THE UNIVERSITY OF ZAMBIA

SCHOOL OF NATURAL SCIENCES

Department Of Physics

PHY 1010/1015

Laboratory Manual

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Table of contents

Introduction

This collection of experiments constitutes the introductory physics laboratory manual used by the Department of Physics, School of Natural Sciences, University of Zambia.

- Read the laboratory manual before coming to the laboratory to become familiar with the experiment. The lecture and experiment are NOT in perfect sync, so the student is expected to go through the textbook also.
- You will work with a laboratory partner to take data, but you are individually responsible for your own data. All subsequent calculations, graphs, etc. are also your own individual responsibility.

Physics Laboratory Safety Rules

1. Wear a laboratory coat during the experiment.
2. Food and drink are not permitted in the laboratory session at any time.
3. Do not set equipment too close to the edge of the table.
4. Do not activate any circuit or apparatus until the instructor inspects it.
5. Never touch a live circuit or electrical equipment with wet hands.
6. Only use laboratory equipment for the instructional purpose for which they were intended.
7. All trash and waste materials should be disposed of in the proper container.
8. Any equipment except the computer not in use should be turned off.
9. Do not take apart any apparatus or piece of equipment.
10. All damaged equipment should be immediately reported to the laboratory technical staff/instructor.
11. Accidents and emergencies must be immediately reported to the laboratory technical staff/instructor.

12. Leave your laboratory station neat, clean and organized at the end of each laboratory session.

Laboratory Report Format

A laboratory report should have the following features.

- It should be concise but also contain the necessary details and well-developed explanations.
- It should be organized.
- It should contain all the relevant information and reasoning.
- Each laboratory report will be graded out of 15 marks.

The report should have the following components in the order given.

1. Experiment title, Aims/ Objectives of the experiment.
2. Apparatus: include a list of all laboratory apparatus and equipment required in the experiment.
3. Theory: Brief summary of the theoretical background of the experiment expressed in own words including formulae where necessary.
4. Procedure: Step by step illustration of how the experiment was set up and activities performed. It should include well-labelled diagrams where necessary.
5. Data Collection: must include tables with column headings and units. Data consists of those values measured directly using the apparatus
6. Data Analysis: Manipulation of collected data using methods and equations from the theory to get answers or results as assumed in the objective.
7. Graphical Analysis: Expression of collected data in form of well labelled graphs with appropriate scales, units, title, and error bars etc.
8. Discussion: State briefly what you did in the laboratory and learned during the laboratory session. Suggestions to improve the results can be included.

9. Conclusion: Presentation of results and errors involved. Comparison of experimental data with standard values.
10. Provide answers to questions.

TUTORIAL 1

Significant Figures

The significant figures express the accuracy with which the physical quantity may be expressed. They are the digits which give useful information about the accuracy of measurement.

The greater the number of significant figures obtained when making a measurement, the more acurate the measurement. Conversely, a measurement made to only a few significant figures is not a very accurate one. For example, a measurement of 5.32 means the quantity can be relied on as accurate to three significant figures and a measurement of 5.321 is said to be accurate to four significant figures.

The following rules have been set up for determining the number of significant figures.

1. All non-zero digits are significant.

For example, 243.48 contains five significant figures.

2. All zeroes occurring between two non-zero digits are significant.

3. All zeroes to the right of a decimal point and to the left of a non-zero digit are not significant.

For example, 0.00678 contains three significant figures. The single zero conventionally placed to the left of the decimal point in such an expression is also not significant.

4. (a) All zeroes to the right of a decimal point are significant if they are not followed by a non-zero digit.

For example, 30.00 contains four significant figures.

(b) All zeroes to the right of the last non-zero digit after the decimal point are significant.

For example, 0.054300 contains five significant figures.

5. (a) All zeroes to the right of the last (rightmost) non-zero digit are not significant.

For example, 3030 contains three significant figures.

(b) All zeroes to the right of the last non-zero digit are significant if they come from a measurement.

Suppose that the distance between two objects is measured to be 3030 m. Then 3030 m contains four significant figures.

(c) A change of units does not change the number of significant figures in a measurement. For example, the length x = 2.308 cm has four significant digits. In different units, the same length can be written as x = 23.08 mm and x = 0.00002308 km. All these numbers have the same number of significant figures namely four, the digits 2, 3, 0 and 8.

Rounding Off the Digits

Rounding off a number is done to obtain its value with a definite number of significant figures. For this following are the rules:

1. If the digit to drop is less than 5, then the preceding digit is not changed. For example, 1.24 is rounded off to 1.2.
2. If the digit to drop is greater than 5, then the preceding digit is raised by 1. For example, 19.48 is rounded off to 19.5.

The International System of Units (SI Units)

These are six fundamental units of physical quantities.

Physical quantity	**Unit**
Length	M
Mass	Kg
Time	S
Temperature	K
Current	A
Amount of substance	mol

The other units are derived from the fundamental units.

TUTORIAL 2

Errors and Uncertainties

Types of errors

An error is a difference between the **real value** and the **experimental value.** There are two major types of errors in the measurement of physical quantities.

- Random error
- Systematic error

Random error

Random error occurs when repeated measurements of the quantity give different values under the same conditions. It occurs due to reasons such as parallax error, carelessness in recording reading or wrong techniques. The random error can be reduced by taking several readings of the same quantity and then taking their mean value.

Systematic error

Systematic errors occur when all the measurements of physical quantities are affected equally, these give the consistent difference in the readings. Systematic errors may occur due to:

- Zero error in measuring instrument
- Poor calibration of the instrument
- Incorrect calibration on the measuring instruments.

Systematic errors can be reduced by comparing the instrument with another instrument that is known to be more accurate. It is reduced by applying a correction factor to all the readings taken on an instrument.

Precision and Accuracy

Accuracy is the closeness of the **measured values** to the **true value.**

Precision is the closeness of the **measured values to each other:** the closer they are to each other, the more precise they are.

Uncertainty in Measurement

The **interval** in which the **true value** lies is called the uncertainty in the measurement.

The absolute uncertainty in the mean value of measurements is half the **range of the measurements.**

For example, the measurements of the diameter of a pin are as follows.

0.25mm, 0.24mm, 0.26mm, 0.23mm, 0.27mm.

$$\text{Mean} = \frac{(0.25 + 0.24 + 0.26 + 0.23 + 0.27)}{5} = 0.25 \text{ mm}$$

Range = 0.27 - 0.23 = 0.04mm

Absolute Uncertainty = ± 0.04/2 = ± 0.02

So, the mean value of diameter = 0.25 ± 0.02 mm

Percentage Uncertainty

$$\text{Percentage uncertainty} = \left(\frac{\text{Absolute uncertainty}}{\text{Mean value}}\right) \times 100$$

In the above example,

$$\text{Percentage uncertainty} = \left(\frac{0.02}{0.25}\right) \times 100 = 8\%$$

Sometimes, the **resolution** of the device - the smallest measurement possible - is taken as the absolute uncertainty.

For example, for a meter rule, the resolution is 1 mm and hence the absolute uncertainty in the measurements using a meter rule is 1 mm. If the device is a Vernier Calliper, the resolution 0.01mm is the absolute uncertainty.

Combining Uncertainties

Case 1

When physical quantities are added or subtracted in an equation, the absolute uncertainty of each value is added together.

Example

Length of a copper wire at 30°C = 18.2mm ± 0.04 cm and at 60°C 19.7mm ± 0.02 cm. Find the absolute uncertainty and the extension of the wire.

Absolute uncertainty = 0.04 + 0.02 = 0.06

Extension of the wire = (19.7 - 18.2) ± 0.06 = 1.5 ± 0.06 mm

Case 2

When physical quantities are multiplied or divided in an equation, the percentage uncertainty of each value is added together.

Example

The weight of an iron block is 8.0 ± 0.3 N and is placed on a wooden base of area, 3.5 ± 0.2 m^2. Find the percentage uncertainties of the values and then calculate the pressure exerted by the block.

$$\text{Percentage uncertainty in weight} = \left(\frac{0.3}{8}\right) \times 100 = 3.75$$

$$\text{Percentage uncertainty in area} = \left(\frac{0.2}{3.5}\right) \times 100 = 5.71$$

Percentage uncertainty = 3.75 + 5.71 = 9.46

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}} = \frac{8}{3.5} = 2.3 \text{ Pa}$$

$$\text{Absolute uncertainty in pressure} = \left(\frac{9.46}{100}\right) \times 2.3 = 0.22$$

Since both the weight and the area have been approximated to two significant figures, the final answer must take the same form:

Pressure = 2.3 ± 0.22 Pa

Case 3

When a measurement is raised to the power **n**, the percentage uncertainty is multiplied by **n**.

Example

Suppose the length of a cube is 5.7 ± 0.2 cm. Then to find the absolute uncertainty in the volume,

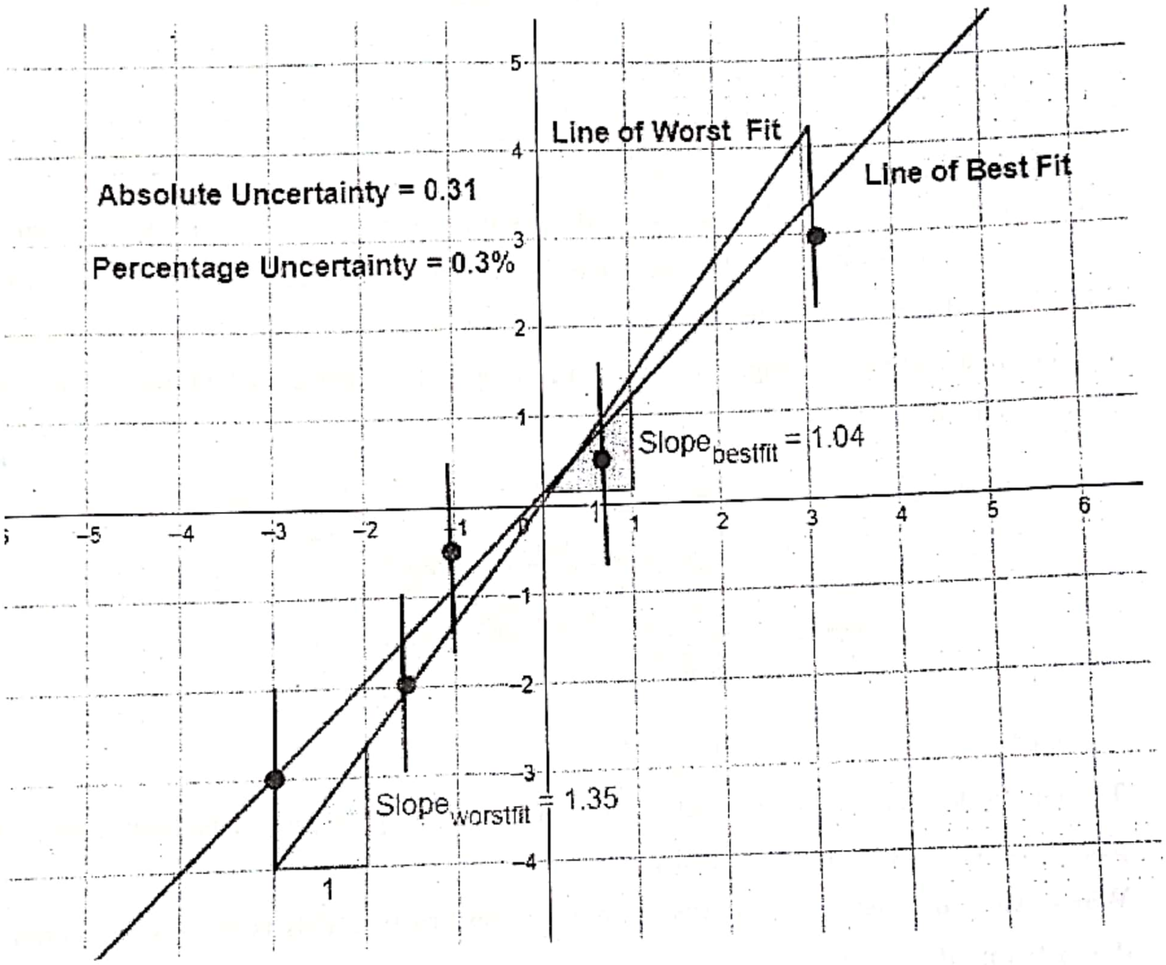
Volume = 5.7^3 = 190 cm^3

Percentage uncertainty in volume = 3 × (0.2/5.7) x 100 = 10.5%

Absolute uncertainty in the volume = 190 ± 10.5 cm^3

Error bars, line of best fit and line of worst fit

When data is plotted based on the experimental data, an error bar can be created for each data point, either vertically, horizontally or even in both directions.



If the absolute uncertainty is b and the y value is a,

y values of error bar = a ± b

This way, error bars can be constructed for each data point. Then, the line of best fit and the line of worst fit - connecting the lowest error bar value and the highest error bar value - can be drawn.

Absolute Uncertainty = Positive value of the difference of gradient between the line of best fit and the line of worst fit

$$\text{Percentage uncertainty} = \left(\frac{\text{Absolute uncertainty}}{\text{gradient of the line of best fit}}\right) \times 100$$

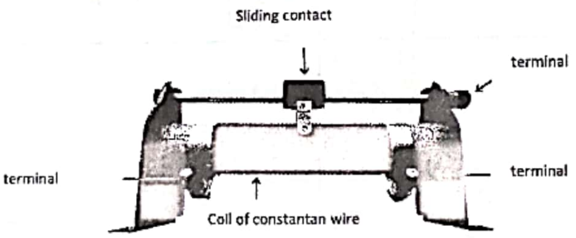
Absolute uncertainty in the above example = |1.04 - 1.35| = 0.31

$$\text{Percentage uncertainty in the above example} = \left(\frac{0.31}{1.04}\right) \times 100 = 0.3\ \%$$

TUTORIAL 3

Rheostat

A rheostat is a wire-wound resistor around a hollow tube with three terminals as shown. A fixed voltage is usually applied between the two fixed terminals. The output voltage is taken from a fixed terminal and the variable terminal. By changing the position of the variable terminal one can get a voltage ranging from zero up to the voltage applied between the two fixed terminals.



Terminals at the bottom are fixed.

Terminal at the top; sliding contact can be shifted to change values of resistance with any point between the two fixed terminals.

When using the rheostat, you must note its current rating. This is usually indicated on the instrument. Do not allow a current higher than the specified one to pass through the rheostat. If you do, the rheostat will be damaged/burnt, and you will be held responsible.

Experiment 1

VERNIER CALIPERS

Aim

The aim of the experiment is to measure

1. the thickness and breadth of a flat plate
2. the internal and external diameter of a hollow cylinder and
3. the depth of a blind hole cylinder with a Vernier calliper.

Apparatus

Vernier calliper, flat plate, hollow cylinder and blind hole cylinder

Description of the Vernier calliper: Vernier calliper was invented by the French mathematician Pierre Vernier. It is used to measure the length of a rod or cylinder, diameter of a sphere, the internal and external diameters of a hollow cylinder and the depth of a small vessel. The construction of a Vernier calliper is shown in the following labelled diagram.

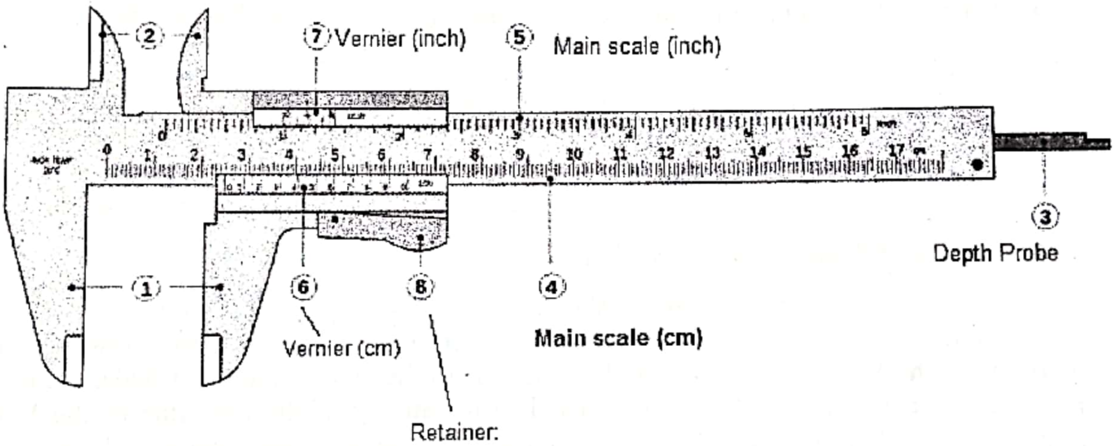


Figure 1.1: Parts of a Vernier calliper

1. **Outside jaws**: used to measure external dimensions of an object.
2. **Inside jaws**: used to measure the internal dimensions of an object.
3. **Depth probe**: used to measure depth of an object
4. **Main scale** (cm)
5. **Main scale** (inch)
6. **Vernier** (cm)
7. **Vernier** (inch)
8. **Retainer**: used to retain the object within the jaws of the Vernier callipers.

The **main scale** consists of a steel metallic strip graduated in centimetres at one edge and inches at the other edge. It carries the inner and outer measuring jaws. When the two jaws are in contact, the zero of the main scale and the zero of the Vernier scale should coincide.

A **Vernier scale** slides over the main scale and is graduated with a number of divisions. The Vernier scale can be fixed at any position on the main scale using a retainer.

There are two jaws perpendicular to the main scale. One of the jaws is fixed at the left end of the main scale and other jaw is fixed on the frame of the Vernier scale. The lower outside jaws are used to measure the length or the external diameter of an object (rod or cylinder) and the upper jaws are used to measure the internal diameter of a hollow cylinder. The Vernier calliper is provided with a long thin strip attached at the back of the Vernier scale. This strip is used to measure the depth of any small vessel.

Least count: The least distance which can be measured accurately by an instrument is called the least count of that instrument.

Least Count (LC) = smallest Main Scale Division (MSD) ÷ total Vernier Scale Division (VSD)

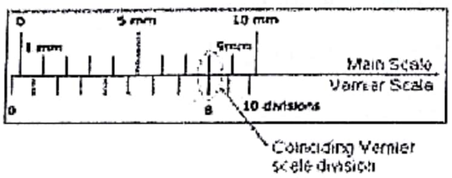
OR

$$Least\ Count\ (LC) = \frac{smallest\ Main\ Scale\ Division\ (MSD)}{total\ Number\ of\ divisons\ on\ vernier\ scale}$$

Zero Error and Zero Error Correction

To find the zero error, shut the jaws of Vernier Callipers gently. If the zero line of the Vernier range coincides with the zero of the main scale then the zero error is zero. However, if the zero line of the Vernier scale gets on the right side of the zero of the main scale, the error is positive and correction should be subtracted. Alternatively, if the zero line of the Vernier scale is on the left side of zero of the main scale the error is negative and the correction should be added.

Negative Error



Calculation of Negative error

Coinciding vernier scale div = 8

Difference = Total div. - Coinciding div.

= 10 - 8 = 2

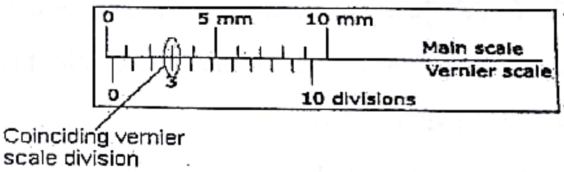
Now, Zero error = Difference X Least count

= 2 X 0.01cm

= -0.02 cm

The minus sign indicates the negative error in vernier caliper.

Positive Error



Calculation of Positive error:

Coinciding vernier scale Div. = 3

Zero Error = Coinciding V.S Div. X Least count

= 3 X 0.01cm

= +0.03cm

Thus it is positive error it is indicated with "+".

Figure 1.2. Negative Zero Correction **Figure 1.3. Positive Zero Correction**

Procedure

1. Determine the least count of the Vernier calliper given to you using the formula given above

2. Fix the flat plate between the jaws and note the main scale reading (i.e., Note the main scale division by which the zero mark of the Vernier scale is ahead).

3. Now find the Vernier scale reading. For this, note the Vernier scale division which coincides with any of the main scale division. Multiply this number of the Vernier division with the least count to get the Vernier scale reading.

4. Find the total reading by adding the main scale and Vernier scale readings.

5. Repeat the experiment and note the readings at different places along the flat plate and find their mean.

6. Repeat the same procedure for the hollow cylinder and blind hole cylinder.

Data

The least count of the Vernier calliper is = ...cm

1. Measurement of the thickness of the flat plate

Table 1.1 Data Collected

No.	Main Scale reading (MSR) cm	Vernier Scale Reading (VSR)		Total reading = MSR+VSR cm
		Coinciding division of Vernier scale	VSR = coinciding division of Vernier × least count cm	
1				
2				
3				
4				
5				

Mean thickness of the flat plate = ... cm

2. Measurement of the breadth of the flat plate

Table 1.2: Data Collected

No.	Main Scale Reading (MSR) cm	Vernier Scale Reading (VSR)		Total reading = MSR+VSR cm
		Coinciding division of Vernier scale	VSR = coinciding division of Vernier × least count cm	
1				
2				
3				
4				
5				

Mean breadth of the flat plate = ... cm

3. Measurement of the internal diameter of the hollow cylinder

Table 1.3: Data Collected

No.	Main Scale Reading (MSR) cm	Vernier Scale Reading (VSR)		Total reading = MSR + VSR cm
		Coinciding division of Vernier scale	VSR = coinciding division of Vernier × least count cm	
1				
2				
3				
4				
5				

Mean internal diameter of the hollow cylinder = ... cm

4. **Measurement of the external diameter of the hollow cylinder**

Table 1.4: Data Collected

No.	Main scale reading (MSR) cm	Vernier Scale Reading (VSR)		Total reading = MSR+VSR cm
		Coinciding division of Vernier scale	VSR = coinciding division of Vernier × least count cm	
1				
2				
3				

Take five (5) Readings

Mean external diameter of the hollow cylinder = ... cm

5. Measurement of the length (depth) of the blind hole cylinder

Table 1.5: Data Collected

No.	Main scale reading (MSR) cm	Vernier Scale Reading (VSR)		Total reading= MSR + VSR cm
		Coinciding division of Vernier scale	VSR = coinciding division of Vernier × least count cm	
1				
2				
3				

Take five (5) readings

Mean length of the blind hole cylinder = ... cm

Results

1. Thickness of the flat plate = ... cm
2. Breadth of the flat plate = ... cm
3. Internal diameter of the hollow cylinder = ... cm
4. External diameter of the hollow cylinder = ... cm
5. Length of the blind hole cylinder = ... cm

Precautions

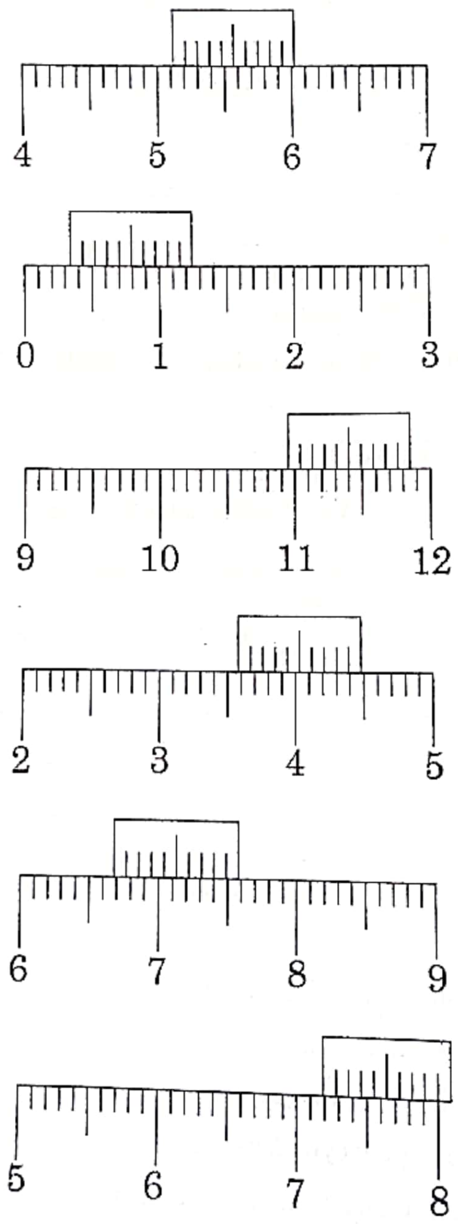
(1) The object should not be pressed too hard or kept too loose in between the jaws.

(2) While taking the readings, the eyes must be kept perpendicular to the scale.

(3) To avoid the non-uniformity of the object, the readings should be taken at different points along the object.

Questions

State the reading on the Vernier callipers in each case.



Experiment 2

MICROMETER SCREW GAUGE

Aim

The aim of the experiment is

- to measure the diameter of the given marble and calculate its volume
- to measure the diameter of the given wire and find its volume.

Apparatus

Micrometer screw gauge, meter rule, marble, wire

Description of the micrometre screw gauge:- A micrometre screw gauge is used for measuring dimensions smaller than those measured by the Vernier calliper. It can be used for measuring accurately the diameter of a thin wire or the thickness of a sheet of metal.

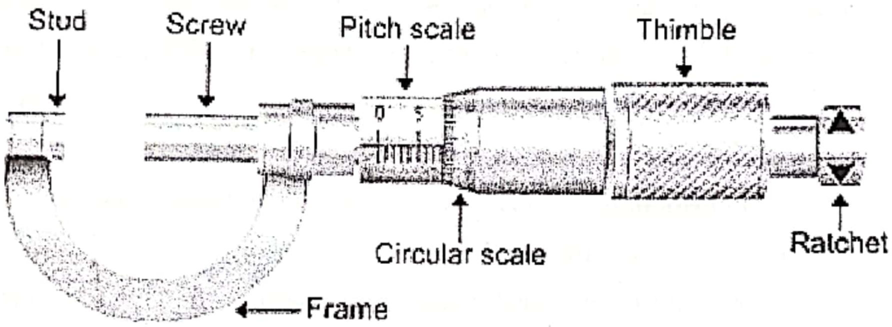


Figure 2.1: Parts of a micrometre screw gauge

It consists of a U-shaped frame fitted with a screwed spindle which is attached to a thimble. Parallel to the axis of the thimble, a scale graduated in **mm** is engraved. This is called the **pitch scale**. A sleeve is attached to the head of the screw. The head of the screw has a ratchet which avoids undue tightening of the screw. On the thimble, there is a circular scale known as the **head scale** which is divided into 50 equal parts. When the screw is worked, the sleeve moves over the pitch scale. A stud with a plane end surface called the anvil is fixed on the 'U' frame exactly opposite to the tip of the screw. When the tip of the screw is in contact with the anvil, usually, the zero of the head scale coincides with the zero of the pitch scale.

Pitch of the Screw Gauge

The pitch of the screw is the distance moved by the spindle per revolution. To find this, the distance advanced by the head scale over the pitch scale for a definite number of complete rotations of the screw is determined.

$$\text{Pitch of the screw} = \frac{\text{Distance moved by the screw}}{\text{Number of complete rotations}}$$

Least Count of the Screw Gauge

The Least count (LC) is the distance moved by the tip of the screw when the screw is turned through 1 division of the head scale. The least count can be calculated using the formula

$$\text{Least Count (LC)} = \frac{\text{Pitch}}{\text{Total number of divisions on the circular scale}}$$

Zero Error and Zero Correction

To get the correct measurement, zero error must be considered. For this purpose, the screw is rotated forward till the screw just touches the anvil and the edge of the cap is on the zero mark of the pitch scale. The screw gauge is held keeping the pitch scale vertical with its zero downwards.

When this is done, anyone of the following three situations can arise:

1. The zero mark of the circular scale comes on the reference line. In this case, the zero error and the zero correction, both are nil.
2. The zero mark of the circular scale remains above the reference line and does not cross it. In this case, the zero error is positive depending on how many divisions it is above the reference line.
3. The zero mark of the circular scale is below the reference line. In this case, the zero error is negative depending on how many divisions it is below the reference line.

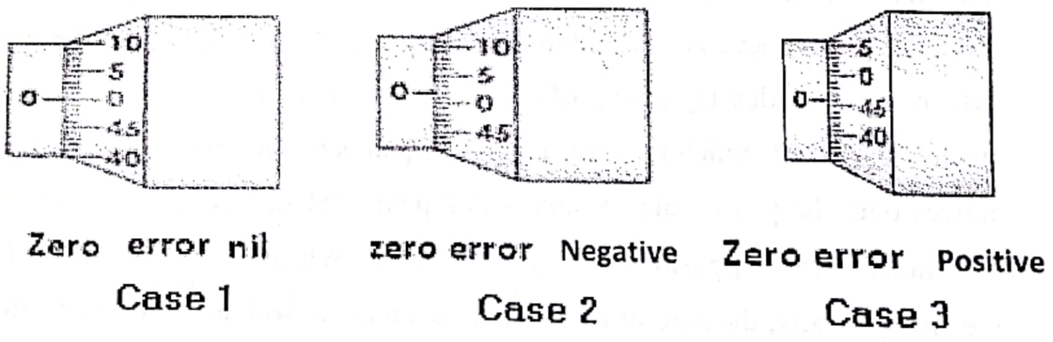


Figure 2.2: Zero Errors

Zero error = 0 mm　　Zero error = - 0.02 mm　　Zero error = +0.04 mm

No zero error correction Zero correction = +0.02mm Zero correction = -0.04mm

Procedure

1. To find the diameter of the marble

The object is placed between the jaws which are moved by the thimble. The ratchet knob is used to adjust the object firmly between the jaws. The pitch scale reading is taken by considering the marking on the sleeve which is visible just to the left of the thimble. It is also important to note that the 0.5 mm divisions that are provided below the main scale should also be considered while taking the reading. This is known as Pitch Scale Reading (PSR). The Head Scale Reading (HSR) is taken by observing the marking on the thimble that coincides with the main scale on the sleeve.

Head Scale Reading (H.S.R.) = coinciding division x Least Count of screw gauge
Total reading (T.R.) = PSR + HSR+ zero correction
Repeat the experiment three times and record the observations in each set in a tabular form.

If D be the mean diameter of the marble, then, the volume of the marble is given by the following equation

$$V = \frac{4}{3}\pi\left(\frac{D}{2}\right)^3$$

2. To find the diameter of the wire

Measure the length of the wire using a metre rule.

Place the wire between the anvil and the screw and note down the PSR and HSR. Find the total reading as before.
If r is the radius of the wire, and l is the mean length of the wire, then, the volume of the wire is given by

$$V = \pi r^2 l$$

Data

Determination of the Least Count of the micrometre

The number of divisions on the thimble = ...
Distance moved by screw for one revolution of the thimble =........... mm
Pitch = ...

Number of divisions on the circular scale = …….

Hence, least count = …………………..mm

Zero Error

zero error (e) = ………..mm

zero correction (c) = …….mm.

Table 1:- To find the diameter of the marble

No.	PSR	HSR = coinciding division×least count (mm)	PSR+HSR	Total reading=PSR+HSR+zero correction (mm)
1				
2				
3				
4				
5				

Mean diameter of the marble=……………………..mm

Find the volume of the marble using the equation given. Show your working.

Table 2:- To find the diameter of the wire

No.	PSR	HSR = coinciding division×least count (mm)	PSR+HSR	Total reading=PSR+HSR+zero correction (mm)
1				
2				
3				
4				
5				

Mean diameter of the wire =………………………..mm

Find the volume of the wire using the equation given. Show your working.

Results:

Diameter of the marble =……………………..mm

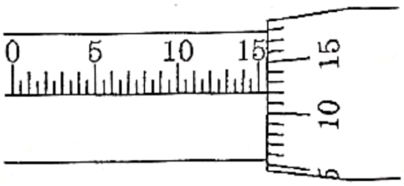
Volume of the marble =.............................mm

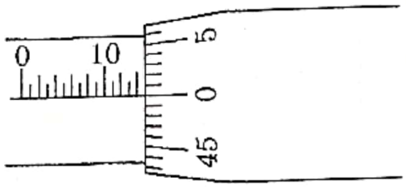
Diameter of the wire =.............................mm

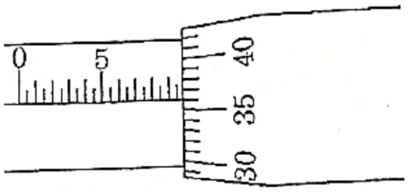
Volume of the wire =.............................mm

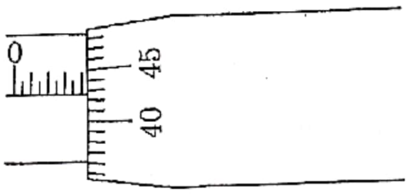
Questions

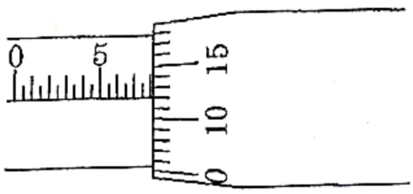
State the reading on the Micrometre screw gauge in each case.

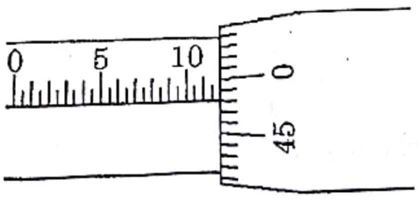












Experiment 3

MEASUREMENT OF ACCELERATION DUE TO GRAVITY

Aim

The aim of this experiment is to measure the acceleration due to gravity (g) by the free-fall method.

Apparatus

Millisecond timer, metal ball, trapdoor and electromagnet.

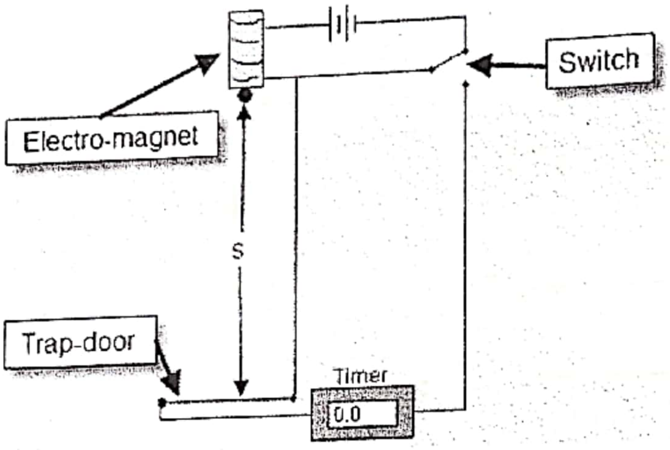


Figure 3.1: Acceleration due to gravity apparatus set up

Theory

The equation of motion for free fall is given by

$$S = ut + \frac{1}{2} at^2$$

Since the ball begins from rest (u=0 m/s) and the acceleration is the acceleration of free fall, the above equation reduces to

$$S = \frac{1}{2} gt^2.$$

Cross-multiply to get g.

$$g = \frac{2S}{t^2}$$

The value of g can be calculated graphically as follows.

Comparing the equation $S = \frac{1}{2}gt^2$ to the equation of a straight line

$$y = mx + c$$

shows that if a graph is plotted with t^2 along the X-axis and S against the Y-axis would be a straight line passing through the origin. The gradient of this graph would be

$$\text{gradient} = \frac{1}{2}g$$

Therefore, acceleration due to gravity, g = 2×gradient

Procedure

1. Set up the apparatus as shown in figure 3.1.
2. Measure the distance S using a metre rule.
3. Flick the switch (to switch off the power for the electromagnet) to release the ball. The millisecond timer starts when the ball is released and stops when the ball hits the trapdoor. Record the time from the millisecond timer. Repeat this several times and find a mean value of time (t).
4. Repeat the experiment for different values of S.
5. Calculate the values for g using the equation $S = (g/2)\,t^2$. Obtain an average value for g.
6. To find the value of g using a graphical method, draw a graph of S against t^2 and use the gradient to find a value for *g*.

Sample Data

Table 3.1: Data Collected

Height S (cm)	Time of free fall (s)					Mean time (t) s	t^2 s^2	Theoretical g ms^{-2}
	1	2	3	4	5			
80	0.395	0.412	0.408	0.395	0.405			
70	0.375	0.365	0.376	0.383	0.381			
60	0.350	0.348	0.347	0.352	0.345			
50	0.321	0.324	0.315	0.317	0.325			
40	0.281	0.275	0.286	0.278	0.283			
30	0.251	0.254	0.245	0.247	0.250			
20	0.201	0.198	0.195	0.208	0.205			
10	0.153	0.134	0.148	0.152	0.132			

RESULTS

The acceleration due to gravity using theoretical method =...............................

The acceleration due to gravity using graphical method =...............................

NOTE

Even though you switch off the power for the electromagnet (and in so doing switch on the timer) it will not lose its magnetism immediately, therefore the ball will not fall straight away. This means that the reading on the timer will always be (slightly) longer than the time for which the ball was dropping.

Experiment-4

STRETCHING OF SPRINGS: -HOOKE'S LAW

Aim:- The aim of this experiment is

(i) to measure the extension produced in spring for various loads

(ii) to determine the spring constant of the spring.

Apparatus

Rigid stand and clamp, spring, metre rule, masses and scale pan

Theory

Hooke's Law states that when a force is applied to a spring, the extension of that spring will be directly proportional to the amount of force applied.

This can be written as

$$F \propto x$$

where x is the extension produced in the spring and F=Mg is the force applied where M is the mass which produces the extension and g is the acceleration due to graviy.

$$F = kx$$

where k = the spring constant, the rate at which the spring is displaced **(N/m)**.

Procedure

- Set up the apparatus as shown below.
- The spring is fixed at one end of the clamp, hanging parallel to the ruler (meter scale).
- Fix the pin at the lower end of the spring such that it moves lightly over the vertical metre rule.

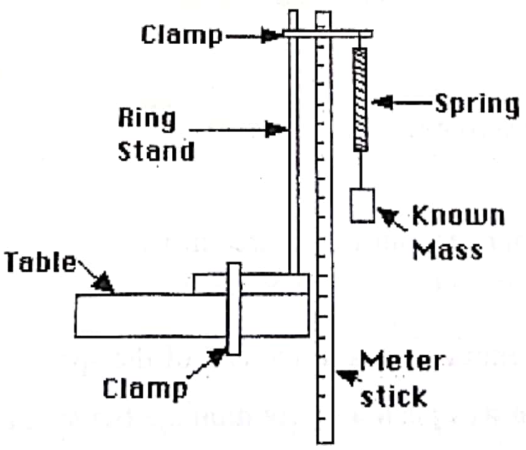


Figure 4.1: Hooke's Law apparatus

- Note down the pointer reading when no mass is added to the scale pan (original length).
- Place a mass of 50 g on the scale pan. The spring starts to extend downwards. Note down the pointer reading (stretched length).
- The extension is calculated using the following equation.

  Extension= stretched length-original length

- Go on increasing the mass in the scale pan and for each mass, record the position of the pointer. You should obtain at least **six** readings.
- Repeat the experiment for decreasing load and record all your readings in the table.

Data

Table 4.1: Data Collected

Mass (kg)	Weight (N)	Pointer readings		Extension		Mean extension (x)
		Increasing load mm	Decreasing load mm	Increasing load mm	Decreasing load mm	mm

- Plot a graph of weight against extension, choosing the correct origin and scales. Determine the gradient of the graph. Use the gradient to calculate the spring constant. Give the value of the calculated k in S.I. units.

Results

The spring constant of the spring=……………………..Nm^{-1}

Safety Notes:

- Be sure to keep your feet out of the area in which the masses will fall if the spring breaks!
- You need to hang enough mass to the end of the spring to get a measurable stretch, but **too much force will permanently damage the spring**. In such a case, the spring will exceed its "*elastic limit*".

Experiment 5

THE VIBRATION MASS-SPRING SYSTEM

Aim:- The aim of the experiment is to measure the period of oscillations for different loads and hence determine the spring constant.

Apparatus:- Rigid stand and clamp, spring, metre rule, masses and scale pan, stopwatch

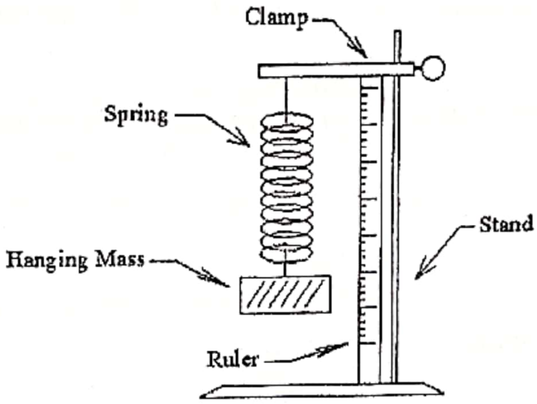


Figure 5.1: Mass-spring system

Theory

When a loaded spring is stretched beyond its equilibrium position and then released, it will start vertical vibrations. The period of vibration (T) is the time required to complete one vibration.

Let M= mass of the applied load

m= mass of the scale pan

s= mass of the spring

k= the spring constant.

Then,
$$T = 2\pi\sqrt{\frac{(M+m+s/3)}{k}}$$

$$T^2 = 4\pi^2 \frac{(M+m+s/3)}{k}$$

$$T^2 = \frac{4\pi^2}{k}\ (M+m+s/3)$$

Comparing this equation with the equation of a straight line shows that if a graph is plotted with T^2 along the Y-axis and (M + m + s/3) along the X-axis, the gradient of the graph will be $\frac{4\pi^2}{k}$.

Procedure

- Set up the apparatus as shown.
- The spring is fixed at one end of the clamp, hanging parallel with the metre rule.
- Add a load M to the scale pan and set it in vertical vibrations. Obtain the time taken for 20 oscillations twice.
- Find the mean time (t) for 20 vibrations and hence find the period (T = t/20).
- Repeat the measurements with different loads. Take the readings for 20,40,60,80 and 100 grams.
- Obtain the mass of the scale pan and the spring using the balance.

Data

Mass of the scale pan, m =....................

Mass of the spring, s =..................

Effective mass of the spring, s/3 = ...

Table 5.1: Data Collected

Mass (M) (g)	(M+m+s/3) (g)	Time for 20 vibrations		Mean time (t) for 20 vibrations (s)	Period (T) (s)	T^2 (s^2)
		t_1 (s)	t_2 (s)			

- Plot a graph of T^2 on the Y-axis and (M + m + s/3) on the X-axis. Determine the gradient of the graph. Use the gradient to calculate the spring constant.

Result

The spring constant of the spring =........................

Experiment 6

SIMPLE PENDULUM

Aim

The aim of the experiment is to measure the acceleration due to gravity (g) by measuring the period of oscillations of a simple pendulum.

Apparatus

Pendulum bob, String, Metre Ruler, Clamp and Stand, Stopwatch

Theory

A simple pendulum is made of a long string and a tiny sphere made of wood, steel or lead. When displaced to an initial angle and released, the pendulum will swing back and forth with the periodic motion. For a simple pendulum, the period is the time taken to complete one full oscillation.

The period of oscillation of a simple pendulum may be found by the formula

$$T = 2\pi\sqrt{\frac{l}{g}}$$

where 'l' is the length of the pendulum and 'g' is the acceleration due to gravity.

$$T^2 = \frac{4\pi^2}{g}l$$

If a graph is plotted with l along the X-axis and T^2 along the y-axis, the graph would be a straight line passing through the origin.

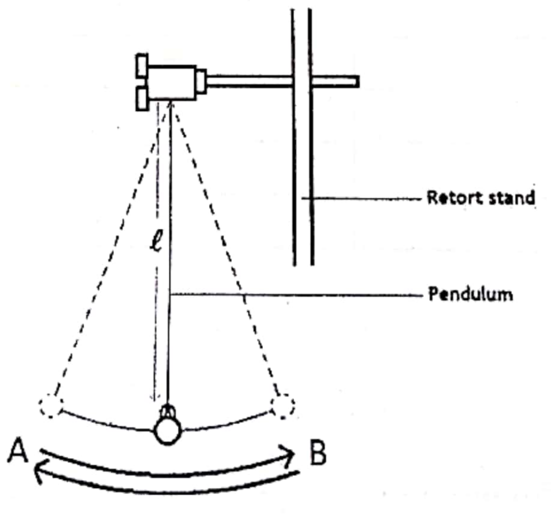


Figure 6.1: A Simple pendulum

Procedure

- Suspend the pendulum bob from the clamp attached to the clamp stand so that the pendulum length is 0.30m.
- Displace the pendulum by angle less than 10° from the vertical to set it in simple harmonic motion.
- Measure the time taken for the pendulum to complete 20 oscillations. Repeat this twice or more and take an average. Find the time taken for one oscillation (T).
- Repeat the experiment for pendulums of length: 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1.0m.
- Plot a graph of pendulum length, *l*, against T^2
- Plot a line of best fit and calculate its gradient. Find the acceleration due to gravity g.
- Calculate the percentage difference of your value from the accepted value.

Data

Table 6.1 Data Collected

Length (*l*) m	Time for 20 oscillations		Average time(t) s	Period (T)= t/20 s	T^2 s^2
	t_1 s	t_2 s			
0.3					
0.4					
0.5					
0.6					
0.7					
0.8					
0.9					
1.0					

Result

Acceleration due to gravity =........................m/s^2

Experiment 7

SPECIFIC LATENT HEAT OF FUSION OF ICE

Aim

The aim of the experiment is to measure the specific latent heat of fusion of ice using the law of conservation of energy.

Apparatus

A copper calorimeter in lagging , Thermometer, ice blocks, Stop watch

Theory

In a solid the molecules are held together more or less rigidly within a crystalline structure by the mutual attraction of the atoms or molecules. If the solid is to change state and become a liquid, its molecules must absorb energy so as to increase the separation between the molecules. When the molecules gain enough energy to slide over one another, the solid turns into a free-flowing liquid.

One method of providing energy to a solid is to heat it. The heat energy absorbed by the solid results in an increase in the separation of molecules. In other words, the molecular potential energy is increased and not the molecular kinetic energy. Therefore, the heat absorbed by the solid does not result in a temperature rise as the solid changes into a liquid.

The quantity of heat absorbed by each gram of a solid in changing into a liquid is called latent heat of fusion of the substance.

Let ΔQ_f = heat of fusion

ΔQ_i = heat change of the ice-water mixture

ΔQ_w = heat change of warm water

ΔQ_c = heat change of the calorimeter

Note that a heat change ΔQ is positive if heat is absorbed and negative if heat is lost.

From the law of conservation of energy,

Heat lost = heat gained

Hence $$\Delta Q_f + \Delta Q_i + \Delta Q_w + \Delta Q_c = 0$$

Let the specific heat of water (C_w) = 4.184 J/g°C and C_c be the specific heat capacity of the material of the calorimeter.

Figure 7.1: A calorimeter

Procedure

Part A: Determination of the specific heat capacity C_C of the calorimeter

- Measure the mass of the calorimeter (M_c) and fill it to half-full with water at room temperature θ_1.
- Measure the mass of the calorimeter plus water at temperature θ_1.
- Place the calorimeter back into the container with the lagging and add about 30 ml of water heated to a temperature θ_2 (about 40°C).
- Replace the cover at once, insert the thermometer and stir gently. After some time the temperature of the mixture reaches a steady value θ_3. Record this temperature.
- Weigh the calorimeter with water at temperature θ_3.

Data

Mass of the calorimeter (M_C) = ...g

Mass of (calorimeter + water at temperature θ_1) = $M_C + M_W$=............g

Mass of (calorimeter + water at temperature θ_1 + water at temperature θ_2),

$M_C + M_W + m$ = ...g

Here, M_W corresponds to the mass of water at temperature θ_1 and m the mass of water at temperature θ_2.

Temperature θ_1 =.........

Temperature θ_2=......... (Read this temperature before adding water into the calorimeter)

Temperature θ_3 =.........

From the law of conservation of energy, it follows that

$$(M_C C_C + M_W C_W)(\theta_3 - \theta_1) = mC_w(\theta_2 - \theta_3)$$

The above equation is used to calculate the value of C_C.

Compare your value with the correct value, 390 $JKg^{-1} K^{-1}$ (0.093 cal $g^{-1} C^{-1}$) and calculate the percentage of error of your result. Given that CW= 1 cal g^{-1} $°C^{-1}$ = 4184 $J.Kg^{-1}K^{-1}$

Part B: Determination of latent heat of fusion of ice

- Empty the calorimeter, dry it and weigh it.
- Add water at room temperature θ_1 into the calorimeter to make it about half-full and weigh it.
- Select two or three medium sized pieces of ice and wipe them dry. Keep the cover of the calorimeter ready with the thermometer in place. Add the ice into the calorimeter, replace the cover and start the stop watch immediately. Record the temperature every 15 seconds while stirring gently.
- After about 10 readings, start to take readings every 30 seconds, while stirring.
- Once the reading reaches θ_2 (lowest steady temperature), start taking readings every minute and after about five minutes continue to take readings every 2 minutes for about 15 minutes.
- Weigh the calorimeter.

Data

Mass of the calorimeter = M_C= ....g

Mass of (calorimeter + water at temperature θ_1) = $M_C + M_W$= ....g

Mass of (calorimeter + water + ice water) = $M_C + M_W + m$ = ...g

Temperature θ_1 =.................

Table 7.1.

Time(t) s	Temperature (θ) °C

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To find θ_3, the minimum temperature reached, the following graphical method is used.

- Plot a graph of temperature (θ) against time (t). The graph is expected to be as shown below.

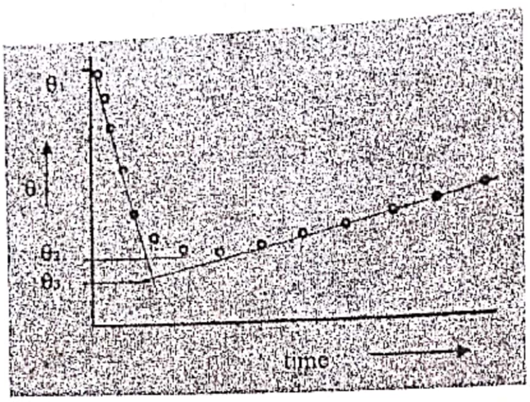

Figure 7.2. Graph of Temperature (o) Vs Time t (sec)

- Draw the asymptotes as shown and determine θ_3. Calculate the various heat changes.

ΔQ_W = heat exchange of water at temperature $\theta_1 = M_W C_W (\theta_3 - \theta_1)$

ΔQ_C = heat exchange of calorimeter at temperature $\theta_1 = M_C C_C (\theta_3 - \theta_1)$

ΔQ_i = heat used by water (formed from ice) to reach the temperature $\theta_3 = m\, C_W\, \theta_3$

Note that the temperature of melting ice is 0°C. Therefore, heat used to change ice into water is

$$\Delta Q_f = (M_w C_w + M_C C_C)(\theta_3 - \theta_1) - mC_w\theta_3$$

Latent heat of fusion of ice, $L_f = \frac{\Delta Q_f}{m}$

Results

Specific latent heat of fusion of ice = ...

Questions

1. Compare your experimental result with the standard value (335 kJ/kg).
2. Calculate the percentage of error. Comment on your result.

Experiment 8

OHM'S LAW

Aim

The aims of the experiment are as follows.

1. Verification of Ohm's Law
2. To determine the resistance of a resistor by plotting a graph of potential difference (V) versus current (I) using Ohm's Law.

Apparatus

Battery, Ammeter, Voltmeter, Resistor, rheostat, Switch, filament lamp.

Theory

The current flowing through a resistor is directly proportional to the voltage across the resistor, if the temperature is constant.

$$\frac{V}{I} = constant$$

$$\frac{V}{I} = R \qquad (1)$$

$$V = IR$$

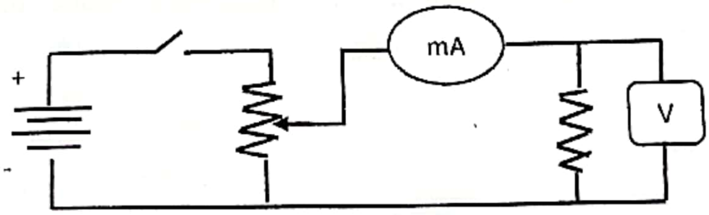

Figure 8.1: Circuit diagram

Procedure

Part I- Voltage - current (V-I) characteristics of a fixed resistor

- Connect the circuit as shown in figure 8.1. DO NOT switch power on until circuit is checked.
- After the demonstrator inspects and approves the circuit, switch the power on.
- Record the current passing through the ammeter and the potential difference across the resistor using an ammeter and the voltmeter respectively.
- By adjusting the rheostat, take at least six sets of data for different voltage and current values. Plot a graph of voltage (y-axis) against current (x-axis).
- Theoretically, the resistance of the resistor can be found by using equation (1). Graphically, resistance can be found by taking the gradient of the graph.

  Resistance = gradient of the V-I graph.

Data

Table 8.1: Data Collected

NO.	Voltage (V) Volts	Current (I) Amps	Resistance (R) $\frac{V}{I}$ Ohms
1			
2			
3			
4			
5			
6			

Resistance obtained from the graph = ……………………….

Part II- Voltage- current (V-I) characteristics of a filament lamp

- Repeat the experiment with the resistor replaced by a filament lamp.
- Plot a graph of voltage against current and determine the resistance of the filament from the slope of the graph as in the first part.

Risk assessment

Table 8.2: Precaution

Hazard	Risk	Control measures
Hot lamps can burn	Burns to the skin from hot lamps	Do not touch the lamp while the circuit is connected. Allow time for the lamp to cool.

Experiment 9

SERIES AND PARALLEL ELECTRIC CIRCUITS

Aim

The aim of this experiment is to study resistors connected in series and parallel.

Apparatus

Resistors, ammeter, voltmeter, power supply

Theory

Series circuits

The current passing through all resistors connected in series is the same.

If a number of resistors R_1, R_2, R_3 ...Rn are connected in series, the equivalent resistance is

$$R = R_1 + R_2 + R_3 + \dots + R_n$$

The voltage across each resistor depends on the individual resistance of the resistor.

The sum of the voltage drops across all resistors = Battery voltage

$$V = V_1 + V_2 + V_3$$

Parallel circuits

If a number of resistors R_1, R_2, R_3 ...Rn are connected in parallel, the equivalent resistance is

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots + \frac{1}{R_n}$$

The potential difference across each resistor is the same but the current through each resistor depends on the particular resistor's resistance. High resistors pass less current.

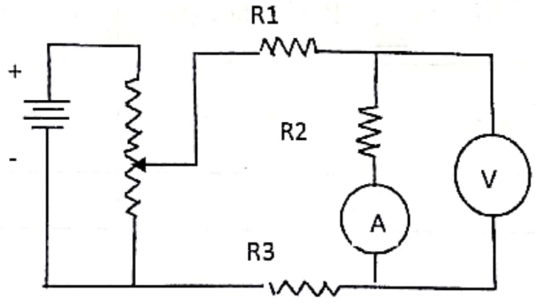

Figure. 9.1: Series circuit

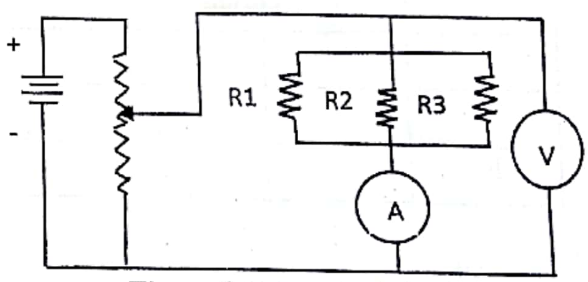

Figure 9.2: Parallel circuit

Procedure

- Using an ohmmeter, measure the resistance of each resistor provided. Record the values.
- Using the power supply and three resistors given, construct a series circuit as shown in figure 9.1.

- Calculate the experimental value of the equivalent resistance for the series circuit.
- Using the same resistors, construct a parallel circuit as shown in figure 9.2.
- Calculate the experimental value of the equivalent resistance for the parallel circuit.

Data

1. **Table 9.1: Series circuits**

R (resistor)	V (volts)	I (amps)	Experimental Resistance $[\frac{V}{I}]$ (Ω)	Measured Resistance (Ω)	Theoretical Resistance (Ω)
R_1					
R_2					
R_3					

2. **Table 9.2: Parallel circuits**

R (resistor)	V (volts)	I (amps)	Experimental Resistance $[\frac{V}{I}]$ (Ω)	Measured Resistance (Ω)	Theoretical Resistance (Ω)
R_1					
R_2					
R_3					

Results

Theoretical resistance of the series circuit=..................

Measured resistance of the series circuit=...............

Theoretical resistance of the parallel circuit=..................

Measured resistance of the parallel circuit=...............

Experiment 10

DETERMINATION OF REFRACTIVE INDEX OF A GLASS BLOCK

Aim

The aim of this experiment is to determine the refractive index of a glass block using Snell's law.

Apparatus

Ray box, glass block, protractor, sheet of paper

Theory

The Law of Refraction (Snell's Law) relates how a ray of light will behave when passing from one media to the other.

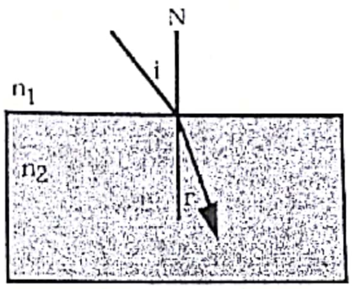

Figure 10.1: Refraction of light

The Snell's law is given by

$$n_1 \sin i = n_2 \sin r$$

where n_1 and n_2 are the refractive indices of for the two different media.

For air, $n_1 = 1$ and $n_2 = n_g$, the refractive index of the glass.. Then the above equation becomes

$$\text{Refractive index of glass block } (n_g) = \frac{\sin i}{\sin r}$$

Procedure

- Place the rectangular glass box at the centre of a clean white paper and trace around it. Draw a line normal to the glass box.
- Use a ray box to shine a ray of light at the point where the normal meets the block. This is the incident ray. The angle between the normal and the incident ray is called the angle of incidence.
- Using a pencil on the paper, mark (with a cross) the path of the incident ray and the ray that leaves the block.

- Remove the glass block. Draw a line joining each cross to the point where the normal meets the block to show the paths of the light rays.
- Measure the angle of incidence and angle of refraction.
- Repeat the experiment with different angles of incidence.
- Tabulate the values of the angles i and r, and also using the calculator, the values of sin i and sin r. Calculate the refractive index of the glass block.
- Plot the graph of sin i against sin r. Calculate the gradient from the graph to determine the refractive index of the rectangular glass block.

Data

Table 10.1 Data Collected

No	Angle of incidence (i) °	Angle of refraction (r) °	sin i	sin r	Refractive index (n)
1					
2					
3					
4					
5					

Mean refractive index of the glass block = ...

Risk assessment

Table 10.2: Precaution

Hazard	**Consequence**	**Control measures**
Ray box gets hot	Minor burns	Do not touch bulb, allow time to cool
Semi-dark environment	Increased trip hazard	Ensure environment is clear of potential trip hazards before lowering lights

Results

Mean refractive index of the glass block =...................

Refractive index of the glass block (graphically) =.....................