Centre Number	Class Index Number	Name	Class
S3016			

RAFFLES INSTITUTION

2024 Preliminary Examination

PHYSICS **Higher 2** Paper 4 Practical	**9749/04** **12 August 2024** **2 hours 30 minutes**

READ THESE INSTRUCTIONS FIRST

Write your index number, name and class in the spaces provided at the top of this page.

Write in dark blue or black pen on both sides of the paper.

You may use an HB pencil for any diagrams, graphs or rough working.

Do not use staples, paper clips, glue or correction fluid.

Answer **all** questions.

Candidates answer on the Question Paper.

You will be allowed a maximum of one hour to work with the apparatus for Questions 1 and 2, and maximum of one hour for Question 3. You are advised to spend approximately 30 minutes for Question 4.

Write your answers in the spaces provided on the question paper.

The use of an approved scientific calculator is expected, where appropriate.

You may lose marks if you do not show your working or if you do not use appropriate units.

Give details of the practical shift and laboratory in the boxes provided.

At the end of the examination, fasten all your work securely together.

The number of marks is given in brackets [ ] at the end of each question or part question.

Shift
Laboratory

For Examiner's Use	
1	/ 12
2	/ 10
3	/ 22
4	/ 11
Total	/ 55

1 In this experiment, you will investigate the force required to lift different masses.

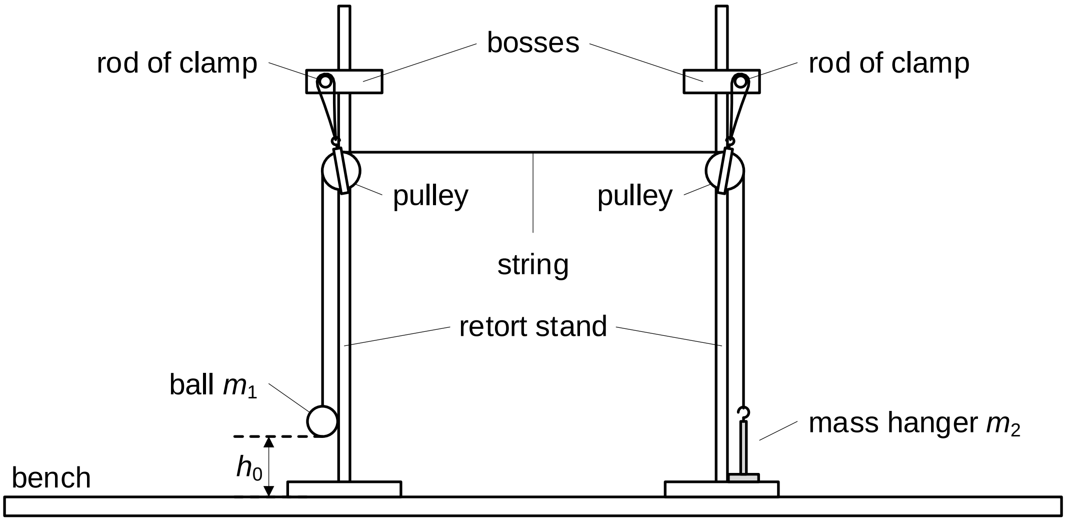


Fig. 1.1

(a) Set up the apparatus as shown in Fig. 1.1. Hang the pulleys to the rods of the clamps. The top of the pulleys should be approximately 42 cm above the bench.

Pass the string through the pulleys. Attach the end of the string with a small loop to the mass hanger and the other end to a ball of modelling clay.

The mass of the ball is m_1 and the mass of the mass hanger is m_2.

Ensure that the ball is suspended above the bench while the mass hanger is resting on the base of the retort stand with the string taut.

Adjust the distance between the retort stands until h_0 is about 5 cm above the bench.

Measure and record h_0.

h_0 = 0.050 m or 5.0 cm ....

(b) Raise the ball to a height h above the bench as shown in Fig. 1.2.

Release the ball such that it moves in a circular path.

Ensure that the string is taut and the mass hanger is resting on the base of the retort stand at the point of release of the ball.

The **minimum** height of the ball required **to just lift** the mass hanger off the base of the retort stand is h.

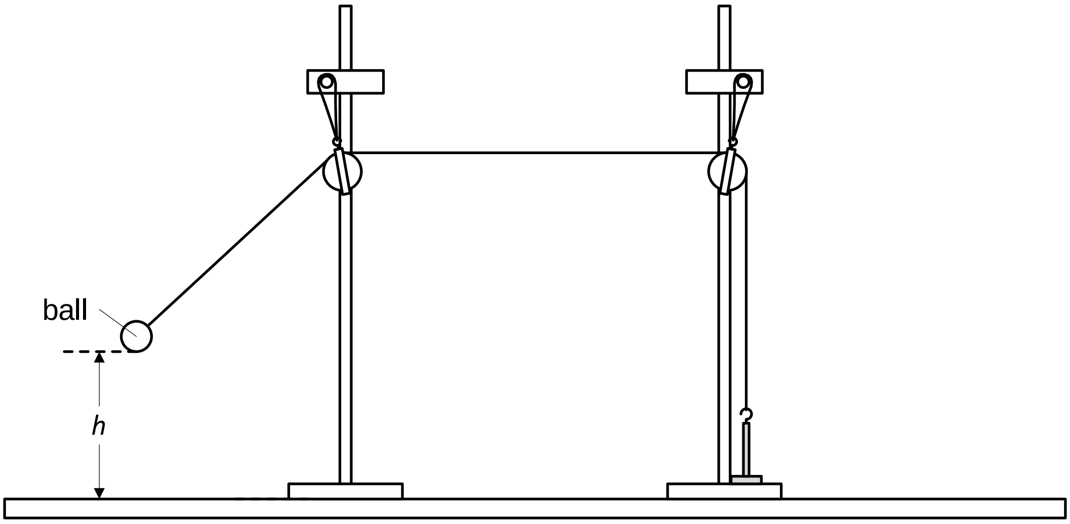


Fig. 1.2

Measure and record h.

Calculate Δh where $\Delta h = h - h_0$.

Minimum height

$h_1 = 0.074$ m; $h_2 = 0.075$ m

$\langle h \rangle = \frac{1}{2}(0.074 + 0.075) = 0.075$ m

$\Delta h = \langle h \rangle - h_0 = 0.075 - 0.050 = 0.025$ m

h = 0.075 m or 7.5 cm ....

Δh = 0.025 m or 2.5 cm ....

[1]

(c) Using the same ball of mass m_1, vary m_2 by adding slotted masses to the mass hanger and repeat **(b)**.

Present your results clearly.

m_2 / kg	h_1 / m	h_2 / m	$\langle h \rangle$ / m	Δh / m
0.050	0.074	0.075	0.075	0.025
0.060	0.103	0.101	0.102	0.052
0.070	0.133	0.132	0.133	0.083
0.080	0.162	0.158	0.160	0.110
0.090	0.202	0.196	0.199	0.149

[3]

(d) Δh and m_2 are related by the expression:

$$\Delta h = \frac{a\,m_2}{m_1} - a$$

where a and m_1 are constants.

(i) Plot a graph of Δh against m_2 to determine a and m_1.

Plot a graph of Δh against m_2 where the gradient is a/m_1 and the vertical intercept is $-a$.

Using the points (0.05450,0.036) and (0.08900,0.142),

$$\text{gradient} = \frac{0.142 - 0.036}{0.08900 - 0.05450} = \frac{0.106}{0.0345} = 3.07 \qquad \text{(3 s.f.)}$$

$$\text{vertical intercept} = 0.142 - 3.07 \times 0.08900 = 0.142 - 0.273 = -0.131$$

$$a = -\text{vertical intercept} = 0.131\ \text{m}$$

$$m_1 = \frac{a}{\text{gradient}} = \frac{0.131}{3.07} = 0.0427\ \text{kg}$$

a = 0.131 m ....

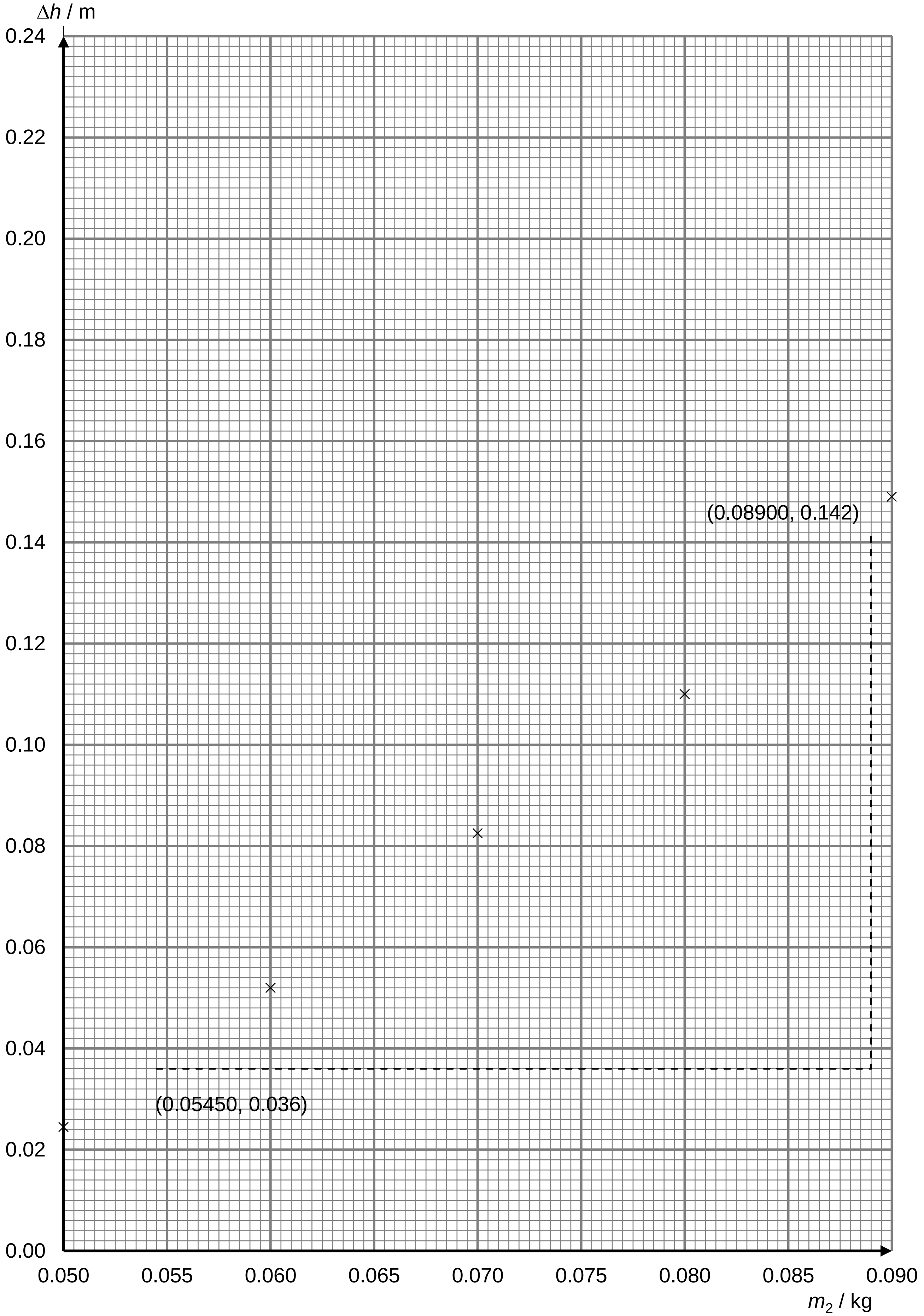
m_1 = 0.0427 kg ....

[5]

(ii) Explain the significance of the horizontal intercept of the graph.

The horizontal intercept ($\Delta h = 0$) represents the mass of the load (m_2) that is equal to the mass of the ball, i.e., $m_2 = m_1$.

[1]


Δh / m
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
(0.08900, 0.142)
(0.05450, 0.036)
0.050
0.055
0.060
0.065
0.070
0.075
0.080
0.085
0.090
m2 / kg

(e) **(i)** Suggest one significant source of uncertainty in this experiment.

1. The tension supporting the ball and the mass hanger are not equal as the pulleys are not smooth. This affects the accuracy of h or Δh.

2. The tension supporting the ball and the mass hanger are not equal as the pulleys accelerates/moves when the ball is released. This affects the accuracy of h or Δh.

3. Imprecise to judge when m_2 just lift off affecting the precision of h or Δh.

4. The inability to steadily handhold the ruler and the ball affects the accuracy of h or Δh.

[1]

(ii) Suggest an improvement that could be made to the experiment to reduce the uncertainty identified in **(e)(i)**.

You may suggest the use of other apparatus or a different procedure.

1. Lubricate the axles of the pulleys so that friction is reduced.

2. Fix the pulleys to the rods of the clamps by tying them tightly to the rods.

3. Use of electronic balance to monitor when contact force becomes zero.

4. Support the ruler with retort stand and clamp. The ball can be displaced by pulling the excess string (at lower end of ball). This also ensures that the string supporting the ball is always under tension.

[1]

[Total: 12]

2 In this experiment, you will investigate the properties of a dry cell.

(a) Set up the circuit as shown in Fig. 2.1.

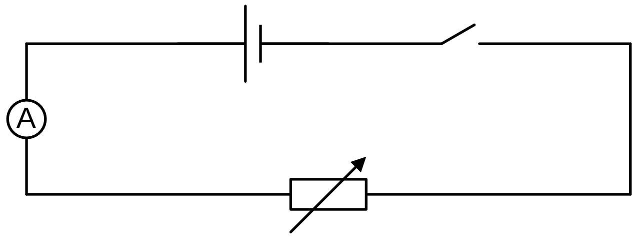


Fig. 2.1

(b) **(i)** Close the switch. Adjust the resistance of the variable resistor until the ammeter reading I is as close to 0.5 A as possible. Measure and record the ammeter reading I.

I = 0.501 A ....

(ii) Open the switch.

(c) A resistor of resistance *R* is made using three 1.0 Ω resistors connected as shown in Fig. 2.2.

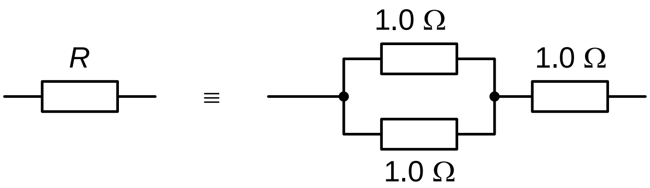


Fig. 2.2

Set up the circuit as shown in Fig. 2.3. The resistance of the variable resistor should be the same as that in **(b)(i)**.

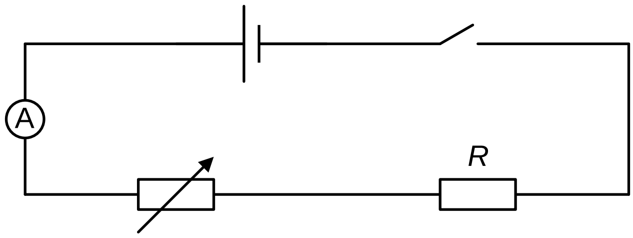


Fig. 2.3

(i) Record the effective resistance *R*.

R = 1.5 Ω ....

(ii) Close the switch.

Measure and record the ammeter reading I.

I = 0.330 A ....

(iii) Open the switch.

(d) Vary *R* by re-arranging the 1.0 Ω resistors and repeat **(c)**.

You may use any number of the 1.0 Ω resistors.

Present your results clearly.

R / Ω	I / A	I^{-1} / A^{-1}
0.33	0.450	2.22
0.50	0.430	2.33
0.67	0.410	2.44
1.0	0.373	2.68
1.5	0.330	3.03
2.0	0.295	3.39
3.0	0.244	4.10

[3]

(e) *R* and *I* are related by the expression:

$$\frac{1}{I}=\frac{R}{E}+\frac{r}{E}$$

where *E* is the electromotive force (e.m.f.) of the dry cell and *r* is the sum of the resistance of the variable resistor and the internal resistance of the dry cell.

Plot a suitable graph to determine a value for *E* and *r*.

Plot a graph of $\frac{1}{I}$ against *R* where the gradient is $\frac{1}{E}$ and the vertical intercept is $\frac{r}{E}$.

Using the points (0.250,2.150) and (2.800,3.950),

$$\text{gradient}=\frac{3.950-2.150}{2.800-0.250}=\frac{1.800}{2.550}=0.7059 \quad \text{(3 s.f.)}$$

$$\text{vertical intercept}=3.950-0.7059\times 2.800=3.950-1.977=1.973$$

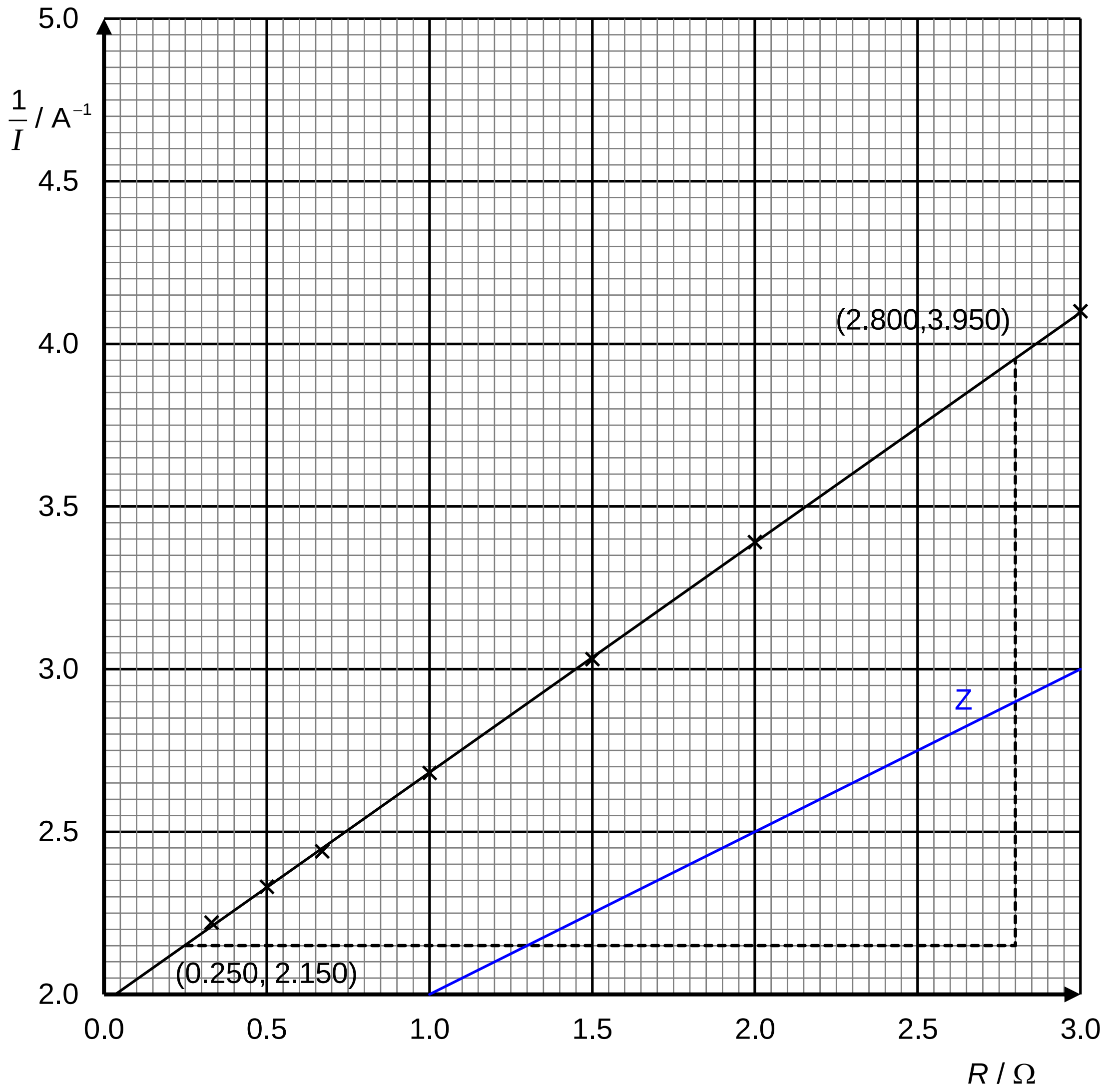
$$E=\frac{1}{\text{gradient}}=\frac{1}{0.7059}=1.417\text{ V}$$

$$r=E\times\text{vertical intercept}=1.417\times 1.973=2.796\ \Omega$$

E = 1.417 V ....

r = 2.796 Ω ....

[6]



(f) Without taking further readings, sketch a line on your graph to show the results you would expect if the experiment was repeated with a dry cell with a larger e.m.f. and a smaller internal resistance than the one used.

Label this line Z. [1]

A larger e.m.f. implies a lower gradient.

A smaller internal resistance and a larger e.m.f. implies a lower vertical intercept.

[Z should not intersect Y.]

[Total: 10]

3 An interrupted pendulum is a simple pendulum which strikes a rod below its pivot during its oscillation, causing the pendulum to deviate from its original trajectory into a trajectory of a smaller radius.

In this experiment, you will investigate how the behaviour of an interrupted pendulum depends on the position of the rod and the initial angle of release.

You have been provided with a simple pendulum and a wooden rod.

(a) Set up the apparatus as shown in Fig. 3.1.

Attach the wooden rod to the retort stand with the boss. Ensure that the wooden rod is below the pivot such that the string of the pendulum is just touching the rod, with the string remaining vertical.

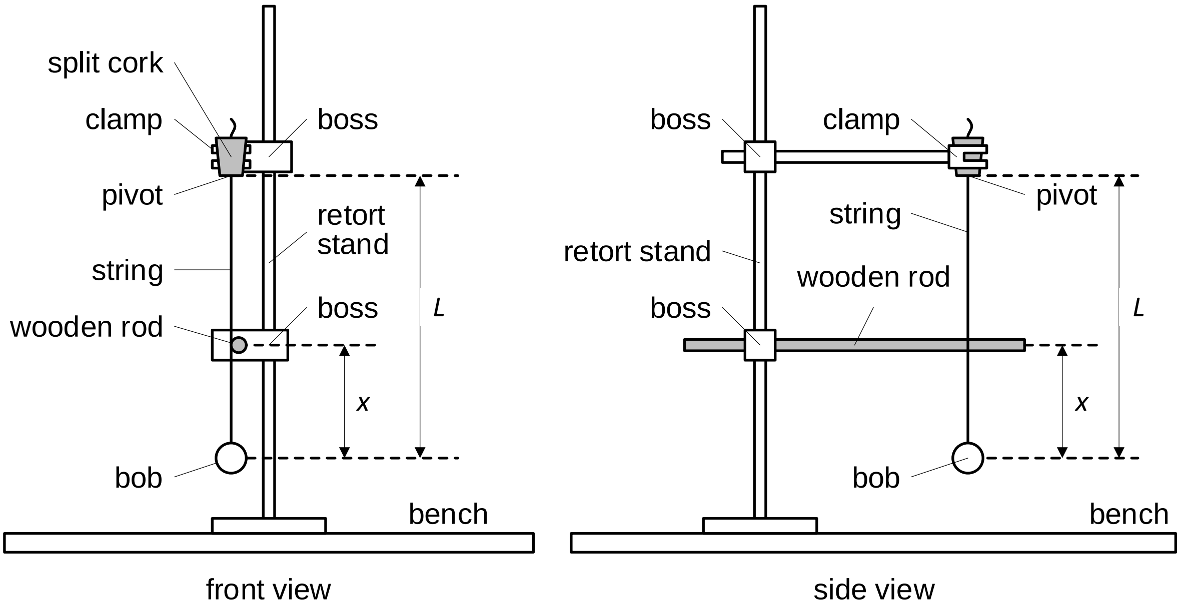


Fig. 3.1

The length of the pendulum is L. The distance between the rod and the pendulum bob is x.

Adjust the positions of the pendulum and the rod so that L is approximately 50 cm and x is approximately 10 cm.

(i) Measure and record L and x.

L = 50.1 cm ....

x = 10.0 cm ....

[1]

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

Percentage uncertainty in *L*

$$\frac{\Delta L}{L} \times 100\% = \frac{0.3}{50.1} \times 100\% = 0.60\%$$

percentage uncertainty in *L* = 0.60% ....

[1]

(iii) Estimate the percentage uncertainty in your value of *x*.

Percentage uncertainty in *x*

$$\frac{\Delta x}{x} \times 100\% = \frac{0.4}{10.0} \times 100\% = 4.0\%$$

percentage uncertainty in *x* = 4.0% ....

[1]

(b) **(i)** Displace the pendulum by a small angle θ away from the rod, as shown in Fig. 3.2. Ensure that θ does not exceed 5°.

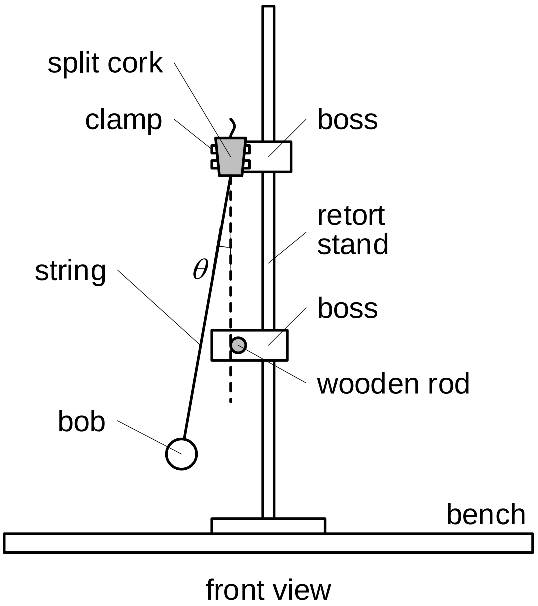


Fig. 3.2

Release the pendulum from this angle. It will swing and oscillate, with the string striking the rod halfway through its oscillation.

Record your value of θ.

Determine the period T of these oscillations.

Timing for 20 oscillations

$t_1 = 20.66$ s ; $t_2 = 20.64$ s

$$\langle t \rangle = \frac{20.66 + 20.64}{2} = 20.65 \text{ s}$$

Period

$$T = \frac{\langle t \rangle}{20} = \frac{20.65}{20} = 1.033 \text{ s}$$

θ = 5° ....

T = 1.033 s ....

[2]

(ii) Adjust the wooden rod so that x is approximately 30 cm.

Measure and record your value of x. Repeat **(b)(i)**, using the same value of θ.

Timing for 20 oscillations

$$t_1 = 25.18 \text{ s}; \; t_2 = 25.20 \text{ s}$$

$$\langle t \rangle = \frac{25.18 + 25.20}{2} = 25.19 \text{ s}$$

Period

$$T = \frac{\langle t \rangle}{20} = \frac{25.19}{20} = 1.260 \text{ s}$$

x = 30.0 cm ....

T = 1.260 s ....

[1]

(c) It is suggested that

$$T = p\sqrt{x} + q$$

where p and q are constants.

Use your values in **(a)(i)**, **(b)(i)** and **(b)(ii)** to determine a value for p.

Using the periods from **(b)(i)** and **(b)(ii)**,

$$1.033 = p\sqrt{0.100} + q$$

$$1.260 = p\sqrt{0.300} + q$$

Solving,

$$p = \frac{1.260 - 1.033}{\sqrt{0.300} - \sqrt{0.100}} = \frac{0.227}{0.231} = 0.983 \text{ s m}^{-1/2}$$

p = $0.983 \text{ s m}^{-1/2}$ ....

[2]

(d) At larger angles of oscillation, the period T of an interrupted pendulum is thought to be dependent on the angle of release θ. You will now investigate this dependency.

In the following experiment, you will use the **same value** of x throughout.

(i) Choose **one** value of x from your values in either **(a)(i)** or **(b)(ii)** to use in the following experiment.

Record your choice of x and the period T_x of the oscillation of the pendulum at this value of x from your values in either **(b)(i)** or **(b)(ii)**.

x = 30.0 cm ....

T_x = 1.260 s ....

Explain your choice of x.

Using a larger x results in a longer period T, which reduces the percentage uncertainty

in both x and T.

....

[1]

(ii) Displace the pendulum away from the rod by an angle θ, as shown in Fig. 3.2, where θ is approximately $30°$.

Measure and record θ.

θ = 30° ....

(iii) Estimate the percentage uncertainty in your value of θ.

Percentage uncertainty in θ

$$\frac{\Delta\theta}{\theta} \times 100\% = \frac{3}{30} \times 100\% = 10\%$$

percentage uncertainty in θ = 10% ....

[1]

(iv) Release the pendulum from this angle, allowing it to oscillate.

Determine the period T of these oscillations.

For $\theta = 30°$, timing for 20 oscillations

$t_1 = 25.56$ s ; $t_2 = 25.65$ s

$$\langle t \rangle = \frac{25.56 + 25.65}{2} = 25.61 \text{ s}$$

Period

$$T = \frac{\langle t \rangle}{20} = \frac{25.61}{20} = 1.281 \text{ s}$$

T = 1.281 s ....

(e) Repeat steps **(d)(ii)** and **(d)(iv)** with a larger value of θ where $\theta \leq 60°$.

For $\theta = 60°$, timing for 20 oscillations

$t_1 = 26.78$ s ; $t_2 = 26.73$ s

$$\langle t \rangle = \frac{26.78 + 26.73}{2} = 26.76 \text{ s}$$

Period

$$T = \frac{\langle t \rangle}{20} = \frac{26.76}{20} = 1.338 \text{ s}$$

θ = 60° ....

T = 1.338 s ....

[1]

(f) It is suggested that

$$t = k\sqrt{\frac{L}{x}}\,\theta^2$$

where k is a constant, θ is in radians, and t is given by

$$t = \frac{T}{T_x} - 1$$

(i) Use your value of L in **(a)(i)** and your values of x, T_x, θ and T in **(d)** and **(e)** to determine two values of k.

Rearranging the equation,

$$k = \frac{T/T_x - 1}{\sqrt{L/x}\cdot\theta^2}$$

$$k_1 = \frac{T_1/T_x - 1}{\sqrt{L/x}\cdot\theta^2} = \frac{1.281/1.260 - 1}{\sqrt{0.500/0.300}\cdot(\pi/6)^2} = 0.0471\text{ rad}^{-2}$$

$$k_2 = \frac{T_2/T_x - 1}{\sqrt{L/x}\cdot\theta^2} = \frac{1.338/1.260 - 1}{\sqrt{0.500/0.300}\cdot(\pi/3)^2} = 0.0437\text{ rad}^{-2}$$

first value of k = 0.0471 rad^{-2}

second value of k = 0.0437 rad^{-2}

[2]

(ii) State whether or not the results of your experiment support the suggested relationship. Justify your conclusion by referring to your values in **(a)(ii)**, **(a)(iii)** and **(d)(iii)**.

Percentage uncertainty $= \dfrac{\frac{1}{2}(k_1 - k_2)}{\frac{1}{2}(k_1 + k_2)} \times 100 = \dfrac{\frac{1}{2}(0.0471 - 0.0437)}{\frac{1}{2}(0.0471 + 0.0437)} \times 100\% = 3.7\%$

Since the percentage uncertainty in k (3.7%) is smaller than the sum of the percentage uncertainties of 22% due to L, x and θ ($\frac{1}{2}\times 0.60 + \frac{1}{2}\times 4.0 + 2\times 10 = 22\%$), the results support the suggested relationship.

[1]

(g) Remove the wooden rod so that the pendulum is now able to swing freely as a simple pendulum.

Vary L and determine the period of oscillation T, using the same value of θ in **(b)(i)**.

Present your results clearly.

Use your results to estimate a value of L for the simple pendulum where the value of T is the same as your answer in **(b)(i)**.

L / m	Timing for 20 oscillations			T / s
	t_1 / s	t_2 / s	$\langle t \rangle$ / s	
0.500	28.50	28.51	28.51	1.426
0.300	22.04	22.00	22.02	1.101

Assuming $T = m\sqrt{L} + c$,

$$m = \frac{1.426 - 1.101}{\sqrt{0.500} - \sqrt{0.300}} = \frac{0.325}{0.159} = 2.04$$

$$c = 1.426 - 2.04 \times \sqrt{0.500} = 1.426 - 1.44 = -0.01$$

$$L = \left(\frac{T - c}{m}\right)^2 = \left[\frac{1.033 - (-0.01)}{2.04}\right]^2 = 0.261\text{ m}$$

Assuming $T = mL + c$,

$$m = \frac{1.426 - 1.101}{0.500 - 0.300} = \frac{0.325}{0.200} = 1.63$$

$$c = 1.426 - 1.63 \times 0.500 = 1.426 - 0.815 = 0.611$$

$$L = \frac{T - c}{m} = \frac{1.033 - 0.611}{1.63} = 0.259\text{ m}$$

Both methods above are equivalent to $\Delta T = m\sqrt{L} + c$ or $\Delta T = mL + c$.

L = 0.261 m ....

[3]

(h) An engineer wishes to design an amusement park ride based on an interrupted pendulum, with the bob representing the ride carriage.

However, instead of getting the carriage to oscillate, the engineer wants the carriage to swing and make a full circle around the rod, with the string looping around the rod.

It is suggested that the ratio $\frac{x}{L}$ is directly proportional to $1-\cos\theta_0$, where θ_0 is the minimum angle of release from the vertical for the carriage to complete a full circle around the rod.

Explain how you would investigate this relationship.

Your account should include:

- your experimental procedure
- control of variables
- how you would use your results to show direct proportionality
- how you would use your results to find the minimum angle of release for an amusement park ride where $L = 100$ cm and $x = 70$ cm.

1. Set up the apparatus as shown in Fig. 3.2.

2. Measure the length L of the pendulum with a metre rule.

3. Measure the distance between the bob and the wooden rod x with a metre rule.

4. Displace and release the pendulum at angle θ (from downward vertical) and observe whether the bob is able to make full revolution around the rod. Measure this angle with a protractor.

5. Increase the angle θ (til minimum angle θ_0) and repeat step 4 if the pendulum is unable to make full revolution. Conversely, decrease the angle θ (til minimum angle θ_0) if the pendulum is able to make full revolution.

6. Repeat steps 2 to 5 for 8 sets of x and θ_0 by adjusting the height of the wooden rod.

7. Since $\frac{x}{L} = k(1-\cos\theta_0)$, plot a graph of $\frac{x}{L}$ against $1-\cos\theta_0$. If the suggested relationship is true, then a straight-line graph will be obtained with a gradient of k and a vertical-intercept of zero.

Alternatively, plot a graph of $\frac{x}{L}$ against $\cos\theta_0$. If the suggested relationship is true, then a straight-line graph will be obtained with a gradient of $-k$ and a vertical-intercept of k.

8. From the straight-line graph drawn, determine the value of $X = 1-\cos\theta_0$ for which $x/L = 0.70$. Then, $\theta_0 = \cos^{-1}(1-X)$.

[5]

[Total: 22]

4 A thermoelectric cooler is made up of pairs of n- and p-type semiconductors sandwiched between two metal contact plates. This arrangement enables the semiconductor pairs to be electrically connected in series. The metal contact plates are in turn glued to flat ceramic substrates.

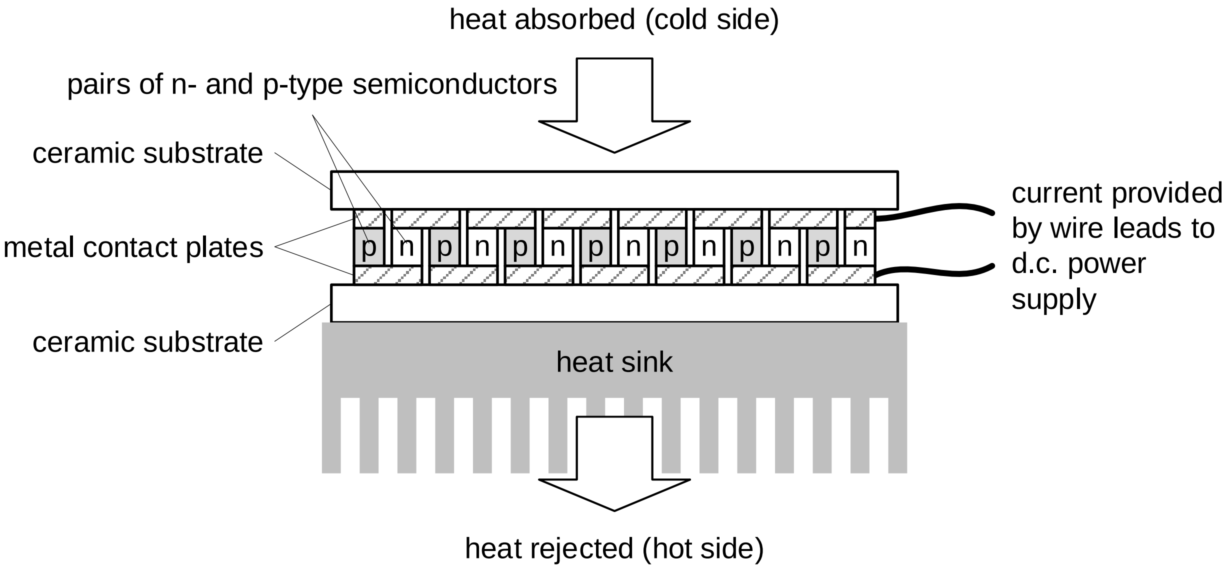


Fig. 4.1 Cross section of a thermoelectric cooler.

When current flows through the semiconductors, heat is absorbed by the thermoelectric cooler at the cold side and rejected by the heat sink at the hot side as shown in Fig. 4.1.

The thermoelectric cooler unit can be used to cool a beaker of water. The rate of heat transfer P across the thermoelectric cooler depends on the current I through the thermoelectric cooler and the N number of pairs of n- and p-type semiconductors.

The rate of heat transfer P is given by

$$P = k\, I^{\alpha}\, N^{\beta}$$

where k, α and β are constants.

Design an experiment to determine the values of α and β.

You are provided with thermoelectric coolers of different number of pairs of n- and p-type semiconductors with heat sinks attached.

Draw a diagram to show the arrangement of your apparatus. You should pay particular attention to:

- the equipment you would use
- the procedure to be followed
- the control variables
- any precautions that would be taken to improve the accuracy of the experiment.

Diagram

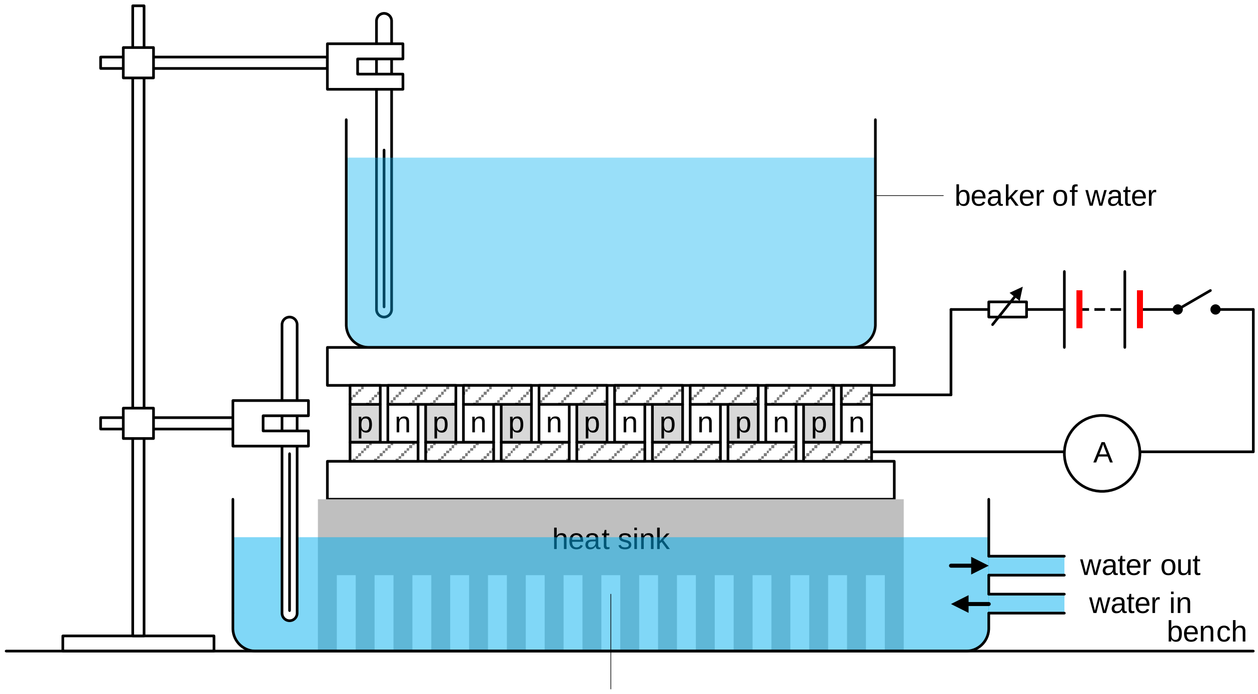


Fig. 1

1. Measure the mass m_0 of an empty beaker with an electronic balance. Fill up the beaker and measure the mass m_1 of beaker and water with the electronic balance.

   Mass of water $m = m_1 - m_0$.

2. Set up the apparatus as shown in Fig. 1.

   Place the beaker of water on the “cold” side of the thermoelectric cooler. Place a thermometer in the beaker to measure its temperature.

   The fins of the heat sink are fully immersed in a water bath. Place a thermometer in the water bath to monitor its temperature. A constant flow of water into and out of the water bath ensures that the temperature of the water bath remains constant.

   Connect the thermoelectric cooler to a power supply, switch, variable resistor and ammeter.

3. Set the rheostat to its maximum resistance and close the switch. Adjust the resistance of the rheostat to obtain a suitable current. Measure the current I through the thermoelectric cooler with an ammeter.

4. Measure the temperature θ of the beaker of water with a thermometer.

5. Measure the time taken t for the temperature of beaker of water to fall from room temperature θ_i to a lower temperature θ_f with a stopwatch. Open the switch once final temperature is reached.

6. The rate of heat transfer by the thermoelectric cooler $P = \dfrac{mc(\theta_f - \theta_i)}{t}$ where c is the specific heat capacity of water.

7. Pour away the water and allow the beaker to return to room temperature θ_i.

Experiment 1

8. Repeat steps 2 to 7 for 8-10 sets of I and P by varying the resistance of the rheostat or e.m.f. of the power supply.

9. The N number of pairs of n- and p-type semiconductor is kept constant by using the same thermoelectric cooler.

Experiment 2

10. Repeat steps 2 to 7 for 8-10 sets of N and P by using thermoelectric cooler with different number of pairs of n- and p-type semiconductor.

11. The current I through the thermoelectric cooler is kept constant by adjusting the rheostat if necessary.

    Note: Current I will vary even for same e.m.f./rheostat setting when a different thermoelectric cooler is used.

12. For both experiments 1 and 2, the temperature of the water bath is kept constant by constant flow of cool water into and warm water out of the water bath.

    Note: The rate of heat transfer by the thermoelectric cooler is also dependent on the temperature of the heat sink. So, it is important to keep the temperature of the heat sink constant using water bath with continuous flowing water.

Analysis [2]

$P = k\, I^{\alpha}\, N^{\beta}$

$\lg P = \alpha \lg I + \lg\left(kN^{\beta}\right)$	$\lg P = \beta \lg N + \lg\left(kI^{\alpha}\right)$
Plot a graph of $\lg P$ against $\lg I$.	Plot a graph of $\lg P$ against $\lg N$.
If the relationship is true, a straight line will be obtained where α is the gradient and $\lg\left(kN^{\beta}\right)$ is the vertical intercept.	If the relationship is true, a straight line will be obtained where β is the gradient and $\lg\left(kI^{\alpha}\right)$ is the vertical intercept.

Additional Details for Reliability [2]

1. Conduct a preliminary experiment to determine the minimum current for the lowest numbers of pairs of n- and p-type semiconductors which can produce an appreciable temperature drop of the water and beaker over a reasonable duration of time.

2. Ensure that the maximum current rating of the thermoelectric cooler is not exceeded to protect it from damage.

3. Ensure good thermal contact between the beaker and the thermoelectric cooler by applying thermal paste between the two surfaces.

4. Account for the heat capacity of the beaker to more accurately calculate the rate of heat transfer by the thermoelectric cooler.

5. Insulate the walls of the beaker and cover up the beaker with insulating material to prevent heat gain from surrounding air. This ensures that the decrease in temperature of water and beaker is due to heat transferred by the thermoelectric cooler.

6. Gently stir the water in the beaker with a stirrer to ensure that temperature is uniform throughout the water in the beaker.

7. Allow thermoelectric cooler/heat sink to cool down after every experiment to reduce the effect of residual thermal energy on subsequent experiments.

8. Account for rate of heat loss to (for $\theta > \theta_{\text{room}}$) rate of heat gain (for $\theta < \theta_{\text{room}}$) from the surrounding by measuring $P = \dfrac{mc(\theta_i - \theta_f)}{t}$ without the themoelectric cooler.

[Total: 11]