2024 CA2 Physics P4 Mark Scheme

1 In this experiment, you will investigate the effect of friction on a simple pulley system.

(a) You are provided with a spring of unstretched length L_0, as shown in Fig. 1.1.

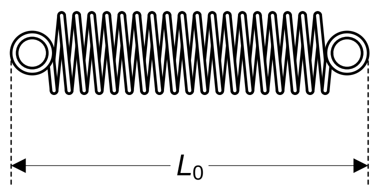


Fig. 1.1

Measure and record L_0.

L_0 = 4.1 cm .... [1]

- Some students did not measure from the extreme ends of the rings. Read the question carefully!
- When using ruler to measure length, instrument uncertainty = 0.1 cm. So L_0 should be recorded to 1 dp.

(b) Set up the apparatus as shown in Fig. 1.2.

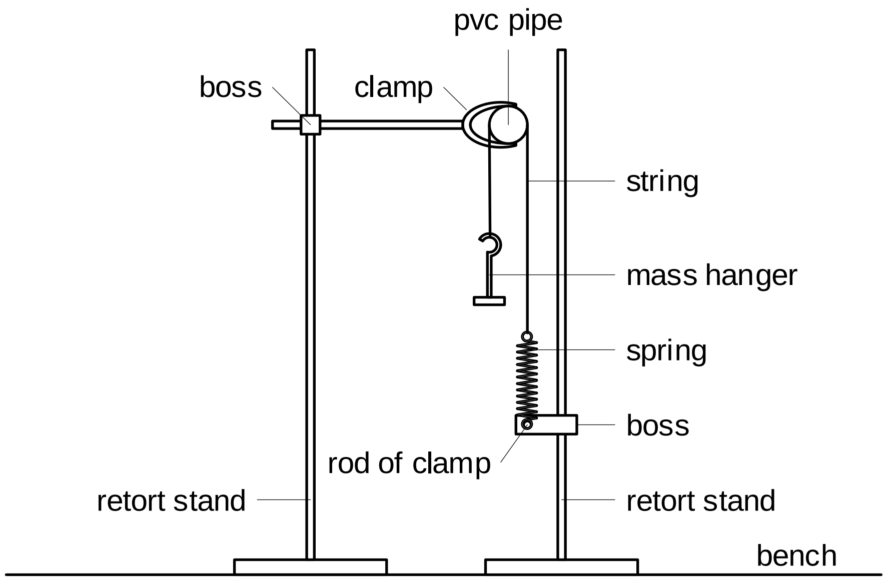


Fig. 1.2

Ensure that the pipe remains horizontal at all times, and that the strings on each side of the pipe are vertical and parallel with each other.

The spring should only stretch minimally at this instant.

(i) Place a 50 g slotted mass onto the mass hanger and **slowly** lower the mass hanger, allowing the spring to extend to a new equilibrium length L_1,

Measure and record L_1.

L_1 = 6.1 cm .... [1]

(ii) Calculate the extension x_1 of the spring from its unstretched length, where

$$x_1 = L_1 - L_0$$

$x_1 = L_1 - L_0 = 6.1 - 4.1 = 2.0$ cm

x_1 = 2.0 cm .... [1]

- You should show the working for your calculation.

(iii) Pull the mass hanger downwards by about 10 cm, causing the spring to extend further. Hold the hanger while allowing it to **slowly** rise upwards until the spring retracts to another equilibrium length L_2, where L_2 is larger than L_1.

Measure and record L_2.

L_2 = 11.3 cm ....

(iv) Calculate the new extension x_2 of the spring from its unstretched length, where

$$x_2 = L_2 - L_0$$

$x_2 = L_2 - L_0 = 11.3 - 4.1 = 7.2$ cm

x_2 = 7.2 cm .... [1]

(c) Theory suggests that x_1 and x_2 are related by the expression

$$\ln\frac{x_2}{x_1} = 2\beta\theta$$

where β is a constant and θ is the angle of contact (expressed in radians) between the string and the pipe, as shown in Fig. 1.3.

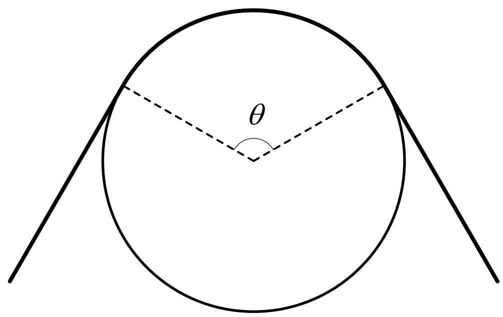


Fig. 1.3

(i) State the value of θ for the set-up in Fig. 1.2.

θ = π rad .... [1]

- Some students recorded the answer in degrees, when the question asked for radians.

(ii) Determine a value for β.

$$\beta = \frac{\ln(x_2/x_1)}{2\theta} = \frac{\ln(7.2/2.0)}{2\pi} = 0.204 \text{ rad}^{-1}$$

β = 0.204 rad^{-1} .... [1]

(iii) The experiment is repeated with different numbers of slotted masses to obtain more values of x_1 and x_2.

State how a straight line graph can be plotted and used to determine the value of β, assuming the theory is correct.

$$\ln\frac{x_2}{x_1} = 2\beta\pi \Rightarrow \frac{x_2}{x_1} = e^{2\beta\pi} \Rightarrow x_2 = \left(e^{2\beta\pi}\right)x_1$$

Plot a graph of x_2 against x_1 where the gradient is $e^{2\beta\pi}$ and the vertical intercept is zero.

Hence, $\beta = \frac{1}{2\pi}\ln(\text{gradient})$.

or

$$\ln\frac{x_2}{x_1} = 2\beta\pi \Rightarrow \ln x_2 - \ln x_1 = 2\beta\pi \Rightarrow \ln x_2 = \ln x_1 + 2\beta\pi$$

Plot a graph of $\ln x_2$ against $\ln x_1$ where the gradient is 1 and the vertical intercept is $2\beta\pi$. Hence, $\beta = \frac{1}{2\pi}(\text{vertical intercept})$. [2]

Many students said to plot $\ln\frac{x_2}{x_1}$ vs θ. But θ is a constant!

(iv) State the value of β if the pipe is frictionless. Explain your answer.

If the pipe is frictionless, $x_1 = x_2$, as the spring will retract back to an extension of x_1 after being stretched further. Hence, $\ln(x_2/x_1) = \ln(1) = 0$ and this implies $\beta = 0$. [2]

Note:

β is the coefficient of friction between the string and the pipe (You're not expected to know. Hence, $\beta = 0$ when the pipe is frictionless.

[Total: 10]

2 In this experiment, you will investigate an electrical circuit.

(a) Component Z in the circuit shown in Fig. 2.1 is a combination of resistors X.

The values of the resistance of X is $2.2\,\Omega$.

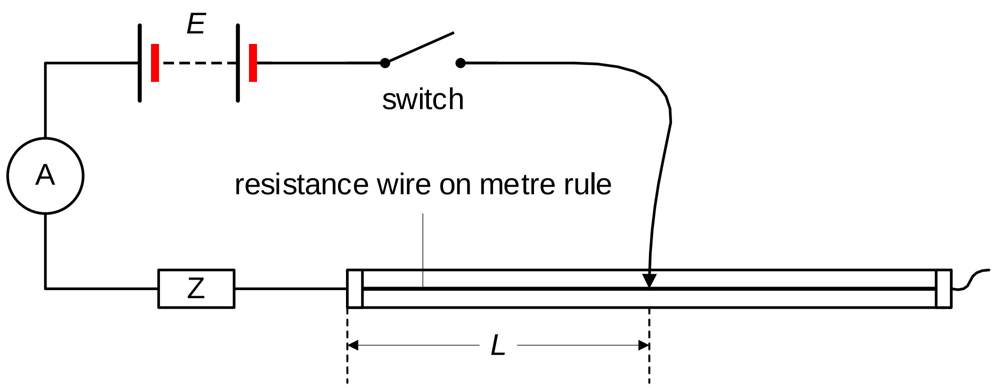
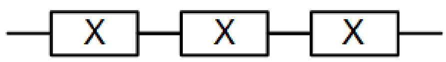


Fig. 2.1

Set up the circuit in Fig. 2.1 such that Z is a combination of X, X and Y connected in series.

Draw this series combination.

Calculate the effective resistance R_Z of Z.



$R_Z = 2.2 + 2.2 + 2.2 = 6.6\ \Omega$

R_Z = 6.6 Ω .... [1]

Close the switch.

Adjust length L to obtain an ammeter reading I of approximately 0.10 A.

Measure and record I and L.

I = 99.7 mA (to 0.1 mA) ....

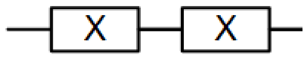
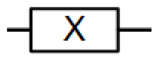
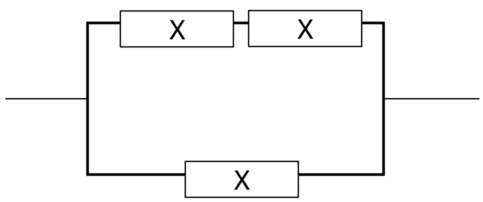
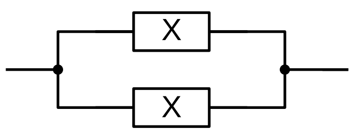
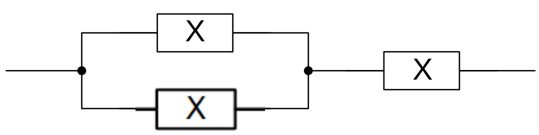
L = 0.410 m (to 0.1 cm) .... [1]

- For I, you should use the most sensitive setting possible, which is the 200 mA setting, which can measure to 0.1 mA. If you record in A, then you should record to 4 dp.

Open the switch.

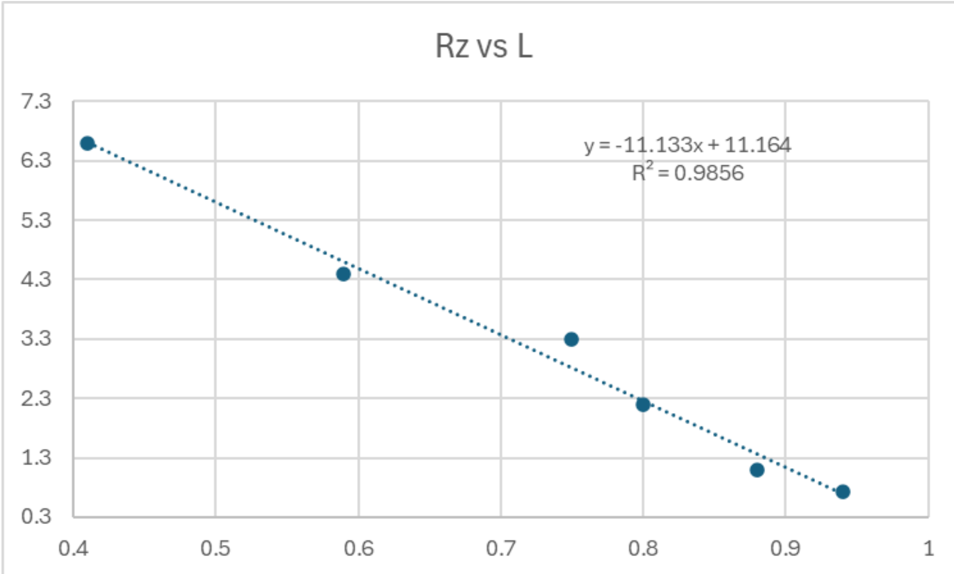
(b) Vary R_z using different combinations of X, and repeat **(a)**, keeping I constant throughout.

Present your results clearly. Include drawings of the different combinations of X.

Connections of X, X and Y	R_z / Ω	L / m
	6.6	0.410
	4.4	0.590
	2.2	0.800
	1.5	0.868
	1.1	0.880
	3.3	0.750

[3]

- Some students didn't present their data in a table form.
- Don't do working in the table. That makes the table look very untidy.



(c) R_z and L are related by the expression

$$E = IR_z + kIL$$

where E is the electromotive force of the cell and k is a constant.

Plot a suitable graph to determine a value for k.

$$R_z = \frac{E}{I} - kL$$

Plot a graph of R_z against L where the gradient is $-k$ and the vertical intercept is $\frac{E}{I}$.

gradient $= -11.1$

Resistance per unit length

$k = -\text{gradient} = 11.1\ \Omega\ \text{m}^{-1}$

k = $11.1\ \Omega\ \text{m}^{-1}$ [5]

- Some students plotted more complicated graphs, eg *IR* vs *IL* etc. Learn to identify the simplest possible graph to plot, in order to save time.
- Some students forgot the units of *k*.

(d) The experiment is repeated using a resistance wire of the same material but with a smaller diameter.

Sketch a line on your graph grid on Page 8 to show the expected result.

Label this line W. [1]

The resistance per unit length of a thinner wire will be higher. So for the same R_z, to get the same current, you need a shorter length of the resistance wire (i.e. L will be smaller).

Also, y intercept = $\frac{E}{I}$, which remains the same.

These 2 facts combined means that the new line will be to the left of the old line, but with the same y intercept. So the new line will become steeper (draw and see for yourself).

[Total: 11]

3 In this experiment, you will investigate how the following properties affect the period of the oscillation of a suspended closed loop wire.

- the perimeter of the closed loop wire
- the shape of the closed loop wire
- the ratio of certain dimensions of the closed loop wire

(a) **(i)** Bend the **longer** wire to form a square shape of length L, as shown in Fig. 3.1.

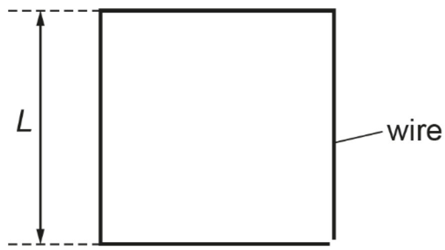


Fig. 3.1

Measure and record L.

L = 13.0 cm

L = ...13.0.......... cm [1]

(ii) Estimate the percentage uncertainty in your value of L.

$$\frac{\Delta L}{L} \times 100\% = \frac{0.5}{13.0} \times 100\% = 3.8\%$$

percentage uncertainty in L = ...3.8%.......... [1]

- There is a lot of unavoidable inaccuracies in measuring L eg the copper wire is not straight etc. So ΔL should be more than 0.1 cm.

(b) (i) Place the cork in the clamp and attach the clamp to the stand using the boss.

Hang the wire square from the pin as shown in Fig. 3.2.

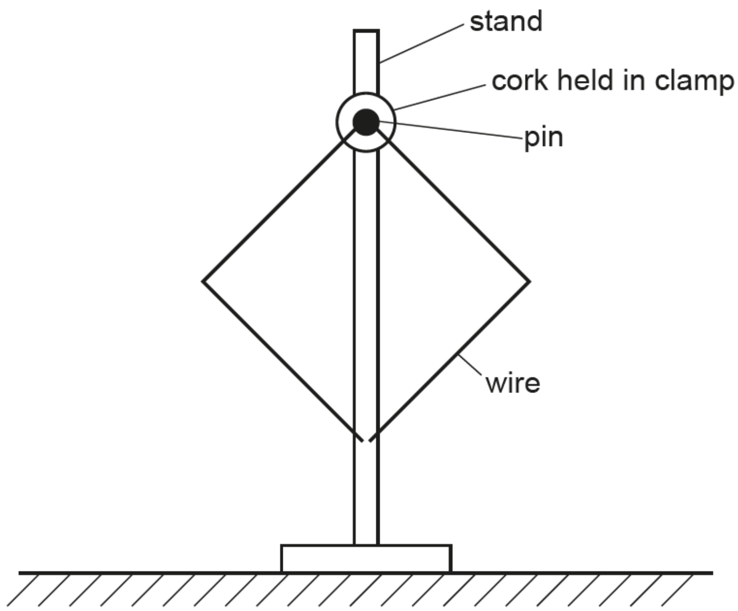


Fig. 3.2

Gently displace the wire square and release it so that it oscillates as shown in Fig. 3.3.

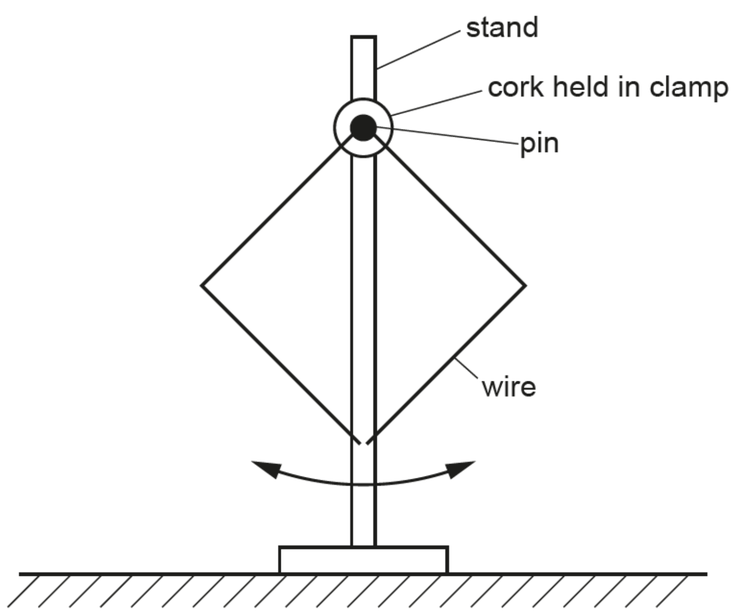


Fig. 3.3

Determine the period T of the oscillations.

$T = (15.6 + 15.5)/(2\times20)$
$= 0.780$ s

T = ...0.780............ s [2]

- Timings should be more than 10 s to reduce percentage error.
- You should repeat the timing and take average to reduce random error.

(ii) Calculate T^2.

$T^2 = 0.780^2 = 0.608$ s^2

T^2 = ...0.608............ s^2 [1]

(iii) Justify the number of significant figures you have given for your value of T^2.

Since T is expressed to 3 significant figures, T^2 will also be expressed to 3 significant figures.

[1]

(c) Remove the wire square from the pin.

Form a new square shape of length L using the **shorter** wire.

Measure and record L.

$L = 6.3$ cm

L = ...6.3............ cm

Repeat **(b)(i)** and **(b)(ii)**.

$T = (11.0 + 11.1)/(2\times20)$
$= 0.553$ s

$T^2 = 0.553^2 = 0.306$ s^2

T = ...0.553............ s

T^2 = ...0.306............ s^2
[2]

(d) It is suggested that the relationship between T and L is

$$T^2 = \frac{L}{k}$$

where k is a constant.

(i) Using your data, calculate two values of k.

$$T^2 = \frac{L}{k}$$

$$k = \frac{L}{T^2}$$

$$k_1 = \frac{13.0}{0.6077} = 21.4 \text{ cm s}^{-2}$$ [1] check for correct calculations

$$k_2 = \frac{6.3}{0.3058} = 20 \text{ cm s}^{-2}$$

first value of k = 21.4 cm s^{-2}

second value of k = 20 cm s^{-2}

[1]

- Some students forgot to give the units of k.
- k_2 should be 2 sf, since L = 6.3 cm which is 2 sf.

(ii) State whether the results of your experiment support the suggested relationship. Justify your conclusion by referring to your answer **(a)(ii)**.

$$\frac{\Delta k}{\langle k \rangle} \times 100\% = \frac{21.4 - 20.6}{21.4} \times 100\% = 3.7\%$$

The actual percentage difference of k of 3.7% is smaller than the theoretical percentage uncertainty of L calculated in (a)(ii) of 3.8%. Hence, my results support the suggested relationship.

(We can ignore the uncertainty of T as it is small compared to L)

[1]

- Some students tried to include the percentage uncertainty in T as well, which is not wrong. But many of them calculated ΔT wrongly. See below:

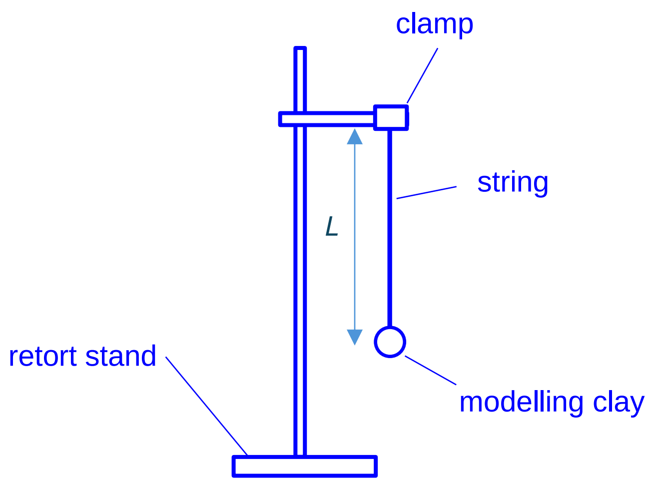
$$\Delta T = \frac{\Delta t}{\text{No. of oscillations}}$$

(e) To model the behaviour of the oscillation of the square shape in **(a)**, a pendulum having the same mass as the wire is used.

Plan an investigation to determine the length of the pendulum such that the period is the same as your answer in **(b)(i)**.

Your account should include:

- a labelled diagram
- your experimental procedure
- how you would determine the length of the pendulum.



1. Measure the mass of the wire, *m* using electronic balance. Using modelling clay, make a sphere with mass *m*.
2. Set up the apparatus as shown.
3. Measure, *L*, the length of the pendulum from the point of suspension to the centre of the bob using a metre rule.
4. Measure the time *t* for *n* oscillations of the pendulum with a stopwatch.
5. Period of the pendulum, $T = t / n$
6. By varying *L*, repeat step 3 to 5 until you have 6 sets of *T* and *L*. Ensure that the period in (b)(i) is within the range of *T* found.
7. Plot a graph of *T* against *L* and draw a best fit curve.
8. Read off the value of *L* where *T* = period in (b)(i).

- Many students forgot that the length of a pendulum is measured to the centre of the bob.
- Some students did not give the equation for calculating *T*.
- Some students did not mention plotting a graph.
- The question did not ask you to verify the relartionship between T and L, so there is no need to assume $T = aL^b$.

[4]

(f) Remove the wire square from the pin.

(i) Form an equilateral triangle using the **shorter** wire and determine the period T of the oscillations.

$T = (11.0 + 10.7)/(2 \times 20)$
$= 0.542$ s

T = 0.542 s [1]

(ii) Repeated **(f)(i)** for a shape of a circle.

$T = (11.3 + 11.5)/(2 \times 20)$
$= 0.570$ s

T = 0.570 s [1]

(g) In a separate investigation, a wire of total length 100.0 cm is bent to form a rectangle with length x and width y. The values of x and y are varied, keeping the perimeter of the rectangular wire constant as shown in Fig. 3.4.

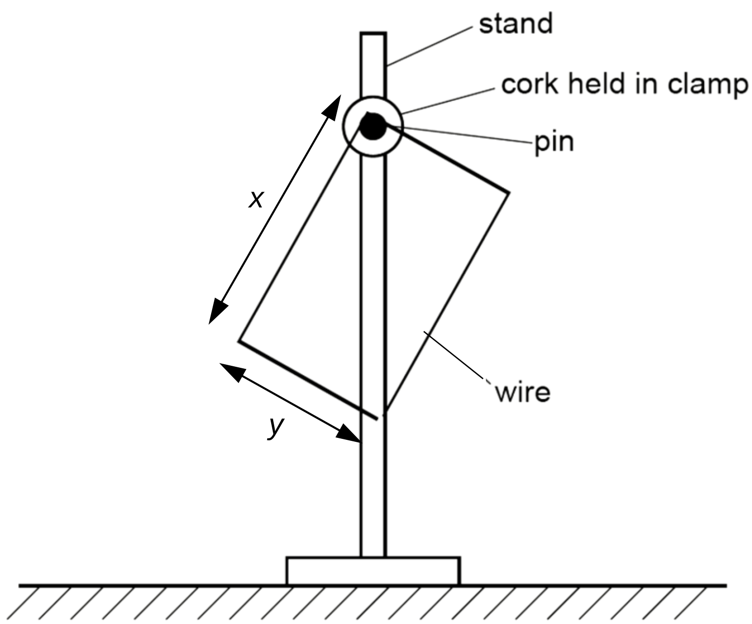


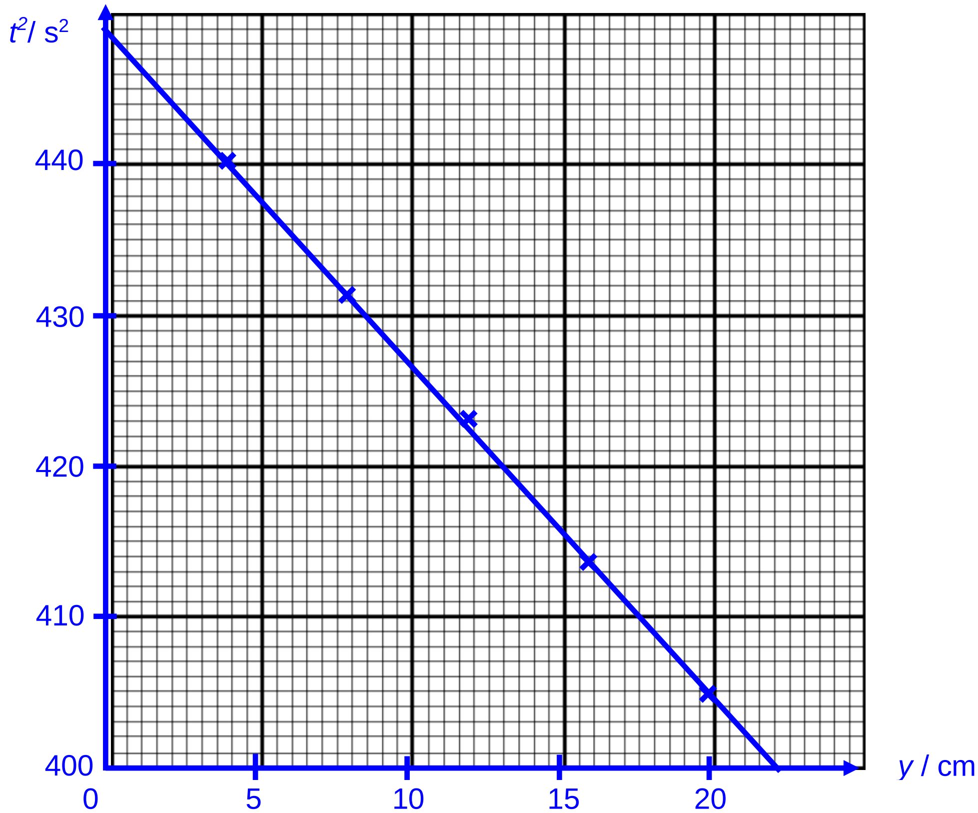
Fig. 3.4

The time for 20 complete oscillations, t, of the rectangular wire is measured using a more precise method. The results for x, y and t were recorded.

x / cm	46.0	42.0	38.0	34.0	30.0
y / cm	4.0	8.0	12.0	16.0	20.0
t / s	20.98	20.77	20.57	20.34	20.12
t^2 / s^2	440.2	431.4	423.1	413.7	404.8

(i) Complete the above table. [2]

(ii) Plot t^2 against y on the grid and draw the straight line of best fit.



[2]

(iii) Use your graph to determine the period of a straight rod of length 50 cm suspended at one end.

At $y = 0$, the rectangle wire has the same structure as a straight rod.

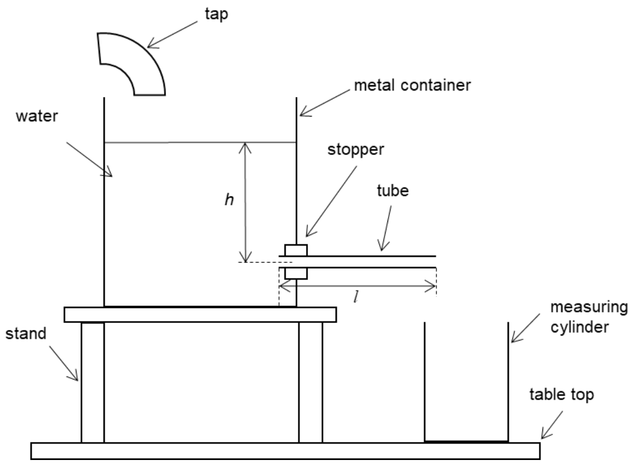
At $y = 0$, $t^2 = 449.0\ s^2$ [1]

$T = \dfrac{\sqrt{449.0}}{20} = 1.059\ s$ [1]

period of straight rod = ... s [2]

[Total: 22]

- Some students calculated *t*, and forgot to divide by the no. of oscillations to get *T*.
- Some students did not notice that the y intercept can be read off the graph, and wasted time calculating it.
- Some students tried to find the value of *t* for *y* = 50 cm instead, which is valid. But that means they had to calculate the value of t^2 as it could not be read from the graph. So it's worth a bit of your time to look at the data available to you before deciding your course of action.

4	Suggested solution
	

- Setup the apparatus as shown above

<u>1st experiment</u>

1. Measure the length of the tube *l* using a metre rule
2. Switch on the tap and let the water flow into the metal container. Adjust the flow of the water such that the height of the water in the metal container remains the same.
3. Measure the height of the water from the centre of the tube *h* using a metre rule
4. Place a measuring cylinder below the tube to collect the water. Start the stop watch at the same time.
5. Stop the stopwatch after the measuring cylinder is about three quarter full. Record down the time *t* and read of the volume of the water collected from the measuring cylinder. Determine the flow rate *F* by dividing the volume of water collected in time *t.*
6. By adjusting the flow rate of water from the tap, obtain 6 more different values of *h*. Repeat experiment step 2 to 5 to obtain the respectively flow rate. The same tube has to be used for all different *h* to ensure *l* remains constant

<u>2nd experiment</u>

7. By using tubes of different length, obtain 6 different values of *l*. For each value of *l*, repeat step 1 to 5 to obtain the respective flow rate. Ensure the height of the water is the same for all different *l*.

<u>Analysis</u>

- For 1st experiment, using the equation $F = \frac{k\, d^4\, h^n}{l^m}$, $\ln F = n\ln(h) + \ln(\frac{k\, d^4}{l^m})$, plot ln *F* against ln *h* where *n* is the gradient.

	• For 2nd experiment, using the equation $F = \frac{k\, d^4\, h^n}{l^m}$, $\ln F = -m\ln(l) + \ln(k\, d^4\, h^n)$, plot ln *F* against ln *l* where -*m* is the gradient. Control variable • Measure the inner diameter of the tube using a vernier calipers. Ensure only tubes with the same diameter is used for the experiment Accuracy • Ensure the tube is horizontal by measuring the distance between 2 different points on the tube to the table top and ensuring they are the same • To measure *h* accurately, make a mark on the inside of the can beside the centre of the hole. Then make another mark to indicate the desired height of the water level. Use the metre rule to measure the vertical distance between the 2 marks before filling the container with water up to the 2nd mark. Safety • Place a towel below the measuring cylinder to capture any spillage.

- Many students drew the container floating in air. You need to draw it on a stand.
- Most students did not realise that for each reading, the water level needs to be kept at a constant height. Otherwise the flow rate will fall as the water level falls.
- Some students did not mention the instruments to be used to measure *h, l* and *t*.
- To measure the volume of water accurately, you should use a measuring cylinder and not a beaker. The uncertanty of a beaker is quite big.
- Some students did not explain how to calculate the flow rate. You should give the equation to be used.
- Some students said, for example, '$F = \frac{500}{t}$'. This is a bit confusing. What does the '500' stand for? Instead, you should write '$F = \frac{V}{t}$', assuming you have already defined *V* and *t*.
- Some students did not realise that you have to do 2 separate experiments, one to find *n* and one to find *m*.
- Look at steps 6 and 7. You should mention what you should keep constant in these steps, instead of somewhere else, in case the marker forgets that you have already mentioned it. **Make it easy for the marker to give you marks**.
- Analysis: you need to show the linearization of the equation before you say plot what graph.
- For the 2nd experiment: note that the gradient = -m, not +m.
- Writing about control variables is standard. Many students didn't write about control variables.
- Safety: there is no electrical equipment in this experiment. So you shouldn't talk about spilling water on electrical equipment.