A-Level Physics Paper 5 Practice

Capybara

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Instructions

Answer all questions. You may use a calculator. You should show all your working and use appropriate units. The total mark for this paper is 30.

Question 1 [15 marks]

A capacitor is connected to a reed switch, a d.c. power supply of negligible internal resistance and a resistor as shown in Figure 1.1.

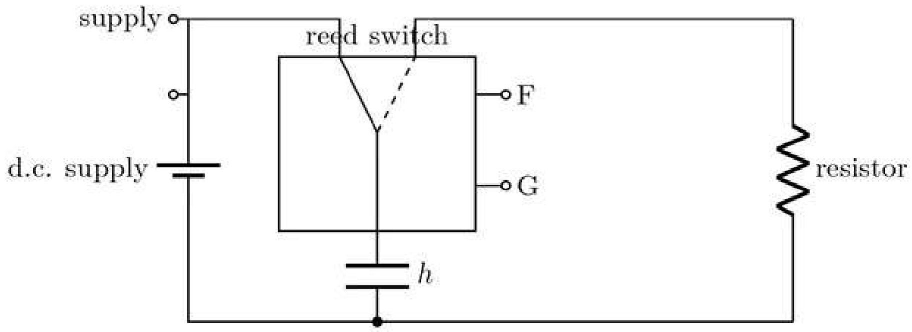


Figure 1: Figure 1.1

The reed switch is a device that contains a two-way switch S that connects the capacitor either to the d.c. supply or to the resistor. An alternating current is supplied to terminals F and G of the reed switch. This causes switch S to vibrate. The frequency f of switch S is the same as the frequency of the alternating current. For half of one cycle of the alternating current, the capacitor is charged from the d.c. supply. For the other half of the cycle, the capacitor discharges through the resistor. The mean current in the resistor is I.

The capacitor is created from two circular metal plates in air. The plates each have area A. The plates are separated by a small distance h. It is suggested that I is related to h by the relationship:

$$\frac{KA}{h} = \frac{I}{fE} \tag{1}$$

where E is the electromotive force (e.m.f.) of the d.c. supply and K is a constant.

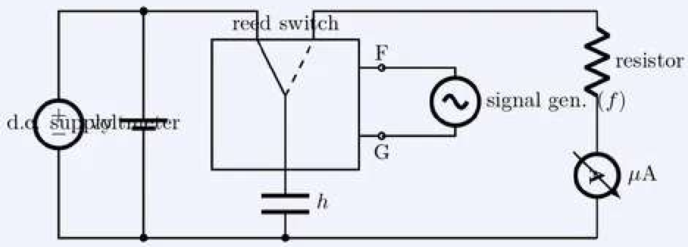
Plan a laboratory experiment to test the relationship between I and h. Explain how the results could be used to determine a value for K.

(Solution & Analysis)

1. Variables:

- **Independent variable:** Separation between the plates, h.
- **Dependent variable:** Mean current, I.
- **Control variables:** E.m.f of the power supply (E), Frequency of the reed switch (f), Area of the circular metal plates (A).

2. Equipment & Diagram Setup: Connect a digital voltmeter in parallel across the d.c. supply to monitor E. Connect a signal generator to terminals F and G to drive the reed switch at a known, constant frequency f. Insert a sensitive digital microammeter in series with the resistor R to measure the discharge current I.



3. Procedure:

- Measure the diameter d of the circular plates using vernier calipers. Take measurements at multiple orientations to find an average d, then calculate $A = \frac{\pi d^2}{4}$.
- Set up the plates securely on insulating stands. Use a micrometer screw gauge or Vernier calipers to measure the initial separation h.
- Turn on the signal generator (set to a fixed frequency f) and the d.c. power supply (set to a fixed e.m.f E).
- Record the reading on the microammeter for the mean current I.
- Vary the separation h by carefully adjusting the stands, measuring the new h, and recording the corresponding new current I. Repeat this to obtain at least 6 distinct sets of readings over a wide range.

4. Analysis: Rearranging the given equation yields: $I = (KAfE)\frac{1}{h}$. Plot a graph of I (on the y-axis) against $\frac{1}{h}$ (on the x-axis). If the theoretical relationship holds true, the graph will be a straight line passing through the origin. The gradient m of this line of best fit will be equal to $KAfE$. The constant K can then be calculated using $K = \frac{m}{AfE}$.

5. Safety & Details:

- **Safety:** Ensure the power supply is switched off before adjusting the plates to avoid the risk of electric shock from charge stored on the plates.
- **Accuracy:** Keep the plates away from large metallic objects or walls to reduce stray capacitance. Ensure the resistor R is small enough so that the time constant $\tau = RC$ is much less than the discharge time $\frac{1}{2f}$, ensuring the capacitor fully discharges each cycle.

Question 2 [15 marks]

A bar is fixed between two stands. A rod of mass M is suspended from the bar by two parallel strings as shown in Figure 2.1.

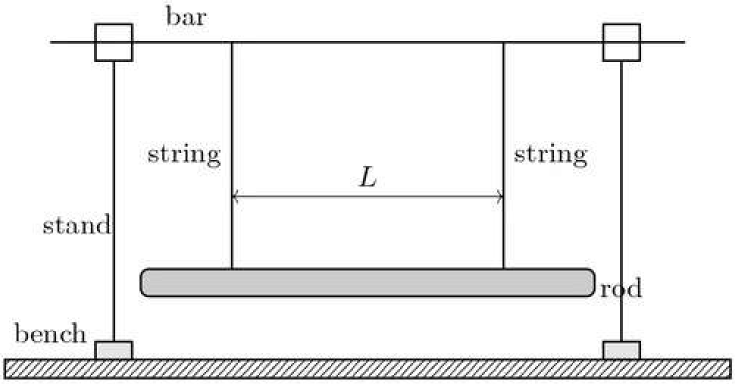


Figure 2: Figure 2.1

The separation of the two strings is L. One end of the rod is displaced horizontally and then released. The rod rotates with oscillations about its centre. The time for 10 oscillations is t. The period T of the oscillations is determined. The experiment is repeated for different values of L. It is suggested that T and L are related by the equation:

$$T = \frac{2\pi}{L}\sqrt{\frac{\alpha D}{Mg}} \tag{2}$$

where g is the acceleration of free fall, D is the distance between the bar and the rod, and α is a constant.

(a) A graph is plotted of T^2 on the y-axis against $\frac{1}{L^2}$ on the x-axis. Determine an expression for the gradient. [1]

(Solution & Analysis)

Squaring both sides of the given equation:

$$T^2 = \frac{4\pi^2}{L^2}\left(\frac{\alpha D}{Mg}\right) \implies T^2 = \left(\frac{4\pi^2 \alpha D}{Mg}\right)\frac{1}{L^2}$$

Comparing this to the equation of a straight line through the origin ($y = mx$), the gradient m is:

$$\text{Gradient} = \frac{4\pi^2 \alpha D}{Mg}$$

(b) Values of L and t are given in Table 2.1. Calculate and record values of T/s and T^2/s^2. Include the absolute uncertainties in T and T^2.

(Solution & Analysis)

L/cm	t/s	$\frac{1}{L^2}$/m^{-2}	T/s	T^2/s^2
27.4	15.8 ± 0.2	13.3	1.58 ± 0.02	2.50 ± 0.06
30.4	14.5 ± 0.2	10.8	1.45 ± 0.02	2.10 ± 0.06
34.8	12.6 ± 0.2	8.26	1.26 ± 0.02	1.59 ± 0.05
40.8	10.8 ± 0.2	6.01	1.08 ± 0.02	1.17 ± 0.04
48.4	9.2 ± 0.2	4.27	0.92 ± 0.02	0.85 ± 0.04
55.2	8.0 ± 0.2	3.28	0.80 ± 0.02	0.64 ± 0.03

Note on Uncertainty Calculation for T^2: Since $T = t/10$, $\Delta T = 0.2/10 = 0.02$ s. For T^2, fractional uncertainty is doubled: $\frac{\Delta(T^2)}{T^2} = 2\left(\frac{\Delta T}{T}\right)$. Example for row 1: $\Delta(T^2) = 2 \times \left(\frac{0.02}{1.58}\right) \times 1.58^2 \approx 0.0632 \rightarrow 0.06$ s^2.

(c)(iii) Determine the gradient of the line of best fit. Include the absolute uncertainty in your answer. [2]

(Solution & Analysis)

From the plotted graph (refer to data points):

$$\text{Gradient (best fit)} = m_{\text{best}} = \frac{2.28 - 0.4}{12.0 - 1.9} = \frac{1.88}{10.1} \approx 0.186 \text{ s}^2\text{m}^2$$

Using the worst acceptable lines (steepest and shallowest fits allowed by error bars):

$$m_{\max} = \frac{2.3 - 0.4}{12.0 - 2.2} \approx 0.194 \text{ s}^2\text{m}^2 \quad \text{and} \quad m_{\min} = \frac{2.22 - 0.4}{12.0 - 1.7} \approx 0.177 \text{ s}^2\text{m}^2$$

$$\Delta m = \frac{m_{\max} - m_{\min}}{2} = \frac{0.194 - 0.177}{2} = 0.0085 \approx 0.010 \text{ s}^2\text{m}^2$$

Final Gradient $= 0.186 \pm 0.010$ s^{2}m^2

(d) The distance between the bar and the rod is measured several times: 0.826 m, 0.829 m, 0.824 m, 0.821 m. Determine the mean distance D. Include the absolute uncertainty. [1]

(Solution & Analysis)

$$\bar{D} = \frac{0.826 + 0.829 + 0.824 + 0.821}{4} = 0.825 \text{ m}$$

$$\Delta D = \frac{D_{\max} - D_{\min}}{2} = \frac{0.829 - 0.821}{2} = 0.004 \text{ m}$$

$$D = 0.825 \pm 0.004 \text{ m}$$

(e)(i) Using your answers to 2(a), 2(c)(iii) and 2(d), determine the value of α. Include an appropriate unit. Data: $g = 9.81$ ms^{-2}, $M = (97 \pm 2)$ g. [2]

(Solution & Analysis)

Rearranging the gradient formula from (a): $\alpha = \frac{m \cdot M \cdot g}{4\pi^2 D}$ Substitute the values (converting M to kg: 97 g = 0.097 kg):

$$\alpha = \frac{0.186 \times 0.097 \times 9.81}{4\pi^2 \times 0.825} = \frac{0.1770}{32.57} \approx 0.00543 \text{ kg m}^2$$

To find units, look at the equation: $\alpha = \frac{[m][M][g]}{[D]} = \frac{(\text{s}^2\text{m}^2)\cdot\text{kg}\cdot(\text{ms}^{-2})}{\text{m}} = \text{kg m}^2$

$$\alpha = 0.00543 \text{ kg m}^2$$

(e)(ii) Determine the percentage uncertainty in α. [1]

(Solution & Analysis)

Add the percentage uncertainties of the variables in the multiplication/division block ($m, M,$ and D):

$$\%\Delta\alpha = \%\Delta m + \%\Delta M + \%\Delta D$$

$$\%\Delta\alpha = \left(\frac{0.010}{0.186} \times 100\%\right) + \left(\frac{2}{97} \times 100\%\right) + \left(\frac{0.004}{0.825} \times 100\%\right)$$

$$\%\Delta\alpha = 5.38\% + 2.06\% + 0.48\% \approx 7.92\% \rightarrow \mathbf{8\%}$$

(f) The experiment is repeated. Determine the separation L of the two strings that gives a value of T of (2.20 ± 0.02) s. Include the absolute uncertainty. [2]

(Solution & Analysis)

From our graph's relationship, $T^2 = m\left(\frac{1}{L^2}\right)$, therefore $L = \frac{\sqrt{m}}{T}$.

$$L = \frac{\sqrt{0.186}}{2.20} \approx 0.196 \text{ m}$$

To find the uncertainty, we use the fractional approach:

$$\frac{\Delta L}{L} = \frac{1}{2}\left(\frac{\Delta m}{m}\right) + \left(\frac{\Delta T}{T}\right)$$

$$\frac{\Delta L}{L} = \frac{1}{2}\left(\frac{0.010}{0.186}\right) + \left(\frac{0.02}{2.20}\right) = 0.0269 + 0.0091 = 0.0360$$

$$\Delta L = 0.196 \times 0.0360 \approx 0.007 \text{ m}$$

Final Answer: $L = 0.196 \pm 0.007$ m