2**.

[1]

Fig. 4.2



(iv) A different student calculates their gradient to be $2.05 \text{ s}^2 \text{ kg}^{-1}$.

Show that the spring constant of the oscillating system is approximately 19 N m^{-1} .

$$T = 2\pi\sqrt{m/k}, \text{ so } T^2 = (4\pi^2/k) m$$

$$\text{compare with } y = mx: \text{ gradient} = 4\pi^2/k$$

$$k = 4\pi^2 \div \text{gradient} = 4\pi^2 \div 2.05$$

$$k = 19.3 \text{ N m}^{-1} \approx 19 \text{ N m}^{-1}$$

[2]

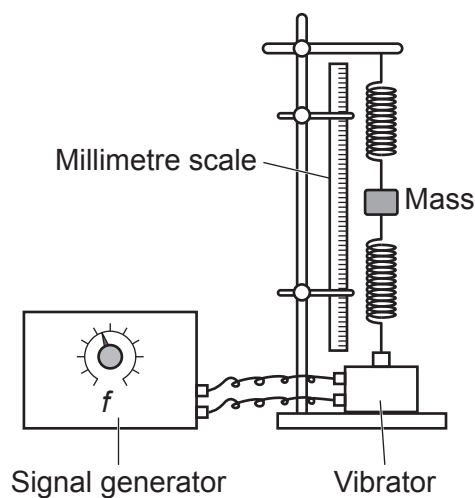
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Question 4 continues on page 20

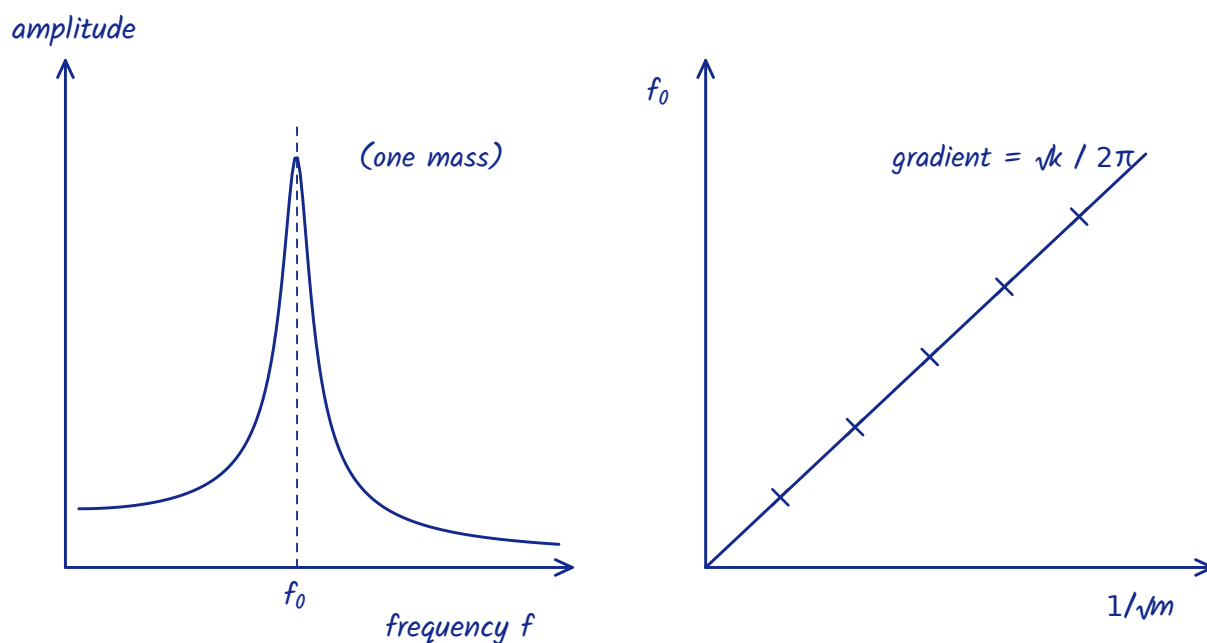
- (d) The student develops their experiment to investigate resonance. In the modified experiment, the oscillations are driven by a signal generator and vibrator as shown in **Fig. 4.3**.

Fig. 4.3



- (i)* Suggest how the student could use this apparatus to investigate how the resonant frequency of the system varies with mass. You should describe the experimental process including:
- How the student could obtain precise determinations of the resonant frequencies.
 - Describe and explain the relationship between resonant frequency and mass you would expect the student to obtain.
 - Include in your explanations how the amplitude would vary with frequency for a given mass.

You may use diagrams in your response.



For a fixed mass, start the signal generator at a low frequency and slowly increase f , recording the amplitude of the mass on the millimetre scale at each frequency (a pointer on the mass reduces parallax). Take smaller steps of f near the peak.

The resonant frequency f_0 is where the amplitude is maximum. For a precise f_0 , once the peak is found go back and forth either side of it using the finest scale of a calibrated signal generator, repeat and take a mean; or plot amplitude against f to find f_0 .

Repeat for a range of masses (e.g. 0.10 to 0.70 kg), keeping the spring and vibrator amplitude the same, and plot f_0 against $1/\sqrt{m}$.

Amplitude against f (sketch): small at low and high f , rising to a sharp peak at f_0 , where the driving frequency equals the natural frequency and energy transfer is maximum.

$f_0 = (1/2\pi)\sqrt{k/m}$, so f_0 decreases as m increases: $f_0 \propto 1/\sqrt{m}$, a straight line through the origin of gradient $\sqrt{k}/2\pi$. [6]

- (ii) Measurements of mass in space can be challenging. Suggest briefly how to adapt the method shown in **Fig. 4.3** to measure mass in zero g environments.

Estimate a reasonable spring constant for the system, if it were to be used to measure an astronaut's mass.

Assume that the time period of the system is designed to be about 2 s for a typical mass.

In zero g , fix the springs horizontally between two rigid supports with the astronaut strapped to a seat between them. Displace and let oscillate freely (no vibrator), time T , and use $m = kT^2/4\pi^2$ with a known k .

Astronaut $m \approx 75$ kg, $T = 2$ s: $k = 4\pi^2 m/T^2 = 4\pi^2 \times 75 \div 2^2 \approx 740$ N m⁻¹.

[3]

END OF QUESTION PAPER

[illegible]

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