H2 Physics Prelim P4 (2023)
Suggested solutions

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

(a) Set up the circuit as shown in Fig. 1.1.

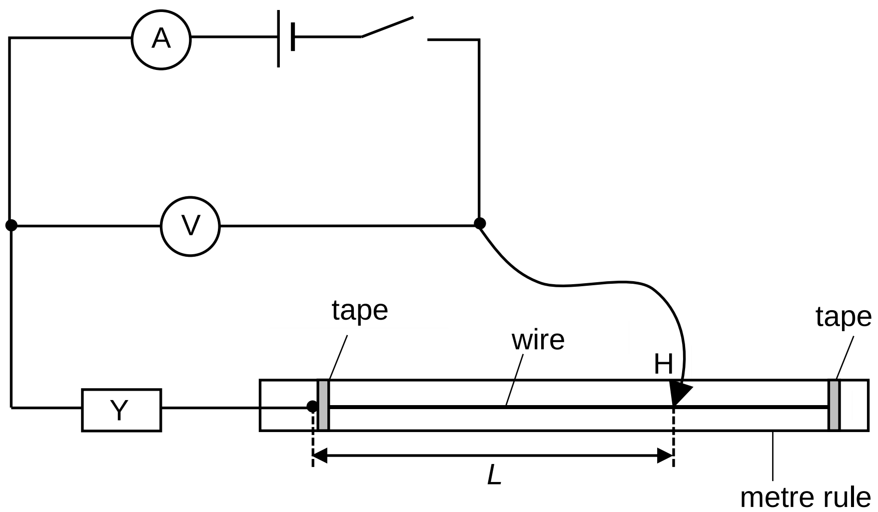


Fig. 1.1

H is a crocodile clip that is free to move along the wire.

Y is a resistor with resistance *R*.

(b) Adjust length *L* to approximately 0.10 m.

Measure and record *L*.

L = 0.100 m

(c) Close the switch.

Measure and record the current I and the potential difference *V*.

I = 85.93 mA

V = 1.0135 V [1]

Marker's comments:

- Many candidates converted current from mA to A wrongly which carried over to their table readings and calculations being wrong.
- A small number of candidates connected the wires wrongly and ended up with wrong values/trend for the table values.
- A significant number of candidates manipulated the equation wrongly, e.g., decided to plot *V* against *L*, without realising that it is not a linear relationship.

(d) Repeat **(b)** and **(c)** for different values of *L* by varying the position of H.

L /m	I /mA	V /V	$\frac{V}{I}$ /Ω
0.100	85.93	1.0135	11.79
0.200	80.65	1.0376	12.87
0.300	75.98	1.0715	14.10
0.400	71.20	1.0936	15.36
0.500	68.04	1.1116	16.34
0.600	64.17	1.1221	17.49
0.690	61.32	1.1393	18.58

[4]

(e) *V* and *L* are related by the expression

$$V = IR + kIL$$

where *k* is a constant.

Plot a suitable graph to determine *R* and *k*.

$V = IR + kIL \quad \Rightarrow \frac{V}{I} = R + kL$

Plot a graph of $\frac{V}{I}$ against *L*, where the gradient is *k* and the vertical intercept is *R*.

Gradient $= \frac{19.60 - 11.90}{0.780 - 0.110} = \frac{7.70}{0.670} = 11.5$ (3 s.f.)

$\therefore k = 11.5\ \Omega\ \text{m}^{-1}$

From graph, vertical intercept = 10.65 Ω

$\therefore R = 10.65\ \Omega$

OR

Using (0.780, 19.60) and gradient = 11.5

$19.60 = C + (11.5)(0.780)$

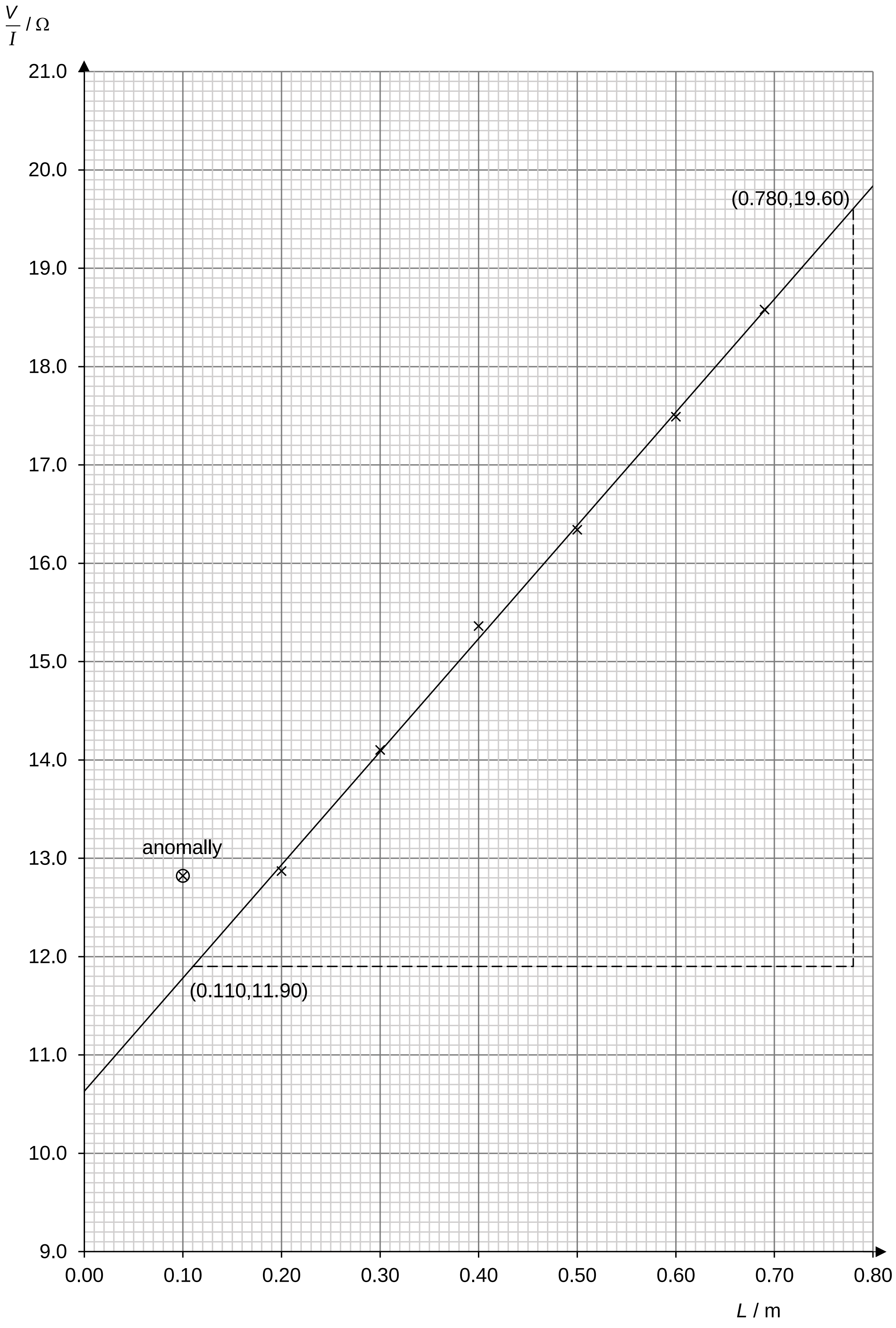
$C = 10.63$

$\therefore R = 10.63\ \Omega$

R = 10.65 Ω

k = 11.5 Ω m^{-1} [6]

[Total: 11]


V/I / Ω
21.0
20.0
19.0
18.0
17.0
16.0
15.0
14.0
13.0
12.0
11.0
10.0
9.0
(0.780,19.60)
anomally
(0.110,11.90)
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
L / m

2 In this experiment, you will investigate the equilibrium of a metre rule.

(a) **(i)** You have been provided with a metre rule with a spring attached, as shown in Fig. 2.1.

Fig. 2.1

(ii) The length of the unstretched spring is L_0, as shown in Fig. 2.2.

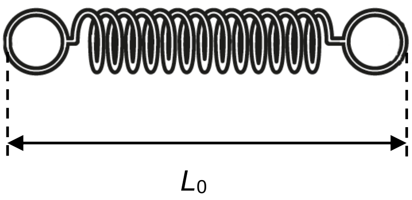


Fig. 2.2

Measure and record L_0.

L_0 = 4.2 cm .... [1]

(b) Set up the apparatus as shown in Fig. 2.3.

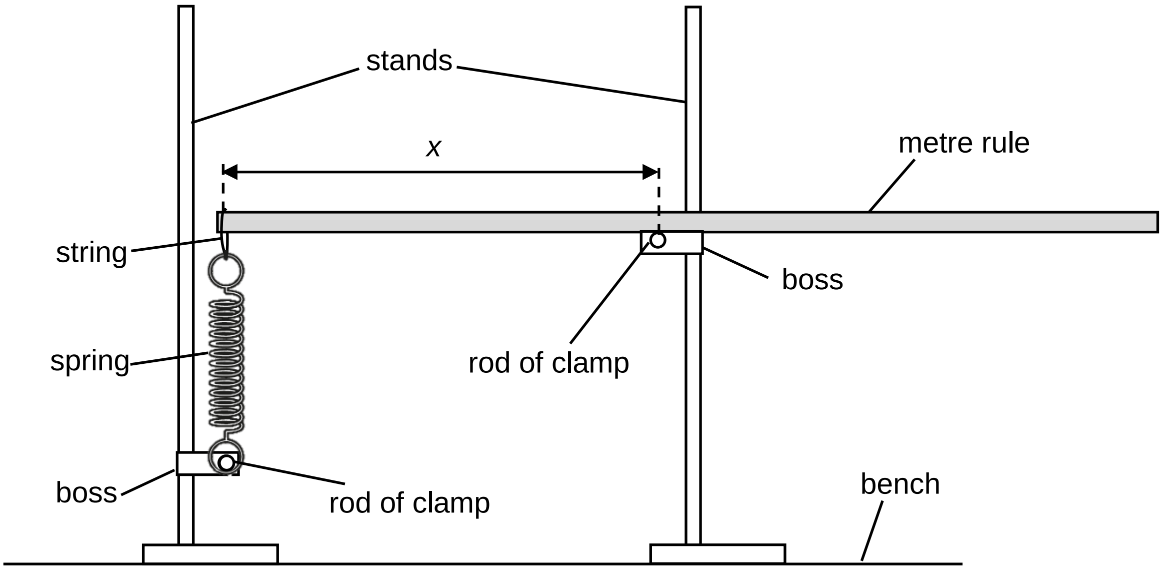


Fig. 2.3

The metre rule is placed on top of one of the rods.

The distance x between the hole with the string and the centre of the rod is shown in Fig. 2.3.

Set x to be about 50 cm and adjust the apparatus until the metre rule is horizontal and the spring is vertical and unstretched.

Without changing the heights of the rods of the clamps, gradually shift one of the retort stands until x is 30 cm. The metre rule will tilt and the spring will stretch as shown in Fig. 2.4.

(i) Make the necessary adjustment to the apparatus so that the spring remains vertical.

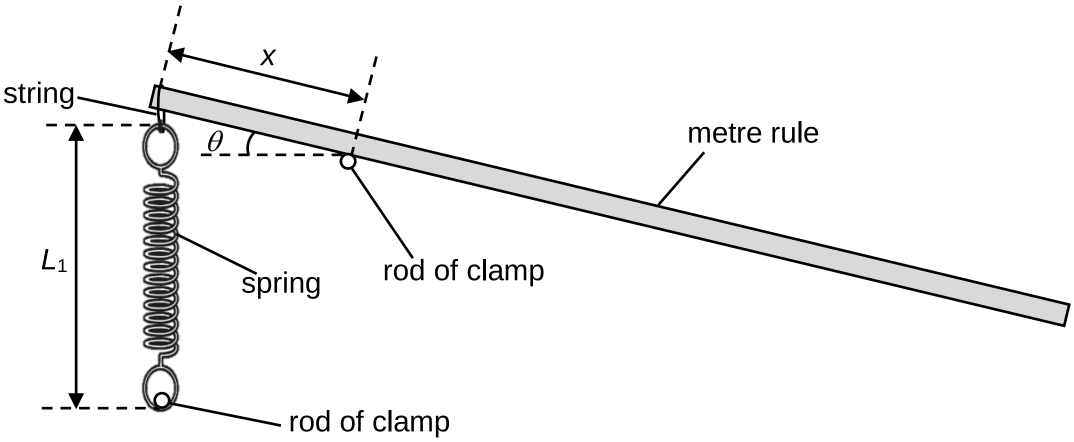


Fig. 2.4

The length of the stretched spring is L_1.

The angle between the rule and the horizontal is θ, as shown in Fig. 2.4.

Measure and record x and L_1 and hence, determine $\sin\theta$.

Extension of spring = $L_1 - L_0$ = 7.0 – 4.2 = 2.8 cm

$$\sin\theta = \frac{e}{x} = \frac{2.8}{30.0} = 0.093$$

x = 30.0 cm

L_1 = 7.0 cm

$\sin\theta$ = 0.093

[2]

(ii) Decrease distance *x* and repeat **(b)(i)**.

Extension of spring = $L_1 - L_0$ = 7.8 – 4.2 = 3.6 cm

$$\sin\theta = \frac{e}{x} = \frac{3.6}{24.5} = 0.15$$

x = 24.5 cm

L_1 = 7.8 cm

$\sin\theta$ = 0.15

[1]

(iii) It is suggested that the relationship between $\sin\theta$ and *x* is given by:

$$\sin\theta = P\,(\frac{l}{2x^2} - \frac{1}{x})$$

where *l* is the length of the metre rule and *P* is a constant.

Determine the average value of *P* using your values in **(b)(i)** and **(b)(ii)**.

1st set of readings :

$$\sin\theta = P\,(\frac{l}{2x^2} - \frac{1}{x})$$

$$0.093 = P\,(\frac{100}{2(30.0)^2} - \frac{1}{(30.0)})$$

$$P = 4.19$$

2nd set of readings :

$$\sin\theta = P\,(\frac{l}{2x^2} - \frac{1}{x})$$

$$0.15 = P\,(\frac{100}{2(24.5)^2} - \frac{1}{(24.5)})$$

$$P = 3.53$$

$< P >$ = ½ (4.19 + 3.53) = 3.86 cm

P = 3.86 cm [2]

(iv) Theory suggests that:

$$P = \frac{mg}{k}$$

where k is the spring constant of the spring, g is 9.81 m s^{-2} and m is the mass of the metre rule with a value of 80 g.

Calculate k.

$$P = \frac{mg}{k}$$

$$k = \frac{(0.080)(9.81)}{(3.86 \times 10^{-2})}$$

$$= 20.3 \text{ N m}^{-1}$$

k = 20.3 N m^{-1} .... [2]

(c) **(i)** The experiment is repeated for more values of x.

Assuming the relationships in **(b)(iii)** and **(b)(iv)** are correct, state the graph that you would plot in order to determine the value of the spring constant k.

Explain how k is determined from the graph.

Plot a graph of $\sin\theta$ against $\frac{l}{2x^2} - \frac{1}{x}$.

Determine value of gradient (P).

hence $k = \frac{mg}{\text{gradient}}$

(ii) Use the relationship in **(b)(iii)** to determine the value of *x* when $\theta = 0$.

State the significance of this value of *x*.

$$\sin\theta = P\,(\frac{l}{2x^2} - \frac{1}{x})$$

$$0 = P\,(\frac{100}{2x^2} - \frac{1}{x})$$

$$\frac{100}{2x^2} = \frac{1}{x}$$

$$100x = 2x^2$$

$$x = 50 \text{ cm}$$

It represents the distance from the hole with the string to the centre of gravity of the metre rule (or position of the centre of gravity).

3 In this experiment you will investigate the behaviour of an oscillating system.

(a) Measure and record the length of the metal rod.

length of metal rod = 0.302 m ....

(b) **(i)** Measure and record the diameter d of the wire.

zero-error of micrometer screw gauge: Nil

d = 0.71 mm, 0.71 mm, 0.71 mm

d = 0.71 mm .... [1]

(ii) Measure and record the length of the wire.

length of wire = 0.500 m .... [1]

(iii) Coil the wire evenly on to the plastic tube to form a uniform spiral leaving two straight lengths of about 5 cm at the ends as shown in Fig. 3.1.

Fig. 3.1

Measure the lengths of the straight parts and hence, calculate the length l of the wire in the spiral.

l = 0.500 – 0.045 – 0.045 = 0.410 m

l = 0.410 m .... [1]

(iv) Estimate the percentage uncertainty in the value of l.

$$\frac{\Delta l}{l} = \frac{0.9}{41} \times 100 = 2.195\,\% \approx 2.2\,\%$$

percentage uncertainty in l = 2.2 % .... [1]

(c) Bend one end of the wire by 90° from about 2 cm from the end of the wire as shown in Fig. 3.2.

Using scotch-tape, attach the bent end to the centre of the metal rod as shown in Fig. 3.3.

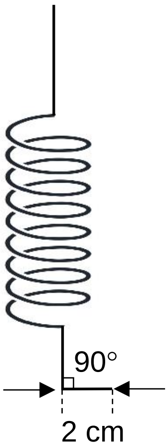


Fig. 3.2

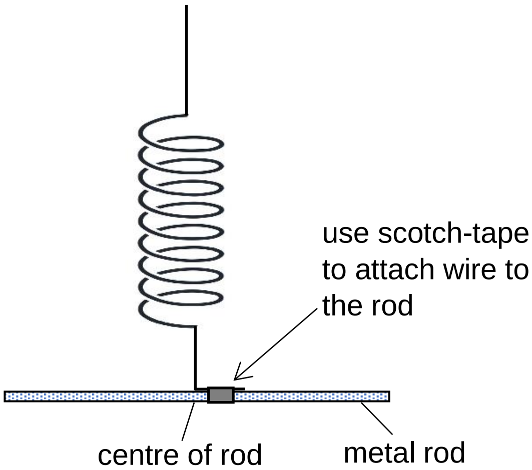


Fig. 3.3

Attach the plasticine spheres to the ends of the metal rod such that their centres coincide with the ends of the rod as shown in Fig. 3.4.

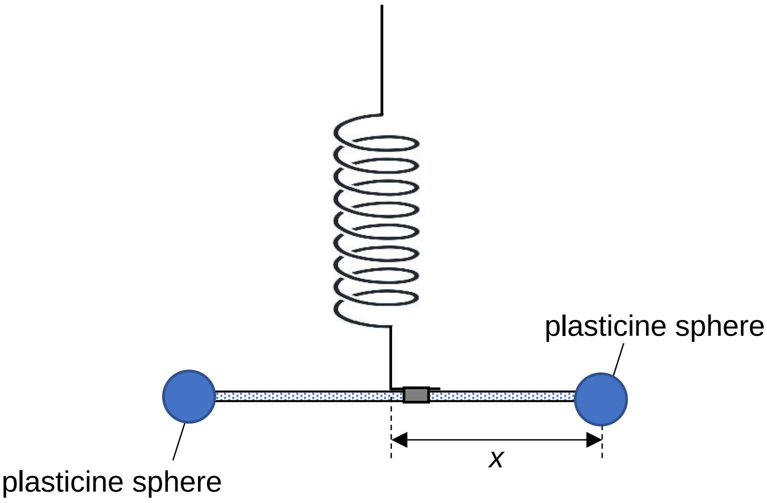


Fig. 3.4

(i) Record the distance x between the centre of each plasticine sphere and the centre of the rod.

Average distance = (0.151 + 0.151) / 2 = 0.151 m

x = 0.151 m .... [1]

(ii) Clamp the spring as shown in Fig. 3.5, such that the rod is horizontal.

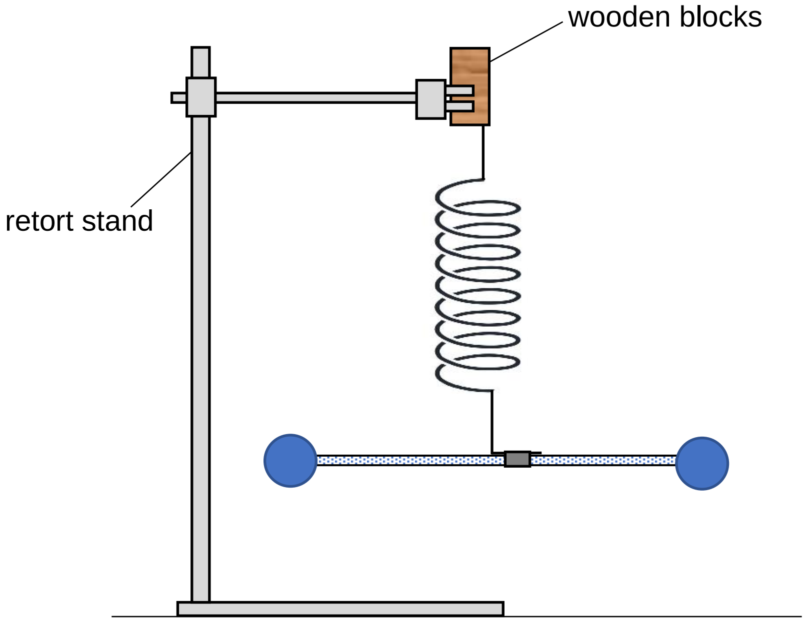


Fig. 3.5

Move one of the plasticine spheres so that the rod turns about a vertical axis. Release the sphere.

The rod will oscillate about a vertical axis.

Determine the period T of these oscillations.

Time t for 10 oscillations = 23.41 s, 23.43 s $\Rightarrow$ average t = 23.42 s

$\therefore$ period T = 2.342 s

T = 2.342 s [1]

(iii) Estimate the percentage uncertainty in the value of T.

Uncertainty in t is estimated to be 0.3 s.

$$\frac{\Delta T}{T} = \frac{\Delta t}{t} = \frac{0.3}{23.42} \times 100 = 1.3\ \%$$

percentage uncertainty in T = 1.3 % [1]

(d) Move the plasticine spheres closer to the centre of the rod such that x is now 9 cm. The two spheres should be equidistant from the centre of the metal rod.

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

Average distance = (0.090 + 0.090) / 2 = 0.090 m

Time t for 15 oscillations = 27.62 s, 27.58 s
$\therefore$ period T = 27.60/15 = 1.840 s

x = 0.090 m

T = 1.840 s [1]

(e) It is suggested that

$$T^2 = k\frac{l}{d^4}\left(0.012 + x^2\right)$$

where k is a constant and d, x and l are in metres.

(i) Use your values from **(b)(i)**, **(b)(iii)** **(c)(i)**, **(c)(ii)** and **(d)** to determine two numerical values of k.

d / 10^{-4} m	l / m	T / s	T^2 / s^2	x / m	k / s^2 kg^{-1} m
7.1	0.41	2.342	5.485	0.151	9.77×10^{-11}
7.1	0.41	1.840	3.386	0.090	10.4×10^{-11}

[1]

(ii) State whether the results of your experiment support the suggested relationship.

Justify your conclusion by referring to your answers in **(b)(iv)** and **(c)(iii)**.

$$\langle k\rangle = \frac{k_1 + k_2}{2} = \frac{(9.77 + 10.4)\times 10^{-11}}{2} = 10.085\times 10^{-11} \approx 10.1\times 10^{-11}$$

$$\therefore \frac{\Delta k}{\langle k\rangle}\times 100 = \frac{k_2 - \langle k\rangle}{\langle k\rangle}\times 100 = \frac{(10.4 - 10.1)\times 10^{-11}}{10.1\times 10^{-11}}\times 100 = 2.97\,\% \approx 3.0\,\%$$

The { % uncertainty in l + [2 (% uncertainty in T)]} =

2.2 % + 2(1.3 %) = 4.8%

Since the % difference in the two k values is only 3.0 % which is lower than the total % uncertainties of 4.8 % in l and in T^2, my results support the suggested relationship.

[1]

(iii) The constant k is related to the shear modulus G of the material of the wire by the equation,

$$k = \frac{64\pi}{25G}$$

and the units of k are kg^{-1} m s^2.

Calculate the value of G with its units.

$$k = \frac{64\pi}{25G} \Rightarrow G = \frac{64\pi}{25k} = \frac{64\pi}{25\times 10.1\times 10^{-11}}$$

$$= 7.963\times 10^{10} \approx 8.0\times 10^{10}\ \text{kg m}^{-1}\,\text{s}^{-2}\ (\text{or Nm}^{-2}, \text{or Pa})$$

(f) **(i)** Suggest one significant source of error in this experiment.

1. As the given wire was not perfectly straight, it was difficult to measure its length accurately.
2. As the spiral was shaped/made by hand, the wire could not be bent into a sharp corner at the point of intersection between the end of the spiral and the start of the straight parts of the wire. Thus, it was difficult to measure the straight parts accurately. These difficulties thus increase the uncertainty in the measurement of l, the length of the spiral part.)
3. Discussion on measurement of x (e.g. it is difficult to determine the centre of plasticine)
4. Discussion on plasticine spheres being non-uniform in shape affecting the centre of mass of the system and hence affecting the accuracy of period T (improvement is to use hard / rigid spheres)
5. Discussion on the rod not oscillating in a single plane, hence affecting the accuracy of period T (improvement is to use hard / rigid spheres)

[1]

(ii) Suggest an improvement that could be made to the experiment to reduce the error identified in **(f)(i)**.
You may suggest the use of other apparatus or a different procedure.

1. Use string to trace out the length of the wire and use a metre rule to measure the length of string that is traced out.
2. In order that the point of intersection between the end of the spiral and the start of the straight parts of the wire be a well-defined point, the spiral could be machine made instead of handmade.
3. Use vernier calipers to measure the diameter of the sphere. *x* will be the distance from the centre of the rod to the inner edge of the sphere + half the diameter of the sphere.
4. Use hard / rigid spheres e.g. ball bearings / glass balls with a hole drilled in the centre.
5. There are several reasons why the rod is not oscillating in a single plane e.g. c.g. not at the centre of rod, rod not horizontal. Any improvements that address one of these reasons will be accepted.

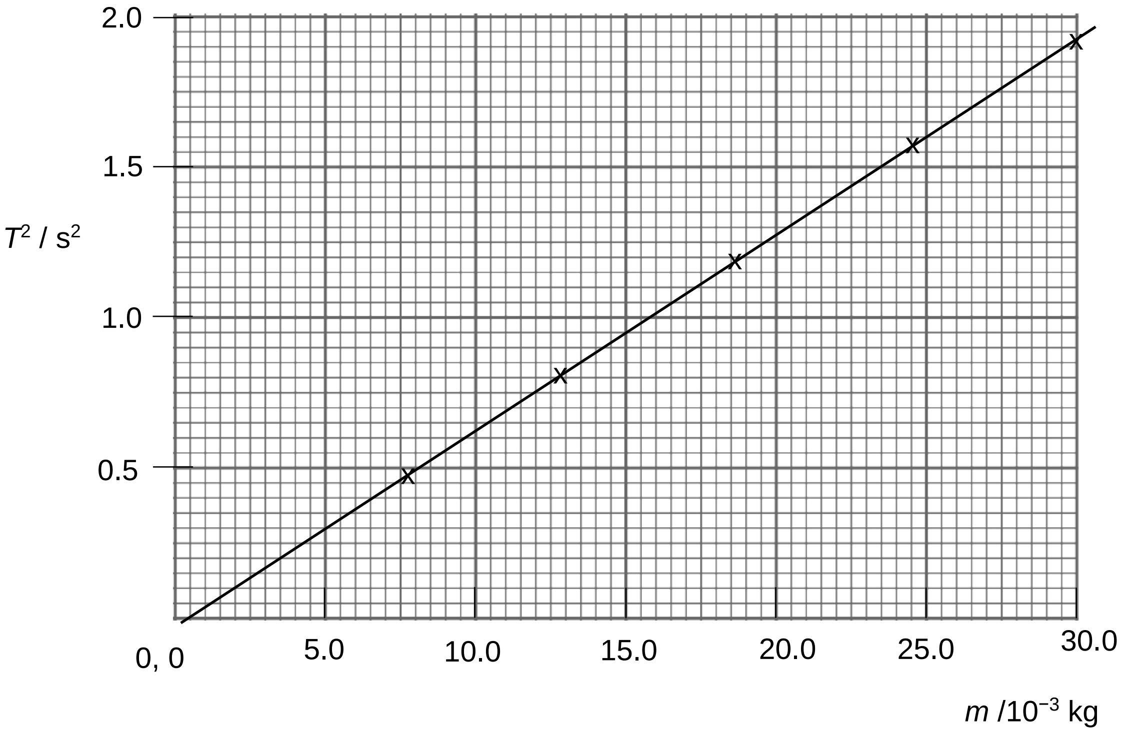
[1]

(g) The experiment is repeated without the plasticine spheres but with rods of different masses.

The following results for m and T^2 were recorded.

m / 10^{-3} kg	7.80	12.71	18.62	24.58	30.00
T^2 / s^2	0.4802	0.8124	1.192	1.575	1.922

(i) Plot T^2 against m on the grid provided and draw the line of best fit.



[2]

(ii) Deduce the relationship between T^2 and m.

If your BFL does not cut the origin:
Since the graph drawn is a straight line, T^2 is linearly related to m.
OR $T^2 = km + c$ where k and c are constants.
If your BFL cuts the origin:
Since the graph drawn is a straight line and passes through the origin, T^2 is proportional to m.
OR $T^2 = km$ where k is a constant.

[1]

(h) The behaviour of the oscillating system with the plasticine spheres also depends on the elasticity of the material of the wire.

It is suggested that the period *T* is inversely proportional to the elasticity *E* of the material of the wire.

Explain how you would investigate this relationship.

You would be provided with wires of known elasticity.

Your account should include:

- your experimental procedure
- control of variables
- how you would use your results to show inverse proportionality. [4]

Solutions

1. Using wires of the same length and diameter of cross-section but made from 10 different materials of known elasticity *E*, coil the wires to form spirals of the same length. [1]
2. Using the same set-up as shown in Fig. 3.5 and following (c)(iii), measure and record the period *T* of torsional oscillation of each coiled wire. [1]
3. Plot a graph of *T* against $1/E$.
4. If a straight line graph passing through origin is obtained, the inverse proportionality is shown. [1]
5. The same metal rod (and plasticine spheres) should be used. The plasticine spheres, if used, should also be attached at the same positions on the rod throughout the experiment. [1]

[Total: 21]

4 Fig. 4.1 shows a setup used to illustrate the operation of an eddy current brake.

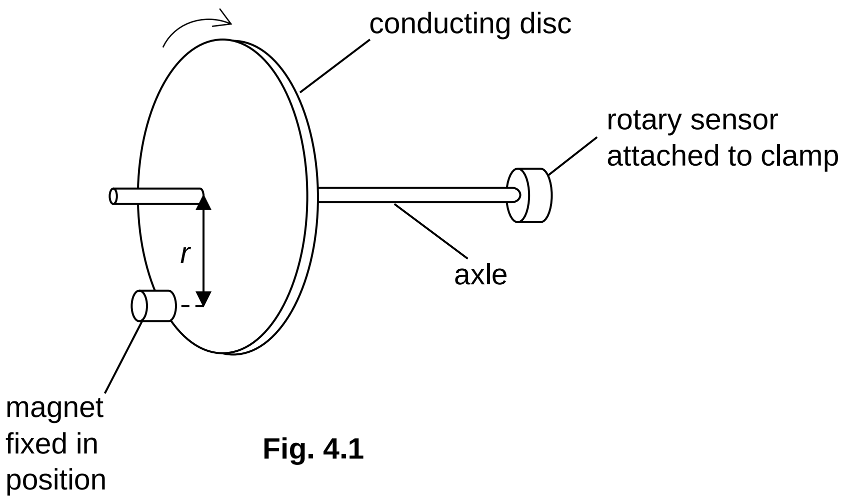


Fig. 4.1

The magnet is at a distance *r* from the centre of the axle and close to the conducting disc. The magnetic field at the disc due to the magnet has a flux density *B*. As the disc rotates about its axle, an eddy current is induced in the disc which slows down the rotation.

Regardless of how fast the disc is rotating, the time *T* taken for the disc to slow down to half its original angular speed is given by

$$T = kB^m r^n$$

where *k* and *m* and *n* are constants.

Design an experiment to determine the values of *m* and *n*.

Draw a diagram to show the arrangement of your apparatus. The axle of the disc is connected to a rotary sensor that will measure and display the angular speed of the disc.

Pay particular attention to

(a) the equipment you would use
(b) the material to be used for the conducting disc
(c) the procedure to be followed
(d) the control of variables
(e) any precautions that should be taken to improve the accuracy and safety of the experiment.

Diagram

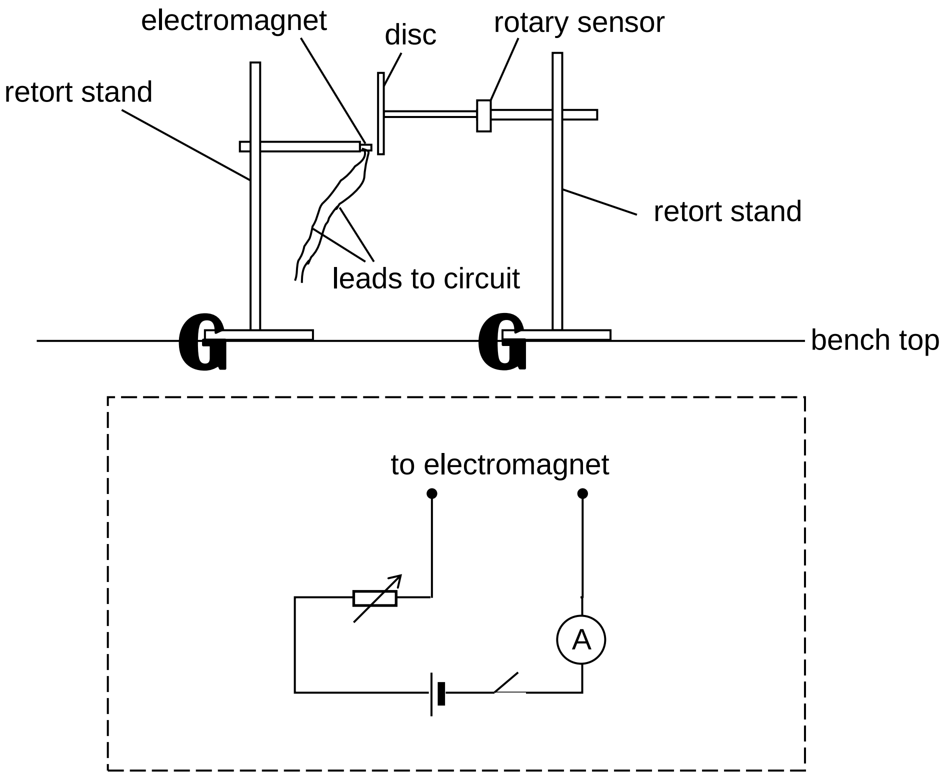


Fig. 1

1. Problem Definition

<u>Experiment 1</u>

Independent variable: magnetic flux density *B* at the disc

Dependent variable: time *T* taken for the disc to slow down to half its original angular speed

Control variables:
material of the conducting disc
thickness of the conducting disc
mass of the conducting disc
the distance *x* of the electromagnet from the disc
distance *r* of the magnet from the axle of the disc

<u>Experiment 2</u>

Independent variable: distance *r* of magnet from the axle of the disc

Dependent variable: time *T* taken for the disc to slow down to half its original angular speed

Control variables:
material of the conducting disc
thickness of the conducting disc
mass of the conducting disc
the distance *x* of the electromagnet from the disc
current I in the solenoid.

2. Procedure

1. Set up the apparatus as shown in Fig. 1.
   The electromagnet is constructed by coiling copper wire round an iron rod.
2. The electromagnet is positioned at a constant distance *x* of 5 mm from the disc. The distance is measured with a ruler.
3. Measure the distance *r* between the axis of the electromagnet from the axle of the disc with a ruler.
4. An aluminium disc of appropriate diameter (e.g., 30 cm) and thickness (about 1 mm) is used as the conducting disc.
5. Turn on the circuit. Measure and record the value of the current I shown on the ammeter.
6. Set the disc into rotation by hand. Read and record the initial angular speed of the disc.
7. When the angular speed of the disc reaches a suitable value (e.g., 300 revolutions per minute, rpm), start the stopwatch. When the angular speed decreases to half the value (e.g.,150 rpm), stop the stopwatch. Record the time *T*.

8. **Experiment 1: variation of *T* with *B*, keeping *r* constant**
   Since the magnetic flux density is proportional to the current I, we can investigate the variation of *T* with I instead.

   Repeat steps 1 to 7 to obtain a total of 10 sets of readings for *T* and current I by adjusting the rheostat resistance each time. The current I is measured with an ammeter.

9. The distances *r* and *x* are kept constant by keeping the position of the magnet fixed.

10. **Experiment 2: variation of *T* with *r*, keeping I constant**
    Repeat steps 1 to 7 to obtain a total of 10 sets of readings for *T* and *r* by adjusting the clamp of the retort stand to move the magnet closer to the axle each time.

11. Check that the distance *x* is constant for each set of readings.
    The magnetic flux density *B* is kept constant by keeping the current I constant.
    The mass, thickness and material of the disc are kept constant by using the same disc for the whole experiment.

3. Analysis

$T = kB^m r^n$ and $B = k'I \Rightarrow T = kk'^m I^m r^n = CI^m r^n$ where *C* is a constant.

To determine *m* from Experiment 1:

$\lg T = \lg\left(Cr^n\right) + m\lg I$ where *r* is constant.

Plot a graph of lg*T* against lg$I$, such that gradient = *m* and vertical-intercept $\lg\left(Cr^n\right)$.

To determine *n* from Experiment 2:

$\lg T = \lg\left(CI^m\right) + n\lg r$, where I is constant.

Plot a graph of lg*T* against lg*r* such that gradient = *n* and vertical-intercept $\lg\left(CI^m\right)$.

4. Safety Precautions

1. Using G-clamp, clamp the base of the retort stand to the bench top to prevent it from toppling.

5. Additional Details

1. Conduct preliminary experiment to check if the variation of T is large as B and r are varied. If the variation of T is too small, increase the number of turns of the electromagnet or use a power source of higher e.m.f..
2. Adjust the direction of the Hall probe until the maximum value of the magnetic flux density is obtained.
3. Measure B using Hall probe first in one direction and then in the opposite direction and calculate the average.
4. Ensure that the setup is far from all ferromagnetic materials which will modify the magnetic field of the magnet.
5. Correcting Earth's magnetic field in the calculation of B.