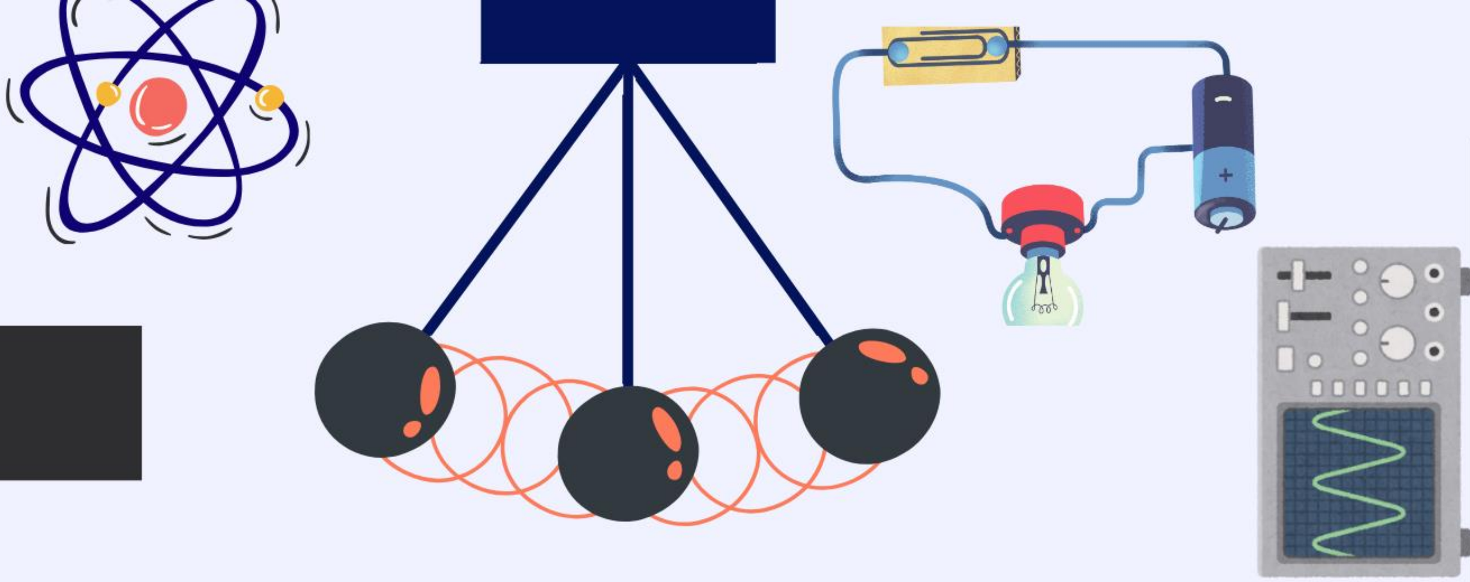

O-LEVEL PRACTICAL

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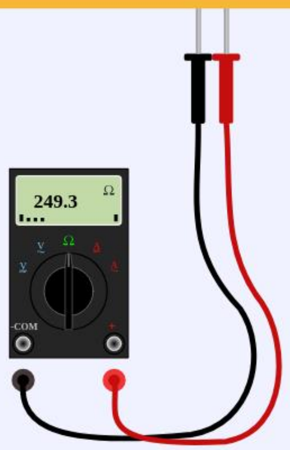

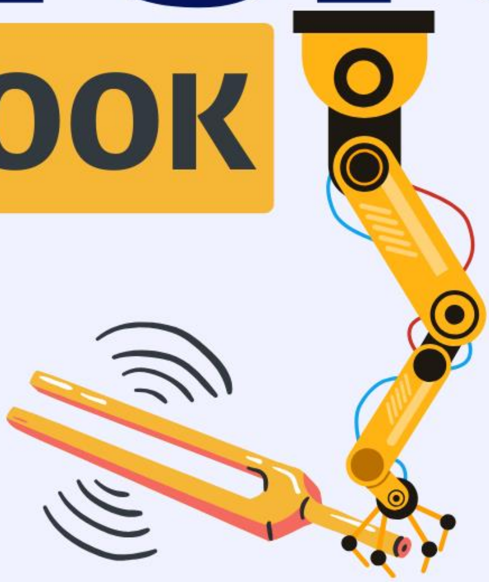

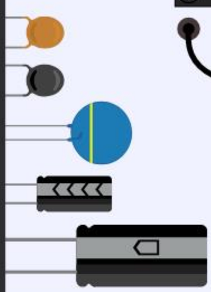

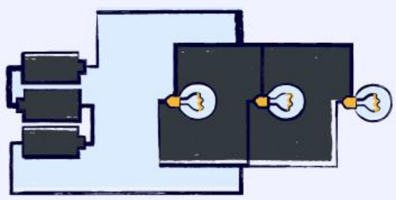

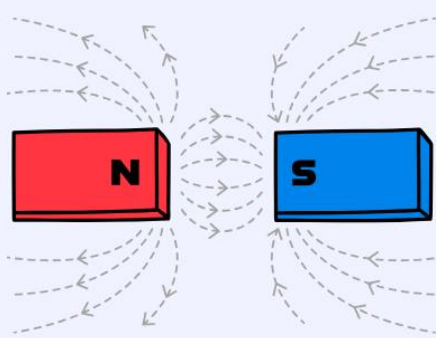

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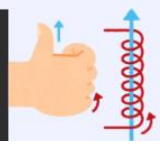
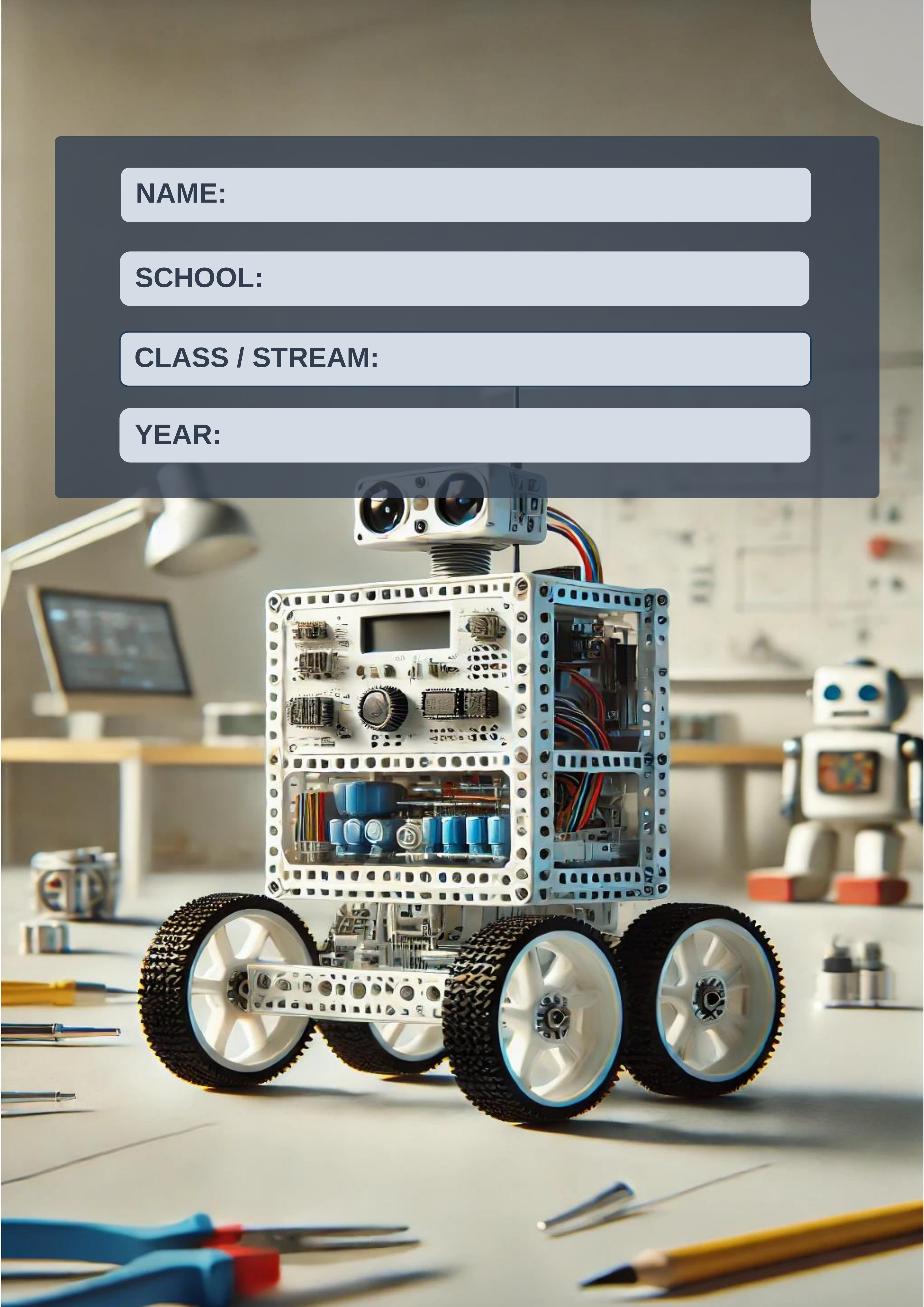


2025 Edition

Practical Physics

A Competence-Based Approach

This book is dedicated to all physics students, may your imaginations and experiments lead to revelations that will inspire the future



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1.0 PREFACE AND INTRODUCTION

Embracing Competence-Based Methodologies

The landscape of education is constantly evolving, one of the most significant shifts in recent years has been towards competence-based approaches which emphasize not just the acquisition of knowledge, but the development of skills and competencies that students can apply in real-world situations. The new lower secondary curriculum for physics reflects this shift, moving away from rote learning and towards a more hands-on, inquiry-based approach to understanding the physical world.

The New Approach to Practical Physics

Traditionally, practical physics assessments involved following a set of predefined instructions to achieve a particular result. While this method ensured that students could carry out experiments, it often lacked engagement with the underlying principles and theories. Students might complete an experiment successfully without truly understanding why they were performing each step or how the results related to the theoretical concepts they had learned in class.

In this new approach, practical physics is assessed differently. Students are no longer passive recipients of instructions; instead, they are active participants in the learning process. They are required to write extensive practical reports that demonstrate their understanding of the theory behind the experiments, their ability to apply this theory to solve real-world problems, and their proficiency in using scientific methods and techniques.

Writing Practical Reports

One of the key components of the new assessment strategy is the practical report. These reports are not merely records of what students did during an experiment; they are comprehensive documents that include:

- **Title**: A detailed title of the experiment, including its aim / objective and the scientific concepts being investigated.
- **Hypothesis**: A clear statement of the expected / guessed outcome based on theoretical understanding of the concepts.
- **Materials and Methods**: A detailed description of the apparatus used and the procedures followed, written in the student's own words; whenever possible, a diagram should also be included to show how the apparatus were arranged.
- **Choosing variables:** The student has to choose their own dependent & independent variables basing on the theoretical knowledge they are applying and what variables they can control.
- **Data Collection**: Systematic recording of observations and measurements.
- **Analysis:** Interpretation of the data, including calculations, graphs, and discussion of errors and uncertainties.

- **Conclusion**: A summary of the findings, how they relate to the hypothesis, and their implications for the scientific theory.
- **Possible sources of error**: Almost every measurement has an error within it, the errors could be human errors, rounding errors, parallax errors, errors in instruments and more. Knowing these errors allows you to mitigate them so as to get reliable conclusions.

Real-World Problem Solving

The heart of this new approach is problem-solving. Instead of conducting experiments in isolation, students are presented with real-world problems that require them to use their knowledge and skills to find solutions. This method encourages critical thinking, creativity, and practical application of theoretical concepts. For example, rather than simply measuring the resistance of a wire, students might be asked to investigate the design & properties of a heating element for a specific application, taking into account factors such as efficiency, safety, and cost.

Encouraging Innovation and Creativity

By allowing students to use their own techniques and methods, the competence-based approach fosters innovation and creativity. Students are not limited to a single way of conducting an experiment; they are encouraged to think outside the box, try different approaches, and learn from their successes and failures. This freedom helps students develop a deeper understanding of scientific principles and how they can be applied in various contexts.

Preparing for the Future

The skills and competencies developed through this new approach to practical physics are essential for students' future success, both in their academic pursuits and in their careers. Whether they go on to become scientists, engineers, doctors, or professionals in any field, the ability to think critically, solve problems, and apply knowledge practically will serve them well.

Finally, this practical book aims to guide students through this exciting and challenging new approach to learning physics. It provides a comprehensive framework for conducting experiments, writing reports, and solving real-world problems, all while developing the skills and competencies that are essential for success in the 21st century. Let us embark on this journey of discovery and innovation together, as we explore the fascinating world of physics through a hands-on, inquiry-based approach.

Byakatonda Denis.

2.0 WHY PRACTICAL PHYSICS?

Physics 'practicals' are a vital part of learning physics, offering hands-on activities that help you understand the concepts you learn in class. By doing experiments, you get to see how the principles of physics work in real life, making the subject more interesting and easier to grasp.

Exploring Scientific Questions

Physics practicals help you explore scientific questions through experiments. Instead of just reading about theories, you get to test them out. For example, you might conduct an experiment to see how a spring stretches when you add weights to it, which helps you understand Hooke's Law. This way, you see the relationship between force and extension firsthand. Doing these investigations helps you learn how to ask questions, design experiments, collect data, and make sense of your results.

Solving Real-World Problems

Physics practicals often involve solving real-world problems. You use your knowledge to tackle challenges you might encounter in everyday life, such as figuring out which material is best for insulating a house by measuring how well different materials keep heat. These activities encourage you to think critically and creatively, applying what you know to solve practical problems.

Demonstrating and Verifying Physics Laws

Through practical experiments, you get to prove and understand fundamental laws of physics. For instance, you might measure the current and voltage in a circuit to verify Ohm's Law or use light experiments to see how reflection and refraction work. These experiments help you see that the laws you learn about in textbooks really do apply in the real world.

Precision in Measurement and Data Collection

Practical physics teaches you how to measure accurately and collect data. You'll use tools like meter rules, stopwatches, voltmeters, and ammeters to gather precise information. Learning to measure correctly and record your observations carefully is crucial for ensuring validity and reliability of the results of your experiments.

Developing Experimental Design Skills

Physics practicals help you learn how to design your own experiments. You'll figure out what variables to control, how to set up your experiment, and how to ensure your results are reliable. This process teaches you the scientific method and helps you become a better problem-solver. For example, designing an experiment to see how different angles affect a projectile's motion requires careful planning and thinking.

Understanding Complex Systems through Simulations

Sometimes, it's not practical or safe experiment on certain concepts in the lab. That's where simulations come in. Using computer models or laboratory models, you can study things that are too complex or dangerous to experiment with directly. Simulations help you visualize and understand difficult concepts in a safe and cost-effective way.

3.0 THE SCIENTIFIC METHOD

To understand the natural world around us, physicists follow a standard logical framework known as the **scientific method**. This framework is similar to a detective's investigation, ensuring that all possible questions are answered before making conclusions.

By learning and applying the scientific method, you will develop critical thinking and problem-solving skills that extend beyond physics into everyday life.

Figure 2.0 Steps in the scientific method

The scientific method generally follows these key steps:

Observation and Questioning:

The process begins with careful observation of the world. Scientists look for patterns, anomalies, or phenomena that spark curiosity.

Examples: Why do objects fall to the ground? What causes the phases of the Moon?

Once an observation is made, it leads to a question—often framed as, "How does this happen?" or "Why does this occur?"

Before proposing an explanation, scientists often review existing knowledge and previous research. This step prevents duplication of efforts and allows scientists to build on already established knowledge.

Hypothesis Formation

A hypothesis is an educated guess or a proposed explanation for the observation. The hypothesis doesn't have to be a correct explanation but it must be testable and falsifiable, meaning it can be proven false through experiments or evidence. Examples of hypotheses include;

Objects fall to the ground because they are attracted by Earth's gravity.

The moon's shape changes throughout the month because the moon rotates around the earth so it appears in different shapes depending on which parts are illuminated.

Experimentation

To test whether a hypothesis is true or false, an experiment is designed and conducted. The experiments are designed such that only one variable is changed at a time while others remain constant, this enables the experimenter to know how such a variable affects the process.

The experiments should be standard, i.e. easy to replicate; other scientists should be able to perform the same experiment and achieve the similar results.

Data Collection and Analysis

During the experiment, data is collected in a structured format (tables, charts, graphs). This data is then analyzed to identify trends or patterns.

Example: In testing Hooke's law, data about extension and applied force is collected, a graph of the extension of a spring against the applied force is plotted; a straight line shows that the material under investigation obeys Hooke's law.

Conclusion

Based on the data, the hypothesis is either supported or refuted. If the hypothesis is supported, it may lead to further testing or refinement. If refuted, a new hypothesis is formed, and the cycle begins again.

The final step involves sharing findings with the scientific community through publications, presentations, or discussions. This ensures transparency, encourages collaboration and it is through such that new knowledge is discovered.

The vernier caliper is a versatile instrument used to measure internal and external dimensions as well as depths. It offers more precision than a standard ruler, typically up to 0.1 mm or 0.02 mm depending on the model.

How to Use a Vernier Caliper:

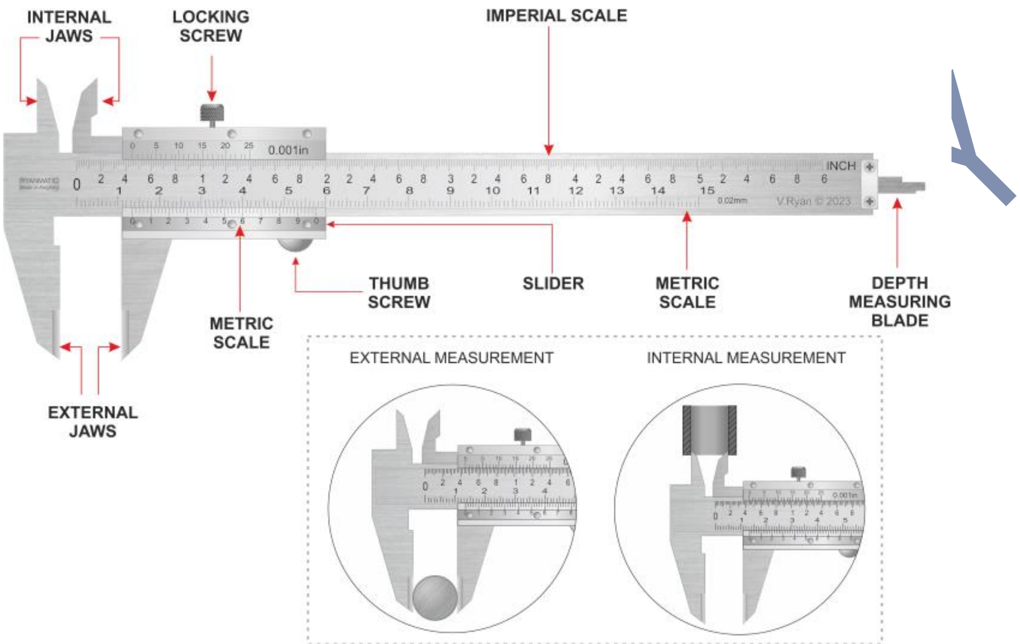


Figure 4.3 How to use a vernier caliper.

Measuring External Dimensions:

- Place the object between the outside jaws (Figure 4.3).
- Slide the vernier scale until the jaws grip the object snugly, (Figure 4.3).

Measuring Internal Dimensions:

- Insert the inside jaws into the space to be measured and expand them until they fit snugly.

Measuring Depth:

- Extend the depth rod into the hole or opening of the depth to be measured.

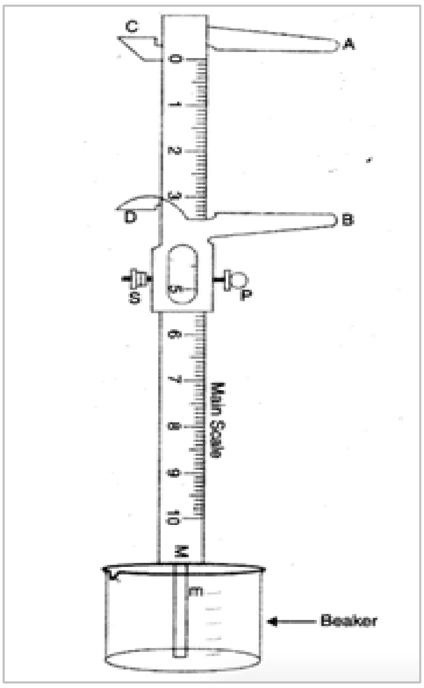
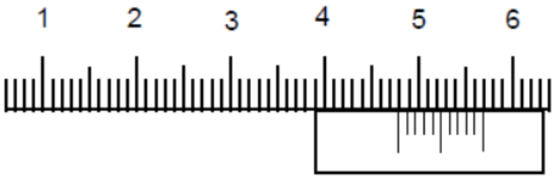
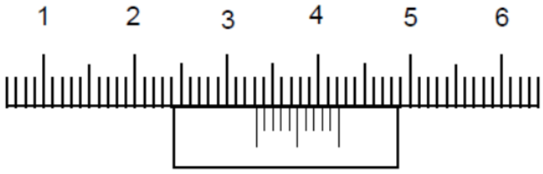


Figure 4.4 Measuring depth with a vernier caliper.

2. Measure the internal and external diameters of a 250 ml beaker school laboratory, then use your results to calculate the a) thickness of the beaker b) Internal and external surface areas of the beaker. Suggest why your answer may not be accurate. (The figure provided here is for reference purpose only, you're required to take measurements from an actual beaker in the lab)

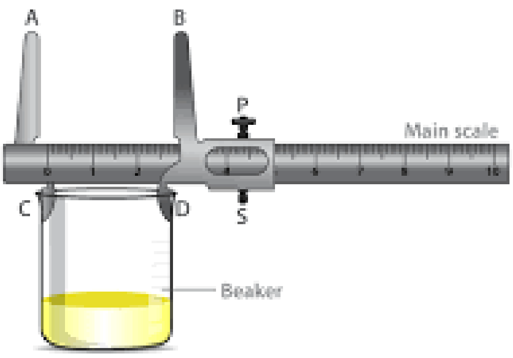


Figure 4.6 Measuring the diameter of a beaker.

3. Could you suggest any other objects whose dimensions can best be measured by a vernier caliper?

c) Micrometer Screw Gauge

The micrometer screw gauge is a more precise instrument used to measure very small dimensions, typically to the nearest 0.01 mm. It is commonly used for measuring the diameter of thin wires or small objects.

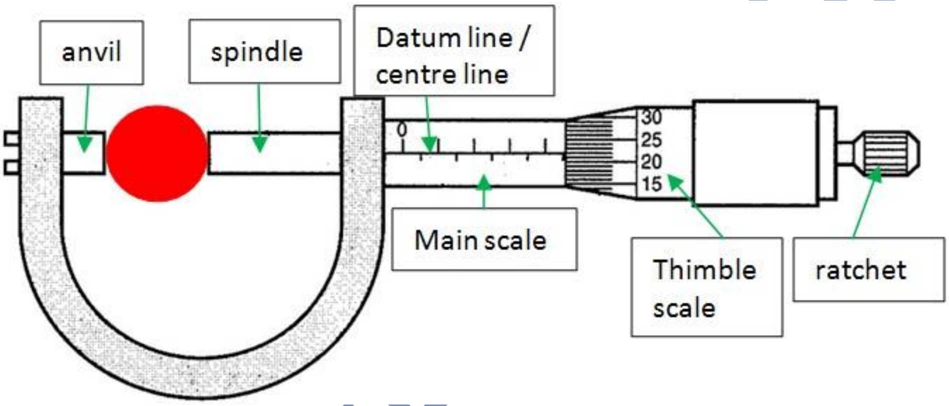


Figure 4.7 Parts of a micrometer screw gauge.

How to Use a Micrometer Screw Gauge:

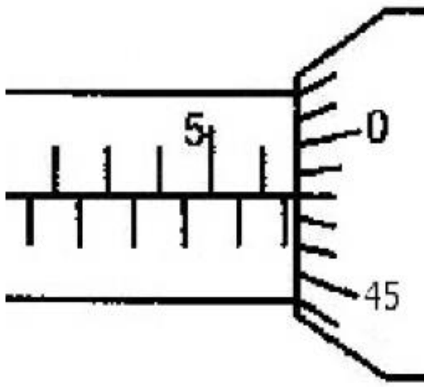
Measuring an Object:

- Place the object between the anvil and spindle.
- Rotate the thimble until the object is gently held. Use the ratchet stop to avoid excessive pressure.

Taking the Reading:

- Read the main scale on the sleeve. This gives the whole millimeters and half-millimeter increments.
- Read the thimble scale, which shows the additional measurement in hundredths of a millimeter.
- Add these readings together for the final result.

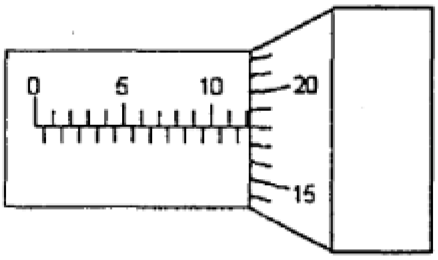
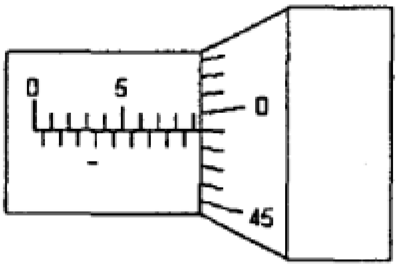
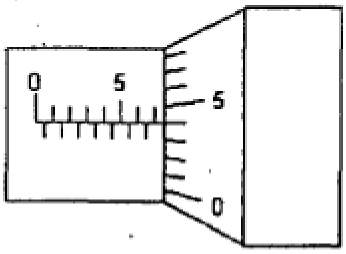
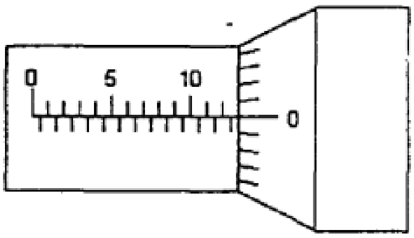
Example: If the main scale reads 6.5 mm and the thimble scale reads 48 (with each division representing 0.01 mm):



Total reading = 6.5 mm + (48 × 0.01) mm = 6.98 mm.

TRY IT OUT

1. For each of the figures, determine the reading micrometer screw gauge.

2. Using a micrometer screw gauge, measure the thickness of this practical workbook. Repeat the procedure using another micrometer screw gauge and comment on the two results.

Zero Errors in a Micrometer Screw Gauge

A **zero error** occurs when the micrometer screw gauge does not read exactly **zero** when the anvil and spindle are fully closed.

This can happen due to wear and tear, improper calibration, or manufacturing imperfections. A zero error affects the accuracy of measurements, but it can be detected and corrected.

To detect zero a zero error, close the anvil and spindle gently using the **ratchet stop** to ensure consistent pressure and observe the alignment of the thimble's **zero mark** with the sleeve's datum line. If the zero aligns perfectly, there is no zero error but if the zero does not align, the instrument has a zero error that needs to be accounted for depending on how far the zero is displaced from the reference line.

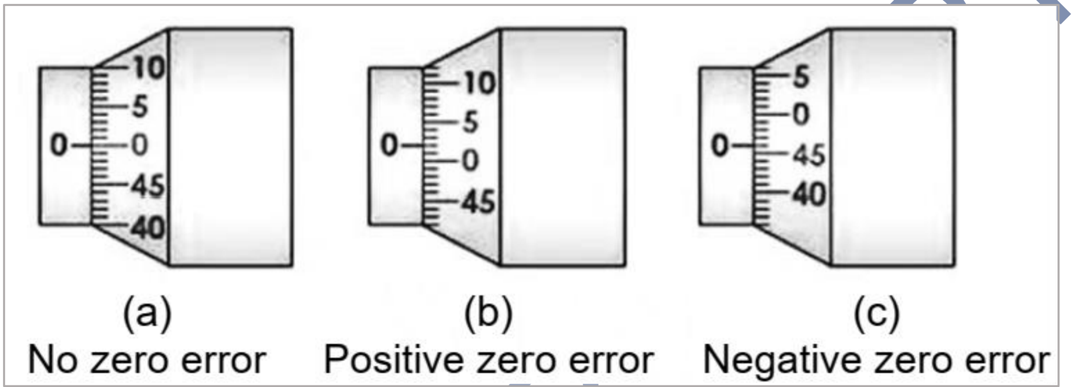


Figure 4.8 types of zero errors in a micrometer screw gauge.

Zero errors in a micrometer screw gauge are of two types:

Positive Zero Error: Occurs when the **zero mark** on the thimble scale is **below** the horizontal reference line (datum line) on the sleeve when the anvil and spindle are in contact. This means the micrometer will read a value greater than the actual measurement. To correct this error in measurements, we subtract the positive zero error from all measurements.

Negative Zero Error: Occurs when the **zero mark** on the thimble scale is **above** the datum line on the sleeve when the anvil and spindle are in contact. This means the micrometer will read a value smaller than the actual measurement. To correct this error in measurements; we add the negative zero error to all measurements taken.

Comparison of Vernier Caliper and Micrometer Screw Gauge

Feature	Vernier Caliper	Micrometer Screw Gauge
Measurement Range	Larger (up to 200 mm or more)	Smaller (up to 25 mm)
Accuracy	Typically, 0.1 mm	Typically, 0.01 mm
Applications	General-purpose measurements	High-precision tasks

4.2 Measurement of angles

Protractors

A protractor is a semicircular or circular tool used for measuring angles in degrees (°).

To use it, place the midpoint of the protractor at the vertex of the angle, align one side of the angle with the zero line of the protractor, and read the scale where the other side of the angle intersects the protractor.

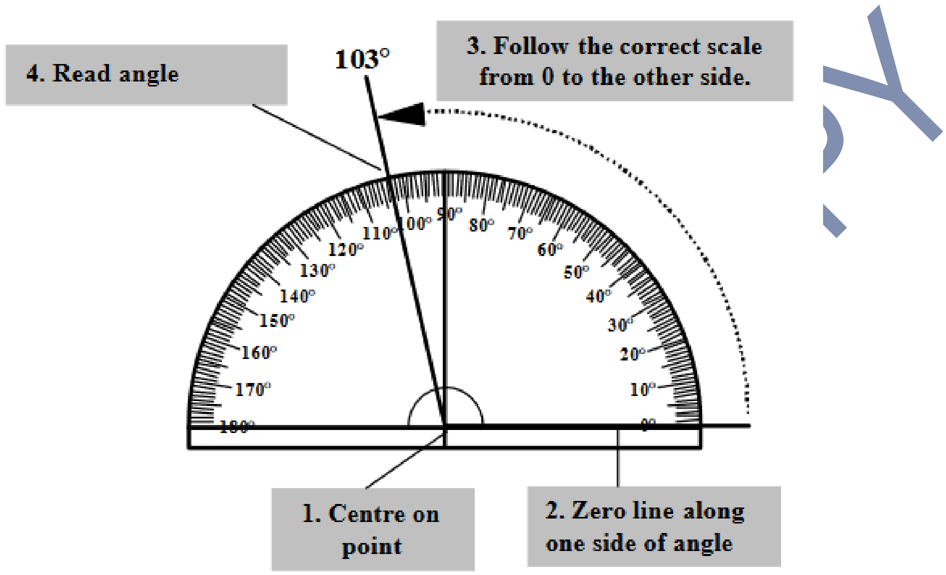


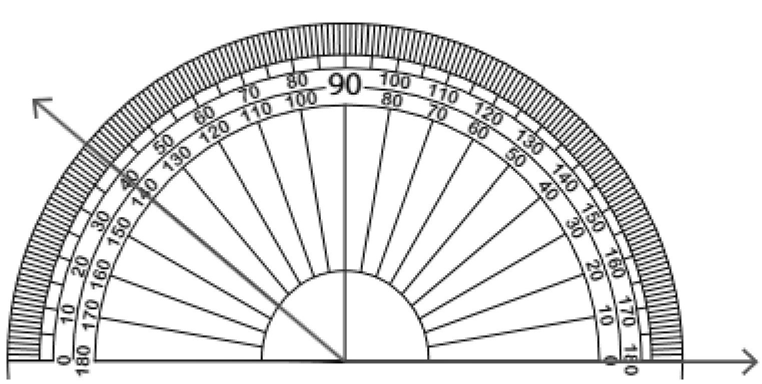
Figure 4.9 How to use a protractor.

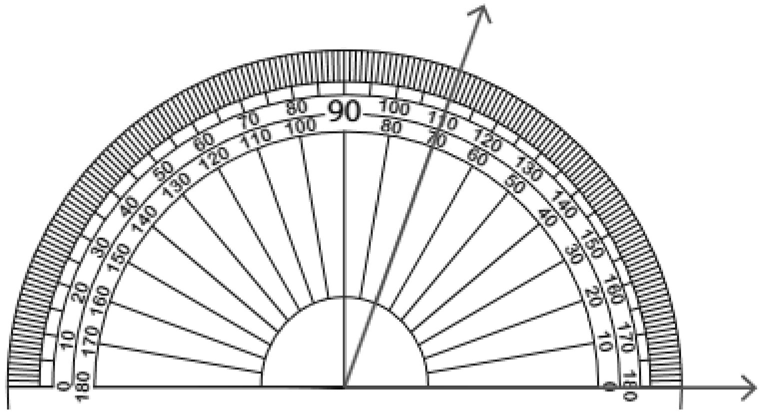
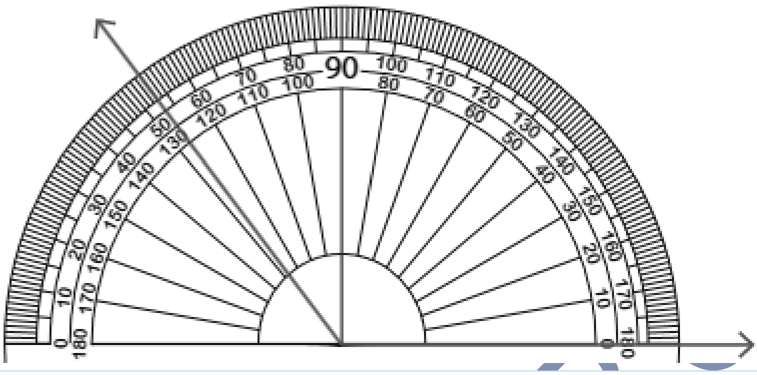
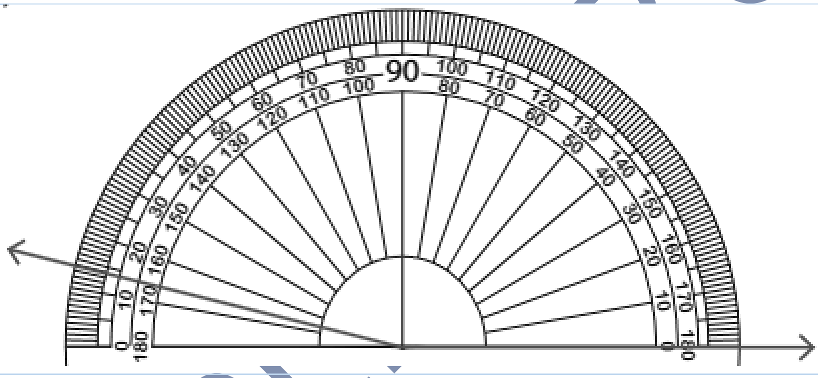
The least count of a standard protractor is 1 degree. Some protractors have finer graduations with a least count of 0.5 degrees. The accuracy is usually ± 0.5 degrees.

Angles are mostly read to the nearest whole number (e.g., 45°) or to one decimal place (e.g., 45.0°) depending on the type of protractor and its least count.

TRY IT OUT

1. Read and state the angle between the arrows shown in each of the diagrams below. (read directly from the protractors)



2. Using a protractor, measure and state the marked angle in each of the figures below.

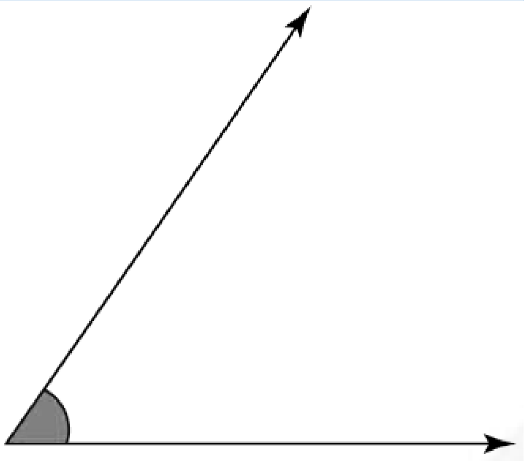
	

Figure 4.11 Digital stop clock.

These devices can be analog or digital. The time is read directly from the digital display or analog dials. For accuracy, ensure to start and stop the clock precisely at the beginning and end of the event being measured.

The least count of a stop clock can be as small as 0.01 seconds for digital models hence these are read to two decimal places for digital models (e.g., 0 mins, 12 seconds & 34 microseconds, $00{:}12{:}34 \Rightarrow 12.34\ s$), on the other hand, most analog stopwatches have a least count of 0.5 seconds or 0.1 seconds, which means their values are read to 1 decimal place, e.g., 12.5s, 30.0s, 46.5s.

TRY IT OUT

Suspend a pendulum bob on a retort stand using a thread, displace the pendulum bob and let it make 15 oscillations. Using a stop clock or stop watch, measure the time taken to make the 15 oscillations. What are some possible sources of error in this measurement.

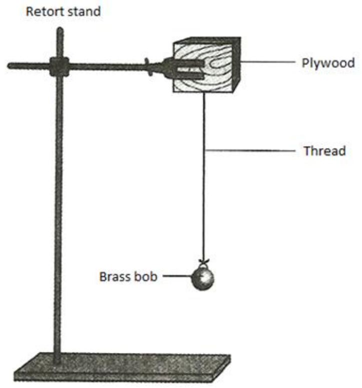


Figure 4.12 A simple pendulum.

4.4 Measurement of Mass and Weight

In physics, **mass** and **weight** are distinct but closely related concepts. Understanding their differences and knowing how to measure them accurately is essential for various applications in science and engineering.

Mass is a measure of the amount of matter in an object. It is a scalar quantity, meaning it has magnitude but no direction, and is typically measured in **kilograms (kg)** or **grams (g)** in the SI system. **Mass remains constant** for an object regardless of its location (e.g., Earth, Moon, or outer space).

Weight on the other hand is the gravitational force acting on an object due to its mass. It is a vector quantity, meaning it has both magnitude and direction (toward the center of the Earth or another celestial body). Weight is given by:

$$Weight = Mass \times Acceleration\ due\ to\ gravity(g)$$

Weight is measured in **newtons (N)**. It varies depending on the gravitational field strength of the location.

a) Beam Balance

This is a classic instrument for measuring mass in the laboratory. It has two pans balanced on a horizontal beam. Standard masses are placed on one pan, and the object to be measured is placed on the other.

Figure 4.13 A beam balance.

The weights on one pan are adjusted until the beam is perfectly horizontal; then the mass of the object equals the sum of the standard masses.

b) Electronic Balance

A digital device that measures mass electronically using sensors. The unknown mass is placed on the platform and the mass is displayed digitally in kilograms or grams.

Figure 4.14 An electronic beam balance.

c) Triple-Beam Balance

This is a mechanical balance with three sliding weights on calibrated beams. The instrument is first adjusted (by moving the masses on the beam) so that the pointer is at the zero mark, the unknown weight is placed on the pan and the masses are moved again to restore balance. The unknown mass is read directly from the horizontal scale by adding the masses on the three beams.

Figure 4.15 A triple beam balance.

d) Spring Balance

(a)

This device that measures weight by the extension of a spring, based on Hooke's law.

To determine weight of an object, the object is hanged freely on the hook and the weight is read directly from the scale.

Figure 4.16 (a), (b) Spring balances of different weight ranges.

TRY IT OUT

Using a triple beam balance, determine the mass of an empty beaker, Fill the beaker with 150 ml of water and measure the total weight; finally determine the mass of the 150 ml of water alone.

Repeat the procedures above using a digital beam balance. Are your values the same? What could be the possible sources of error when using each of the instruments?

To get a correct reading, connect the voltmeter in parallel with the component across which the potential difference is to be measured. The value of p.d, in Volts is read directly from the meter's display.

The least count of a voltmeter depends on its range and design, often 0.1 volts for some meters and 0.01 volts for others. Therefore, some voltmeters are read to 1 decimal place while others in 2 decimal places.

Just like ammeters, some voltmeters have 2 terminals while others have 3, for those with 3 terminals, use the common (black) terminal and one of the 2 red terminals depending on which range of voltage you're measuring. Also ensure that you're reading from the right scale depending on the terminals used.

TRY IT OUT

Connect a bulb, dry cells and switch as shown below ensuring that the bulb gives light.

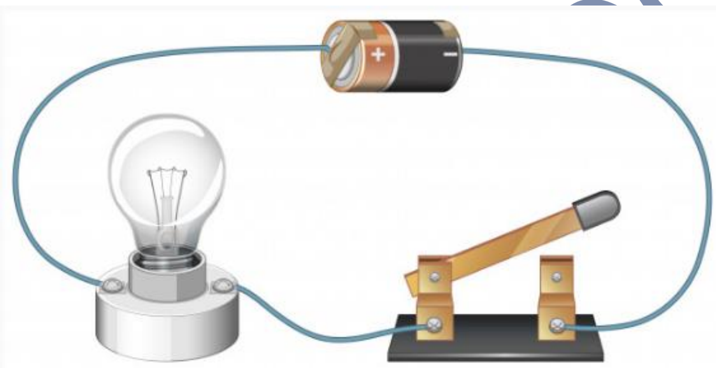


Figure 4.21 A simple circuit.

Next, connect a voltmeter and ammeter appropriately to measure the value of current and potential difference across the bulb (use the space below to show an adjusted circuit containing the ammeter and voltmeter).

Voltmeter	Voltage	volts (V)	0.1 V or 0.01 V	1 d.p or 2 d.p
Ammeter	Current	amperes (A)	0.1 A or 0.01 A	1 d.p or 2 d.p
Measuring Cylinder	Volume	mL, L	1 mL	0 d.p or 1 d.p
Beaker	Volume	mL, L	10 mL or 20 mL or 50 mL	0 d.p
Spring Balance	Weight	N	Varies depending on the type & range	Depends on the least count of the instrument
Beam Balance	Mass	g, kg	Varies depending on the type & range	Depends on the least count of the instrument

5.0 DATA COLLECTION AND MANIPULATION

In physics practical, handling and manipulating data accurately is important. Understanding the rules for working with significant figures and decimal places ensures that your calculations are precise and reliable.

In the previous section, you were introduced to some laboratory instruments that we use to take measurements and collect data. This section will focus on how to manipulate data through various mathematical operations, focusing on significant figures, decimal places, and working with physical and mathematical constant values like π (pi), e and float values.

5.1 Significant Figures and Decimal Places

Significant Figures are the digits in a number that contribute to its accuracy. This includes all non-zero digits, any zeros between significant digits, and trailing zeros in a decimal number.

Decimal Places refer to the number of digits to the right of the decimal point. Significant figures & decimal concepts help maintain precision in your calculations.

How to count Significant Figures

- **Non-Zero Digits:** All non-zero digits (1-9) are always significant, e.g.,123 has 3 significant figures, 56.789 has 5 significant figures.
- **Trapped (or Captive) Zeros:** These are zeros located between non-zero digits, they are counted as significant; e.g., 1002 has 4 significant figures, 3.0701 has 5 significant figures.
- **Leading Zeros**: Leading zeros (zeros before the first non-zero digit) are not significant. e.g., 0.0056 has 2 significant figures, 0.000789 has 3 significant figures.
- **Trailing (or terminal) Zeros:** Trailing zeros (zeros at the end of a number) are significant only if they represent the accuracy or precision of an instrument, e.g.; if 23.0 cm is read from a meter rule, it has 3 significant figures, 30° from a protractor has 2 significant figures.
- **Scientific Notation:** Scientific notation is often used to clearly indicate the number of significant figures. In scientific notation, all digits in the coefficient are significant, e.g., in 4.00×10^{3}, the coefficient (4.00) has 3 significant figures, in 1.230×10^{-4}, The coefficient (1.230) has 4 significant figures.
- **Exact Numbers:** If a number was obtained by counting, e.g., 20 oscillations, 10 apples, 2 beakers, then the number is considered to be exact. Exact numbers have an infinite number of significant figures. If a number is part of a definition, then the number is also exact. For example, 1 cm is defined as exactly 100 m. Therefore, in the statement 1 m = 100 cm, both the 1 & 100 have an infinite number of significant figures.

5.2 Addition and Subtraction

When adding or subtracting numbers, the result should be rounded off to the same number of decimal places as the value with the fewest decimal places. For example;

12.345 + 7.1=19.4

12.345 (has 3 decimal places) + 7.1 (has 1 decimal place) = 19.445 (3 decimal places)

But since 7.1 has the least number of decimal places in the above calculation (i.e. 1 decimal place), then the final answer has to be rounded off to 1 decimal place; 19.4 (1 decimal place).

Confirm the same rule is followed for the next examples.

- 25.678 (3 d.p) - 3.12 (2 d.p) = 22.56 (2 d.p).
- 100.01 (2 d.p) + 2.1 (1 d.p) = 102.1 (1 d.p).

5.3 Multiplication and Division

For multiplication and division, the result should have the same number of significant figures as the measurement with the fewest significant figures.

- 4.56 (3 significant figures) × 1.4 (2 significant figures) = 6.384, which is rounded to 6.4 (2 significant figures).
- 3.123 (4 significant figures) ÷ 2.1 (2 significant figures) = 1.487142857, which is rounded to 1.5 (2 significant figures).
- 5.678 (4 significant figures) × 2.0 (2 significant figures) = 11.356, which is rounded to 11 (2 significant figures).

Note: Much as reciprocals are obtained by dividing 1 by a given number, they follow quite a different rule; since 1 is a constant value in this case, it is considered to have an infinite number of significant figures (see *float* values), therefore, we consider the significant figures of the denominator, e.g., $\frac{1}{2.6} = 0.38$ since the denominator has 2 S.F.

5.4 Trigonometric Functions

Trigonometric functions can be very sensitive to the precision used; when using trigonometric functions like sine, cosine, and tangent, the result should be written to three decimal places.

5.5 Square Roots

For square roots, the number of significant figures in the result should be the same as the number of significant figures in the original number.

- $\sqrt{4.00}$ (3 significant figures) = 2.00 (3 significant figures).
- $\sqrt{16.56}$ (4 significant figures) = 4.069 (4 significant figures).
- $\sqrt{9.7}$ (2 significant figures) = 3.1 (2 significant figures).

5.6 Float & Constant Values

Constants such as π (pi) & acceleration due to gravity, g are used frequently in physics calculations, some of these constants have a defined number of decimal places & significant figures while others have an infinite number of decimal places & significant figures, these are known as *float* values. When dealing with float values & constants, the rules of arithmetic operations are the same as those already described.

E.g., 2.4 π = 7.5 (2 significant figures), since π has an infinite number of significant figures and 2.4 has 2 S.F, we consider the one with the least significant figures for the final result.

TRY IT OUT

Evaluate the following expressions using the precision rules of decimal places and significant figures.

1) $\frac{0.045 \times 0.00465}{4.2}$

2) $(15.3 - 11.56)^2$

3) $\frac{4\pi^2}{3.8}$, where $4\pi^2$ is a constant

4) $\sqrt{\frac{0.630}{9.8}}$

5) $\frac{1}{12.5} + \frac{1}{19.3}$

6) $\frac{20.0 \times 66.6}{20.0 + 66.6}$

7) $\frac{17.27}{20}$, where 20 is a float value

5.7 Recording values in the table of results

It is important to maintain a consistent number of decimal places in a given column in the table, this creates uniformity and ensures that all values have been recorded to the same level of accuracy.

Having a uniform number of decimal places in a column of directly measured values from an instrument is often obvious since each instrument gives readings already fixed to a certain number of decimal places. The problem arises when dealing with 'calculated columns.

For 'calculated columns' of addition & subtraction, we simply add the values and record the answer with the least decimal places involved in the calculation. e.g., if a table has a column of x and y, and we need a column of $x + y$,

$x(m)$	$y\ (m)$	$x + y\ (cm)$
0.20	0.180	0.38
0.30	0.362	0.66
0.40	0.451	0.85
0.50	0.663	1.16

Note that the values in the '$x + y$' column are all uniformly written to 2 dp.

For calculated columns involving **multiplication and division** however, numbers with different numbers of decimal places are likely to be obtained since multiplication and division prioritize significant figures over decimal places.

In such cases, to create a uniform number of decimal places in the column, we base on the "***largest product***" or the "***largest quotient***" in the table to fix the number of decimal places for the rest of the column; e.g.

$x(m)$	$y(cm)$	$y(m)$	$xy(m^2)$
0.05	26.1	0.261	0.01
0.10	31.0	0.310	0.03
0.15	38.0	0.380	0.06
0.20	45.0	0.450	0.09
0.25	53.2	0.532	0.13
0.30	**62.0**	**0.620**	**0.19**

In the column of xy, we first calculate all values here using the rules of multiplication, which obviously favor significant figures and **not** decimal places.

We then identify the ***largest value*** (*largest product*) in the column, in this case, it is; $0.30(2sf) \times 0.620(3sf) = 0.19(2sf)$. This value has 2sf but most importantly, it has 2dp, thus for uniformity, the rest of the smaller values in the column of xy are recorded to 2dp.

Below are some practice tables, complete them as you practice the concepts of data manipulation.

Practice Table 1

The values of u (cm) and v (cm) were read from a meter rule.

$u\ (cm)$	$v\ (cm)$	$(u+v)\ (cm)$	$uv\ (cm^2)$	$\frac{v}{u}$	$\cos u$	$\log v$	$uv\cos u\ (cm^2)$	$\log uv$
20.0	66.6							
25.0	41.7							
30.0	32.8							
35.0	28.5							
40.0	26.5							
45.0	24.2							

Practice Table 2

Assume, $T = \frac{t}{20}$ where 20 is a float value, the values of l and t were read from a meter rule and stop watch respectively.

$l\ (m)$	$t\ (s)$	T (s)	$T^2(s^2)$	$l^3(m^3)$	$\frac{1}{T^2}\ (s^{-2})$
0.900	17.75				
0.800	15.25				
0.700	12.94				
0.600	10.62				
0.500	8.40				
0.400	6.50				

Practice Table 3

The values of y (cm) and v (v) were read from a meter rule and voltmeter respectively.

$y\ (cm)$	$V\ (V)$	$\frac{1}{y}(cm^{-1})$	$\frac{1}{V}(V^{-1})$
30.0	0.90		
40.0	0.95		
50.0	1.15		
60.0	1.35		
70.0	1.55		

6.0 DATA ANALYSIS

Analyzing data is an important part of any experiment. It involves interpreting the collected data to identify patterns and relationships or performing calculations to draw meaningful conclusions. In this section, we explore some common statistical measures & methods of analyzing data;

6.1 Using Mean or Average:

Average provides a simple summary of a set of data by giving a central value of the data. Average is got by dividing the sum of all the data by the number of data values.

$$Average = \frac{sum\ of\ all\ values}{number\ of\ items}$$

Average is useful when you want to find the central tendency of the data and when the data distribution is approximately symmetrical without extreme outliers (values that deviate too much from others).

As an example, suppose you're given different samples of the same stone and you are to find the density of the stone; assume the data about the mass, M and volume, V of each sample is collected as follows.

Sample	M (g)	V (cm^3)	ρ (g/cm^3)
1	50	20	2.5
2	60	25	2.4
3	55	22	2.5
4	65	27	2.4
5	70	28	2.5

Since the samples are having slightly different densities; we can take the average to cater for all of them.

$$Mean\ Density = \frac{Sum\ of\ densities}{Number\ of\ samples}$$

$$= \frac{(2.5\ +\ 2.4\ +\ 2.5\ +\ 2.4\ +\ 2.5)}{5}$$

$$= 2.46\ g/cm^3$$

6.2 Mode

The mode is the value that appears the greatest number of times. Using data table from the previous example; we could take the modal density as 2.5 g/cm^3 which is still not far from the average value obtained above.

Mode is most useful when the data set has outlier values (those that are too unique; too large or too small). Outlier values can greatly affect averages, that's why we sometimes use mode as it is less affected by these extreme values.

6.3 Median

Median is the middle value when the data is ordered from smallest to largest. If there's an even number of observations, median is the average of the two middle numbers. Median is best used for analyzing data which has outliers or is skewed, since it is also less affected by extreme values.

6.4 Graphical Analysis

Graphs are used to visually represent data, making it easier to identify patterns, trends, and relationships. Graphical analysis is preferred when you want to find the relationship between 2 variables; graphs can show us if the variables are;

a) Directly proportional to each other, e.g., voltage & current, force & extension, etc. this can be seen if the graph is plotted and both quantities increase or decrease at the together or when we obtain a straight line with positive gradient.

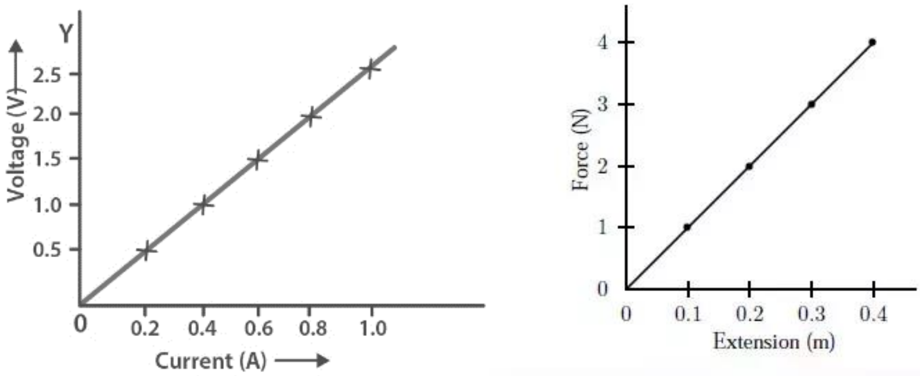


Figure 4.0 Graphs showing quantities that are directly proportional

b) Inversely proportional to each other, e.g., pressure & volume (Boyle's law), deceleration, etc. this can be seen if the graph is plotted and one quantity decreases when the other increases, or a straight line with negative gradient.

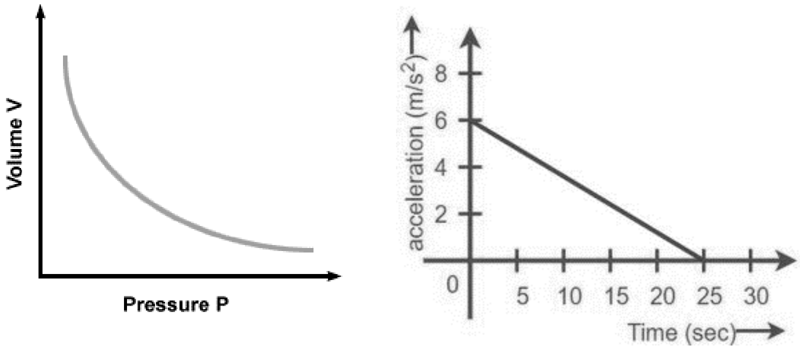


Figure 4.1 Graphs showing quantities that are inversely proportional

Plotting Graphs for Experimental Data

Graphing is an essential skill in physics that helps visualize and interpret experimental data. The following are some best practices when plotting graphs for experimental data.

Finding a Suitable and Convenient Scale

Choosing the right scale is crucial for accurately representing your data. When choosing a scale, aim to use as much of the graph paper as possible to enhance readability. Scales that result in a crowded or sparsely populated graph should be avoided.

The most common way of finding a scale is to divide the range of the given values by the available spaces on the graph paper.

$$scale = \frac{highest\ value - lowest\ value}{Number\ of\ available\ spaces\ on\ the\ axis}$$

Be sure to select scales that are easy multiples to simplify your work; these include 1, 2, 2.5, 5, or 10 units per division. This simplifies plotting points and reading values.

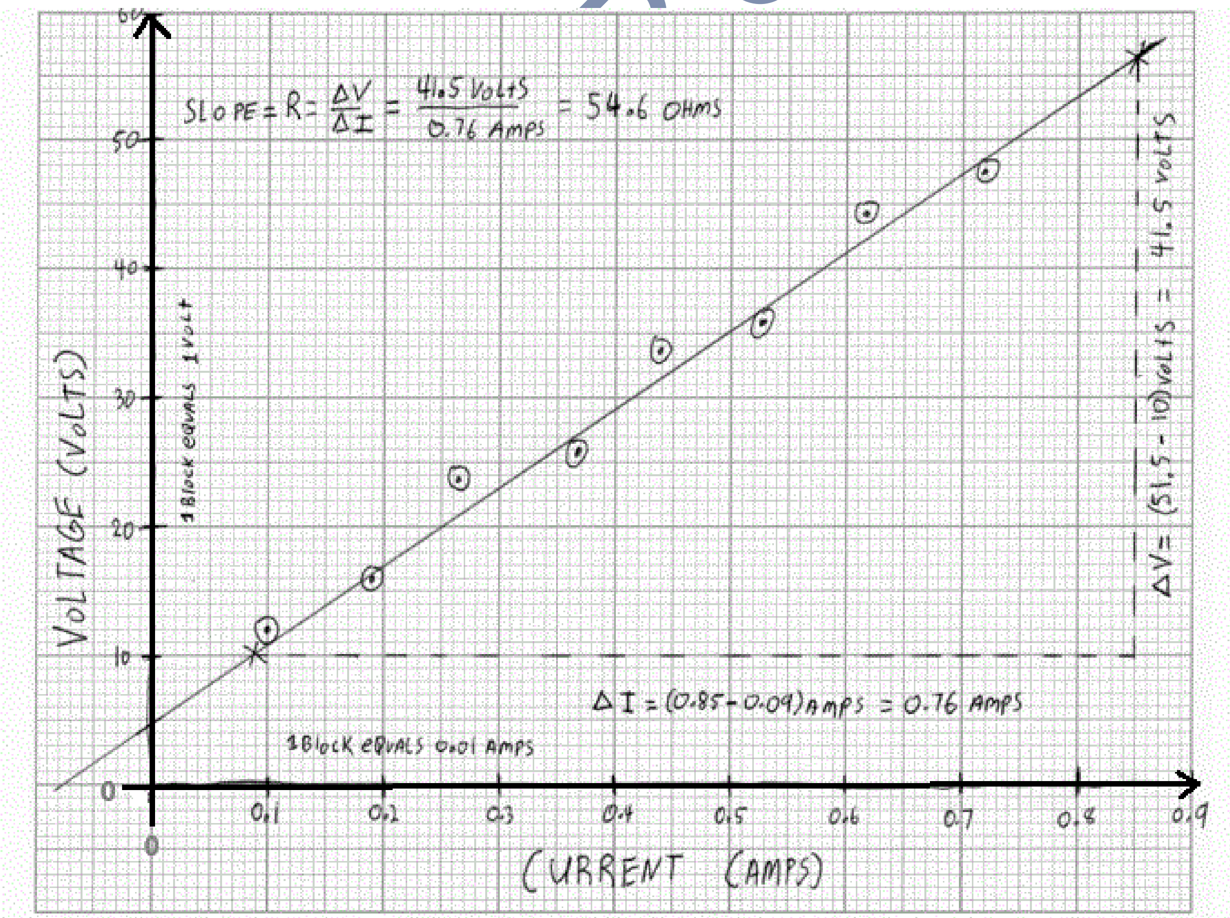


Figure 4.3 A graph with a vertical scale of 10 and horizontal scale of 0.1. Both axes start at 0.

Finding Suitable Starting Values

Deciding where to start your axes can make your graph clearer:

- **Include Zero**: If the data includes or is near zero, start your axes at zero to give a complete view of the trend. If you intend to use your graph to find y-intercept, then the x-axis must start at zero, for x-intercept, then the y-axis must start at zero.
- **Non-Zero Start**: If your data doesn't include zero and the data values are far from zero, then starting your axis at zero will waste space, it is better in this case to use a starting value that is slightly lower than your smallest data value for that axis.

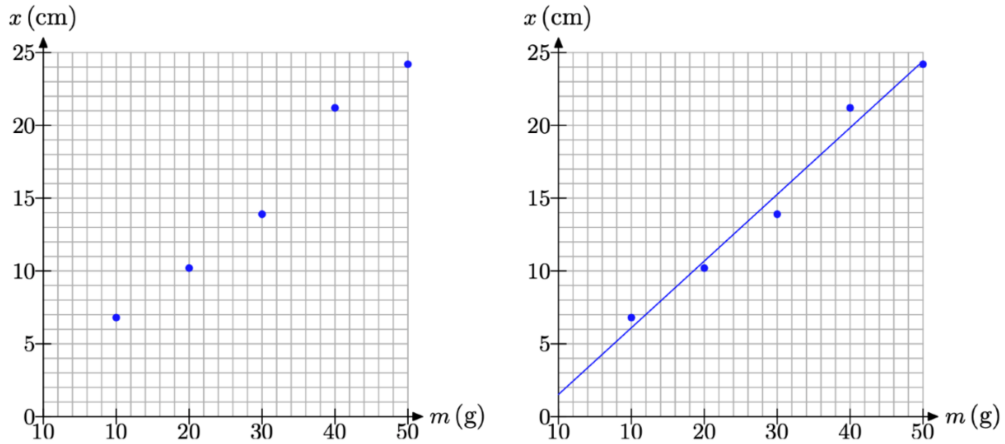
Axis Titles and Units

Proper labeling is vital for understanding the graph:

- **Descriptive Titles**: Clearly indicate the title for the graph basing on the variables plotted; e.g. “A graph of T against L”, “A graph of Distance against Time”
- **Units**: Always include labels and units next to the horizontal and vertical axes. This helps in accurately interpreting the data values.
- **Variable Placement**: we plot the independent variable on the vertical axis (y - axis) and the dependent variable on the horizontal axis (x - axis); this is a standard convention.

Line of best fit

When the plotted points show a sufficient pattern but cannot be joined together with one straight line, then a line of best fit is drawn.



(a) Scaling the axes and plotting the data. (b) Drawing the “line of best fit.”

Figure 4.4 Drawing the line of best fit.

The line of best fit is one that best expresses the relationship between the plotted points. It aims to represent the pattern of the data as accurately as possible. When drawing the line of best fit, first identify the general trend of the plotted values, then aim to have an equal number of points above and below the line, also ensure that is passes close to as many points as possible. Points that are far away from the line of best fit are usually outliers and off-the-trend.

TRY IT OUT

1. Complete the table below; Plot a graph of $\frac{100-l}{l}$ against R and determine the slope of the graph.

$R\ (\Omega)$	$l\ (cm)$	$(100-l)\ (cm)$	$\frac{100-l}{l}$
1	75.0		
2	60.9		
3	50.9		
4	44.1		
5	38.4		
6	34.4		

2. Complete the table below; Plot a graph of T^2 against x^2, determine the intercept on the T^2 axis and the slope of the graph.

$x\ (cm)$	$x^2(cm^2)$	$T\ (s)$	$T^2(s^2)$
0.10		0.73	
0.15		0.75	
0.20		0.80	
0.25		0.85	
0.30		0.93	
0.35		1.00	

3. Complete the table below; Plot a graph of $\frac{1}{l^2}$ against $\sin^2 i$, find the gradient of your graph and the intercept on the $\frac{1}{l^2}$ axis.

$i\ (^0)$	$\sin i$	$\sin^2 i$	$l\ (cm)$	$\frac{1}{l^2}\ (cm^2)$
10			6.5	
20			6.6	
30			6.8	
40			7.1	
50			7.4	
60			7.9	

7.0 WRITING A PRACTICAL REPORT

Writing a practical report is an essential skill in practical physics. It helps you to document your experiment and key findings.

A practical report typically consists of, title, Hypothesis, Apparatus and Materials, Setup diagram, Procedures, Data Collection, Data Analysis & Conclusion.

1. Title or Aim

The title should be concise yet descriptive, indicating the main focus of the experiment. A good title gives the reader a clear idea of what to expect from the report and why the practical investigation was done.

2. Choosing Variables

Variables are quantities or characteristics that can be measured in some way within the experiment; we always need to state our variables especially if the experiment involves *comparing two quantities* and how they relate with one another. Variables are also necessary if graphs are to be used during your data analysis.

Identifying and choosing the correct variables is crucial for a successful experiment. There are three main types of variables:

- **Independent Variable:** This is the variable that you change or manipulate in the experiment. It is the cause that affects the outcome.
- **Dependent Variable:** This is the variable that you measure. It is the effect or outcome that happens as a result of changing the independent variable.
- **Control Variables:** These are the variables that you keep constant to ensure that the test results are due to the independent and dependent variables alone.

To choose the right variables, focus on what you are trying to achieve with the experiment and the theory behind the experiment you are doing (if it is known) – for this physics formulas are a good place to get your variables from.

If say you're doing an experiment to determine resistance of a given material, the related theoretical concepts here include Ohm's law; which is summarized mathematically as $V = IR$, from the formula, we can see that to find resistance, we shall need the potential difference, V and current, I; these become our variables. We then determine which one can easily be changed easily and make it the independent variable – for this case, we can easily change the current by using a rheostat in the circuit.

Note: If the experiment is going to be done in one trial, then there's no need to identify which variable is dependent or independent; using the above example, you can just take one measurement of V and one for I and then calculate resistance. However, you are advised not to rely on answers from single trials as they may yield results with a big error without any other value to be compared to. Only do single trials in cases where the variables can't be changed easily.

3. Hypothesis

The hypothesis is a statement predicting the outcome of the experiment based on prior knowledge or research. It should be clear and testable, providing a foundation for the experiment. However, not all experiments require a hypothesis, it is mostly useful for experiments whose outcome is predictable based on a certain set of outcomes; e.g., in an experiment to investigate the relationship between mass and length of a swinging pendulum, the possible hypotheses can be, "***the period of oscillation of a pendulum is not affected by the mass of the bob***" or "***the period of oscillation of a pendulum increases with increase in the mass of the bob***" or "***the period of oscillation of a pendulum decreases with increase in the mass of the bob***", the experiment can then be carried out to prove if the hypothesis is true or otherwise.

As you can see in the example above, such an experiment has a defined set of outcomes (which can be guessed). The experiment is then carried out to determine if the hypothesis is true or false.

4. Experimental Setup Diagram

The setup diagram is a visual representation of the experimental setup. It helps readers understand how the apparatus and materials are arranged and connected. A clear and accurate diagram can be helpful in replicating the experiment and understanding the procedure.

Remember, *"a good picture is worth a thousand words"*. Some best practices when drawing setup diagrams

- *Drawing the Diagram*: Use simple, labeled sketches to illustrate the arrangement of equipment. Ensure all components mentioned in the apparatus list are included in the diagram.
- *Labeling*: Clearly label all parts of the setup. Use arrows or lines to point to specific components. If your diagram uses internationally recognized symbols for the apparatus, then you do not need to label.
- *Neatness and Clarity*: Ensure the diagram is neat and easy to read. Avoid cluttering the diagram with too much information; focus on the essential components and their connections.
- *Consistency*: Ensure the diagram matches the written procedures and descriptions in the report. Any disagreements between the procedures and the diagram can lead to confusion or errors when trying to replicate the experiment.

5. Apparatus and Materials

In this section, you list all the laboratory equipment (apparatus) and any other objects (materials) needed for the experiment. Providing a detailed list ensures that anyone replicating the experiment knows exactly what is required.

Practical Report: An Example

Problem: A newly launched company in your area wants to start manufacturing submersible water heaters. To accomplish this, they need to use a high resistance conducting material. A senior engineer has advised them that to make better heaters, that efficiently convert electric to heat energy, the material's resistance should be higher than 3 Ω.

Task: As a student of physics, you are provided with a sample X of the material that they want to use for the heater. Carryout an investigation to determine if the material is suitable for use.

Solution:

Title: An experiment to determine the Resistance of a Material to check if it is suitable for use in a Heater.

Hypothesis: The material has a high resistance ($R > 3\ \Omega$), and will be suitable for use in a heater as it will convert electrical energy into heat efficiently.

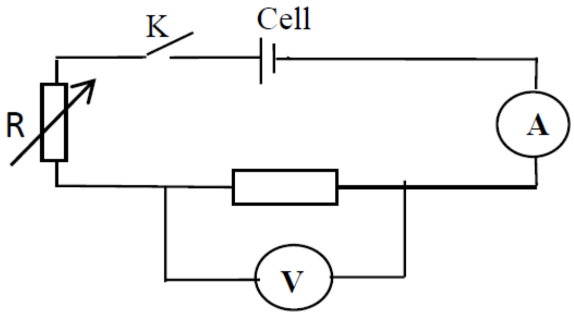
Variables:

- Independent variable: Voltage or Potential difference (because this is the quantity or variable you change during the experiment to observe how it affects current)
- Dependent variable: Current (because it depends on the applied voltage and resistance of the material)
- Control variables: Temperature (because temperature must be kept constant throughout the experiment to keep the values of resistance reliable, ensuring that resistance obtained entirely depends on voltage and current)

Apparatus and Materials:

Ammeter, Voltmeter, Power supply (Dry cells), Rheostat, Connecting wires, Material sample, Jockey, crocodile clips.

Experimental setup diagram:



Procedures:

a) The circuit is set up as shown in the diagram above, with the material sample connected in series with the ammeter and the dry cells.
b) The voltmeter is connected in parallel across the material sample.

From the graph of V against **I**, a straight line passing through the origin was obtained which indicates that as potential difference increases, so does the current. The gradient or slope of the line $\left(\frac{Change\ in\ V}{Change\ in\ I}\right)$ is the resistance of the material;

$$Slope = \frac{Change\ in\ V}{Change\ in\ I} = \frac{2.5 - 0}{1.0 - 0} = 2.5\ \Omega$$

Note: The values used in this experiment were not obtained from a practical experiment, in practice, the values obtained usually do not all lie along one straight line; in these cases, a ***line of best fit*** is drawn as an average line for all plotted points.

Conclusion: The experiment successfully determined the resistance of the material sample to be 2.5 Ω. This value is less than the recommended 3 Ω that was, therefore, the material is not suitable for use in designing the heater, as it cannot efficiently convert electrical energy into heat.

The hypothesis that a material has a high resistance was not supported by the experimental data.

Possible sources of error	**Precautions taken**
Parallax error when viewing the pointer on the ammeter and voltmeter	I viewed the pointer from multiple angles to ensure accuracy
Zero error; some meters were not set to zero at the start of the experiment	I accounted for zero errors on my measurements. I used well calibrated instruments
Resistance of connecting wires	I used thick and shorter wires of low resistance
Human errors (such as improper placement of instruments and inconsistent readings)	Great care was taken to reduce human error. Multiple results were also taken to outweigh errors in some measurements
Fluctuations / changes in voltage	The experiment was done within a short time before the cells were drained.

8.0 THEORY OF COMMON EXPERIMENTS

Understanding the underlying theory before carrying out an experiment is very important as it provides a foundational context for the procedures and outcomes. It allows you to grasp the principles and concepts that govern the experiment, ensuring you can easily understand what you are observing and why it occurs.

Applying theoretical knowledge to practical scenarios, encourages critical thinking and problem-solving. It also helps in predicting results, troubleshooting issues, and interpreting experimental data accurately.

Without this theoretical understanding, experiments may become mere procedural tasks, losing the educational value and the opportunity to connect practical experiences with scientific principles.

8.1 Density of Liquids and Solids

Density (ρ) is defined as the mass per unit volume of a substance. It is expressed in units of grams per cubic centimeter (g/cm³) or kilograms per cubic meter (kg/m³).

$$1\text{g/cm}^3 = 1000\ \text{kg/m}^3$$

Each substance has a unique value of density which is why we commonly use density to identify substances. and

Mathematically, density is the mass (m) of a substance divided by its volume (V).

$$\rho = \frac{m}{v}$$

Mass (m) is the amount of matter in an object, measured in grams (g) or kilograms (kg) while Volume (V) is the amount of space an object occupies, measured in cubic centimeters (cm³) or cubic meters (m³).

8.2 Measuring the Density of a Liquid

Apparatus: Measuring cylinder: to measure volume, beam balance: to measure the mass, liquid sample.

Procedure:

- Measure the mass of the empty measuring cylinder using the balance, e.g., m_b.
- Fill the measuring cylinder with a known volume of the liquid, V.
- Measure the mass of the measuring cylinder with the liquid, m_{b+l}.
- Subtract the mass of the empty cylinder from the total mass to find the mass of the liquid, $m_l = m_{b+l} - m_b$.
- Calculate the density using $\rho = \frac{m_l}{V}$
- For accuracy, you can take different measurements and calculate the density in each case, then take the average value.

m_l (g)	V(cm³)	ρ (g/cm³)

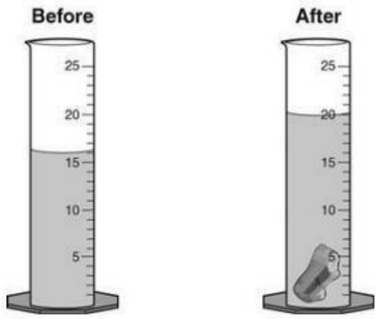
8.3 Measuring the Density of a Solid:

Apparatus: Balance, measuring cylinder or water displacement method, solid sample.

Steps:

- Measure the mass of the solid using the balance.
- If the solid is regular, measure its dimensions and calculate its volume.

- If the solid is irregular, use the displacement method to find its volume, i.e., fill a measuring cylinder with water and record the initial volume, V_1, Submerge the solid in the water and record the new volume, V_2.



- Calculate the volume of the solid by subtracting the initial volume from the new volume, $V = V_2 - V_1$.
- Calculate the density using $\rho = \frac{m}{v}$

Applications of density:

Material Identification: Density is used to identify substances and determine their purity.

Quality Control: Ensures that materials used in manufacturing meet specific density criteria.

Buoyancy and Shipbuilding: Understanding density helps in designing ships and submarines to ensure they float or submerge correctly.

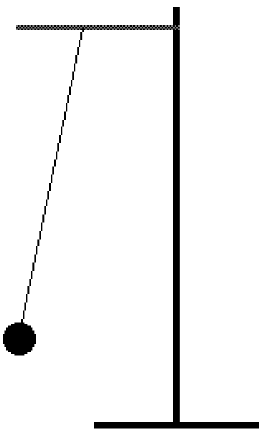
Geology: Helps in identifying minerals and understanding Earth's composition.

8.4 Oscillations and Acceleration Due to Gravity

An oscillation is the to and fro movement of an object. Oscillations occur in many aspects of the physical world, from the atomic scales to large scales; we use oscillations to describe movement of atoms, waves & signals, and a lot more!

The simple pendulum

One of the common oscillating systems we use in the physics laboratory is the simple pendulum; which is a setup involving a small mass attached at the end of a string tied to a fixed support.



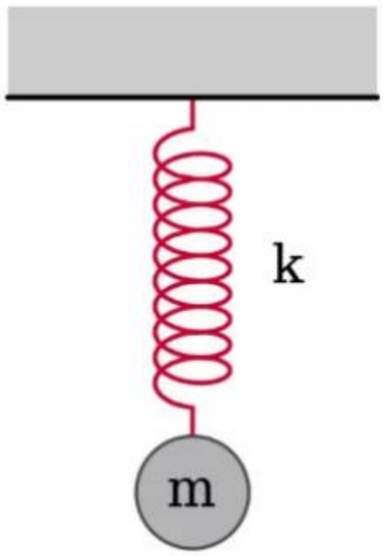
When the small mass is pulled through a certain angle, it starts to oscillate. The period (T) is the time taken for the bob to make one complete oscillation; it is measured in seconds (s).

The relationship between the period of oscillation (T), length of the bob, L and acceleration due to gravity, g is;

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

Most experiments with the simple pendulum are based on this equation.

We can see from the equation that the period of oscillation is not affected by the angle of displacement and the mass of the bob as these variables do not appear in the equation.



The relationship between the period of oscillation, T, and the attached mass is given by the equation: $T = 2\pi\sqrt{\frac{m}{K}}$, where K is the spring constant.

We can design an experiment around this formula to determine some unknown mass, m or to determine the spring constant K.

8.5 Extension and Hooke's Law

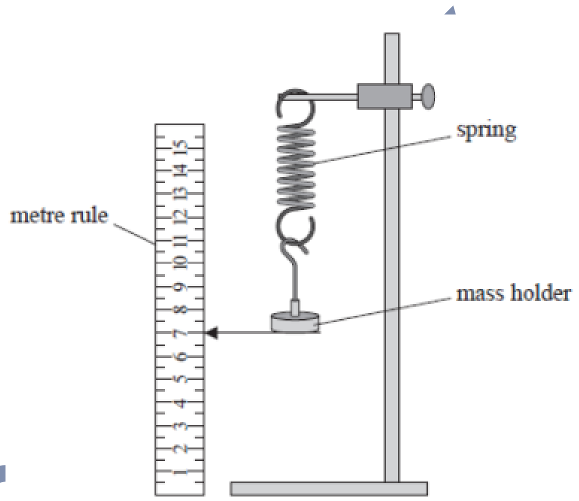
Hooke's Law describes the behavior of springs and other elastic materials like rubber bands. It states that the extension of an elastic material is proportional the applied force provided the elastic limit is not exceeded; mathematically written as, $F = kx$, where, F is the applied force, x is the extension

The Spring Constant (K) is a measure of the stiffness of the spring, if K is high, the spring is very stiff and if K is lower, the spring can easily be stretched or compressed. K is measured in Newton per meter (N/m).

The Elastic Limit is the maximum extent to which a material can be stretched without permanently deforming.

Investigating Hooke's Law:

Apparatus: Spring, weights, ruler, stand, and clamp.

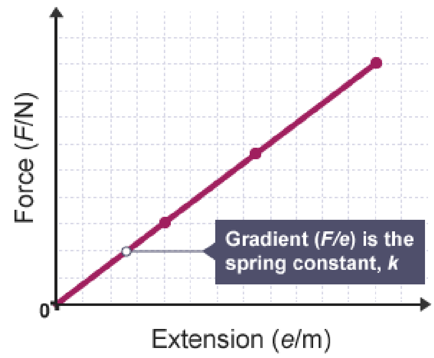


Steps:

- Attach the spring to a stand and measure its original length or position along a meter rule scale.
- Add a known mass to the spring and measure the new length or the new position.
- Calculate the extension x by subtracting the original length from the new length.
- Repeat steps 2) to 3) with different masses and tabulate your results in a table.

M (kg)	F (N)	x(m)

- A graph of the applied force, F is plotted against the extension; a straight line through the origin should be obtained indicating that $F \propto x$.



- The gradient of the graph of F against x gives the spring constant K.

Determining the Elastic Limit:

We can attach different masses to the spring, one at a time as we increase them. For each mass we add, we notice the extension and then remove it to see if the spring or material returns to its original length.

Keep doing this until you identify the point at which the spring no longer returns to its original length when the masses are removed. This point is the elastic limit.

Applications

- **Engineering and Construction:** Hooke's Law is fundamental in designing structures and mechanical components that must withstand forces without permanent deformation.
- **Consumer Products:** It is applied in the design of everyday items like mattresses, car suspensions, and various types of springs.
- **Material Science:** Helps in understanding and predicting the behavior of materials under stress.

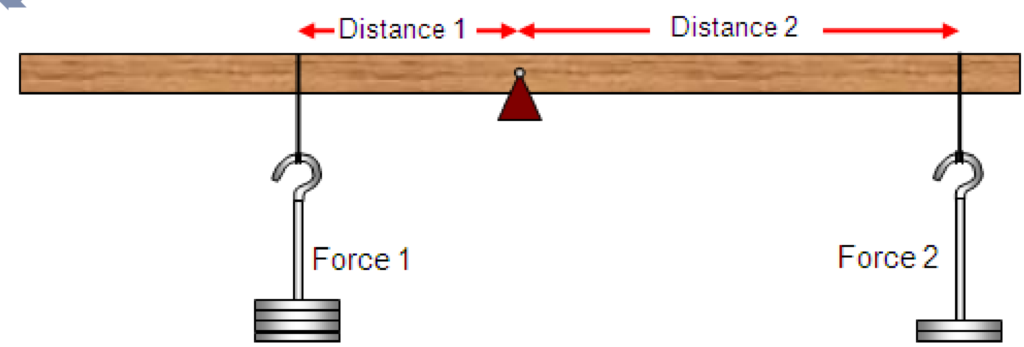
8.6 Moments and Equilibrium

A moment is the turning effect of a force applied to a rotational system at a distance from the axis of rotation. It is a measure of the tendency of the force to cause an object to rotate. Mathematically speaking; a moment is the product of the force (F) and the perpendicular distance (d) from the pivot point or axis of rotation.

$$Moment = F \times d$$

Principle of Moments: For a stiff body to be in equilibrium (a state of balancing), the sum of the clockwise moments about any pivot must equal the sum of the counterclockwise moments about that pivot.

Investigating Moments Using a Meter Rule:



Apparatus: Meter rule, pivot, weights, and a clamp.

Steps:

- Balance the meter rule horizontally on the pivot.
- Hang weights at different distances from the pivot.
- Adjust the weights and their positions until the meter rule is in equilibrium.
- Record the forces and their distances from the pivot.
- Verify the principle of moments by checking that;

$$\sum Clockwise\ Moments = \sum Counterclockwise\ Moments$$

Note: Since most meter rules used in such experiments are not so stiff / rigid, the moments may not exactly be equal but they should be close to each other.

- The experiment can be repeated with different weights attached.

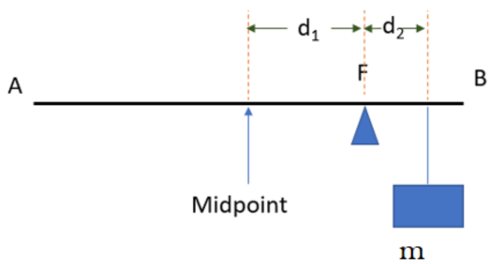
$F_1(N)$	$F_2(N)$	$d_1(m)$	$d_2(N)$	$F_1d_1(Nm)$	$F_2d_2(Nm)$

Determining an unknown Mass

The experiment above can be modified to determine some unknown mass or weight. As long as one of the weights is already known, we can apply the principle of moments to determine the other.

Determining the Mass of a meter rule

We know that for a uniform meter rule, the center of mass or center of gravity acts at its midpoint. By using a known mass, m on one end, we can find determine the mass of the meter rule on the other end which makes the meter rule to balance.



Note: It is not always safe to assume that the midpoint of the meter rule is the $50.0\ cm$ mark, due to manufacturing errors, sometimes the meter rule is not perfectly uniform and the center of gravity is slightly shifted. Always start by balancing the meter rule alone to determine its center of mass.

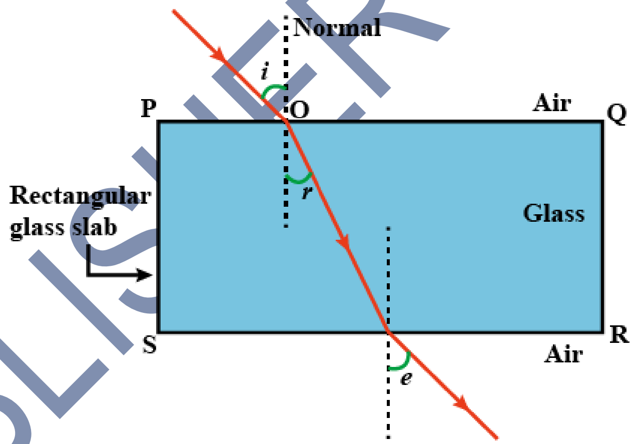
4. Insert an optical pins P and Q along the line of the angle of incidence; you should now see their images P' and Q' in the mirror.
5. Looking through the opposite side, insert pins R and S such that they appear to be in line with P' and Q'.
6. Remove the mirror and pins. Draw a line through the markings left by markings of R and S, this is the reflected ray.
7. Measure the angle of reflection r, this should be equal to i.
8. You can repeat the experiment with different values of angle i

$i(^0)$	$r(^0)$

By projecting line RS behind the mirror and then joining, $P\ to\ P'$ or $Q\ to\ Q'$, we can also show that the distance of the image behind the mirror is the same as the object distance in front of the mirror.

8.8 Refraction of light

Refraction is the bending of light as it passes from one medium to another with different optical densities.



Different materials refract light differently depending on their Refractive Indices (n), the higher it is, the more it bends (or refracts) the light.

Refractive index is the ratio of the sine of the angle of incidence to the sine of the angle of refraction. It is a constant that depends on the nature of the material.

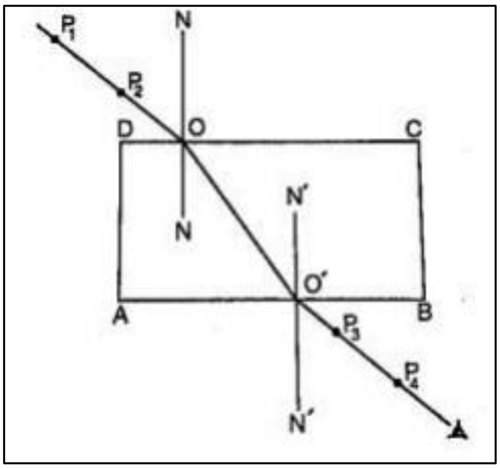
Mathematically;

$$n = \frac{\sin i}{\sin r}$$

In the laboratory, we can verify the laws of refraction and also determine the refractive index of a given material.

Investigating Refraction Using a Glass Block:

Apparatus: Glass block, optical pins, white paper, protractor and soft board.



Steps:

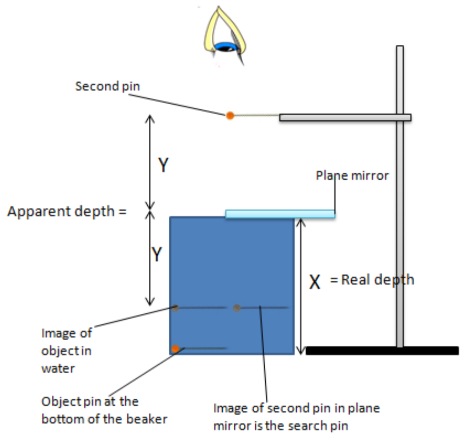
1. Place the glass block on a sheet of white paper and draw its outline ABCD.
2. Remove the glass block & draw a normal on side DC of the glass block.
3. Using a protractor, draw an angle of incidence on the normal at point O, e.g., $i = 30^0$
4. Fix two optical pins P_1 and P_2 along the angle of incidence; replace the glass block back to its outline.
5. Looking through side AB of the glass block, fix pins P_3 and P_4 such that they appear to be in line with the images of P_1 and P_2 seen through the glass block.
6. Draw a line through P_3 and P_4 to meet the glass block at O', Join $O\ to\ O'$ and measure the angle of refraction using a protractor.
7. Repeat the experiment for different values of angle i and measure the corresponding angles of refraction, r.
8. For each case, determine n, the ratio of $\sin i$ to $\sin r$.

$i(^0)$	$r(^0)$	$\sin i$	$\sin r$	n

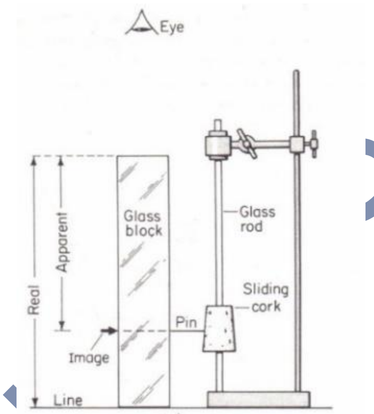
The values "$\boldsymbol{n}$" should be fairly the same (i.e. constant) which proves the second law of reflection. Meanwhile, the value of $\boldsymbol{n}$ is also the refractive index of the material. For accuracy's sake, we can go ahead and find the average value of the refractive index.

We can also plot a graph of $\mathbf{sin}\,\boldsymbol{i}$against $\mathbf{sin}\,\boldsymbol{r}$**,** the result a straight line with positive gradient through the origin.
The gradient of this line would be the refractive index.

$$Gradient\ or\ Slope = \frac{\Delta\ \sin i}{\Delta\ \sin r} = n$$



Real & apparent depth can also be used to determine refractive indices of transparent solids like glass. Instead of a pin, a line is drawn on a piece of paper on which the transparent material such as a glass block is placed.

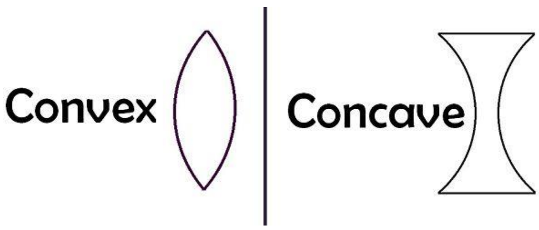


8.9 Lenses and Curved Mirrors

Lenses:

Lenses are transparent optical devices that refract light to converge or diverge the rays. They are used extensively in various applications, including eyeglasses, cameras, and scientific instruments.

Lenses come in two major types; **convex** or converging lens (one that is thicker in the middle than at the edges) and **concave** or diverging Lens (one that is thinner in the middle than at the edges). Due to their diverging nature and the fact they form virtual images, experimenting with concave lenses is a bit challenging, we shall only deal with experiments of convex lenses which form mostly real images (except when the object distance is less than the focal length).



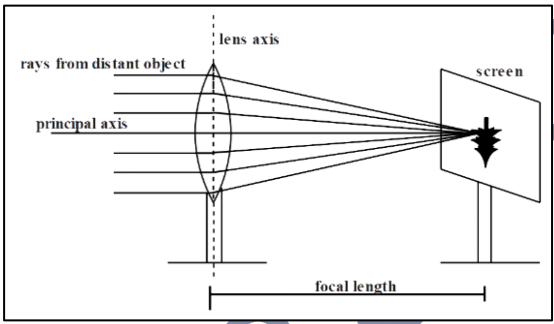
When a lens converges or diverges the light, the rays will always converge to a certain point (for a convex / converging lens) or they will appear to be diverging from a certain point (for a concave / diverging lens); this point is known as the **focal point** of the lens.

Determining the Focal Length of a Convex Lens:

Apparatus: Convex lens, lens holder, meter rule, screen, distant light source (e.g., a lamp or sunlight, or an open window).

Steps:

1. Place the convex lens in the lens holder.
2. Position the lens so that it faces a distant light source, with this setup, light rays are considered to be coming from infinity and thus they converge at the focal point.



3. Move a screen along the principal axis until a sharp image of the light source is formed on the screen.
4. Measure the distance between the lens and the screen. This distance is the focal length of the convex lens.

This method is quick to use but is considered rough and is mostly used to estimate the focal length.

A more accurate way to determine focal length is to use an **illuminated object** together with the lens formula. The lens formula is a mathematical relationship between the focal length, f, object distance, u and image distance, v.

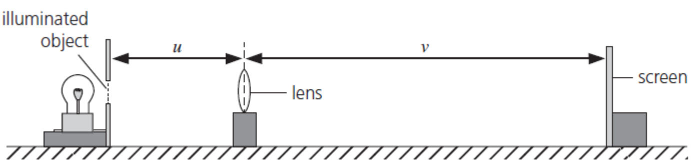
$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

Making f the subject of the formula, we get;

$$f = \frac{uv}{u+v}$$

To use this method;

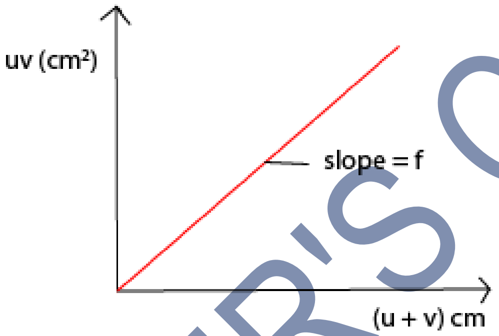
1. The materials are arranged as below;



2. The illuminated object is placed a distance, u from the lens.
3. The screen is moved until a sharp image is formed on it.
4. The distances u and v are measured and recorded.
5. The focal length f of the lens is then got from; $f = \frac{uv}{u+v}$.
6. The experiment can be repeated with different values of u so that different values of f can be got and averaged.

$u\ (cm)$	$v\ (cm)$	$f\ (cm)$

We can also plot a graph of uv against $u + v$, this will yield a straight line through the origin whose slope is equal to the value of f since;

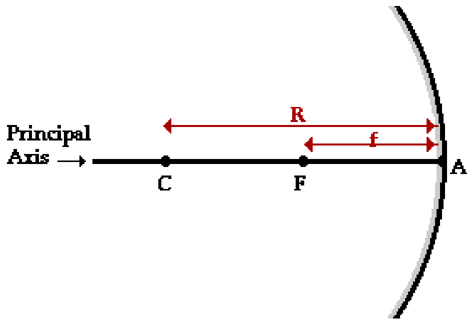


$$slope = \frac{change\ in\ "uv"}{Change\ in\ "u + v"} = f$$

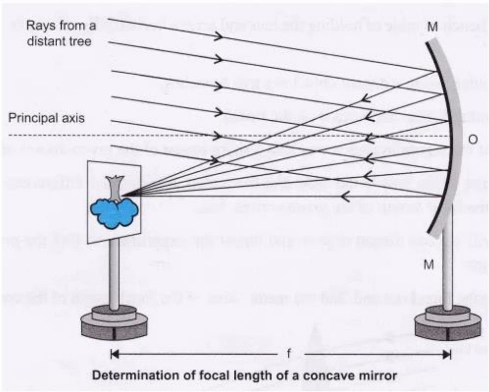
Curved Mirrors

Curved mirrors reflect light to form varying images depending on the location of the object. Just like lenses, curved mirrors are categorized in 2 main types; concave (converging) mirror which have a reflecting surface that curves inward, and convex (diverging) mirrors which have a reflecting surface that curves outward. We shall focus on concave mirrors since they form mostly real images that can easily be experimented with.

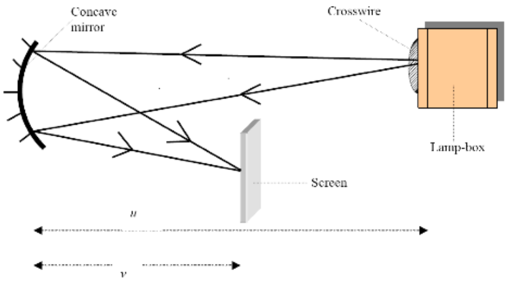
The focal point (F) of the concave mirror is a point where parallel rays of light converge after reflecting from the mirror. The distance from the mirror to the focal point is known as the focal length, f, twice this distance gives us the radius of curvature, r; $r = 2f$.



To determine the focal length of a concave mirror, we focus it towards a distant object such as an open window and then move the screen until a clear image of the window (or another object) is formed on it. At this point, the light rays are considered to be coming from infinity and converging at F, thus f is the distance between the screen and the mirror.



This method is mostly used for rough estimation of focal length, for more accurate considerations; an illuminated object is used as shown below.



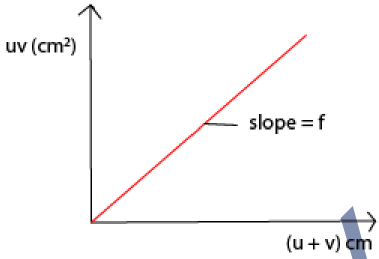
The object (illuminated crosswire) is placed at a known distance u, the screen and lens are adjusted until a clear image is formed in the screen. The image distance v is measured.

The focal length is then calculated from;

$$f = \frac{uv}{u+v}$$

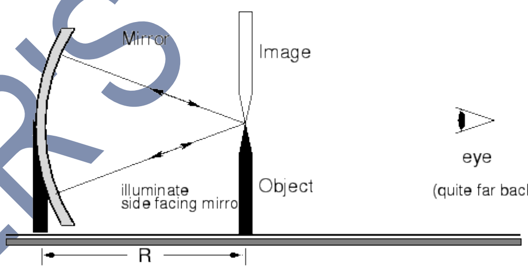
This formula was introduced earlier on the section about lenses.

We can also plot a graph of uv against $u + v$, this will yield a straight line through the origin whose slope is equal to the value of f since;



$$slope = \frac{Change\ in\ "uv"}{Change\ in\ "u+v"} = f$$

Another common method for finding the focal length of a concave mirror is known as the '**no parallax method**'.



Here, an object (usually an optical pin) is moved along the axis of the mirror until its image is seen to coincide with the object pin itself, the distance from the mirror to the point of coincidence is the radius of curvature and since $r = 2f$, the focal length can be calculated. This method works on the theory that when an object is placed at the center of curvature of the concave mirror, C, the image is also formed at C.

8.10 Current Electricity

This is the kind of electricity that flows from one point to another in a closed circuit. Electric current is the flow of electrons in a closed circuit; mathematically speaking, it is the amount of charge flowing through a given point per second; ($I = Q/t$), current is measured in Amperes (A).

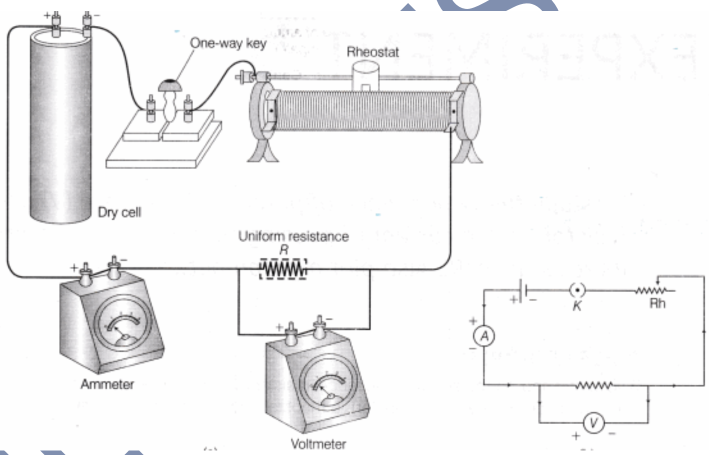
As current flows, so do electrons; however, these electrons constantly collide with stationary atoms converting their kinetic energy into heat and effectively slowing down; This creates a phenomenon known as **Resistance**. Electrical resistance is the opposition that a material offers to the flow of electric current, measured in Ohm (Ω).

Resistance is a fundamental concept in electricity, affecting how circuits function and how electrical energy is consumed. A resistor is a component that provides resistance in a circuit. When current is flowing through a resistor, the battery / source of energy has to do work to push the electrons through the resistance, hence the batteries get used up over time.

Resistance & Heating: Materials with high resistance are preferred when making heating components because they easily convert electricity to heat, while those with low resistance are preferred in transmission lines so that power is transmitted with minimal losses.

Ohm's Law: Ohm's Law states that the current (I) passing through a conductor between two points is directly proportional to the voltage (V) across the two points provided other physical conditions such as temperature remain constant, this is summarized as $V = IR$, where R is a constant of a material known as resistance.

To verify ohm's law, we setup an experiment in which we can vary the current I through a capacitor as well its potential difference, V, then we can use $V = IR$ to find resistance, R. the circuit below is commonly used;

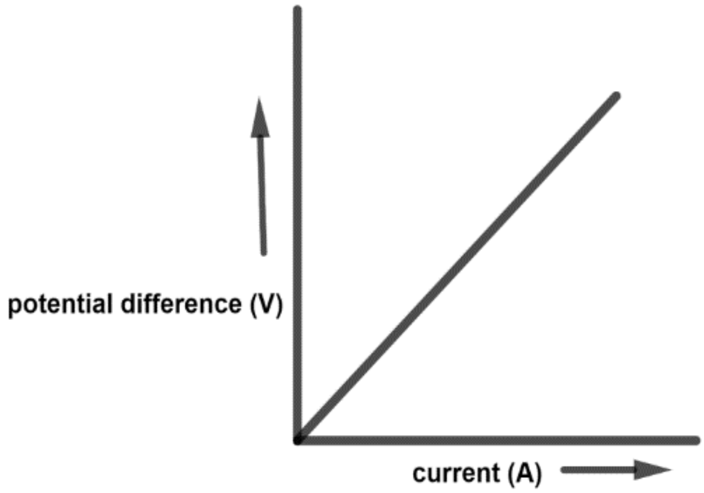


The voltmeter is connected across R to read the potential difference across the resistor, the ammeter is connected is connected in series with R to read the current going through the resistor.

To obtain several values of I and V, the ammeter is added to circuit, by adjusting the ammeter, we change the current and hence the p.d. in the circuit; we can tabulate the values and find the average value of R.

V(v)	I(A)	R(Ω)

We can also plot a graph of V against I, it should give a straight line passing through the origin, this graph proves Ohm's law, that V is proportional to I. The slope of this graph is the value of resistance.



$$Gradient\ or\ Slope = \frac{Change\ in\ V}{Change\ in\ I} \Longrightarrow \frac{V}{I} = R$$

Resistivity (ρ): is the property of a material that describes how strongly it resists current flow, defined by the formula; $R = \rho\frac{L}{A}$, R is resistance of the material, L is the length of the material, and A is its cross-sectional area. This equation tells us that resistance increases with increase in length but decreases with increase in area.

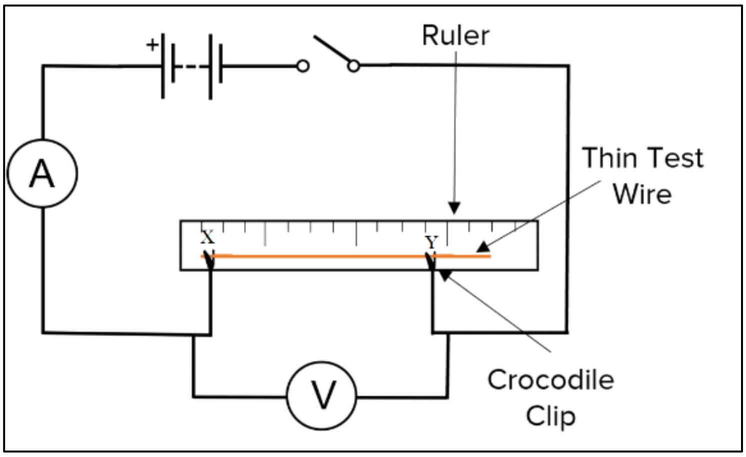
Measuring the Resistance of a Wire:

We can measure the resistance of wires such as Nichrome, Constantan, Copper, etc. in a similar manner described above. We cut a piece of the wire to a known length. Then set up the circuit as already discussed above but with the piece of wire connected instead of the resistor R.

Investigating Factors Affecting Resistance:

As stated already; $R = \rho\frac{L}{A}$, the resistance of a material is directly proportional to the length and inversely proportional to the cross-sectional area. We can investigate these through an experiment too.

To do this, we set up an experiment with the voltmeter across the resistance wire of a given length between the terminals XY, and an ammeter in series with the wire.



The switch is closed, the voltmeter reading V and ammeter reading I are noted and the resistance of the wire is calculated from $V = IR$.

The length of the test wire is increased by adjusting the terminals X or Y, the new values of V and I are noted and the resistance is calculated again as above. The experiment can be repeated with different lengths and the corresponding resistances noted.

L(m)	V(v)	I(A)	R(Ω)

If the experiment is done well, we can observe that as we increase the length of the wire, the resistance also increases. We can also plot a graph of resistance and length and it should be a straight line showing that resistance increases with length.

Repeat the experiment with wires of different lengths and thicknesses to observe how resistance changes.

To investigate the effect of ***cross-sectional area on resistance of the wire***, we follow the same steps but using wires of the same material and length but with different thicknesses / cross sectional areas.

Internal resistance

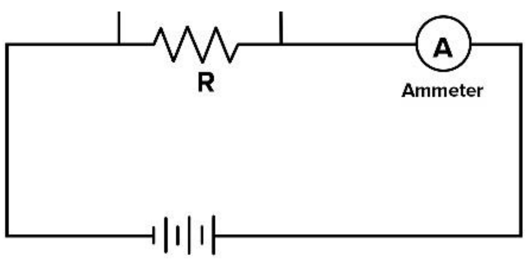
Just like conductors, batteries / cells also have a resistance within them; this is known as internal resistance. This resistance arises due to the fact that the electrodes and electrolytes making up the cell are themselves not perfectly conductive.

Internal resistance can greatly reduce the efficiency of the cell due to energy losses.

The relationship between internal resistance, r, EMF, E and current is;

$$E = I(R + r).$$

To determine the internal resistance, we first measure the EMF of the cell(s), i.e. the voltage of the cell with no resistor connected on it, then we connect a resistor into the circuit and measure the current flowing; we then use the above expression to determine the internal resistance. (R is a standard / known resistance)



9.0 MECHANICS EXPERIMENTS

Problem / Scenario Based Item 1

Scenario: There has been an argument among physics students in the country that the acceleration due to gravity on earth is different for different places on earth depending on altitude. To stop the argument, different students will carry out experiments to determine the acceleration due to gravity at their school locations and you are one of those selected to participate.

Task: Using common laboratory apparatus, carry out an experiment to determine the value of acceleration due to gravity at your school.

My practical work plan

What problem am I solving?

What theoretical knowledge is required?
(include any related formulae)

What data will I collect with my experiment? How will I analyze it to solve the problem in the question?

What apparatus will i need for this investigation?

This is just a work plan, it is not meant to replace the comprehensive report

LAB REPORT

Name: ....

Date: ...... /....... /........ Experiment No.......

GRAPHICAL ANALYSIS

Name: ....

Expt. No. .... Date: .... /..../....

TITLE:

ANALYSIS AND CONCLUSION

LAB REPORT SCORING RUBRIC

Basis of evaluation		Teacher's marks & Comments
Aim of the experiment (2 scores)	☐ A descriptive title/aim/objective of the experiment is well stated (2 pts) ☐ The title / aim / objective is stated but lacking some elements (1 pt) ☐ Irrelevant or no title / aim / is stated (0 pts)	
Hypothesis (2 scores)	☐ Hypothesis is well stated and descriptive (2 pts) ☐ Hypothesis is stated but lacking (1 pts) ☐ Irrelevant, Incorrect or no hypothesis stated (0 pts)	
Experimental Variables (3 scores)	☐ Independent, dependent and control are variables stated (3 pts) ☐ Only 2 variables are stated (2 pts) ☐ Only 1 variable is stated (1 pts) ☐ Irrelevant or no variables stated (0 pts)	
Apparatus (1 score)	☐ Necessary and relevant apparatus mentioned (1 pts) ☐ Irrelevant or no apparatus mentioned (0 pts)	
Setup diagram (2 scores)	☐ Working diagram is presented by the learner showing all relevant components (2 pts) ☐ Diagram is presented but lacking some features (1 pts) ☐ Irrelevant or no diagram presented (0 pts)	
Procedures (3 scores)	☐ Complete, correct and logical procedures presented (3 pts) ☐ Correct procedures but not in a logical and coherent order (2 pts) ☐ Incomplete procedures (1 pts) ☐ Irrelevant or incorrect procedures (0 pts)	

Data collection, presentation and manipulation (4 scores)	☐ Relevant data collected with correct accuracy (significant figures and decimal places) (4 pts) ☐ Relevant data collected but with incorrect precision / accuracy in terms of d. p's and significant figures. (1-3 pts) ☐ Incorrect or irrelevant data collected. (0 pts)	
Data Analysis (4 scores)	☐ Correct data analysis using appropriate techniques i.e. statistics, graphs, etc. (4 pts) ☐ Correct data analysis using inappropriate techniques for the problem. (1-3 pts) ☐ Analysis is partially correct (1-2 pts) ☐ Incorrect or no data analysis presented. (0 pts)	
Conclusion in relation to the hypothesis and the problem in the question (2 scores)	☐ Relevant and meaningful conclusion made. (2 pts) ☐ Conclusion is stated but lacking (1 pts) ☐ No conclusion or interpretation of results made (0 pts)	
Errors and precautions (2 scores)	☐ Possible sources of errors and precautions taken were stated (2 pts) ☐ Errors stated without precautions (1 pts) ☐ No relevant errors / precautions stated (0 pts)	
TOTAL		**................ / 25**

Note: The scores given in the above rubric and scores for each success criteria may vary from one experiment to another, they can be modified for each specific experiment.

Problem / Scenario Based Item 3

Scenario: 'Quantum Electronics' is a new company that plans to start manufacturing torches in your area. They intend to use springs to hold dry cells within their torches. Their chief engineer has advised that for the torches to be long lasting, the springs to be used should obey Hooke's law. The company has therefore decided to send a sample of the spring they plan to use to your school for lab investigation.

Task: As a student of physics, you have been provided with a sample spring that the company intends to use, carry out an investigation on it and make a recommendation.

My practical work plan

What problem am I solving?

What theoretical knowledge is required?
(include any related formulae)

What data will I collect with my experiment? How will I analyze it to solve the problem in the question?

What apparatus will i need for this investigation?

This is just a work plan, it is not meant to replace the comprehensive report

LAB REPORT

Name: ....

Date: ...... /....... /........ Experiment No.......

GRAPHICAL ANALYSIS

Name: ....

Expt. No. .... Date: .... /..../....

TITLE:

ANALYSIS AND CONCLUSION

LAB REPORT SCORING RUBRIC

(For the Examiner)

Basis of evaluation		Teacher's marks Comments
Aim of the experiment (2 scores)	☐ A descriptive title/aim/objective of the experiment is well stated (2 pts) ☐ The title / aim / objective is stated but lacking some elements (1 pt) ☐ Irrelevant or no title / aim / is stated (0 pts)	
Hypothesis (2 scores)	☐ Hypothesis is well stated and descriptive (2 pts) ☐ Hypothesis is stated but lacking (1 pts) ☐ Irrelevant, Incorrect or no hypothesis stated (0 pts)	
Experimental Variables (3 scores)	☐ Independent, dependent and control are variables stated (3 pts) ☐ Only 2 variables are stated (2 pts) ☐ Only 1 variable is stated (1 pts) ☐ Irrelevant or no variables stated (0 pts)	
Apparatus (1 score)	☐ Necessary and relevant apparatus mentioned (1 pts) ☐ Irrelevant or no apparatus mentioned (0 pts)	
Setup diagram (2 scores)	☐ Working diagram is presented by the learner showing all relevant components (2 pts) ☐ Diagram is presented but lacking some features (1 pts) ☐ Irrelevant or no diagram presented (0 pts)	
Procedures (3 scores)	☐ Complete, correct and logical procedures presented (3 pts) ☐ Correct procedures but not in a logical and coherent order (2 pts)	

	☐ Incomplete procedures (1 pts) ☐ Irrelevant or incorrect procedures (0 pts)	
Data collection, presentation and manipulation (4 scores)	☐ Relevant data collected with correct accuracy (significant figures and decimal places) (4 pts) ☐ Relevant data collected but with incorrect precision / accuracy in terms of d. p's and significant figures. (1-3 pts) ☐ Incorrect or irrelevant data collected. (0 pts)	
Data Analysis (4 scores)	☐ Correct data analysis using appropriate techniques i.e. statistics, graphs, etc. (4 pts) ☐ Correct data analysis using inappropriate techniques for the problem. (1-3 pts) ☐ Analysis is partially correct (1-2 pts) ☐ Incorrect or no data analysis presented. (0 pts)	
Conclusion in relation to the hypothesis and the problem in the question (2 scores)	☐ Relevant and meaningful conclusion made. (2 pts) ☐ Conclusion is stated but lacking (1 pts) ☐ No conclusion or interpretation of results made (0 pts)	
Errors and precautions (2 scores)	☐ Possible sources of errors and precautions taken were stated (2 pts) ☐ Errors stated without precautions (1 pts) ☐ No relevant errors / precautions stated (0 pts)	
TOTAL		**................ / 25**

Note to examiners: The scores given in the above rubric and scores for each success criteria may vary from one experiment to another, you may modify them as you deem fit for a specific experiment.

FOR ORDERS, PLEASE CALL OR WHATSAPP

- 0778370148 (CALLS & WHATSAPP)
- 0705272603 (ONLY CALLS)

Problem / Scenario Based Item 4

Scenario: According to the world market, the price of paraffin depends on its purity which also depends on its density. The table below shows how prices vary with density.

Density range	Price (US. Dollars) per 20-liter Jerry can
500 kg/m^3 to 749 kg/m^3	50
750 kg/m^3 to 950 kg/m^3	60
Above 950 kg/m^3	65

Uganda has just started mining & purifying crude oil from its reserves. It is expected that 3,000,000 liters of paraffin will be produced per day.

Task: You are provided a sample of paraffin that Uganda will be producing; carry out an investigation to determine how much money Uganda will be making from paraffin per day; assuming all the paraffin is sold.

My practical work plan

What problem am I solving?

What theoretical knowledge is required?
(include any related formulae)

What data will I collect with my experiment? How will I analyze it to solve the problem in the question?

What apparatus will i need for this investigation?

This is just a work plan, it is not meant to replace the comprehensive report

LAB REPORT

Name: ....

Date: ...... /....... /........ Experiment No.......

EXAM QUESTIONS

QUESTION 1 [UNEB, UCE 2024, PHY PAPER 3]

Your brother wants to equip the physics laboratory of his school with concave mirrors. He wishes to buy concave mirrors of focal lengths between 9.0 cm and 11.0 cm inclusive. Your brother has received samples of concave mirrors from a supplier who claims that they are of the required range of focal lengths, however, your brother wants to confirm the supplier's claims before buying the concave mirrors but lacks the knowledge.

You have been provided with a sample of the concave mirror that was supplied to your brother.

Task: Determine whether or not your brother should buy the concave mirrors.

QUESTION 2 [UNEB, UCE 2024, PHY PAPER 3]

During school project work, you came up with an idea of making your own dry cell whose quality is comparable to that of the dry cells on the open market. Through research, you found out that the quality of a dry cell is affected by its internal resistance.

The dry cells on the market are of EMF 1.5 V, however, their internal resistances are not indicated. You wish to determine the internal resistance of one of these cells so that you use it as a standard when making yours.

Your teacher has provided you with a sample of a new dry cells from the market.

Task: determine the internal resistance you will base on when making your cell

QUESTION 3 [UNEB, UCE 2024, PHY PAPER 2]

Your school wishes to buy glass blocks of refractive indices between 1.4 and 1.6 inclusive, to be used during physics practical lessons. The director of studies (DOS) has received samples of glass blocks from a supplier who claims that they are of the required range of refractive indices.

The DOS wants you to confirm the supplier' s claims but lacks knowledge yet both the physics teacher and the laboratory attendant are absent.

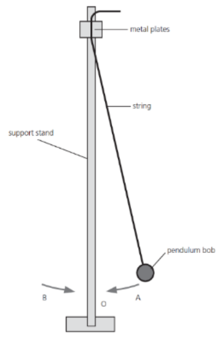
You have been provided with a sample of the glass block that was delivered to the DOS.

APPENDIX

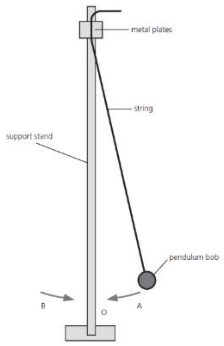
APPARATUS AND HINTS FOR SELECTED PROBLEMS

MECHANICS EXPERIMENTS

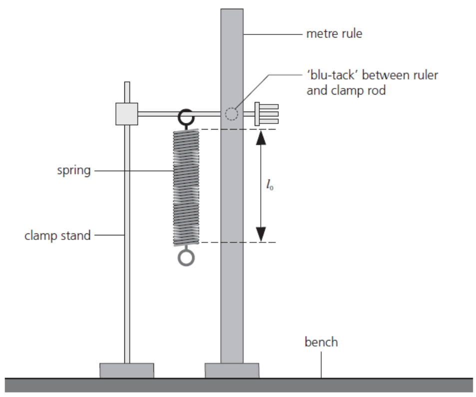
SCENARIO BASED ITEM 1

Apparatus Required	Theoretical Background
Option I ▪ Pendulum bob or mass ▪ Thread (about 1.5) ▪ Retort stands with clamp ▪ Stop clock / watch Option II ▪ Tape measure ▪ Solid object e.g. a mass ▪ Stop clock / watch ▪ Ticker timer (optional)	**Option I** The problem is to determine acceleration due to gravity. One option is for the student to use an oscillating pendulum bob. The relationship between period of oscillation and length of the pendulum is; $\boldsymbol{T = 2\pi\sqrt{\frac{L}{g}}}$, where T is the period and L is the length. The experimenter may determine g, by determining the period of oscillation T for a given length L, then substitute for them in the expression to get g.  *(see more details in the 'theory' section of the book under oscillations)* **Option II** The second option is to use a freely falling object. The object can be made to freely fall from rest from a vertical height h, and the time for the fall is determined. Then the acceleration due to gravity can be determined by the equations of motion, i.e. $\boldsymbol{h = ut + \frac{1}{2}gt^2}$

SCENARIO BASED ITEM 2

Apparatus Required	Theoretical Background
▪ Pendulum bob or mass ▪ Thread (about 1.5) ▪ Retort stand with clamp ▪ Stop clock / watch	The problem is to investigate the relationship between mass of the pendulum and period of oscillation. From the relationship $\boldsymbol{T = 2\pi\sqrt{\frac{L}{g}}}$, we can see that there's no mass in the equation hence the mass does not affect the period. To prove this however, an experiment is setup using masses instead of a pendulum bob; different masses are used and the period is calculated in each case. 

SCENARIO BASED ITEM 3

Apparatus Required	Theoretical Background
▪ Spring ▪ Masses (50 – 600 g) ▪ Retort stand with 2 clamps ▪ Meter rule	The problem here is to verify if the spring obeys Hooke's law; Extension is directly proportional to the applied force $(F \propto e)$.  To prove this, different masses are hanged on a spring, the extension is measured in each case and a