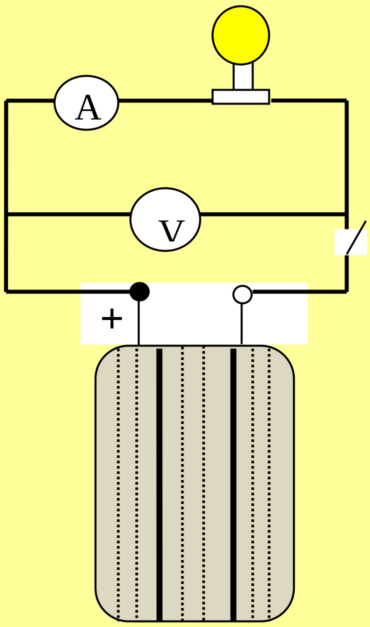
STUDENT REG. NUMBER: ……………………………….

PRACTICAL PHYSICS 1

FIRST YEAR LABORATORY MANUAL

2025 EDITION



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INTRODUCTION

This laboratory manual has been designed for First Year Students taking Physics in the following degree courses: B.Sc, B.Ed, B.Sc (MIT, Metrology, Industrial Chemistry, Geology) and Engineering.

The aim of the lab session is to demonstrate what has been learned in the lectures as well as laying emphasis on laboratory techniques and discipline, data analysis and the interpretation of results. You will learn how to take measurements and estimate reading errors using various instruments, how to analyze and interpret data, how to discuss results and draw intelligent conclusions therefrom. You will be exposed to different types of equipment, illustrating different laboratory and analytic techniques and of course learn some physics.

Each experiment is designed to be completed within a **three (3)** hour session. Pre-prepared worksheets are provided within the manual, which you will be expected to fill in during the course of the experiment. The worksheets include blank data tables, spaces for data manipulation and error calculation, questions on the experiment and spaces for discussion and conclusion. You will also find information on graphical analysis and error analysis (appendix A) which form an important part of the course.

You will be required to plot a rough graph during the experiment (as a rough guide to see that all is going well). This way, you will be able to spot any measurements that may have to be repeated. You will then do all calculations, including error calculations, draw any graphs required and answer any questions posed, write a complete lab report to be handed in for marking.

You will be required to perform a **Minimum of 8 experiments in a semester/part (for Distance Learners)**.

Before you begin your lab sessions, you will be given two tutorial sessions on the following
(i) Laboratory conduct and safety, units, significant figures, how to draw and interpret graphs
(ii) Error analysis:- Types of Errors, How to estimate reading errors, how to reduce or eliminate errors, calculations involving errors with examples
(iii) Skills on report writing

Most of the information that you will need such as resistor color codes, electric symbols etc. are provided at the Appendix.

AIMS OF THE PRACTICAL COURSE

The aims of this course are to:

(a) To demonstrate to you what has been learned in the lectures through well designed studies of experimental and practical physics. In particular, this course will enable you to acquire sufficient understanding and practical knowledge to recognize the usefulness, and limitations, of scientific method and to appreciate its applicability in other disciplines and in everyday life;

(b) Develop in you, attitudes relevant to physics such as
- (i) Concern for accuracy and precision
- (ii) Enquiry Initiative and Inventiveness

(c) Guide you on how to write a good practical or technical report in the accepted formal style

(d) Develop experimental abilities and skills on
- (i) How to use various scientific instruments
- (ii) How to interpret and analyze scientific data
- (iii) How to reduce/eliminate errors and how to calculate errors in readings and measured quantities
- (iv) Laboratory techniques and laboratory safety

OBJECTIVES

At the end of this course, you should be able to

1. Demonstrate experimental skills in relation to scientific instruments and apparatus, including techniques of operation and aspects of safety.

2. Identify problems to be investigated in a given experiment, plan and carry out investigations, including the selection and techniques to be used, choice of apparatus, measuring devices and materials. You should be able to use apparatus, handle measuring devices and materials effectively and safely;

3. Follow written instructions for the assembly and use of apparatus provided. Indicate how you carried out a required instruction and describe precautions taken in carrying out a procedure;

4. Interpret, evaluate and report upon observations and experimental data. In particular, you should be able to

   - Present your data graphically where appropriate, using suitable axes and scales and plotting the points accurately
   - Determine a gradient, intercept or intersection on a graph

5. To discuss results and draw intelligent conclusions. Comment on a procedure used in an experiment and suggest any improvements where necessary.

INSTRUCTIONS TO THE STUDENT

Before you come to the lab, make sure you have done a sufficient preliminary reading of the experiment to be performed to have the nature of the problem to be investigated and a plan of campaign clear in your mind. Bring with you, to the lab, a notebook, a lab manual and a calculator.

While in the laboratory

(a) Look at your apparatus

Before taking any measurements, check that you have all the apparatus needed. Study your apparatus to know the function of every control, knob, switch, screw, slice, locking device etc. If anything is missing, or you need extra equipment, ask the lab technologist.

(b) Assemble the apparatus/draw circuit diagram

Assemble the apparatus and have the set-up checked by the demonstrator. Observe the following for electrical experiments

(i) *Always draw the circuit diagram first*. This way, it is easier to spot any anomalies in the circuit.

(ii) *Have the circuit checked by your demonstrator before you switch on or connect to power supplier or cells.* This is to ensure that no damage is caused to any electrical equipment as a result of wrong connections.

(iii) *Do not switch electronic equipment ON and OFF:-* Most strain and damage occurs with electronic equipment when it is switched on, while it is warming up. Many parts may be temporarily overloaded under such abnormal conditions.

(c) Taking readings

Record all original readings in your notebook without any processing or editing. Sample tables are provided to help you record your readings. Give the unit and estimated error for every reading. Fill in (using ink) the data sheet(s) provided or required with the actual observations made during the experiment. ***Data sheets and reports written in pencil are not acceptable***.

(d) Repeat Readings

It is better to repeat measurements so as to obtain both an average value with a smaller random error and an indication of the size of the random error. Suitable data sheets are provided in the manual.

(e) Plot rough Graphs

Plot a rough graph during the experiment (as a rough guide to see that all is going well). This way, you will be able to spot any measurements that may have to be repeated.

(f) Present your data to the Demonstrator

You should make sure that your data has been verified, certified and signed by your lab demonstrator before you leave the lab. Unsigned data will not be marked.

(g) Presentation and marking

In marking, emphasis will be laid on the following

- Clarity and neatness of work; graphs in particular
- Realistic estimation of errors, signs of initiative and common sense in taking precautions as a means of improving the results and minimizing errors
- Error analysis
- Clearly explained and well-thought-out comments and conclusions, among others

(h) Submission

The reports ***MUST be submitted within ONE WEEK after carrying out the experiment***.

LABORATORY REPORT WRITING

This format will guide you on how to write a good laboratory or technical report. Study it carefully and observe the same format in your report writing. Remember, an important part of your grade in this course depends on your performance in the laboratory and the way you present your report.

FORMAT OF THE LAB REPORT

- When writing your report, please observe the following

(i) Always begin a new report on a fresh (ruled) page

(ii) Your report should contain good written language i.e., the language should be clear, logically express your ideas, contain proper syntax (spelling and punctuation's) and intelligible with the purpose of being understood.

- The Report should follow a logical order (style) and should come under some of the following headings

(a) CODE & TITLE OF THE EXPERIMENT:- This is important for ease of referencing and identification e.g., "EXP A2: THE SIMPLE PENDULUM". The Title tells the reader what the report is all about.

(b) DATE:- This is important because the nature of some phenomena like radioactivity, changes with time. As such, the results obtained are depended on the date of measurement.

(c) NAME OF PARTNERS:- List the collaborators involved in the investigation (experiment).

(d) **OBJECTIVES (AIMS)**:- They set the targets or the goals of the investigation e.g. *"To determine* ***g*** *using a simple pendulum".*

(e) THEORY (INTRODUCTION):- You should provide the introduction to the experiment that sets the scene for what follows. It shows the relation of your practical work to some theoretical body of knowledge. You should highlight any assumptions and approximations if any.

(f) LIST OF APPARATUS:- List all the apparatus required for the particular experiment.

(g) METHOD (PROCEDURE):- Your procedures (including all the details and steps) must be reported (in past tense) in clear and telling manner in the sequence in which they were executed. You should prefer the passive voice to the active voice i.e., the notion of objectivity to subjectivity e.g., you should use phrases like "*This and that was done ….*", rather than "*I did this and that …*", which is rather too egotistical. Notably, the use of an active voice in the first person plural to imply the reader and the writer i.e., "we" is allowed.

- You should include diagrams/figures to illustrate the set-up where necessary. Such diagrams should be reasonably large, well labeled, numbered serially and consecutively in order of their appearance and with figure captions e.g., "*Fig. A3.1: Schematic illustration of a simple pendulum*".

- ***Precautions (if any)***:- You should highlight any potential risks, damages, or hazards, which may be caused e.g., when the equipment is mishandled.

(h) RESULTS:- Your results should be neatly presentation either in text, tables or using graphs. Tables and graphs should be numbered with titles e.g., "*Table 3.1: Variation of Voltage with current in a resistor*". Where relevant, units should always be quoted e.g., in headings of tables, axes of graphs and in statements of results. All units must be in SI or derived SI units.

(i) DATA ANALYSIS (Calculations, Graphs, Error analysis etc):- This is where you provide sufficient evidence upon which your investigations stands or fails.

Note: During the experiment, you should collect as much data required as possible and sketch out essential graphs, diagrams and calculations while the experiment is running. This will help you see if there are any gaps or erroneous measurements that need to be repeated.

Calculations

All calculations should be clearly shown. You should also show how you compute errors associated with derived quantities (*see Error analysis pg. xiv*). You should observe consistence of *SI* units and avoid spurious expressions of accuracy e.g., x = 4.3333 cm (obtained from a calculation) is unrealistic and inconsistent with the level of accuracy as determined by the equipment (e.g., meter rule in this case).

Error Analysis

Since accuracy cannot be increased without limit, experimental error is thus the discrepancy between the observed and the expected result. You should take into account the contributions from zero errors, systematic errors, reading errors random errors etc. (see Pg. xiv for details).

Graphs

You should draw all graphs on graph paper. *Each graph should be headed with a brief tittle or have a figure caption*. Note the following when drawing graphs:

- The readings used for plotting graphs should appear on the same double page as the graph, commonly opposite the graphs so as to leave the whole page clear for this graph. Error bars should be drawn according to the errors estimated for either or both coordinates, specially for the square variables.

- Always ***plot the effect*** (physical quantity which is varied in consciously controlled steps e.g., pendulum length) ***against the cause*** (physical quantity which is then measured e.g., pendulum period). For a linear relationship of the form $y = mx + c$; y is the measured variable and is plotted on the vertical axis while x is the controlled variable and is plotted on the horizontal axis. *Both axes should be labeled with appropriate titles and relevant units*

- *Choose suitable scales* and draw the graph as large as possible, preferably covering ***three quarters of the page***

- Use a sharp pencil to draw all graphs. Data points should be clearly marked (using crosses (**+**) or circles(**O**)) with error bars ($\pm\Delta x$) where necessary.

Drawing curved graphs

- If when plotted, the data points indicate a curve, draw a smooth curve through the points. It does not matter if some points lie outside the curve. Never join the dots to give a linked line.

Slopes

- Always choose the largest possible triangle from which to calculate the slopes. The larger the values of the sides of the triangle, the smaller the percentage error in them. Remember -The vertical and horizontal values must be measured in the units of the scales of the graphs, NOT in "cm" or "squares". For example, for a linear relationship of the form

$$y = mx + c$$

a straight line graph on the ***x - y*** coordinate frame can be drawn, as shown below

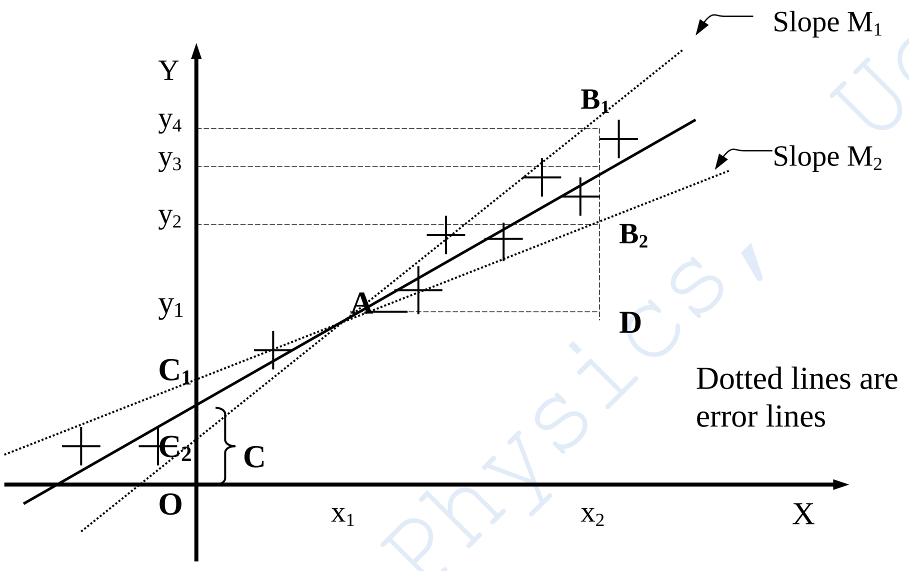

Fig. 1. Illustration of how to calculate slopes from linear graphs

From the graph,

Slope M_1 = $\left(\frac{B_1D}{AD}\right) = \frac{y_4 - y_1}{x_2 - x_1}$ and Slope M_2 = $\left(\frac{B_2D}{AD}\right) = \frac{y_2 - y_1}{x_2 - x_1}$

Intercept $C_1 = OC_1$ and Intercept $C_2 = OC_2$

Therefore;

Mean Slope, $\overline{M} = \left|\frac{Slope\ M_1 + Slope\ M_2}{2}\right|$ ....(1)

Error in Slope, $\Delta\overline{M} = \left\{\frac{Slope\ M_1 - Slope\ M_2}{\frac{1}{2}\left(Slope\ M_1 + Slope\ M_2\right)}\right\}$ ....(2)

Percentage error in Slope = $\frac{\Delta\overline{M}}{\overline{M}} \times 100$ ....(3)

Average intercept C = $\frac{OC_1 + OC_2}{2}$ ....(4)

NB. Graphical analysis is the best most accurate method of obtaining your final result as compared to doing calculations from each individual pair of results and then averaging. However, the accuracy of the graph may be affected by the choice of the slope. The most accurate slope measured is made from a line inclined approximately 45^{o} to the axis.

(j) **DISCUSSIONS**:- Examine by argument, your case supported by your results. In particular, discuss the sources of error in the experiment and whether they are acceptable. Compare and contrast your result with those of any previous investigations or standard values (from theory). Justify for the discrepancies. In particular, your discussions should answer the following questions; *What is What is the significance of your results? Can you explain any unexpected findings? Are there ways of improving the experiment?*

(k) **CONCLUSIONS**:- This is where you sum up and decisively justify your results. Your conclusion should reflect the objectives. It should be a short and thoughtful summary of your discussions/findings.

(l) **REFERENCES**:- Cite/list any references used.

INTRODUCTORY EXPERIMENT
<u>Experiment A0: Precision Measurements</u>

Introduction
Whenever we make a measurement, the level of accuracy in that measurement depends on the instrument used. For precision and high accuracy measurements, we employ the use of high precision instruments.
In this experiment, you are going to perform measurements of various parameters on various objects using appropriate instruments.

Objectives
To study some of the instruments and methods used in precision measurements, and to compute the volume and density of various items

Apparatus
You will require a metre rule, vernier calipers, micrometer screw gauge, electronic balance and traveling microscope. The objects you require include a copper cylinder, steel ball and glass capillary tube.

The micrometer screw gauge
In order to measure lengths to a higher degree of accuracy than the millimeter, Pierre Vernier (1580-1637) designed a scale which is now known as a Vernier scale. Such a scale, V, is made to slide along a millimeter scale, M, as shown in the figure 1.1.

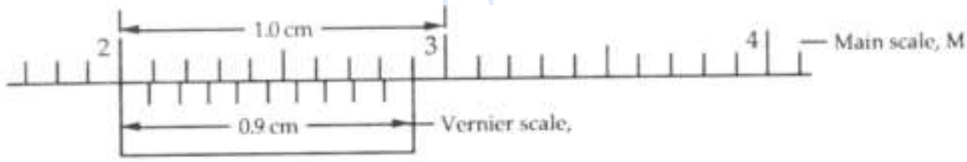

Fig. 1.1. The vernier Scale

The vernier scale has a length of 0.9cm and 10 divisions. Hence, each division on the vernier scale is 0.1mm less than each division on the millimeter scale i.e., 0.1- 0.09cm = 0.01cm = 0.1mm. This difference between the smallest division on the millimeter scale and one vernier division is called the least count.
When a vernier scale is used, one looks along this scale, V, and the main scale, M, and notes down the division on V which coincides with one of the divisions on M. The measured length is then computed as follows.

Length = scale reading immediately to the left of vernier zero +
(vernier division of coincidence x least count)

The vernier scale may be linear as the ones in the vernier calipers, Fortin's barometer and in the travelling microscope, or circular as the ones in the micrometer screw gauge and in the spectrometer, figure 1.2.

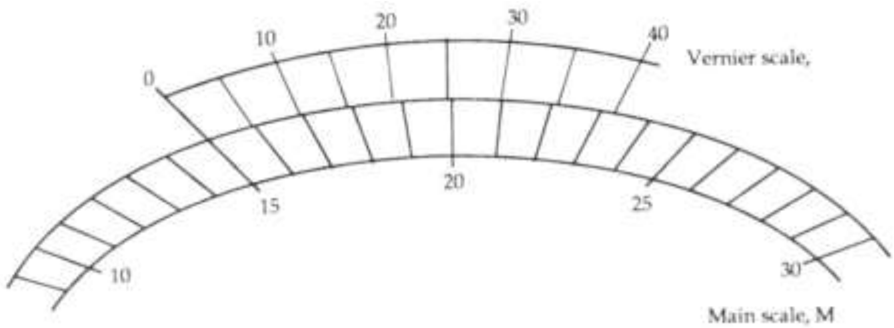

Fig. 1.2. Circular vernier scale

The micrometer screw gauge

When measuring a length using a micrometer screw gauge, the main scale is marked in 1/2mm divisions and a circular vernier scale divides this into 50 divisions. Thus, one division on the vernier scale corresponds to 0.01mm, figure 1.3.

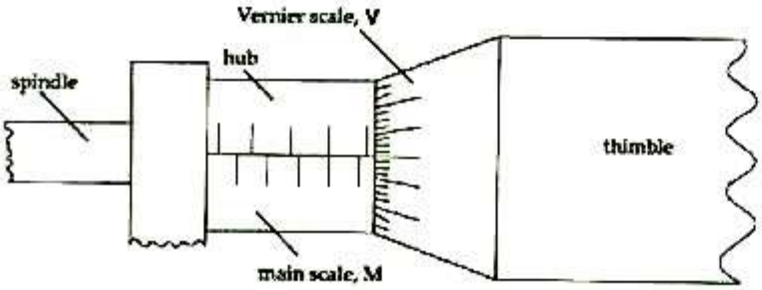

Fig. 1.3. The micrometer screw gauge

Method

1. Record in the worksheet, the Zero and Reading errors of the various instruments provided.

2. Using each of the instruments (where feasible), measure and record in the worksheet, the dimensions of the objects provided. At least two instruments should be used for each measurement and the precision obtained in each case compared. All weightings should be done on the electronic balance.

3. Using a traveling microscope, measure the internal diameter of the capillary tube as follows:

4.

   (i) First, position the cross wires of the traveling microscope at one end of the tube as shown in Fig. 1.4 and record the vernier reading (say reading A)

   (ii) Now move the cross wires to the other edge of the capillary tube using the sliding knobe on the traveling microscope and record the new vernier reading (say reading B). Be

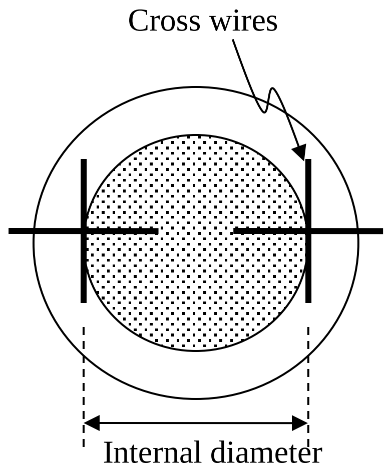

Fig. 1.4

careful not to move the telescope in the process.

(iii) Now Compute the diameter of the capillary tube as the difference in the two readings (B –A).

5. Calculate the volume and density of the metal objects and the capacity of the capillary tube determined. Tabulate your results in *Table 1* and show all your workings.

6. Work out the errors in the volumes and densities calculated in 4 above by using the reading errors of the appropriate instruments. Show all your workings. Refer to the section on errors in this manual for instructions on how to calculate errors.

7. Using an ammeter, a milliammeter and a microammeter, measure the current in the electrical circuits already set up for you. Estimate and record the zero and reading errors in each case. Record your data in *Table 2*

Table 1: Table 1: Measurements and Errors

Object	*Measurement*				
	Instrument	**Meter Rule**	**Vernier Calipers**	**Micrometer screw gauge**	**Weighting Balance**
	Zero Error	±	±	±	±
	Reading Error	±	±	±	±
Copper Cylinder	Height				
	Diameter				
Steel Ball	Diameter				
Copper Wire	Length				
	Diameter				
Capillary Tube	Length				
	Diameter				

Table 2: Volume and Density

	Volume	Error	**Density**	**Error**
Copper Cylinder		±		±
Steel Ball		±		±
Capillary Tube		±		±

Table 3: Current and Errors

Instrument	*Current*	*Error*	*Unit*	
Ammeter		±		

Milliammeter		±		
Microammeter		±		

1. Answers the following questions
   a) Why is it appropriate to use the meter rule for measuring the length of the copper wire but the micrometer screw gauge for the diameter?
   b) What are the potential sources of error in each experiment, and how can they be minimized or accounted for?
   c) What is the importance of calculating the error in the volume and density measurements, and how do these errors influence your final results?
   d) How does the precision of the Vernier calipers compare to that of the micrometer screw gauge, and in what situations is one preferred over the other?
2. Discussion
   - Compare the measured values of density for the copper cylinder and steel ball with their known values from the reference book.
   - Discuss the precision of the instruments used. For example, the micrometer screw gauge provides a higher precision than the Vernier calipers.
   - Analyze the errors encountered during measurements. Comment on whether the zero errors and reading errors significantly affected the result.
3. Conclusion
   - The volume of the copper cylinder was found to be …… ± …… (units), and its density was …… ± …… (units).
   - The volume of the steel ball was found to be …… ± …… (units), and its density was …… ± …… (units).
   - The internal diameter of the capillary tube was …… ± …… (units).

Write similar conclusions for the steel ball and capillary tube and compare your values with the correct values for the densities of copper and steel and comment. The true value may be found in the reference book: Kaye G. W. C. and Labye., Tables of Physical and Chemical Constants, 15th Ed., Longman, 1986.

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Example: These results were compared with the known values of copper and steel densities, and the experimental values were close/within acceptable error margins, demonstrating the precision of the instruments used. The accuracy of the instruments, calibration errors, and other factors like parallax could have contributed to the slight deviations observed.

MECHANICS

Experiment: A-1: Parallelogram and Triangle of Forces

In this experiment, you are going to will verify the theorems of Parallelogram and Triangle of forces.

Objectives

To verify the parallelogram and Triangle Theorems

Apparatus

Force Board (A), pulleys (B1 and B2), sheet of paper (C), string (D), Selection of weights (W)

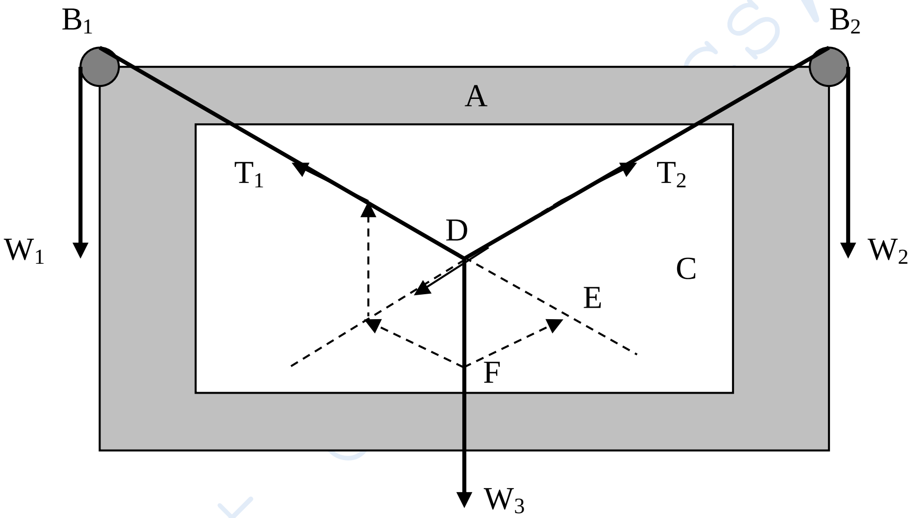


Figure A-1. T_1 and T_2 represent tensions in the string

Theory

Parallelogram Theorem

If two concurrent coplanar forces are represented in magnitude and direction by the sides of a parallelogram, drawn from one angular point, then their resultant is represented in magnitude and direction by the diagonal of the parallelogram drawn from the same point (see Fig. A-1.)

Triangle Theorem

If three concurrent coplanar forces are in equilibrium, then their magnitudes and directions may be represented by the sides of a triangle.

Method

1. Set up the apparatus as shown in Fig. A-1
2. Adjust the three weights W_1, W_2 and W_3 to produce equilibrium. Arrange such that DB_1, DB_2 and DW_3 are fairly central on the sheet of paper. Record the mass and weights of the three masses (W_1, W_2 and W_3) in Table A-1 together with errors in their measurements

3. Transfer the directions of T_1, T_2 and W_3 carefully to the sheet of paper.

4. Remove the sheet of paper from the force board

5. Using a suitable scale (e.g., 1 cm to represent 1N), mark lengths along DB_1 and BW_3 to represent the forces T_1 (i.e., W_1) and T_2 (i.e., W_3) respectively

6. Repeat steps 1 to 5 using another set of weights W_1, W_2 and W_3

Parallelogram Theorem

Complete the parallelogram and draw the diagonal from point D. This diagonal should be collinear with DB_2, act in opposite direction and be equal in magnitude to T_2 since T_2 is the equilibrant of T_1 and W_3. This verifies the parallelogram theorem

Triangle Theorem

Produce B_1D towards E. Using a suitable scale, mark off lengths along DE and DF to represent the forces T_1 (i.e., W_1) and W_3. Join the ends of these lengths with FE. The line FE should be parallel to DB_2, and have a length which represents T_2 (i.e., W_2) according to the scale used. This verifies the Triangle theorem.

Results

Table A-1

Units	*Mass ±..... (Kg)*	*Weight ±........ (N)*
W_1		
W_2		
W_3		

NB: You must hand in the original Ray Diagrams

Questions

1. How do you convert Kilograms to Newtons?

2. Comment on your drawings and state whether or not you have verified the two theorems

1. What are the sources of error in this experiment?

Conclusions

Write suitable conclusion reflecting the objectives

Experiment: A-2: Acceleration Due to Gravity - The Simple Pendulum

Introduction

The simple pendulum is a simple mechanical device that executes simple harmonic motion (SHM) under certain conditions. On applying mathematical treatment, a simple formula for its period (T) is derived which can be used to determine the value of acceleration due to gravity (g).

In this experiment, you are going to determine the value of the acceleration due to gravity (***g***), in Nairobi using a simple pendulum. At the end of the experiment, answer all the questions based on the experiment.

Objectives

In this experiment, you should be able to determine

1. *The acceleration due to gravity (g) using a simple pendulum*
2. *The effect of the amplitude (θ) of swing on the periodic time (T) of a simple pendulum*

Apparatus

You are provided with a pendulum bob, string, a clamp mounted on a stand, stopwatch, a metre rule and a steel ball.

Theory

An ideal model of a simple pendulum consists of a small mass (bob) of mass M attached to a thread of length (l) and allowed to oscillate freely in a vertical plane under the action of gravity (Fig. 1). In this case it is assumed that the bob is a point mass of negligible dimensions suspended by an inextensible string of negligible mass.

The motion of a simple pendulum can be analyzed using Newton's second law (***F*** = M***a***). From the ideal mode of Fig 1, when the string is displaced by an angle (θ) from the equilibrium position, the component of the weight (Mg) which acts on the bob as a restoring force (F) is $F = Mg\sin\theta$.

Thus, from Newton's second law, it thus follows that

$$- Mg\sin\theta = M\mathbf{a} = M\frac{dv}{dt} \qquad \text{...(1)}$$

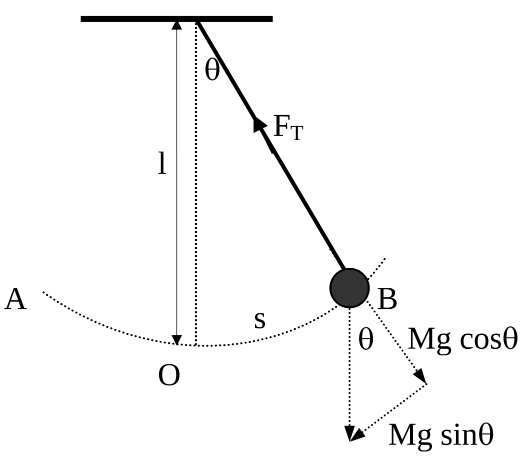


Fig. A-2: The simple pendulum

From Fig.1,

- Force $Mg\cos\theta$ balances Tension (F_T).
- $Mg\sin\theta$ is the unbalanced force and as a result causes motion along the arc AB.

But $v = l\omega$, where l = length of the pendulum and ω is the angular velocity ($\omega = \frac{d\theta}{dt}$).

$$\text{Hence} \quad -Mg\sin\theta = M\frac{d}{d}(l\omega) = ml\frac{d}{dt}\left(\frac{d\theta}{dt}\right) = M\left(\frac{d^2\theta}{dt^2}\right)$$

$$\Rightarrow \quad g\sin\theta = l\frac{d^2\theta}{dt^2}$$

$$\text{Or} \quad \Rightarrow \quad \frac{d^2\theta}{dt^2} + \frac{g}{l}\sin\theta = 0$$

If θ is small (< 10°), then, $sin\theta \approx \theta$ in radians (from series expansion*)

$$\Rightarrow \quad \frac{d^2\theta}{dt^2} + \frac{g}{l}\theta = 0 \qquad \text{...(2a)}$$

Equation (2a) is similar to a simple harmonic motion (SHM) equation of the form

$$\frac{d^2x}{dt^2} + k^2x = 0 \qquad \text{where} \qquad k = \sqrt{\left(\frac{g}{l}\right)} \text{ and } \theta = x.$$

The solution of equation (2a) has the form

$$\theta = \sin\sqrt{\left(\frac{g}{l}\right)}t \qquad \text{...(2b)}$$

For a complete oscillation, we set $t = T$ (the period) and $\theta = 2\pi$, hence equation (2b) is satisfied i.e., $2\pi = T\sqrt{\left(\frac{g}{l}\right)}$

$$\therefore \quad T = 2\pi\sqrt{\left(\frac{l}{g}\right)} = \frac{2\pi}{\omega} \qquad \text{..................................(3)}$$

where ω is a constant called the angular frequency and $\omega^2 = g/l$.

Thus equation (3) can be used to determine the acceleration due to gravity (g) from measurements of the period (T) and length (l).

Note: For the actual solution shown in Fig. *1*, T is given by

$$T = 2\pi\sqrt{\left(\frac{l+c}{g}\right)}$$

where c is a constant length from the point of attachment of the thread to the centre of gravity of the bob.

Part A: To determine the value of (g)

Procedure

1. Set the pendulum string to 50 cm. Displace the bob through a small angle ($\theta < 10^o$) and let it swing with small oscillations as shown in Fig. 1.

2. Record the time for 50 oscillations. (HINT: Begin your counting through the equilibrium position).

3. Repeat step 1 for a number of different pendulum lengths between 50 and 100 cm. Record the reading errors in both the time (t) and length (l). Tabulate your results as shown in Table 1.
4. Determine and also record the error in T and T^2 (i.e. $2Tdt$).

Results

Table 1.

Length (l)	***Time (t) for 50 Oscillations*** *±…(s)*	***Average t*** ±…….(s)	***Period (T)*** *±…… (s)*	T^2	$\pm 2Tdt$
0.5 m	Set 1				
	Set 2				
0.6 m	Set 1				
	Set 2				
0.7 m	Set 1				
	Set 2				
0.8 m	Set 1				
	Set 2				
0.9 m	Set 1				
	Set 2				
1.0 m	Set 1				
	Set 2				

Reading error: Length = ±………….. Time = ±……………

Data Analysis

(a) Using equation (3), draw a suitable graph from which you can deduce the value of acceleration due to gravity, ***g***. Plot the error bars on your graph and draw slope lines for maximum and minimum slopes. Compute the average slope with errors and calculate the percentage error in ***g*** as well.

(b) Provide short answers to the following Questions:

Activity

1. What is the purpose of timing 50 oscillations instead of only one to determine the periodic time?

2. Why must the size of the amplitude be small?

3. Compare your value of $\boldsymbol{g}$ obtained with the standard value of $\boldsymbol{g}$ in Nairobi ($\boldsymbol{g}$ = 9.81 ms^{-2}) and comment on these two values i.e., why aren't the two values the same?

4. What pendulum length in Nairobi would have a time period of 1s?

5. What are the assumptions implied by the ideal model of a simple pendulum?

Discussions

Discuss your results in comparison to standard value of $\boldsymbol{g}$ in Nairobi.

Part B: To investigate the effect of the amplitude on the periodic time (T)

In this part, you are going to investigate the relation between θ and the time period (T) of a simple pendulum.

Procedure

1. Fix the length of the pendulum to say 70 cm. Adjust the amplitude of the swing to about 10^o with the help of a protractor and set the pendulum to swing as in Fig. 1. Record the time for 50 oscillations. Tabulate your results as shown in Table 2.

2. Repeat for different values of amplitude ranging between 10^o and 70^o. Record the reading errors in both the amplitude and the time.

Results

Table 2.

Amplitude (θ) $\pm$	***Time (t) for 50 Oscillations $\pm$..(s)***	***Average t $\pm$ ……..(s)***	***Period (T)***	*$\pm dT$*
10^o	Set 1			
	Set 2			
20^o	Set 1			
	Set 2			
……….	Set 1			
	Set 2			
70^o	Set 1			
	Set 2			

Data Analysis

(a) Plot a graph of the period (T) against the amplitude (θ). The time period axis should be between the minimum and maximum (T) only. Draw the curve carefully, plotting the error bar in (T) and (θ).

(b) What can you deduce from the graph about the relationship between the amplitude θ of swing and the period (T) for a constant length ℓ?

(c) Answer the following questions

> ### *Activity*
>
> 
>
> 1. A pendulum of length (0.600 ± 0.002)m is used to determine the value of g. The value of T was found to be (1.55 ± 0.01)s. Find the percentage error on the value of g.
> 2. Derive an equation for the time period of a simple pendulum for which amplitudes are not small. (HINT: Look up Halliday and Resnick).

Discussions

Discuss your results appropriately

Conclusions

Write suitable conclusion reflecting the objectives

Experiment: A-3: Principles of Equilibrium

In this experiment you are going to verify the necessary and sufficient conditions for a rigid body to remain in static equilibrium using a simple supported beam.

Objectives To verify the principles of equilibrium using a simple supported beam.

Apparatus

A beam AB resting on two supports attached to weighing scales R_1 and R_2, a set of masses

Theory

Consider a beam of length AB carrying weights $\boldsymbol{W_1}$ and $\boldsymbol{W_2}$ and being supported by two springs of tensions $\boldsymbol{R_1}$ and $\boldsymbol{R_2}$ respectively as shown in Fig. 3-1. We can see that for the beam to remain in equilibrium, the total upward force ($\boldsymbol{R_1}$ and $\boldsymbol{R_2}$) should balance the total downward force ($\boldsymbol{W_1}$ and $\boldsymbol{W_2}$).

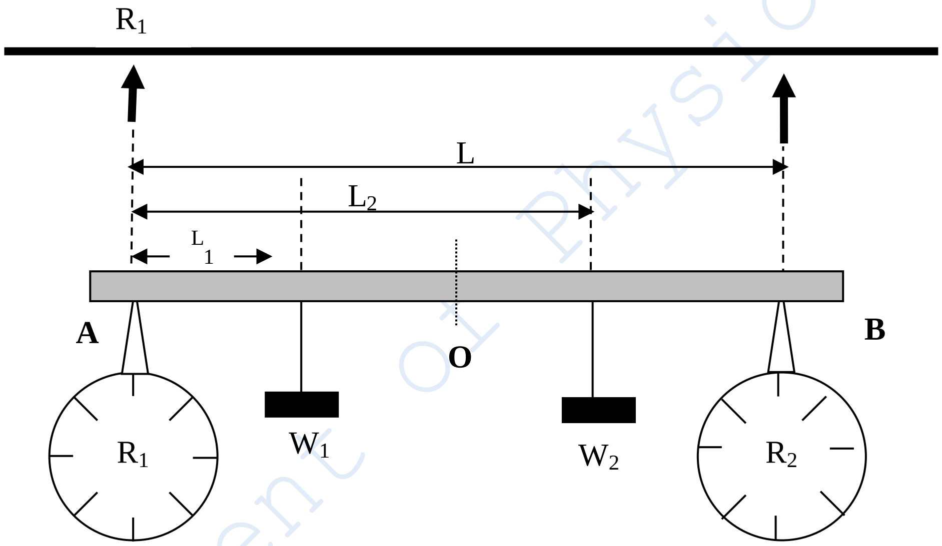


Fig. 3-1.

Additionally, forces $\boldsymbol{W_1}$ and $\boldsymbol{R_2}$ act tc i-clockwise direction about point ***O*** while $\mathbf{W_2}$ and $\boldsymbol{R_1}$ acts to turn the body in a clockwise direction. This turning effect of a force is the moment. *The moment (M) of a force about a point is the product of the force and the perpendicular distance from the point to the line of action of the force*. Thus, for static equilibrium of the beam, the sum of clockwise moments about any point = the sum of anti-clockwise moment about the same point (called principle of moments). For example, taking moments about point A we have

$$R_2 \times L = (W_1 \times L_1) + (W_2 \times L_2)$$

(clockwise moments) *(anti-clockwise moments)*

Generally, the necessary and sufficient conditions for equilibrium of parallel forces are

(i) *The sum of external forces on the body (beam) must be zero*

(i) *The sum of the moments on the body (beam) must be zero (i.e., sum of clockwise moments = sum of anti-clockwise moments)*

Method

1. Set up the apparatus as shown in Fig. 3-1.

2. Adjust the scales to zero before loading the masses.

3. Place weights W_1 (= 50g) at a distance of L_1 (= 0.1 m) and W_2 (= 50g) at a distance of L_2 on the beam as shown in the figure.

4. Move the weight W_2 until equilibrium is achieved and record the readings on the scales R_1 and R_2 in worksheet 3-1.

5. Measure the distances L_1, L_2 and L using a metre rule stick.

6. Vary the loads W_1 and W_2 and note the new scale readings R_1 and R_2 as well L_1 and L_2 (and L if any). Record all your readings in the worksheet

7. Answer the questions that follow

Results

Total length of beam (between supports), L =

Worksheet A-3.1

	First Try		***Second Try***	
	Value .±…	Units	Value….±…	Units
W_1				
W_2				
L_1				
L_2				
R_1				
R_2				

Analysis

1. $R_1 + R_2$ should equal to $W_1 + W_2$. Check that this is true using the worksheet below

Worksheet A-3.2

	First Try		***Second Try***	
	Value…±…	Units	Value…±…	Units
$R_1 + R_2 = R$				
$W_1 + W_2 = W$				

2. By taking moments about the left hand support (point A) we have:

$$R_2 \times L = (W_1 \times L_1) + (W_2 \times L_2)$$

Therefore $$R_2 = \left(\frac{(W_1 \times L_1) + (W_2 \times L_2)}{L} \right)$$

Calculate the value of R_2 and check that the calculated value = scale reading for R_2. This verifies the second theorem of equilibrium. Record all your results in the worksheet.

Worksheet A – 3.3

	First Try		*Second Try*	
	Value…±…	Units	Value…±…	Units
R_2 Scale reading				
R_2 Calculated				

Similarly, take moments about the right-hand support (point B) to find R_1 using ($L - L_2$), and ($L - L_1$) as the distance of the loads W_2 and W_1 from the support respectively. Record your results in the worksheet and check all units carefully.

Worksheet A -3.4

	First Try		*Second Try*	
	Value…±…	Units	Value…±…	Units
R_1 Scale reading				
R_1 Calculated				

1. State the reading errors in:
   (i) Mass = ±
   (ii) Length = ±
   (iii) Scale reading of R = ±

2. Calculate the error in $R_1 + R_2$
3. Calculate the error in $W_1 + W_2$

4. What other sources of error are there in this experiment?

5. What would you expect if one of the loads (e.g., W_2) was directly over the support?

6. What would happen if W, the sum of the weights acted upwards?

Conclusions

Make a statement as to whether or not the principles of equilibrium were verified in your experiment.

Experiment A-5: Variable Inertia Bar

Introduction

A rigid body can simultaneously undergo two kinds of motion i.e., it can change the position of its centre of mass (C.M) in space (translational motion) and/or it can change its orientation in space (rotational motion about some axis). In this experiment, we shall study a rotating rigid body and verify the laws of conservation of angular momentum

Objectives

1. To show that the angular acceleration of a rotating system is proportional to the applied torque.

2. To show that the moment of inertia of the system varies with the square of the distance of the rotating mass from the center of rotation.

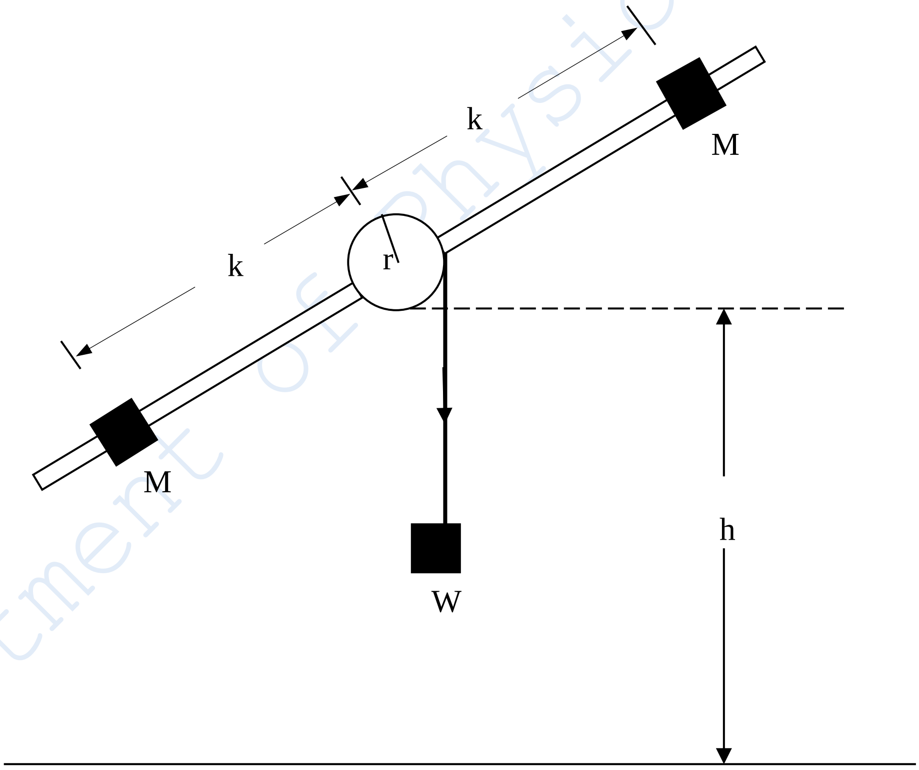


Fig. 5-1

Apparatus

A light bar with sliding masses *M* rotating about a central spindle. A cord wrapped around the spindle and a weight suspended from the free end. (When the assembly is released, the weight descends a distance *h* metres, giving the inertia bar an angular acceleration, α rad per square second. A stopwatch is used to time the descent.)

Theory I

When a pair of equal and parallel forces (couple) acting on a body in opposite direction they produces a turning effect called a *torque* ($\Im$) or *the moment of a couple*. T*orque* ($\Im$) is fiven by

$$\Im = \boldsymbol{Fr\sin\theta}$$

where F = the force due to the couple

The torque causes the body to rotate and the applied Torque is proprtional to the angular acceleration

$$\Im = I\alpha \qquad \text{……………………………………………(5.1)}$$

where α = angular acceleration and
I = moment of inertia

From figure 5-1 above, $\Im = Wr$ and the linear acceleration $a = \dfrac{2h}{t^2}$ assuming the mass begins from rest

where W = weight of mass at end of string
r = radius of spindle
a = *linear* acceleration of mass W
h = height descended
t = time of descent

Since $\alpha = a/r$, then substituting for α in equation (5.1) we have

$$\Im = Wr = I\alpha = I\frac{a}{r} = I\frac{2h}{t^2 r}$$

$$\Rightarrow \qquad W = \frac{2hI}{t^2 r^2}, \text{ so that}$$

$$\Rightarrow \qquad W = Kt^{-2} \text{ where } K = \frac{2hI}{r^2} \qquad \text{………………………..(5.2)}$$

K is a constant

Method I

1. Cut a length of cord just sufficient to allow the falling mass to reach the floor. Knot one end and thread the cord through the small hole in the spindle. Attach the free and to the weight carrier (W).

2. Rotate the spindle thus winding on the cord, ensuring that the adjacent turns are evenly arranged. Use a metre stick to check when the bottom of the carrier is exactly one metre from the floor.
3. Release the inertia bar and start the stopwatch simultaneously. Stop the watch when the weight strikes the floor. Note the time t and return the weight to its former height by winding in the same direction as before.
4. Repeat the process with five or six different weights (W). Use worksheet 5-1 to record your readings

5. Plot a graph W against I/t^2

Theory II

$I = Mk$ (to be demonstrated)

where M is the mass on the bar and k is the radius of gyration.

From Equation 5.1, $T = I\alpha$

$$\Rightarrow \qquad \alpha = \frac{T}{I} = \frac{Wr}{Mk}$$

But from equation 5.2, $W = \dfrac{2hI}{t^2 r^2}$, Therefore

$$\Rightarrow \qquad \alpha = \frac{Wr}{Mk} = \frac{a}{r} = \frac{2h}{t^2 r} \qquad \text{...(5.3)}$$

h, r, W, and M are constants; therefore $1/t^2$ is proportional to $1/k$.

Method II

(In general the same as for Method I)

1. Using a fixed weight by varying the position of the masses, M, from the center, obtain a set of values of time of fall, t, for each value of k, the distance of the mass, M, from the centre.
2. Plot a graph of t^2 against k.

Results

Worksheet 5-1

Weight W ± ……..(N)	Time (t) ± ……..(s)	t^2 ±……(s)	$1/t^2$ ±……(s^{-1})

Worksheet 5-2

Time (t) ± ……..(s)	t^2 ±……(s)	Distamce k ±……

Analysis

1. Plot a graph of W against $1/t^2$ including error bars on both W and $1/t^2$
2. Plot a graph of t^2 against k including error bars on t^2.
3. Comment on your two graphs and state whether or not the objectives of the experiments have been achieved.
4. Assume no error in W. What other errors are found in this experiment?

Conclusions

Write suitable conclusion reflecting the objectives

PROPERTIES OF MATTER

<u>Experiment B-6: Young's Modulus of Elasticity</u>

In this experiment, you are going to determine the Young's modulus of a wire

Objectives

To determine Young's modulus (E) for a wire

Apparatus

Two long wires of the material *X* and *Y* suspended side by side from the same support. The ends of the two wires are attached to frames connected by a spirit level *S*, one end of which rests on a screw *C* operated by a graduated wheel *B*. The movement of *B* can be measured as a fixed scale graduated in mm. The heavy weight *W* and the initial loading *L* ensures that the wires are taut and free from kinks. The overall arrangement (due to C.F. Searle) avoids any errors due to temperature changes or yielding of the support.

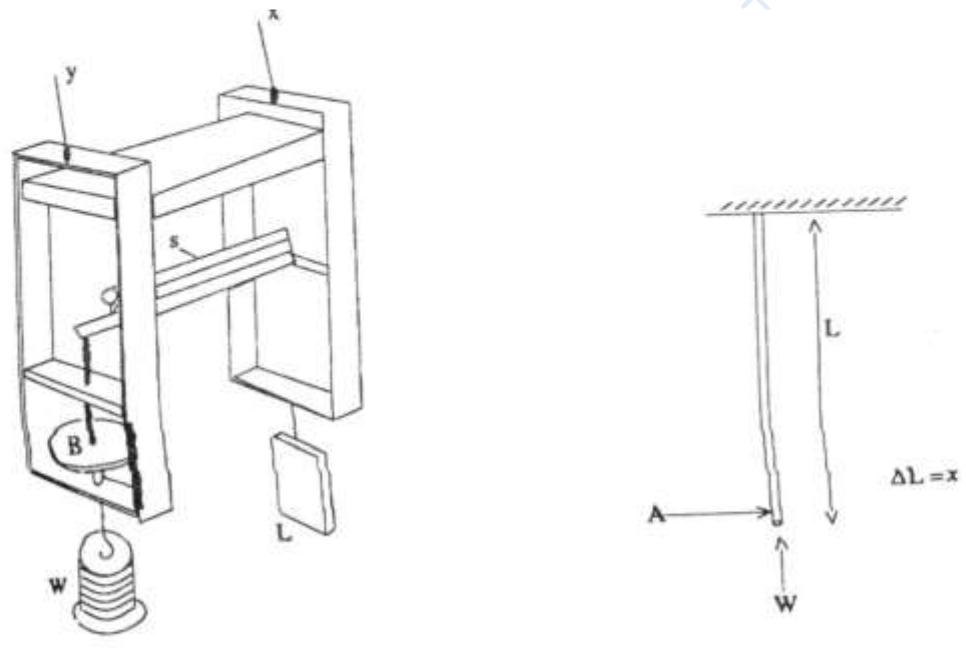


Fig. 6-1.

Theory

Elasticity is the property of a material by virtue to which deformation caused by applied load disappears upon the removal of the load. Within the elastic limit, Hook's law is obeyed i.e.,

$$E = \frac{Stress\ (\sigma)}{Strain\ (\varepsilon)} \qquad \text{……………………………………(6.1)}$$

where E is the Young's modulus, .

But $\sigma = \dfrac{Applied\ Force}{Cross\ sectional\ Area}$ and $\varepsilon = \dfrac{Change\ in\ Length}{Original\ Length}$.

Thus in terms of material parameters, E can be written as

$$E = \frac{Stress}{Strain} = \frac{(Mg/A)}{(x/L)} = \left(\frac{MgL}{\pi \frac{d^2}{4} x}\right) Nm^{-2}$$

Or $$E = \frac{MgL}{Ax} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (6.2)$$

where A is the cross-sectional area of the wire $\left(A = \dfrac{\pi d^2}{4}\right)$.

Therefore, E can be determined from measurements of Mg (=*Weight*, W) and x.

where M = mass hanging on wire
g = acceleration due to gravity
d = diameter of wire
W = weight (in newtons)
L = Original length of wirein metres
A = cross sectional area of wire in metres squared
x = extension, metres

***NOTE**: Equation 6.2 applies only within the elastic region up to the limit of proportionality.*

Method

1. Measure the 'original' length of the test wire Y using a metre rule.

2. Measure the diameter of the wire using a micrometer screw gauge. Take readings at several points along the length of the wire and then calculate the mean diameter.

3. With the initial load in place, adjust the spirit level by means of the wheel B so that it is horizontal. Note the reading on the scale.

4. Add an extending load to the pan in steps up to a maximum total load of 3.5kg. After each step, adjust the spirit level so that it is horizontal and take the readings at each step as before. Use worksheet 6 to record your readings

5. Remove the load step by step, and record the scale readings at each step as before.

Results

Readings

Original length of wire L = ………….. ± m

Original Diameter of wire = …………… ± m

Mean diameter = ………… ± m

Initial reading of scale A = ……….. ±

Worksheet 6

Extending load, W = mg (kg)	W (N)	Scale A Reading			
		Loading	Unloading	Mean	Extension, x (m)

Analysis

1. Plot a graph of extending load, W (in newtons) versus extension, x (in metres). The graph should be a straight line possibly through the origin. The slope of the graph is $\frac{EA}{L}$ where A is the cross-sectional area of the wire.

2. From your graph, calculate the slope of the graph (=EA/L) and the cross-sectional area of the wire.
3. From the value of the slope, determine the value of Young's modulus and the error in your value.

   Error in calculation (i.e. error in E = (% error in L) + 2 (% error in d) + (% error in slope)

6. Comment on your value and the error.

7. Answer the following Questions

Questions

(a) Why is it acceptable to use a metre rule to measure L, while a micrometer screw is used to measure d?

(b) What is the yield strength?

Discussions

Compare the calculated value of *E* with the accepted value for the material of the wire and comment. The accepted value of E can be obtained from relevant textbooks.

Conclusions

Write suitable conclusion reflecting the objectives

Experiment B-7: Viscosity

Introduction

When a fluid flows through a pipe or conduit, the layers of the fluid adjacent to the walls stick to the walls thereby causing a viscous drag between these layers and the adjacent layers of the fluid. This tends to stop the flow of the fluid.

The property by virtue of which a liquid opposes relative motion between its different layers is called viscosity. By definition, *Viscosity is the internal friction in a fluid or it is the stickiness within the fluid that offers resistance to its flow*. For instance, honey is a fluid of high viscosity, whereas water is a fluid of fairly low viscosity. Viscous friction (viscosity) increases with speed of flow. A perfect fluid is one in which there is no internal friction within the fluid. In this experiment, you are going to measure the viscosity of water.

Objective

To measure the coefficient of viscosity of water.

Apparatus

Aspirator, length of capillary tubing, stop watch, thermometer, beaker

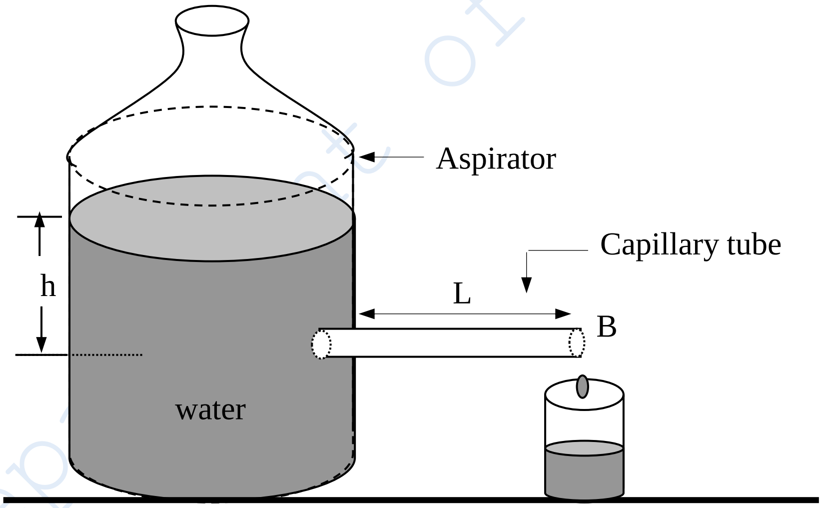


Fig. 7-1

Theory

For a real (viscous) fluid flowing in a a long horizontal pipe, it will gradually slow down and stop due to frictional resistance generated by viscous forces. To keep a real fluid flowing, a pressure difference between the ends of the pipe must be provided so that the excess pressure at the upstream pushes the fluid along and overcomes the frictional resistance.

According to ***Poiseuille's equation***, the pressure difference($\Delta P = P_1 - P_2$) required to maintain the flow along a tube is proportional to the coefficient of viscosity (η), the length of pipe (L) and the rate of flow or delivery (Q) and inversely proportional to the fourth power of the radius (r) of the tube.

$$\Delta P = \frac{8L\eta}{\pi r^4} Q \qquad \text{.....................................} \quad \text{....(8.1)}$$

where

Q = volume of water flowing per second through the tube of length L and radius r.

But the pressure difference ΔP between the ends of the tube is also given by

$$\Delta P = g\rho h \qquad \text{...(8.2)}$$

where
- g = acceleration due to gravity
- ρ = density of the fluid
- h = height in metres

Take Note

The dependence on r^4 implies that for the same rate of delivery, a much larger pressure difference is required to push a viscous fluid through a small pipe than through a large one.

Method

1. Set up the apparatus as shown in Fig 7-1.

2. Adjust the rate of flow through the capillary tube so that water emerges slowly in drops from B. Smear a little Vaseline under the end B to prevent water running along the outside of the tube.

3. Weigh a clean dry beaker and record its mass.

4. Time the collection of about 50ml of water and reweigh the beaker plus water. Record this as the second scale reading in worksheet 7.

5. Repeat the water collection several times, and note the room temperature each time. Use Table 7 to record your readings.

6. Measure the length (L) of the capillary tube. Measure the diameter (d) of the capillary tube using the travelling microscope. Remember to level the microscope before use. A separate capillary tube is provided for this purpose. Do not remove the one fixed to the aspirator.

7. Fill the data into the tables provided and calculated the coefficient of viscosity of water.

Worksheet 7

First scale reading (= initial Mass of beaker plus water (kg))	Second scale reading (= Final Mass of beaker plus water (kg))	Difference = Mass of water (kg)	Room Temp (^oC)	Time (s)	

Mass of beaker =………….. Length of capillary tube = …………..

NB. Volume flow per second, Q (kg/m^3s) = (mass of water)/time

Traveling microscope measurement: (To find the internal radius of capillary tube).

Average diameter = Radius =

Error in scale of microscope = Error in radius =

Density of liquid (water) =

Height, h =

Analysis

1. From the data, calculate the coefficient of viscosity (η) for each volume of water (Q) timed.

2. Calculate the average coefficient of viscosity

3. What are the units of viscosity? Derive this by balancing the units

4. Now calculate the error in your value of viscosity using one set of data.

Discussions

What is the accepted value for the coefficient of viscosity of water at room temperature? Is your value within experimental error of this accepted value? If not, Why? *Note: The standard value of the coefficient of viscosity can be obtained from relevant textbooks.*

How does the coefficient of viscosity vary with temperature? Why?

Answer the following Questions

Activity

1. Explain why a slight buildup of plaque in the arteries may cause high blood pressure due to overwoking the heart. [HINT: see Equation 8.1]

2. Explain the old saying that blood is thicker than water. [HINT: η_{H_2O} = 1.1 x 10^{-3} N s m^{-2} and η_{blood} = 2.1 x 10^{-3} *N s* m^{-2}.]

Conclusions

Write suitable conclusion reflecting the objectives

HEAT
<u>Experiment C-8: Linear Expansion</u>

When a material (e.g. metal) is heated, it increases in length. *The change in size of materials when subjected to heat is called thermal expansion.* In this experiment, you are going to measure the coefficient of linear expansion of copper

Objectives
To measure the coefficient of linear expansion of copper.

Apparatus (see Fig.8-1 below)

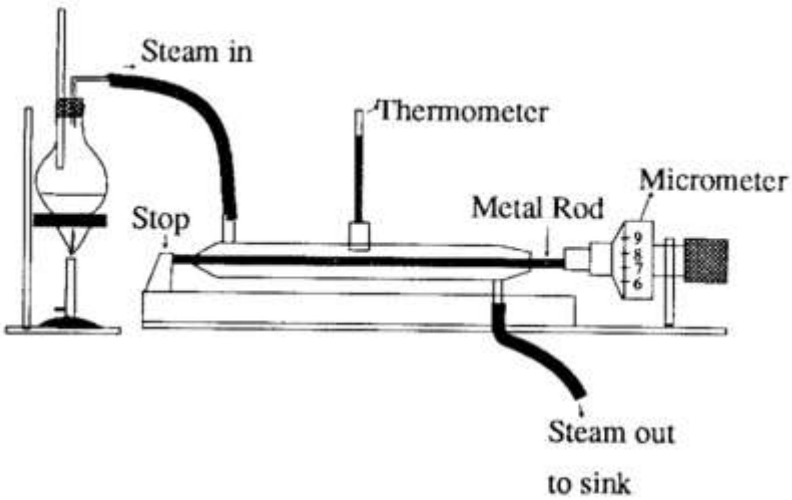


Fig.8-1.

Theory

If a solid bar of metal is heated, the increase in length ΔL of the material is directly proportional to the increase in temperature ΔT and to the original length (L_1) of the material. i.e.

$$\Delta L = \alpha L_1 \Delta T$$

where α is the average coefficient of linear expansion of the metal over the temperature range.

But $\Delta L = L_2 - L_1$ and $\Delta T = T_2 - T_1$ where L_1 is the length of the bar at temperature T_1 °C and L_2 is its length at temperature T_2 °C. Thus

$$L_2 - L_1 = \alpha L_1 (T_2 - T_1)$$

Making α the subject of the formula, we have

$$\alpha = \frac{L_2 - L_1}{L_1(T_2 - T_1)} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(1)$$

Method

1. Remove the bar of metal from the steam jacket and measure its length L_1, and temperature T_1

2. Replace the bar in its steam jacket and adjust the micrometer until it just tips the end of the bar. Record the micrometer reading E_1. Repeat this measurement three times to obtain an average value.

3. Reset the micrometer back from the end of the bar to allow room for expansion of the bar.
4. Heat the water in the flask and allow steam to flow around the bar until the expansion is complete. This will take 10 to 15 minutes.
5. With steam still passing through the jacket record the new reading E_2 on the micrometer (repeat this reading 3 times) and temperature of the steam T_2.

Results

Worksheet 8

	Readings			***Error***	***unit***
Initial length of bar, L_1					
Initial temperature of bar, T_1					
Final temperature of bar, T_2					
Initial micrometer setting, E_1					
Final micrometer setting, E_2					

Analysis

1. Using equation (1) Calculate the coefficient of linear expansion of the copper and the error in the value.

   Average E_1 =

   Average E_2 =

   Expansion of bar = E_2 - E_1 = ΔL = $(L_2 - L_1)$ =

   Error in expansion of bar =

Temperature difference $T_2 - T_1$ =

Error in temperature difference =

2. Substitute the values into the equation for the coefficient of expansion. $\alpha = \dfrac{L_2 - L_1}{L_1(T_2 - T_1)}$

   and calculate α

3. Calculate the error in the value of α where

$$\frac{\Delta\alpha}{\alpha} = \frac{\Delta Expansion}{Expansion}.$$

This gives the fractional error.

Questions

1. What would happen if the micrometer screw gauge was not reset back from the end of the bar.

2. Why is it necessary to measure the expansion with a micrometer screw gauge, whereas the initial length of the bar can be measured with a meter rule?

Discussions

Compare your value of α with the standard value, which may be found from relevant textbooks and comment

Conclusions

Write suitable conclusion reflecting the objectives

Experiment C-9: Specific Heat Capacity by the Method of Mixtures

Specific heat is the quantity of heat required to raise the temperature of 1Kg of a material by 1^{o}C. In this experiment you are going to determine the specific heat capacity of Zinc.

Objectives

To determine the specific heat capacity of zinc by the method of mixtures.

Apparatus

Thermometer, zinc, copper calorimeter with insulating jacket, cold water, bunsen burner, beaker, cotton wool, tripod, gauze, chemical balance.

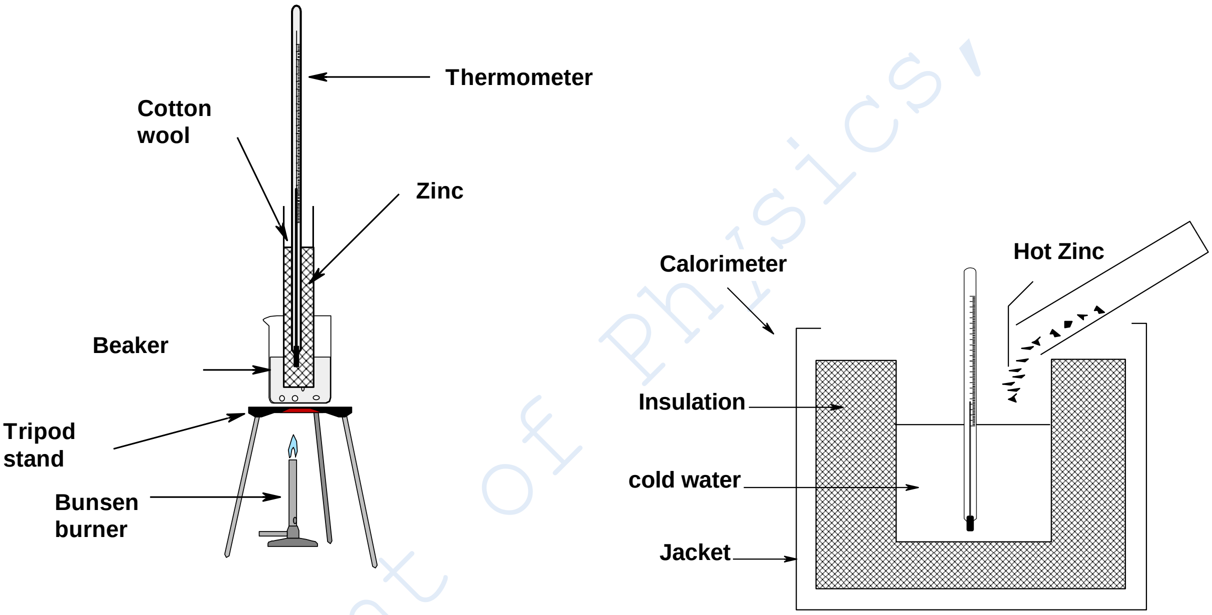


Fig. 9-1

Theory

The specific heat capacity (C) of a material is given by the relation

$$c = \frac{\text{Quantity of heat (Q)}}{\text{Mass (m)} \times \text{temperature rise } (\theta)} = \frac{Q}{m\theta} \qquad (\text{J kg}^{-1}\ \text{K}^{-1}) \qquad \ldots\ldots\ldots\ldots.(9.1)$$

If hot zinc is added to cold water in a calorimeter, which is insulated, then from equation (9.1) we see that:

Heat (Q) gained by water and calorimeter = Heat (Q) lost by the zinc particles i.e.,

$$(M_w C_w + M_c C_c)(T_2 - T_1) = M_{zn} C_{zn} (T_3 - T_2) \qquad \ldots\ldots\ldots\ldots.(9.2)$$

where M_w = mass of water
C_w = specific heat of water

M_c = mass of calorimeter

T_2 = final temperature of mixture

C_c = specific heat of calorimeter

T_1 = initial temperature of water

M_{zn} = mass of zinc

C_{zn} = specific heat of zinc

T_3 = temperature of hot zinc

Thus Equation (9.2) can be used to find the specific heat capacity of Zinc (C_{zn}) if the other parameters are known.

Method

1. Setup the apparatus as shown in Fig. 9-1. Put the thermometer into the boiling tube and put as much zinc as possible around the thermometer. Place some cotton wool on top .

2. Place the boiling tube in a beaker of water and heat to boil. Keep the water boiling for at least five minutes.

3. Meanwhile, weigh the calorimeter empty and record its mass (M_c) then add about 1/3 full of water and record the new mass (M_1).

4. Replace the calorimeter in its jacket. Record the temperature (T_1) of the water. Record the temperature of the hot zinc, (T_3).

5. Remove the cotton wool and the thermometer from the boiling tube, and immediately pour the zinc into the calorimeter. Stir the contents of the calorimeter and record the highest temperature (T_2) reached. Remove the thermometer.

6. Weigh the calorimeter and its contents and record this as mass M_2. Record the data in the work sheet and evaluate the specific heat capacity of zinc.

Results

Worksheet 9

	Reading	Reading Error (±)	units
Mass of Calorimeter, M_c			
Mass of Calorimeter + cold water, M_1			
Temperature of cold water, T_1			
Temperature of hot Zinc, T_3			
Temperature of mixture, T_2			
Mass of Calorimeter, water + Zinc, M_2			

Analysis

	Value	Error	Unit
Mass of cold water $M_w = M_1 - M_c$			
Mass of Zinc $M_{zn} = M_2 - M_1$			
Increase in temperature water and calorimeter $(T_2 - T_1)$			
Decrease in temperature of zinc $(T_3 - T_2)$			

Specific heat capacity of water = 4186 J/kg deg C
Specific heat capacity of copper = 380 J/kg deg C

1. Using these values, calculate the specific heat capacity of zinc.

2. Calculate the error in the specific heat of Zinc.

Questions

1. What are the sources of error in this experiment?
2. Why is water the medium used in so many heat exchange processes?

Discussions

Compare and contrast the specific heat for zinc obtained in this experiment with the standard value. You can get the standard value for the specific heat capacity of zinc from relevant textbooks or from Tables of Physical Constants.

Conclusions

Write suitable conclusion reflecting the objectives

Experiment C-10: Thermal Conductivity – Searle's Bar

Introduction

The thermal conductivity of a material is the rate of flow of heat through the material per unit area per unit temperature gradient. In this experiment, you will determine the thermal conductivity of copper.

Objectives

To measure the thermal conductivity coefficient of copper using Searle's apparatus.

Apparatus

AB is a solid copper bar, which is heated at end A by steam. At end B, a coil carrying water is wrapped around the bar. Thermometers T_1, T_2, T_3 and T_4 are inserted. The apparatus is well lagged and is enclosed in a wooden box.

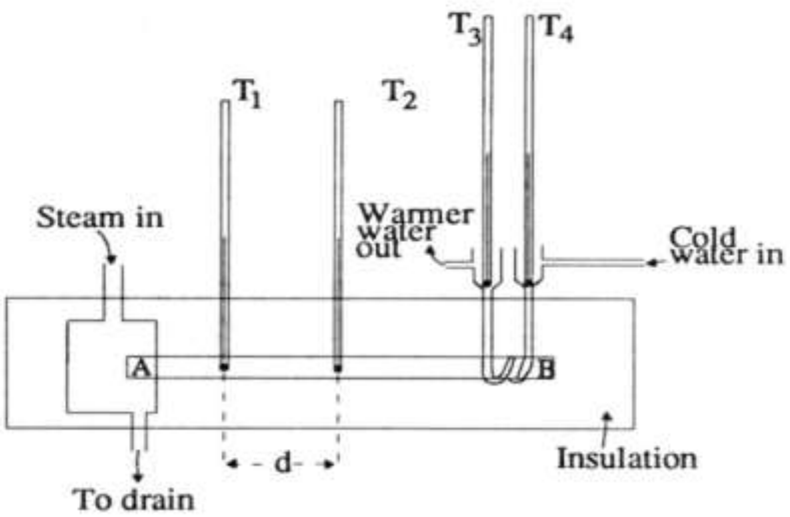


Fig. 10.

Theory

Consider a copper rod AB heated at end A by steam while end B is maintained at a lower temperature by passing cold water. If the temperature difference between the ends of the bar is δT (= T_2-T_1), then the rate of heat flow (Q/t) by conduction along the copper rod is given by:

$$\frac{Q}{t} = KA\frac{(T_1 - T_2)}{d} \tag{1}$$

where K = coefficient of thermal conductivity

A = cross sectional area of bar

$\frac{T_1 - T_2}{d}$ = temperature gradient

If it is assumed that the rate of heat transfer along the bar is constant, this rate is equal to the rate of gain of heat by the water at end B, i.e.,

$$\frac{Q}{t} = \frac{m}{t} C(T_3 - T_4) \qquad (2)$$

where m = mass of water flowing through the coil at B in t seconds.
C = specific heat of water
T_3 = temperature of output water
T_4 = temperature of input water

Combining Q/t from equations (1) and (2), K can be evaluated from the equation

$$KA\frac{(T_1 - T_2)}{d} = \frac{m}{t} C.(T_3 - T_4)$$

$$\Rightarrow \qquad K = \frac{mCd}{t} \frac{(T_3 - T_4)}{(T_1 - T_2)} \qquad (3)$$

Method

1. Take several readings of the diameter of the copper bar using the vernier calipers provided. Record all readings and get their average.

2. Measure and record the distance d between the thermometers T_1 and T_2

3. Close up the wooden box and heat the water in the steam generator.

4. Adjust the constant head device to give a small rate of flow of water through the coil at the end B. Loosen thermometers T_3 and T_4 momentarily to eliminate the air pockets in the water jacket, then insert the stoppers securely so that there are no leaks.

5. While the steam is circulating around end A, record temperatures T_1, T_2, T_3 and T_4 every five minutes. The purpose of these readings is to enable you to ascertain easily when the steady state has been reached, i.e. that none of the temperatures is changing with time.

6. When this state has been reached, the temperature difference between T_3 and T_4 should be about 10^{o}C. Adjust the water flow if necessary.

7. Then record the mass of water collected from exit B in a beaker during a time of five minutes. If marked fluctuations appear in any of the temperatures during water collection, repeat this reading and take an average.

8. Record all data in worksheet 10-1 and 10-2. Calculate the value of K, and estimate its error.

Results

Worksheet 10-1

	Reading	Average Reading	Error in Reading(±)	units
Bar diameter				
Cross section area of bar, *A*				
Distance (d) between thermometer T_1 and T_2				
Mass of water collected in 15 minutes				
Average mass of water per second (m/s)				

Analysis

Worksheet 10-2

Time, mins	$T_1\,^{o}C$	$T_2\,^{o}C$	$T_3\,^{o}C$	$T_4\,^{o}C$

1. Identify the steady state conditions
2. Calculate the value of K and the error in this value

Questions

1. Explain why this method is not a good one for poor thermal conductors
2. Due you think that the accuracy of the experiment would be improved if a bar of larger diameter was used?

Discussions

By what percentage does your value of K deviate from the standard value of K for copper? You can get the standard value of K from relevant textbooks or from Tables of Physical Constants.

Conclusions

Write suitable conclusion reflecting the objectives

Experiment C-11: Newton's Law Of Cooling

Introduction

Newton's law of cooling states that in conditions of forced convection (i.e. a draught), the rate of heat loss from a body is directly proportional to the excess temperature of the body over that of its surroundings. Newton's law of cooling is an approximation, which can be used only when a body cannot surround itself with a layer of warm air, i.e. in conditions of force convection. In still air, the approximation can still be used provided that temperature differences do not exceed about 30K. We use the law to predict heat losses of a body at various temperatures so that we can design suitable heating systems or make corrections for any losses which may occur during measurements of heat.

Objectives

To investigate Newton's law of cooling.

Apparatus

Bunsen burner, tripod, gauze, beakers, thermometer, stopwatch.

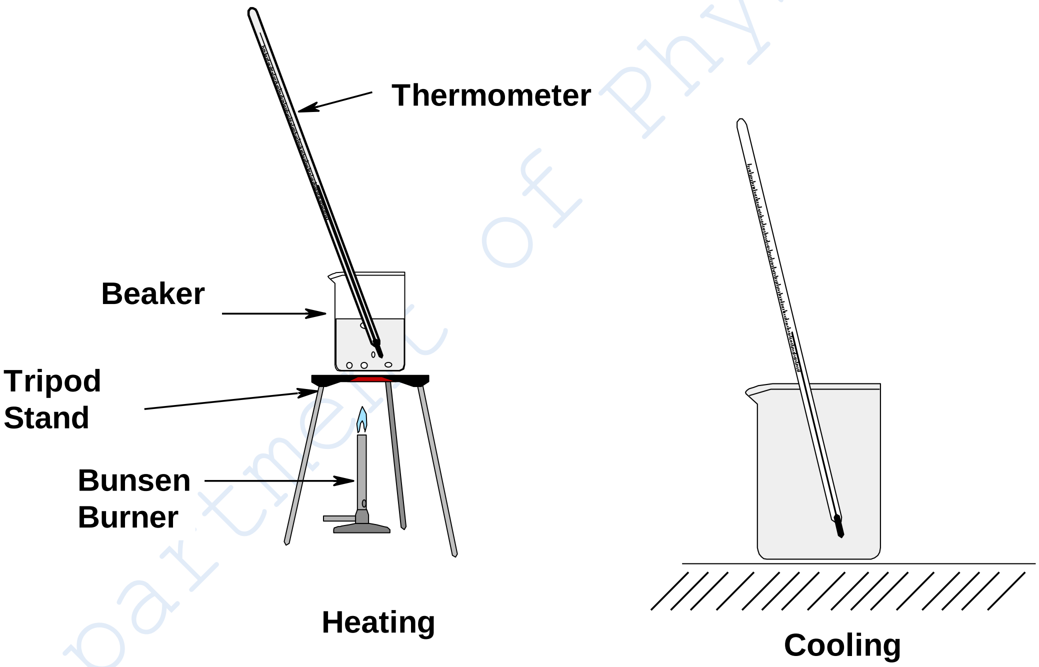


Figure 11-1

Theory

Newton's law of cooling states that in conditions of forced convection (i.e. a draught), the rate of heat loss from a body is directly proportional to the excess temperature of the body over that of its surroundings.

To obtain the rate of cooling, we first plot a cooling curve as shown in Fig 11.2(a). The rate of cooling at any instant is then given by the corresponding slope, j, of the curve. This rate of cooling j is proportional to the excess temperature (θ) at that instant as shown in Fig 11-2(b) i.e,

$$j_1 \propto \theta_1; j_2 \propto \theta_2; etc.$$

or in general,

$$j = k\theta \qquad \text{...(11.1)}$$

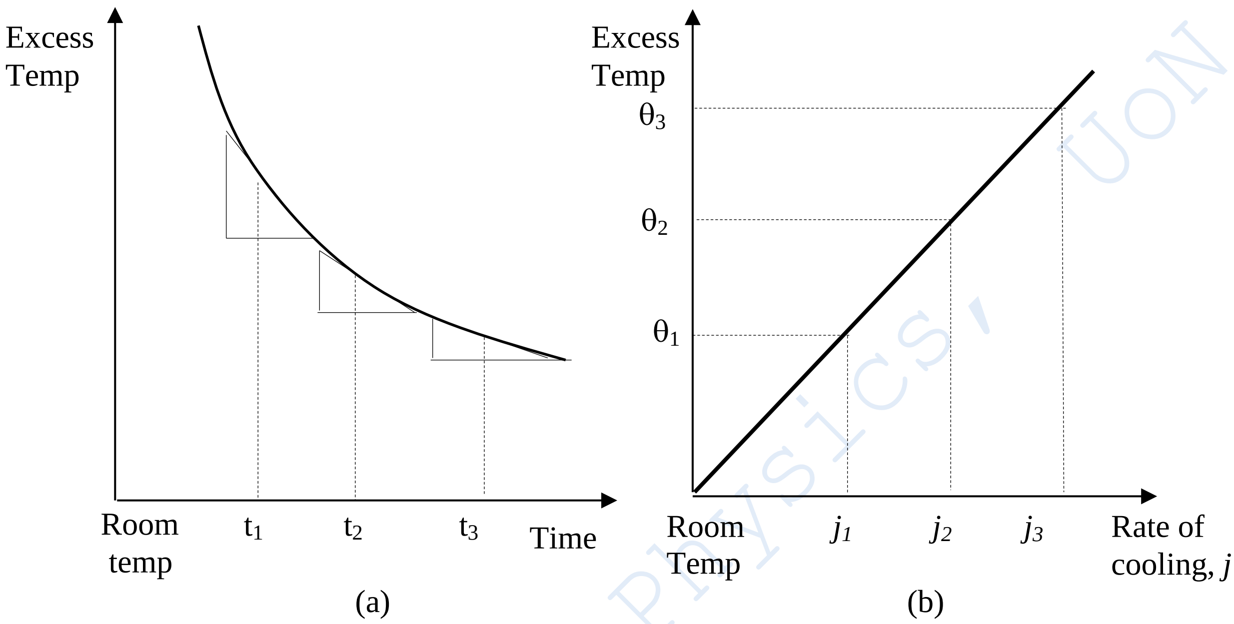


Figure 11-2

Method

1. Heat the liquid to temperature close to 60^{o}C as shown in Fig 11.1. and thereafter withdraw the source of heat from the liquid.

2. Record the temperature of the liquid every minute, until the temperature reaches about 35^{o}C

Results

Worksheet 11

Room temperature = …………………..

Temperature (^{o}C)	Time (min)	Temperature (^{o}C)	Time (min)	Temperature (^{o}C)	Time (min)

Analysis

1. Plot a graph using all the data of excess temperature versus time. The excess temperature is obtained by subtracting the room temperature from a given temperature.

2. From the graph, determine the rate of cooling *j*, at particular instances of time

Temperature (^{o}C)	Temperature Excess (^{o}C)	Slope, j^{o}C/min

3. Plot a graph of temperature excess against rate of cooling, *j*.

Discussions

Comment on your results.

Conclusions

Write suitable conclusion reflecting the objectives.

Experiment C-12: Boyle’s Law

Introduction
Boyle's Law is a fundamental principle in physics that describes the relationship between the pressure and volume of a gas at constant temperature. This experiment aims to verify Boyle's Law using standard laboratory apparatus.

Objectives

1. To verify Boyle’s law
2. To determine atmospheric pressure graphically

Apparatus

Standard Boyle’s law apparatus with a volume of air enclosed in a length of tube. The Pressure is supplied by a mechanical pump or a compressed air source in the lab.

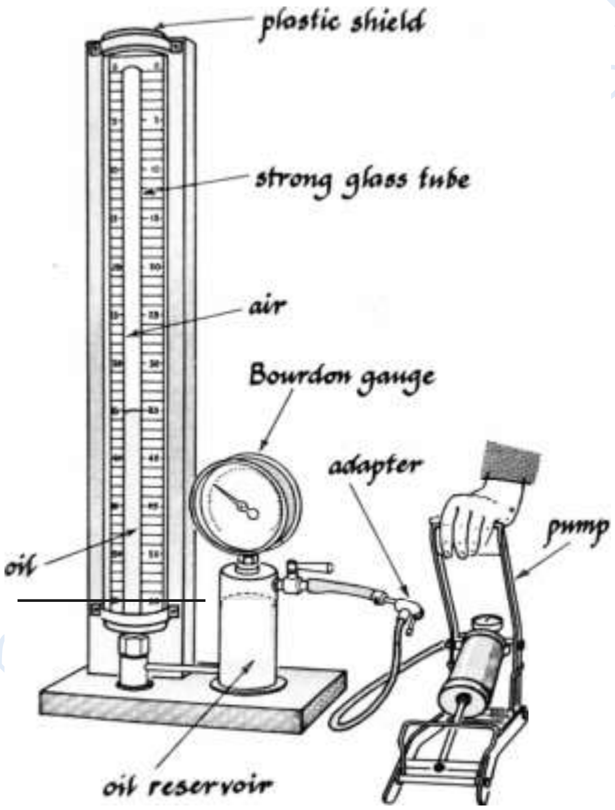


Figure 12-1. Boyles apparatus

Theory

Boyle's Law states that for a given mass of an ideal gas at constant temperature, the volume of the gas is inversely proportional to its pressure. Mathematically, this relationship is expressed as:

$P \propto \frac{1}{V}$ or $PV=k$ (at constant temperature)

where P is the pressure, V is the volume, and k is a constant of proportionality.

Procedure

1. Connect the mechanical pump to the pressure gauge. Ensure there are no leaks in the system.
2. Pump air into the apparatus until the reading on the pressure gauge is 3 x 10^{-5} N/m^2.
3. Upon attaining the pressure is step 2 above, lock the needle valve/tap to keep the system air-tight.
4. Record the value of volume of the fixed mass of air enclosed above the oil against the pressure reading on the pressure gauge.
5. Open the needle valve slowly and carefully reduce the pressure in the system by 0.1 x 10^{-5} N/m^2.
6. Repeat steps 4 and 5, until the pressure gauge reading of the system is at minimum.

Results.

Reading error from the volume =

Reading error from the Pressure gauge =

Room Temperature=

Worksheet 12.

Pressure (N/m^2)	Volume (cm^3)	1/V (m^{-3})	Pressure (N/m^2)(cont'd)	Volume (cm^3) (cont'd)	1/V (m^{-3})

Analysis.

Boyle's law verifies the inverse proportionality of volume and pressure. Volume and pressure being proportional a graph from the two should satisfy the general relation ***y = mx + c*** .

Volume and Pressure being inversely proportional a general curve of the two should be a negative gradient slope and Pressure against volume reciprocal a positive gradient slope.

- Plot a graph of P versus $\frac{1}{V}$.
- Comment on your graph.
- Determine the intercept on y-axis and hence the atmospheric pressure

Discussions

1. Based on your graph and calculations, does your data support Boyle's Law?
2. Discuss any sources of error in the experiment and their potential impact on your results.
3. How would changes in temperature affect the results of this experiment?
4. Explain how Boyle's Law applies to real-world situations, such as in the behaviour of the human lungs or in industrial gas storage.

Conclusion

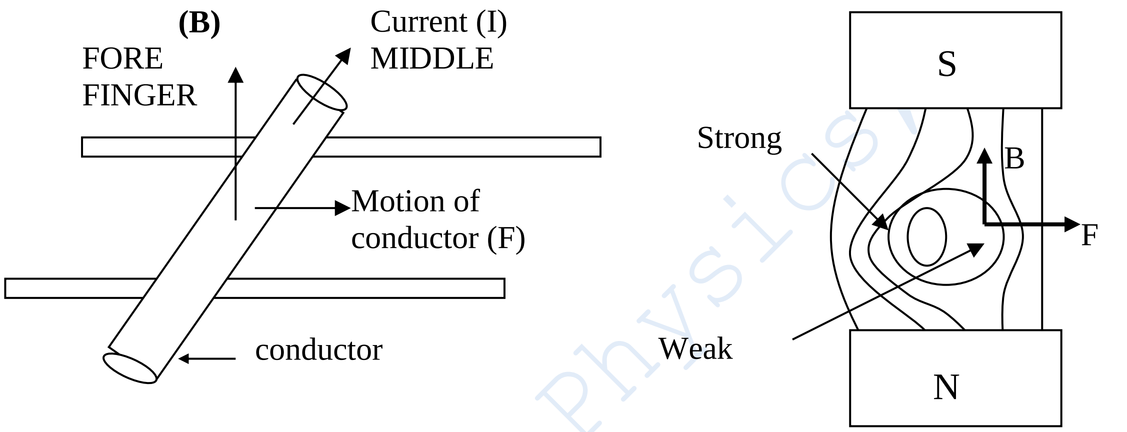
Write a suitable conclusion reflecting the objective of this experiment.

WAVE MOTION

Experiment *D-14:* Standing Waves in a Taut String

Introduction

When a current carrying conductor is placed in a magnetic field (Fig. 14-1), it experiences a magnetic force (***Lorentz force***) and this force is such as to move the conductor from the region of stronger magnetic field to that of weaker magnetic field as shown in Fig. 13-1(b) according to *The Left Hand Rule*. If an *ac* current is used, the conductor (wire) will vibrate between the pole-pieces of a strong magnet setting up standing waves. Why is this so?



(a) Magnetic force on a conductor (b) The field around the conductor

Figure 14-1

In this experiment, you will set up standing waves in a string carrying an **ac** current and study the harmonics of the string.

Objectives

To study the relationship between resonant frequency and the tension in a taut string.

Apparatus

A thin wire of mass per unit length *m*, set up as shown, with an electrically driven vibrator and a set of weights, horse-shoe magnet, balance, signal generator.

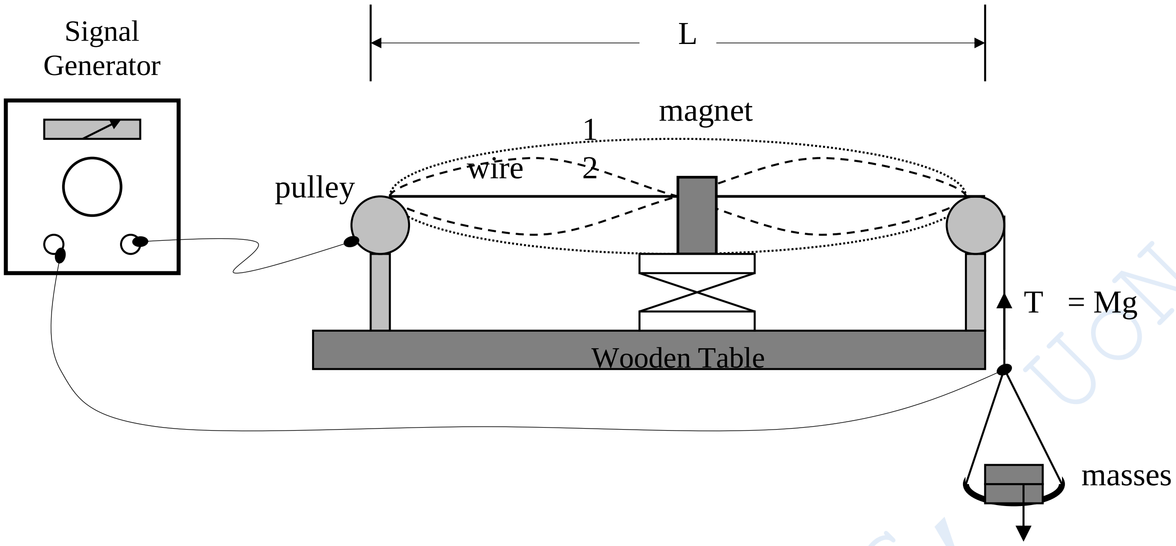
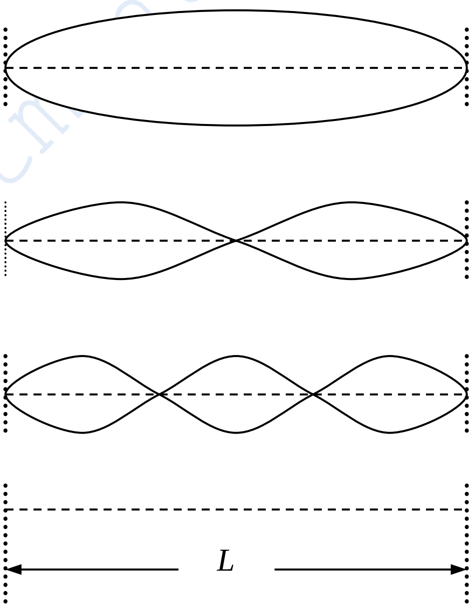


Figure 14-2

Theory

For a string carrying an alternating current of variable frequency and located between the pole-pieces of a strong magnet, it can be maintained in vibration by bringing it into resonance with an external harmonic force (the ***Lorentz force***).

When the applied frequency of *ac* current is equal to a natural frequency of the string, then under constant tension, the string will resonate in one of its modes of vibration as shown below.



Fundamental (1st Harmonic): $\lambda_1 = 2L;\quad f_1 = \dfrac{V}{\lambda_1} = \dfrac{1}{2L}\sqrt{\dfrac{T}{m}}$

2nd Harmonic (1st Overtone): $\lambda_2 = \dfrac{2L}{2};\quad f_2 = \dfrac{2}{2L}\sqrt{\dfrac{T}{m}}$

3rd Harmonic: $\lambda_3 = \dfrac{2L}{3};\quad f_3 = \dfrac{3}{2L}\sqrt{\dfrac{T}{m}}$

Nth Harmonic: $\lambda_n = \dfrac{2L}{n};\quad f_n = \dfrac{n}{2L}\sqrt{\dfrac{T}{m}}$

Figure 13: Modes of vibration in a fixed wire/string

where λ is the wavelength of the wave and *L* is the length of the string, *T* is the tension in the string and *m* is its mass per unit length.

Since $T = Mg$ (weight of the masses), then

$$f_n = \frac{n}{2L}\sqrt{\frac{Mg}{m}} \qquad \text{..................................(1)}$$

For the first harmonic, $f_1 = \frac{1}{2L}\sqrt{\frac{Mg}{m}}$ Or $f_1^2 = \frac{1}{4L^2}\cdot\frac{Mg}{m}$

$$\Rightarrow \qquad f_1^2 = \left(\frac{g}{4L^2 m}\right).M \qquad \text{......................................(2)}$$

Hence, if a graph of f_1^2 against *M* is plotted, a straight line should result of slope $\frac{g}{4L^2 m}$ from which *m* can be determined.

Method

1. Set up the apparatus as shown in Fig. 14-2. Length L should be between 1.0 and 1.5 m. *Note: that the position of the magnet is not very critical as long as it is not located at a node preferably it is to be located at an anti-node.*

2. Use a sample of wire to measure *m.*
3. *Attach a* mass of 150 g at the end of the string (or on the pan)

4. *Switch on t*he signal generator and vary the frequency (*f*) slowly from zero Hz. When the string vibrates clearly, in its first harmonic, note the corresponding value of *f i.e.,* (f_1).

5. With the same mass, increase the frequency (*f*) to roughly twice this value and observe the second harmonic. Note the new value of *f*, (f_2).

6. Where possible, observe and record the frequencies of higher harmonics, f_n.

7. Increase the mass and repeat steps 4 – 6 for a range of values of M. Tabulate your data in worksheet 14.

Take Note

Unwanted resonances originating in the vibrator itself may be observed. Be careful that the frequency readings refer to a consistent set of harmonics.

Results

Length of sample of wire =

Mass of wire sample =

Mass per unit length ,*m*, of the wire =

N.B. Remember to give the error in each value.

Worksheet 14

M (kg)	f_1 (Hz)	f_2 (Hz)	f_3 (Hz)	f_1^2 (Hz^2)

Analysis

1. Plot a graph of f_1^2 against M, indicating error bars on f_1^2.

   Note. Since the tension (T) is the sum of the weight of masses on the pan (Load = Mg) plus the weight of the pan (M_pg) i.e., $T = Mg + M_pg$ *the* graph may not pass through the origin.
2. Calculate the slope of the graph.

3. From the slope of the graph, calculate the value for m and compare this with the measured value.

Questions

1. Are the two value of *m* within experiments error? Show by calculation.

2. How are the frequencies of the overtones related to that of the fundamental frequency? Does your data confirms this?

3. Give two examples of resonance which are of practical importance.

Discussions

Comment on the relationship between the resonant frequency and the tension in a taut string.

Conclusions

Write suitable conclusion reflecting the objectives

OPTICS

Experiment E-15: Laws of Reflection

Introduction

In this experiment, you are going to very the laws of refraction using a plane mirror and verify the general relationship for spherical mirrors.

Objectives

1. To verify the laws of the reflection
2. To investigation some properties of spherical mirrors.

PART A: PLANE MIRROR

Apparatus

Plane mirror, pins, drawing board and paper.

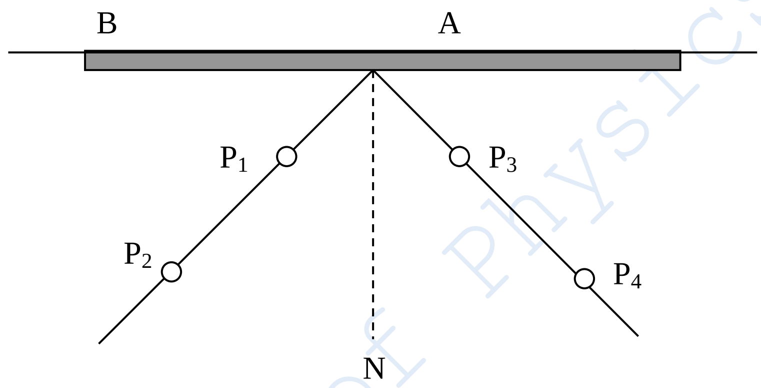


Figure 15-1

Theory

Laws of Reflection

The incident ray, the reflected ray and the normal, at the point of incidence, all lie in the same plane.

The angle of incidence is equal to the angle of reflection.

Method

1. Place the mirror along a line BC which is drawn on a paper placed on the drawing board.

2. Insert pins P_1 and P_2 into the drawing table. Look in the direction P_3 and P_4 until pins P_1 and P_2 are seen in the same line.

3. Insert pins P_3 and P_4 into the drawing board in line with the images of P_1 and P_2 such that when looking into the mirror all the four pins appear to lie in line.

4. Draw a line on the drawing board to mark the reflecting surface of the mirror.

5. Remove the mirror and pins from the paper. Draw AN (the normal) perpendicular to BAC. Join points P_3 and P_4, and P_1 and P_2 and extend the lines to point A.

6. Join points P_1 and P_2 and points P_3 and P_4 respectively and extend the lines to point A.

7. Measure the angles of incidence and reflection. Use worksheet 15-1 to record your data

Results

Worksheet 15-1: Plane Mirror

	Angle	Error
Angle of incidence, i		
Angle of reflection, r		

N.B. *Hand in original ray diagrams*

Analysis

1. Are the two laws of reflection verified? Justify

2. What sort of image is seen in a plane mirror?

PART B: SPHERICAL MIRRORS

In this part, you are going to verify the general relationship for spherical mirrors given by Eqn 15.1

Apparatus

You are provided with an optical bench and fittings, pins, a lamp-house (illuminated object), concave and convex mirrors and a screen S.

Theory

The position and size of an image formed by spherical mirrors may be obtained either by geometrical construction (see Fig. 15-2) or by using the general relationship for lenses and mirrors which is given by

$$\frac{1}{u}+\frac{1}{v}=\frac{1}{f} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(15.1)$$

where u = object distance
v = image distance
f = focal length

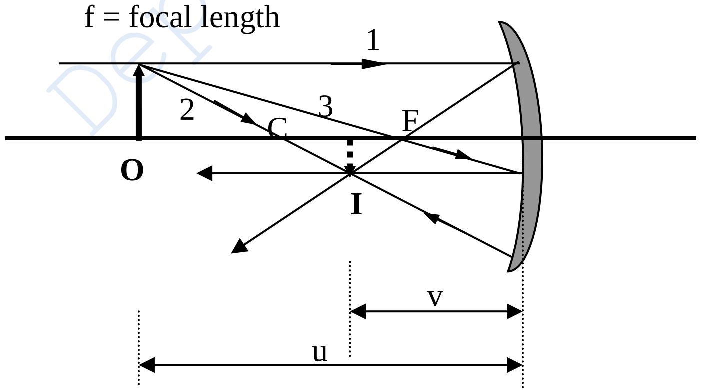


Figure 15-2a. principle rays of a converging mirror

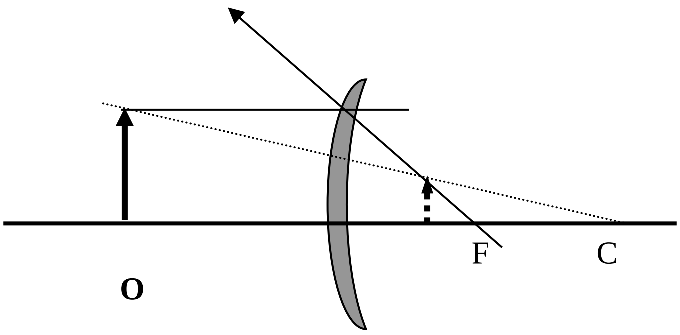


Figure 15-2b. Principle rays for a convex mirror

In geometrical optics, the following rules apply
A ray from the object (ray 1) which enters the mirror parallel to the principal axis will be reflected back through the focus
A ray from object (ray 2) which enters the mirror through the centre of curvature (C) will be reflected back along the same path
A ray from object (ray 3) which enters the mirror through the focal point emerges parallel to the principal axis

Method

(a) *Concave Mirrors*

Set up the apparatus as shown in Fig 15-3 and switch on the illuminated object

Move the concave mirror slowly away from the illuminated object until it projects an image of the illuminated object onto itself. Move the mirror such that a good clear focus is obtained.
Measure the distance between the mirror and the object/image. Half the distance is the focal length.

Set the mirror at a distance greater than 2f away from the object. Use the screen to locate the image and measure v (image distance) for u >2f, u =2 f, $(2f > u > f)$, u = f and u < f. In each case, record the types of images observed.

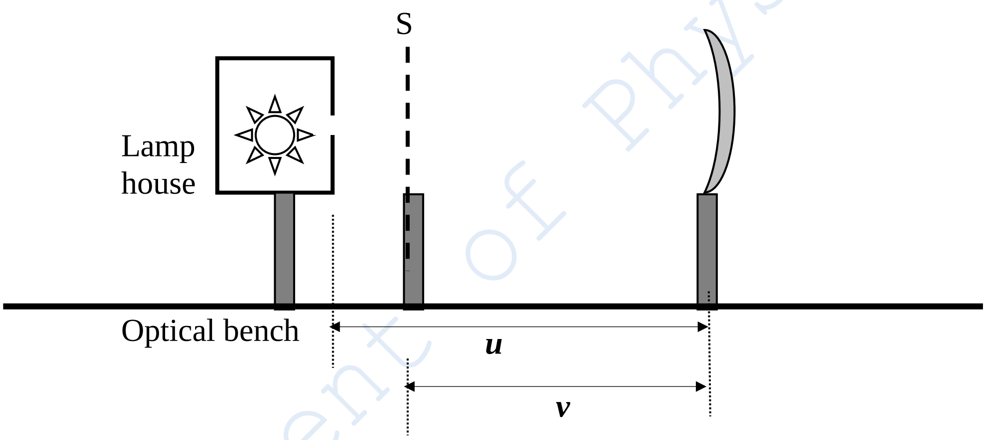


Figure 15-3

(b) *Convex Mirrors*
Now set the apparatus as shown in Figure 15-4. using the convex mirror and one of the pins as the object.

Using the other pin as the search pin, locate the virtual images in the convex mirrors using the method of no parallax

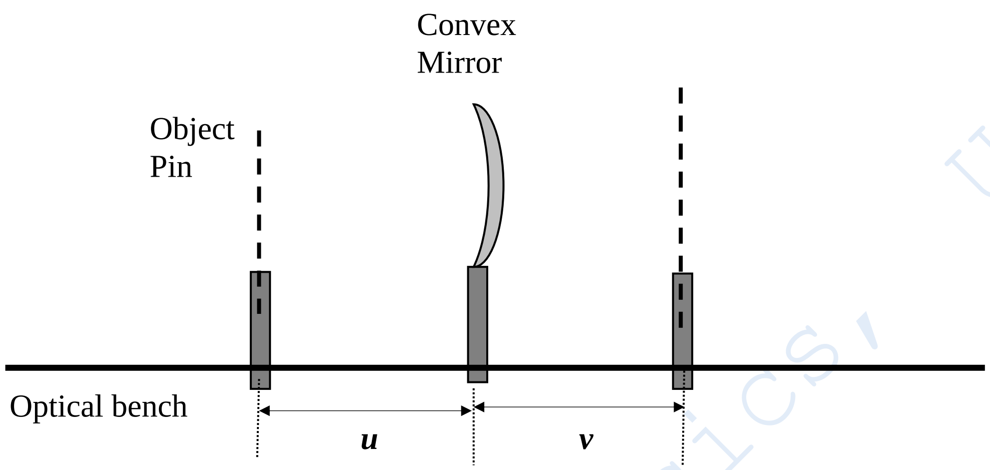


Figure 15-4

Results 2

Worksheet 15-2: Spherical Mirrors

Concave Mirror

Object distance u = ….± ……

Image distance u = ….± ……

Focal length f = ½ u = ….± ……

	u±	1/u ±	v±	1/v ±	Is image?		
					real	upright	Magnified
u > 2f							
u = 2f							
2f > u > f							
u = f							
u < f							

Analysis
Plot a graph of 1/v Vs 1/u and from it, determine the value of f

Convex mirror

U ±	V ±	F ±
Average f		

1. Calculate the error in f for the convex mirror

2. What sort of image does the convex mirror produce?

Discussions
Discuss your results in relation to the laws of reflection for plane mirrors and spherical mirrors

Conclusions
Write suitable conclusion reflecting the objectives

Experiment E-16: Laws of Refraction and Properties of Lenses

Introduction

For a ray of light passing from one medium to another, its speed changes and as a result, its direction also changes as shown in Fig. 16-1. The change in direction when light enters a different medium is known as **refraction** and it obeys Snell's law given by:

$$\frac{Sin\ i}{Sin\ r} = constant = n$$

where i is the angle of incidence, r is the angle of refraction and n is the refractive index

Objectives

1. To verify the laws of refraction and determine refractive index of glass
1. To investigate properties of lenses.

PART A: The Laws of Refraction.

Experiment 1: Snell's Law

Apparatus

A rectangular glass block. Set of 4 pins, a drawing board and paper

Theory

Laws of refraction

(1) The incident ray, the refracted ray and the normal, at the point of incidence, all lie in the same planes.

(2) Snell's law is obeyed i.e. $\frac{Sin\ i}{Sin\ r} = constant = n$ where n is the refractive index of medium 2 (if medium 1 is air).

Method

1. Place a rectangular glass block ABCD on a paper on the drawing board as in Fig. 16-1.
2. Insert pins P_1 and P_2 into the drawing board and look in along the direction of pins P_3 and P_4 until the pins P_1 and P_2 are seen in a line.

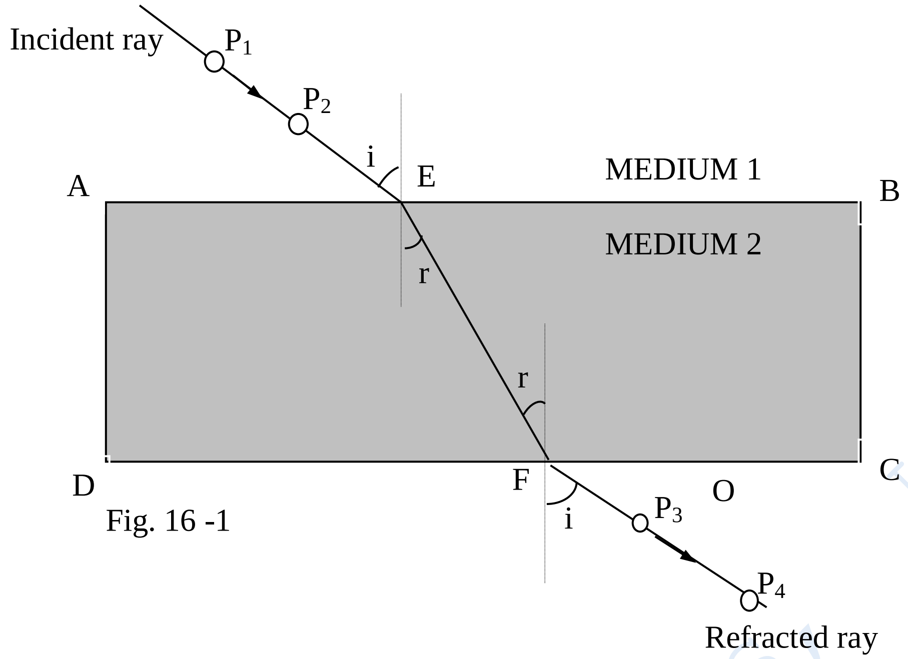


Fig. 16 -1

Insert pins P_3 and P_4 in the drawing board in line with the images of P_1 and P_2 such that when looking in the glass block all the four pins appear in line. Draw the outline of the glass block on the drawing paper.

Remove the glass block and pins from the paper and draw the normals at point E and F and join EF
Measure the angles *i* and *r* with a protractor and calculate the refractive index. Record your data in worksheet 16-1.

Results

Worksheet 16-1: Laws of refraction

i ±…	*Sin i*	*r* ±…	*Sin r*	*Refractive index, n*
Average *n*				

N.B. Hand in original ray diagrams.
Experiment 2: Real and apparent Depth
In this experiment, you are going to determine the refractive index of glass, which is given by Eqn (16-1) by using a glass block and traveling microscope:

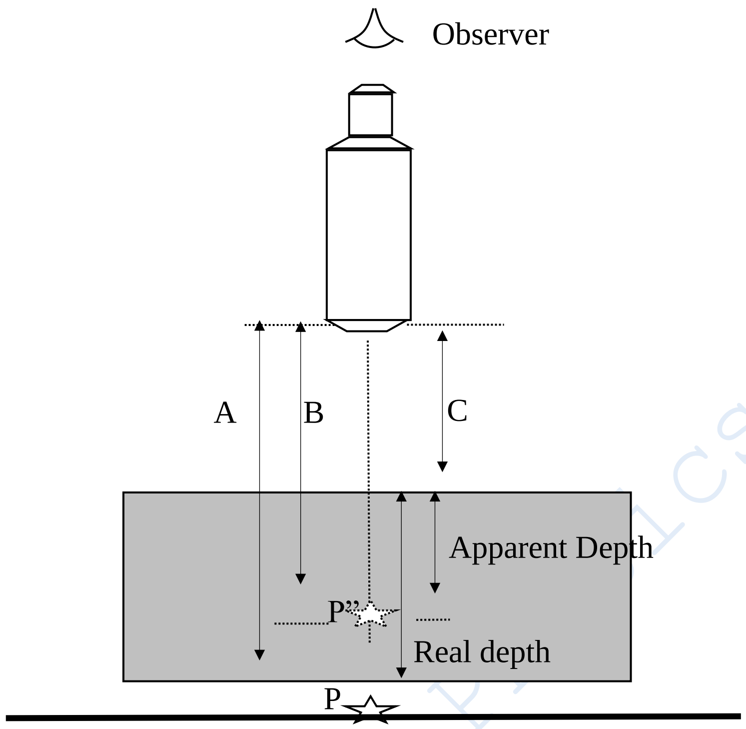
$$\text{Refractive index } n = \frac{\text{real depth}}{apparent\ depth} \qquad (16\text{-}1)$$

Apparatus
Traveling microscope with vernier scale, glass block, chalk powder or pen

Method

1. Mark an ink spot P on a piece of paper placed on the bench

Place the traveling microscope (that moves vertically) on the paper and adjust it so as to bring the spot P in focus. Note the reading on the vernier as reading A.



Now place the glass block over the mark P and re-adust the microscope to bring P into focus again (at P") and note the reading on the vernier as reading B.

Finally, place the ink spot on top of the glass block and take the reading of the vernier (reading C) when the mark is in focus in the microscope.

Results

Worksheet 16-2: Real and apparent depth

	value	Error (±…)	units
1st vernier reading = A			
2nd vernier reading = C			
3rd vernier reading = B			
Real depth = A-C			
Apparent depth = B - C			
Refractive index			

Analysis

1. Are the first and second laws of refraction have been verified ?
2. Compare the values of n obtained in experiment 1 and in experiment 2.

PART B: LENSES

Experiment 1: Properties of lenses
Apparatus

An illuminated object, pins, screen, concave and convex lenses

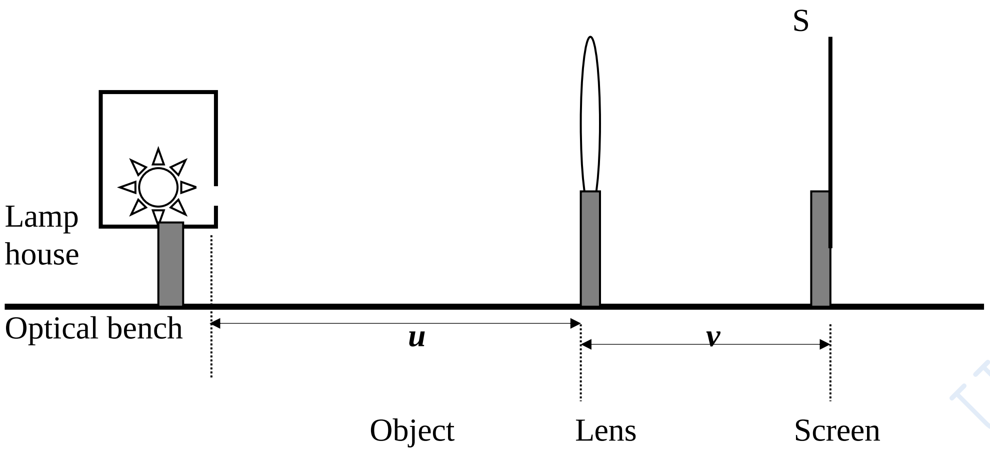


Figure 16-2

Theory
The location and type of image formed by lenses may be obtained either by geometrical construction (see Fig. 16-3) or by using the general relationship for lenses and mirrors which is given by

$$\frac{1}{u}+\frac{1}{v}=\frac{1}{f} \qquad \text{..(15.1)}$$

where u = object distance
v = image distance
f = focal length

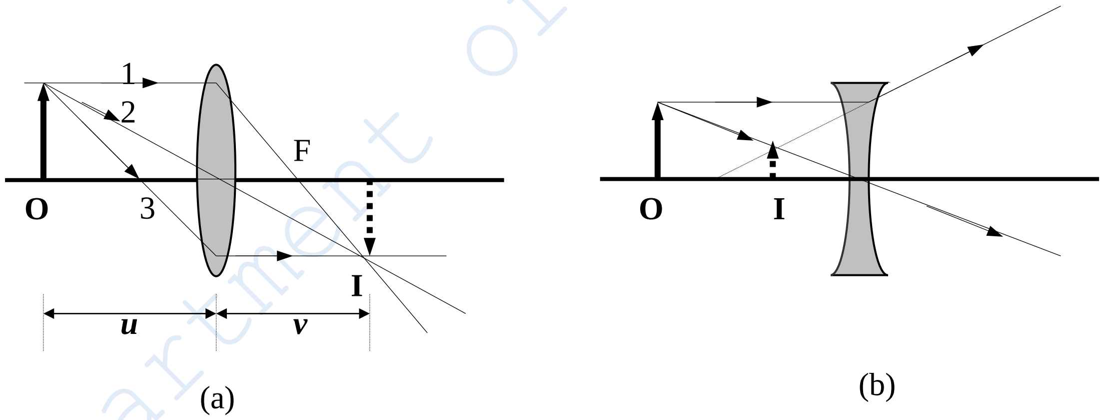


Figure 16-3. Ray diagrams for (a) Convex and (b) Concave lenses

In geometrical optics, the following rules apply
A ray from the object (ray 1) which enters the lens parallel to the principal axis will be refracted through the focal point
A ray from object (ray 2) which goes through the centre of the lens will emerge undeviated

Method

(a) Convex Lens
Establish a rough value for the focal length of the convex lens by focussing on a distant object (e.g. window of laboratory) on the screen.

Arrange the apparatus as shown in Fig 16-2. Switch on the illuminated object and place it at a position greater than *2f* from the lens. Move the screen S until a clear image is focused on it.
Measure the distance (u) from the object to the lens and the distance (v) from the lens to the screen (*v*). Use worksheet 16-3 to record your data
Repeat the above steps for positions of object;
$u > 2f$, $u = 2f$, $2f > u > f$, $u = f$ *and* $u < 2f$
In each case, record the type of image observed
Calculate f using the above values of u and v

(b) Concave Lens

In the case of a concave lens, use the method of no parallax to locate virtual images using the tall search pins provided. Record data in worksheet 16-4.

Results

***Worksheet 16-3:* Convex lens**

	u	*v*	*f*	Type of image		
Units				Real/ virtual	Upright/ inverted	Magnified/ diminished
$u > 2f$						
$u = 2f$						
$2f > u > f$						
$u = f$						
$u < f$						

Plot a graph of 1/u vs 1/v and from it, determine the value of f

***Worksheet 16-4:* Concave lens**

U ±	***V*** ±	***F*** ±
Average f		

Experiment 2: Combination of Lenses

The focal length of the concave lens can be determined by combining the concave lens with a convex lens of shorter focal length than itself. The focal length of the combination (*F*) is given by:

$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2}$$

where f_1 = focal length of convex lens
f_2 = focal length of concave lens

F is determined by using the combination lens to form a real image on a screen, whence:

$$\frac{1}{F} = \frac{1}{u} + \frac{1}{v}$$

If f_1 is known then F can be calculated.

Method

Replace the lens in Fig. 16-2 with a combination of two lenses: a convex lens behind the concave lens

Using the illuminated object, move the screen until a clear image is observed. Measure the object distance (u) and image distance (v). Repeat experiment for a set of object distances. Record your data in worksheet 16-5.

Results

***Worksheet 16-5:* Combination of lenses**

U ±	***V*** ±	***F*** ±
Average f		

Analysis

1. Focal length of convex lens, f_1 (from worksheet 16-3) =

2. Using the eqn $\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2}$, Calculate f_2 using values of f_1 and F.

3. How does this value compare with that obtained from worksheet 16-4?

Activity

1. A certain glass has a refractive index of 1.50 when in contact with air. Calculate
   (i) the angle of refraction in glass when a light ray is incident at 30^o with the normal
   (ii) at what angle of incidence would one need to shine a beam of light so as to emerge in glass at 36^o

2. State any three applications of refraction.

Discussions

Discuss your results in relation to the laws of refraction and properties of lenses

Conclusions

Write suitable conclusion reflecting the objectives

<u>Experiment E-17: The Spectometer – Refractive Index</u>

Introduction

In this experiment, you will use the spectrometer to measure the refractive index of a glass prism using monochromatic light from a sodium lamp. For basic introduction of the spectrometer, refer to Appendix C.

Objectives

To measure the refractive index of a glass prism using a spectrometer.

Apparatus

Spectrometer, glass prism, sodium lamp

Theory

When a ray of light passes through a prism, it undergoes refraction and the emergent ray bends towards the base BC of the prism as shown in Fig. 17-1.

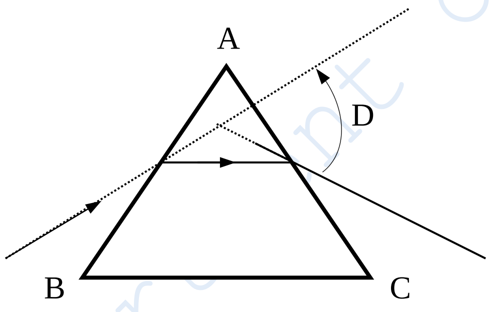


Figure 17-1

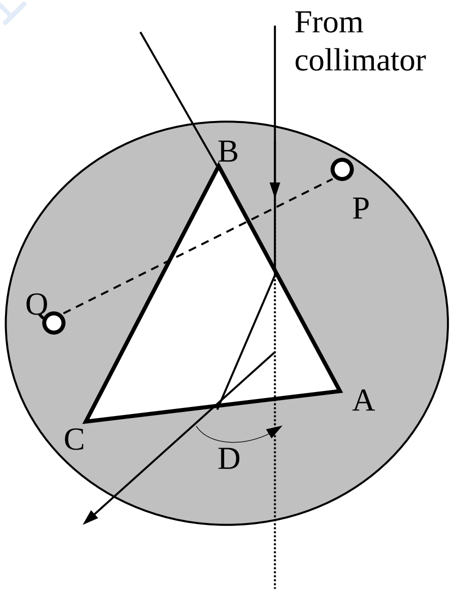


Figure 17-2

The deviations D is the angle between the direction of the incident ray and the emergent ray. The angle of deviation depends on the angle of incidence and for a certain value of the angle of incidence, the angle of deviation is minimum. If D is the angle of minimum deviation for the prism of refracting angle, A, then the refractive index *n* of the material of the prism is given by

$$n = \left(\frac{Sin\frac{A+D}{2}}{Sin\frac{A}{2}} \right) \qquad \text{.................................(17.1)}$$

Method

PART 1: To Determe the refracting angle of the prism

The glass prism provided has two polished faces and the angle of the prism is the angle between these faces. Before the experiment, see that the polished faces are clean.

Adjustments

NB: The circular (main) scale is divided into degrees and half degrees. The vernier scale has 30 equal divisions, so that each division on the vernier corresponds to 1/30th of the smallest division on the main scale, i.e. to 1/30th of ½ ^{0}. So each division on the vernier scale is 1' (one minute of arch). Note that the 0^0 and 360^0 marks coincide on the main scale.

Procedure

1. Mount the prism as indicated in Fig.17-3 below such that the parallel beam of light from the collimator falls on ***both*** the reflecting polished faces AB and AC. This will be the case when the image of the slit can be seen by the reflected light from both faces.

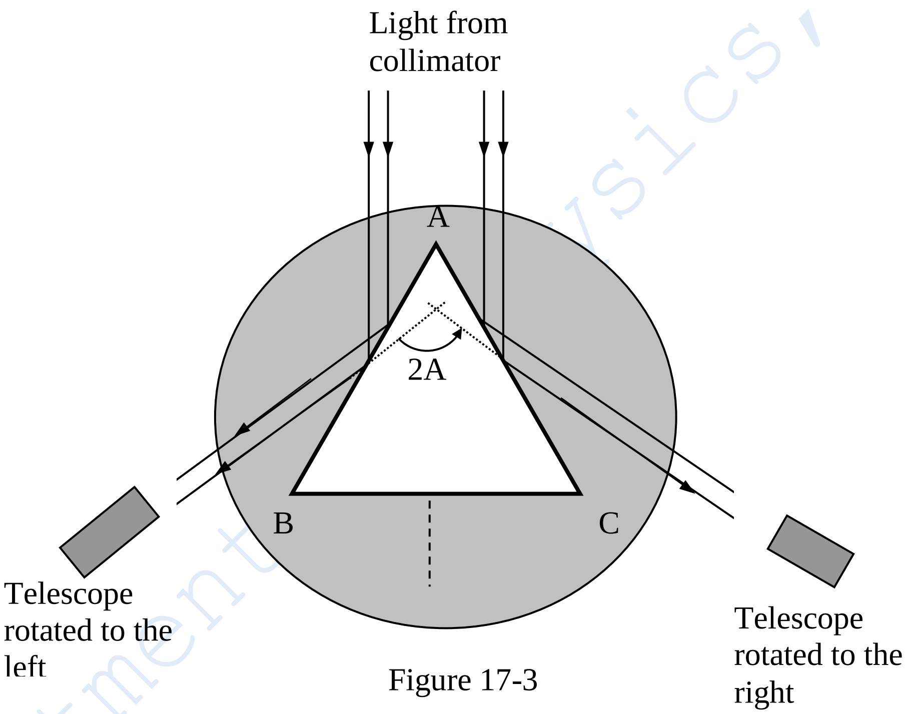


Figure 17-3

2. Illuminate the slit with the sodium lamp.

3. Now make the slit narrow and rotate the telescope to receive the reflected light from, say face AB and work at the tangent screw to bring the center of the image exactly on the vertical cross-wire. Note the reading on both verniers V_1 and V_2.

4. Similarly, direct the telescope to receive the image of the slit caused by reflection from face AC and as before take the readings on both verniers V_1 and V_2. Enter your readings in Table 1 below.

Take Note
The angle of the prism is half the angle through which the telescope is rotated. Take care reading V_1 and V_2 at "zero" or 360).

Table 1

Vernier Readings	Telescope rotated to the Left (±……….)	Telescope rotated to the Right (±……..….)	Difference $\theta = 2A$	Angle of Prism $A = \theta/2$
V_1				
V_2				

Mean A = (with error ± S); where ± S is the error in the vernier reading

Hint: Before taking the difference θ^o, particular attention must be paid to what happens when the telescope rotates through the 360^o mark!

PART 2: To determine the angle of Minimum Deviation (D)

Procedure

1. Mount the prism centrally on the table in such a way that one of its reflecting faces (say AB) is perpendicular to the line joining the two leveling screws P and Q as shown in fig.2. Rotate the table so that light from the collimator is incident on face AB and after refraction emerges out the face AC.

2. Look through AC and locate the position of the refracted image with the naked eye. Bring the telescope in this position to receive the image of the slit in the center of view.

3. Now rotate the prism table in such a direction that the telescope has to be moved towards the line of the collimator axis in order to keep the image in the center of the field of view. It is clear, that as the prism table is rotated in this direction, the deviation decreases. When the position of minimum deviation is reached, the image becomes stationary for very small rotation of the prism table either way. Further rotation of the table makes the image move backwards.

4. The telescope is finally adjusted till the image is on the vertical wire in the stationary position from which it moves backwards in whichever direction the prism table is rotated. Now take the reading of both the verniers V_1 and V_2.

5. Remove the prism, and bring the telescope in a line with the collimator to view the image of the slit directly. Read the vernier when the telescope is adjusted so that the image is on the vertical crosswire. Enter the readings in the Table 2 below.

Results

Table 2

Vernier Readings	Prism in minimum Deviation position (θ_1) (±….)	Straight through reading without Prism (θ_2) (±……..….)	Difference $\theta_1 - \theta_2 = D$
V_1			
V_2			

Mean D = ………………… Error in D = ± …………….

Analysis

(a) Calculate the refractive index n of the material of the prism using Equation (17.1)

(b) Estimate error in n by substituting
   (i) A - δS for A and $D - 2\delta S$ for D, and also
   (ii) A + δS for A and $D + 2\delta S$ for D where $\pm\,\delta S$ is the error in the vernier readings.

   Note: The value of n should be quoted to 3 decimal places. This is the minimum accuracy expected with the spectrometer if the experiment is performed carefully.

(c) Show how the following relation is derived; $n = \left(\dfrac{Sin\,\frac{A+D}{2}}{Sin\,\frac{A}{2}} \right)$. You can refer to standard textbooks

(c) Why is the telescope adjusted for a distant object?
(d) When will the minimum deviation occur in this experiment.

Discussions

Discuss your findings appropriately

Conclusions

Write suitable conclusion reflecting the objectives

ELECTRICITY

Experiment F-18: Ohm's Law

Introduction
In this experiment, you are going to verify Ohm's law

Objectives

1. To verify Ohm's law for a metallic conductor
2. To show that $R = R_1 + R_2 + R_3$ for resistances in series
3. To show that $1/R = 1/R_1 + 1/R_2 + 1/R_3$ for resistance in parallel
4. To show that Ohm's law is not obeyed by a semiconductor.

Apparatus

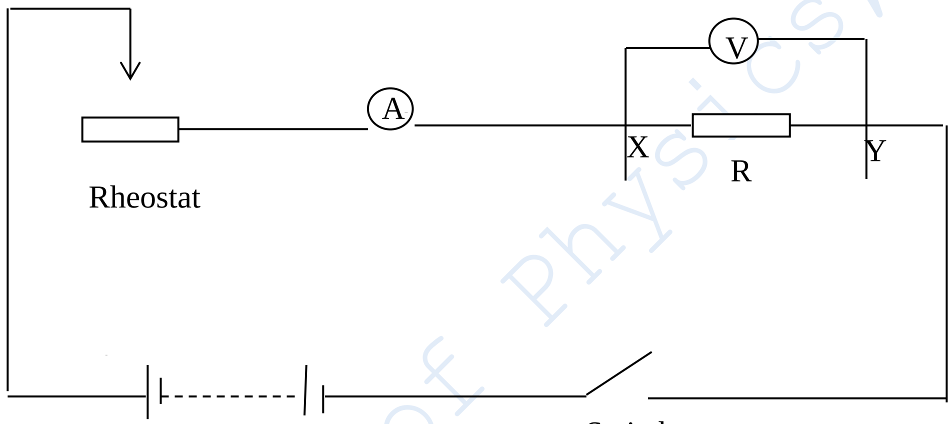


Fig. 18

Theory
Ohm's law for a metal conductor states that $V=RI$ at constant temperature, where V = voltage (volts), I = current (amps) R = resistance (ohms)

Method A
1. Connect the circuit as shown in Fig. 18. Use the rheostat to adjust the current flowing through the unknown resistance R1.

2. Record the ammeter and voltmeter readings.

3. By varying the rheostat, repeat steps 2 and 3 until six readings are recorded.

4. Reverse the terminals of the resistance, i.e. X and Y, and record another set of reading.

5. Repeat method A using resistors R_2 and R_3 respectively and hence evaluate the values of R_2 and R_3 from the graphs.

Analysis A

Use your experiment values of *V* and *I* to plot a graph of *V* versus *I*. A straight line graph proves Ohm's law. Find *R* from the slope of your graph.

Method B: (Combination of Resistors)

1. Repeat method A above but with the resistor R in Fig. 18 replaced with resistors R_1, R_2 and R_3 arranged in series. Plot a graph of V versus I and from your graph, find the sum (R_T) for the three resistors in series.

2. Repeat method A above but with the resistor R in Fig. 18 replaced with resistors R_1, R_2 and R_3 arranged in parallel. Plot a graph of V versus I and from your graph, find the sum (R_T) for the three resistors in parallel.

3. Determine the values of the resistors R_1, R_2 and R_3 from their colour codes and hence evaluate their combined resistances in series and in parallel respectively

4. Record all values on the worksheet and test to see if the relationships for resistors in series and in parallel hold.

Method C : The semiconductor (Diode)

1. Repeat the first part of the experiment using a semiconductor and draw the graph of *V* against *I*. Remember to take a few readings with forward bias and a few with reverse bias.
2. A graph other than a straight line shows that Ohm's law is not obeyed.

Results

Worksheet 18-1: To verify Ohm's law

Resistor	Forward Current		Reversed Connections	
	V (volts)	I (Amps)	V (volts)	I (Amps)
R_1				
R_2				
R_3				

Analysis

1. On the same graph, plot graphs of V versus I for resistos R_1, R_2 and R_3 respectively.

2. Determine the slopes of the graphs and hence the values of R_1, R_2 and R_3.

3. Read the actual values of the resistors using the colour code and compare with your experimental values. Tabulate your results below.

	From graph	From colour codes	Units
R1			
R2			
R3			

Worksheet 18-2: Combination of resistors

Combination	Forward Current		Reversed Connections	
	V (volts)	I (Amps)	V (volts)	I (Amps)
Resistors in Series (R1, R2 & R3)				
Resistors in Parallel (R1, R2 & R3)				

4. On the same graph, plot graphs of V versus I for the total resistance for the series and parallel circuits.
5. From your graphs, determine the values of R in series and R in parallel.
6. Compare your experimental results with values obtained using the formulae.

	From graph	From formula	Units
R (series)			
R (Parallel)			

Worksheet 18-3: Semiconductor

Forward Curreny		Reversed Connections	
V (volts)	I (Amps)	V (volts)	I (Amps)

6. Plot a graph of V versus I for the semiconductor
7. Comment on your graph. Is Ohm's law verified/obeyed?

Discussions

Discuss the sources of error in the measurements of resistances. Is this the most accurate way of measuring resistance? If not, what would you use and why?

Conclusions

Write suitable conclusion reflecting the objectives

Experiment F-19: The Thermistor

Introduction

In this experiment, you are going to determine the resistance characteristics of a thermistor.

Course Objectives

To determine the resistance characteristics of a thermistor.

Apparatus

Metre-bridge, cell, standard resistance box (R) sensitive galvanometer (G), switch (K) beaker of glycerine, Bunsen burner.

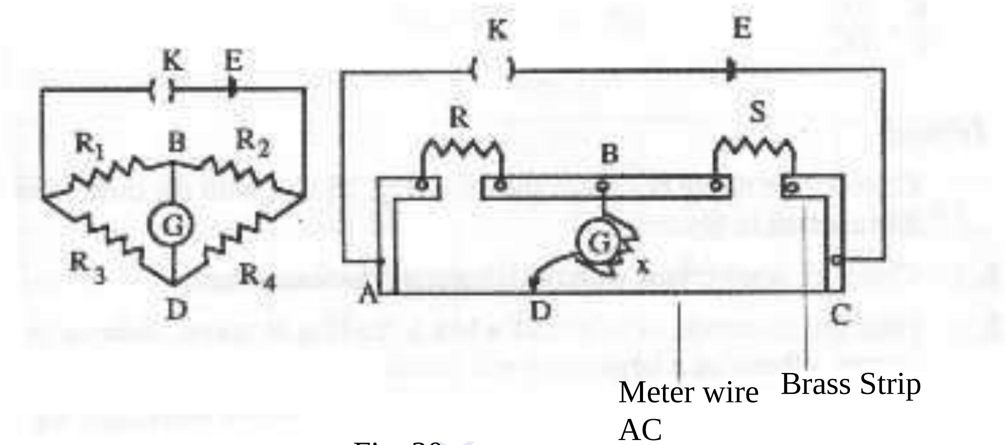


Fig. 20

Theory

The metre-bridge is a convenient form of the wheatstone bridge arrangement

(Fig. 20). When the switch K is closed and the resistances are such that when no current flows through the galvanometer G, then the bridge is balanced. It can be shown that:

$$R_1 / R_2 = R_3 / R_4$$

The metre-bridge consists of a meter length of uniform resistance wire AC alongside a metre rule and soldered at A and C using brass strips of negligible resistance. A third brass strip is arranged. Since the resistance of a uniform wire is proportional to its length then, if D is the balance point:

$$\frac{R}{S} = \frac{AD}{DC} = \frac{L_1}{L_2}$$

Method

1. Connect the metre bridge with the thermistor S immersed in glycerine
2. Check all connections with the laboratory demonstrator
3. Heat the glycerine slowly and when a reading is taken, remove the burner otherwise a large error will occur.
4. Close switch K. Move the slidding contact along the resistance wire until a point of balance is obtained where the galvanometer reads zero. The shunt X should be on.
5. Turn the shunt off to find the balance point more accurately.
6. Record the lengths L_1 and L_2, and the temperature of the glycerine.
7. Repeat the measurements at five or six different temperatures of the glycerine taking a wide range of temperature. (Consult the laboratory demonstrator for the temperature range appropriate for the thermistor you are using.)

Analysis

The resistance of the wire is directly proportional to its length. The resistance of the Thermistor at each temperature may thus be calculated.

$$S = \frac{R.L_2}{L_1}$$

Plot a graph of the log of the resistance against the temperature.

Plot a graph of log S gainst the temperature. Comment on your results

Work sheet 20

Temperature	L_1	L_2	S	Log S

Questions

1. Why do you use a shunt on the galvanometer.
2. Why do you use a metre bridge for the measurements rather than a voltmeter and an ammeter.
3. Why is it simpler to plot the log of the resistance of the thermistor against temperature
4. State two practical applications of the thermistor.

Conclusions

Write suitable conclusion reflecting the objectives

Experiment F- 20: The Pontentiometer

The potentiometer is essentially a device for measuring or comparing potential differences. In this experiment, you are to compare the ***e.m.f***'*s* of two cells using a potentiometer.

Objectives

*To determine the **Emf** of a dry cells*

Course Objectives

At the end of this course, you should be able to

2. Explain and apply the laws of thermodynamics to solve problems related to energy conversions in thermodynamic systems.

Apparatus

You are provided with a potentiometer with sliding contact, accumulator (driving voltage), galvanometer, switch, a variable resistor and an ammeter.

Theory

The essential features of a potentiometer are

(i) A steady source of potential known as a 'driver cell', D, and

(ii) a resistor AB of uniform resistance of r Ω cm^{-1} through which the accumulator sends a steady current (I) as shown in Fig. 1

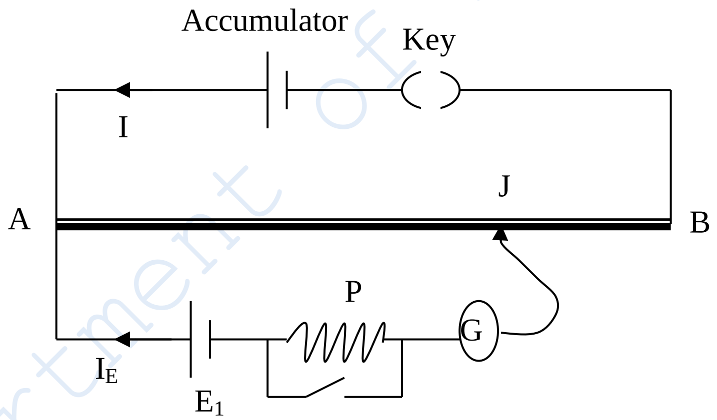


Figure 20.1. The

The potential difference (*p.d.*) between point A and any other point (J) along AB of the wire is therefore proportional to the length AJ and is given by:

$$V_{AJ} = I \times (\text{resistance of AJ}) = I \times \frac{\rho L}{A} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (20.1)$$

where ρ = resistivity of the wire; A = cross sectional area of wire and L = length AJ

Hence P.d. (V) $\propto L$ since I, ρ and A are constant along the wire.

If a cell of **e.m.f,** E_1 (E_1less than p.d. between A and B) is now connected as shown in the figure above, a position for J can be found for which the sensitive galvanometer (G) shows no deflection (the potentiometer is balanced). Thus;

$$E_1 = p.d. \text{ across } AJ = I.L_1(r)$$

Or $$E_1 \propto L_1$$

NB. Cell E_1 drives a current (I_E) in the opposite direction to that of current I.

If now E_1 is replaced by a cell of known **e.m.f** (E_2), then and a new balance point, L_2 can be found such that

$$E_2 \propto L_2$$

Combining these equations we see that $$\frac{E_1}{E_2} = \frac{L_1}{L_2}$$

Or $$E_1 = \frac{L_1}{L_2} E_2 \qquad \text{……………………… ………(20.2)}$$

This is the principle of a potentiometer and the **e.m.f** of an unknown cell (E_1) can be found using Equation (20.2) if E_2 is known.

Procedure

1. Connect the circuit as shown in Fig. 20.1 with the with the standard cell in place in place of E_1.. Be sure that the positive poles of both the accumulator and the standard cell are both connected to A. Get the circuit checked by the lecturer in charge.

2. Device P is a protective high resistor. Switch on the driver cell circuit and adjust J until a position of no deflection is found in the galvanometer. Switch out the protective resistor and make the final adjustments. Measure the balance length AJ.

3. Reverse the connections of the driver cell and again obtain the balance length AJ. Calculate the mean balance length. Use the form of tabular column (Table 1) below to record your readings.

4. Repeat this procedure for the Leclanche cell and then the Danielle cell, noting the lengths required to obtain the balance. You will need to assemble these cells and add the correct liquids to them.
5. Repeat all the measurements at least once to obtain mean values for the lengths.

Results

Worksheet 20

	Standard Cell		Leclanche Cell	Daniel cell
Balance length = … .cm				
On reversing = … .cm				
Mean length = …..cm				
Setting error = ± ….cm				
e.m.f of cell (V)				
Error in e.m.f = ± ….V				

Data Analysis

Since the E.M.F. of the standard cell is known, the E.M.F. of the Leclanche and Daniel cells may be calculated.

Calculate the **e.m.f**’s of these cells assuming the **e.m.f** of the standard cell is …………V.

Questions

1. Why must the E.M.F. of the driver cell be greater than that of the cell under test?
2. A potentiometer can be considered as a voltmeter with an infinite resistance. Why?
3. What factors limit the accuracy of a potentiometer?
4. What was the objective of reversing the terminals of the cell?
5. How would the accuracy of your result be affected if the protective resistor is not switched out of the circuit?

Discussions

Comment briefly on your findings

Conclusions

Write suitable conclusion reflecting the objectives

Experiment F-21: The Oscilloscope

Introduction

The oscilloscope can be used to determine the frequency and voltage of an alternating current among other applications. The signal to be studied is applied to the Y plates (vertical movement) as shown in Fig. 21-1 and the internally generated wave sweeps the electron beam (seen as a spot on the screen) horizontally at some pre-determined rate. This rate is set using the 'time/div' control.

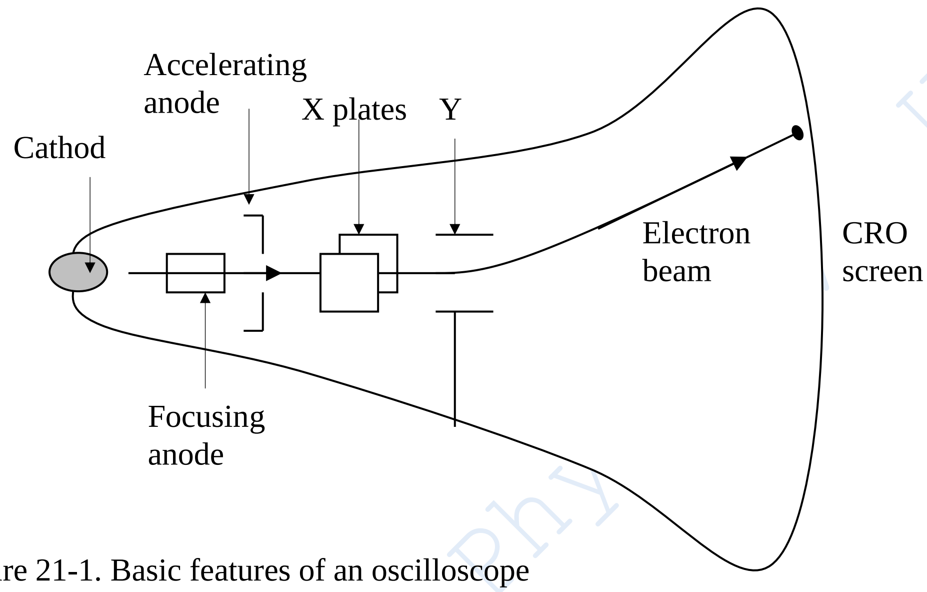


Figure 21-1. Basic features of an oscilloscope

In this experiment, you will learn how to use the oscilloscope and investigate some simple applications of the oscilloscope.

Objectives

1. To learn how to use the oscilloscope and measure the frequency and voltage of *ac* current
2. To investigate some simple applications of the oscilloscope

Apparatus

Signal generator, dual beam oscilloscope, circuit boards containing RCL circuits with different values of R, and with variable capacitor and inductor.

PART 1

Procedure

1. Connect the signal generator up to the oscilloscope as shown in Fig. 21-2. Set the generator to output sine wave at frequency of 500 Hz. You should see a steady sine wave on the screen. If not, press in the trigger level button. Adjust the intensity and focus controls to give a sharp, but not too bright, image.

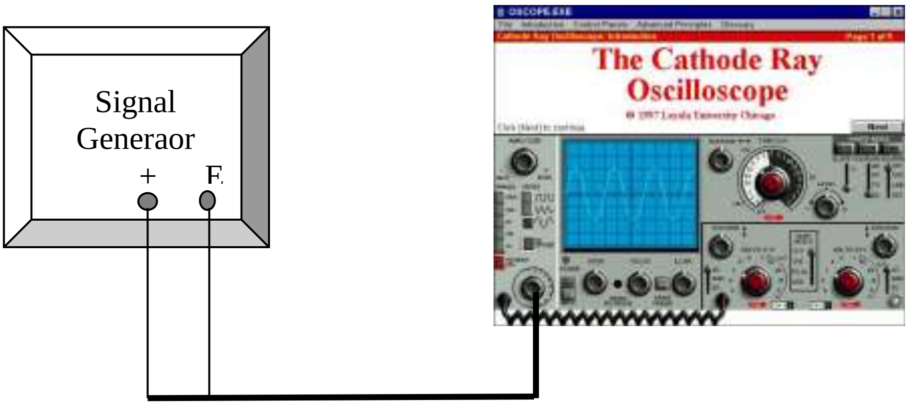


Fig. 21-2

2. Calibrate the instrument by ensuring that the calculated frequency = input frequency of 500Hz. The output frequency (f) is calculated from measurements of the wavelength (length) of the wave seen on the screen and the periodic time T where $f = 1/T$. Adjust the wavelength (using the fine adjustment knob on the length/div control knob) as necessary to achieve this. Once calibrated, do not adjust the fine adjustment knob for the rest of the experiment.
3. Set the signal generator to generate frequency of 1000 Hz and measure the wavelength (length) of the wave seen on the screen and calculate the frequency. Use worksheet 21-1 to tabulate your data.
4. Repeat step 3 for frequency of 1500 Hz.

5. Now set the voltage output of the generator to 1 and measure the voltage on the screen. Repeat for settings of 2 and 3 volts. In the same manner as in step 2, remember to calibrate the equipment before taking readings.

6. Now set the generator to give out square waves at 500 Hz and voltage output setting 3. Measure the frequency and voltage of the wave. Tabulate your data in worksheet 21-1. Comment and compare your results from the sine and square waves.

Results:

Worksheet 21-1: Sine wave

Generator frequency (Hz)	**Length on screen/ Wavelength (cm)**	**Time/div (secs)**	**Period/Total Time (s)**	**Oscilloscope frequency (Hz)**
500				
1000				
1500				

Generator Voltage setting	**Height on the screen (cm)**	**Volt/div (volts)**	**Voltage (volts)**
1			
2			
3			

Worksheet 21-2: Square wave

Generator frequency (Hz)	**Length on the screen (cm)**	**Time/div (secs)**	**Period/Total time (s)**	**Oscilloscope frequency (Hz)**
500				
1000				

Generator Voltage setting	**Height on the screen (cm)**	**Volt/div (volts)**	**Voltage (volts)**
1			
2			
3			

Part II: Discharge of a capacitor in an RCL circuit

THEORY

A series circuit containing a resistor, capacitor and inductor will resonate with a frequency of ω under certain conditions. The signal generator charges and discharges the capacitor twice during one period causing oscillations in the circuit. The nature of the capacitor's discharge depends on the values of the circuit components according to the equation:

$$\frac{R}{2L} > \frac{1}{\sqrt{LC}} \quad (a\ periodic\ or\ smoth\ discharge)$$

$$\frac{R}{2L} < \frac{1}{\sqrt{LC}} \quad (oscillatory\ discharge)$$

Since the capacitor is being discharged, the amplitude of the oscillations in the second case decreases with time, i.e. damped oscillations as shown below.

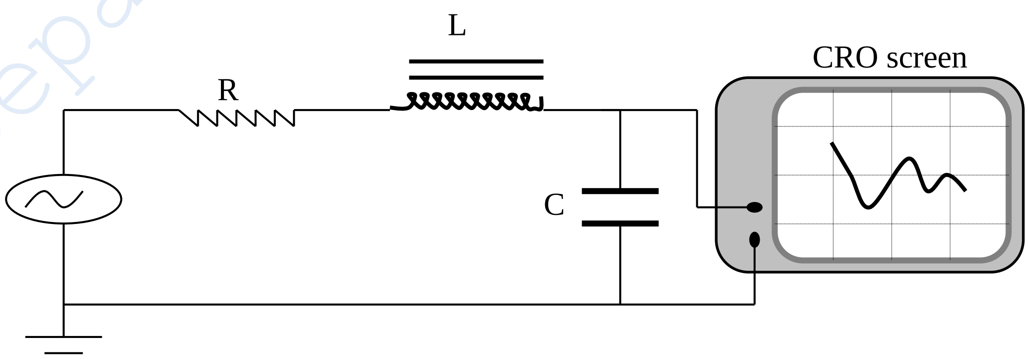


Fig. 21-3

Procedure

1. Some RCL circuits have already been prepared on circuit boards. Choose the one with R = 100 Ω and connect the oscilloscope to the terminals as shown in Fig. 21-3.
2. Draw the curve seen on the oscilloscope screen (R = 100Ω, C = 4700pF, L = 0.4 H). Repeat for R = 1000 Ω and 10,000 Ω (or 100, 000 Ω).

3. Draw the curves obtained when C and L are varied. In either case, state whether the discharge is oscillatory or periodic. Is this borne out of theory? If not, why not?
4. Investigate what happens to the curve on the oscilloscope screen when R and C are interchanged. In each case say whether the discharge is oscillatory or periodic. Is this borne out by theory? If not, why not.

Discussions

Discuss your findings appropriately

Conclusions

Write suitable conclusion reflecting the objectives.

RADIOACTIVITY

Experiment N-1: Radioactivity Decay Analogue

Introduction

Radioactivity decay follows a statistical process, which may be simulated. In this experiment, you are going to simulate the process by throwing on the floor or table a known number of dice (or wooden cubes) with one of their faces marked. The dice with marked faces uppermost are removed after each throw. The process of removing the dice is analogous to the decaying of atoms of a radioactive element and follows the same statistical laws as decaying atoms.

For the provided number of dice, you will determine the number of throws, which will be made for half the total number of the dice to be removed. The number of throws may be considered as analogous to the half-life. To understand the equations used in the theory, questions are given for you to work through.

Objectives

At the end of this experiment you should be able to simulate Radioactive decay using statistical process.

Apparatus

About 200 cubes with one face marked, a large and a small box

Theory

The *Rutherfold* and *Soddy* law states that at any instant of time t, the rate of decay of radioactive atoms (dN/dt) is proportional to the number of atoms N present at that instant. As an equation this can be expressed as

$$-\frac{dN}{dt} \propto N$$

Or $$\frac{dN}{dt} = -\lambda\, N \qquad \text{.................................(1)}$$

where λ is the decay constant and the negative sign means that the number of atoms remaining is decreasing. Note that for a particular element, the decay constant is constant, but varies for different elements. The solution of equation (1) has the form

$$N = N_o e^{-\lambda t} \qquad \text{............................(2)}$$

The time taken for half the number of atoms to decay is called the half-life (T) and it is given by

$$T = \frac{0.693}{\lambda} \qquad \text{.......................................(3)}$$

Procedure

1. Count the number of dice (or wooden cubes) N_o, you are provided with in the large box

2. Throw all the dice on the table or floor

3. Remove the dice whose marked faces are uppermost and record their number ($dN = N_o - N$) against the number of throws T and put them into the small box. Make your recordings in Table 1.

4. Return the remaining dice back into the large box and note the number N. Repeat steps 2 and 3. Repeat until the remaining dice is less than 1/16 of the original number N_o.

Results

Initial number of dice N_o = ...

Table 1

Number of throws ***T***	Number of dice removed ***dN***	Number of dice remaining ***N***	***lnN***

Analysis

(a) Plot a graph of number of dice remaining (N) against the number of throws T. From the graph, determine the number of throws required to have a number of dice decay to $N_o/2$, $N_o/4$, $N_o/8$, $N_o/16$, hence the mean number of throws for half-life T. Compare the value you obtain to the value computed in question (4). Give reasons for any difference.

(b) Plot a graph of lnN versus T. Determine the slope of the graph and hence the decay constant of the dice. Compare the value you obtain with the value computed in question (4). Give reasons for any difference observed.

(c) Answer the following questions

Questions

1. Show that equation (2) satisfies equation (1)
2. Derive equation (3) starting with equation (2)
3. What is the shape of the graph of the natural logarithm of equation (2). Does the slope have any physical meaning?
4. Suppose you are provided with 500 dice. Calculate the number of throws that is equivalent to one half-life and the decay constant for the process.

Discussions

Discuss your results in comparison to theory

Conclusions

Write a suitable conclusion

RENEWABLE ENERGY

Experiment S-1: PV Panel Characteristics

Introduction

Power generation from solar photovoltaic (PV) panel has long been seen as a clean sustainable energy technology which draws upon the renewable energy source – the sun. The direct conversion of sunlight to electricity occurs without any moving parts or environmental emissions during operation. Solar PV is now, after hydro and wind power, the third most important renewable energy source in terms of globally installed capacity.

A **solar panel**, or **photovoltaic panel**, is an electrical device that converts light energy into direct current (DC) electricity by the "**Photovoltaic Effect**". The operation of a photovoltaic (PV) panel requires 3 basic attributes:

- The absorption of light, generating electron-hole pairs
- Separation of charge carriers of opposite types.
- The separate extraction of carriers to an external circuit.

Solar cells (Fig 1a) are the building blocks of photovoltaic modules, otherwise known as solar panels. When more power is required than a single cell can deliver, cells are connected together to form PV solar panels (Fig b). For example, Fig 1(b) shows a crystalline-silicon panel comprising of 4 solar cells. To power a bigger devive such as a house or a power plant, the panels are arranged in multiples as arrays as shown in Fig 1(c).

(a) Solar cell *(b) Solar Panel with 4 solar cells* *(c) Solar Array*

Figure1. Arrangement of solar panels to form PV modules

Connecting Solar Panels

For a consistent amount of incident light, there is a maximum amount of current a solar panel can produce. If a load demands more current, then one has to connect more solar panels in parallel to meet the additional current demand. In the same way DC batteries can be connected in series or in parallel.

Connecting panels in series increases the energy for each charge (i.e., the voltage (which is energy per charge) and hence the power output. The current however remains constant. This is one reason why solar panels are connected in series in solar panels, to be able to provide enough voltage to meet the rated requirements.

In this experiment, you are going to investigate the power output of PV panels when solar panels are connected in series and in parallel.

	Objectives To investigate the power output of PV panels when solar panels are connected in series and in parallel.

Apparatus

- Component board with PV modules and resistors
- A lamp
- Electric Leads
- Digital Ammeter and Voltmeter
- Miniature light bulb

Method

You are provided with solar panels from ***Tough Stuff Co. Ltd, Model: TSI-501*** with the following specifications:

Power Rating = DC 5.7V, 1W

P_{Max} = 1W

I_{PMax} = 174mA

V_{PMax} = 5.7V

V_{OC} = 7.5V

I_{SC} = 240mA

Max Sys V = 5.7V

PART 1

1. Arrange the circuit as shown in Figure 2 below. Connect a digital ammeter in series with the load and a voltmeter directly across the PV panel terminals. Use a load resistor of 0.5Ω or as provided

2. Illuminate one PV solar panel with an incandescent lamp and keep the amount of light incident on the panel constant by keeping the distance between the lamp and the panel constant for all measurements. (Use a distance of 30 cm)

3. To keep the lamps from getting too hot, turn off the lamps between actual measurements.

4. Switch on the circuit and simultaneously measure and record the voltage and current being delivered with the 0.5Ω resistor. Use Table 1 to record your measurements

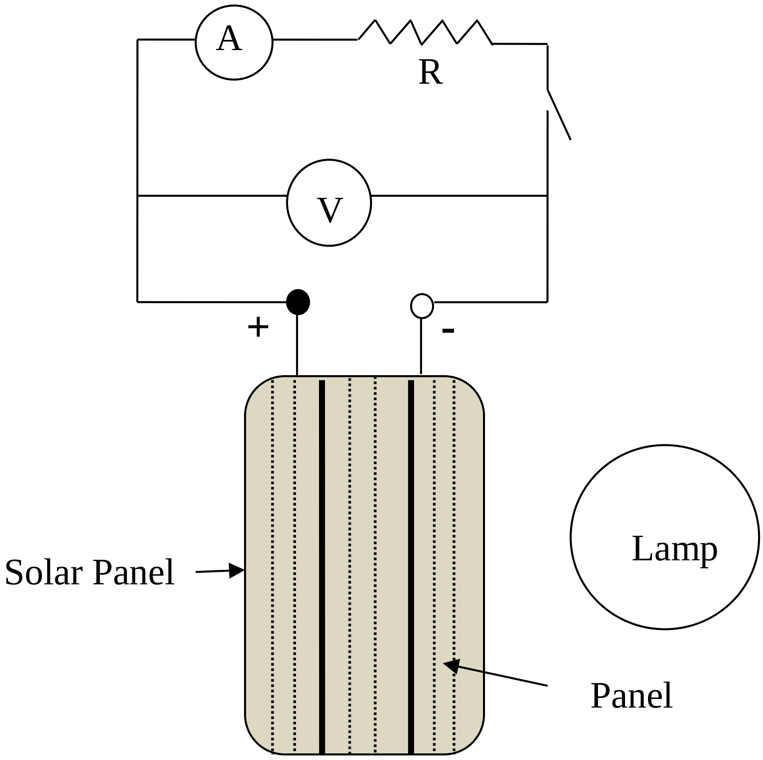


Fig 2. Circuit arrangement of PV solar panel

5. Now connect the second 0.5Ω resistor in parallel with the first resistor. This will decrease the resistance by a factor of 2. Measure the voltage, and current, and determine the power.

   How does the power, current & voltage compare to the measurement with just one resistor? NB. One would expect the current to double when the resistance decreases by a factor of 2. Is this the case?

PART II: CONNECTING SOLAR PANELS IN PARALLEL

6. **Using the set up in 5 above (with R_T = 0.5 Ω), connect the second PV panel in PARALLEL** with the first one and illuminate each panel with a lamp. Measure and record the voltage, current and calculate the power. How does the power compare with the two previous measurements ?

7. **Using the same setup now with R_T = 0.25 Ω, connect the PV panel in PARALLE** and illuminate each panel with a lamp. Measure and record the voltage, current and calculate the power. How does the power compare with that in experiment 6 above ?

PART III: CONNECTING PANELS IN SERIES

8. **Now connect the two panels in SERIES** to a 0.5Ω resistor and illuminate each panel with a lamp. Measure and record the voltage, and current, and calculate the power. How does the Power compare with one 0.5Ω resistor connected to one panel measured in part 4 above ? How much did the voltage and current change?

9. **Now connect the two panels in SERIES** to a 0.25Ω resistor and illuminate each panel with a lamp. Measure and record the voltage, and current, and calculate the power. How does the Power compare with one 0.5Ω resistor connected to one panel measured in part 4 above ? How much did the voltage and current change?

Results

Table S-1: Power output from panel combinations

	Voltage(V) ±….. (V)	Current (I) ±…(A)	Power(P) = IV (W)	Remarks
One Panel, One resistor (R_T = 0.5 Ω)				
One Panel, Two resistors (R_T = 0.25 Ω)				
Two Panels in Parallel, Two resistors: (R_T = 0.25 Ω)				
Two Panels in Parallel, One resistor: (R_T = 0.5 Ω)				
Two Panels in Series, Two resistor: (R_T = 0.25 Ω)				
Two Panels in Series, One resistor: (R_T = 0.5 Ω)				

Analysis

Explain why we have to connect PV panels in series and in parallel

Discussions

Write down your comments and what you have learned from this experiment

Experiment S-2: Rated Voltage and Power of a Device

Introduction

Devices are designed to operate at a specific Voltage and Power for optimal performance. For example, the miniature bulb you are provided with requires at least 2W and 12V to light properly. The PV panels provided are rated 5.7V and 1W. So there is need to connect the PV panels in series to obtain the required voltage needed for the bulb to light properly. If we need to light more bulbs we would need to increase the current capability. This will require adding more panels in series to obtain the proper voltage, and then connecting this set of connected series panels in parallel to increase the current being delivered to the bulbs.

As you can see, it takes a combination of panels to construct a solar panel. **Some panels must be connected in series to meet the desired voltage and these series connected panels must be connected in parallel to produce the needed current**. In this experiment, you are going to establish the combination of PV panels for an electric circuit that can deliver the rated voltage and power to a device using a light bulb as a load.

Objectives

To obtain the rated voltage and power of a device through combination of solar panes.

Apparatus

- Component board with PV modules and resistors
- A lamp
- Electric Leads
- DC meter and Voltmeter
- Miniature light bulb
- Switch

Method

You are provided with solar panels from ***Tough Stuff Co. Ltd, Model: TSI-501*** with the following specifications:

Power Rating = DC 5.7V, 1W

P_{Max} = 1W

I_{PMax} = 174mA

V_{PMax} = 5.7V

V_{OC} = 7.5V

I_{SC} = 240mA

Max Sys V = 5.7V

1. Using one panel, connect the miniature light bulb as the load and measure and record the current and voltage by connecting an ammeter (1A ammeter) in series with the bulb and a voltmeter across the PV panel terminals as shown in Fig 1. below. Calculate the power being delivered to the bulb. Also note the brightness of the miniature bulb. (**DIM, BRIGHT, BRIGHTEST**).

2. Now **connect the second PV panel in PARALLEL** with the first one and illuminate each panel with a lamp. Measure and record the voltage, current and power delivered to the miniature bulb. Is the bulb brighter than it was in step 1?

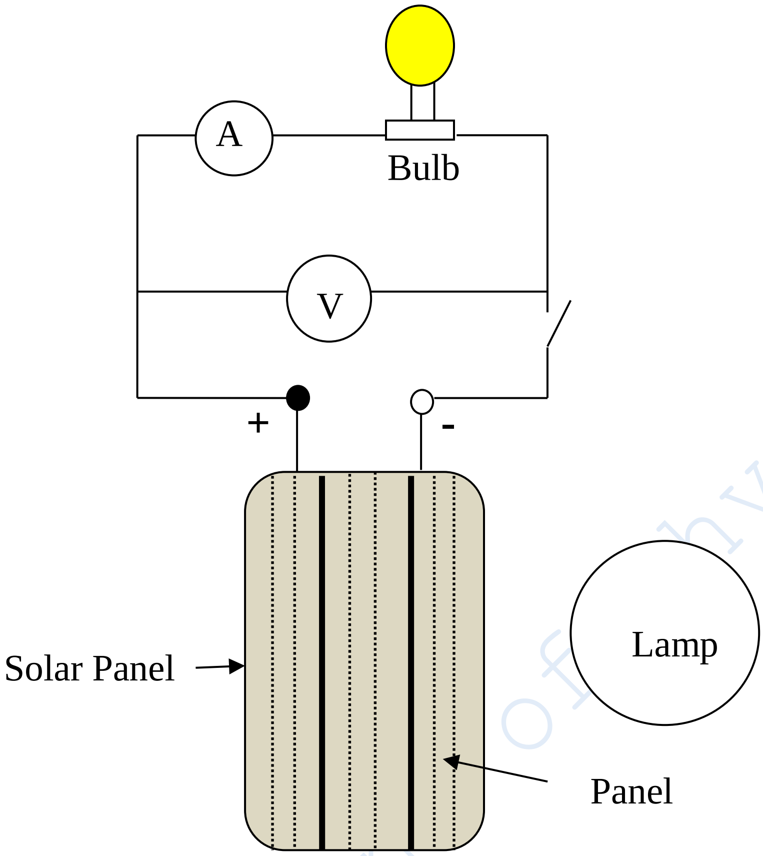


Fig 1. Circuit arrangement of PV solar panel

3. **Connect the two PV panels in SERIES**. Again, measure and record the voltage, current, and calculate the power. Is the bulb brighter than it was in step 1 and 2?

Results

Table 2: Power output with a light bulb

	Voltage(V) ±….. (V)	**Current (I) ±…(A)**	**Power(P) = IV (W)**	**Bulb brightness**
One Panel				
Two Panels in Parallel				
Two Panels in Series				

Analysis

Which produces the brightest light output, the panels connected in series or parallel?

Exercise

Assume each PV Panel is capable of delivering 0.5V and 1.5 Amps. How would you connect PV panels to obtain 3V with a power output of 9 Watts?

Conclusions

Write down your comments and what you have learned from this experiment

APPENDIX A

Error Analysis

What is an error?

- An error is a way of indicating the range of uncertainty of a measurement and depends on
  - (i) Experimental procedure
  - (j) Instrument used e.g., metre rule has a reading error (sensitivity) of ± 1mm. A reading error is the (±) the smallest division on the measuring scale. Instrument errors are (a) zero error and (b) reading error

TYPES OF ERRORS

- The two fundamental types of errors that may occur when you make a measurement are namely;

(a) ***Random errors***:– Occurs when repeated measurements of the same quantity gives rise to different values. They arise due to

- (i) Errors of judgement:- such as the interpretation of the actual position of the pointer on a measuring scale (parallax error).
- (ii) Fluctuating conditions e.g., temperature, pressure or voltage may vary during the measurement, affecting the results.
- (iii) Unexpected disturbances e.g., sudden stray mechanical vibrations caused on the benches affect the experimental set up and hence the results obtained. Similar stray electrical pulses and magnetic fields do affect readings.

Random errors can be eliminated by repeating the measurement several times and taking an average (mean) reading.

(b) ***Systematic errors***:- This refers to an effect that influences all measurements of a particular quantity equally e.g., if a voltmeter has an undetected 'zero error' and reads 0.2V 'too large' when 'disconnected', then an absolute systematic error of +0.2V will occur in all measurements. On the other hand, if the meter is incorrectly 'calibrated' then a systematic % error will occur in all measurements. For example, if a 'full scale deflection' (*fsd*) of the meter is actually10V when the meter scale indicates 9V, then all readings taken with the meter on that range have a systematic error of {-(10-9/10)V} = -10% and will be 10% "too small".

Systematic errors arise due to

- (i) Instrument used
- (ii) Personal contributions such as when to start and stop a timing or
- (iii) Assumptions made in theory

Systematic errors are difficult to detect (since they affect all results equally) and can usually only be found by checking and properly calibrating the instrument in which the error is suspected against a known reliable instrument.

The accuracy of reading of a single quantity is usually determined by the reading error. The reading error is the plus or minus (±) the smallest division on that measuring scale. However, if the division is large, then one may estimate to the nearest half-division or 1/10 of this, if the eye can estimate position between graduations. For example, for a metre rule subdivided into mm, the reading error is ± 1mm whereas for a commonly used laboratory thermometer whose smallest division is 1^{o}C, the reading error is $\pm 0.5^{o}$C. On the other hand, if an accurate instrument is used to measure the radius of an irregular wire, then, the instrument readings can be used to determine the accuracy.

- A measurement is said to be *accurate* if the measured values cluster closely about the true value i.e., it has little or no systematic and/or random errors. A measurement is said to be *precise* if the spread of measured values is small. Precision and accuracy are both limited by the sensitivity of the measuring device e.g., the sensitivity of a metre rule subdivided in mm is 1 mm.

- ***Note***: A precise measurement can be very precise but not accurate if the systematic error(s) are large. E.g., a cheap digital watch reading 10:35:17 AM is very precise (time is given to the sec), but if the watch runs several minutes slow, then this value isn't very accurate. On the other hand, a grandmother clock might be very accurate (i.e., display the correct time), but if the clock has no second hand, it isn't precise. A high-quality measurement, like those used to define standards, is both precise and accurate. Precision and accuracy are both limited by the sensitivity of the measuring devices.

Error Presentation

- There are two types of quoting errors in a value i.e. *absolute error* and *percentage error* e.g., if a voltmeter reads 5.0 V when the reading might reasonably represent a value between 4.9 V and 5.1 V then the reading can be quoted as

An absolute error ; $x \pm dx$ i.e., (5.0 ± 0.1)V

A percentage error; $x \pm \left(\frac{dx}{x} \times 100\% \right)$ i.e., 5.0V $\pm$ 2%

How to reduce Errors

(a) Measuring a multiple of the quantity

Suppose, for example, that you can start and stop a stopwatch with an accuracy of about 0.2 sec. and that you are determining the period of a pendulum (1 sec. say). Then if you time just one swing, your result will be 1.0 $\pm$ 0.2 sec. If you time one hundred swings, you will get a total time of 100.0 $\pm$ 0.2 sec. and the period will be 1.000 $\pm$ 0.002 sec thereby reducing the error.

(b) Taking the measurement several times

On the average, the result you get will be sometimes greater, or smaller, than the 'correct' result. The average of your readings should then be close to the true value. The more readings you take, the better. The accuracy of your final answer can be roughly determined from the spread of your readings, i.e. if you get 1.22 cm., 1.26 cm., 1.24 cm., - you could quote your reading as 1.24 $\pm$ 0.02 cm. This is the 'worst' error – it exactly covers the range of your results. In fact, it is likely that your mean value is more accurate than this and you can quote what is known as the "***probable error***" which is defined as

$$P.E = 0.7\, x\, .\sqrt{\frac{\sum \left(x_i - \bar{x}\right)^2}{n(n-1)}}$$

where $\bar{x}$ is the average of your readings, n is the number of readings taken, and the x_i are the actual readings.

Obviously it takes longer to work this out, than to just look at the spread. Anyway the equation is not valid unless you have at least about 10 readings. We will be satisfied with the simpler method, while hoping that occasionally you might calculate the probable error.

Calculations of Propagated Errors

In most experiments, the *measured quantities* are used to determine a *derived quantity*. As such, the errors in the initially measured quantities (which are introduced when reading the scale) are propagated to the derived quantity. The total error in any calculated (derived) quantity is evaluated by taking into consideration the errors in all the measured values involved in calculating that quantity. The following rules apply

(a) Addition or Subtraction

Suppose you want to determine a quantity *q*, which depends on two measured quantities x and y i.e.,

$$q = x - y \qquad \text{...(1)}$$

Suppose *x* and *y* have errors *dx* and *dy*. Then the biggest and smallest values of *q* you get are

$$q_1 = (x + \delta x) - (y - \delta y) = (x - y) + (\delta x + \delta y) = q + \delta q$$
$$q_2 = (x - \delta x) - (y + \delta y) = (x - y) - (\delta x + dy) = q - \delta q$$

So, in either case

$$\delta q = \delta x + \delta y \qquad \text{...(1a)}$$

or the percentage error is

$$\frac{\delta q}{q} = \left(\frac{\delta x}{x} \times 100\right) + \left(\frac{\delta y}{y} \times 100\right) \qquad \text{.......................................(1b)}$$

In other words, you have added the errors. This gives the worst possible values of *q* i.e., when the errors in *x* and *y* both act in the same direction. Generally it can be shown that the likely estimated error in *q* is given by

$$\delta q = \sqrt{(\delta x)^2 + (\delta y)^2}$$

The same equation holds if q = x + y.

Example:

If q = *a* + *b* where *a* = 4.5 $\pm$ 0.1cm, *b* = 3.6 $\pm$ 0.2 cm then;

$$dq = 0.1 + 0.2 = 0.3 \text{ cm.}$$
$$\Rightarrow \quad q = 8.1 \pm 0.3 \text{ cm.}$$

OR

$$\Rightarrow \quad q = 8.1 \pm \left(\frac{0.3}{8.1}\right) \times 100\% = 8.1 \pm 3.7\% \text{ cm.}$$

General rule (Addition & Subtraction)

The *total absolute or percentage error* is the *sum of the individual absolute errors or percentage errors* i.e.,

- If $q = a + b + c$; then $dq = da + db + dc$
- If $q = a - b - c$; then $dq = da + db + dc$

(b) Multiplication and Division

Let us take three simple examples,

(i) $\boldsymbol{q = xy}$ ……………………………………………………………………(2)

Then $(q + \delta q) = (x + \delta x)(y + \delta y)$ gives the largest error in q. Hence

$$(q + dq) = xy + xdy + ydx + dxdy$$

$$\Rightarrow \quad q\left(1+\frac{dq}{q}\right) = xy\left(1+\frac{dx}{x}+\frac{dy}{y}+\frac{dxdy}{xy}\right)$$

$$\Rightarrow \quad \left(1+\frac{dq}{q}\right) = \left(1+\frac{dx}{x}+\frac{dy}{y}+\frac{dxdy}{xy}\right)$$

Now δx and δy are small errors, so $\left(\frac{dxdy}{xy}\right)$ is very small (we hope:). Therefore

$$\frac{\delta q}{q} \approx \frac{\delta x}{x} + \frac{\delta y}{y}$$

Thus the absolute and percentage errors can be given by

$$dq = q\left(\frac{\delta x}{x} + \frac{\delta y}{y}\right) \qquad \text{……………………………………(2a)}$$

and

$$\%\ \text{error} \quad = \left(\frac{\delta q}{q}\ x\ 100\%\right) = \left(\frac{\delta x}{x} + \frac{\delta y}{y}\right)100\% \qquad \text{………………(2b)}$$

(ii) $\boldsymbol{q = x^2 = xx}$ ……………………………………………………………………(3)

In this case we can easily see from above that the largest error in q is

$$\delta q = \left(\frac{\delta x}{x} + \frac{\delta x}{x}\right)q = 2\frac{\delta x}{x}.q = 2dx.x \qquad \text{…………………………(3a)}$$

(iii) $\boldsymbol{q = x/y}$ ……………………………………………………………………(4)

Likewise, in this case, we can easily see that the largest error in q is

$$q + \delta q = \frac{x+\delta x}{y-\delta y}$$

$$\Rightarrow \qquad \delta q = \frac{x+\delta x}{y-\delta y} - \frac{x}{y} = \frac{y\delta x + x\delta y}{y(y-\delta y)}$$

$$\Rightarrow \qquad \frac{\delta q}{q} = \frac{y\delta x}{x(y-\delta y)} + \frac{\delta y}{y-\delta y}$$

If we neglect δy in the denominator (it is much smaller than y), then $\frac{\delta q}{q} \approx \frac{\delta x}{x} + \frac{\delta y}{y}$

Hence the absolute error becomes

$$\delta q = \left(\frac{\delta x}{x} + \frac{\delta y}{y}\right) q \qquad \text{..(4a)}$$

Example:

If $a = 5.6 \pm 0.1$g and $b = 50.0 \pm 0.1$ cm

then the error in x = (a + b) is $= \frac{0.1}{5.6} + \frac{0.1}{50.0} = 0.0175.....+ 0.002 = 0.0198$

Final error is hence

$$dx = 11.2(0.0198) = 0.2g/m$$

NB. The error has the same number of decimal places as the actual value

General rule (Multiplication and subtraction)

The *total fractional error is the sum of the individual fractional errors OR The total percentage (%) error* is the *sum of the individual % errors i.e.,*

- If $x = ab$ or $x = a/b$ then $\frac{dx}{x} = \frac{da}{a} + \frac{db}{b}$

$$\Rightarrow dx = \left(\frac{da}{a} + \frac{db}{b}\right)x$$

$$\text{OR \% Error} = \left(\frac{da}{a} + \frac{db}{b}\right)100\%$$

Quantities with Powers:-

Consider an equation of the form

$$q = \frac{x^a}{y^b} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Then the worst error is given by

$$(q + \delta q) = (x + \delta x)^a (y - \delta y)^{-b}$$

or $$q(1 + \frac{\delta q}{q}) = x^a y^{-b} \left(1 + \frac{\delta x}{x}\right)^a \left(1 - \frac{\delta y}{y}\right)^{-b}$$

Using equation (5) we can cancel q and $x^a y^{-b}$

$$\Rightarrow 1 + \frac{\delta q}{q} = \left(1 + \frac{\delta x}{x}\right)^a \left(1 - \frac{\delta y}{y}\right)^{-b}$$

Expanding by the binomial theorem, we get

$$1 + \frac{\delta q}{q} \approx \left(1 + a\frac{\delta x}{x}\right)\left(1 + a\frac{\delta x}{x}\right)\left(1 + b\frac{\delta y}{y}\right) \approx 1 + a\frac{\delta x}{x} + b\frac{\delta y}{y}$$

Hence the absolute and percentage errors can be given by

$$\frac{\delta q}{q} = a\frac{\delta x}{x} + b\frac{\delta y}{y} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5a)$$

and % error in q is $= a\left(\frac{\delta x}{x}\, x\, 100\%\right) + b\left(\frac{\delta y}{y}\, x\, 100\%\right)$ $\qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5b)$

Note:

1. The quantities, $\frac{\delta q}{q}, \frac{\delta x}{x}$ etc are known as relative errors. Once again, the likely error can be shown to be $\frac{\delta q}{q} = \sqrt{a^2\left(\frac{\delta x}{x}\right)^2} + \sqrt{b\left(\frac{\delta y}{y}\right)^2}$
2. The effect of each quantity on the final error depends on its power in the equation (a or b), but there is no difference between quantities in the numerator or denominator. This agrees with the three simple results already obtained.
3. The percentage error is always rounded up to whole number.

Example

If q = T^2 where T = (1.2 $\pm$ 0.2)sec, then dq = $2\frac{dT}{T} = 0.33s$.

$\Rightarrow$ q = (1.44 $\pm$ 0.33)s

General rule (Powers)

For a quantity raised to power *n*, the *total percentage error* is *n times the % error* i.e., the % error adds i.e.,

- If $q = a^n$ then $\frac{dq}{q} = n\frac{da}{a}$
- If $q = \frac{x^n}{y^m}$ $\Rightarrow$ $\frac{dq}{q} = n\frac{dx}{x} + m\frac{dy}{y}$

Error in logarithmic functions.

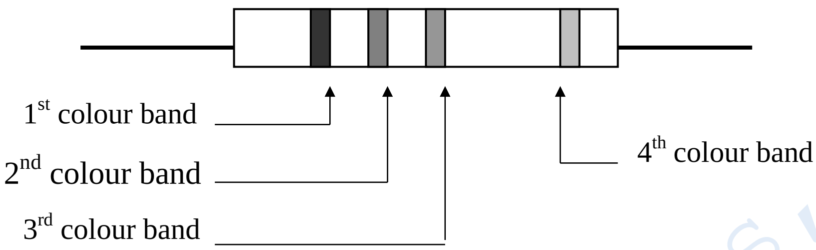
If $q = e^Z$ then $\frac{dq}{q} = dz$. Or *dq = q.dz*

If $q = \log_e z$, then $dq = \frac{dz}{z}$. Or dq = dz/z

APPENDIX B

<u>Resistor Colour Codes</u>

The value of most carbon resistors are given by manufactures using colour codes. Normally, a resistor is labeled with three of four colour bans, where the first three bands and the fourth band represent the value of resistance and the tolerance in percentage respectively as shown in the figure below



1^{st} colour band	=	1^{st} digit
2^{nd} colour band	=	2^{nd} digit
3^{rd} colour band	=	Multiplier, i.e., an index of ten (10^x), where ^{x} represents the value indicated by colour
4^{th} colour band	=	Tolerance in %

Note: The first three colours bands are always grouped slightly away from the fourth band for identification purposes.

TABLE 1: Value of colour codes in the bands

Colour	*1^{st} digit*	*2^{nd} digit*	*3^{rd} digit*
Silver			10^{-2}
Gold			10^{-1}
Black		0	10^{0}
Brown	1	1	10^{1}
Red	2	2	10^{2}
Orange	3	3	10^{3}
Yellow	4	4	10^{4}
Green	5	5	10^{5}
Blue	6	6	10^{6}
Violet	7	7	10^{7}
Grey	8	8	10^{8}
White	9	9	10^{9}

TOLERANCE

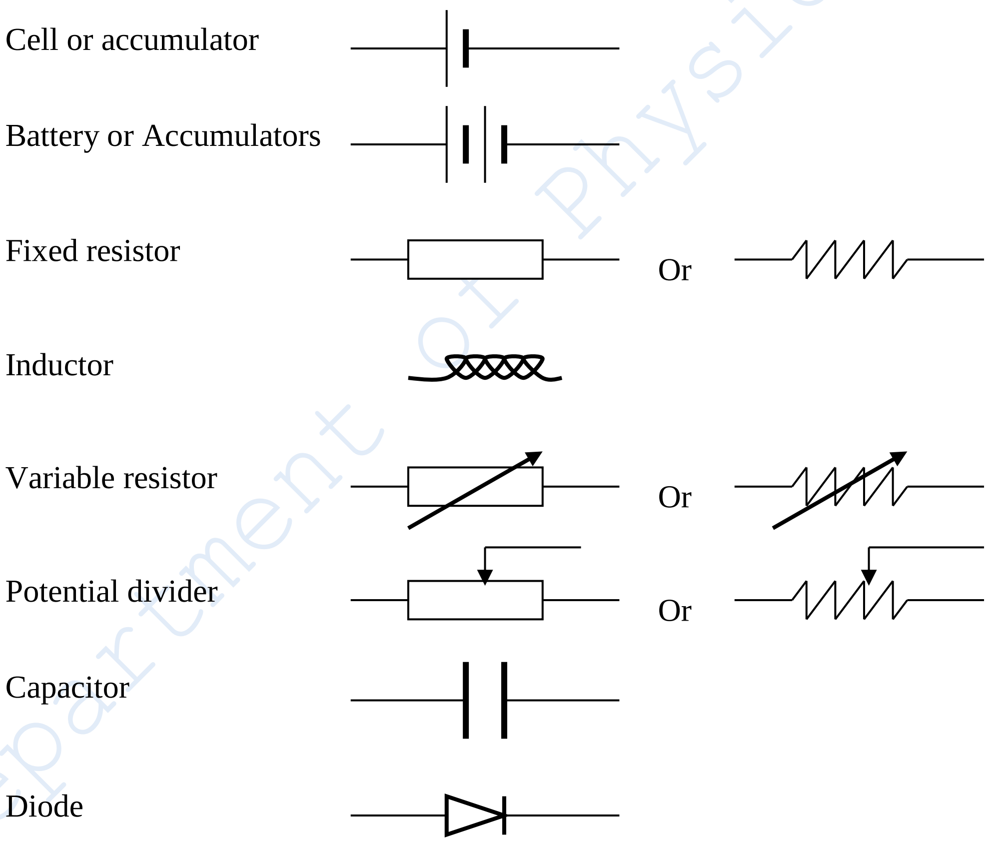
Gold	± 5 %
Silver	± 10 %
Salmon	± 20 %
No band	± 20 %

Examples

TABLE 2: If a resistor has the following colour codes, then their values are as follows:

1st colour	*2nd colour*	*3rd colour*	*Tolerance*	*VALUE*
Brawn	Black	black	No band	10 ± 20 %
Orange	White	Black	Gold	39 ± 5 %
Red	Black	Brown	Gold	200 ± 5 %
Green	Black	Brown	Silver	510 ± 10 %
Red	Red	Red	Silver	2.2K ± 20 %
Brown	Black	green	Salmon	1M ± 20 %

SOME CIRCUIT SYMBOLS



APPENDIX C

A General Introduction to the Spectrometer

A spectrometer is an optical instrument for producing and analyzing spectra (A spectrum is what you see when you white light is split into colours using a dispersing element (a **prism** or a **diffraction grating**). The importance of the spectrometer as a scientific instrument is based on a simple but crucial fact. Light is emitted or absorbed when an electron changes its orbit within an individual atom. Because of this, the spectrometer is a powerful tool for investigating the structure of atoms. It's also a powerful tool for determining which atoms are present in a substance. Chemists use it to determine the constituents of molecules, and astronomers use it to determine the constituents of stars that are millions of light years away. It can also be used to measure refractive index of a prism. A spectrometer consists of three basic components: a **collimator**, a **dispersion** element and **a telescope**. The light to be analyzed enters the collimator through a narrow slit positioned in front of the collimator. When the collimator is focused, the light leaving the collimator is a thin, parallel beam, which ensures that all the light from the slit strikes the dispersing element at the same angle of incidence. This is necessary if a sharp image is to be formed. The dispersing element bends the beam of light. If the beam is composed of many different colors, each color is dispersed to a different angle. The telescope can be rotated to collect the dispersed light at very precisely measured angles. With the telescope focused at infinity and positioned at an angle to collect the light of a particular color, a precise image of the collimator slit can be seen.