

FOREWORD

The idea of publishing this book was born after realising the difficulty involved in establishing a sound library for the school. This is due to the fact that text books are too expensive to afford if every student is to have access to them.

The school administration and the teaching staff have therefore offered to subsidize the cost of text books in terms of service and materials to allow every student to afford these books.

I therefore thank the teachers so much for their unending endeavors in preparing these books with the aim of facilitating our students' learning.

Thank you indeed.

**HEADMASTER
FOR ADMINISTRATION**

MASTER KEY TO 'O' LEVEL PHYSICS

S.1 & S.2

EIGHTH EDITION

2017

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PREFACE

Basic knowledge about our world is rapidly increasing as a result of the advancement in all scientific fields. This expansion results in the application of much of this knowledge in our modern society. Therefore, at no other time in our history has it been as important as it is today for students to understand *physical laws* or *principles* and their applications in daily life. It is the laws and concepts of physics that often help us to describe and give scientific explanation to the both naturally and artificially phenomenon that occur around us and deep in the space beyond our planet.

Secondary School is the starting point for students who select scientific careers in later life. The “*Master Key to Physics*” presents a modern and easy approach to the teaching of physical science at secondary level with specific emphasis on fundamental principles and concepts.

This book helps students to know the *what*, *why* and *how* of physics at secondary level. The contents of the book are based on students’ common activities, interests, and experiences. All the concepts and principles dealt with in each unit relate to the central theme of the unit. They offer the student an opportunity to explore the field in depth, and to experience some of the excitement that comes with the discovery of new ideas.

Mathematical problems are one of the more serious difficulties encountered in a course in physics. They always tend to make the subject difficult to students. In this book, as each new kind of problem appears, a detailed example is given. Some of the examples begin with *Steps in solving problems*, which help to the student to develop sense of direction. The steps in these examples are explained into detail. The examples are immediately followed by Self-Check questions to confirm the understanding of the problem. The questions range from simple ones to more difficult ones. Throughout the book there are many simple experiments with plenty of guidance on the results of these experiments.

Every important definition or formula is highlighted or *italicized*.

In calculations, simple numbers have been used to keep the arithmetic as straight-forward as possible. There is orderly flow of information in solving example.

Finally, it is my sincere hope that the users of this will find this it useful and be forced to agree that indeed it is a “*Master Key*” to Physics which is widely believed to be “*unlockable*”.

ACKNOWLEDGEMENT

I am grateful to all the people who helped either directly or indirectly in writing of this book. I would like to thank the administration of Light Academy for the encouragement and financial support towards the printing of the book.

I also wish to express my gratitude to my colligues Mr. Hakan Ulus and Mr. Enos for proof reading the book.

Finally, I would like to thank the director Mr. Ilihan Edogan for supporting the idea of writing the book to up lift the standard of the school.

DEDICATION

I dedicate this book to my late parents, Late Dega Nassur and Late Odaya Jenner, may the Almighty Allah rest their souls in eternal peace, my guardian Mr. Yasin Mustafa who has been the driving force behind my education, brothers, sisters and finally to friends who missed my company during the period of compiling the book. May Almighty Allah bless us all!!

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HOW TO USE THIS BOOK

The “**Master Key to Physics**” aims at giving you the opportunity to understand the basic principles of Physics and practice your Physics by giving detailed examples and self-check questions on topics that form the core of all „O“ level syllabuses. Each chapter begins with *chapter outline* and *learning objectives*. The learning objectives tell you about the most important ideas and areas in that chapter. These will help you to have the idea of what you should cover in any topic and prepare for the work on that chapter. And help you to remain focused when revising that chapter. And once you have an idea of what you should cover in any topic, you can start on the self-questions. There are two types of questions:

- Worked examples and Self-Check questions.

The examples and the questions are either from **UNEB** examination papers or are specially devised to fill in gaps and avoid unnecessary repetition. They are all of „O“ level standard, but some are of course easier than others. They are worked a little more detailed than those we would expect from a good candidate. This is to ensure clarity.

With each example you should gain confidence and improve your technique. Once you have studied the examples, try the self-check questions before checking the answers.

Note: The examples can be used in a variety of ways, but a suggested routine is:

- Read the question carefully. So many marks are lost by careless reading which leads to misfiring of the question.
- Without looking at the answer, have a go at answering it in note form with sketch diagrams where necessary. Consult the start of the chapter and your text book at this stage. Try the numerical problems.
- Consult the answer to find out if and where you have gone wrong and go through it very carefully. Follow any algebra through stage by stage. But **do not** just find your mistakes- learn from them.

A common question that an „O“ level student will ask is: Many people say that Mathematics is the mother of Science. What if my mathematics is **not** strong?

If you are having trouble with the mathematics, read through the working very carefully ask someone to explain for you the steps you do not understand. If you consult a mathematics text book remember that it may go into much more detail than you need. But do not worry too much since the examination board is aware of the problem and try to make sure that they are testing mainly your physics and not your mathematics. But of course you do not have to relax, rather work hard to develop your mathematics strongly.

Abbreviations/Symbols

Physics all over the world use a consistent set of symbols and abbreviations. You should be familiar with them. Most of the symbols used in physics are Roman and Greek letters. Some of which are: α - Alpha, β - Beta, γ - gamma, λ - lambda, μ - mu, θ - theta, η - eta, ϕ - phi, ρ - rho, and π - pi.

Study Skills

What kind of learner Are you?

To get the most out of your studies, you should find out how you learn best – that is, what kind of learner you are.

Types of learners

There are three types of learners, namely:

- auditory learner
- visual learner
- kinesthetic learner

- An *auditory learner* learns by listening. If you are an auditory learner, you should find friends to study with, so you can ask questions and discuss the text. If you have to study alone, you can reinforce your learning by reciting the key concepts out loud.
- A *visual learner* learns by reading. If you learn best this way, you should concentrate on finding a quiet place where you can focus on material you are reading.
- A *kinesthetic learner* learns by doing. If you learn best by doing something, you have to be creative in the way in which you study. For example, highlight your text or take notes as you read. Think about practical ways to apply what you are reading about.

LEARNING SKILLS

In this final section, you are going to examine some specific suggestions on how you can make your study time more valuable. Not every method will be appropriate for your study habits. Choose what you think will help you, or adapt some to fit your needs. Ignore those that you feel won't contribute to your understanding of the materials.

SQ3R method

The SQ3R stands for: Survey, Question, Read, Recite, and Review

SQ3R was developed in 1941 by Francis P. Robinson of Ohio State University. It's an old system, but it still works. Millions of students have successfully used this system, or a variation of it, to improve their reading and studying. SQ3R stands for Survey, Questions, Read, Recite, and Review. Let's take a look at each one of these elements in SQ3R.

Survey

You first survey the material you are going to study. The purpose of the survey step in SQ3R is to help you become familiar with your text book organization. To survey material you are about to read, look quickly at the following types of features:

- Titles and other headings.
- Illustration, diagrams, charts, maps and graphs.
- Text printed in highlighted boxes.
- Boldface and italic type.
- Self-check questions.
- Summary, if appropriate.

Scanning these features will give you a good idea of what topics you are about to study.

Questions

The next step in the **SQ3R** method is question. This step requires you to go through the pages you are about to read and turn the headings into questions. Doing this helps direct your reading and your thinking. Then as you read and study the material, you can look for the answers to your questions. For example, look at the first few headings at the beginning of this book. Here is how you can turn them into questions:

- What is physics?
- How important is physics to us or why is physics taught in Secondary Schools?
- What are the meanings of the following words?
 - Hypothesis
 - Scientific law or Scientific Principle
 - Scientific theory

Note: *The better your questions are, the better will be your understanding of the material.*

The 1st R Read

Begin to read the material slowly and carefully, one section at a time. Don't worry about how long it takes. As you read, look for answers to the questions you have just formed under „Q“ above. Make brief notes, and look up any words you don't understand. If you have completed the first two steps (*Survey and questions*), the material should seem familiar to you. You are prepared to read the new material more efficiently. You have an idea of the information you are required to learn and you are able to read with clearer intent. You know why you are reading a section and what to focus on. Specifically, mark definitions, formulae, examples, names, principles, rules, and characteristics.

The 2nd R Recite

Every time you come to a new heading in the text, stop and repeat, either silently or loud, the main point is to help you to remember what you have just read. Recite it from memory or refer to your marginal notes or the information you have highlighted. If you have trouble with this step, reread the section until it becomes clear to you. Reciting the material in your own words is a tremendous aid to learning .It makes it easier to retain the information.

The 3rd R Review

Review any material you read as soon as you can. Review it again before you complete a self-check and gain confidence before you prepare for an examination .This part of **SQ3R** helps to keep information fresh in your mind. I believe by now you should be able to agree that; the SQ3R method is real helping to make your revisions effective.

- Note:**
- (i) One way to review is to resurvey the material you have read. Or go over the notes you have made to see if they still make sense. Reread any passages and that you have underlined or highlighted.
 - (ii) Another method you can use in the review step is to go back over the questions you developed for each heading. See if you can answer them. If not, look back and refresh your memory about that particular topic. Then continue with your review until you are satisfied that you know the material well.

PREPARING FOR EXAMINATION

Revision

Literally, revision means „seeing again“ and it is a vital part of learning, though the word often gets used simply to mean preparation for an examination or a test. It is found out that the amount that can be recalled drops dramatically unless the new ideas are revised or reviewed. If one reviews his notes most often, it is possible to get the stage where nearly 100% recall is achievable long after the last review. It is also possible that one can forget every thing after **not** reviewing for a long period of time. The explanations to these facts lie in the changes that take place in the cells of the brain and in the connections between them.

If you follow the suggestions in this study unit, you should have no difficulty when reviewing in preparation for an examination. Use these tools, along with answers to the “self – checks,” to prepare for the examination. Don’t just “read” physics. Make your revision effective by involving the hands in going over the examples, drawing and labeling diagrams, trying to answer the questions on examination past papers. Familiarity with and understanding of the text material, diagrams, examples past paper questions will make *taking the examination* much easier.

TAKING EXAMINATIONS

Begin by surveying the examination questions. Read the directions/instructions carefully and be sure to follow them exactly. Do the easy questions first. Skip any you are unsure of. While taking the examination, maintain a positive attitude. If you feel negative thoughts creeping in, say to yourself, “I’ve studied hard.”

Types of questions

There are two types of questions:

- Multiple Choice
- Structured and semi-structure

Multiple Choice questions

Before you do anything on the question paper,

- First write your name and then read the instructions carefully.
- Read the questions very carefully. Careless reading of the instructions and the questions often leads to loss of marks. Carefully reading of the instructions and the questions help you to know exactly what you are to do and how to do it.

For multiple type questions, try to answer from your mind before you look at the answers.

- Read each answer thoroughly even if you think you have already spotted the correct one. Note that some answers may be correct. But the question always requires you to choose the most correct answer. Be aware the wrong answers are always plausible.
- Be active: sketch a diagram; write down a relationship, do anything that helps you think clearly.
- Do not be worried by too many of one letter since they are random.
- Be absolutely sure to get the easier questions right, by not rushing them. The questions carry the same marks.
- Finally if in doubt guess, illuminate the patently wrong answers first. If you can whittle the choice down to two you have a 50% chance of being right.

For Structured and semi-structured questions:

- Use simple straightforward English.
- Use clear-labeled diagrams.
- Where necessary leave space so you can add answers that occur to you later.
- Explain all your working and put in correct **units**. Remember wrong units led to loss of marks.
- Round off your final answers to a sensible number of significant figures.
- Check your work as you continue.
- Look at the marks given besides the question to gauge how much detail is likely to be expected and, in the case of papers where you answer on the question paper, look at the space available. For example, six marks probably mean six important ideas are needed in the answer.

Terms used in setting examination questions

For getting high marks in structured and semi-structured questions, you have to understand the meanings of the following common terms used in setting the questions.

- Define:** State precisely the meaning of terms or words. E.g. define the term density.
- State:** Name, mention or give the condition of a thing. E.g. state the S.I unit of pressure.
- Describe:** Give a detailed account or representation of something in words, e.g. describe an experiment to verify Hooke's law.
- Identify:** Recognize or prove something as being a certain. E.g. the factors that affect density of a substance.
- Name:** Write down, mention or state. E.g. name the parts labeled in a diagram.
- Determine:** Ascertain something after some observation, solve a problem or find out. E.g. determine the refractive index of a glass block.
- Explain:** Give a detailed account of something. E.g. explain what happens to a ball bearing released in a viscous fluid in a tall cylinder.
- Discuss:** Give points and general description in writing either for or against a statement. E.g. discuss the effect of temperature on density of water.
- Suggest:** Put forward an idea. E.g. suggest what would happen to pressure of a gas if the volume of the gas is reduced.
- Calculate:** Work out a problem mathematically. E.g. calculate the focal length of a converging lens.
- Outline:** Give the main points. E.g. outline the steps followed in determining the relative density of a substance.
- Distinguish:** Make, show or recognize differences. E.g. distinguish between density and relative density of a substance.

CHAPTER ONE

INTRODUCTION TO PHYSICS

LEARNING OBJECTIVES

By the end of this chapter, you should be able to:

1. Define: - Physics,
- Matter and
- Energy.
 2. State: - The aims and objectives of teaching physics.
 3. Define: - Hypothesis,
- Scientific Theory and
- Scientific law or principle.
 4. State: - the states of matter and give examples in each case.
-

1.1 INTRODUCTION TO PHYSICS

At secondary level, science is divided into:

- Biological Science and
- Physical Science

Biological Science - is the branch of Science which deals with the study of living things.

Physical Science - is a branch which deals with the study of non-living things.

Physical Science is further divided into *Physics* and *Chemistry*.

Physics

Physics is a branch of physical science, which deals with the study of matter in relation to energy.

Matter - is anything that occupies space and has mass.

Energy - is the ability to do work.

In physics, the main topics studied include:

- Mechanics, Optics (Light), Waves, Electricity & Magnetism, and Modern Physics.

1.2 Aims and Objectives of teaching Physics

(a) Aims

- (i) To make a society that knows about physics and enjoys the fruits of physics. E.g. Physics teachers, Engineers, Electricians, Electronic (T.V, Computer, Radio, Watch etc) technicians, medicine doctors.
- (ii) To make a society that understands everyday phenomena (happenings) both naturally and artificially and their scientific explanations.
- (iii) To produce a large number of people capable of harnessing natural resources e.g. minerals, scientifically and technically in an innovative way for the service of the society.
- (iv) To produce an effective team workers for the advancement of knowledge.

(b) Objectives

- (i) To make the student aware of the effects of scientific discoveries and knowledge on everyday life through the application of physics.
- (ii) To help the student understand the world around us.
- (iii) To enable the student to develop an experimental attitude of the mind by performing experiments and to equip him/her with the techniques of performing the experiments, making correct observations, recording the values and drawing appropriate conclusion from the experimental data.
- (iv) To prepare the student to pass examinations in physics for further studies.
- (v) To familiarise the student with the scientific Hypothesis, Theories, Principles and laws.

1.3 Hypothesis, Theory and Law (Principle)

(a) Hypothesis - *is a scientific idea put forward and is still in the stage of experimental investigation.*

However, if proved to be correct and therefore generally accepted, it then becomes a scientific law or principle.

(b) Scientific Law or Principle

A Scientific Law or Principle is a generalised statement of observed facts.

(c) Scientific Theory:

A Scientific Theory is an idea put forward to explain the existence of a scientific law or principle.

1.4 Characteristics of Materials

All the materials/substances that exist in the universe either naturally or artificially are scientifically called *matter*. Every matter has some characteristic properties which make it different from others.

Examples of such properties are: State, Colour, Density, Smell, etc.

These properties are called the *physical properties* of matter. Using a simple classification, based on the physical properties of matter, matter can be classified into several classes. However, it is convenient to first classify matter according to the *physical states* and then further classification to be considered after words.

States (Phases) of Matter

Matter exists in three states namely:

- (i) Solid, e.g. stone, wood etc.
- (ii) Liquid e.g. water, paraffin etc.
- (iii) Gas e.g. oxygen, nitrogen etc.

Self-Check 1.0

1. (a) Define the following terms.
(i) Physics (ii) Matter (iii) Energy
(b) State any **three** aims and **three** objectives of teaching physics in secondary schools.
2. Define the following terms
(a) Hypothesis (b) Scientific law or scientific principle
(c) Scientific theory
3. State the states of matter. In each case, give **two** examples.

CHAPTER TWO

MEASUREMENT

LEARNING OBJECTIVES

By the end of this chapter, you should be able to:

1. Explain how to use:
 - the meter rule, the Vernier callipers and the micrometer screw gauge for measuring length,
 - beam balance, spring balance and electric balance for measuring mass and
 - Stop watches, watches for measuring time.
2. Recognise and state:
 - the S.I units/other units for the three fundamental quantities.
3. Convert other metric units to S.I unit and vice versa.
4. Express numbers in scientific notation or standard order.
5. Use the formula for calculating: Area and Volume.

2.1 Measurement: -is essential in physics. Before any measurement is taken, the quantity to be measured and its *unit* must be specified.

(a) Physical Quantities of Matter

These are the measurable properties of matter E.g. length, mass, speed etc. They are expressed in terms of a numerical *value* and a *unit*. There are so many quantities that can be measured in physics. However, some of the quantities are defined by using basic quantities.

(b) Basic Quantities

These are quantities of matter that are used to define other quantities of matter. The basic quantities of matter are:

- Length,
- Mass and
- Time.

Since these quantities are used to define other units, they are referred to as *fundamental quantities*.

(c) S.I system of Units

The S.I system of units is an International System of units based on the MKS (metre-kilogram-second) system. It is abbreviated as **SI** in all languages and is derived from French Le Système International d'Unités.

The basic quantities and their S.I units are shown in the table 2.1 below.

Basic quantity	Name of Unit	Symbol of SI Unit
Length	Metre	m
Mass	Kilogram	kg
Time	Second	s

Table 2.1

NB: When writing the names or symbols of the units, note that:

- Symbols of units have **no** plural forms.

e.g. we write: 2 kg **not** 2 kgs
 5 m **not** 5 ms

(d) Prefixes

A prefix is a word or letter placed before another. Examples of prefixes are:
 micro (μ), milli (m), centi (c), deci (d), kilo (k), mega (M), giga (G) and tera (T).

Prefixes can be used with the units for measuring quantities.

E.g. <i>kilo</i> with <i>gram</i>	forming	<i>kilogram</i> (kg),
<i>kilo</i> with <i>meter</i>	forming	<i>kilometer</i> (km),
<i>milli</i> with <i>meter</i>	forming	<i>millimeter</i> (mm),
<i>kilo</i> with <i>byte</i>	forming	<i>kilobyte</i> (kB),
<i>mega</i> with <i>byte</i>	forming	<i>megabyte</i> (MB),
<i>giga</i> with <i>byte</i>	forming	<i>gigabyte</i> (GB) etc.

(e) Multiples and Sub-multiples

Multiples and sub-multiples are shown in tables 2.2 and table 2.3 below.

Multiples	Prefix	Symbol
10^3	Kilo	k
10^6	Mega	M
10^9	Giga	G
10^{12}	Tera	T

Table 2.2 Multiples

Sub-multiples	Prefix	Symbol
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

Table 2.3 Sub-multiples

2.11 Instruments used for measurement

The devices used for measuring quantities are called *instruments*. Those used to measure the basic quantities are given in the table 2.4 below.

Basic quantity	Instruments
Length	- Metre rule, Tape measure, Vernier calipers and Micrometer screw gauge
Mass	- Electronic balance, Beam balance, Spring balance and triple balance.
Time	- Stop watch and Watch

Table 2.4 Instruments for measuring the basic quantities of matter

2.12 Measurement of Length

Length is measured by using the *Tape measure*, *Metre rule*, *Vernier calipers* and the *Micrometer screw gauge*.

The choice of the instrument to be used depends on:

- The size of the distance to be measured (how long and short the distance is) and
- The accuracy to which the measurement is needed.

(i) Measurement of Long distance

Long distances are measured using, the *metre rule* and the *tape measure*. Both instruments are calibrated (graduated) in metres (m), centimeters (cm) and millimeters (mm).

$$1 \text{ m} = 100 \text{ cm} \text{ and } 1 \text{ cm} = 10 \text{ mm}$$

$$\therefore 1 \text{ m} = 100 \times 10 = 1000 \text{ mm}$$

The larger unit is kilometer (km).

$$1 \text{ km} = 1000 \text{ m}$$

Note: Due to wear at the edges, when using the metre rule, it is advisable to start measuring from the 10 cm mark and deducting 10 cm from the total measurement.

(ii) Measurement of Small and very small distances

For *small distances*, the Vernier calipers or the engineers calipers is used. While for *very small distances* such as the diameter of copper wire, thickness of paper, the micrometer screw gauge is used. Both the Vernier calipers and the micrometer screw gauge give readings with reasonable accuracy.

(a) The Vernier Caliper

A *Caliper* is a mechanical device used to determine small lengths with reasonable accuracy.

Types of Vernier Callipers

There are two types of Vernier Callipers

- (i) Simple caliper (commonly called Engineer's caliper) and
- (ii) Complex vernier

(i) Simple caliper

Simple calipers have two movable parts/legs of some desired shape and length to meet the surfaces whose separation is to be measured. The adjusted width between the leg tips is then placed against some length scale. E.g metre rule and the reading taken.

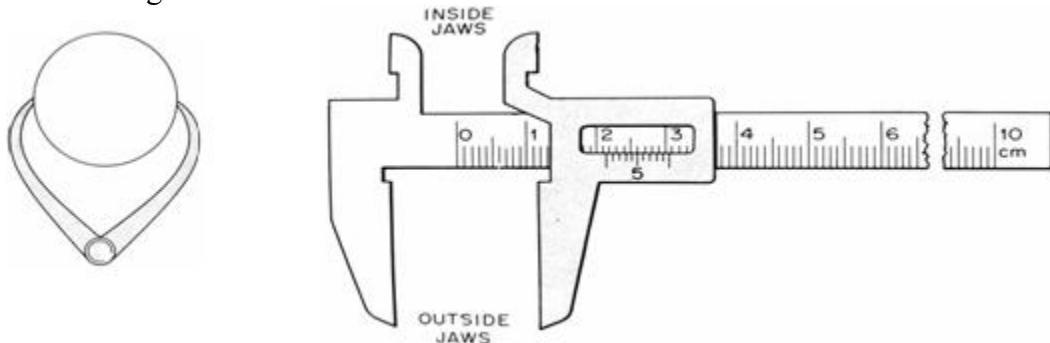
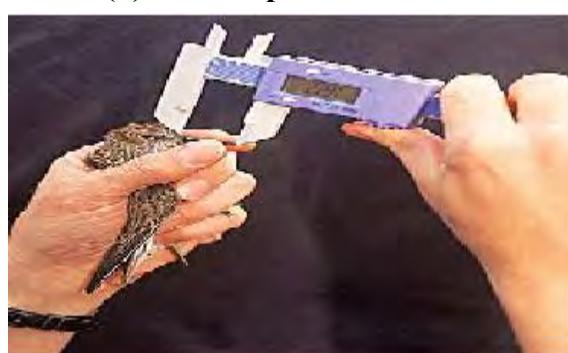


Figure 2.1 Engineer's caliper

Figure 2.2 The mechanical Vernier calipers

For measuring the internal diameter of a pipe, the caliper is turned the other way round. This way, the tips of the jaws point outward.

(ii) Complex vernier



The more complex vernier caliper has two types of scale that allow direct reading of the adjusted width between the jaws. The types of the complex vernier are mechanical and digital. Figure 2.2 below shows the mechanical vernier.

Figure 2.3 Showing a digital vernier being used to measure length of a bird

How to use the Vernier calipers

The movable jaw is adjusted until it grips the object to be measured and then the reading is taken as described below.

How to read the Vernier

(i) *The Digital Vernier calipers*

Once the vernier is adjusted to the width of the object to be measured, a reading is taken directly from a small screen engraved on it.

E.g. in figure 2.3, the length of the bird's beak is 2.20 cm.

(ii) *The Mechanical Vernier*

For the mechanical vernier, the reading is taken in three steps:

Step I Read and record the main scale reading at the zero mark of the vernier scale to an accuracy of one millimeter.

E.g. 2.1 cm.

Step II Read and record the vernier scale reading at the position on the vernier where a mark on it is coincident (i.e. coincides) with a mark (division) on the main scale in tenths of millimeters.

E.g. let the 6th vernier division coincide with a mark on the main

scale. In tenths, 6 becomes $\frac{6}{10} = 0.6 \text{ mm} = 0.06 \text{ cm}$

Step III Get the sum of the two readings (i.e add the main scale reading and the vernier scale reading to get the total reading).

Main scale reading = 2.10 cm

Vernier scale reading = + 0.06 cm

Total reading = 2.16 cm

Example 1

The S.1 students of TLA measured the thickness of a desk top during physics lesson and found that the main scale reading before the zero mark of the vernier scale to be 4.4 cm. Find the thickness of the desk top if the 4th vernier mark coincides with one of the marks on the main scale.

Solution Main scale reading = 4.40 cm

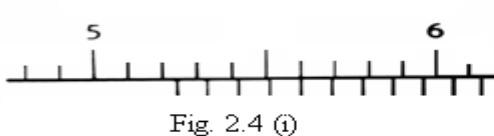
Vernier scale reading 4th = $\frac{4}{100} = 0.04 \text{ cm}$

Total reading = 4.44 cm

Note: Instead of dividing the vernier reading by 10 to get the answer in mm and then by 10 to change to cm, we can divide the value directly by 100 to get the answer once in cm.

Example 2

Find the readings of the verniers shown figures 2.4 (i) and (ii) below.



Solution:	(i)	Main scale reading	= 5.20 cm
		Vernier scale reading $4^{\text{th}} = \frac{4}{100}$	= + 0.04 cm
		Total reading	<u>5.24 cm</u>
	(ii)	Main scale reading	= 0.80 cm
		Vernier scale reading $8^{\text{th}} = \frac{8}{100}$	= + 0.08 cm
		Total reading	<u>0.88 cm</u>

(b) The Micrometer screw gauge

The Micrometer screw gauge is an instrument used to measure very small distances. The Micrometer screw gauge is calibrated in mm on the sleeve and some small divisions on the thimble scale.

There are two types of thimble readings:

- (i) One with 50 divisions on the thimble scale and
- (ii) The other with 100 divisions on the thimble scale.

However, the two types give the same reading when used to measure the same distance. The diagram of the micrometer screw gauge is shown in the figure 2.5 below.

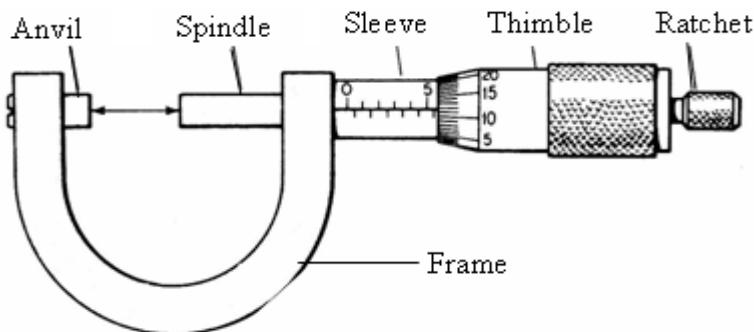


Figure 2.5 Micrometer screw gauges

How to use the Micrometer screw gauge

- Place the object whose thickness is to be measured in between the jaws (the anvil and the spindle) of the micrometer.
- Rotate the ratchet clockwise until the jaws touch the object. As soon as the object is gripped tight enough, it starts to slip, making a characteristic sound.
- Take the reading in three steps as shown below.

Step I: Read and record the reading on the sleeve scale at the edge of the thimble in millimeters and half millimeters. E.g. 4.0 mm.

Step II: Read and record the reading on the thimble scale opposite to the centerline on the sleeve scale (i.e. where a division on the thimble scale coincides with the centerline on the sleeve scale) in **hundredths** of millimeters.

E.g. Let the 33rd division coincide with the centerline.

In hundredths, 33 becomes $\frac{33}{100} = 0.33 \text{ mm}$

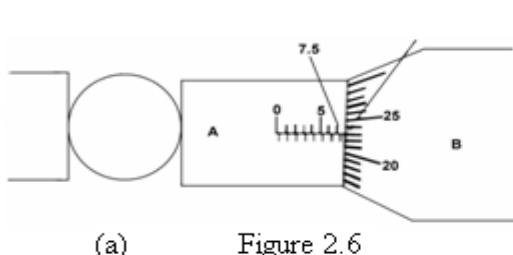
Step III Get the sum of the two readings i.e. sleeve scale reading and the thimble scale reading.

$$\begin{array}{lcl}
 \text{Sleeve scale reading} & = & 4.00 \text{ mm} \\
 \text{Thimble scale reading} & = & + 0.33 \text{ mm} \\
 \text{Total reading} & = & \underline{\underline{4.33 \text{ mm}}}
 \end{array}$$

Note: If the answer is required in cm or m, you convert it as required.

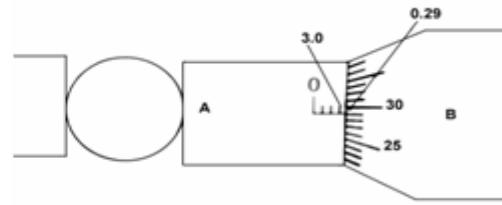
Example 1

Find the reading on the micrometer screw gauge shown in the diagrams below.



(a)

Figure 2.6



(b)

Figure 2.7

Solution

(a) Sleeve scale reading = 3.00 mm

$$\text{Thimble scale reading, } \frac{29}{100} = + 0.29 \text{ mm}$$

$$\text{Total reading} = \underline{\underline{3.29 \text{ mm}}}$$

(b) Sleeve scale reading = 7.50 mm

$$\text{Thimble scale reading, } \frac{23}{100} = + 0.23 \text{ mm}$$

$$\text{Total reading} = \underline{\underline{7.73 \text{ mm}}}$$

SELF-CHECK 2.0

1. (a) Draw and label the diagram of the Vernier calipers.
 (b) Find the thickness of a text book measured using a vernier caliper if the main scale reading is 24 mm and the 8th vernier mark coincides with one of the marks on the main scale.
 (c) Find the reading on the verniers shown in the diagrams below.

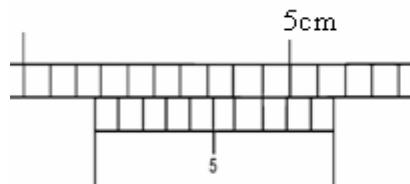


Figure 2.9 (i)

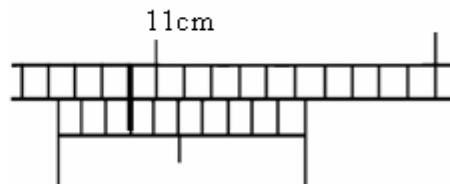


Figure 2.9 (ii)

2. (a) Draw and label the diagram of the micrometer screw gauge.
 (b) Find the reading on the micrometer screw gauge shown in figures 2.10 below.

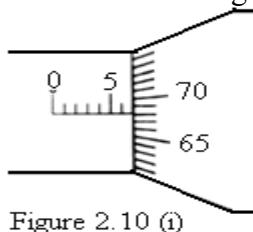


Figure 2.10 (i)

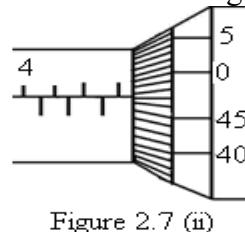


Figure 2.7 (ii)

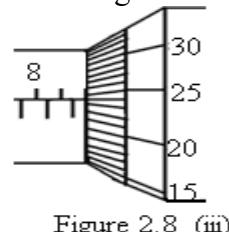


Figure 2.8 (iii)

2.13 Measurement of Area (Two dimensions)

Regular Surfaces

The area of regular surfaces is found by measuring any two of the following dimensions and then applying the appropriate formula.

- Length (l), width (w), height (h), side (s), radius (r) and diameter

Units of area

The SI unit for area is *square metre* (m^2).

Other units are: - mm^2 , cm^2 , km^2 and hectare.

$$1 \text{ m}^2 = 100 \times 100 = 10,000 \text{ cm}^2$$

$$1 \text{ cm}^2 = 10 \times 10 = 100 \text{ mm}^2$$

$$1 \text{ m}^2 = 1000 \times 1000 = 1,000,000 \text{ mm}^2$$

Table 2.5 below shows the common regular surfaces and their respective formulae.

Figure	Name	Dimensions	Formula
	Rectangle	l and w	$A = lw$
	Square	s	$A = s^2$
	Triangle	b and h	$A = 1/2bh$
	Circle	r and d	$A = \pi r^2$

Fig. 2.5

(c) Measurement of Volume (Three dimensions)

(i) Regular Solids

The volume of regular solids is determined by measuring the dimensions and then applying an appropriate formula.

Units of Volume

The SI unit of volume is metre cubed, (m^3).

Other units are: mm^3 , cm^3 .

$$1 \text{ m}^3 = 1\,000\,000 \text{ cm}^3$$

$$1 \text{ cm}^3 = 0.000\,001 \text{ m}^3$$

The table below shows the common regular solids and their respective formulae.

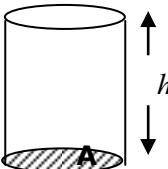
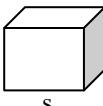
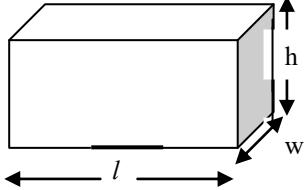
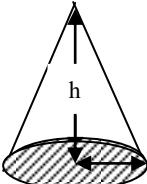
Figure	Name	Dimensions	Formula
	Cylinder	r , or d & h	$V = Ah$ or $V = \pi r^2 h$ or $V = \frac{1}{4}\pi d^2 h$
	Cube	s	$V = s^3$
	Cuboid	l, w, h	$V = lwh$
	Sphere	r or d	$V = \frac{4}{3}\pi r^3$ or $V = \frac{1}{6}\pi d^3$
	Cone	r & h	$V = \frac{1}{3}\pi r^2 h$

Table 2.6

(ii) Irregular Solids

The volume of irregular solids is determined by using displacement method. In this method, the solid is fully or wholly immersed in a liquid and the volume of the liquid displaced is measured. This method operates on the principle that “A body fully or wholly immersed in a fluid (liquid) displaces its own volume”.

Apparatus/requirements used to measure the volume of irregular solid are:

- Measuring cylinder, water and a piece of thin silk thread.
- Measuring cylinder, overflow (displacement) can, water and a piece of silk thread.

Measuring the volume of irregular solid

1. Using a measuring cylinder

- Fill a measuring cylinder with water.
- Read and record the initial reading.
- Tie the irregular object with a piece of thin silk thread and lower it carefully into the water in the cylinder until it is fully immersed.
- Shake it gently to remove any air bubbles.
- Read and record the final reading.

Diagram showing measurement of volume of irregular object

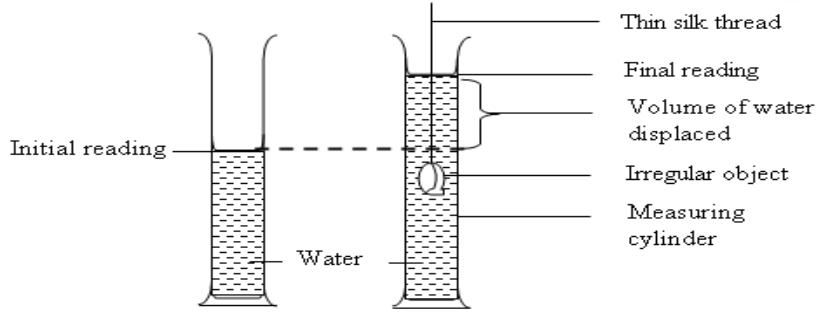


Figure 2.11 (ii)

Before immersing After immersing

The volume is calculated from the formula:

$$\text{Volume of irregular object} = \text{Final reading} - \text{Initial reading}$$

2. Using an Overflow can and measuring cylinder

- Fill an overflow can with water until water flows out through the spout and wait until the water ceases dripping and then place a dry measuring cylinder below the spout.
- Tie the irregular object with a piece of thin silk thread and lower it carefully into the water in the overflow can until it is fully immersed.
- Shake it gently to remove any air bubbles.
- Wait until the water ceases dripping into the measuring cylinder.
- Read and record the volume of the displaced water in the cylinder.

Diagram showing measurement of volume of irregular object

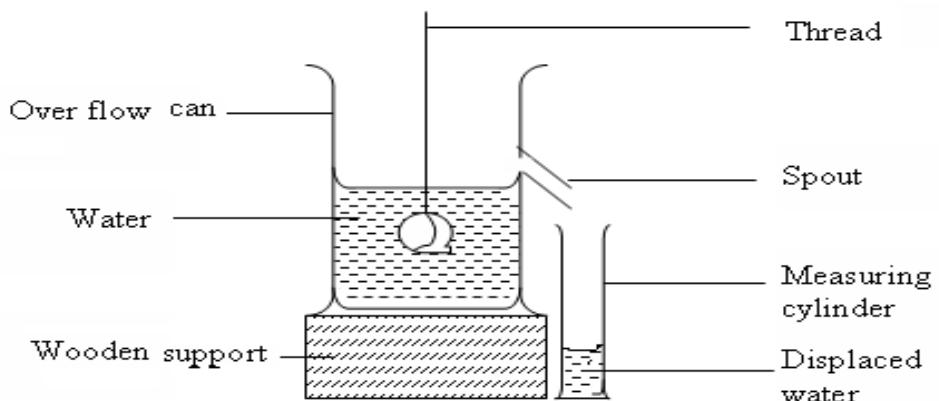


Figure 2.10

$$\text{Volume of object} = \text{Volume of displaced water}$$

(iii) Measurement of volume of Liquids

The volume of a given liquid is determined by using a measuring cylinder.

The liquid is carefully poured into the measuring cylinder and the volume is read off by placing the eye level in line with the bottom of the meniscus of the liquid surface in order to avoid error due to parallax.

Diagram showing correct reading of measuring cylinder

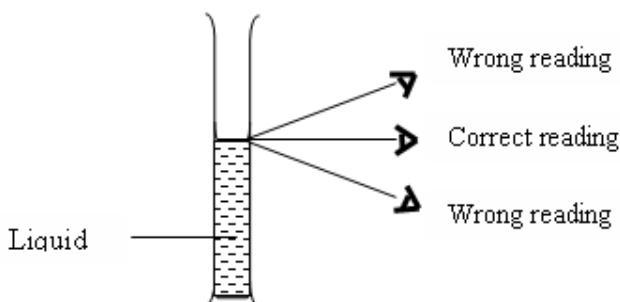


Figure 2.13

Specified volumes of liquids are accurately measured by using specific instruments such as:

- Burette, Pipette and Syringe.

Note: *The first two are commonly used in Volumetric analysis in Chemistry practical.*

(iv) Gases

The volume of gases is measured by using a syringe. The gas syringe is connected to the gas supply with a help of rubber tubing. Due to the gas pressure the piston moves backwards and the required volume is noted from the scale.

Unit for measuring Volume

The SI unit for volume is metre cubed (m^3)

$$1 \text{ m}^3 = 1\,000\,000 \text{ cm}^3$$

$$1 \text{ dm}^3 = 1\,000 \text{ cm}^3$$

$$1 \text{ litre} = 1 \text{ dm}^3$$

$$\therefore 1 \text{ litre} = 1\,000 \text{ cm}^3$$

2.2 Measurement of Mass

Mass is a measure of the amount of matter in an object. Or it is the quantity of matter in a body. It is constant everywhere. That is, it does not vary from place.

The mass of an object is commonly measured by comparing it with a standard (known) mass.

The instruments used to measure mass are:

- Beam balance,
- Triple balance,
- Lever arm,
- Electric balance,
- Chemical balance and
- Spring balance.

The unit for measuring mass

The SI unit for mass is the kilogram (kg).

Other units include: milligrams (mg), grams (g) and tonne (ton).

$$1 \text{ kg} = 1000 \text{ g}$$

$$1 \text{ g} = 1000 \text{ mg}$$

$$1 \text{ ton} = 1000 \text{ kg}$$

2.3 Measurement of Time

Time is measured using: watches and stopwatches (both mechanical and digital).

Due to accuracy and easy in reading, the digital stopwatches are preferred. They measure to 0.01 second.

Units for measuring time

The SI unit for time is *second (s)*.

Other metric units include:

- Minute (*min*), hour (*hr*), day, week, month, year, decade, century, millennium.

$$1 \text{ hr} = 60 \text{ min}$$

$$1 \text{ min} = 60 \text{ s}$$

$$1 \text{ hr} = 60 \times 60 = 3600 \text{ s}$$

$$\therefore 1 \text{ hr} = 3600 \text{ s}$$

Worked Examples

Conversion from one unit to another

1. Convert the following as required.

- | | | | |
|---------|------------------------|------|------------------------|
| (a) (i) | 5 000 m to km. | (ii) | 60 m to cm |
| (b) (i) | 2 kg to gram. | (ii) | 500 g to kg. |
| (c) (i) | 24 hr to seconds. | (ii) | 30 minutes to seconds. |
| | (iii) 1800 s to hours. | (iv) | 900 s to minutes. |

Solution

(a) (i)	$1 \text{ km} = 1000 \text{ m}$	(ii)	$1 \text{ m} = 100 \text{ cm}$
	$y = 5000 \text{ m}$		$60 \text{ m} = r \text{ cm}$
	$1000 \text{ m} \times y = 1 \text{ km} \times 5000 \text{ m}$		$1 \text{ m} \times r = 60 \text{ m} \times 100 \text{ cm}$

$$y = \frac{1 \text{ km} \times 5000 \text{ m}}{1000 \text{ m}}$$

$$r = \frac{60 \text{ m} \times 100 \text{ cm}}{1 \text{ m}}$$

$$\therefore y = 5 \text{ km}$$

$$\therefore r = 6000 \text{ cm}$$

(b) (i)	$1 \text{ kg} = 1000 \text{ g}$	(ii)	$1 \text{ kg} = 1000 \text{ g}$
	$2 \text{ kg} = t$		$z = 500 \text{ g}$
	$1 \text{ kg} \times t = 2 \text{ kg} \times 1000 \text{ g}$		$1000 \text{ g} \times z = 1 \text{ kg} \times 500 \text{ g}$
	$t = \frac{2 \text{ kg} \times 1000 \text{ g}}{1 \text{ kg}}$		$z = \frac{1 \text{ kg} \times 500 \text{ g}}{1000 \text{ g}}$

$$\therefore t = 2000 \text{ g}$$

$$\therefore z = 0.5 \text{ Kg}$$

$$\begin{array}{ll}
 \text{(c) (i)} & 1 \text{ hr} = (60 \times 60) \text{ s} \\
 & 24 \text{ hr} = t \\
 & 1 \text{ hr} \times t = 24 \text{ hr} \times (60 \times 60) \text{ s} \\
 & t = \frac{24 \text{ hr} \times 60 \times 60 \text{ s}}{1 \text{ hr}} \\
 & \therefore t = 86400 \text{ s}
 \end{array}
 \quad
 \begin{array}{ll}
 \text{(ii)} & 1 \text{ min} = 60 \text{ s} \\
 & 30 \text{ min} = v \\
 & 1 \text{ min} \times v = 30 \text{ min} \times 60 \text{ s} \\
 & v = \frac{30 \text{ min} \times 60 \text{ s}}{1 \text{ min}} \\
 & \therefore v = 1800 \text{ s}
 \end{array}$$

$$\begin{array}{ll}
 \text{(iii)} & 1 \text{ hr} = 3600 \text{ s} \\
 & h = 1800 \text{ s} \\
 & 3600 \text{ s} \times h = 1 \text{ hr} \times 1800 \text{ s} \\
 & h = \frac{1 \text{ hr} \times 1800 \text{ s}}{3600 \text{ s}} \\
 & \therefore h = \frac{1}{2} \text{ hr}
 \end{array}
 \quad
 \begin{array}{ll}
 \text{(iv)} & 1 \text{ min} = 60 \text{ s} \\
 & q = 900 \text{ s} \\
 & 60 \text{ s} \times q = 1 \text{ min} \times 900 \text{ s} \\
 & q = \frac{1 \text{ min} \times 900 \text{ s}}{60 \text{ s}} \\
 & \therefore q = 15 \text{ min}
 \end{array}$$

Self-Check 2.1

1. Convert the following as required.

- | | | |
|------------|--|---|
| (a) | (i) 10,000 m to km. | (ii) 20 m to cm |
| (b) | (i) 25 kg to gram. | (ii) 2000 g to kg. |
| (c) | (i) 12 hr to seconds. | (ii) $\frac{1}{4}$ hr to seconds. |
| (d) | (i) 20 000 cm ³ to m ³ | (ii) 50 m ³ to cm ³ |

2.4 Significant Figures

Measurements are always given correct to a certain number of significant figures.

To determine the number of significant figures, in a measurement the following rules may be useful.

- (i) All non-zero digits (1, 2, 3, 4, 5, 6, 7, 8, 9) are significant.
E.g. 5.23cm has 3 significant figures (3 s.f.)
- (ii) All zeros between non-zero digits are significant.
E.g. 4.002 has 4 s.f.
- (iii) All zeros to the right of a decimal point and following a non-zero digit are significant.
E.g. 62.00 has 4 s.f.
- (iv) A zero before a decimal point and zero(s) after a decimal point but before a non-zero digit are not significant.
E.g. 0.2, 0.005, 0.000004 all have 1 s.f.

NB: When handling calculations, the final answer should always be given with only as many significant figures as that number involved in the calculation which has the least number of significant figures.

Example:

A rectangular block of wood measures 5.24 cm by 3.64 cm by 0.63 cm respectively.

Calculate the volume of the block of wood.

Solution: $l = 5.24 \text{ cm}$, $w = 3.64 \text{ cm}$, $h = 0.63 \text{ cm}$.

$$\begin{aligned} \text{Applying} & \quad \text{Volume} = lwh \\ & = 5.24 \times 3.64 \times 0.63 \\ & = 12.016368 \\ & = 12 \text{ cm}^3 \end{aligned}$$

Explanation: Since the measurement with the least number of sfg is 0.63, which is 2 sfg, the final answer must have 2 sfg.

Self-Check 2.2

1. How many significant figures are there in each of the following numbers:
 (a) 4.02 (b) 0.008 (c) 8 600 (d) 1 049 (e) 0.0002
2. The following values were taken as part of a set of experimental data:
 25.57 cm and 8.48 mm. Find the sum of the two figures.
3. A water tank measures by 4.5 m by 3.25 m by 5.5 m. Calculate giving the answers with the correct number of sfg.
 (a) Base area (b) Volume of the tank.

2.5 SCIENTIFIC NOTATION (Exponential or Standard Notation)

Scientific Notation is a short way of writing or expressing very large or very small numbers using powers of 10.

The number is expressed in the form: $M \times 10^n$

Where: M - is a positive number ($1 \leq M < 10$).
 n - is \pm integer (number)

(a) Determination of the arithmetic sign of n

The arithmetic sign of n is determined by using any one of the following simple rule.

- (i) The direction of the movement of the decimal point.
- (ii) The value of the number given.

Rule:

- (i) When the decimal point is moved from right to left, the power of 10 is positive and when moved from left to right, the power of 10 is negative.
- (ii) When the value of the number given is greater than 10, the power of 10 is positive and negative when the number is less than 1 (i.e. when the number begins with 0....).
- (iii) When the value of the number given is 1 or greater than 1 but less than 10, the power of 10 is zero.

Examples

Express the following numbers in exponential notation.

(i) 25000 (ii) 0.000024 (iii) 250×4 (iv) $\frac{1}{4} \times 1200$

Solution

(i) 25 000

In (i), the decimal point is not shown but its position is understood. For such numbers, the position of the decimal number is always after the last digit. For this case the decimal point is after the last zero. We move the decimal point from that position and put it in between the first two digits in order to make it less than 10 but greater than 1.

To get the power of 10, we count the number of digits between the original position of the decimal point and the new position. Then the number becomes $= 2.5 \times 10^4$

(ii) 0.000024

In (ii), the position of the decimal point is clearly seen. We move it from left to right and put it between the first two non-zero digits in order to make it less than 10 but greater than 1.

To get the power of 10, we again count the number of digits between the original position of the decimal point and the new position. Then the number becomes $= 2.4 \times 10^{-5}$

For the case of (iii) and (iv), we first work out the answers and then use the same procedure to express the answers.

$$\begin{array}{ll} \text{(iii)} & 250 \times 4 = 1000 \\ & = 1 \times 10^3 \end{array} \quad \begin{array}{ll} \text{(iv)} & \frac{1}{4} \times 1200 = 3000 \\ & = 3 \times 10^3 \end{array}$$

Try (iii) and (iv)? Answers (i) 4200 (iii) 0.085

(b) Working out numbers with powers of 10

In working out numbers expressed using powers of ten, we use the following

rules. (i) When multiplying powers of ten, add the exponents together.

(ii) When dividing powers of ten subtract the exponents.

Examples

Work out the following numbers

(a) $10^4 \times 10^8$ (b) $10^6 \times 10^{-3}$ (c) $\frac{6 \times 10^6}{2 \times 10^3}$ (d) $\frac{1.5 \times 10^5}{2 \times 10^{-2}}$

Solution:

$$\begin{array}{ll} \text{(a)} & 10^4 \times 10^8 = 10^{(4+8)} \\ & = 10^{12} \end{array} \quad \begin{array}{ll} \text{(d)} & \frac{1.5 \times 10^5}{2 \times 10^{-2}} = \frac{1.5 \times 10^{(5-(-2))}}{2} \\ & = 0.75 \times 10^{(5+2)} \end{array}$$

$$\begin{array}{ll} \text{(b)} & 10^6 \times 10^{-3} = 10^{(6+(-3))} \\ & = 10^3 \end{array} \quad \begin{array}{ll} & = 7.5 \times 10^{-1} \times 10^7 \\ & = 7.5 \times 10^{(-1+7)} \end{array}$$

$$\begin{array}{ll} \text{(c)} & \frac{6 \times 10^6}{2 \times 10^3} = \frac{6 \times 10^{(6-3)}}{2} \\ & = 3 \times 10^3 \end{array} \quad \begin{array}{ll} & = 7.5 \times 10^6 \end{array}$$

Self-Check 2.3

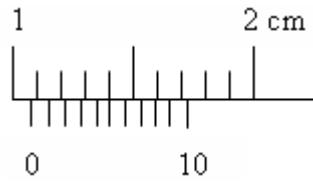
Write the following numbers in scientific notation.

- (a) (i) 0.000222 (ii) 0.0025 (b) (i) 5620 (ii) 75000
(c) (i) 120 million (ii) 20 (d) (i) 5 (ii) 55 x
20
(e) (i) 25 km in m (ii) 10 g in kg.

Self-Check 2.4

1. Which of the following is a fundamental quantity?
A. Time B. Density C. Volume D. Area
2. What does a beam balance measure?
A. Area B. Mass C. Length D. Density
3. Which one of the following is not a method of science?
A. Measurement B. Observation
C. Experimentation D. Presentation
4. Which one of the following are not matter?
I. Steam II. Pencil III. Light IV. Space
A. I and II B. II and III C. III and IV D. I and IV.
5. How many cubic centimeters are there in a litre?
A. 500 B. 100 C. 2000 D. 1000
6. The sides of a black board are 2m and 5m, What is the surface area in m^2 ?
A. 0.1 B. 10 C. 1 D. 7
7. How many mm^2 are in 0.032 dm^2 .
A. 3.2 B. 320 C. 32 D. 0.0032
8. Find the correct expression.
A. Litre is a unit of length.
B. 1 A is equal to 1 ten-thousandth of a micron.
C. A day is equal to one complete rotation of the earth.
D. A graduated cylinder is used to measure volume.
9. What is equivalent to 5 minutes?
A. 30s B. 60s C. 120s D. 300s
10. How many minutes are there between 05: 30 and 21:15?
A. 715 B. 945 C. 1595 D. 900
11. The width of a meter rule is accurately measured by a
A. micrometer screw gauge B. vernier caliper
C. tape measure D. meter rule

12. A set of apparatus that is suitable for measurement of the volume of an irregular object includes;
- A. Over flow can, measuring cylinder, irregular object and a string.
 - B. Measuring cylinder, irregular object, over flow cans, flask
 - C. Overflow can., Irregular objects, string, retort sand and burette
 - D. Burette, overflows can, irregular object, a string, measuring cylinder, and retort stand.
13. Convert 25cm^3 into m^3
- A. 02.5×10^5
 - B. 2.5×10^2
 - C. 2.5×10^{-1}
 - D. 2.5×10^{-5}
14. The figure shows vernier calipers. The diameter of the object is



- A. 1.05 cm
 - B. 1.06 cm
 - C. 1.56 cm
 - D. 1.60 cm
15. Three of the fundamental physical quantities are:
- A. Density, mass and time
 - B. Length, time and mass
 - C. Length, time and weight
 - D. Volume, density and mass

That was a good revision test. Do not be unduly worried if you made a slip or two in your working. Try to avoid doing so, of course, but you are doing fine.

Now on to the next Chapter.

CHAPTER THREE

DENSITY AND RELATIVE DENSITY

LEARNING OBJECTIVES

By the end of this chapter, you should be able to:

1. Define: - Density and state its S.I unit and the other unit.
 2. Determine experimentally the densities of:
 - Regular and Irregular Solids,
 - Liquids and
 - Gases/Air.
 3. Solve numerical problems on density and density of mixtures.
 4. Define: - Relative Density (R.D)
 - Determine experimentally the R.D of;
 - Solids and
 - Liquids.
 5. Solve numerical problems on relative density of solids and liquids.
-

3.0 Density

Definition: Density is defined as mass per unit volume of a substance.

Mathematically, it is expressed as: Density = $\frac{\text{Mass}}{\text{Volume}}$

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

(a) S.I Unit

The SI unit of density is kg/m^3 (kgm^{-3}). It is a derived unit. I.e. a unit derived from the units of the quantities in the formula of density.

(b) Derivation of the unit

From Density = $\frac{m(\text{kg})}{v(\text{m}^3)}$ we have;

$$= \frac{kg}{m^3}$$

Conveniently expressed as = kg/m^3 or kgm^{-3}

The smaller unit of density is g/cm^3 (g cm^{-3}).

Note: The density of a substance is subject to variation depending on the prevailing physical factors.

3.1 (a) Factors that affect density

There are two physical factors that affect the density of a substance. These are:

- Temperature and Pressure.

(i) Effect of Temperature on density of substances

Substances expand and contract when their temperatures changes. The expansion and the contraction cause increase and decrease in the volume. Since, density is the ratio of mass to volume of a substance and then there will be change in the value of the density.

Effect of High temperature

At high temperature, a substance absorbs heat energy and expands and the volume is increased. Since the mass remains constant, the value of the density (i.e. the ratio of mass to volume) becomes low i.e. the density becomes low.

Effect of low temperature

At low temperature, a substance loses heat energy and contracts. The volume decreases. Dividing the constant mass by the reduced volume gives a higher density than the density under normal conditions.

(ii) Effect of Pressure on Density of substances

Pressure as a determining factor of density mostly affects the density of gases.

High pressure

High pressure squeezes the gas molecules into a smaller volume. If a given mass of a gas is contained within a smaller volume, the ratio of mass to volume results to a higher density.

Low pressure

At low pressure, the gas molecules occupy a larger volume and therefore, the density becomes low.

Note: As a result of the above factors, when stating densities of gases, the temperature and pressure values **must** be stated as well.

The table 3.1 below shows the densities of some common substances/ materials.

Substance	Density in kg m ⁻³
(a) Solids:	- Ice
	920 (9×10^2)
	- Aluminium
	2,700 (2.7×10^3)
(b) Liquids:	- Copper
	8,900 (8.9×10^3)
	- Lead
	11,300 (1.13×10^4)
Gases (at *stp)	- Water
	1,000 (1×10^3)
	- Paraffin, gasoline
	800 (8×10^2)
	- Mercury
	13,600 (1.36×10^4)
(b) Gases (at *stp)	- Air
	1.30
	- Hydrogen
	0.09
	- Oxygen
	1.43
	- Carbon dioxide
	1.98

Table 3.1

Note: (i) The above density values are **not** be memorised except for water.
(ii) *stp - stands for Standard Temperature and Pressure.

(b) Uses of Density

Density is used to:

- (i) Identify materials.
- (ii) Determine the purity of a material.
- (iii) Choose light gases for filling meteorological balloons.

(c) Importance of density

The densities of materials are important to architects and engineers in the design of structures. For example, aircrafts and overhead cables for the transmission of electricity are made of aluminium alloy. This is because aluminium has low density (i.e. is light) and is quite strong.

Worked Examples

Calculating density

Steps in problem solving

Before solving any problem, ask yourself the following questions.

- What is asked in the question?
- What information is given to help solve the problem?
- What are the equation(s) to solve the problem?
- Are units of the quantities given matching?

These questions can only be answered when you collect the data.

1. A glass stopper has a volume of 16 cm^3 and a mass of 40 g. Calculate the density of the glass stopper in: (i) g/cm^3 (ii) kg/m^3

Solution

Data: $m = 40 \text{ g}$, $v = 16 \text{ cm}^3$, $\rho = ?$

$$\text{(i) Density} = \frac{m}{v} = \frac{40}{16} = 2.5 \text{ g/cm}^3$$

Note: For (ii), the units of mass and volume in the data are small units. But you are required to get the answer in kg/m^3 . This means that the mass must be in kg and the volume in m^3 . So first convert the mass from gram to kg and volume from cm^3 to m^3 .

$$\text{Converting the units: (ii) Mass: } 40\text{g} = \frac{40}{1000} = 0.04 \text{ kg} = 4.0 \times 10^{-2} \text{ kg}$$

$$\text{Vol; } 16 \text{ cm}^3 = \frac{16}{1000000} = 0.000016 = 1.6 \times 10^{-6} \text{ m}^3$$

Now calculate the density:

$$\rho = \frac{m}{v} = \frac{4.0 \times 10^{-2}}{1.6 \times 10^{-6}} = 2.5 \times 10^3 \text{ kg/m}^3$$

2. The mass of 24.4 cm^3 of mercury is 332 g. Find the density of mercury.

Solution: Data: $m = 166 \text{ g}$, $v = 12.2 \text{ cm}^3$, $\rho = ?$

$$\rho = \frac{m}{v} = \frac{332}{24.4} = \underline{\underline{13.6 \text{ g/cm}^3}}$$

Solution: Data: (a) $v = 25 \text{ cm}^3$, $m = 67.5 \text{ g}$, $\rho = ?$

$$\rho = \frac{m}{v} = \frac{67.5}{25} = 2.7 \text{ g/cm}^3$$

(b) First convert the mass and the volume into their respective SI units.

$$\Rightarrow \text{Converting the mass: } 1 \text{ kg} = 1000 \text{ g}$$

$$m = 67.5 \text{ g}$$

$$= \frac{1 \times 67.5}{1000}$$

$$\therefore m = 0.0675 \text{ kg}$$

\Rightarrow Converting the volume: $1 \text{ m}^3 = 1\ 000\ 000 \text{ cm}^3$

$$v = 25 \text{ cm}^3$$

$$= \frac{1x25}{1\,000\,000}$$

$$\therefore v = 0.000\ 025 \text{ m}^3$$

Now applying the formula

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

we have;

$$= \frac{0.0675}{0.000025}$$

$$\therefore \rho = 2700 \text{ kg/m}^3 \text{ or } 2.7 \times 10^3 \text{ kgm}^{-3}$$

Calculating mass

4. The density of copper is 8.9 g/cm^3 . What is the mass of 100 cm^3 of copper?

Solution: Data: $\rho = 8.9 \text{ g/cm}^3$, $v = 100 \text{ cm}^3$, $m = ?$

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

$$8.9 = \frac{m}{100}$$

$$m = 8.9 \times 100$$

$$\therefore m = 890 \text{ g}$$

Calculating volume

5. Calculate the volume of a block of expanded polystyrene of mass 400 g if its density is 16 kg/m³.

Solution **Data:** $m = 400 \text{ g}$, $\rho = 16 \text{ kg/m}^3$, $v = ?$

Note: The mass must be converted to kilograms to match the density unit.

$$m = \frac{400}{1000} = 0.4 \text{ kg}$$

Rearranging the formula for calculating density we have:

$$v = \frac{m}{\rho} = \frac{0.4}{16} = 0.025 \text{ m}^3$$

3.2 Measurement of Density

(a) To find the density of a Regular Solid

- Measure the dimensions of the solid object i.e. length, width, height or diameter, using an appropriate instrument.
- Calculate the volume of the object from the appropriate formula.
Say volume of object = $y \text{ m}^3$
- Find the mass of the object using a triple balance. Say mass = $x \text{ kg}$.
- Calculate the density from the formula

$$\text{Density} = \frac{m}{v}$$

$$\therefore \text{Density} = \frac{x}{y} \text{ kg m}^{-3}$$

Examples

1. A cuboid of wood of mass 20 g measures 5 cm by 4 cm by 2 cm. Find its density.

Solution: **Data:** $m = 20 \text{ g}$, $l = 5 \text{ cm}$, $w = 4 \text{ cm}$, $h = 2 \text{ cm}$, $\rho = ?$

Notice from the data that mass is given and volume is not given. Therefore, we first get the volume by substituting the dimensions in the formula of volume of a cuboid.

$$v = lwh = 5 \times 4 \times 2 = 40 \text{ cm}^3$$

$$\text{Now calculate the density, } \rho = \frac{m}{v} = \frac{20}{40} = 0.5 \text{ g/cm}^3$$

2. A spherical metal made of aluminium weighs 90.477 g in air. If the diameter of the sphere is 4.0 cm³, find the density of the sphere. (Take $\pi = 3.14$)

Solution: **Data:** $m = 90.477 \text{ g}$, $d = 4.0 \text{ cm}$ ($r = 2 \text{ cm}$), $v = ?$, $\rho = ?$

$$v = \frac{4}{3} \pi r^3 = \frac{4 \times 3.14 \times 2^3}{3} = \frac{4 \times 3.14 \times 2 \times 2 \times 2}{3} = 33.49 \text{ cm}^3$$

$$\text{Applying the formula } \rho = \frac{m}{v} = \frac{90.477}{33.49} = 2.7 \text{ g/cm}^3$$

(b) To find the density of an Irregular Solid

- Pour water in a measuring cylinder and record the first reading of the water level, say $x \text{ cm}^3$
- Tie the irregular solid with a piece of thin silk thread and carefully immerse it into the water in the measuring cylinder.
- Read and record the second reading of the water level, say $y \text{ cm}^3$.
- Find the volume of the irregular solid from the formula:

$$\begin{aligned}\text{Volume of object} &= (\text{Second reading} - \text{First reading}) \\ &= (y - x) \text{ cm}^3\end{aligned}$$

- Determine the mass of the solid on a triple balance, say mass = $z \text{ g}$.

Calculation;

Results: Mass of object in air = $z \text{ g}$
Volume of object = $(y - x) \text{ cm}^3$
Using the formula

$$\text{Density} = \frac{m}{v} = \frac{z \text{ g}}{(y - x) \text{ cm}^3} = \left(\frac{z}{y - x} \right) \text{ g/cm}^3$$

Example

When a piece of irregular stone of mass 164.5 g was immersed in 300 cm^3 of water in a measuring cylinder, the level of water rose to 370 cm^3 . Calculate the density of the stone.

Solution: Data: Density of stone, ρ = ?

$$\begin{aligned}\text{Mass of stone in air} &= 164.5 \text{ g} \\ \text{Initial reading of water} &= 300 \text{ cm}^3 \\ \text{Final reading} &= 370 \text{ cm}^3 \\ \text{Volume of stone} &= \text{Final reading} - \text{Initial reading} \\ &= 370 - 300 \\ &= 70 \text{ cm}^3\end{aligned}$$

$$\begin{aligned}\text{Density} &= \frac{m}{v} \\ &= \frac{164.5}{70} \\ \therefore \rho &= 2.35 \text{ g/cm}^3\end{aligned}$$

(b) To find the density of liquid e.g. Paraffin

Procedure

- Weigh an empty beaker on a triple balance, say x grams.
- Pour a known volume, v , of the liquid in the beaker.
- Weigh the beaker and the liquid (paraffin). Let the total mass be y grams.
- Calculate the density as below:

Results:

Mass of empty beaker	$= x \text{ g}$
Mass of beaker + Paraffin	$= y \text{ g}$
Mass of paraffin only	$= (y - x) \text{ g}$
Volume of paraffin	$= v \text{ cm}^3$

$$\begin{aligned}\text{Density} &= \frac{m}{v} \\ &= \frac{(y - x)}{v} \text{ g cm}^{-3}\end{aligned}$$

Example

An empty beaker weighs 120 g in air. And weighs 180 g when filled with 75 cm³ of methylated spirit. Find the density of the methylated spirit.

Solution:

Mass of empty beaker	$= 120 \text{ g}$
Mass of beaker + Paraffin	$= 180 \text{ g}$
Mass of paraffin only	$= (180 - 120) \text{ g}$
Volume of paraffin	$= 75 \text{ cm}^3$

$$\begin{aligned}\text{Density} &= \frac{m}{v} \\ &= \frac{60}{75}\end{aligned}$$

$$\therefore \text{Density of methylated spirit} = 0.8 \text{ g cm}^{-3}$$

3.2 Density of Mixtures

A mixture is a substance that consists of two or more substances physical combined together.

Mixtures are obtained by mixing two or more substances physically. In dealing with the calculations of density of mixtures, the following assumptions are made.

- ❖ The constituents of the mixture do not react with one another.
- ❖ The total mass of the mixture is the sum of the masses of the constituents.
- ❖ The total volume of the mixture is the sum of the volumes of the constituents.

The density of mixtures is calculated from the formula.

$$\text{Density of mixture} = \frac{\text{Mass of mixture}}{\text{Volume of mixture}}$$

- N.B**
- (a) The density of the mixture lies between the densities of its constituents.
 - (b) Calculations on density of mixtures are of two types.
 - (i) Where the masses and volumes of the constituents are given directly.
 - (ii) Where either the masses and densities are given but volumes not given.

Or volumes and densities are given but masses not given.

In the case of the (b) (i), the formula for calculating density of mixture is applied directly after getting the total mass and total volume of the mixture.

While for the case of (b) (ii), we first use the formula for calculating density to get the quantities which are not given. There after we apply the formula of density of mixtures.

(a) Calculating density of a mixture when the masses and the volumes of the constituents are given

Example 1

100 cm³ of fresh water which weighs 100g is mixed with 100cm³ of sea water which weighs 103g .Calculate the density of the mixture?

Hint: *For this type of question, we get the total mass and total volume of the mixture and then substitute the values in the formula of density of mixtures. See examples below.*

Solution:

Mass of fresh water	= 100 g
Mass of sea water	= 103 g
Mass of the mixture	= 100 g + 103g
	= 203 g
Volume of fresh water	= 100 cm ³
Volume of sea water	= 100 cm ³
Volume of the mixture	= 100 cm ³ + 100 cm ³
	= 200 cm ³
Density of mixture	= $\frac{\text{Mass of mixture}}{\text{Volume of mixture}}$
	= $\frac{203}{200}$
.: Density of mixture	= 1.015 g/cm ³

(b) Calculating density of a mixture when either masses or volumes of the constituents are not given

Example 2

0.0018 m³ of fresh water of density 1000 kg/m³ is mixed with 0.0022 m³ of sea water of density 1,025 kg/m³ . Calculate the density of the mixture.

Solution:

Mass of fresh water	= ?
Volume of fresh water	= 0.0018 m ³
Density of fresh water	= 1000 kg/m ³
Mass of sea water	= ?
Volume of sea water	= 0.0022 m ³
Density of fresh water	= 1,025 kg/m ³

Hint: *Note that the masses are not given. So use the formula of density of a substance to get the masses of the constituents first and then follow the steps in example 1 above.*

\Rightarrow Calculating mass of fresh water: $\rho = \frac{m}{v}$

$$m = \rho v$$

$$= 1000 \times 0.0018$$

$$\therefore \text{Mass of fresh water} = 1.8 \text{ kg}$$

$$\Rightarrow \text{Calculating mass of sea water: } \rho = \frac{m}{v}$$

$$m = \rho v$$

$$= 1000 \times 0.0018$$

$$= 1.025 \times 0.0022$$

$$\therefore \text{Mass of fresh water} = 2.255 \text{ kg}$$

Since the masses and the volumes of the constituents are now known, the density of the mixture can be calculated from the data below.

Density of the mixture

$$\begin{aligned} \text{Mass of fresh water} &= 1.8 \text{ kg} \\ \text{Mass of sea water} &= 2.255 \text{ kg} \\ \text{Mass of the mixture} &= 1.8 + 2.255 \\ &= 4.055 \text{ kg} \\ \text{Volume of fresh water} &= 0.0018 \text{ m}^3 \\ \text{Volume of sea water} &= 0.0022 \text{ m}^3 \\ \text{Volume of the mixture} &= 0.0018 \text{ m}^3 + 0.0022 \text{ m}^3 \\ &= 0.004 \text{ cm}^3 \\ \text{Density of mixture} &= \frac{\text{Mass of mixture}}{\text{Volume of mixture}} \\ &= \frac{4.055}{0.004} \end{aligned}$$

$$\therefore \text{Density of mixture} = 1.013 \text{ kg/m}^3$$

Note: The detailed steps are to make you to understand how to solve problems in this topic. But in examination you are required to present your work brief and clear.

3.3

RELATIVE DENSITY (R.D)

Definition

Relative density of a substance is defined as the ratio of the density of a substance to the density of water.

Mathematically, R.D is expressed as:

$$\text{Relative density (R.D)} = \frac{\text{Density of substance}}{\text{Density of water}}$$

If the masses of equal volume of a substance and water are found, then this relation takes the form

$$\text{Relative density (R.D)} = \frac{\text{Mass of any volume of a substance}}{\text{Mass of an equal volume of water}}$$

In a normal weighing, the mass of a substance is proportional to the weight, so it is also true to say;

$$\text{Relative density (R.D)} = \frac{\text{Weight of any volume of a substance}}{\text{Weight of an equal volume of water}}$$

NB: R.D has no unit since it is a ratio of the same quantity i.e. densities, masses or force (weight) as a result the units cancel.

3.31 Measurement of Relative Density (R.D)

(a) To measure the density of Liquid

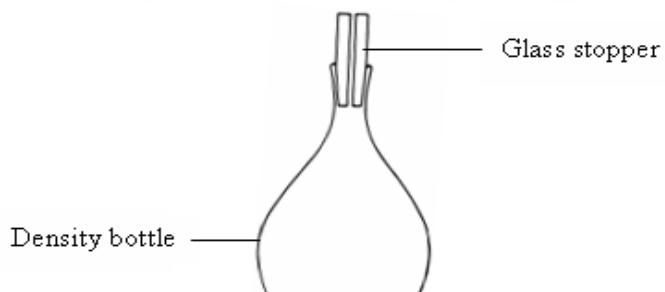


Figure 3.2

The R.D of a liquid is measured by using a *density bottle*. The density bottle has glass stopper with a fine hole through it, so that, when it is filled fully with the liquid and the stopper inserted, the excess liquid rises through the fine hole and runs down the outside.

So long as the bottle is used to the same liquid level at the top of the hole, it will always contain the

same volume of whatever liquid is filled in it provided the temperature remains the same.

Experiment to determine the R.D of liquid e.g. Paraffin

Procedure

- Weigh the density bottle when empty.
- Fill the bottle full with the paraffin.
- Wipe the paraffin that runs out through the hole and weigh the bottle and the paraffin.
- Empty the bottle and clean it thoroughly.
- Refill the bottle with water to the same level and weigh it after wiping the water that flows out.

Calculate the R.D as shown below.

Mass of empty bottle	= x g
Mass of bottle full of liquid	= y g
Mass of bottle full of water	= z g
Mass of liquid	= $(y - x)$ g
Mass of water	= $(z - x)$ g

Applying the formula

$$\begin{aligned}\text{Relative density of liquid} &= \frac{\text{Mass of a substance}}{\text{Mass of equal volume of water}} \\ &= \frac{(y-x)g}{(z-x)g} \\ \therefore \text{R.D} &= \frac{(y-x)}{(z-x)}\end{aligned}$$

(b) Precautions

To obtain accurate result, the following precautions should be taken.

- (i) The outside of the bottle must be wiped dry before weighing.
- (ii) The bottle must **not** be held by the neck with warm hand otherwise some liquid may be lost due to expansion.

Worked Examples

Steps in problem solving

Before solving any problem, ask yourself the following questions.

- What is asked in the question?
- What information is given to help solve the problem?
- What are the equations to solve the problem?

These questions are answered when you collect the data.

Example 1

A density bottle was used to measure the relative density of a liquid and the following results were obtained.

Solution:

Mass of empty density bottle	= 30 g
Mass of bottle full of liquid	= 110 g
Mass of bottle full of water	= 130 g
Mass of liquid	= 110 – 30
	= 80 g
Mass of water	= 130 – 30
	= 100 g

$$\text{Relative density of liquid} = \frac{\text{Mass of a substance}}{\text{Mass of equal volume of water}}$$
$$= \frac{80 \text{ g}}{100 \text{ g}}$$

$$\therefore \text{R.D of liquid} = 0.8$$

Example 2

The mass of an empty density bottle is 46.00 g. When fully filled with water it weighs 96 g. And when full of a liquid of unknown R.D. it weighs 86 g.

Calculate:

- (i) the R.D of the liquid.
- (ii) the density of the liquid.

Solution:

(i)	Mass of empty bottle	= 46 g
	Mass of bottle full of liquid	= 96 g
	Mass of bottle full of water	= 86 g

Mass of liquid	= 86 – 46
	= 40 g
Mass of water	= 96 – 46
	= 50 g

$$\text{Relative Density of liquid} = \frac{\text{Mass of liquid}}{\text{Mass of water}}$$
$$= \frac{40 \text{ g}}{50 \text{ g}}$$

$$\therefore \text{R.D of liquid} = 0.8$$

$$(ii) \quad R.D \text{ of liquid} = 0.8, \text{ density of water} = 1000 \text{ kgm}^{-3}$$

$$\text{Relative density (R.D)} = \frac{\text{Density of a substance}}{\text{Density of water}}$$

$$0.8 = \frac{\text{Density of a substance}}{1000}$$

$$\text{Density of liquid} = 0.8 \times 1000$$

$$\therefore \text{Density of liquid} = 800 \text{ kgm}^{-3}$$

(c) To measure the Relative Density of Solid

The R.D of solid/liquid substances can best be measured by applying *Archimedes's Principle* to be discussed in detail later.

Archimedes's Principle stats that:

When a body is wholly or partially immersed in a fluid, it experiences an upthrust equal to the weight of fluid displaced.

Procedure

- Suspend the solid whose relative is to be determined from a spring balance by means of light string in air and record its weight.
- Immerse the solid wholly in water and record its apparent weight.

Results:

$$\text{Let: Weight of solid object in air} = W_a \text{ N}$$

$$\text{Weight of solid object in water (Apparent weight)} = W_w \text{ N}$$

Calculation:

$$\begin{aligned} \text{Upthrust (Loss in weight of object)} &= \text{Weight of water displaced} \\ &= \text{Weight in air} - \text{Apparent weight} \\ \therefore \text{Upthrust} &= (W_a - W_w) \text{ N} \end{aligned}$$

$$\text{But Volume of water displaced} = \text{Volume of the solid immersed}$$

$$\begin{aligned} \text{From} \quad \text{Relative Density} &= \frac{\text{Weight of substance}}{\text{Weight of an equal volume of water}} \\ &= \frac{W_a}{(W_{a1} - W_w)} \end{aligned}$$

$$\text{I.e.} \quad \text{Relative Density (R.D)} = \frac{\text{Weight of substance in air}}{\text{Upthrust in water}}$$

Note: For details on R.D of solids, see chapter 10.

Examples

1. A piece of aluminium weighs 80 N in air and 50.37 N when completely immersed in water. Calculate the relative density of glass.

Solution: (Remember the steps in problem solving!!)

$$\begin{aligned}\text{Weight of solid object in air} &= 80 \text{ N} \\ \text{Weight of solid object in water (Apparent weight)} &= 50.37 \text{ N} \\ \text{Weight of water displaced} = \text{Upthrust in water} &= 80 - 50.37 \text{ N} \\ &= 29.63 \text{ N} \\ \text{Relative Density} &= \frac{\text{Weight of substance in air}}{\text{Upthrust in water}} \\ &= \frac{80}{29.63} \\ &= 2.699966 \\ \therefore \text{Relative Density} &= 2.7\end{aligned}$$

SELF-CHECK 3.0

1. To calculate the density of an object, which one of the following must be known?
I. Height II. Volume III Area IV Mass V Weight
A. I and II B. II and V. C. III and IV D. II and IV A
2. A block of wood 10m x 5m x 4m has a mass of 80 000 kg. What is the density of this wood?
A. 2000kg/m² B. 4000kg/m² C. 200 kg/m² D. 400 kg/m²
3. The density of gold is 19.3 g/cm³. What is the mass of 10cm³ gold?
A. 19.3 g B. 0.193g C. 1.93g D. 193g
- 4.. What is the mass of the copper cube having each side 2cm? (take $c_{\text{copper}} = 9\text{g/cm}^3$)
A. 0.18g B. 72g C. 180g D. 36g
5. What is the volume of 60g wood ? ($d_{\text{wood}} = 0.6 \text{ g / cm}^3$)
A. 10cm³ B. 36cm³ C. 100cm³ D. 360cm³

6. Study the table below and use it to spot the correct answer.

Material	Density (g/cm ³)	Mass (g)
K	3	60
L	9	180
M	6	360
N	5	200

From the values shown in the table which material has the biggest volume?

- A. K B. L C. M D. N
7. What is the volume and mass of the block which measures by 2m, by 3m by 5m if its density is 1500kg/m³?
 A. 50m³; 75 000 kg B. 100 m³; 75 000 kg
 C. 30m³; 75 000 kg D. 30 m³; 75 000 kg
8. Two litres of corn oil has a mass of 1. 85kg. What is the density of the oil?
 A. 1850kg/m² B. 925kg/m² C. 185kg/m² D. 92.5kg/m²
9. If an object of volume 0.02m³ weighs 500 N in a liquid of density 2000kg/m³, what is the weight in air?
 A. 900 N B. 1000 N C. 400 N D. 600 N
10. Which one of the following is the SI unit of density?
 A. kgm³ B. kg/m⁻³ C. g/cm³ D. kg/m³)
11. If 10g water and 10cm³ alcohol are mixed what will be the mass of the mixture?
 ($d_{alcohol} = 0.80 \text{ g/cm}^3$)
 A. 18g B. 20g C. 16g D. 19g
12. A tin containing 5 litres of paint has a mass of 8.5kg. The mass of the empty tin is 2.0kg, the density of the paint is
 A. 1.3kg m^{-3} B. $1.3 \times 10^3\text{kg m}^{-3}$ C. $1.7 \times 10^3\text{kg m}^{-3}$ D. $2.1 \times 10^3\text{kg m}^{-3}$
13. A rectangular block of tin is 0.5m long and 0.01m thick. Find the width of the block if its mass and density are 0.45kg and 9000 kg m⁻³ respectively.
 A. $0.005 \times 0.45 \times 9000m$ B. $\frac{0.45}{9000 \times 0.005}$
 C. $\frac{0.005}{0.45 \times 9000}m$ D. $\frac{0.45 \times 0.005}{9000}m$
14. A box of dimensions 0.2m by 0.3m by 0.5m is full of a gas of density 200kg/m³. The mass of the gas is
 A. $3 \times 10^{-2}\text{kg}$ B. $6.0 \times 10^0\text{kg}$ C. $2 \times 10^2\text{kg}$ D. $6.7 \times 10^3\text{kg}$
15. A piece of material of mass 200g has a density of 25kgm⁻³. Calculate its volume in m³.
 A. $\frac{200}{25}$ B. $\frac{200}{1000 \times 25}$ C. $\frac{1000 \times 25}{200}$ D. $\frac{1000 \times 200}{25}$

16. Two solid cubes have the same mass but their edges are in the ratio 4:1. What is the ratio of their densities?
 A. 1:4 B. 1:8 C. 1:16 D. 1: 64
17. A tin containing $6 \times 10^{-3} \text{ m}^3$ of paint has a mass of 8kg. If the mass of the empty tin with the lid is 0.5kg, calculate the density of the paint in kgm^{-3}
 A. $\frac{8 \times 0.5}{6 \times 10^{-3}}$ B. $\frac{7.5}{6 \times 10^{-3}}$ C. $\frac{8 \times 10^6}{6 \times 10^{-3}}$ D. $\frac{8.5 \times 10^6}{6 \times 10^{-3}}$
18. A tank 2 m tall base area of 2.5 m^2 is filled to the brim with a liquid which exerts a force of 40000N at the bottom. Calculate the density of the liquid.
 A. $\frac{4000}{25 \times 2 \times 10} \text{ kgm}^{-3}$ B. $\frac{40000}{2.5 \times 2 \times 10} \text{ kgm}^{-3}$ C. $\frac{40000}{25 \times 2 \times 10} \text{ kgm}^{-3}$ D. $\frac{40000}{2.5 \times 2} \text{ kgm}^{-3}$
19. The following reading were recorded when measuring the density of a stone; Mass of the stone = 25g, volume of water = 25 cm^3 , volume of water and stone = 35 cm^3 . What is the density of the stone?
 A. $\frac{25}{10} \text{ g/cm}^3$ B. $\frac{35}{30} \text{ g/cm}^3$ C. 10 g/cm^3 D. $\frac{25}{35} \text{ g/cm}^3$
20. Liquid Y of a volume 0.40 m^3 and density 900 kg/m^3 is mixed with liquid Z of volume 0.35 m^3 and density 800 kg/m^3 . Calculate the density of the mixture.
 A. 800 kg/m^3 B. 840 kg/m^3 C. 850 kg/m^3 D. 900 kg/m^3

CHAPTER FOUR

PARTICULATE NATURE OF MATTER

LEARNING OBJECTIVES

By the end of this topic you should be able to:

1. Define: - Matter.
2. State: (i) - The states of matter.
(ii) - The differences between the states of matter.
3. (a) State: - Kinetic Theory of Matter.
(b) Describe an experiment (Brownian Motion) to proof the kinetic theory
(c) The effect of heat on Brownian Motion.
(d) Use the Kinetic Theory to explain change of state.
4. List and define the Properties of Matter.
 - Molecular forces (Cohesion and Adhesion),
 - Diffusion, Capillarity,
 - Surface tension, and
 - Elasticity.
5. Describe experiments to show:
 - Diffusion in liquids and gases.
 - Surface tension.
 - The effect of detergents on surface tension.

4.1 Matter

Definition: Matter is any thing that occupies space and has mass.

States (Phases) of Matter

There are three states of matter namely:

- | | | | |
|------|--------|------|-----------------------|
| (iv) | Solid, | e.g. | stone, wood etc. |
| (v) | Liquid | e.g. | water, paraffin etc. |
| (vi) | Gas | e.g. | oxygen, nitrogen etc. |

Each of these states is made up of so many tiny particles called atoms and molecules. The arrangement of these particles and the magnitude of the forces holding them makes one state different from other states.

Note: Examples of things which are not matter are:- Light, Sound and Heat.

4.11 Differences in the three states of matter

(a) Solids

- (i) The molecules are closely packed and are arranged in a regular pattern called *lattice*.
- (ii) The forces holding the molecules are strong as such
- (iii) The molecules are not free to move.
- (iv) The molecules vibrate about a fixed position.
- (v) Solids have a definite shape and volume.
- (vi) There is very little diffusion in solids. E.g. Naphthalene.
- (vii) Due to the close packing of the particles, solids cannot be compressed.

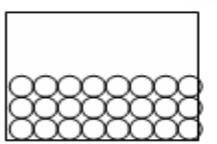
(b) Liquids

- (i) The particles in liquid are fairly close to each other and are in irregular pattern.
- (ii) The forces holding the molecules are weak.
- (iii) The molecules move randomly throughout the liquid.
- (iv) Liquids have definite volume but no definite shape. They take the shape of the container in which they are placed and then acquire a definite volume.
- (v) Liquids have slow diffusion.
- (vi) They cannot be compressed.

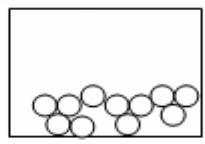
(c) Gases

- (i) The particles in a gases are far apart from each other.
- (ii) The forces holding the molecules are very weak.
- (iii) The particles move randomly and at comparatively high velocities.
- (iv) Gases have no definite shape and no definite volume. They fill the whole container they are placed in.
- (v) There is high rate of diffusion in gases.
- (vi) Gases are quite easy to compress. This is because there are large spaces between the particles.

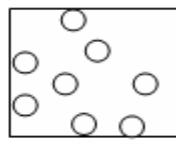
The diagrams showing a model representation of the three states of matter



(a) Solid



(b) Liquid



(c) Gas

Figure 4.0

Note: *The diagrams in figure 4.0 show that the molecules are of the same size for all the three states. However, is not the case. Even for the same state, particle size is different for different substances.*

4.2 Kinetic Theory of Matter

The kinetic theory of matter states that:

1. Matter is made up small particles called *atoms or molecules*.
2. The molecules are in a constant random motion.
3. The speed of movement of the particles increases when temperature increases.
4. The particles (molecules) in gases move faster than those of liquids and those of liquids move faster than those of solids.

4.21 Assumptions of Kinetic Theory of Gases

1. Molecules of gases move in straight line with a very great speed or velocity until they collide with each other or with the walls of the container in they are placed. Pressure of a gas is due to collisions of the gas molecules with the walls of the container. This pressure increases as the temperature increases.
2. The volume of the gas molecules is negligible compared to the total volume of the container; so the molecules can be taken to be points of negligible volume.
3. The forces of attraction between the gas molecules are negligible.
4. The average kinetic energy of the molecules is a measure of the temperature of the gas.
5. The collisions of the molecules are perfectly elastic. (i.e. When molecules collide, there is no loss in kinetic energy).

4.22 The proof of Kinetic Theory of Matter

The kinetic theory of matter can be proved by:

- (i) Brownian Motion and
- (ii) Diffusion.

Experiment 4.0 To demonstrate kinetic theory of matter using *Brownian motion*.

Apparatus/Requirements

A smoke cell, microscope, source of light, glass rod or convex lens, smouldering cigarette or paper.

Procedure

- Place the source of light at a small distance such that the rays are incident on to the window of the glass cell.
- Place the glass rod or converging lens between the source of light and the smoke cell.
- Adjust the object distance such that the light rays are in focus in the smoke cell thus strongly illuminating it.
- Fill the smoke cell with some smoke from a smouldering paper.
- View the smoke particles from above using a microscope as show in the figure below.

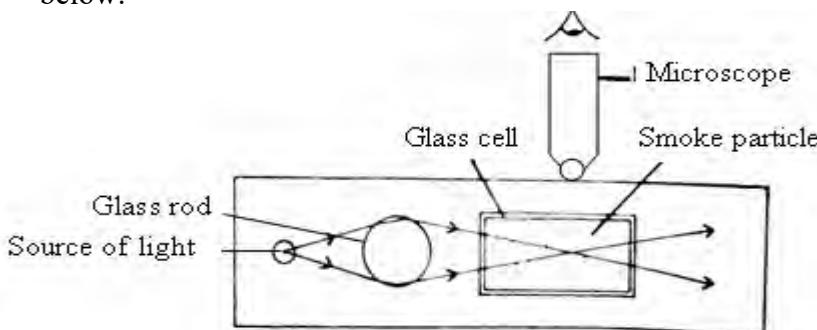


Figure 4.1

Observation

The white specks of the smoke particles are seen moving with constant random motion.

Explanation

The random motion of the smoke particles is due to the bombardment with the air molecules which are in a constant random motion. The air molecules can not be seen, only their effects can be seen.

NB: If the smoke cell is replaced by a glass container containing water with some pollen grains suspended in it, the pollen grains will also be seen moving with a constant random motion.

Effect of heat on Brownian motion

When the temperature of the smoke cell is increased, the smoke particles are seen moving faster.

Explanation

Due to the increase in temperature, the molecules acquire kinetic energy. The kinetic energy is directly proportional to the velocity of the particles (i.e. from $K.E = \frac{1}{2}mv^2$) hence increased velocity.

4.23 Effect of Heat on Matter

(a) Heating Solid

When a solid is heated, its particles acquire kinetic energy and vibrate more violently. The particles continue to vibrate until a point is reached when the vibration overcome the *binding force* (forces of attraction between the particles). The crystalline structure corrupts and the particles become mobile. At this point the solid *melts* or *fuses* (i.e. changes to liquid at a constant temperature called *melting point*). The process is called *melting or fusion*.

On further heating of the liquid, the molecules of the liquid acquire increased kinetic energy. The kinetic energy continues to increase until they overcome the forces of attraction between the molecules. At this point the liquid *boils* (i.e. changes to vapour at a constant temperature called the *boiling point*). And the process is called *boiling or evaporation*.

(b) Effect of Cooling

When a gas or vapour at a higher temperature is cooled, the kinetic energy of the particles also reduces. Since the kinetic energy of the particles is directly proportional to their velocity (speed) of the particles gradually decreases until the forces of attraction between the particles build up and the particles come closer i.e. they condense. At this point, the gas changes to liquid at a constant temperature. The process is called condensation.

Cooling the liquid further causes more loss in kinetic energy until eventually the particles settle to form a solid at a constant temperature called *freezing point*. The process involved is called *freezing or solidifying*.



Figure 4.2

For example when ice is heated, it changes to liquid water. On heating the water, it changes to vapour. If the vapour is cooled, it condenses to liquid. On further cooling of the liquid it changes to ice.

4.3 Properties of Matter

The properties of matter are as a result of the behaviour of its molecules. The properties resulting from the behaviour of molecules include:

- (i) Molecular forces,
- (ii) Diffusion,
- (iii) Capillarity,
- (iv) Surface tension and
- (v) Elasticity.

4.31 Molecular forces

A molecular force refers to the attractive force that exists between molecules. The molecules may be of the same substance or of different substances.

Types of molecular forces

There are two types of molecular forces namely:

- Cohesion and
- Adhesion.

(i) Cohesion

Cohesion is the force of attraction between the molecules of the same kind.

E.g. The force of attraction between water molecules.

(ii) Adhesion

Adhesion is the force of attraction between molecules of different substances.

E.g. The force of attraction between water molecules and glass molecules.

The magnitude of cohesion and adhesion determine:

- The shape of liquid meniscus when in contact with other substances.
- Ability to wet substances and
- The rise or fall in a capillary tube.

For example:

- (i) Water in a glass tube wets glass. This is because the adhesion is greater than cohesion. The result is that the meniscus of water curves upwards as shown in figure 4.3
- (ii) Mercury in a glass tube does not wet glass because cohesion is greater than adhesion. The result is that the meniscus of mercury curves downward. See figure 4.3 (ii)

Diagrams showing the meniscus of water and mercury

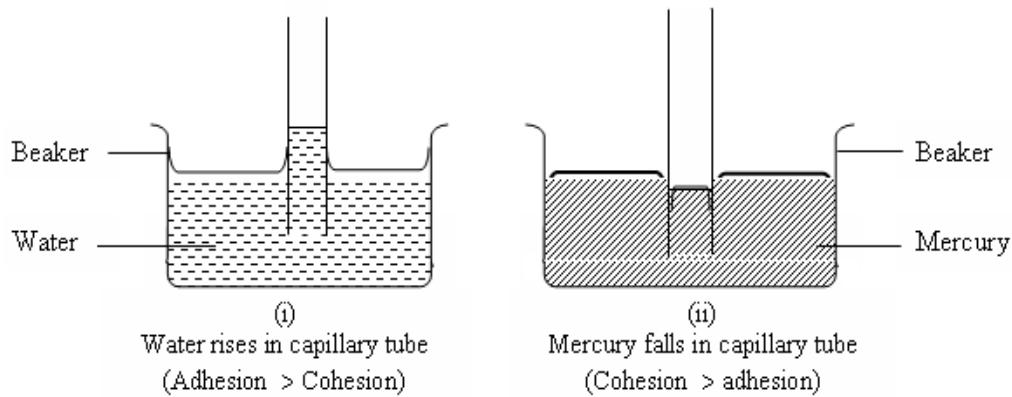


Figure 4.3

4.32 Diffusion

Diffusion is the spreading of molecules of one substance in to the molecules of another substance. Or

Diffusion is the movement of molecules from a region of high concentration to a region of low concentration.

Factors which determine the rate of diffusion depends

The rate of diffusion depends on the following factors:

- (i) Size of the diffusing molecules,
- (ii) Molecular weight
- (iii) Temperature
- (iv) Pressure
- (v) Size of the pore (in the porous material) across which the molecules diffuse

The table below shows the factors which determine the rate of diffusion and there explanations.

Factor of rate of diffusion	Explanation
i) Size of the molecules	Bigger molecules occupy larger space than smaller molecules. As a result it is difficult for them to pass through porous material with small pores. Therefore, low rate of diffusion.
ii) Molecular weight	Lighter molecules diffuse faster than the “massive” molecules.
iii) Temperature	Temperature determines the amount of kinetic energy in a body. Since kinetic energy is directly proportional to velocity of a body, therefore, at high temperature gas molecules gain kinetic energy and diffuse faster than when at low temperature. Therefore the rate of diffusion is higher at high temperature than at low temperature.
iv) Pressure	Pressure mainly affects the rate of diffusion of gases. At higher pressure, the gas molecules are squeezed in a small space. This makes the molecules to collide frequently and move faster than at low pressure. Therefore, rate of diffusion is high at high pressure than at low pressure.
v) Size of the pore in the porous material	A large pore allows many molecules to pass through in a unit time. While a small pore allows very few molecules to pass through. As a result the rate of diffusion is high when the size of the pore is large and low when the size of the pore is small.

Figure 4.1

Diffusion is extremely slow in solids, average in liquids and very fast in gases. For example a small amount of perfume or ammonium gas placed at one corner of a room spreads quickly and fills the whole room.

Experiment 4.2 To show diffusion in liquid e.g. Water

Apparatus/Requirements

A beaker, Crystal of potassium permanganate, water and a glass tube.

- Procedure:**
- Fill a beaker with clean water.
 - Drop a fairly large crystal of potassium permanganate in the middle of the bottom of beaker with a help of a glass tube.
 - Leave the set up to stand for some time.

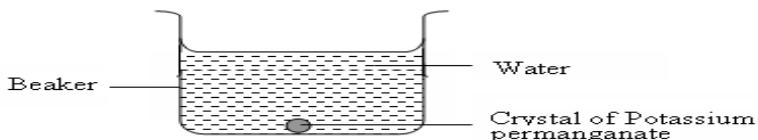


Figure 4.4

Observation

The crystal dissolved and spread through out the water forming a purple solution.

Explanation

The molecules of the potassium permanganate moved slowly moved in to the molecules of water to give the purple colour. We say that the molecules of potassium permanganate diffused into the molecules of water.

Experiment 4.3 To show diffusion in gases

Apparatus/Requirements

Porous pot, manometer, water, a delivery tube, hydrogen gas and air.

Procedure

- Arrange the apparatus as shown in the diagram below.

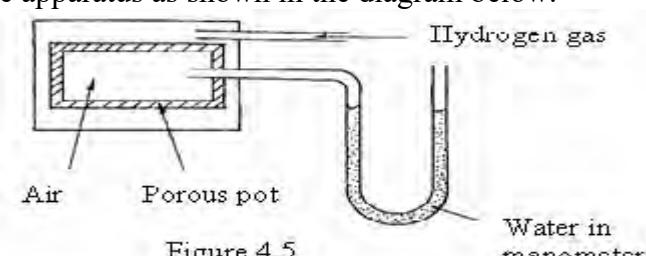


Figure 4.5

- Supply hydrogen gas into the space surrounding the porous pot and observe the water levels in the arms of the manometer.

Observation: The level of the liquid in the left arm of the manometer falls, while that in the right arm rises.

Explanation:

The hydrogen molecules increase the pressure inside the porous pot. And the pressure acts on the water surface in the limb of the manometer thus pushing the water level downward.

When the hydrogen supply is stopped, the situation is reversed. This is because the hydrogen that diffused into the porous pot diffuses out faster than the air outside porous pot diffuses into the pot.

NB: *Brownian motion and diffusion, in liquid or in gases is a strong evidence of kinetic theory of matter. That is, it shows that matter is made up of small particles and that the particles are in a constant random motion.*

4.33 Capillarity

Capillarity is the rise or fall of liquid in a capillary tube.

Capillary rise is due to adhesion being greater than cohesion. Examples of liquids that have capillary rise when a capillary tube is dipped into them are: *Water, paraffin and diesel*. While *capillary fall* is due to cohesion being greater than adhesion. Example of liquid that has a capillary fall is mercury.

The diagrams in figure 4.6 show capillary rise and fall in glass tubes of different diameters

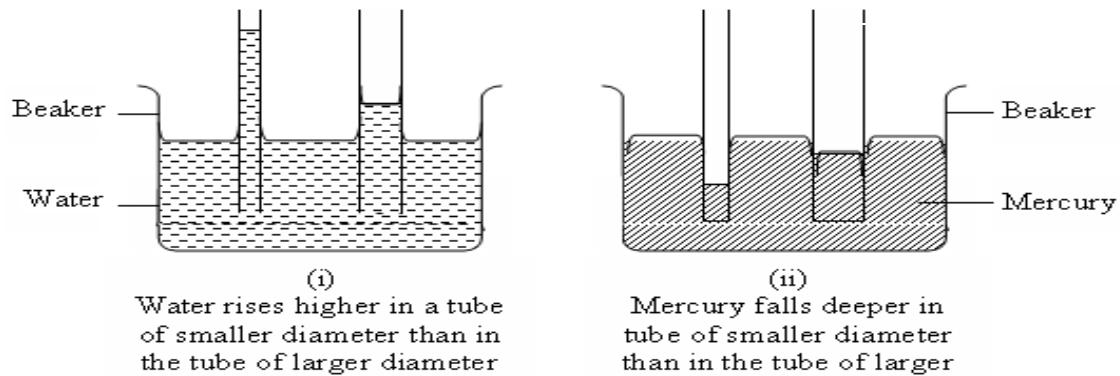


Figure 4.6

Uses of Capillarity

It helps:

- i) Fuel e.g paraffin to rise up in wicks of stoves and lamps.
- ii) Water to move up tree trunks to the leaves.
- iii) Blotting paper to absorb liquids.

4.34 Surface tension

Surface tension is the force on a liquid surface that makes the liquid surface to behave as if it is covered with thin elastic membrane.

Experiment 4.4 To show surface tension in a liquid e.g. water

Apparatus/Requirements: A glass trough, blotting paper, a needle or pin and water.

Procedure

- Fill a beaker with clean water.
- Place a filter paper or blotting paper on the surface in the trough.
- Drop a needle on the blotting paper.
- Leave the apparatus to stand for some time as shown in figure 4.7 below.

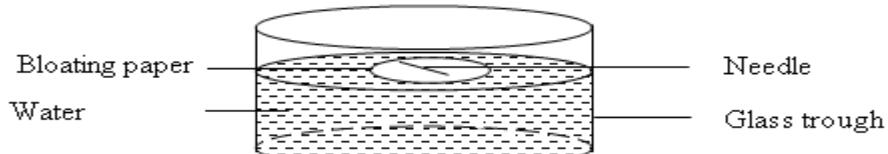


Figure 4.7

Observation

The filter paper absorbs water and sinks to the bottom of the trough.
The needle is seen floating on the water surface.

Conclusion

The surface of liquid water behaves as if it is covered with a thin elastic skin or membrane.

How to reduce or get rid of surface tension

Surface tension in liquids is reduced or got rid of by adding the following.

- (i) Soap solution,
- (ii) Detergent solution,
- (iii) Oil.

These solutions get rid of surface tension by dissolving process.

Experiment 4.5 To show the effect of detergent solution on surface tension

Repeat the experiment 4.4 above.

When the needle is floating, carefully add a detergent solution with a help of syringe to the water and observe.

Observation: The needle quickly sinks to the bottom.

Conclusion: Surface tension can be reduced by detergent solution.

4.35 Elasticity

Elasticity is a property of a material that enables the material to return to its original size and shape after deformation.

Materials that have elasticity (e.g. rubber, foam, metal wires) are said to be elastic. While those which do not have this property (e.g. wood, glass, paper) are said to be inelastic.

Self-Check 4.0

SECTION A

11. In a Brownian motion experiment, the
- A. smoke particles are seen moving about with uniform velocity.
 - B. motion observed is caused by the air molecules colliding with the smoke particles.
 - C. Size of particles are found to increase the motion.
 - D. smoke cell has a vacuum within it.
12. When smoke is introduced in a smoke cell and observed under a microscope, it is observed as particles moving at random. This is mainly because the particles
- A. are hot
 - B. collide with one another
 - C. collide with air molecules
 - D. collide with the walls of the smoke cell
13. Which of the following statements is incorrect when a tin containing air tightly sealed is heated?
- A. the average speed of molecules increases
 - B. the molecules of air hit the walls of the tin harder
 - C. The molecules of the air strike the walls of the tin less often.
 - D. The pressure inside the tin increases.
14. When a room is filled with smoke, the smoke tends to concentrate
- A. around the walls
 - B. close to the walls
 - C. close to the roof
 - D. midway between the roof and the floor
15. Capillary rise in a tube dipped in water is due to
- A. Surface tension
 - B. adhesive force being greater than cohesive force
 - C. high vapour pressure
 - D. Atmospheric pressure acting on the surface of the water
16. Which of the following statements about states of matter is/are true?
- (i) a liquid has a definite volume but no a definite shape.
 - (ii) a vapour has no definite volume and no definite shape.
 - (iii) a solid has a definite volume and shape.
 - (iv) a gas has a definite volume and shape.
- A. (i) and (iii) only
 - B. (i) only
 - C. (i), (ii) and (iii) only
 - D. (iii) only
17. When viewing Brownian motion in a smoke cell the observer sees:
- A. Air molecules moving in a random motion
 - B. air molecules vibrating regularly
 - C. air molecules colliding with each other
 - D. Smoke particles in a random motion.
18. Which of the below is a matter?
- A. Heat
 - B. Sound
 - C. Air
 - D. Light
19. Which of the following statements below is *wrong*?
- A. Matter is made up of atoms.
 - B. Solid, liquid and gas are states of matter.
 - C. Solids and liquids have definite shape and volume.
 - D. Gas molecules move freely.

20. The diagrams in figure show two capillary tubes standing in a trough of mercury and two capillary tubes standing in a trough of water. The correct order of arrangement of the tubes in order of increasing height of the liquid column is;

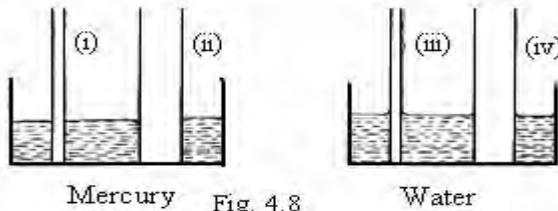


Fig. 4.8

- A. (i), (ii), (iv),(iii) B. (ii), (i), (iv), (iii) C. (ii), (iv), (i), (iii) D. (iii), (iv), (i), (ii)

SECTION B

21. Describe the relationship between molecules of liquids, gases and solids in terms of:
- the arrangement of the molecules through out the bulk of the material,
 - the separation of the molecules,
 - the motion of the molecules and
 - The forces of attraction between the molecules.
22. (a) (i) What is meant by the term *diffusion*?
 (ii) State factors on which diffusion depends.
 (b) Describe an experiment to show diffusion in liquids.
 (c) A porous pot containing air is connected to a water manometer. Explain what happens if hydrogen is let in the space surrounding the as shown in the figure.
 (d) (i) Describe a simple experiment to show surface tension in water.
 (ii) State two factors, which affect surface tension.

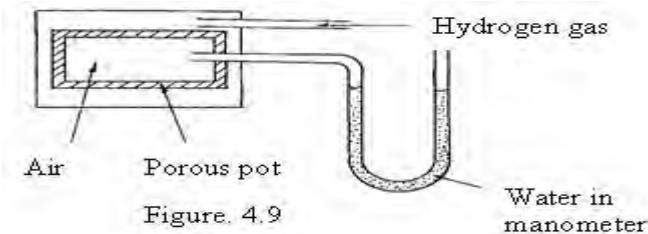
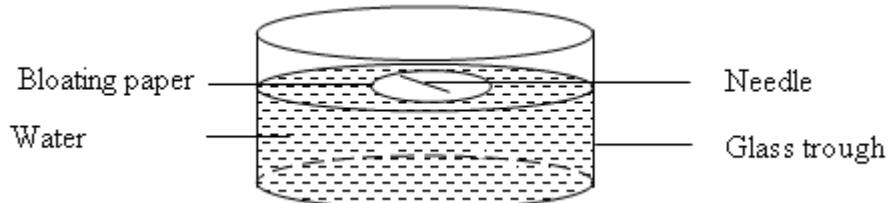


Figure. 4.9

23. A pin is placed on a bloating paper, which is on the surface of water as shown in figure 4.10 below



- (a) Explain what happens after some time.
 (b) Explain what happens when some soap solution is carefully added to the water.

24. Draw a well labelled diagram you would use to describe Brownian motion.
- How is the motion of the smoke particles best described?
 - What accounts for the motion of the smoke particles?
 - The motion is viewed using bigger smoke particles.
What difference in the motion would this lead to.
Give reason for the difference.
25. The diagram in figure 4.11 shows an arrangement for observing Brownian motion.

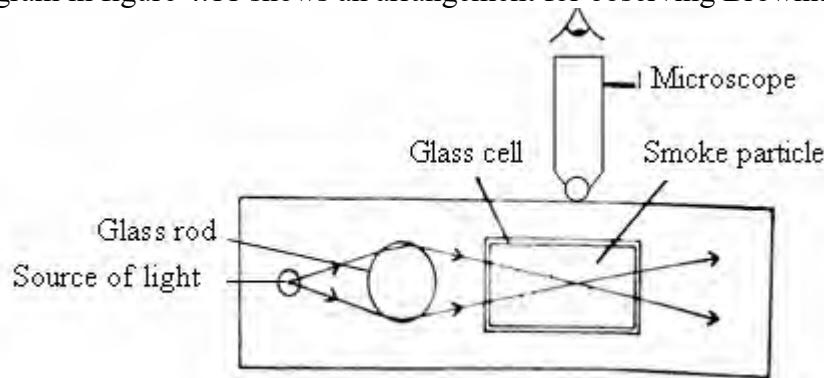


Figure 4.1

- Explain:
 - The observation made.
 - What will be observed when the glass cell temperature is raised.
 - State one factor which determines the rate of diffusion of a gas.
26. (a) Distinguish between cohesion and adhesion.
(b) Sketch diagrams to show the level of liquid in a capillary tube that is immersed in a liquid which has greater;
 - Cohesion than adhesion
 - Adhesion than cohesion
27. (a) Define surface tension.
(b) Describe a simple experiment to show the existence of surface tension in water.
(c) Explain the following observations as fully as you can.
 - A small needle can be floated on the surface of water, but if a drop of detergent is added to the water the needle sinks.
 - Damp courses are used in modern houses.
 - Gases can easily be compressed but liquids cannot.
 - Diffusion occurs more easily in a gas than in a liquid.
28. (a) State the kinetic theory of matter.
(b) Describe experiments, in each case, to show:
 - Diffusion in liquids
 - Diffusion in gases.
- (c) Use kinetic theory to explain the result of your experiment demonstrating the diffusion in gases.

4.4 SIZE OF A MOLECULE

Molecules are so small that we cannot measure their sizes accurately. The approximate size of a molecule can only be estimated through an experiment.

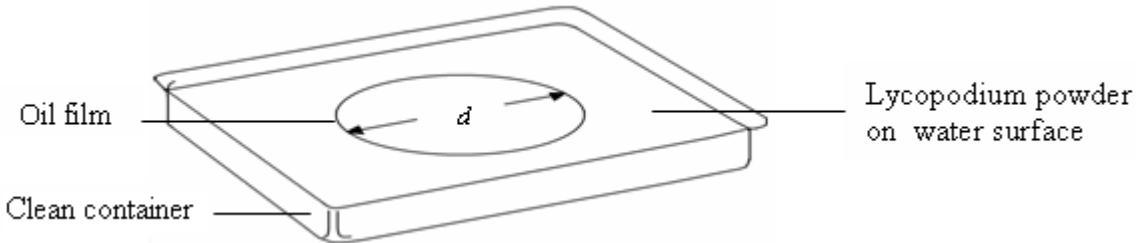
Experiment 4.6 To estimate the size of a molecule

Apparatus/Required

Cooking oil (solute), solvent, clean glass trough, water, burette and lycopodium powder.

Procedure

- (i) Dissolve a small volume, $x \text{ cm}^3$, of vegetable oil (*solute*) in a larger volume, $v \text{ cm}^3$, of petroleum ether (*solvent*) to form a total volume, $V \text{ cm}^3$, of oil-petroleum ether solution.
- (ii) Fill a clean (grease free) trough with water.
- (iii) Sprinkle lycopodium powder uniformly to cover the surface of the water in the trough.
- (iv) Drop a small volume, $y \text{ cm}^3$, of the oil-petroleum ether solution from a burette on to the water surface covered with the lycopodium powder. The oil repels the powder leaving a clear oil film.
- (v) Measure and record the diameter, d , of the circular oil film.



Calculations

(a) To find the volume of the oil film

$$\text{Volume of oil (solute) dissolved} = x \text{ cm}^3$$

$$\text{Volume of petroleum ether used} = v \text{ cm}^3$$

$$\text{Vol. of solution dropped on water} = y \text{ cm}^3$$

$$\text{Total volume of solution, } V, = (x + y) \text{ cm}^3$$

If the total volume, $(x + y)$, cm^3 of oil-petroleum ether solution contains $x \text{ cm}^3$ of oil, then the volume, V , of oil contained in $y \text{ cm}^3$ $= \left(\frac{x}{(x+y)} \right) x \text{ cm}^3$

Note that from the above expression, we can write the form for calculating the volume of oil film as:

$$\text{Volume of the oil film, } V = \left(\frac{\text{Vol. of oil dissolved}}{\text{Total vol. of solution}} \right) \times \text{Vol. of solution dropped}$$

(b) To find the thickness, t , of the oil film (i.e. size of a molecule)

The thickness, t , is found by using any of the following expressions for finding volume of a cylinder.

$$(i) V = At \quad \text{from Volume} = \text{Base area (A)} \times \text{thickness (t)}$$

$$(ii) V = \pi r^2 t \quad \text{from } A = \pi r^2$$

$$(iii) V = \frac{1}{4}\pi d^2 t \quad \text{from } 2r = d, r = \frac{d}{2}, \therefore r^2 = \left(\frac{d}{2}\right)^2 = \frac{d^2}{4},$$

$$\therefore V = \frac{1}{4}\pi d^2 t$$

Substituting for V in the above formulae, we have the following expressions.

$$V \text{ in (i)} \quad At = \left(\frac{x}{(x+y)}\right) x y \quad \therefore t = \frac{1}{A} \left(\frac{x}{(x+y)}\right) x y \text{ cm}$$

$$V \text{ in (ii)} \quad \pi r^2 t = \left(\frac{x}{(x+y)}\right) x y \quad \therefore t = \frac{1}{\pi r^2} \left(\frac{x}{(x+y)}\right) x y \text{ cm}$$

$$V \text{ in (iii)} \quad \frac{1}{4}\pi d^2 t = \left(\frac{x}{(x+y)}\right) x y \quad \therefore t = \frac{4}{\pi d^2} \left(\frac{x}{(x+y)}\right) x y \text{ cm}$$

Assumptions made in the estimation of the size of a molecule

- (i) The oil film is assumed to be one molecule thick.
- (ii) Each molecule is assumed to be a perfect sphere.
- (iii) The spaces between the molecules in the oil film are assumed to be negligible.
- (iv) The oil film is assumed to form a complete circle.

Example 1

1 cm³ of oleic acid was dissolved in 999 cm³ of alcohol to form 1000 cm³ of solution. A 1 cm³ drop of the solution was put on a water surface sprinkled with lycopodium powder. The alcohol dissolved in the water leaving the acid to spread forming a patch of diameter of 28 cm³.

- (a) Calculate the volume of oleic acid in the 1 cm³ drop of the solution.
- (b) Estimate the size of oleic acid molecule.
- (c) Why was lycopodium powder used?

Solution

Volume of oleic acid (solute) dissolved	=	1 cm ³
Volume of alcohol (solvent)	=	999 cm ³
Volume of solution dropped on water	=	1 cm ³
Total volume of solution, of solution	=	(1 + 999) cm ³
	=	1000 cm ³

If the total volume, 1000 cm³ of oleic-alcohol solution contains 1 cm³ of oleic acid, then the volume, 1 cm³ of oleic acid, of oil contained in 1 cm³

$$= \left(\frac{1}{1000}\right) \times 1 \text{ cm}^3 = \frac{1}{1000} = 0.001 \text{ cm}^3$$

The volume of the oleic acid in 1 cm³ of the solution = 0.001 cm³.

(b) **Data:** $d = 28 \text{ cm}$, volume, V , of oleic acid $= 0.001 \text{ cm}^3$, $\pi = \frac{22}{7}$, $t = ?$

Using the formula $V = \frac{1}{4}\pi d^2 t$

$$0.001 = \frac{1}{4} \times \frac{22}{7} \times 28^2 \times t$$

$$t = \frac{0.001 \times 4 \times 7}{22 \times 28 \times 28}$$

$$= \frac{0.028}{17,248}$$

$$\therefore t = 1.62 \times 10^{-6} \text{ cm or } 1.62 \times 10^{-8} \text{ m}$$

Alternatively you can first find the radius and then substitute the value in the formula

$$V = \pi r^2 t \quad \text{From } d = 28 \text{ cm, } r = \frac{1}{2}d = \frac{1}{2} \times 28 = 14 \text{ cm}$$

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

$$0.001 = \frac{22}{7} \times 14 \times 14 \times t = \frac{0.001 \times 7}{22 \times 14 \times 14} = 1.62 \times 10^{-6} \text{ cm or } 1.62 \times 10^{-8} \text{ m}$$

(c) To give clear circular patch of the oleic film.

Self-Check Question 4.1

1. An oil drop of volume 10^{-3} cm^3 forms a patch of an area of 0.785 cm^2 on water surface during an experiment to estimate size of a molecule. If the film is 1 molecule thick, what is the size of the molecule?
 A. $4.06 \times 10^{-4} \text{ cm}$ B. $7.85 \times 10^{-4} \text{ cm}$ C. $9.53 \times 10^{-4} \text{ cm}$ D. $1.27 \times 10^{-3} \text{ cm}$

2. The diagram in figure 4 shows an arrangement for determining the size of an oil molecule.

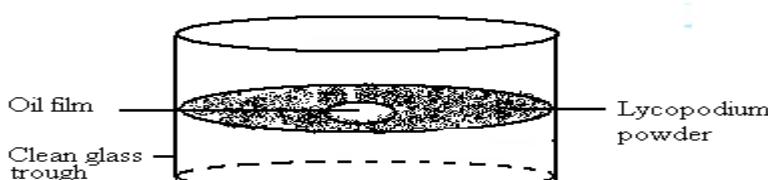


Fig. 4

- (a) State two assumptions made in the experiment
- (b) If $1.8 \times 10^{-4} \text{ cm}^3$ of oil spreads to form a patch of area 150 cm^2 . Calculate the thickness

3. A solution is made by dissolving 1 cm^3 of cooking oil in 199 cm^3 of the methanol. When 0.004 cm^3 of the solution is dropped on the surface of water, an oil film of diameter 12 cm is obtained.
- (i) Calculate the volume of the cooking oil in the film.
 - (ii) Estimate the thickness of a molecule of the cooking oil
 - (iii) State any assumption made in (b) (i).
4. In an experiment to estimate the size of a molecule of olive oil, 0.12 mm^3 of the solution was dropped on a clean water surface in a trough. The oil spreads to form a circular patch of an area of $1.0 \times 10^4 \text{ mm}^2$. Estimate the size of a molecule of olive oil.
5. Suppose an oil drop on water surface sprinkled with lycopodium powder has a volume of 0.10 mm^3 and forms a film of an approximate radius 10 cm, calculate the thickness of the oil film.

CHAPTER FIVE

FORCE

LEARNING OBJECTIVES

By the end of this chapter, you should be able to:

1. (a) Define: - Force.
(b) State and define: the SI unit of force.
 2. List the types of forces.
 3. State the effects of force.
 4. (a) Define acceleration due to gravity
(b) Explain why acceleration due to gravity varies from place to place
(c) Describe an experiment to determine acceleration due to gravity, g.
 5. (a) Define: - Mass and Weight.
(b) State: - The difference between mass and weight.
(c) Use: - $W = mg$, to solve numerical problems.
 6. Define: - Scalar and vector quantities and give examples for each.
 7. Solve numerical problems involving combination vectors (forces).
-

5.1 Force

Force is either a push or pulls that acts on an object. Or

Force is that which changes a body's state of rest or uniform motion in a straight line.

A force cannot be seen and described like an object, but the effects of force on an object can be seen. Just like we can not see wind but we can feel and see the effects in a flying flag or kite or in a tree bending.

(a) SI Unit of force

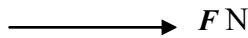
The SI unit of force is called *Newton* (N) and is defined as follows:

A Newton is the force required to give a unit mass (mass of one kilogram) an acceleration of one metre per Second Squared.

(b) Representation of force

Force is a vector quantity i.e. it has both magnitude and direction.

It is represented by a straight line with an arrow at the tip showing the direction in which it acts.



(c) Effects produced by a Force

A force acts in a particular direction and may have any of the following effects on an object.

- It can:
- (i) Make a stationary object to move.
 - (ii) Increase the speed of a moving object.
 - (iii) Decrease or slow down the speed of a moving object or bring a moving object to a rest.
 - (iv) Change the direction of a moving object.
 - (v) Deform (change the shape of) an object.

(d) Types of Forces

There are various types of forces; some of the common ones include the following:

- | | |
|-------------------------|---|
| (i) Gravitational force | - is the force which pulls a body towards the centre of the earth. |
| (ii) Frictional force | - is the force which opposes relative motion between two surfaces in contact. |
| (iii) Centripetal force | - is a force which constrains a body to move in a circular path or orbit. Its direction is towards the centre of the circle. |
| (iv) Magnetic force | - is a force in magnets that causes motion as a result of attraction or repulsion. |
| (v) Electrostatic force | - is a force that causes attraction or repulsion in an electric field due to static charges. |
| (vi) Elastic force | - is a force in a stretched spring or rubber cord. |
| (vii) Upthrust | - is an upward force that acts on a body immersed in a fluid (a liquid or a gas). |
| (viii) Cohesive force | - is a force of attraction between molecules of the same kind. E.g force of attraction between water molecules. |
| (ix) Adhesive force | - is a force of attraction between molecules of different kinds. E.g force of attraction between water molecules and glass molecules. |
| (x) Surface tension | - is the force on a liquid surface which makes the liquid surface to behave like a stretched elastic membrane or skin. |

5.2 (a) Gravitational force

An object released from a height falls down to the ground. This indicates that there is a force acting on the object directed to the centre of the earth. This downward pull is called *gravitational force*.

Gravitational force is the force which pulls a body towards the centre of the earth.

It makes unsupported objects to fall until they reach the ground. The force of gravity pulls all objects at a particular place on the surface of the earth with the same acceleration of free fall called *acceleration due to gravity*.

(b) Acceleration due to gravity, g

Acceleration due to gravity, g , is the acceleration with which the force of gravity pulls all objects on or near the surface of the earth towards its centre.

The average value of g on the surface of the earth is 9.8 ms^{-2} , but it varies slightly from place to place.

(c) The variation of g

The acceleration due to gravity is not constant everywhere. It varies from place to place.

For example g is 9.78 ms^{-2} at the equator, whereas at the poles it is 9.83 ms^{-2} . There are two main causes of this variation.

(i) Variation of g with altitude

Acceleration due to gravity depends on the distance from the centre of the earth. The earth is not a perfect sphere. It is oval in shape; as such places are far away from the centre of the earth while others are near to the centre of the earth. For example the

equatorial radius of the earth is greater than the *polar radius*. That is the distance from the centre of the earth to the equator is greater than the distance from the centre of the earth to the pole. Therefore a body at the equator is slightly further away from the centre of the earth and consequently feels a smaller gravitational attraction. While a body at the poles is nearer to the centre of the earth and therefore experiences a greater gravitational force.

(ii) Rotation of the earth

Because the Earth rotates, its gravitational pull on the body at the equator provides the body with a centripetal acceleration. This effect does not apply at the pole.

In other words, we say that: The value of the Acceleration due to gravity, g , depends on the distance from the centre of the earth to that place. The smaller the distance, the higher the value of g , and vice versa. Since the earth is not a perfect sphere, the distances from the centre of the earth to different points on the surface of the earth is different. Therefore the value of, g , varies from place to place. Thus, in places near to the centre of the earth like the north and south poles, the value of, g , is greater than at equator. It is also greater at sea level than at higher altitudes such as on top of mountains.

The acceleration due to gravity on the moon is about one-sixth of that of the earth.

$$\left(\text{i.e. } \frac{1}{6} \times 9.8 = 1.6 \text{ ms}^{-2}\right).$$

5.3 Mass and Weight of a Body

(a) Mass

Mass is the quantity of matter in a body.

It is constant everywhere. I.e. does not vary from place to place.

SI unit of mass

The SI unit of mass is the kilogram (kg).

(b) Weight (W)

Weight is the gravitational pull on a body by the earth. Or Weight is a measure of the pull of gravity on a body.

The direction of the weight of a body is always towards the centre of the earth.

SI unit of weight

Weight is a kind of force; therefore its SI unit is *Newton*.

Weight is calculated from the formula:

$$\text{Weight} = \text{Mass} \times \text{Acceleration due to gravity}$$

$$\text{In symbols, } W = mg$$

The weight of a body varies from place to place.

Explanation

From the formula $W = mg$, the weight of a body is directly proportional to the acceleration due to gravity. And since the g varies from place to place due to the variation in the distance from the centre of the earth, so does the weight of a body.

Note: Basing on the above explanation, it means that in places near to the centre of the earth like the *North Pole* and *South Pole*, the weight of a body is greater than when at the equator. It is also greater at sea level than at places higher than the sea level.

(c) The Difference between Weight and Mass

Mass	Weight
(i) Quantity of matter in a body	- The pull of earth on a body
(ii) Constant everywhere	- Varies from place to place
(iii) SI unit is kilogram (kg)	- SI unit Newton (N)
(iv) A scalar quantity	- A vector quantity
(v) Measured using beam balance or spring balance or electric balance calibrated in grams or kilograms	- Measured using spring balance or electric balance calibrated in Newtons.

Worked Examples

- Calculate the weight of the following:
 - A box of mass 50 kg
 - A boy of mass 2.5 kg
 - A bull of mass 200 kg
 - A stone of mass 12 g
 - Find the weight of an astronaut whose mass is 75 kg on:
 - The earth
 - The moon (Take $g = 10 \text{ ms}^{-2}$ and g on the moon is $\frac{1}{6}$ th of g the earth)
 - Find the masses of the weights:
 - 400 N
 - 10 N

Solution

$$\begin{array}{ll} \text{1. (a)} & m = 50 \text{ kg}, \quad g = 10 \text{ ms}^{-2}, \quad W = ? \quad \text{(b)} \\ & W = mg \\ & = 50 \times 10 \\ & \therefore W = \mathbf{500 \text{ N}} \end{array} \quad \begin{array}{ll} & m = 2.5 \text{ kg}, \quad g = 10 \text{ ms}^{-2}, \quad W = ? \\ & W = mg \\ & = 2.5 \times 10 \\ & \therefore W = \mathbf{25 \text{ N}} \end{array}$$

$$\begin{array}{ll} \text{(c)} m = 200 \text{ kg}, g = 10 \text{ ms}^{-2}, W = ? & \text{(d)} m = 12 \text{ g}, = \frac{12}{1000} \text{ kg}, g = 10 \text{ ms}^{-2}, W = ? \\ W = mg & W = mg \\ = 200 \times 10 & = 0.012 \times 10 \\ \therefore W = \mathbf{2000 \text{ N}} & \therefore W = \mathbf{0.12 \text{ N}} \end{array}$$

$$\begin{aligned}
 \text{2. (a)} \quad m &= 75 \text{ kg}, \quad g = 10 \text{ ms}^{-2}, \quad W = ? \quad \text{(b)} \quad m = 200 \text{ kg}, \quad g = 10 \text{ ms}^{-2}, \quad W = ? \\
 W &= mg & W &= mg \\
 &= 75 \times 10 & &= 75 \times \frac{1}{6} \times 10 \\
 \therefore W &= 750 \text{ N} & &= 120 \text{ N} \\
 && \therefore W &= 125 \text{ N}
 \end{aligned}$$

$$\begin{array}{ll}
 \text{3. (a) } W = 400 \text{ N, } g = 10 \text{ ms}^{-2}, m = ? & \text{(b) } W = 10 \text{ N, } g = 10 \text{ ms}^{-2}, m = ? \\
 W = mg & W = mg \\
 400 = m \times 10 & 10 = m \times 10 \\
 m = \frac{400}{10} & m = \frac{10}{10} \\
 \therefore m = 40 \text{ kg} & \therefore m = 1 \text{ kg}
 \end{array}$$

Self-Check 5.0

1. What is the mass of a man on the earth if his mass on the moon 60kg.
A. 6kg B. 10kg C. 60kg D. 360kg
2. Assume that you are taking measurements with a spring balance (dynamometer), where can you get the greatest reading for the same object?
A. At the centre of the earth B. On the moon
C. At the equator D. At the poles.
3. What is the name of any push or pull exerted?
A. Mass B. Force C. Friction D. Tension
4. What do we call the pull of gravity on an object?
A. Mass B. Weight C. Moment D. Tension
5. Which one of the following is **not** a measuring tool?
A. Equal-arm balance B. Dynamometer C. Lever D. Ruler
6. Which one of the following is the unit of weight?
A. Newton B. Kilogram C. Meter D. Ton
7. A mass of 60kg weighs 600N on the earth and 100N on the moon. What is the mass and weight of an object on the earth if it weighs 50N on the moon?
A. 60kg mass, 600N weight B. 10kg mass, 60N weight
C. 30kg mass, 300N weight D. 5 kg, mass, 100N weight
8. Which one of the following is a force?
A. Energy B. Mass C. Weight D. Speed
9. Which one of the following statements is **not** correct?
A. Force can change the speed of an object.
B. Force can change the shape of an object.
C. Force can change the direction of motion.
D. Force can change the mass of an object.
10. Which one of the following are SI units of mass and weight?
A. g and n respectively B. N and kg respectively
C. kg and g respectively D. kg and N respectively

5.4 FRICTION

Friction is a force that opposes relative motion between two surfaces in contact with one another.

It results from two surfaces rubbing against each other or moving relative to one another. It can hinder the motion of an object or prevent an object from moving at all.

The strength of frictional force depends on:

- The nature of the surfaces that are in contact,
- The magnitude of the force pushing them together and
- The weight of the object or objects.

In cases involving fluid friction, the force depends upon

- The shape of the object moving through the fluid,
- Viscosity and
- Speed of an object as it moves through the fluid.

(a) The Causes of Friction

Friction is thought to be caused by:

- (i) Small irregularities on the rough surfaces becoming interlocked.
E.g. rubbing two files together.
- (ii) The attractive force between the surface molecules. This factor seems to play major role than interlocking of the small irregularities.

(b) Types of friction

There are two types of friction, namely;

- (i) Static friction and
- (ii) Dynamic (Sliding or kinetic) friction.

1. Static friction

Static friction is the frictional force between two surfaces that are not sliding over each other.

(a) Facts about Static Friction

- ❖ Static friction occurs between stationary objects.
- ❖ It prevents an object from moving against a surface.
- ❖ It is the force that keeps an object e.g. a book from sliding off a desk, even when the desk is slightly tilted, and that allows you to pick up an object without the object slipping through your fingers.
- ❖ Static friction depends on:
 - The coefficient of static friction (μ_s) between the surfaces of the objects in contact,
 - The nature of the surface and
 - The normal reaction (R) of the object.

NB: *In order to move something, you must first overcome the force of static friction between the object and the surface on which it is resting.*

Experiment 5.1 To Measure Static friction

Static friction can be measured using the apparatus shown in figure 5.1 below

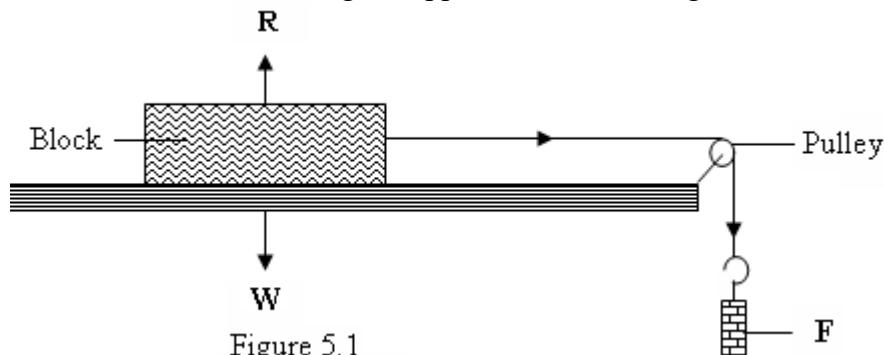


Figure 5.1

- Place a wooden block on a table and connect it by a light string passing over a smooth pulley on to a mass hanger.
- Gradually increase force, F, by first adding 50 g and when the block is about to slide, continue adding small standard (known) 20 g or 10 g on to the mass hanger until the block just begins to slide or move.
- Read and record force, F, (the total mass on the mass hanger) at the point when the block just begins to slide.

Observations

At first the block remained at rest as the force is increased.

After some time, i.e. at certain value of the force on the pan, the block just begun to slip or slide in the direction shown on the diagram.

Explanation

When force, F, on the mass hanger was increased the frictional force that opposes the motion of the block also increases.

As more and more weights were added to the mass hanger, the frictional force reached its maximum value for the two surfaces in contact and began to slide.

Result

The maximum value of the frictional force is equal to the total weight, F, on the mass hanger. This maximum frictional force is called *limiting friction*.

(b) Limiting friction

Limiting friction is the force of friction between two surfaces when they are at the verge of sliding over each other.

The force of friction between an object and a surface can be calculated from the formula:

$$F = \mu R$$

Where: F = the force of friction,
 μ = the coefficient of friction between the object and the surface,
and R = the normal reaction.

(c) Factors which determine the limiting friction

Limiting friction depends on:

- (i) The coefficient of static friction (μ_s) between the object,
- (ii) The nature of the surface and
- (iii) The normal reaction (R) of the object.

These factors are demonstrated by attaching a spring balance calibrated in newtons to two blocks of wood of different weights as shown in the examples A and to the same block B below.

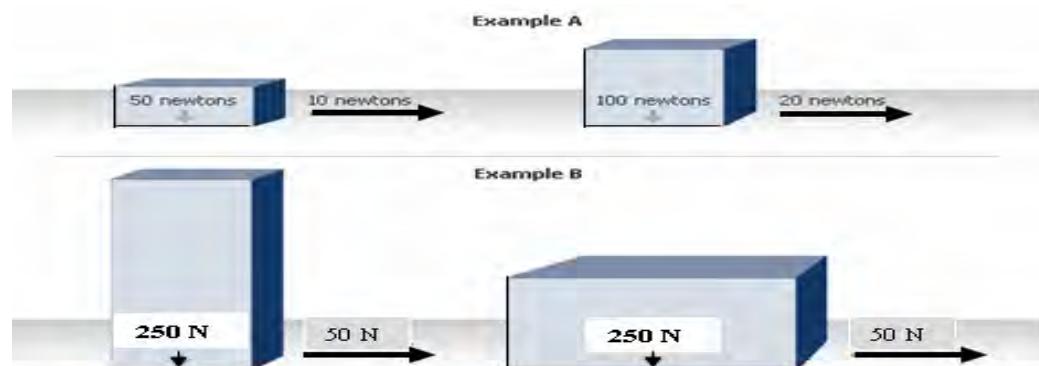


Figure 5.2

In example A, illustrates that limiting friction depends on weight. It shows that if it takes 10 N to slide a block of weight 50N on the floor, it will take 20 N of force to slide a block of weight twice that of 50 N (i.e.100 N).

While example B illustrates that friction is independent of the area in contact. That is it does not depend on the size of surface area in contact between the objects. It shows that the limiting friction required to move 250 N for the different surface areas.

(d) Coefficient of static friction

Coefficient of static friction is the ratio of limiting friction to the normal reaction between surfaces. It is denoted by a symbol, μ , pronounced mew.

Experiment 5.2 To determine the value of coefficient of friction, μ

Apparatus: A wooden block, a string, mass hanger, heavy standard weight (masses), slotted masses of 50 g and 10 g, a smooth pulley and a weighing balance.

Procedure

Arrange the apparatus as shown in figure 5.3 below.

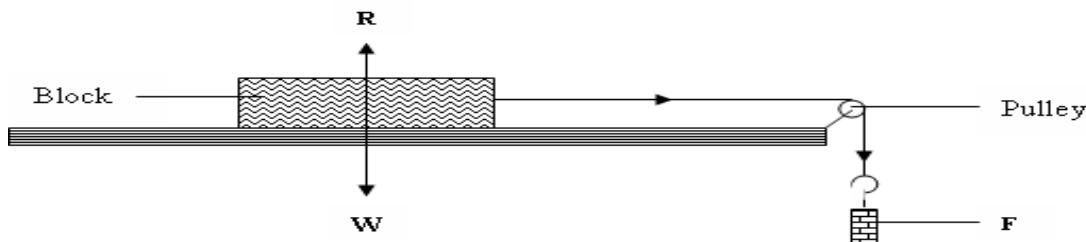


Figure 5.3

- Weigh the block of wood and record its mass, M_b , in kg.
- Gradually increase force, F , by first adding 50 g and when the block is about to slide, continue adding small standard (known) 20 g or 10 g on to the mass hanger until the block just begins to slide or move.
- Record the total mass, m , hence the force F , on the mass hanger.
- Load the block of wood by adding a heavy standard mass $M = 1$ kg.
- Repeat the procedure (b) to (c).
- Now repeat the procedures (b) to (d) for values of $M = 2, 3, 4, 5$ and 6 kg.
- Enter your results in the table 5.1 below.

Table of results

$(M_b + M)/\text{kg}$	$W = (M_b + M)g = R/\text{N}$	m/kg	$F = mg/\text{N}$
$M_b + 0$			
$M_b + 1$			
$M_b + 2$			
$M_b + 3$			
$M_b + 4$			
$M_b + 5$			
$M_b + 6$			

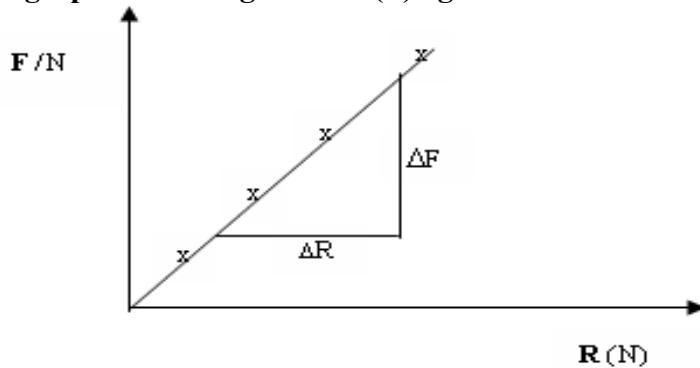
Table 5.1

- Plot a graph of F against R (normal reaction = W).
- Find the slope of the graph.

Note that the value of F is equal to the total weight on the mass hanger which is equal to the *limiting friction* for each total weight.

If the experiment is accurately performed, the graph in the figure below is obtained.

The graph of limiting friction (F) against normal reaction



The slope of the graph is called the *coefficient of friction, μ , and is given by the formula.*

$$\text{Coefficient of static friction, } \mu_s = \frac{\text{Change in Limiting friction} (F)}{\text{Change in Normal Reaction} (R)}$$

$$\mu_s = \frac{\Delta F}{\Delta R}$$

$$\therefore \text{Limiting friction, } F = \mu R$$

Note that:

- ❖ Since normal reaction R , is always greater than the limiting friction F , i.e. $R > F$, the value of μ is always less than 1.

Worked Examples

Example 1

A block of wood of mass 5 kg is placed on a table top. Find the limiting friction if the coefficient of friction is 0.5. (Take $g = 10 \text{ m/s}^2$).

Solution

Data: $\mu = 0.5$, $m = 5 \text{ kg}$, $g = 10 \text{ m/s}^2$, Limiting friction, $F = ?$, $R = ?$

Hint: Limiting friction is calculated from the formula $F = \mu R$. But R is not given in the data. This should not make the whole thing difficult to you.

Always remember that $R = W$. So using the formula $W = mg$, find the value of W and then finally use the formula $F = \mu R$ to get F as shown below.

First calculate W :

$$\begin{aligned} W &= mg \\ &= 5 \times 10 \\ &= 50 \text{ N} \end{aligned}$$

From Weight = Reaction $\therefore R = 50 \text{ N}$

Now that you have known R , you can now use the formula;

$$\begin{aligned} \text{Limiting friction, } F &= \mu R \\ &= 0.5 \times 50 \\ \therefore F &= 25 \text{ N} \end{aligned}$$

Self-check

Try to check your understanding by answering the following questions.

1. A chalk box of mass 400 g is placed on a table. Find the limiting friction if $\mu = 0.2$, ($g = 10 \text{ ms}^{-2}$). **Answer:** 0.8 N
2. A block of wood of mass 2 kg is placed on a table. Find the limiting friction if $\mu = 0.4$, ($g = 10 \text{ ms}^{-2}$). **Answer:** 8 N

2. Kinetic or Sliding friction

The kinetic or sliding friction is the frictional force between any two surfaces that are moving relative to each other.

(a) Facts about kinetic friction

- ❖ It resists the motion of an object as it moves along a surface.
- ❖ Sliding friction occurs between objects as they slide against each other.

(b) Factors on which Sliding friction depends

Like the limiting friction, sliding friction depends on:

- The weight of the sliding object,
- The nature of the surfaces in contact and
- The coefficient of kinetic friction.

Experiment 5.3 To Measure sliding friction

Sliding or kinetic friction can be measured using the apparatus shown in figure 5.4 below

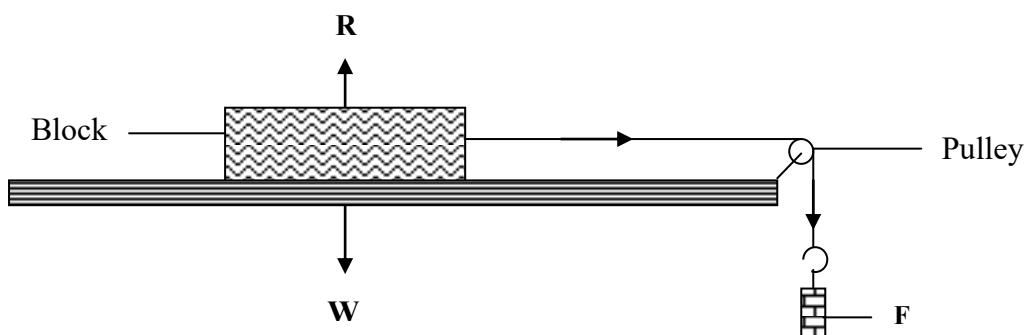


Figure 5.4

- Place a wooden block on a table and connect it by a light string passing over a smooth pulley on to a mass hanger.
- Gradually increase force, F , by first adding 50 g and 20 g or 10 g on to the mass hanger until the block is about to slide.
- Give the block a push.
- Read and record force, F , (the total mass on the mass hanger).

Result

The maximum value of the frictional force is equal to the total weight, F , on the mass hanger. This maximum frictional force is called *sliding or kinetic friction*, F_k .

Note that:

1. The limiting friction is always greater than the sliding friction.
2. The procedure for the measurement of kinetic friction and the coefficient of kinetic friction, μ_k , are the same as for static friction. The only difference is that a push is required for the determination of the kinetic friction at the point when the body is about to slide.

5.6 The angle of friction

When a block of wood is placed on an inclined plane at an angle of friction α , such that the block is just on the point of slipping as shown in the diagram below.

$$R = mg \cos \alpha$$

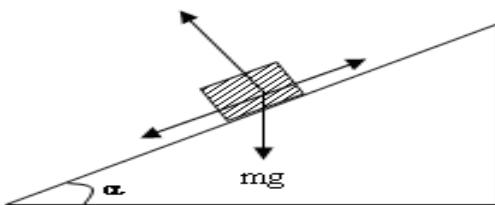


Figure 5.5

$$\text{From Coefficient of friction, } \mu = \frac{\text{Limiting friction}}{\text{Normal Reaction between surfaces}}$$

$$\mu = \frac{F}{R}$$

$$F = \mu R \quad \dots \quad (1)$$

$$\mu = \frac{mg \sin \alpha}{mg \cos \alpha} \quad \text{But } \frac{mg \sin \alpha}{mg \cos \alpha} = \tan \alpha$$

$$\therefore \mu = \tan \alpha \quad \dots \quad (2)$$

Note: That the tangent of the angle of friction is equal to the coefficient of friction.

Substituting equation (1) in equation (2) we have,

$$F = \tan \alpha R$$

Note: Do not worry if you do not understand the steps in the derivation of the above formula. You will understand it when you cover trigonometry in mathematics in S.2.

5.7 (a) Laws of friction

- (i) Friction always opposes motion
- (ii) Friction depends on the nature of the surface in contact.
- (iii) Friction - is much less on smooth surface and is much greater on rough surface.
- (iv) The limiting friction and sliding friction are both proportional to the normal reaction i.e. $F \propto R$

(b) Advantages of Friction

Friction is useful in our daily life. This is seen in the following:

1. **Motion**

Friction allows motion of objects, as seen in the following:

- (i) *Walking* Friction between the foot and the ground allow a person to walk.
In a slippery place, there is no friction. The result is that movement becomes difficult.
- (ii) *Clutch* Friction between clutch plates allows the engine to drive the wheels.
- (iii) *Tyres* Friction between the tyres and the road surface allows the torque of the wheels to push cars or bicycles along the road.
- (iv) *Brakes* Friction between the brake lining and the brake drum halts the vehicle.

2. **Ladder**

Friction between the foot of the ladder and the ground prevents it from slipping off.

3. **Lubrication**

Liquid friction helps to spread oil round an axle.

However, despite these advantages, friction has disadvantages as listed below.

(c) Disadvantages of Friction

- (i) Friction between the moving parts of machines reduces the efficiency of machines and often causes much of the work done by the effort to be wasted.
- (ii) It causes surfaces to wear off. E.g. tyres and soles of shoes.
- (iii) It also causes unnecessary noise and heat.

Where friction becomes a disaster, we can reduce it by applying some methods.

5.8 Ways of reducing friction

1. **Lubrication**

In lubrication, oil or grease is introduced between surfaces that sliding over one another. The oil film keeps rough surfaces apart, thus preventing them from coming into direct contact.

2. **Ball bearings**

Bearing is a mechanical device for decreasing friction in a machine in which a moving part bears—that is, slides or rolls while exerting force—on another part.

Steel ball bearings are used for example in an axle and shaft of the bicycle then the axle and shaft. When the ball bearings are used, the axle and shaft do not slide but roll over one another. *Rolling friction* is less than the sliding friction; therefore friction is lessened by means of ball bearing.

3. **Rollers** Friction can be reduced by placing rollers between the two surfaces in contact.

4. Smoothening of surfaces in contact

Friction can also be reduced by making rough surfaces smooth where necessary.

5. Streamlining Streamlining refers to shaping of an object such that the layer of air easily slides off. Notable examples are seen in:

- aeroplane, submarines, boats, fish, birds etc.

5.9 Fluid Friction

Fluid Friction is a retarding force which acts on a body moving through a fluid.

It is due to the internal friction existing between layers of fluids of a liquid in motion. It is caused by the attraction between the molecules of one layer and the molecules of another layer. The frictional resistance of a fluid (liquid or gas) opposing motion of a body moving through it is called viscosity.

Factors which determine the magnitude of fluid friction

1. Unlike friction between solids" viscosity is proportional to the surface area and the velocity of the object moving through the fluid.
2. *Nature of fluid.* Viscosity depends on the type of fluid for example glycerin, engine oil, and natural honey flow much less easily from a vessel than liquids such as petrol, paraffin and water.
3. *Temperature:* Viscosity of liquids decreases as a temperature of liquid increases while that of gases increases with temperature.

NB: *Liquids which have high viscosity e.g. glycerin, engine oil are called vicious liquids and are used to make lubricants.*

5.10 Scalar and Vector Quantities

(a) Scalar Quantity

A scalar quantity is a quantity which has only magnitude. They only give the amount of things. Examples scalar quantities are:

- Mass	e.g.	5 kg of sugar
- Time		2 hours
- Volume		4 litres
- Density		0.8g/cm ³
- Temperature		50 °C

(b) Vector Quantity

A vector quantity is a quantity which has both magnitude and direction.

Examples of vector quantities are: - Force or weight,

- Velocity,
- Acceleration,
- Momentum.

5.11 Representation of vectors

Vectors are represented by an arrow headed line drawn to scale is called a vector. A vector has the following properties:

- An application point (where it is applied).
- A magnitude (size i.e. how big or small it is).
- A direction.

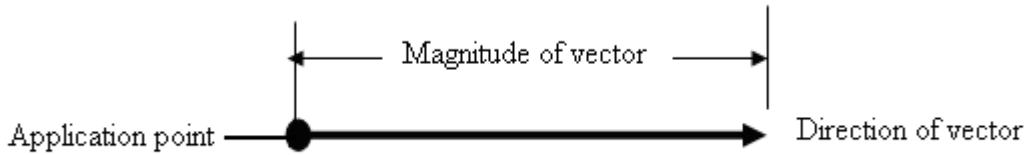


Figure 5.6

5.12 Addition of Forces

When two or more forces act on a body their combined effect called, *resultant force*. The resultant force on the body depends on their relative directions, (i.e. the angle, θ , between the forces).

Resultant force

Resultant force is a single force which has an effect of two or more forces acting at the same point.

The forces which form a resultant force are called *component forces*.

Resultant force is found by using the following equation:

$$\text{Resultant force} = \text{Sum of forces}$$

$$\text{i.e. } \vec{F}_{rr} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \dots$$

Points to note: Since force is a vector, the direction is important. Therefore,

- ❖ If force(s) to the right are taken to be positive, then the one(s) to the left is/are negative. Like wise,
- ❖ If force(s) acting to north or east is/are taken to be positive, then the one(s) acting to south and west respectively is/are taken to be negative.
- ❖ The number of Fs to the right of the above formula = to the number of forces acting on a body.

(a) Forces acting in a straight line

The resultant force due to forces acting in a straight line is got by addition or subtraction of the forces depending on their directions.

(i) Two forces acting on a straight in the same direction ($\theta = 0^\circ$)

Consider two forces F_1 and F_2 acting on body P as shown in figure below.

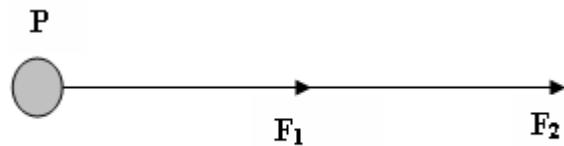


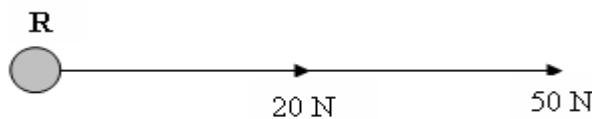
Figure 5.7

Since the forces are acting in the same direction, they are taken to be positive. The resultant force, R, is got by addition of the forces.

$$\text{i.e. } \vec{F}_r = \vec{F}_1 + \vec{F}_2$$

Example 1

Two forces 20 N and 50 N act on body R in the same direction as shown in the diagram below. Find the resultant force.



Data: $F_1 = 20 \text{ N}$, $F_2 = 50 \text{ N}$, $F_r = ?$

$$\begin{aligned} F_r &= \vec{F}_1 + \vec{F}_2 \\ &= 20 \text{ N} + 50 \text{ N} \\ \therefore F_r &= 70 \text{ N} \end{aligned}$$

(ii) Two forces acting on a straight in opposite directions ($\theta = 180^\circ$)

Consider two forces F_1 and F_2 acting on body M in opposite directions as shown in figure 4.8 below.

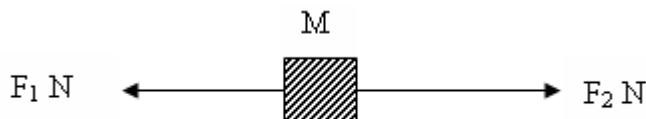


Fig. 5.8

Since the forces are acting in opposite directions, one is taken to be positive and the other negative.

Let F_1 be positive and F_2 be negative.

The resultant force, given by using the equation:

$$\begin{aligned} F_r &= F_1 + F_2 \\ &= F_1 - F_2 \end{aligned}$$

$$\therefore F_r = F_1 - F_2$$

Therefore, the resultant force, $F_r = (F_1 - F_2)$ in the direction of F_1 .

Example 2

Two forces 300 N and 50 N are acting on a body Q as shown in figure 4.9 below. Find the resultant force.

Solution



$$F_1 = 300 \text{ N}, F_2 = 50 \text{ N}$$

Since the forces are acting in opposite directions, one is taken to be positive and the other negative.

Let 300 N be positive and 50 N be negative.

The resultant force, given by using the equation:

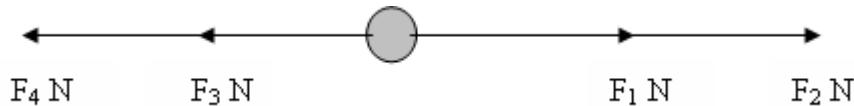
$$\begin{aligned} F_r &= F_1 + F_2 \\ &= 300 + -50 \\ &= 300 - 50 \\ \therefore F_r &= 250 \text{ N} \end{aligned}$$

Therefore the resultant force is 250 N in the direction of 300 N (to the right).

NB: Instead of taking one force to be positive and the other negative, you may simply subtract the smaller force from the larger one.

(iv) More than two forces acting on a straight in opposite directions ($\theta = 180^\circ$)

Consider four forces F_1 , F_2 , F_3 and F_4 acting on body S as shown in the diagram below. Find the resultant force.



Solution

For the case such as above where there are more than two forces acting on a body in opposite direction, follow the following steps.

Step I: Get the resultant forces in the directions shown in the diagram above.

$$\text{Resultant force towards right, } R_r = (F_1 + F_2) \text{ N}$$

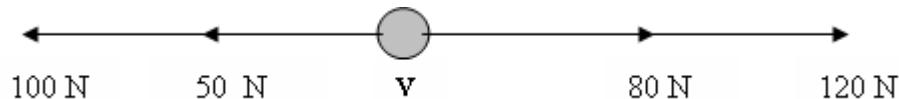
$$\text{Resultant force towards left, } R_l = (F_3 + F_4) \text{ N}$$

Step II: Get the final resultant force, R , of the two resultant forces above.

$$\begin{aligned} \text{Resultant force, } R &= R_r - R_l \\ &= [(F_1 + F_2) - (F_3 + F_4)] \text{ N} \end{aligned}$$

Example 3

Four forces are acting on body V as shown in the diagram below. Find the resultant force.



Solution

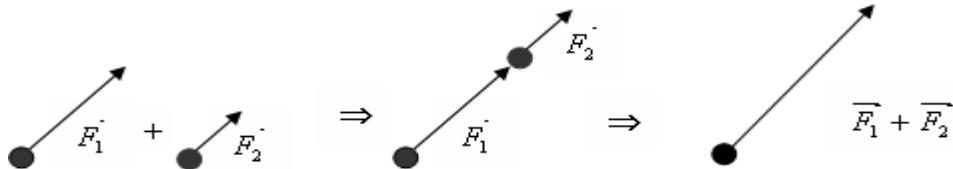
$$\begin{aligned} \text{Resultant force acting towards right } R_r &= (F_1 + F_2) \text{ N} \\ &= 80 \text{ N} + 120 \text{ N} \\ &= 200 \text{ N} \end{aligned}$$

$$\begin{aligned} \text{Resultant force acting towards left } R_l &= (F_3 + F_4) \text{ N} \\ &= 100 \text{ N} + 50 \text{ N} \\ &= 150 \text{ N} \end{aligned}$$

$$\begin{aligned} \text{Resultant force, } R, \text{ acting on } V &= R_r - R_l \\ &= 200 \text{ N} - 150 \text{ N} \\ &= 50 \text{ N acting towards right.} \end{aligned}$$

(b) Parallel forces

The resultant vector for two or more vectors can be represented by a *head-to-tail* addition of arrows. For example if two or more forces act in the same direction, the resultant force is obtained as shown below.



NB: The little arrow over F indicates that we are dealing with vector (a quantity for which direction is important).

c) Forces acting at right angles to each other ($\theta = 90^\circ$)

When two forces act on a body at an angle to each other, the resultant force can be obtained by applying any of the following laws.

- The triangle law of forces and
- The parallelogram law of forces.

(i) Triangle law of forces

The law states that “*if a body is acted upon by two forces that are at an angle to each other, the resultant of the forces is the third line drawn to complete the triangle*”.

For example, if two forces of equal or unequal magnitude, one directed due east and the other directed due north act on an object at rest but free to move in the direction of the resultant force, the magnitude of the resultant force is shown by the length of the arrow representing the resultant force.

Consider the diagram in figure 5.9 below in which two forces F_1 and F_2 act on a body. F_1 acts due north and F_2 act due east as shown below.

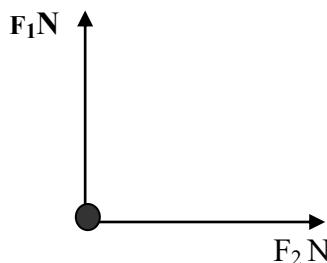
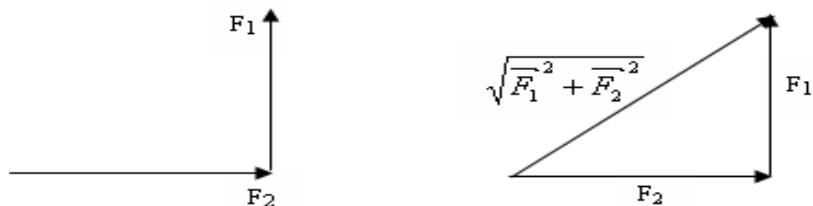


Figure 5.9

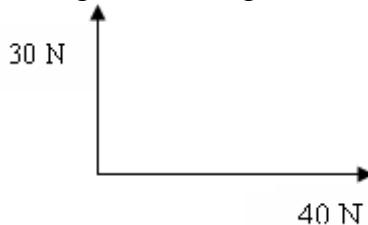
Using the method of *head-to-tail* addition of vectors at right angle, the right angle triangle is completed by using the tail of F_1 on the head of F_2 as shown in the diagrams below and the resultant force, F_r , is got by applying Pythagoras theorem as shown in the diagrams below.



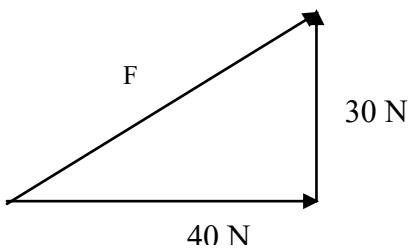
Worked Examples

1. Two forces 30 N and 40 N act on a body of mass 20 kg at right angle to each other. Calculate;
- The resultant force
 - The acceleration of the body.

Solution: (a) A sketch diagram showing the forces



Applying the Triangle law of forces and head-to-tail addition of vectors, we complete the diagram as below.



Using Pythagoras theorem

$$F^2 = 40^2 + 30^2$$

$$\sqrt{F^2} = \sqrt{40^2 + 30^2}$$

$$= \sqrt{1600 + 900}$$

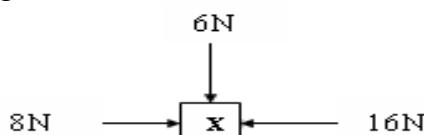
$$= \sqrt{2500}$$

$$\therefore F = 50 \text{ N}$$

- (b) $F = 50 \text{ N}$, $m = 20 \text{ kg}$, $a = ?$

$$F = ma \Rightarrow a = \frac{F}{m} = \frac{50}{20} = 2.5 \text{ ms}^2$$

2. The diagram in the figure shows 3 forces of 8N, 6N and 16N acting on a particle X. Find the resultant force magnitude of the resultant force is



Solution

Step I

First get the resultant force between 8N and 16N, since they are on a straight line.

$$\text{Resultant force} = 16 \text{ N} - 8 \text{ N}$$

= 8N acting to left (the direction of the larger force).

Step II

Join the two forces using a head to tail and complete it to form a right angle triangle. Then find the hypotenous by using Pythagoras Theorem as in example 1 above.

Using Pythagoras theorem

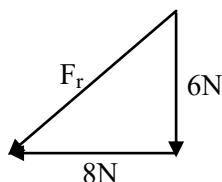
$$F_r^2 = 6^2 + 8^2$$

$$F_r = \sqrt{6^2 + 8^2}$$

$$= \sqrt{36 + 64}$$

$$= \sqrt{100}$$

$$\therefore F_r = 10 \text{ N}$$



(ii) The parallelogram law of forces.

If two forces, acting at one point on the same object, are arranged in magnitude and direction by the sides of a parallelogram drawn from the point, their resultant is represented in both magnitude and direction by the diagonal of the parallelogram drawn from the point.

In this method, the vectors to be added are represented by arrows joined *tail-to-tail* instead of *head-to tail* as before. The resultant is obtained by completing the diagonal of the parallelogram as shown in figure 5.10 below.

Composition and Resolution of Vectors

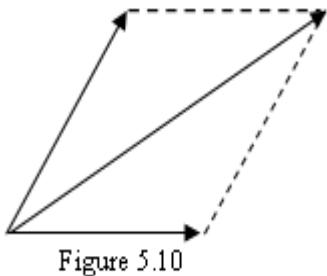


Figure 5.10

Composition of vectors is the substitution of two or more vectors with a single vector which has the same effect as all the separate vectors combined.

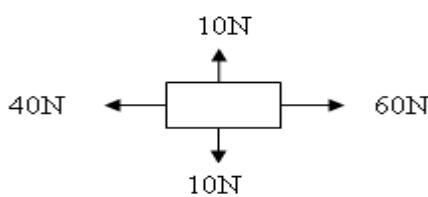
Resolution of vectors is the separation of a single vector into two vectors acting in definite directions upon the same point. Each of the two vectors is called a *component* of the single vector. One is the horizontal component and the other is the vertical component.

Self-Check Questions 5.1

1. Force is given by the product of

A. displacement and velocity	B. displacement and mass
C. acceleration and mass	D. velocity and mass
2. Forces of 60N, 10N, 40N and 10N act on a body as shown in figure 5.11. In which direction does the body move?

A. upwards	B. downwards
C. to the left	D. to the right

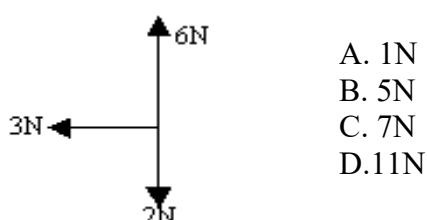


3. right angles. Find their resultant

- | | | | |
|--------|---------|---------|----------|
| A. 7 N | B. 13 N | C. 17 N | D. 169 N |
|--------|---------|---------|----------|
4. A Newton is defined as the

A. unit of force.	B. force which produces an acceleration of 1ms^{-2}
C. force which gives a mass of 1 kg an acceleration of 1ms^{-2}	D. force which gives any mass an acceleration of 1 ms^{-2}
 5. Two forces of 3N and 4N act at point at right angles to each other. The magnitude of their resultant force is

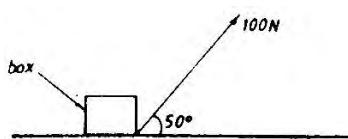
A. 25N	B. 7N	C. 5N	D. 1N
--------	-------	-------	-------
 6. In the diagram in the figure, the magnitude of the resultant force acting on a body P is



- | | | | |
|-------|-------|-------|--------|
| A. 1N | B. 5N | C. 7N | D. 11N |
|-------|-------|-------|--------|

7. A force of 1N acts on a mass of 0.05kg initially at rest. Its acceleration is
 A. 0.05 ms^{-2} . B. 2 ms^{-2} . C. 0.5 ms^{-2} . D. 20 ms^{-2} .
8. Find the force required to give a mass of 500g an acceleration of $2 \times 10^{-2} \text{ ms}^{-2}$.
 A. $1 \times 10^{-2} \text{ N}$ B. $1 \times 10^{-1} \text{ N}$ C. $1 \times 10^2 \text{ N}$ D. $1 \times 10^4 \text{ N}$.
9. In which of the following situations is minimum friction force required.
 A. Sliding down a slope B. Walking along a road.
 C. Leaning a ladder against a wall D. Designing brake blocks for bicycle.
10. Which one of the following are true statements about friction?
 (i) It does not oppose friction.
 (ii) It causes wearing of surface.
 (iii) It decreases as weight of a body decreases.
 (iv) It can be reduced by applying oil between surfaces.
 A. (i) only. B. (i) and (iii) only. C. (ii), (iii) and (iv). D. All
11. Which of the following physical properties changes when a body is moved from the earth to Pluto (outermost planet of the solar system)?
 A. mass B. volume C. weight D. density
12. Which of the following group consists of vectors only
 A. momentum, acceleration, time, energy
 B. speed, velocity, displacement, energy
 C. displacement, velocity, acceleration, force
 D. velocity, work, power, momentum
13. A force of 10N acts on a body and produces an acceleration of 2ms^{-2} . The mass of the body is
 A. 0.2 kg B. 5.0 kg C. 20.0kg D. 50.0kg
14. A stone of mass 2.5g is thrown with an average force of 5.0N. Find the average acceleration in m/s^2 .
 A. 5.0×10^{-4} B. 2.0×10^{-3} C. 25×10^2 D. 2.0×10^3
15. Two forces act on chest, one of them is 50N and due northeast, and the other one is 75N and due south west. What is the resultant force?
 A. 125 N due Northwest B. 125N due southwest
 C. 25N due North West D. 25 N due south west
16. Which of the following sets contains only vector quantities?
 A. Weight, displacement, acceleration, magnetic field.
 B. Energy, electric field, momentum, distance.
 C. Mass, velocity, force, speed.
 D. Specific heat capacity, power, time, volume.
17. A block of mass 10 kg accelerates uniformly at a rate of 3 ms^{-2} along a horizontal table when a force of 40N acts on it. Find the frictional force between the block and the table
 A. 10N B. 13.3N C. 30N D. 70N
18. Which one of the following quantities is the odd one out?
 A. force. B. velocity. C. momentum. D. kinetic energy.
19. Find the force that acts on a body of mass 0.05kg accelerating at 20 m/s^2
 A.1.0N B.10N C.100N D.400N

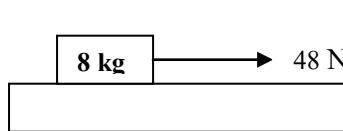
20. A box is pulled horizontally with a force of 100N inclined at an angle 50° to the horizontal as shown in the figure 5.12. The effective force, in Newton, is



- A. $100/\sin$
B. $100\sin 50^\circ$
C. $100/\cos 50^\circ$
D. $100\cos 50^\circ$

Figure 5.12

21. A block of mass 8kg slides on a rough horizontal surface under the action of a force of 48N as shown in the figure below. If the block moves with an acceleration of 5 ms^{-2} , calculate the frictional force on the block



- A. 6N
B. 8N
C. 40N
D. 48N

Figure 5.13

22. What is the force that slows down or stops sliding?

- A. Weight B. Gravity C. Friction D. Tension

23. A force of 20N acts on an object and there is 5N frictional force between the object and the surface. What is the net force on the object and its direction?

- A. 15 N in the direction of 20 N B. 15 N in the direction of the frictional force.
C. 25 N in the direction of 20 N D. 25 N in the direction of frictional force.

24. Which one of the following is a vector quantity?

- A. Force B. Time C. Temperature. D. Mass

25. Three forces 25N, 30N, 40N act on object on the same line either in the same direction or in opposite directions. Which one of the following can not be the resultant of these forces?

- A. 5N B. 15N C. 35N D. 95

SECTION B

(Where necessary take $g = 10 \text{ ms}^{-2}$)

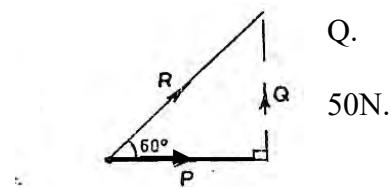
26. (a) Distinguish between weight and mass of a body.
 (b) The force of gravity on the moon is one-sixth of that on the earth. Determine the weight of a 12 kg mass on:
 (i) The earth, (ii) The moon?
 (c) Explain why the weight of a body on earth may vary from place to place.
27. (a) (i) What is meant by dynamic friction?
 (ii) Describe, with the aid of a diagram, an experiment to determine the limiting friction between two surfaces in contact.
 (iii) State the any **two** factors, which affect friction.
 (b) Give **two** applications of friction.

- 28.** (a) What is a vector quantity?
 (b) Two forces of 30N and 40N act perpendicularly on an object of mass 10 kg as shown in the figure. Calculate:



Figure 5.14

- (i) The magnitude of the resultant force on the object.
 (ii) The acceleration of the object.



- (c) The figure shows the resultant R of two forces P and Q . R makes an angle of 60^0 with a horizontal and P is 50N. Find the magnitude of:
 (i) Q
 (ii) R

- (d) Two forces of 6N and 10N act at the same time on a body P of mass 500g as shown in the figure 5.15. Find the:



- (i) Resultant force on P .
 (ii) Acceleration of P .

Figure

- 29.** A body of mass 5 kg is acted upon by two forces of 3 N and 4 N at right angles to one another. Find: (a) By calculation the resultant of the two forces.
 (b) The acceleration of the body.

CHAPTER SIX

TURNING EFFECTS OF FORCES

LEARNING OBJECTIVES

By the end of this chapter, you should be able to:

1. (a) Define: - Moment.
(b) State: - The SI unit of moment.
 2. (a) State : - The Principle of moments.
 - The conditions for a body to be in equilibrium.
(b) Define: - Centre of gravity.
(c) Describe: - Experiments to determine the centre of gravity of:
 - Regular body e.g lamina,
 - Irregular lamina.
 3. (a) State: - Applications of Principle of moments
(b) Describe: - Experiments:
 - To determine the mass of a uniform body.
 - To determine the mass/weight of an object.
 4. (a) Define: - The terms Stability and equilibrium.
(b) State: - The types of equilibrium.
 - Factors which determine the type of equilibrium.
(c) Describe: - How to make a body stable
-

6.1 TURNING EFFECTS OF FORCES

The turning effects of forces are seen in the following actions:

- Opening or closing - a door, window, lid of a container e.g. a Jeri can, turning on a tap etc.
- Doing or undoing a nut using a spanner.
- Two kids playing on a see-saw,
- etc.

(a) Factors determining the effect of a turning force

There are two factors which determine the effect of a turning force. They include:

- (i) The magnitude of the force.
- (ii) The perpendicular distance from the line of action of the force to the pivot.

The combined effect of the above factors is called *moment*.

(b) Moment

Moment of a force about a point is the product of the force and the perpendicular distance from the line of action of the force to the point.

(c) The S.I unit of moment

S.I unit of moment = Nm (Newton metre)

Consider the diagram in figure 6.1 below in which a uniform metre rule is balanced on a knife edge at its centre.

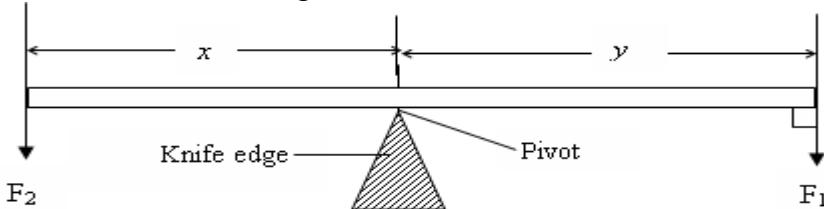


Figure 6.1

The moment about the pivot due to forces, F_1 and F_2 , is got by using the formula:

$$\text{Moment} = \text{Force} \times \text{Perpendicular distance from the pivot to the line of action of the force}$$

$$\begin{aligned}\text{Moment due to } F_1 &= F_1 \times y \\ &= F_1 y \text{ Nm} \quad (\text{Clockwise moment})\end{aligned}$$

$$\begin{aligned}\text{Moment due to } F_2 &= F_2 \times x \\ &= F_2 x \text{ Nm} \quad (\text{Anti-Clockwise moment})\end{aligned}$$

If the two moments are equal, i.e $F_1 y = F_2 x$, the body is said to be in equilibrium according to the *principle of moments*.

6.11 The Principle of Moment:

The Principle of Moment states that:

When a body is in equilibrium, the sum of clockwise moments about any point is equal to the sum of anti-clockwise moments about the same point.

(a) A Couple or Torque (Parallel forces)

A couple refers to two equal and opposite parallel forces whose lines of action do not meet.

A couple produces rotation and can only be stopped or balanced by an equal and opposite couple.

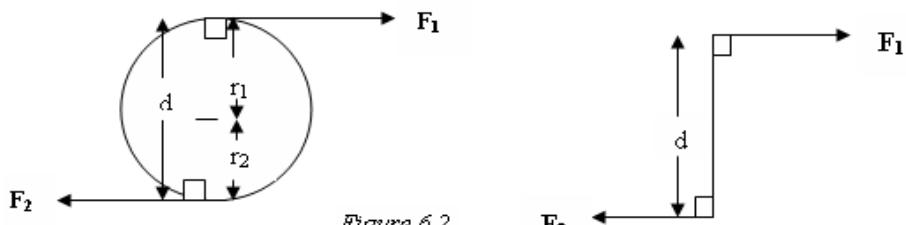


Figure 6.2

Where: $r_1 = r_2$ = radius of the circle $r_1 + r_2 = d$ = diameter of the circle

$$F_1 = F_2$$

Characteristics of a body under the action of a couple

- (i) The resultant force on the body is zero.
- (ii) The turning effects of the forces cause a rotational effect.
- (iii) The forces act in opposite directions.

(b) Moment of a couple (Torque)

The moment of a couple is equal to the product of one force and the perpendicular distance between the two forces.

The moment due to the couple in figure 6.1 above is given by the formula:

$$\begin{aligned} \text{Moment of a couple} &= \text{One force} \times \text{the perpendicular distance between the forces} \\ &= F_1 \times d \quad \text{Nm} \end{aligned}$$

$$\begin{aligned} \text{Or } \text{Moment of a couple} &= \text{One force} \times \text{the perpendicular distance between the forces} \\ &= F_2 \times d \quad \text{Nm} \end{aligned}$$

$$\text{Or } \text{Moment of a couple} = (F_1r_1 + F_2r_2) \quad \text{Nm}$$

6.12 Parallel Forces in Equilibrium

(a) Conditions for a body in equilibrium

The following are the conditions for a body to be in equilibrium when under the action of a number of parallel forces.

- (i) *The sum of forces acting in one direction is equal to the sum of forces acting in the opposite direction. I.e. the net resultant force on the body is zero.*
- (ii) *When a body is in equilibrium, the sum of clockwise moments about any point is equal to the sum of anti-clockwise moments about the same point.*

Consider the diagrams in figures 6.3 and 6.4 showing a uniform body in equilibrium under the action of parallel forces below for conditions (i) and (ii) above.

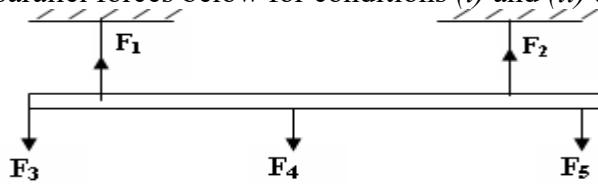


Fig. 6.3

In the diagram, three forces (F_3 , F_4 and F_5) act downward and two forces (F_1 and F_2) act upward and since the body is in equilibrium, then

\Rightarrow Using condition (i) above we have:

$$\begin{aligned} \text{Sum of Upward forces} &= \text{Sum of Downward forces} \\ \therefore (F_1 + F_2) &= (F_3 + F_4 + F_5) \end{aligned}$$

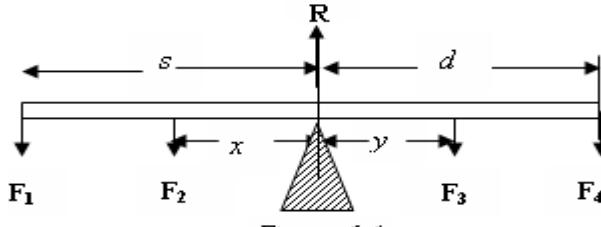


Figure 6.4

$$\text{Sum of Clockwise moments} = \text{Sum of Anti-clockwise moments}$$

$$\therefore F_3y + F_4d = F_1s + F_2x$$

\Rightarrow And Using condition (i) above we have:

$$R = F_1 + F_2 + F_3 + F_4$$

(b) Resultant Moment

When dealing with problems involving a number of moments acting on a body which is NOT in equilibrium, the following steps are taken:

- (i) Draw the sketch diagram indicating all the forces and their respective distances from the pivot (fulcrum).
- (ii) Give a positive sign to anticlockwise moments and a negative sign to clockwise moment(s).

- (iii) Add the moments algebraically. The numerical value of the answer gives the magnitude of the resultant moment and the arithmetic sign of the answer gives the direction of the resultant moment.

Example 1 Two forces 20 N and 50 N act on a body as shown in figure 6.5. If the 20 N is 0.1 m from the pivot and has clockwise effect while 50 N is 0.2 m from the pivot and has anti-clockwise effect.

- (a) Sketch the diagram showing all the forces and their respective distances from the pivot.
 (b) Calculate the resultant moment on the body.

Solution:

(a)

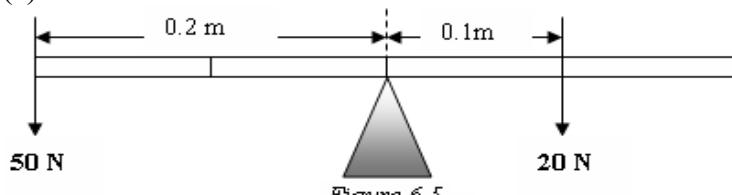


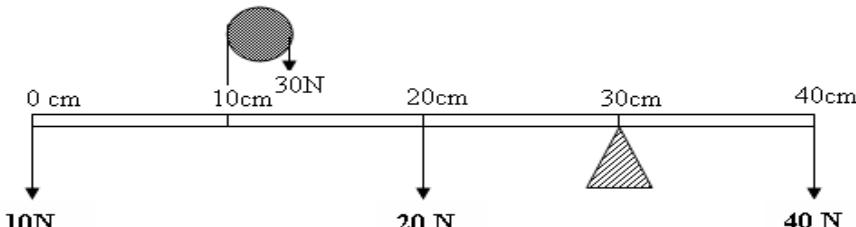
Figure 6.5

$$\begin{aligned}
 \text{(b) Resultant moment} &= -(20 \times 0.1) + +(50 \times 0.2) \\
 &= -2.0 \quad + \quad 10 \\
 &= +8 \text{ Nm}
 \end{aligned}$$

Hence the resultant moment is 5 Nm acting in anti-clockwise direction.

2. Four forces, 10 N, 20 N, 40 N, act downward and 30 N acts upward on a body which is 40 cm long. The 10 N is hung at 0 cm mark, the 30 N acts at 10 cm mark, 20 N acts at 20 cm mark and 40 N acts at 40 cm mark. If the knife edge is placed at 30 cm mark, calculate the resultant moment on the body,

The sketch of the diagram showing the four forces acting on a body.



Calculations

$$\begin{aligned}
 \text{Resultant moment} &= +10 \times \left(\frac{30 - 0}{100} \right) + 20 \times \left(\frac{30 - 20}{100} \right) - 30 \times \left(\frac{30 - 10}{100} \right) - 40 \times \left(\frac{40 - 0}{100} \right) \\
 &= +10 \times \frac{30}{100} \quad + \quad 20 \times \frac{10}{100} \quad - \quad 30 \times \frac{20}{100} \quad - \quad 40 \times \frac{10}{100} \\
 &= \frac{300}{100} \quad + \quad \frac{200}{100} \quad + \quad -\frac{600}{100} \quad + \quad -\frac{400}{100} \\
 &= +3 \quad + \quad 2 \quad - \quad 6 \quad - \quad 4 \\
 &= +5 \quad - \quad 10 \\
 &= -5 \text{ Nm}
 \end{aligned}$$

Hence the resultant moment is 5 Nm acting in a clockwise direction.

6.2 Centre of Gravity

Every body may be regarded as being made up of a very large number of very tiny and equal particles (according to Dalton Atomic theory). Each of these particles is pulled towards the centre of the earth as shown in figure 6.6 below.

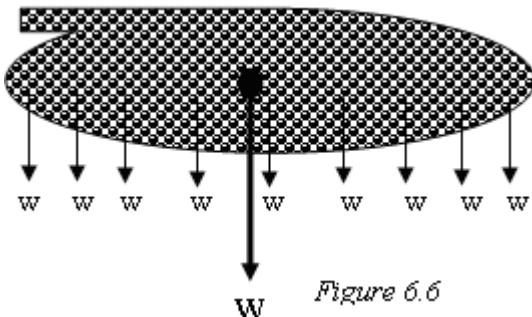


Figure 6.6

Thus, the earth's pull on the body consists of very large number of equal parallel forces. The resultant of the forces is equal to the total force of gravity on the body and it acts through a point **G** called the *centre of gravity*.

Definition: *The centre of gravity of a body is defined as the point of application of the resultant force due to the earth's attraction on it.*

Resultant force is a single force which has an effect of two or more forces acting on a body.

6.21 Methods to locate the Centre of gravity of a body

The method chosen to determine the centre of gravity of a body depends on the following factors:

- The nature and

- The shape of the body.

The shape may either be regular or irregular.

(a) A regular body

The centre of gravity of a regular body is found by using:

- Blancing and
- Intersection of diagonal method.

(i) Balancing method

The centre of gravity of a long uniform object such as a metre rule may be determined by balancing method.

In this method, the metre rule may be balanced on a knife edge or hang from a loop of thread and then adjusted until it balances horizontally.

The point at the knife edge is the centre of gravity.

Note:

- *A uniform metre rule or a uniform body is one in which the particles are uniformly distributed.*
- *The centre of gravity of a uniform body is always at its centre.*

(ii) Intersection of diagonals method

This method applies mostly to two dimensional figures e.g a rectangular lamina or cardboard.

Experiment: To determine the centre of gravity of a regular lamina

Procedure

Draw straight lines along the diagonals of the lamina as shown in figure 6.7 diagram below.

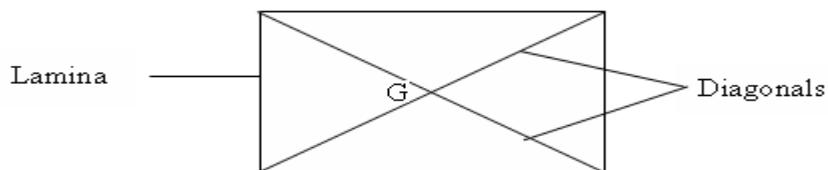


Figure 6.7

The point of intersection **G** is the centre of gravity.

(b) Irregular Body

The centre of gravity of irregular body is determined by using *plumb line method*.

Experiment 6.1 To determine the centre of gravity of irregular lamina

Apparatus

Retort stand/Clamp, a pin fixed to a rubber band, plumb, thin string, paper punch machine

Procedure

- Make three holes at well spaced intervals round the edge of the lamina and label them A, B and C.
- Tie one end of the string to the plumb and tie the other end to form a loop so that it can easily be suspended from the support pin.
- Using hole A, suspend the lamina and the plumb from the support pin and wait until the two come to a rest.
- Mark two crosses with a thin pencil point on the plumb line one near hole A and the other below it.
- Remove the plumb and the lamina.
- Join the two crosses on a straight line.
- Repeat procedures (c) to (f) for the remaining holes B and C.

Observation

All the three straight lines intersect at a common point G as shown in figure 6.7 below.

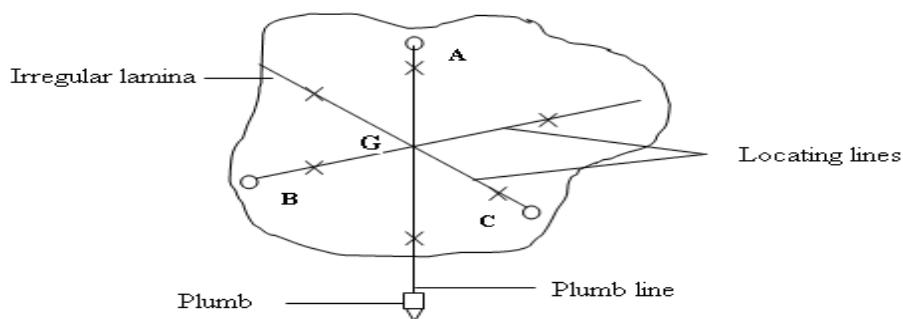


Figure 6.8

Conclusion: Since the centre of gravity lies on the straight lines drawn on the lamina, it must be situated at the point of *intersection G*.

Note: (i) *In the laboratory, the plumb can be replaced by a pendulum bob.*

(ii) *Not always that the centre of gravity of a body lies within the material, it may also be at a point in the air near by.*

The best examples are: - tripod and a laboratory stool.

6.23 Applications of the Principle of Moments

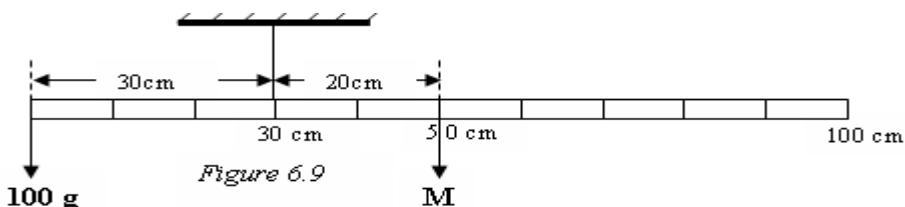
The principle of moment is applied in: the following.

- (i) The determination of Mass or weight of a uniform metre rule.
- (ii) The determination of Mass or weight of an object.

(a) Determination of the mass of a uniform metre rule using a standard (known) mass.

- Suspend a uniform metre rule using a loop of thread from a support.
- Adjust the metre rule until it balances horizontally.
- Read and record the value at the pivot, say 50 cm.
- Suspend a standard mass say 100 g by means of a thread at 0 cm mark.
- Readjust the position of the metre rule until it balances horizontally again.
- Read and record the new value at the point of pivot, say 30 cm.
- Measure and record the respective perpendicular distances from 100 g mass and M from the pivot.

Consider the diagram in figure 6.9 below



Applying the principle of moments

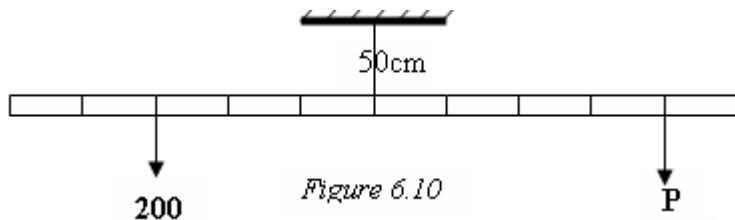
$$\begin{aligned}
 \text{Clockwise moment} &= \text{Anti-Clockwise moments} \\
 M \times (50 - 30) \text{ cm} &= 100 \text{ g} \times (30 - 0) \text{ cm} \\
 M \times 20 \text{ cm} &= 100 \text{ g} \times 30 \text{ cm} \\
 \frac{M \times 20 \text{ cm}}{20 \text{ cm}} &= \frac{100 \text{ g} \times 30 \text{ cm}}{20 \text{ cm}} \\
 M &= 150 \text{ g}
 \end{aligned}$$

(b) Determination of the mass or weight of an object using a uniform metre rule and a standard mass or weight

Procedure

- Suspend a uniform metre rule using a loop of thread from a support.
- Adjust the metre rule until it balances horizontally.
- Read and record the cm mark at the pivot.
- By means of a thread, suspend a standard mass, say, 200 g and the object whose mass is to be determined on either sides of the pivot.
- Readjust their distances from the pivot until the metre rule once more balances horizontally.
- Measure and record their respective perpendicular distances from the pivot.

For calculations consider the diagram in figure 6.10 below



Applying the principle of moments

$$\begin{aligned}
 \text{Clockwise moment} &= \text{Anti-Clockwise moments} \\
 P \times (90 - 50) \text{ cm} &= 200 \text{ g} \times (50 - 20) \text{ cm} \\
 P \times 40 \text{ cm} &= 200 \text{ g} \times 30 \text{ cm} \\
 \frac{P \times 40 \text{ cm}}{40 \text{ cm}} &= \frac{200 \text{ g} \times 30 \text{ cm}}{40 \text{ cm}} \\
 P &= 150 \text{ g}
 \end{aligned}$$

NB: To get the weight (W) of the object, we use the formula:

$$\begin{aligned}
 W &= mg \\
 \text{Where: } g &= \text{gravity and} \\
 m &= \text{mass of the object in kg.}
 \end{aligned}$$

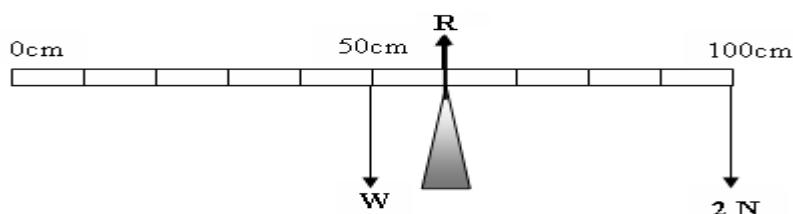
To get the weight once, we use a standard weight directly instead of a standard mass.

Worked Examples

Note: When solving problems involving the law of moments, identify the force(s) which has/have clockwise moment(s) and anti-clock wise moment(s). So that you substitute them correctly. Experience has shown that many students tend to forget this as such they put clockwise moments under anti-clock wise moments and vice versa.

1. A uniform metre rule balances horizontally on a knife edge placed at 60 cm when 2 N weight is suspended at one end.
 - (a) With a help of diagram show at which end of the metre rule the 2 N weight must be suspended.
 - (b) Calculate: (i) the weight,
(ii) the mass of the metre rule,
(iii) the reaction, R , at the knife edge. (Take $g = 10 \text{ ms}^{-2}$)

Solution: (a)



Since the metre rule is uniform, its weight W acts through centre, i.e at 50cm mark, then the 2 N weight must be suspended on the other side of the pivot so as to balance it.

(b) (i) Applying the principle of moments

$$\begin{aligned} \text{Clockwise moment} &= \text{Anti-Clockwise moments} \\ 2 \text{ N} \times (100 - 60) \text{ cm} &= W \times (60 - 50) \text{ cm} \\ 2 \text{ N} \times 40 \text{ cm} &= W \times 10 \text{ cm} \\ \frac{2 \text{ N} \times 40 \text{ cm}}{10 \text{ cm}} &= \frac{W \times 10 \text{ cm}}{10 \text{ cm}} \\ W &= 8 \text{ N} \end{aligned}$$

(ii) $W = 8 \text{ N}$, $g = 10 \text{ ms}^{-2}$, $m = ?$

Using $W = mg$

$$\begin{aligned} 8 &= m \times 10 \\ m &= \frac{8}{10} \\ m &= 0.8 \text{ kg} \end{aligned}$$

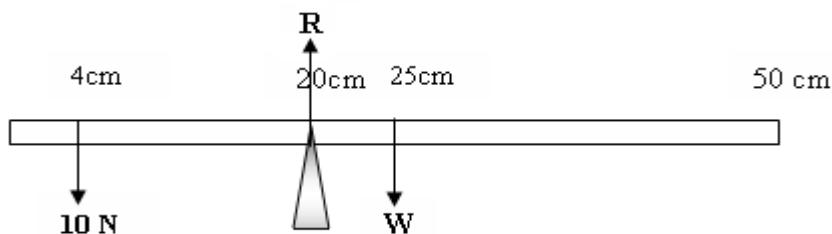
(iii) Applying the condition for a body in equilibrium,
(The upward force) = (Sum of downward forces)

$$\begin{aligned} R &= W + 2 \text{ N} \\ &= 8 \text{ N} + 2 \text{ N} \\ \therefore R &= 10 \text{ N} \end{aligned}$$

2. A uniform half-metre rule is freely pivoted at the 20 cm mark and it balances horizontally when a weight of 10 N is suspended at the 4 cm mark.
- (a) Draw a sketch diagram showing all the forces acting on the metre rule.
- (b) Calculate: (i) the weight of the metre rule.
(ii) the reaction at the knife edge.

Solution

- (a) A sketch diagram showing the forces acting on a half-metre rule



- (b) (i) Applying the principle of moments

$$\begin{aligned} \text{Clockwise moment} &= \text{Anti-Clockwise moments} \\ W \times (25 - 20) \text{ cm} &= 10 \times (20 - 4) \text{ cm} \\ W \times 5 \text{ cm} &= 10 \times 16 \text{ cm} \\ \frac{W \times 5 \text{ cm}}{5 \text{ cm}} &= \frac{10 \text{ N} \times 16 \text{ cm}}{5 \text{ cm}} \\ &= \frac{160}{5} \text{ N} \\ \therefore W &= 32 \text{ N} \end{aligned}$$

- (ii) Applying **(Upward force) = (Sum of downward forces)**

we have: $R = W + 10 \text{ N}$
 $= 32 \text{ N} + 10 \text{ N}$
 $\therefore R = 42 \text{ N}$

6.3 Stability and Equilibrium

(a) Stability

Stability, in physics and engineering, refers to the property of a body that causes it to return to its original position or motion as a result of the action of the restoring forces, or torques, once the body has been disturbed from a condition of equilibrium or steady motion.

In simple terms we can define stability as the difficulty in causing a body to fall or topple over.

(b) Equilibrium

Equilibrium refers to the state of a body where the net force acting on the body is zero. In the case of a stationary body, the large-scale property of the position of the body will remain unchanged over time.

6.31 Types of Equilibrium

Mechanical equilibrium can be of three kinds:

- (i) Stable Equilibrium,
- (iii) Unstable Equilibrium and
- (iv) Neutral Equilibrium

(a) Stable Equilibrium

Stable equilibrium is a state of a body in which on a slight displacement it returns to its original position.

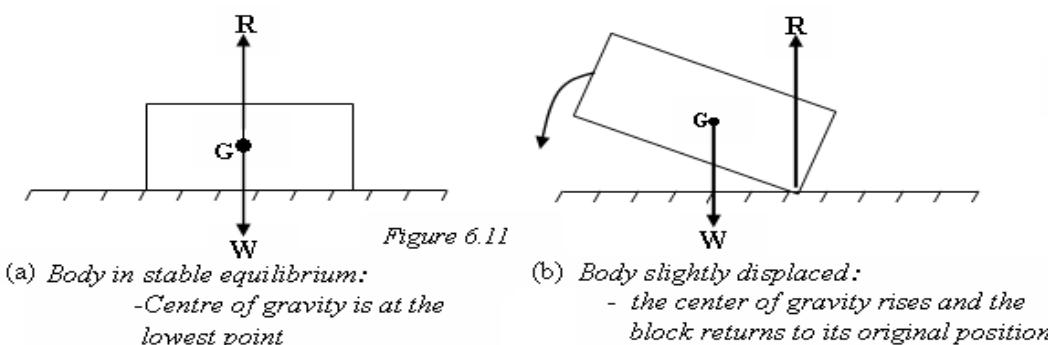
Characteristics of a body in stable equilibrium

A body in a stable equilibrium is characterized by or is associated with the following:

- (i) The centre of gravity of the body is at the lowest position.
- (ii) The base area is large.

Thus on a slight displacement of a body in stable equilibrium, the centre of gravity is raised and the body returns to its original position after the displacement.

Consider a glass block resting on a table as shown in figure 6.11 below.



Explanation

The block of glass exerts force, W , (its weight) on the table and the table exerts an upward force called reaction force, R , equal to the weight of the block. Since the weight and the reaction are equal and opposite forces, the resultant force on the block is zero, so the block is stable (i.e. does not move).

When the block is tilted slightly, the two forces act as shown in figure 6.11 (b). The reaction, R, acts at the point of contact while the weight, W, still acts through G, the centre of gravity, but outside the point of contact. The result is a couple, two equal and opposite parallel forces, which tend to rotate the block in anti-clockwise direction and therefore, the block falls back to its original position.

(b) Unstable Equilibrium

Unstable equilibrium refers to a state of a body in which on a slight displacement it does not return to its original position.

Characteristics of a body in unstable equilibrium

A body in an unstable equilibrium is associated with the following:

- (i) The centre of gravity of the body is at the highest position.
- (ii) The base area is small.

Thus on a slight displacement of a body in unstable equilibrium lowers the centre of gravity and the body does not return to its original position after the displacement; it topples over.

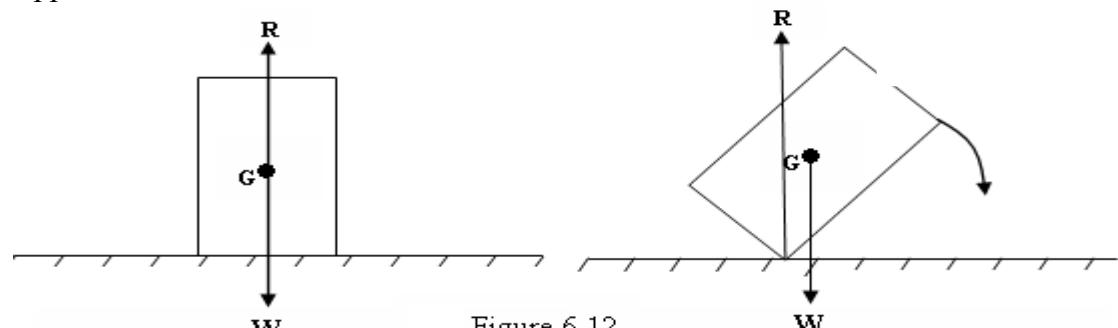


Figure 6.12

- (a) *Body in unstable equilibrium:*
- Centre of gravity at highest point

- (b) *On slight displacement:*
- the centre of gravity is lowered and
- the block topples over.

Explanation

In figure 6.12 (a), the block is in an unstable equilibrium. When it is tilted slightly, the two forces act as shown in figure 6.12 (b). The reaction, R, acts at the point of contact while the weight, W, still acts through G, the centre of gravity, but outside the point of contact. The result is a couple, two equal and opposite parallel forces which tend to rotate the block in *clockwise direction* and does not return to its original position, hence topples over.

(c) Neutral Equilibrium

This is a state of a body in which on slight displacement its centre of gravity is neither raised nor lowered.

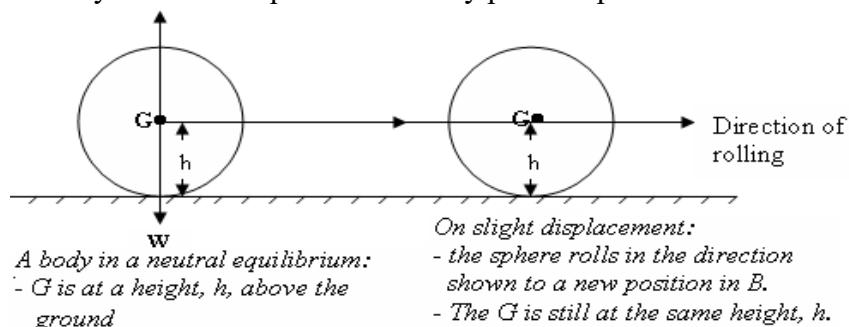
Characteristics of a body in neutral equilibrium

A body in a neutral equilibrium is associated with the following:

- (i) The centre of gravity of the body is always at the same height and directly above the point of contact.
- (ii) The area in contact is very small.

A slight displacement does not alter the position of the centre of gravity, thus the body is always at rest whichever position it is placed.

Example of a body in neutral equilibrium is any perfect sphere.



NB: Using the characteristics of a body in stable equilibrium, a body be designed such that it is in stable equilibrium.

6.32 Making a body Stable

In engineering, the stability of a structure is increased by:

- (i) Making its base wide and
- (ii) Keeping its centre of gravity as low as possible by putting more weight in the lower part than in the upper part.

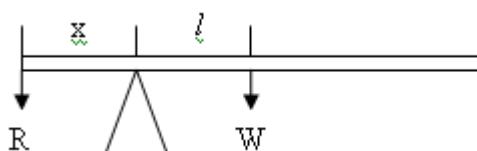
Notable examples are seen in the following:

- (i) Racing cars - which have both a low centre of gravity and a wide wheel base.
- (ii) Modern Isuzu/Scania coach buses
 - They have fairly wide wheel base and low centre of gravity which is achieved by packing load in boots.

Note: The old system of loading buses on the racks of buses raises the centre of gravity of the bus thus making it unstable on the road.

Self-Check 6.0

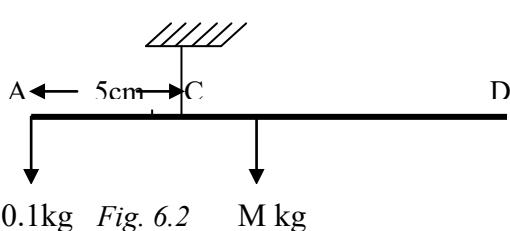
1. Figure 6.1 shows a uniform beam in equilibrium when a force R acts on it at one end. Find the weight W of the beam.



- | | | | |
|----|----------------|----|----------------|
| A. | $\frac{x}{Rl}$ | B. | $\frac{Rl}{x}$ |
| C. | $\frac{l}{Rx}$ | D. | $\frac{Rx}{l}$ |

Figure 6.1

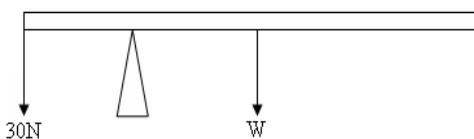
2. The diagram in the figure 6.2 shows a uniform half-meter rule suspended at point C. The mass of the rule is



- | | |
|----|----------|
| A. | 0.020 kg |
| B. | 0.025 kg |
| C. | 0.100 kg |
| D. | 0.125 kg |

0.1kg Fig. 6.2 M kg

3. A uniform wooden beam of weight W is pivoted at a distance $\frac{1}{5}$ of its length from the end A and kept in equilibrium by applying a force of 30 N as shown in figure 6.3. The force exerted by the pivot on the beam is
A. 50 B. 40 C. 30 D. 20



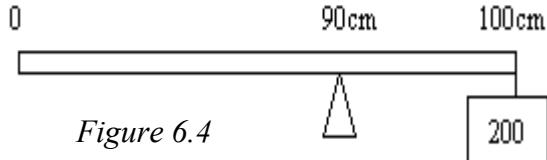


Figure 6.4

5. Which one of the following statements is true about two equal forces acting on a bar of length l , shown in the figure.

 - (i) The resultant force on the bar is zero.
 - (ii) The forces cause a rotational effect.
 - (iii) The forces act in opposite directions.
 - (iv) The forces produce different turning effects.

A. (i) only B. (i) and (ii) only C. (i),(ii) and (iii) only D. All

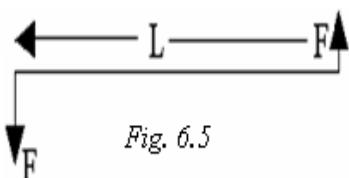


Fig. 6.5

6. The figure below shows a uniform metre rule of mass 0.1kg pivoted at the 80 cm mark. It balances horizontally when a mass P is hanging at the 95 cm mark. Find P.

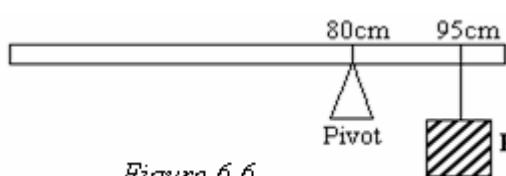
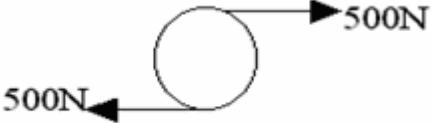


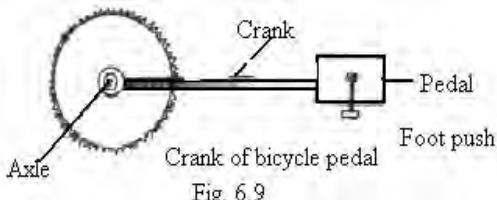
Figure 6.6

7.  A uniform metre-rule is pivoted at its centre shown in the figure. If the rule is in equilibrium, find value of F .

A. 4 N B. 33.3 N
 C. 50 N D. 100 N

- 8.
- 
- Fig. 6.8
- The shaft in an engine is subjected to two parallel but opposite forces of 500N each as shown in the figure. The rotation is best stopped by applying
- A. Two forces of 500 N acting at right angles to each other
 B. A single force of 1000 N.
 C. Two parallel but opposite forces of 500 N
 D. A single force of 250 N.

9. The above figure shows a crank of a bicycle pedal. The force a cyclist exerts on the pedal varies from a minimum to maximum. When does the



cyclist exert maximum turning effort?
 A. crank makes 90° with the foot push
 B. crank makes 0° with the foot push
 C. cyclist is climbing a hill
 D. cyclist is turning a corner

10. Find the weight, w, of a uniform metre rule if a force of 60 N at one end balances it as shown figure.

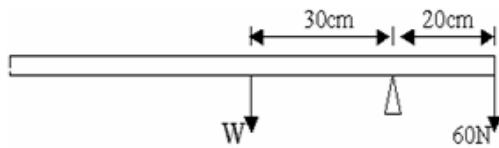
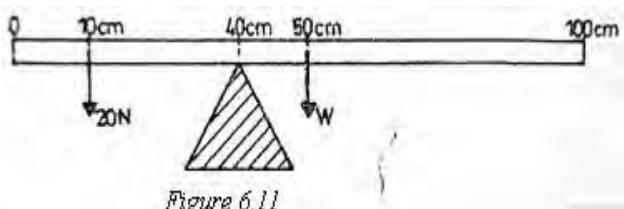


Figure 6.10

- A. 24 N B. 40 N C. 90 N D. 100 N

SECTIONS B

11. (a) (i) Define moment of a force and state its SI unit.
 (ii) State the principle of moments.
 (iii) State the conditions for a body to be in equilibrium.



(b) A uniform meter ruler is pivoted at the 40 cm mark as shown in the fig. 6.11. The meter ruler is in equilibrium under its weight W and a 20 N force acting at the 10 cm mark. Calculate:
 (i) The weight W of the metre rule.
 (ii) The reaction at the knife edge.

12. (a) What is meant by *centre of gravity*?
 (b) (i) Describe an experiment to determine the centre of gravity of an irregular lamina.
 (ii) Describe how you would measure the mass of a metre rule using a known mass and a knife-edge only.
 (c) If the metre is in equilibrium when weights of 10N, 2N and 5N are attached to it as shown in figure 6.12.

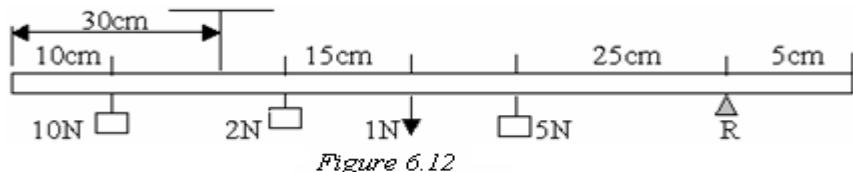


Figure 6.12

Calculate the: (i) Tension in the string.
 (ii) Normal reaction, R, at the wedge.

14. (a) State (i) the types of equilibrium.
 (ii) the characteristics associated with the types of equilibrium you have stated in 5 (a) above.
- (b) Explain giving reasons whether it is advisable to load a bus on the rack.
 Describe how you would design a given structure to have a high stability.
- (c) A uniform beam of weight 2.5 N is pivoted at its mid-point P, as shown in figure 6.14.

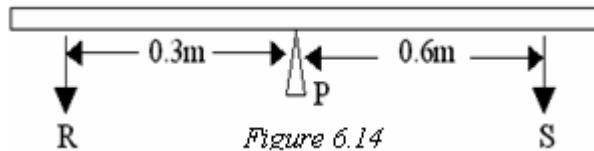


Figure 6.14

The beam remains in equilibrium when force R and S act on it. If R is 5N, find the:

- (i) Value of S.
 (ii) Reaction at the pivot

CHAPTER SEVEN

WORK, POWER AND ENERGY

LEARNING OBJECTIVES

By the end of this chapter, you should be able to:

1. (a) Define: -The following terms and state their SI units;
- Work and Power
(b) Describe an experiment to measure human power
(c) Solve numerical problems involving; Work done and Power
 2. (a) Define: - the term Energy and state its S.I unit.
(b) State: (i) - the Law of Conservation of energy
(ii) - the forms and sources of energy
 3. (a) Define: - Potential and Kinetic Energy
(b) Describe the Interchange between P.E and K.E.
(c) Solve numerical problems involving P.E and K.E
 4. (a) State: - The components of Internal-Combustion Engine.
(b) Describe:- The mechanism of Four-stroke and Two-stroke Engines
(c) State: - The factors that limit the efficiency of Internal-Combustion engines
(d) Explain: - How to improve the efficiency of Internal-Combustion engines.
-

7.10 WORK

(a) Introduction

The word “work” in everyday life describes any activity which requires muscular or mental effort. But in Physics, work has a special meaning. In the scientific sense, work involves motion and work is done when a force changes the position or speed of an object.

Definition: Work is the product of a force applied to a body and the displacement of the body in the direction of the applied force.

Mathematically, it is expressed as:

Work done = Force (F) \times Distance (s) moved in the direction of the force

$$\text{Work done} = Fs$$

Note: 1. Work is only said to be done when a force moves its point of application along the direction of its line of action.
2. If a force acts on a body and there is no motion, then there is no work done.
3. The distance must be in metres.

While work is done on a body, there is a transfer of energy to the body, and so work can be said to be energy in transit.

(b) Factors which determine the amount of work done

From the formula of work, we can see that the amount of work done depends on:

- (i) The magnitude (size) of the force applied.
- (ii) The distance moved.

The S.I unit of work is joule, J.

A joule is defined as the *work done when a force of one Newton (1N) moves through a distance of one metre (1m)*.

Larger units are:

- the kilojoule (kJ) and
- the megajoule (MJ)

$$\begin{aligned}1 \text{ kJ} &= 1\ 000 \text{ J} \quad (10^3 \text{ J}) \\1 \text{ MJ} &= 1\ 000\ 000 \text{ J} \quad (10^6 \text{ J})\end{aligned}$$

Work is also done in moving against some opposing force such as gravity and any form of resistance to the motion of the force.

For example:

- (i) When a crane is lifting a heavy load, work is done against the force of gravity. Or when a person lifts a load to a given height.
- (ii) When a nail being driven into a wooden block by hammering, work is done against the resistance of the wood.

Worked Examples

- Calculate work done by an engine which exerts a force of 9000N over a distance of 6 m.

Solution: Force, F = 9000 N, Distance, s = 6 m, Work done = ?

$$\begin{aligned}\text{Work done} &= \text{Force} \times \text{Distance} \\&= F \times s \\&= 9000 \times 6\end{aligned}$$

$$\therefore \text{Work done} = \mathbf{54,000 \text{ J} \quad \text{Or } 54 \text{ kJ}}$$

- A man lifts a box of mass 3 kg vertical upwards through 2 m. If the gravitational field, g is 10 m/s^2 , calculate the work done by the man in lifting the box.

Solution: Mass of box = 3 kg, gravitational field, g = 10 m/s^2 Force, F = mg, Distance, s = 2 m, Work done = ?

$$\begin{aligned}\text{Work done} &= \text{Force} \times \text{Distance} \\&= mg \times s \\&= 3 \times 10 \times 2\end{aligned}$$

$$\therefore \text{Work done} = \mathbf{60 \text{ J}}$$

- In the diagram below, a force of 10 N acts on a block of weight 30 N placed on a rough table as shown in figure 7.1 below.

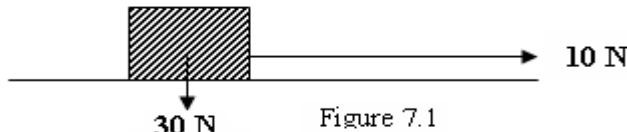


Figure 7.1

Given that μ is 0.2 and the block moves through a distance of 3 m.

Calculate:

- (a) the useful work,
- (b) the useless work; done if the block moves 3 m along the direction of the 10 N and the coefficient of friction is 0.2.

Solution: Method I

(a) Force applied, $F = 10 \text{ N}$, $s = 3 \text{ m}$, $\mu = 0.2$, Weight, $W = R = 30 \text{ N}$

$$\begin{aligned}\text{Useful work done} &= \text{Resultant force} \times \text{Distance moved} \\ &= (\text{Force applied} - \text{Frictional force}) \times s \\ &= [10 - (\mu R)] \times 3 \quad \text{Where: } \mu R = \text{Frictional force and} \\ &= [10 - (0.2 \times 30)] \times 3 \quad R = \text{Weight of the object} \\ &= (10 - 6) \times 3 \\ &= 4 \times 3 \text{ N}\end{aligned}$$

$\therefore \text{Useful work done} = 12 \text{ J}$

Method II

Step I: First calculate the frictional force

$$\begin{aligned}\text{Frictional force} &= \mu R \\ &= 0.2 \times 30 \\ &= 6 \text{ N}\end{aligned}$$

Step II: Calculate the Resultant Force

$$\begin{aligned}\text{Resultant Force} &= \text{Force applied} - \text{Frictional force} \\ &= 10 - 6 \\ &= 4 \text{ N}\end{aligned}$$

Step III: Now calculate the useful work done from the formula:

$$\begin{aligned}\text{Work done} &= \text{Resultant force} \times \text{Distance} \\ &= 4 \times 3\end{aligned}$$

$\therefore \text{Useful work done} = 12 \text{ J}$

7.2 POWER

Power is defined as the *rate of doing work*. Or

Power is the rate of performing work or transferring energy.

Power measures how quickly work is done.

Mathematically speaking, power is equal to the work done divided by the time interval over which the work is performed.

$$\text{i.e. Power} = \frac{\text{Work done}}{\text{Time taken}}$$

In the sense of power being defined as *rate of transfer of energy*, we can also mathematically express power as:

$$\text{Power} = \frac{\text{Energy change}}{\text{Time taken}}$$

S.I unit of power

The S.I unit of power is the **Watt (W)**.

The watt is defined as *the rate of doing work at one joule per second*.

$$\begin{aligned}1 \text{ Watt} &= 1 \text{ Joule per second.} \\ \text{i.e. } 1 \text{ W} &= 1 \text{ J/s}\end{aligned}$$

Larger units of power are:

- The Kilowatt (kW) and
- Mega watt (MW)

$$\begin{aligned}1 \text{ kW} &= 1000 \text{ W} \quad (10^3 \text{ W}) \\ 1 \text{ MW} &= 1 \ 000 \ 000 \text{ W} \quad (10^6 \text{ W}) \\ 1 \text{ MW} &= 1 \ 000 \text{ kW}\end{aligned}$$

- NB:**
1. Engine power is sometimes measured in horse power (hp).
1 hp = 746 W $\approx \frac{3}{4}$ kW
 2. From Work done = Force x Distance

$$\text{Power} = \frac{F \times s}{t} = F \times \frac{s}{t}$$
 But Velocity = $\frac{s}{t}$

$$\therefore \text{Power} = \text{Force} \times \text{Velocity}$$

Worked Examples

1. Calculate the power of a water pump which can fill a water tank 10 m height with 3000 kg of water in 20 s. (Assume $g = 10 \text{ ms}^{-2}$).

Solution: $m = 3000 \text{ kg}$, $h = 10 \text{ m}$, $g = 10 \text{ m}^{-2}$, $P = ?$

We can solve this problem by using any one of the methods below.

Method I

Step I: First calculate the work done.

$$\begin{aligned}\text{Work done} &= \text{Force} \times \text{Distance} \\ &= mg \times s \\ &= 3000 \times 10 \times 10\end{aligned}$$

$$\therefore \text{Work done} = 300,000 \text{ J or } 3 \times 10^5 \text{ J}$$

Step II: Now calculate the power from the formula:

$$\begin{aligned}\text{Power} &= \frac{\text{Work done}}{\text{Time taken}} \\ &= \frac{300,000}{20} \\ \therefore \text{Power} &= 15,000 \text{ W}\end{aligned}$$

Method II Substitute the values in the data collected directly as shown below.

$$\begin{aligned}\text{Power} &= \frac{\text{Work done}}{\text{Time taken}} \\ &= \frac{\text{Force} \times \text{Distance}}{\text{Time taken}} \\ &= \frac{\text{Mass} \times \text{Acceleration due to gravity} \times \text{Distance}}{\text{Time taken}} \\ &= \frac{mgs}{t} \\ &= \frac{3000 \times 10 \times 10}{20} \\ \therefore \text{Power} &= 15,000 \text{ W}\end{aligned}$$

2. A man lifts a box of mass 10 kg through a vertical height of 2 m in 4 seconds. Calculate the power he developed.

Solution: $m = 10 \text{ kg}$, $h = 2 \text{ m}$, $t = 4 \text{ s}$, $g = 10 \text{ m}^{-2}$, $P = ?$

$$\begin{aligned}\text{Using the formula } \text{Power} &= \frac{F \times s}{t} \\ &= \frac{mgs}{t} \\ &= \frac{10 \times 10 \times 2}{4} \\ &= \mathbf{50 \text{ W}}\end{aligned}$$

7.21 Measurement of Human Power

The rate of working of a person is at its highest when he or she is running up a hill or up stairs lifting his or her own weight. So human power can be measured by measuring the total vertical height of a stairway and the time taken to run up the vertical height.

Experiment

Apparatus: Stop watch, Weighing scale, a long flight of steps.

Procedure

- ❖ Run up a long flight of steps while someone times you using a stop watch.
- ❖ Make three attempts each time the person records the time taken.
- ❖ Weigh your self on weighing machine to get your mass.

Calculations

⇒ Calculating the Vertical height

Measure the height of one step and count the number of steps you climbed.

Find the total vertical height from the formula:

$$\text{Vertical height} = \text{Height of one step} \times \text{Number of steps}$$

⇒ Average time taken

Find the average time taken from the formula;

$$\text{Average time taken} = \frac{\text{Sum of time taken}}{\text{Number of attempts}}$$

For the case of above, Average time taken, $t = \frac{t_1 + t_2 + t_3}{3}$

Where $t_1 + t_2 + t_3$ are the times taken in seconds in the three attempts.

⇒ The Power

The power can then be calculated using any one of the following methods.

Method I

Step I: First calculate work done:

$$\begin{aligned}
 \text{Work done by the boy} &= \text{Force overcome} \times \text{Vertical distance climbed} \\
 &= mg h \\
 \text{Where } h &= \text{Height of 1 step} \times \text{Number of steps in metres} \\
 \therefore \text{Work done by the boy} &= mg \times \text{Height of 1 step} \times \text{Number of steps}
 \end{aligned}$$

Step II: Now calculate the power developed from the formula:

$$\begin{aligned}
 \text{Power} &= \frac{\text{Work done}}{\text{Time taken}} \\
 &= \frac{mg \times h}{t} \quad h = \text{as defined in step I above.} \\
 \therefore \text{Power} &= \left(\frac{mg}{t} \right) \times \\
 &\qquad \qquad \qquad \text{Height of one step} \times \text{Number of steps}
 \end{aligned}$$

Method II

Simply calculate the power from the formula

$$\text{Power} = \left(\frac{mg}{t} \right) \times$$

$$\text{Height of one step} \times \text{Number of steps}$$

Example

1. A boy of mass 60 kg runs up a flight of 60 steps in 10 seconds. If the height of one step is 20 cm, calculate the power he developed.

Solution

When collecting the data, always remember that the h must be in metres.

$$m = 60 \text{ kg}, t = 10 \text{ s}, \text{height of 1 step} = 20 \text{ cm} = \frac{20}{100} = 0.2 \text{ m}$$

Method I

Step I: First calculate work done:

$$\begin{aligned}
 \text{Work done by the boy} &= \text{Force overcome} \times \text{Vertical distance climbed} \\
 &= mgh \\
 &= mg \times \text{Height of 1 step} \times \text{Number of steps} \\
 &= 60 \times 0.2 \times 60 \\
 \therefore \text{Work done by the boy} &= 720 \text{ J}
 \end{aligned}$$

Step II: Now calculate the power developed from the formula:

$$\begin{aligned}
 \text{Power} &= \frac{\text{Work done}}{\text{Time taken}} \\
 &= \frac{720}{10} \\
 \therefore \text{Power} &= 72 \text{ W}
 \end{aligned}$$

Method II

Simply calculate the power from the formula

$$\text{Power} = \frac{mg}{t} \times \text{Height of one} \times \text{Number of steps}$$

$$= \frac{60 \times 10}{10} \times 0.2 \times 60$$

$$\therefore \text{Power} = 72 \text{ W}$$

7.3 ENERGY

Energy is defined as, *capacity of matter to perform work*. Or *Energy is the ability to work*.

(a) The S.I unit of energy

Like work, the SI unit of energy is joule, J.

Energy exists in various forms, including

- Mechanical, thermal, chemical, electrical, radiant, and atomic.

All forms of energy are interconvertable by appropriate processes. In the process of transformation either kinetic or potential energy may be lost or gained, but the sum total of the two remains always the same. This is in accordance with the *Law of Conservation of Energy*.

(b) The Law of Conservation of Energy

The law states that: *Energy can neither be created nor destroyed, but only changes from one form to another thus the sum total always remains the same.*

7.31 Forms of energy

Energy exists in various forms. The various forms are shown in the table below.

Form of energy		Example
Mechanical energy - Potential (gravitational) - Potential (elastic) - Kinetic energy	Is the type of energy possessed by a body by a reason of its position at rest or on motion.	- Energy stored in a book resting on a table. - A stretched spring or catapult - A shot fired from a gun.
Chemical energy	The type of energy released during a chemical reaction.	- Energy stored in fuels and energy giving foods that becomes active when oxidized by oxygen. - Energy stored in battery cells.

Nuclear (atomic) energy	Is the energy released by nuclei of heavy atoms of disintegrating radioactive elements.	- Energy stored in the nucleus of an atom
Electrical energy	The type of energy produced by electric cells, generators etc.	- Energy produced in electric appliances such as cooker, filament lamp etc.
Radiant energy (heat and light)		- Infra-red rays.
Sound energy	Type of energy produced by vibrating objects.	- Vibrational energy.

Table 7.1

7.32 Sources of Energy

Sources of energy are the raw materials for production of energy. They can be classified into two main categories namely:

- (i) Renewable energy sources
- (ii) Non-renewable energy sources.

(a) Renewable energy sources

These are energy sources which cannot be exhausted.

Examples of renewable sources of energy include:

- Solar energy - energy tapped from the sun using solar panels.
- Hydroelectric energy - electric energy produced from falling water which rotates turbines connected to generator which intern produce electricity.
- Wind energy - electric energy produced from moving air which rotates turbines connected to generator which intern produce electricity.

(b) Non-renewable energy sources.

These are energy sources which once used cannot be replaced.

Examples of non-renewable sources of energy include:

- Fossil fuels (oil, coal and natural gas. Fossil fuels are formed from remains of plants and animals which have accumulated over millions of years).
- Nuclear energy.

7.33 Mechanical Energy

In mechanics, energy is divided into two kinds, namely:

- Potential energy and
- Kinetic energy.

(a) Potential energy (p.e)

Potential energy is the form of energy possessed by a body as a result of its position at rest.

For example, a body lifted to a height, h , above the surface of the earth is said to possess p.e.

When something is lifted vertically upwards, work is done against the gravitational force acting on the body (i.e its weight) and this work is stored in the body as gravitational potential energy.

Another example of Potential energy is the elastic potential energy stored in a stretched spring or catapult.

Formula of Potential Energy

Suppose a body of mass m kg is raised to a height of h metres at a place where the acceleration due to gravity is g m/s².

$$\text{Then Force overcome (Weight), } F = mg \quad \dots \quad (1)$$

$$\text{Work done on the body} = F \times s \quad \dots \quad (2)$$

Substituting equation (1) in equation (2) i.e replacing F in equation (2) with mg in equation (1) we have,

$$\text{Work done on the body} = mg \times s$$

But the work done = gravitational potential energy (p.e) and $s = h$,

$$\therefore P.E = mgh$$

Recall that: m = mass of the body in kg.

g = acceleration due to gravity (m/s²).

h = height in metres.

Example

1. A box of mass 5 kg is raised to a height of 2 metres above the ground. Calculate the potential energy stored in the stone (take $g = 10$ ms⁻²)

Solution: Mass of box = 5 kg, gravitational field, $g = 10\text{m/s}^2$ Height, $h = 2\text{ m}$,

$$\begin{aligned} \text{Applying} \quad P.E &= mgh \\ &= 5 \times 10 \times 2 \\ \therefore P.E &= 100 \text{ J or } 0.1 \text{ kJ} \end{aligned}$$

2. A man has raised a load of 25 kg on a platform 160 cm vertically above the ground. If the value of gravity is 10m/s², calculate the potential energy gained by the box when it is on the platform.

Solution: Mass of stone = 25 kg, gravitational field, $g = 10\text{m/s}^2$

$$\text{Height, } h = 160 \text{ cm} = \frac{160}{100} = 1.6 \text{ m, P.E} = ?$$

$$\begin{aligned} P.E &= mgh \\ &= 25 \times 10 \times 1.6 \\ \therefore P.E &= 400 \text{ J or } 0.4 \text{ kJ} \end{aligned}$$

(b) Kinetic energy (k.e)

Kinetic energy is the energy possessed by a moving body.

Examples of kinetic energy include:

- Moving bullet, Moving car, etc.

A body possessing k.e does work by overcoming resistance force when it strikes something.

Formula of Kinetic energy (k.e)

Kinetic energy can be calculated from the formula;

$$\text{K.E.} = \frac{1}{2}mv^2 \quad \text{Where } m = \text{mass (kg)}, v = \text{velocity (m/s)}.$$

Note that: Kinetic energy is directly proportional to the speed or velocity of a body. Therefore, the faster the body moves, the more the kinetic energy it has.

The derivation of the above formula, $K.E = \frac{1}{2}mv^2$. (NB: NOT important at 'O' Level)

Consider a body of mass, m , moving with an initial velocity, u , from rest and is acted upon by a force, F . The force gives the body an acceleration, a , and acquires a final velocity, v , after covering a distance, s in metres.

These quantities are related by the equation of linear motion (See chapter 11).

$$\begin{aligned} \text{Now } \quad & \text{Work done} = \text{Force} \times \text{Distance} \\ & = F \times s \\ \text{But } \quad & F = ma \quad (\text{Newton's second law of motion}) \end{aligned}$$

∴ Substituting for F, we have:

Substituting equation (1) in equation (2), i.e. substituting for a in equation (2), we obtain

$$\begin{aligned}\text{Work done} &= \frac{mv^2 s}{2s} \\ &= \frac{1}{2}mv^2\end{aligned}$$

By the law of conservation of energy, the work done by the force \mathbf{F} in pushing the body through the distance s will all be converted into kinetic energy of the body.

$$\text{K.E} = \frac{1}{2}mv^2$$

Worked Examples

1. Calculate the k.e of a bullet of mass 0.05 kg moving with velocity of 500 m/s.

Solution: $m = 0.05 \text{ kg}$, $v = 500 \text{ m/s}$, k.e = ?

$$\text{Kinetic Energy} = \frac{1}{2}m v^2 = \frac{1}{2} \times 0.05 \times 500^2 = 6,250 \text{ J or } 6.25 \text{ kJ}$$

2. A 10 g bullet traveling at 400 m/s penetrates 20 cm into a wooden block. Calculate the average force exerted by the bullet.

Solution: $m = 10 \text{ g} = \frac{10}{1000} \text{ kg}$, $v = 400 \text{ m/s}$, distance = 20 cm = $\frac{20}{100} \text{ m}$, k.e = ?

Note: This question seem to be difficult and quite different.

Hint: The work done in penetrating the block is related to the average force by the formula:

Work Done = Fs , so find the work done first and then use the above formula to find F .

$$\text{Kinetic Energy} = \frac{1}{2} \times m v^2 = \frac{1}{2} \times 10 \times 400^2 = \frac{1 \times 10 \times 400 \times 400}{2 \times 1000} = 5 \times 40 \times 4 = 800 \text{ J}$$

This kinetic energy is converted into work in penetrating the wooden block

Applying	Work done	= Force x Distance
	800	= $F \times \frac{20}{100}$
	20 F	= 800×100
	F	= $\frac{800 \times 100}{20}$
	$\therefore F$	= 4 000 N

7.34 The Law of Conservation of Energy

The law states that: *Energy can neither be created nor destroyed, but only changes from one form to another.*

Interchange of Energy between P.e and K.e

Energy is interchangeable between p.e and k.e depending on the body's present state. This interchange between p.e and k.e is seen in the following:

- (i) Simple pendulum.
- (ii) Falling object e.g. stone.

(a) Simple pendulum

In a swinging pendulum bob, the energy of the bob can be either p.e or k.e or both. This is explained in the diagram below.

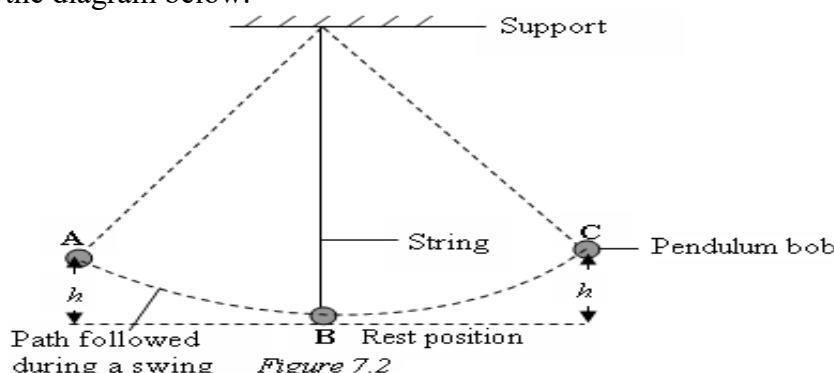


Figure 7.2

Facts about a swinging pendulum

- At the extreme ends (A and C) of the swing, the energy is all potential energy and maximum since h is maximum at A and C.
- When passing through the rest position (i.e B), it is all kinetic energy and maximum. This is because at B, $v = \text{maximum}$ and $h = 0$. And since $h = 0$, P.e = 0.
 - While at the intermediate points (i.e between AB and BC) the energy is partly kinetic and partly potential.

(b) Falling object e.g stone

Consider a piece of stone raised to a certain height above the ground level and let to fall.

At the maximum height, it possesses potential energy and no kinetic energy.

As the stone falls, its velocity increases. Since kinetic energy is directly proportional to the square of the velocity, then the k.e of the stone increases at the expense of the p.e (i.e at any particular moment, the stone possesses both p.e and k.e).

Ignoring the energy losses due to the air resistance, then the loss in p.e is equal to the gain in k.e in accordance with the *Law of Conservation of Energy*.

Consider the diagram below

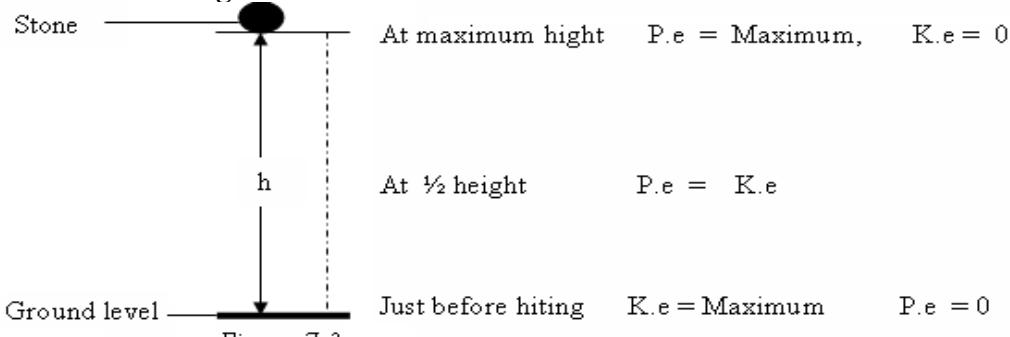


Figure 7.3

Note that: Potential energy decreases from maximum to zero and the kinetic energy increases to maximum. This is because as the h value decreases to zero, the velocity increases to maximum.

(c) Energy Transformations

By means of suitable mechanisms and apparatus, energy can be transformed from one form to another. This is shown in the table 7.2 below.

Activity	Energy Transformation
1. A boy running up a stair case	Chemical energy in the muscles is converted to K.E and then to p.e. (C.E \rightarrow K.E \rightarrow P.E)
2. Running water at a hydroelectric power station (water turning turbine which finally drives a generator)	P.E is converted to K.E and then electrical energy. (P.E \rightarrow K.E \rightarrow E.E)
3. A stone dropped from rest at a certain height until it hits the ground.	P.E is converted K.E then to heat and sound energy. (P.E \rightarrow K.E \rightarrow H.E \rightarrow S.E)
4. A moving car	Chemical energy due to the burning of fuel in the engine is converted to heat energy which is converted by pistons to kinetic energy. (C.E \rightarrow H.E \rightarrow K.E)
5. A coal fired engine drives a dynamo which lights a bulb.	Chemical energy is converted to heat energy, kinetic energy, electrical energy and lastly to light energy. (C.E \rightarrow H.E \rightarrow K.E \rightarrow E.E \rightarrow L.E)
6. A torch bulb flashing.	Chemical energy is converted to electrical energy, light energy and heat energy. (C.E \rightarrow E.E \rightarrow L.E \rightarrow H.E)

Figure 7.2

7.4 Engines

An engine is a machine for converting energy into motion or mechanical work. The energy is usually supplied in the form of a chemical fuel, such as oil or gasoline, steam, or electricity, and the mechanical work is most commonly delivered in the form of rotary motion of a shaft.

(a) Classification of Engines

Engines are usually classified according to the following:

- (i) The form of energy they utilize, as:
 - *Steam, compressed air, and gasoline;*
- (ii) The type of motion of their principal parts, as:
 - *Reciprocating and rotary;*
- (iii) The place where the exchange from chemical to heat energy takes place, as:
 - *Internal-combustion and external combustion;*
- (iv) The method by which the engine is cooled, as:
 - *Air-cooled or Water-cooled;*
- (v) The position of the cylinders of the engine, as:
 - *V, in-line, and radial;*
- (vi) The number of strokes of the piston for a complete cycle, as:
 - *Two-stroke and Four-stroke;*
- (vii) The type of cycle, as:
 - *Otto (in ordinary gasoline engines) and diesel; and*
- (viii) The use for which the engine is intended, as:
 - *Automobile and*
 - *Airplane engines.*

NB: *Engines are often called motors, although the term motor is sometimes restricted to engines that transform electrical energy into mechanical energy. Other specialized engines are the windmill, gas turbine, steam turbine, and rocket and jet engines.*

(b) Internal Combustion Engine (Heat Engines)

A heat engine is a machine which changes heat energy (obtained by burning fuel) to kinetic energy. The common heat engines are:

- (i) Petrol Engine and
- (ii) Diesel Engine

In internal combustion engine e.g. petrol engine or diesel engine, fuel is burnt in the cylinder where the energy change occurs.

(c) The Components of Internal-Combustion Engine

The basic components of an internal-combustion engine are:

- (i) *The engine block,* - made of cast iron or aluminum alloy and houses the cylinders, pistons, and crankshaft.
- (ii) *Cylinder head* - This is the upper part of the engine. It is bolted to the top of the block and seals the tops of the cylinders.
- (iii) *Cylinders* - This refers to the cylindrical space in which the piston reciprocates (i.e. moves freely up and down).

- (iv) *Pistons* -These are cylindrical metals fitted with rings for tight fitting. They move up and down thus compressing the mixture of air and fuel against the cylinder head prior to ignition. The top of the piston forms the floor of the combustion chamber.
- (v) *Valves block* An engine valve is a metal shaft with a disk at one end fitted to the opening. And the other end of the shaft is mechanically linked to camshaft.
- There are two valves:
 - *Inlet valve* - Controls the entry of fuel vapour in to the combustion engine.
 - *Outlet valve* - control the exit of exhaust gases out of the combustion chamber.
- (vi) *Crankshaft* This is the part of the engine which transforms the reciprocating motion of the piston into rotary motion. It rotates at speeds ranging from about 600 to thousands of revolutions per minute (rpm), depending on how much fuel is delivered to the cylinders thus allowing the up and down movement of the piston.
- (vii) *Camshaft* This a round rod with odd-shaped lobes located inside the engine block or in the cylinder head.

7.41 Petrol (Otto-cycle) engine (Four-stroke engine)

The ordinary Otto-cycle engine is a four-stroke engine; that is, in a complete power cycle, its pistons make four strokes, two toward the head (closed head) of the cylinder and two away from the head. In a gasoline engine a volatile mixture of fuel and air is ignited within a cylinder causing a sudden expenditure of gases. The expanding gases push down on a piston which turns the crankshaft.

A stroke is one movement of the piston either up or down. Most cars use four stroke cycle. The piston moves four strokes and the repeats the action continuously.

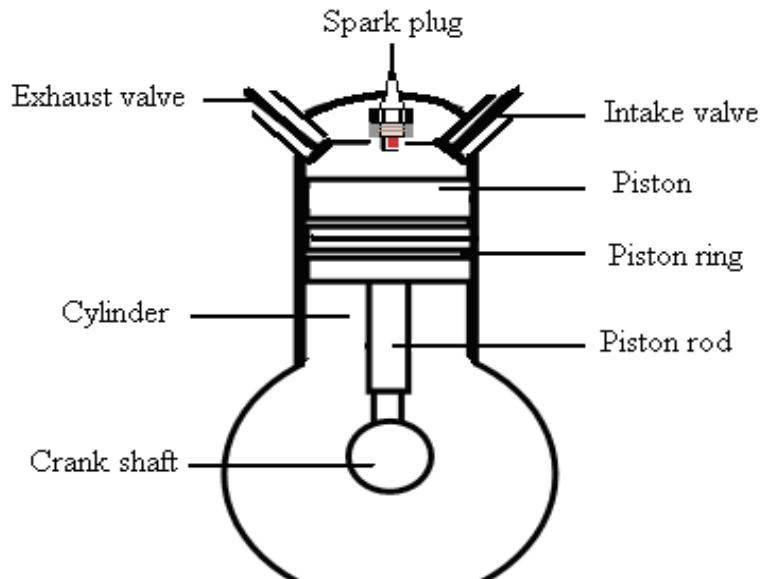


Figure 7.5

Mechanism of a four stroke engine

The mechanism of the four stroke engine is divided into:

- Intake stroke, Compression stroke, Power stroke and Exhaust stroke.

What happen in every stroke are illustrated in the diagrams below.

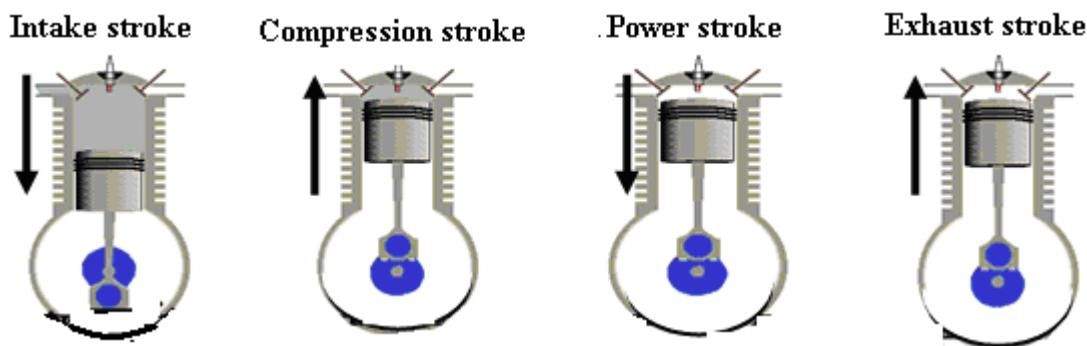


Figure 7.6

1. Intake

During intake (the first stroke of the cycle), the piston moves down (i.e. away from the cylinder head), the intake valve opens. A quantity of a fuel and air mixture is drawn into the combustion chamber.

2. Compression stroke

During the compression stroke, the valve closes, piston moves up and the fuel-air mixture is compressed.

3. Power stroke (the moment when the piston reaches the end of this stroke)

In the power stroke, both valves close and the volume of the combustion chamber is at a minimum, the spark plug produces electric spark, the fuel mixture ignites and burns. The expanding gaseous products exert pressure on the piston and force it down.

4. Exhaust stroke

During the final stroke (exhaust stroke), the exhaust valve opens and the piston moves up, driving the exhaust gases out of the combustion chamber and leaving the cylinder ready to repeat the cycle.

7.42 Diesel Engine

A Diesel Engine is a type of internal-combustion engine in which heat caused by air compression ignites the fuel.

The essential parts of diesel engines are similar to gasoline internal-combustion engines. But they differ in the following ways.

- They do not use spark plugs for igniting the air-fuel mixture.
- Diesel engines compress air inside the cylinders with greater force than a gasoline engine does, producing temperatures hot enough to ignite the diesel fuel on contact.
- Combustion takes place at constant volume rather than at constant pressure.
- During the intake stroke, air is only drawn.

Like petrol engines, most diesel engines are four-stroke engines but they operate differently than the four-stroke Otto-cycle engines.

Mechanism of Four stroke Diesel Engines

1. **Intake stroke** During the intake stroke, the inlet valve opens; air is drawn into the combustion chamber.
2. **Compression stroke** On the second, or compression, stroke the air is compressed to a small fraction of its former volume and is heated to approximately 440° C by this compression.
3. **Power stroke** At the end of the compression stroke, vaporized fuel is injected into the combustion chamber and burns instantly because of the high temperature of the air in the chamber. This combustion forces the piston down.
4. **Exhaust stroke** During the final stroke (exhaust stroke), the exhaust valve opens and the piston moves up, driving the exhaust gases out of the combustion chamber and leaving the cylinder ready to repeat the cycle.

Facts about Diesel Engines

- ❖ Diesels engines are, in general, slow-speed engines with crankshaft speeds of 100 to 750 revolutions per minute (rpm) as compared to 2500 to 5000 rpm for typical Otto-cycle engines.
- ❖ Some types of diesel engine, however, have speeds up to 2000 rpm. Because they use compression ratios of 14 or more to 1, they are generally more heavily built than petrol engines, but this disadvantage is counterbalanced by their greater efficiency and the fact that they can be operated on less expensive fuel oils.
- ❖ They are commonly used in large trucks or buses and machinery.

Advantages of diesel engines over petrol engines

- (i) Diesel engines are more efficient than petrol engines
- (ii) They consume less fuel and therefore, they are less expensive to operate than gasoline-powered engines, partly because diesel fuel costs less.
- (iii) Diesel engines emit fewer waste products than petrol engines.

Disadvantage of diesel engines

Diesel engines produce sooty and smelly smoke.

7.43 Two-Stroke Engines

Mechanism of two-stroke diesel engine

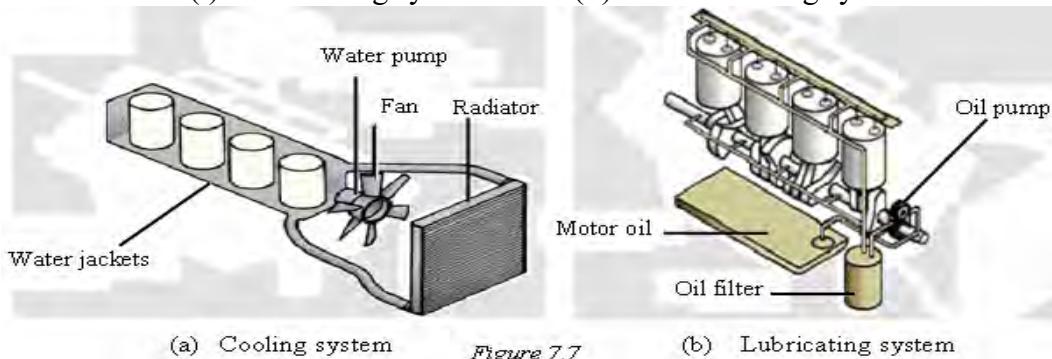
- ❖ In the two-stroke cycle, the fuel mixture or air is introduced through the intake port when the piston is fully withdrawn from the cylinder.
- ❖ The compression stroke follows, and the charge is ignited when the piston reaches the end of this stroke.
- ❖ The piston then moves outward on the power stroke, uncovering the exhaust port and permitting the gases to escape from the combustion chamber.

- NB:**
- *The power of a two-stroke engine is usually double that of a four-stroke engine of comparable size.*
 - *The general principle of the two-stroke engine is to shorten the periods in which fuel is introduced to the combustion chamber and in which the spent gases are exhausted to a small fraction of the duration of a stroke instead of allowing each of these operations to occupy a full stroke.*

7.44 Carburetor and Fuel-Injection System

- (a) **Carburetor** A carburetor is a device that mixes fuel and air for burning in an internal-combustion engine. It atomizes (converts into a vapor of tiny droplets) liquid gasoline. An air-flow carries the atomized gasoline to the engine's cylinders, where the gas is ignited.
- (b) **Fuel-Injection System**
A fuel-injection system is a system of delivering fuel to an internal-combustion engine. In a fuel-injection system, electronically controlled fuel injectors spray measured amounts of fuel into each of the engine's cylinders where the fuel is burned to power the engine.
The fuel-injection system replaces the carburetor in most new vehicles. Its advantage over carburetor is that it provides a more efficient fuel delivery system.
- (c) **Factors limiting the efficiency heat engines**
The efficiency of a modern Otto-cycle engine is limited by a number of factors. These include energy losses: (i) By cooling and (ii) Friction.
- (d) **Improving the efficiency of heat engines**
The efficiency of heat engines is increased by equipping all engines with:

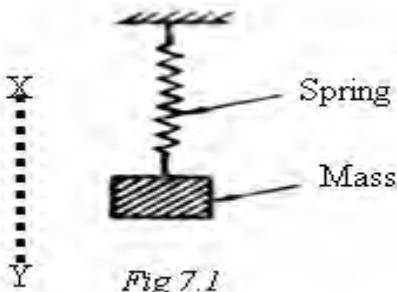
(i) Cooling system and (ii) Lubricating system.



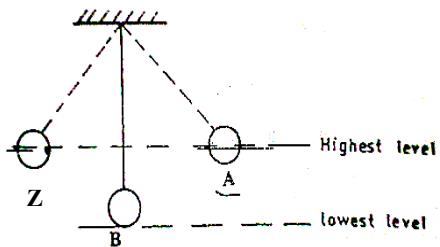
- (a) **Cooling System**
Cooling in engines is achieved by circulating water. A water pump circulates engine coolant, a mixture of water and antifreeze, through the non-moving parts of the engine to absorb heat. The coolant routes through tubes in the radiator, where heat passes through the tubes into the metal fins. A fan blows air through the fins to increase the rate of cooling. In addition to this, the radiator is painted black in order to increase the rate of cooling since „black colour“ is a good emitter of heat energy.
- (b) **Lubricating System**
In the lubricating system, a pump circulates motor oil, the main lubricant in an automobile engine is called *galleries*. It is circulated to all the moving parts of the engine. The lubricating system reduces the friction produced by the engine's moving parts, which rub against each other thousands of times per minute.
NB: *Before the oil circulates, it passes through an oil filter which strains particles from the oil.*

Self-Check 7.0

1. A crane raises a mass of 500 kg vertically upwards at a speed of 10 ms^{-1} . Find the power developed
 A. 5.0×10^0 B. 5.0×10^1 C. 5.0×10^2 D. 5.0×10^4
2. A girl whose mass is 50 kg runs up a staircase 25 m high in 4 s. Find the power she develops.
 A. $\frac{50 \times 4}{25} W$ B. $\frac{50 \times 10}{25 \times 4} W$ C. $\frac{50 \times 25}{4} W$ D. $\frac{50 \times 10 \times 25}{4} W$
3. A train traveling at a constant speed of 20 m/s overcomes a resistive force of 8 kN. The power of the train is
 A. $(8 \times 20) W$ B. $(8 \times 10 \times 20) W$ C. $(8 \times 100 \times 20) W$ D. $(8 \times 1000 \times 20) W$
4. A pump is rated at 400W. How many kilograms of water can it raise in one hour through a height of 72m?
 A. 0.8kg B. 5.6kg C. 33.3kg D. 2000kg
5. A boy carrying a load of 6 kg runs upstairs. If the work that the boy does is 300 J, find the height of the stairs.
 A. 3m B. 5m C. 6m D. 10m
6. Tony can pull a box 2m in 5 sec. Ever (Tony's sister) can pull the same box in 10 sec. Assuming both apply the same force, what is the ratio of Tony's power to the sister's power = ?
 A. 1 B. 2 C. $\frac{1}{2}$ D. 4
7. An engine exerts a force of 2000N at a speed of 15ms^{-1} . Find the power developed by the engine in kW.
 A. 30 000 B. 3 000 C. 300 D. 30
8. A constant force of 5N acts on a body and moves it through a distance of 20m in 10 seconds. Calculate its power.
 A. 2.5W B. 10W C. 40W D. 100W
9. A mouse of mass 0.03 kg climbs through a distance of 2 m up a wall in 4 s. The power expended in watts is
 A. $0.03 \times 2 \times 4 \times 10$ B. $\frac{0.03 \times 4 \times 2}{10}$ C. $\frac{0.03 \times 4 \times 10}{2}$ D. $\frac{0.03 \times 10 \times 2}{4}$
10. A bullet of mass 0.02kg is fired with a speed of 40m s^{-1} . Calculate its kinetic energy.
 A. 0.4 J. B. 0.8 J. C. 16 J. D. 32 J.
11. Which of the following statements is true about an electric motor? It changes
 A. Kinetic energy to electric energy B. Electrical energy to light energy
 C. Electrical energy to kinetic energy D. Chemical energy to electrical energy
12. A body pulls a block of wood with a force of 30N through a distance of 300m in 2 minutes. Find the power he develops, if he pulls the block at a constant speed.
 A. $\frac{30 \times 300}{2}$ B. $\frac{30 \times 300}{2 \times 60}$ C. $\frac{30 \times 2 \times 300}{300}$ D. $\frac{300}{2 \times 60 \times 30}$
13. A ball of 1kg bounces off the ground to a height of 2m after falling from a height of 5m, find the energy lost.
 A. 5 J B. 20 J C. 30 J D. 50 J

- 14.** A man weighing 800N climbs a vertical distance of 15m in 30s. What is the average power output?
 A. $80/3$ W B. $800/15$ W C. 400 W D. 5 kW
- 15.** In which action(s) below is there a work done?
 I. Pushing a wall without moving it. II. Taking a book from a table to a higher shelf.
 III. Walking on a bridge for 50 m
 A. I only B. II only C. III only D. II and III only
- 16.** A bullet of mass 5g is fired at a speed of 400ms^{-1} . How much energy does it have?
 A. $\frac{1}{2} \times 5 \times 10^2 \times 400\text{J}$ B. $\frac{1}{2} \times 5 \times 10^3 \times 400\text{J}$
 C. $\frac{1}{2} \times 5 \times 10^{-3} \times 400 \times 400\text{J}$ D. $\frac{1}{2} \times 5 \times 10^2 \times 400 \times 400\text{J}$
- 17.** Which of the following forms mechanical energy?
 A. Electrical energy and kinetic energy B. Potential energy and nuclear energy
 C. Nuclear energy and kinetic energy D. Potential energy and kinetic energy
- 18.** An object, of mass 2kg, dropped from the top of a building hits the ground with kinetic energy of 900J. The height of the building is
 A. 30m B. 45m C. 90m D. 180m
- 19.** A mass attached to the end of a string moves up and down to maximum and minimum points X and Y as shown in figure 7.1 below. When the mass is at X the
- 
- Fig 7.1*
- A. kinetic energy is maximum, potential energy is minimum
 B. kinetic energy is zero, potential is maximum
 C. kinetic energy is equal to potential energy
 D. kinetic energy and potential energy are both zero
- 20.** An electric motor of power 500 watts lifts an object of 100 kg. How high can the object be raised in 20 sec?
 A. 40m B. 30m C. 20m D. 10m
- 21.** A motor can pull a 400 kg box up to a height of 10m in 4 sec. What is the power of the motor in kW?
 A. 10 B. 20 C. 30 D. 40

- 22.** The diagram in the figure 3 shows an oscillation pendulum bob. Which of the following statements is true about its motion?



- A. the K.E at B is equal to the K.E at A
- B. the K.E at B is less than the P.E at A
- C. the K.E at B is equal to the P.E at A.
- D. the K.E at B is greater than the P.E at Z.

Figure 7.2

- 23.** A toy car is pulled with a force of 10 N for 5m. If the friction force between the block and the surface is 5N, what is the net work done on the toy car?



- A. 50 J
 - B. 100 J
 - C. 200 J
 - D. 25 J
- 24.** The energy changes that take place when a stone falls freely from rest to the ground can be orderly arranged as:
- A. Kinetic energy → Potential energy → Sound energy → Heat.
 - B. Sound energy → Potential energy → Kinetic energy → Heat.
 - C. Potential energy → Sound energy → Kinetic energy → Heat.
 - D. Potential energy → Kinetic energy → Heat energy → Sound.
- 25.** Ali and Veli move identical boxes equal distances in a horizontal direction. Since Ali is a weak child, the time needed for him to carry his box is two times longer than for Veli. Which of the following is true for Ali and Veli.
- A. Ali does less work than Veli
 - B. Veli does less work than Ali.
 - C. Each does the same work.
 - D. Neither Ali nor Veli do any work

SECTION B

- 26.**
- (a) Define the following terms.
 - (i) Work.
 - (ii) Power.
 - (b) State and define the SI units of the terms you have defined above.
 - (c) A crane lifts a load of 3500 N through a vertical height of 5 m in 5 second.
Calculate:
 - (i) the work done.
 - (ii) the power developed by the crane.
- 27.**
- (a) Define the term energy and state the SI unit for measuring it.
 - (b) Distinguish between potential energy and kinetic energy.
 - (c) A block of mass 2 kg falls freely from rest through a distance of 3m. Find the kinetic energy of the block.
- 28.**
- (a) Define a joule.
 - (b) Describe briefly how you can measure your power.
 - (c) A boy of mass 45 kg runs up a flight of 60 steps in 5 seconds. If each step is 12 cm.
Calculate:
 - (i) the work done against gravity by the boy.
 - (ii) the power developed by the boy.
- 29.**
- (a)
 - (i) State the types of heat engines you know.
 - (ii) Describe the mechanism of operation of a four stroke petrol engine.
 - (b)
 - (i) What are the factors that affect the efficiency of an engine?
 - (ii) State how the factors you have stated in (c) above are minimized in a heat engine.

CHAPTER EIGHT

MACHINES

LEARNING OBJECTIVES

By the end of this chapter, you should be able to:

1. Define:
 - Machine,
 - Mechanical Advantage (M.A),
 - Velocity Ratio (V.R),
 - Efficiency (η).
 2. State:
 - The types of machines,
 - Classes of levers,
 - Practical uses of machines.
 3. Carry out calculation on:
 - M.A, V.R and η for the various types of machines.
 4. Sketch graphs of:
 - M.A against load and
 - η against load.
 5. Explain:
 - The shapes of the graphs and
 - Why the graph for efficiency against load levels below 100%.
-

8.1 Machine

Definition: *A machine is a device that makes work easier for man.*

The “machine” is a symbol of modern life. In machines an effort (force) is applied to move a load. The effort can be:

- Muscular effort from man or
- Force derived from an engine.

Principle of Simple Machines

The principle used in simple machines is to produce a big force over a small distance by using a small force over large distance. The force which we apply to the machine is known as effort (E) and the force which we have to overcome is known as load (L).

8.11 Types of machines

There are two types of machines namely:

- Simple machines and
- Complex machines.

(a) Simple Machines

These are devices that work with one movement and change the size and direction of forces. Examples of simple machines are simple tools with one or two parts.

Although simple machines provide the advantage of using less force (effort) and thus making the work easier, they do not reduce the amount of work.

(b) Kinds of Simple Machines

There are six kinds of simple machines. They include the following:

- Lever, Pulley, Wheel and Axle, Inclined plane, Gears, Screws.

Note: *The screw and the wedge are modified forms of inclined plane. So we can say that basically there are four classes of simple machines.*

- 8.12 Levers:** A lever is a rigid bar which is free to move about a fixed point known as the fulcrum or pivot. It is divided into classes.

Classes of Lever

There are three classes of levers, namely:

- (i) the first class lever
- (ii) the second class lever and
- (iii) the third class lever.

(a) First Class Lever

A first class lever is the type of lever in which the fulcrum is in between the effort and the load. Examples of first class levers are:



Pair of scissors

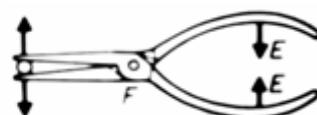
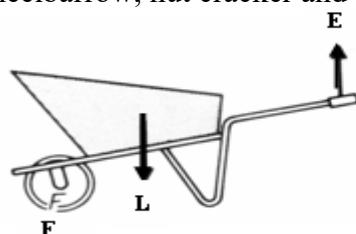


Figure 8.1

Pair of Pliers

(b) Second Class Lever

A second class lever is a lever in which the load is between the effort and the fulcrum. A wheelbarrow, nut cracker and a bottle opener are examples of second class levers.



Wheel barrow



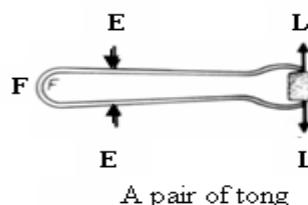
Figure 8.2

Nut Cracker

(c) Third Class Lever

A third class lever is a lever in which the effort is between the load and fulcrum.

Examples of third class levers are:



A pair of tong

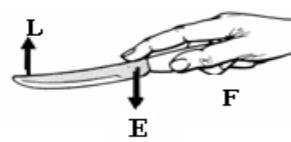
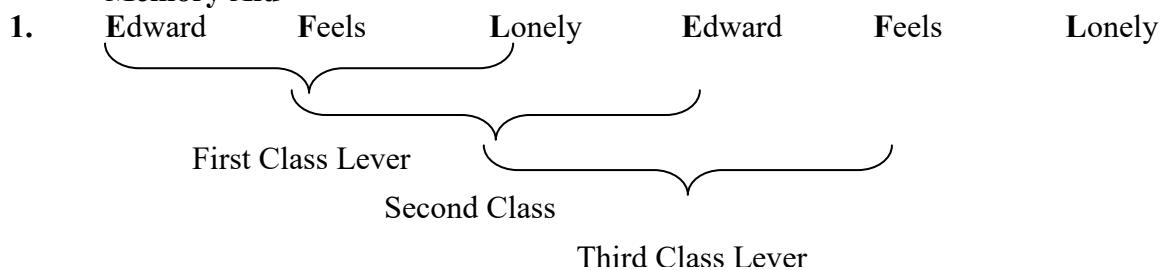


Figure 8.3

Table knife

Memory Aid



2. Use the word **PLE** to remember the classes of lever. When each letter is in the middle beginning from P to E, the order of the classes starts from 1st to 3rd. See summary in the table below.

Position of letter	Class of lever
L P E	1 st
P L E	2 nd
P E L	3 rd

PLE stands for Pivot, Load and effort respectively.

8.13 Mechanical Advantage (M.A)

The relation-ship between the load (L) and the effort (E) acting on a simple machine is called *mechanical advantage*. In ideal conditions (condition where there is no loss in energy due to friction) mechanical advantage is defined as: - *the ratio of the load to the effort*.

$$\text{Mechanical Advantage (M.A)} = \frac{\text{Load (L)}}{\text{Effort (E)}}$$

$$M.A = \frac{L}{E}$$

NB: Mechanical advantage has no unit. This is because it is the ratio of the same quantity i.e. force.

Examples

1. If a lever can be used to overcome a load of 50 N by applying an effort of 10 N. Find the M.A of the ever.

Solution: L = 50 N, E = 10 N, M.A = ?

$$M.A = \frac{L}{E} = \frac{50}{10} = 5$$

2. (a) A lever is used to overcome a load of 2000 N. If the M.A 2, calculate the effort applied.
 (b) If the same lever is used to overcome a load by applying an effort of 50 N, determine the

maximum load that can be overcome.

Solution:

(a) L = 2000 N, E = ?, M.A = 2 (b) L = ?, E = 50 N, M.A = 2

$$M.A = \frac{L}{E}$$

$$2 = \frac{2000}{E}$$

$$2E = 2000$$

$$E = \frac{2000}{2}$$

$$E = 1000 \text{ N}$$

$$M.A = \frac{L}{E}$$

$$2 = \frac{L}{50}$$

$$L = 2 \times 50$$

$$E = 100 \text{ N}$$

8.2 Pulleys

A pulley is a wheel with a grooved rim over which passes a rope or string. The effort is applied to one end of the rope and the disk of the pulley rotates as the rope moves over it.

There may be several pulleys in a frame work called a *block*.

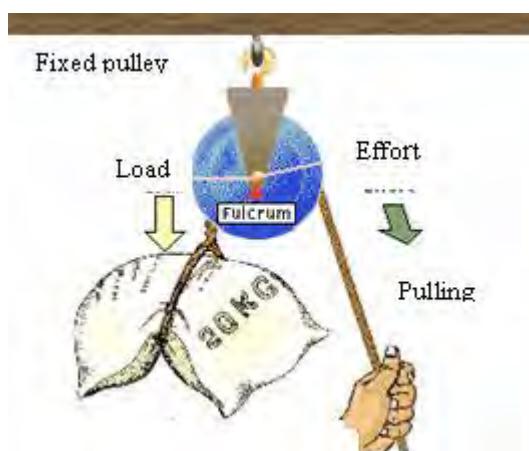
Types of Pulleys

There are several types of pulleys in use. But the most common ones are:

- Single fixed pulley.
- Single movable pulley and
- Block and Tackle system.

Pulleys reduce the effort to lift an object by increasing the distance over which the effort is applied.

8.21 A Single Fixed Pulley



A single fixed pulley is a type of pulley fixed to a support usually up as shown in figure 8.4. A rope passes over the groove of the pulley. One end of the rope is attached to the load and the effort is applied at the other end.

Common examples of a single pulley can be found at the top of a flagpole and in construction sites. Pulling down on the rope causes the flag (load) to move upward. Thus, the pulley changes the direction of the force applied to the rope.

(a) Facts about the Single fixed pulley

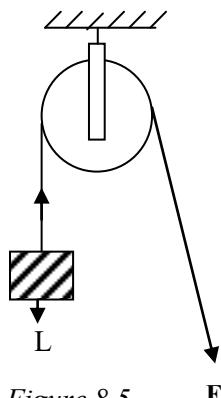


Figure 8.5

- ❖ A single fixed pulley is like first class lever because its fulcrum is in between the load and the effort.
- ❖ The force arms of the pulley are equal to each other, therefore: $E = L$ in an ideal machine. However, in practice the effort applied to overcome the load must be greater than the load. This is due to friction in the moving parts of the pulley.
- ❖ The tension is the same throughout the rope.
- ❖ If we pull the rope down by x m, the load rises up by the same distance, x m, and gains a potential energy.
- ❖ Its diagram is always drawn as simple as in figure 8.5.

(b) To Show that for an ideal condition $E = L$ (i.e.

Neglecting friction)

Neglecting friction, in the system we have:

$$\begin{aligned} \text{Work in put} &= \text{Work out put} \\ \text{Work done by effort} &= \text{Work done by load} \end{aligned}$$

$$\text{Effort} \times \text{Effort distance} = \text{Load} \times \text{Load distance}$$

$$E \times x \text{ m} = L \times x \text{ m}$$

$$E = \frac{L \times x \text{ m}}{x \text{ m}}$$

$$E = L$$

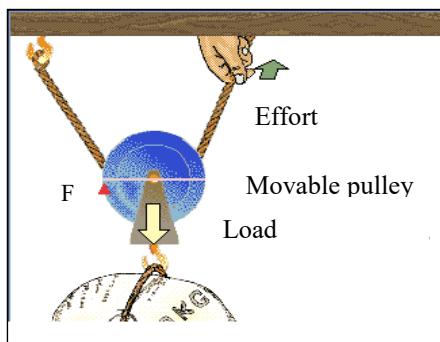
(c) Mechanical Advantage (M.A) of a Single Fixed Pulley

In a single fixed pulley, the tension is the same throughout the rope. Neglecting the weight of the string and the frictional forces in the pulley, we have;

$$\begin{aligned}\text{Load} &= \text{Effort} \\ \text{M.A} &= \frac{\text{Load}}{\text{Effort}} \\ &= \frac{L}{E} \quad \text{But } L = E \\ \therefore \text{M.A} &= 1\end{aligned}$$

- NB:**
- (i) *M.A = 1 means that there is no gain in either force or distance in a fixed pulley, therefore, no mechanical advantage.*
 - (ii) *In reality, the actual MA is slightly less than 1 because of the friction of the rope against the pulley and the friction between the pulley and the axle on which it turns.*
 - (iii) *The primary benefit of a single pulley is to change the direction of the force or to move a load to a point (such as the top of a flagpole) that cannot be reached by the user.*

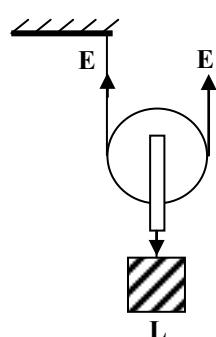
8.22 A Single Movable Pulley



A Single movable pulley is a pulley which moves along a rope with the load attached to it. One end of the rope is tied to a fixed support and passes over the pulley and the other end where the effort is applied goes back up to the user.

Figure 8.6

(a) Facts about a single movable fixed pulley



- ❖ A single movable pulley reduces the amount of effort needed to lift the load. i.e. half the load is necessary to lift a given load.
- ❖ If we pull the rope up by x m, the load rises by half the effort distance (i.e. $\frac{1}{2}x$ m).
- ❖ The tension in the string is equal to the effort applied, so that the total upward pull is twice the effort i.e. $2E$.
- ❖ For simplicity, its diagram is drawn as in figure 8.7

Figure 8.7

(b) Mechanical Advantage of Single movable pulley

Let load of L N be supported by the pulley and that the weight of the pulley and the string plus the frictional force in pulley are negligible.

Since the load is supported by two sections of the string, the effort applied is equal to $2E$.

$$\text{Load} = L \text{ N} \quad \text{and} \quad \text{Effort} = 2E \text{ N} \quad \text{But} \quad \text{Effort} = \text{Load}$$

$$\text{In equilibrium:} \quad \text{Down ward force} = \text{Upward force}$$

$$L = 2E$$

$$\frac{L}{E} = 2 \quad \text{But} \quad \frac{L}{E} = \text{M.A}$$

Alternatively

From

$$L = 2E$$

$$E = \frac{L}{2}$$

Substituting for L and E in

$$\text{M.A} = \frac{L}{E} \quad \text{we have;}$$

$$\text{M.A} = L \div \frac{L}{2}$$

$$= L \times \frac{2}{L}$$

$$\therefore \text{M.A} = 2$$

- NB:** (i) The MA of a movable pulley (or a system of pulleys with a movable part) equals the number of strands of rope coming from the movable part (the load being lifted).
(ii) Since a pulley system with an MA of 2 increases the force by a factor of 2, the pulley system must also double the distance the effort travels. Therefore, in order to raise a load a given distance, the user must pull and take in twice as much rope.

Worked Example

- An effort E is used to raise a load of 200 N. If the effort moves through a distance of 4 m, calculate: (i) the effort (ii) the M.A and (iii) the load distance.

Solution: $E = ?$, $\text{M.A} = ?$, Effort distance = ?, Load distance = 4 m, $L = 200$ N.

(i) In equilibrium;

$$\text{Down ward force} = \text{Upward force}$$

(ii) Mechanical Advantage,

$$\text{M.A} = \frac{\text{Load}}{\text{Effort}}$$

$$L = 2E \quad = \frac{200}{100}$$

$$E = \frac{L}{2} = \frac{200}{2} = 100 \text{ N} \quad \therefore \text{M.A} = 2$$

(iii) Neglecting friction, in the system we have:

$$\text{Work in put} = \text{Work out put}$$

$$\text{Work done by effort} = \text{Work done by load}$$

$$\text{Effort} \times \text{Effort distance} = \text{Load} \times \text{Load distance}$$

$$E \times E.d = L \times Ld$$

$$100 \times 4 = 200 \times Ld$$

$$Ld = \frac{100 \times 4}{200}$$

$$\therefore Ld = 2 \text{ m}$$

8.3 Block and Tackle System

A block and tackle system is a pulley system consisting of both fixed and movable pulleys.

In this system there are two blocks each block contains one or more pulley(s), depending on the M.A required. A single rope is used and passes over the groove of each pulley. The frame work of pulleys is called *block* and the rope passing over each pulley is called the *tackle*.

(a) Practical applications where Block and Tackle system is used

They are commonly used to raise or move load in:

- Sailing ships.
- Cranes,
- Lifts and
- Brake downs.

Diagrams Showing Block and Tackle Systems

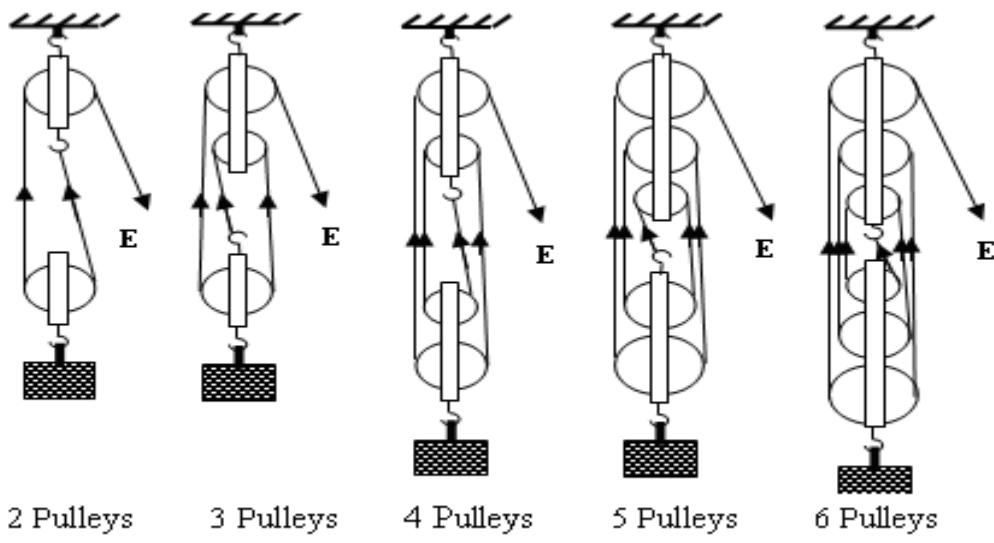


Fig. 8.8

Note: (i) For an odd number of pulleys in the system, the fixed upper block contains more by one and the string starts from the lower block.

(ii) The number of strings supporting the lower movable block is equal to the number of pulleys in the system.

(i) M.A of A Block And Tackle System

In block and tackle system an effort E , is applied and creates a tension, T , in the string. The movable lower block is acted upon by n sections of the string pulling it upwards and the load, L , pulling downwards.

For equilibrium in a perfect machine,

$$\begin{aligned} \text{Downward force} &= \text{Upward force} \\ \text{Load} &= \text{Total upward tension} \\ L &= nT \quad \text{But } T = E \\ L &= nE \end{aligned}$$

Substituting for L in $M.A = \frac{L}{E}$ we obtain:

$$\begin{aligned} M.A &= \frac{nE}{E} \\ \therefore M.A &= n \end{aligned}$$

Where: n = the number of strings supporting the lower block and is also = the total number of pulleys in the system.

- NB:**
- (i) The more the number of pulleys in the system, the higher the M.A and easier to do work.
 - (ii) In practice, however, the M.A is always less than the number of string supporting the lower block or less than the number of pulleys in the system.

Reason: Extra effort is required to overcome:

- (i) Friction in the moving parts of the pulleys
- (ii) The weight of the movable pulley and the string.

(c) Velocity Ratio (V.R) or Speed Ratio

Definition: *The velocity ratio of a machine is defined as: the ratio of the distance moved by the effort to the distance move by the load.*

$$\begin{aligned} \text{Velocity Ratio (V.R)} &= \frac{\text{Distance moved by effort}}{\text{Distance moved by load}} \\ V.R &= \frac{\text{Distance moved by effort}}{\text{Distance moved by load}} \end{aligned}$$

In any system of block and tackle, to raise the load by a distance of x m, each string supporting the load shortens by x m. The effort is therefore applied through a total distance of nx metres.

$$\text{From } V.R = \frac{\text{Distance moved by effort}}{\text{Distance moved by load}}$$

$$V.R = \frac{nx}{x}$$

$$V.R = n$$

\therefore the V.R of a block and tackle system = the number of strings supporting the lower block.
= the number of pulleys in the system

(d) Calculations for Perfect pulley systems

Steps in problem solving

Before solving any problem, ask yourself the following questions.

- ❖ What is asked in the question?
- ❖ What information is given to help you to solve the problem?
- ❖ What are the equations to solve the problem?

These questions can only be answered when you collect the data.

Example 1

A force of 10 N is required to raise a load, L, using a smooth (frictionless) and weightless block and tackle system of four pulleys. Calculate:

- (a) (i) Load,
(ii) M.A and
(b) Effort distance if the load rises by 2 m.

Solution: E = 10 N, M.A = ?, Effort dist = ?, Load dist = 2 m, L = ?, No. of pulleys = 4

(a) (i) In equilibrium; (ii) Mechanical Advantage,

$$\begin{aligned} \text{Down ward force} &= \text{Upward force} & \text{M.A} &= \frac{\text{Load}}{\text{Effort}} \\ L &= 4E & &= \frac{40}{10} \\ &= 4 \times 10 & \therefore \text{M.A} &= 4 \\ \therefore L &= 40 \text{ N} \end{aligned}$$

(iii) Neglecting friction, in the system we have:

$$\begin{aligned} \text{Work in put} &= \text{Work out put} \\ \text{Work done by effort} &= \text{Work done by load} \\ \text{Effort} \times \text{Effort distance} &= \text{Load} \times \text{Load distance} \\ E \times E.d &= L \times L.d \\ 10 \times E.d &= 40 \times 2 \\ E.d &= \frac{40 \times 2}{10} \\ \therefore E.d &= 8 \text{ m} \end{aligned}$$

8.31 The Principle of Work

The Principle of Work states that:

The amount of work output is always less than the amount of work input.

(a) Efficiency (η) of a Machine

Definition: *The efficiency of a machine is the ratio of work output to work input.*

Efficiency is always expressed in percentage form i.e.

$$\text{Efficiency} = \frac{\text{Work output}}{\text{Work input}} \times 100$$

NB: *Work output = Work done by the load*
Work input = Work done by the effort

(b) Relation between M.A, V.R and η

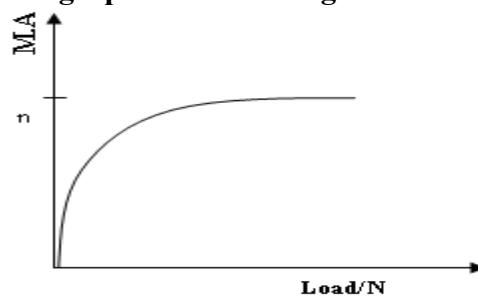
$$\begin{aligned}
 \text{From} \quad \text{Efficiency} &= \frac{\text{Work output}}{\text{Work input}} \times 100 \\
 \text{Efficiency} &= \frac{\text{Load} \times \text{distance moved by load}}{\text{Effort} \times \text{distance moved by effort}} \times 100 \\
 \text{Efficiency} &= \frac{\text{Load}}{\text{Effort}} \times \frac{\text{Distance moved by load}}{\text{Distance moved by effort}} \times 100 \\
 &= \text{M.A} \times \frac{1}{V.R} \times 100 \\
 \eta &= \frac{M.A}{V.A} \times 100
 \end{aligned}$$

- NB:** (a) This equation is useful only for solving problems. It is not a fundamental definition for efficiency and should NOT be used as such.
- (b) Efficiency of a machine is always less than 100.
Reasons: (i) Because of frictional forces between the moving parts of a machine.
(ii) For the case of pulleys, other reasons are:
- The weight of the string and
- the weight of the lower movable block.
- (c) Efficiency of a machine can be increased by:
(i) Lubricating the moving parts of the machine
(ii) For the case of pulleys, by making the string and the block plus the pulley(s) as light as possible.

8.32 Graphical Relations between M.A and Load and Efficiency and Load

When we plot M.A or η against load, the following graphs are obtained.

The graph of $M.A = n$ against Load



The graph of η against Load

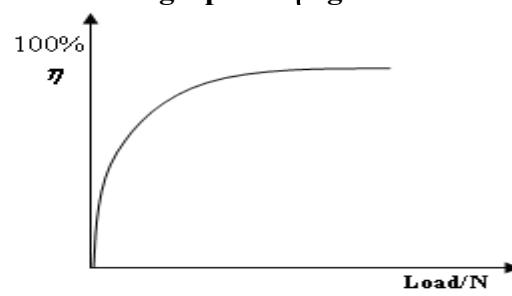


Figure 8.9

Explanation of the Shapes of the graphs

In both graphs, a small increase in load causes high increase in $M.A$ and η . On further increase on the load, the graphs begin to level as $M.A$ and η approach their maximum values. At a certain value of load, the $M.A$ and η reach their maximum values and then remain constant, hence, the graphs level.

- NB:** For figure (a), the graph levels at the value of the $M.A$. While for figure (b), the graph levels below 100% for imperfect machines and levels at 100% for perfect machines.

Worked Examples

1. (a) Define the following terms

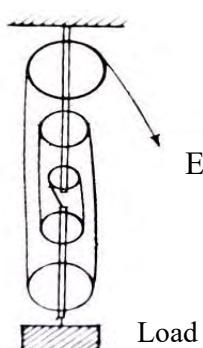


Figure 8.10

- (b) The diagram in the figure shows a pulley system used to raise a load.
- Mechanical advantage
 - Velocity ratio
- (c) What is the velocity ratio of the system?
- Find how far the load is raised if the effort moves down by 4m.
 - Calculate the effort required to raise a load of 800N, if the mechanical advantage of the system is 4.
 - Calculate the efficiency of the system.
- (d) Explain what happens to the efficiency of the system in (b) above if the load is much:
- less than 800N.
 - more than 800N.
- (e) Draw a sketch graph to show how mechanical advantage of the system in (b) varies with the load.
- (f) Give two practical applications where pulley systems are used.

Solution: (a) (i) Mechanical advantage is the ratio of load to effort.
 (ii) Velocity ratio is the ratio of effort distance to load distance.

(b) (i) V.R = 5
 (ii) Effort distance = 4 m, Load distance = ?, V.R = 5

$$V.R = \frac{\text{Effort distance}}{\text{Load distance}}$$

$$5 = \frac{4}{\text{Load distance}}$$

$$\text{Load distance} = \frac{4}{5}$$

$$\therefore \text{Load distance} = 0.8 \text{ m}$$

(iii) E = ?, L = 800N, M.A = 4.

$$M.A = \frac{\text{Load}}{\text{Effort}}$$

$$4 = \frac{800}{E}$$

$$E = \frac{800}{4}$$

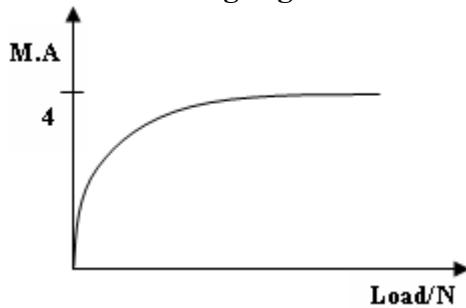
$$\therefore E = 200 \text{ N}$$

(iv) $\eta = ?$, M.A = 4, V.R = 5

$$\eta = \frac{M.A}{V.R} \times 100 = \frac{4}{5} \times 100 = 80\%$$

- (c) (i) The efficiency is less than 80%.
 (ii) The efficiency remains constant at 80%.

(d) The graph of mechanical advantage against load.



- (e)** They are used in: - Cranes, brake downs, ships, docks - for lifting load.

8.4 Inclined Plane

An inclined plane refers to a type of machine in which a plane is inclined to an angle to the horizontal such that one end is higher than the other. It is used to raise heavy load by pulling/pushing it along the sloping surface. This is much easier than lifting the load through the vertical height, h , since the weight of the load acts vertically downwards.

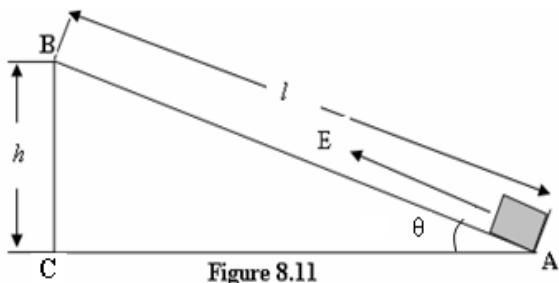


Figure 8.11

In order to raise the load through a vertical height h , the effort, E , is applied through a longer distance, l , equal to the length of the plane and the load is raised through a vertical height, h .

Examples of inclined plane include:

- Sloping roads and
- Stair case.

(a) M.A of an Inclined Plane

The M.A of an inclined plane may be obtained by assuming the machine to be perfect (i.e. neglecting the work done against friction).

Thus,

$$\text{Work output} = \text{Work input}$$

$$\text{Load} \times \text{Distance moved by load} = \text{Effort} \times \text{Distance moved by effort}$$

$$\frac{\text{Load}}{\text{Effort}} = \frac{\text{Distance moved by Effort}}{\text{Distance moved by load}}$$

$$M.A = \frac{l}{h} \quad \text{But in practice } M.A < \frac{l}{h}$$

(b) The V.R of the an Inclined plane

$$\text{Velocity Ratio} = \frac{\text{Distance moved by effort}}{\text{Distance moved by load}}$$

$$V.R = \frac{\text{Length of the plane}, l}{\text{Height of the plane}, h}$$

$$V.R = \frac{l}{h}$$

(c) The V.R of an Inclined plane in terms of angle of inclination, θ , (i.e $\angle BAC$)

$$\text{Velocity Ratio} = \frac{\text{Effort distance}}{\text{Load distance}}$$

Using trigonometry, AB and BC are expressed in terms of $\sin \theta$ and $\tan \theta$ and then substituted in equation 1.

$$\text{From } \sin \theta = \frac{BC}{AB} \\ AB = \frac{BC}{\sin \theta} \quad \dots \dots \dots \quad 2$$

$$\text{And from } \tan \theta = \frac{BC}{AC}$$

Substituting equations (2) and (3) in equation (1) we have:

$$\begin{aligned} V.R &= \frac{BC}{Sin\theta} \div Tan\theta.AC \\ &= \frac{BC}{Sin\theta} \times \frac{1}{Tan\theta.AC} \end{aligned}$$

$$V.R = \frac{BC}{Sin\theta.Tan\theta AC}$$

NB: *The derivation of the formula is not necessary at this level. So you should not get scared. Otherwise you will understand it when you cover trigonometry in mathematics in S.2..*

Example 1

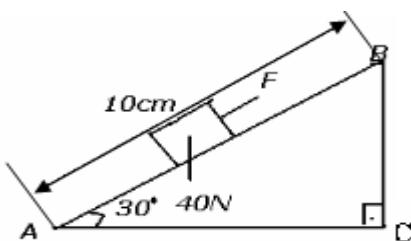


Figure 8.12

A load of 40N is pulled steadily from A to B along an inclined plane by a force F as shown in the figure 8.12. Find the velocity ratio of the system

A. 1.0 B. 1.2 C. 2.0 D. 4.0

Answer = C

How to work it:

$$AC = 10 \text{ cm}, \quad BC = ?, \quad \theta = 30^\circ$$

$$BC = \tan \theta \times AC$$

$$= \tan 30^\circ \times 10$$

$$= 0.5774 \times 10$$

$$BC = 5.774$$

Using the formula

$$V.R = \frac{BC}{\sin\theta \cdot \tan\theta \cdot AC} \text{ we have:}$$

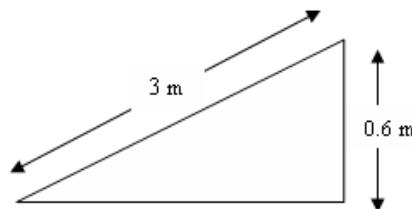
$$V.R = \frac{5.774}{\sin 30^\circ x \tan 30^\circ x 10} = \frac{5.774}{0.5 x 0.5774 x 10} = \frac{5.774}{2.887} = 2$$

Example 3

A wooden plank 3 m long is used to raise a load of 1200 N through a vertical height of 60 cm. If the frictional force between the load and the plane is 40 N, calculate:

- (a) The effort required.
- (b) The mechanical advantage.

Solution: (a)



Data: $L = 1200 \text{ N}$, $E = ?$, $l = 3 \text{ m}$, $h = 60 \text{ cm} = 0.6 \text{ m}$, Frictional force = 40 N.

The effort required can be got by applying the principle of work.

$$\begin{array}{lll} \text{Work input} & = \text{Work output} & + \text{Useless work done} \\ \text{Work done by effort} & = \text{Work done load} & + \text{Work by frictional force} \\ \text{Effort} \times \text{Effort dist.} & = \text{Load} \times \text{Load dist.} & + \text{Frictional force} \times \text{Effort distance} \\ E \times 3 & = 1200 \times 0.6 & + 40 \times 3 \\ E \times 3 & = 720 & + 120 \\ 3E & = 840 \\ E & = \frac{840}{3} \\ \therefore E & = 280 \text{ N} \end{array}$$

$$(b) \quad M.A = \frac{L}{E} = \frac{1200}{280} = 5$$

8.5 Wheel and Axle

A wheel and axle is a type of simple machine made up of a wheel and axle tightly attached to each other so that they turn together about an axis. The effort is applied to

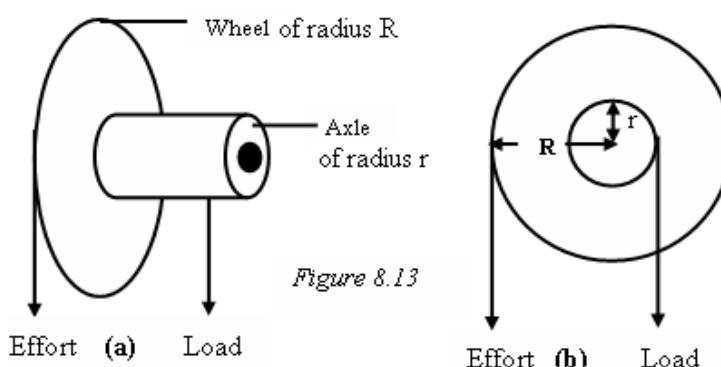


Figure 8.13

the larger wheel and the load is raised by a string attached to the axle as shown in figure 8.13 below.

For one complete turn, the load and the effort move through distances equal to the circumferences of the wheel and the axle respectively.

(a) Facts about the Wheel and Axle

- ❖ A small force applied over a large distance raises a large force over a small distance.
- ❖ A wheel and axle is simply a first class lever which moves in a circle; having the fulcrum at the centre. See figure 8.13 (b).

(b) The V.R of Wheel and Axle

$$\begin{aligned}\text{Velocity Ratio} &= \frac{\text{Distance moved by effort}}{\text{Distance moved by load}} \\ &= \frac{\text{Circumference of the wheel}}{\text{Circumference of the axle}} \\ &= \frac{2\pi R}{2\pi r} \\ V.R &= \frac{R}{r}\end{aligned}$$

Where: R and r are the radius of the wheel and the axle respectively.

The larger the radius of the wheel, the higher the V.R and easier work done..

(c) The M.A of Wheel and Axle

The M.A of wheel and axle is obtained by taking moments of the load and effort about the axis of rotation.

Applying the principle of moments, figure 8.13 (b) we have:

$$\begin{aligned}\text{Clockwise moment} &= \text{Anti-Clockwise moment} \\ \text{Load} \times \text{Radius of axle} &= \text{Effort} \times \text{Radius of the wheel} \\ \frac{\text{Load}}{\text{Effort}} &= \frac{\text{Radius of wheel}}{\text{Radius of axle}} \\ M.A &= \frac{R}{r}\end{aligned}$$

But in practice $M.A < \frac{R}{r}$ due to frictional forces in the machine.

Example

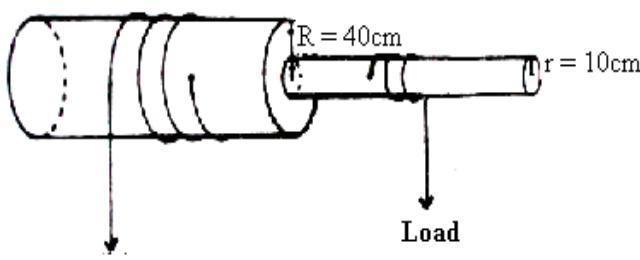


Fig. 8.15

The above figure shows a wheel and axle system. When an effort of 300N is applied, a load of 900N is raised through a distance of 1.0 m. Calculate;

- The velocity ratio.
- The efficiency of the system.

Solution: (a) $R = 40 \text{ cm}, r = 10 \text{ cm}, E = 300 \text{ N}, L = 900 \text{ N}$

$$V.R = \frac{R}{r} = \frac{40}{10} = 4$$

$$(b) \eta = \frac{M.A}{V.R} \times 100 = \frac{L}{E} \times \frac{1}{V.R} \times 100 = \frac{900}{300} \times \frac{1}{4} \times 100 = \frac{3}{4} \times 100 = 75 \%$$

8.6 Gears

A gear is a device which consists of a set of toothed wheels. Gears change the direction and the speed of rotation. They are similar to wheel and axle. In gear wheels, the effort and the load are applied to the shafts connected to the gears.

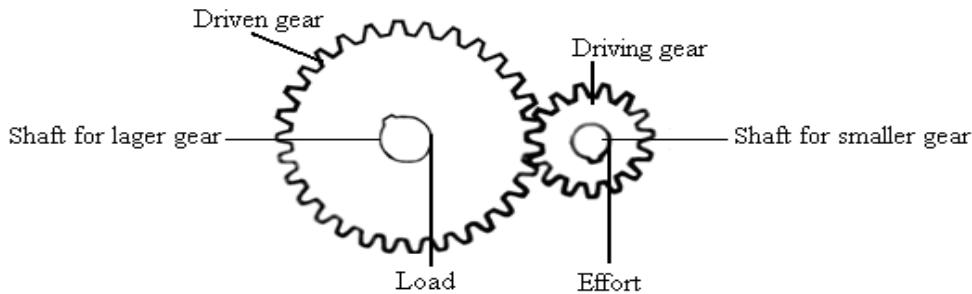


Figure 8.16

(a) Types of gears

There are four types of gear systems, namely:

- Spur gears,
- Worm gear,
- Rack and Pinion and
- Bevel gears

Figure 8.17 below shows the common types of gear systems in use.

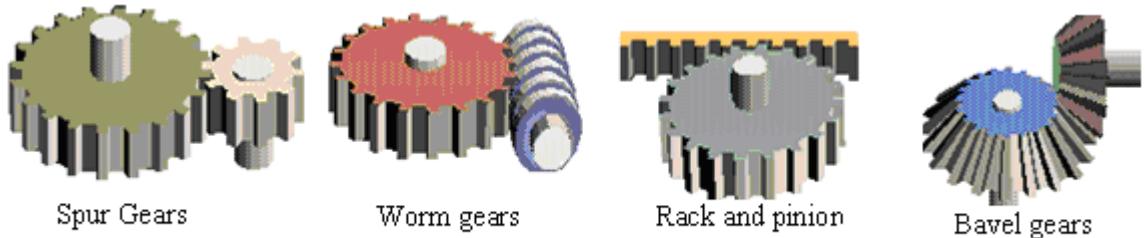


Figure 8.17

(b) Facts about gears

- ❖ When a gear is engaged, the order of the rotation and the speed of the gears change.
- ❖ The number of rotation of gear wheels depends on the ratio of the number of teeth and radii of the wheels.
- ❖ The direction of driven gear is opposite to that of the driving gear.
- ❖ There are several gear systems as shown in figure 8.17 above. But we always consider the spur gears.

(c) The Velocity Ratio of Gears

Whichever the driving and the driven wheel is the V.R is given by the formula:

$$\text{Velocity Ratio} = \frac{\text{Number of teeth in the driven wheel}}{\text{Number of teeth in the driving wheel}}$$

The velocity ratio of gears depends on which gear wheel is the effort applied.

Torque may be applied to the smaller gear in order to increase the torque and decrease the rate of rotation of the larger gear. Or

Torque may be applied to the larger gear in order to decrease the torque and increase the rate of rotation of the smaller gear.

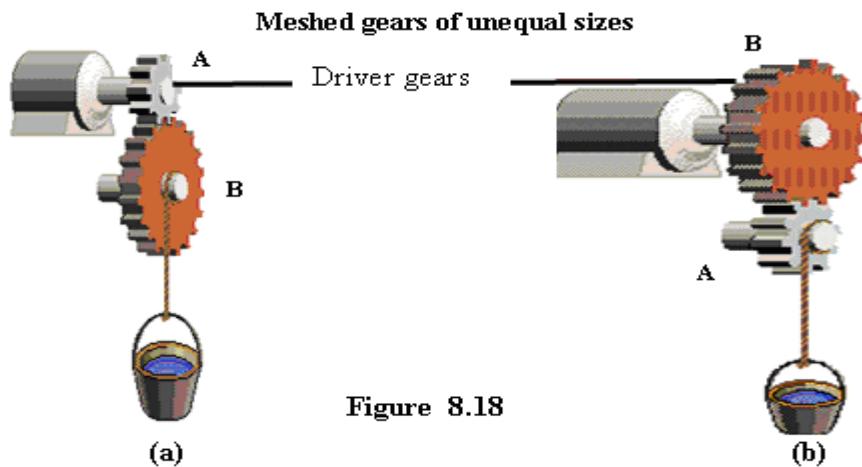


Figure 8.18

Example

1. Two gear wheels A and B with 20 and 10 teeth respectively lock into each other. They are fastened on axles of equal diameters such that a weight of 100 N attached to a string wound around one axle raises a load of 160 N attached to a string wound around the other axle. Calculate:
 - (a) (i) the velocity ratio.
 - (ii) the efficiency of the system, for figure 8.18 (a).
 - (b) (i) the velocity ratio.
 - (ii) the efficiency of the system, for figure 8.18 (b).

Solution: No. of teeth of driving wheel, A = 10, No. of teeth of driven wheel, B = 20,

$$E = 100\text{N}, \quad L = 160\text{ N}$$

$$(a) \quad (i) \quad V.R = \frac{\text{Number of teeth in the driven wheel}}{\text{Number of teeth in the driving wheel}} = \frac{10}{20} = 0.5$$

$$(ii) \quad \eta = \frac{M.A}{V.R} \times 100 = \frac{L}{E} \times \frac{1}{V.R} \times 100 = \frac{160}{100} \times \frac{1}{0.5} \times 100 = \frac{600}{0.5} = 320\%$$

$$(b) \quad (i) \quad V.R = \frac{\text{Number of teeth in the driven wheel}}{\text{Number of teeth in the driving wheel}} = \frac{20}{10} = 2$$

$$(ii) \quad \eta = \frac{M.A}{V.R} \times 100 = \frac{L}{E} \times \frac{1}{V.R} \times 100 = \frac{160}{100} \times \frac{1}{2} \times 100 = 80\%$$

8.7 The Screw

The screw is a slope turning around a pole. It is like spiral stair case. Like a load moving up or down an inclined plane under the effect of an effort, a screw goes in or comes out of a bolt or wood. It is an essential feature of machines such as the vice and the car screw jack. The distance between any two successive threads on a screw is called *pitch*. Normally the vice and the car jack have handles to which effort, E, is applied. When we turn the screw, it changes the direction of the effort. For a complete turn, the load, L, moves a distance equal to the pitch.

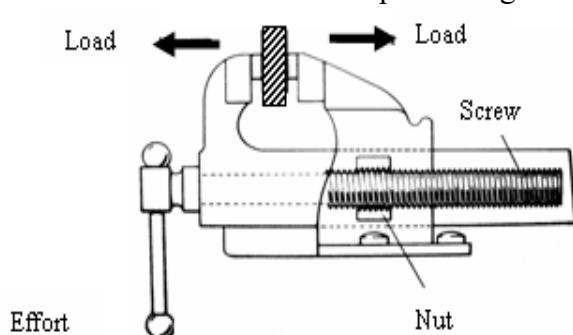


Figure 8.19 Vice

(a) M.A of the screw

The M.A is obtained by assuming the system to perfect i.e. ignoring frictional forces.

Thus, Work done by effort, E = Work done by load, L

Effort x Distance moved by effort = Load x Distance moved by the load

$$\text{Effort} \times \frac{\text{Circumference of the circle traced by effort}}{2\pi} = \text{Load} \times \text{Screw pitch}$$

$$\text{Effort} \times 2\pi l = \text{Load} \times \text{Screw pitch}$$

$$\frac{\text{Load}}{\text{Effort}} = \frac{2\pi l}{\text{Screw pitch}}$$

$$M.A = \frac{2\pi l}{\text{Screw pitch}}$$

(b) The V.R of screw

The V.R of the screw is given by the formula:

$$\text{Velocity Ratio (V.R)} = \frac{\text{Distance moved by effort}}{\text{Distance moved by load}}$$

$$V.R = \frac{2\pi l}{\text{Screw pitch}}$$

Note that: Since the screw is assumed to be perfect $M.A = V.R$

Worked Examples

1. (a) In a screw jack the length of handle is 24 cm and the screw pitch is 2 mm. If it is used to raise a car of mass 2 000 kg, calculate:
 - (i) the effort required.
 - (ii) the V.R.
 - (iii) the M.A.

(b) Give reason for the value of M.A you have obtained in (a) (iii) above.
(Take $g = 10 \text{ m/s}^2$, $\pi = 3.14$)

Solution: (a) $l = 24 \text{ cm} = \frac{24}{100} = 0.24 \text{ m}$, pitch = 2 mm = $\frac{2}{1000} = 0.002 \text{ m}$,
 $L = 2000 \text{ kg} = 2000 \times 10 = 20000 \text{ N}$, $E = ?$

$$\begin{aligned} (i) \quad \text{Effort} \times 2\pi l &= \text{Load} \times \text{Screw pitch} \\ \text{Effort} &= \frac{\text{Load} \times \text{Screw pitch}}{2\pi l} \\ &= \frac{20000 \times 0.002}{2 \times 3.14 \times 0.24} \end{aligned}$$

$$\text{Effort} = 26.54 \text{ N}$$

$$(ii) \quad \text{Velocity Ratio} = \frac{\text{Distance moved by effort}}{\text{Distance moved by load}}$$

$$V.R = \frac{2\pi l}{\text{Screw pitch}}$$

$$= \frac{2 \times 3.14 \times 0.24}{0.002}$$

V.R = 753.6

(iii) $M.A = \frac{L}{E}$ Or $M.A = \frac{2\pi l}{Screw\ pitch}$

$$= \frac{20000}{26.54} = \frac{2 \times 3.14 \times 0.24}{0.002}$$

M.A = 753.6 **M.A = 753.6**

(b) $M.A = V.R$. This is because the screw jack is assumed to be perfect i.e. frictionless.

NB: *In practice the effort must be much greater than 26.54 N in order to overcome friction.*

8.8 The Wedge

The wedge is a kind of simple machine which is an inclined plane having either one or two sloping sides. With a wedge, the sloping surface is pushed through the material which is held still.

Examples of wedges are:

A knife, axe, chisel, needle, nail, razor blade and other cutting tools.

Uses of wedges

Wedges are used to:

- cut materials,
- raise heavy object off the ground,
- split wood etc.

Self-Check 8.0

1. Which one of the following are true for simple machines?
 - I. If there is a gain in force, there is a loss in distance.
 - II. The mechanical advantage is the ratio of the load to the effort.
 - III. There is a gain in work.

A. I-II B. II-III C. I-III D. I-II-III
2. Which one of the following below is an example of a 3rd class lever?

A. tweezers	B. equal-arm balance
C. see-saw	D. fixed pulley
3. The system that uses fixed and movable pulleys is called

A. windlass	B. inclined plane
C. block and tackle	D. lever

4. Which one of the following describes the type of pulley, and the lever that the pulley represents?

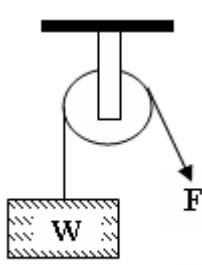


Fig. 8.20

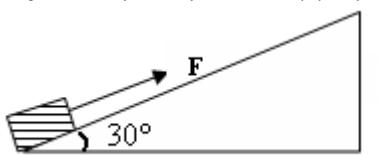
- A. Fixed pulley – Ist class
- B. Fixed pulley – IIIrd class
- C. Movable pulley – IInd class
- D. Movable pulley – IIIrd class.

5. In a windlass, which changes decrease the force needed to pull up the load

- I. increasing the radius of the wheel.
- II. decreasing the radius of the wheel
- III. decreasing the radius of the axle.

- A. I-II
- B. I-III
- C. II only
- D. III only

- .



mass 2 kg to push it on an inclined plane. If $F = 5 \text{ N}$, what is the le

- A. 4 m
- B. 8 m
- C. 12 m
- D. 16 m

Figure 8.21

7. A screw of length 5 cm enters totally into a wooden block after 25 turns. What is the pitch of the screw?

- A. 0.1 cm
- B. 0.2 cm
- C. 0.4 cm
- D. 0.5 cm

8. The maximum efficiency that can be obtained with four pulleys and a mechanical advantage of 3 is?

- A. 100%**
- B. 75%**
- C. 12%**
- D. 1.33%**

9. Calculate the effort when a load of 72 N is raised using a block and tackle system of 5 pulleys and efficiency 80%.

- A. 11.52N
- B. 18N
- C. 57.6N
- D. 288N

10. The block and tackle system in the figure has an efficiency of 80%. The load, which can be lifted by an effort of 10N, is

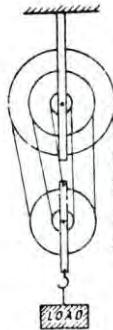


Figure 8.22

- A. 4N

- B. 8N

- C. 40N

- D. 50N

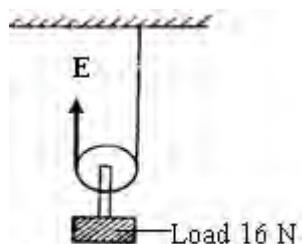
11. A machine which is 80% efficient is run by an engine with an output of 40 watts. The time taken to raise a load of 1500 N through 0.15 m may be

- A. 4.5s
- B. 5.6 s
- C. 7.0s
- D. 28.1s

12. Which of the following statements is true of a wedge used as a simple machine?

- A. Very small force is required to lift a big load.
- B. Work done is always so much.
- C. Effort on the wedge is applied vertically.
- D. There is no frictional force.

13. Calculate the effort when a load of 72 N is raised using a block system of 5 pulleys and efficiency 80%.
- A. 11.52N B. 18N C. 57.6N D. 288N
14. Figure 8.23 shows a light, smooth pulley used to lift a load of 16 N with an effort E. The mechanical advantage of the system is



- A. 128
B. 2
C. 1
D. $\frac{1}{2}$

Figure 8.23

15. Which one of the following is not a correct formula for calculating velocity ratio?

- A. $V.R = \frac{l}{h}$ B. $V.R = \frac{\text{Load distance}}{\text{Effort distance}}$
 C. $V.R = \frac{R}{r}$ D. $V.R = \frac{\text{Number of teeth in driven wheel}}{\text{Number of teeth in the driving wheel}}$

SECTION B

16. (a) What is meant by a first class lever?
 (b) Give two examples of first class lever.
 (c) By means of a lever, an effort of 50 N moves a load of 200 N through a distance of 3m. If the effort moves a distance of 16 m, calculate:
 (i) the mechanical advantage
 (ii) the efficiency of the system.
17. (a) What is meant by efficiency of a machine?
 (b) Draw a single string pulley system of velocity ratio 3.
 (c) State one reason why the efficiency of a machine is always less than 100%.
18. (a) Define efficiency of a machine.

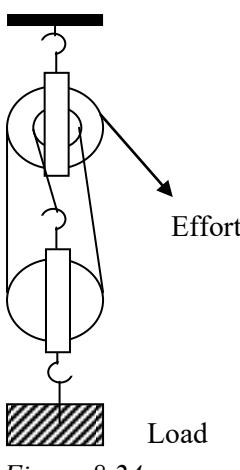
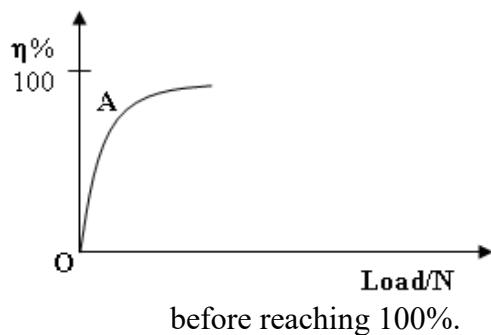


Figure 8.24

- (b) The diagram in figure 8.24 above represents a pulley system in which an effort E is applied to raise the load L.
- (i) Copy the diagram and indicate the forces acting on the string
 (ii) What is the velocity ratio of the system?
 (iii) How far will the load move if the effort moves by 2.4m.
 (iv) What effort would just raise a load of 960 N, if the mechanical advantage is 2.4.
 (v) Use your results above to calculate the efficiency of the pulley system.
- (c) (i) Draw a sketch graph to show how the mechanical advantage of the pulley system in (b) varies with the load.
 (ii) Explain the features of the sketch in (c) (i).
- (d) Give two practical examples where pulley systems are used.

- 19.** (a) Draw a labeled diagram to illustrate the lever principle as applied to a wheelbarrow.

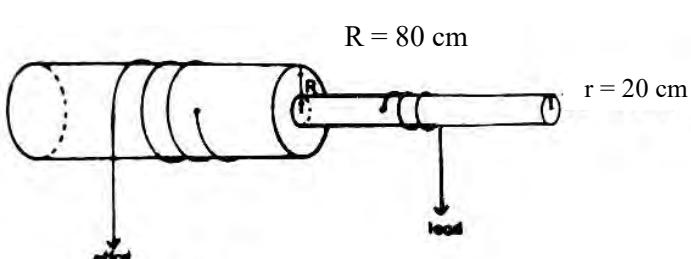


- (b) The graph in the figure shows the variation of the efficiency of a pulley system with load

Explain why:

- (i) part OA of the graph is almost a straight line
 - (ii) from A, the graph curves and finally levels off

- 20.** The figure 8.25 shows a wheel and axle system. When an effort of 300 N is applied, a load of 900 N is raised through a distance of 1.0 m.



Calculate:

- (a) the velocity ratio
 - (b) the efficiency of the system

Figure 8.25

21. (a) State what is meant by each of the following terms as applied to simple machines:

(i) Mechanical advantage (ii) Efficiency

(b) (i) Give two reasons why the efficiency of any simple machine is always less than 100%.

(ii) Give two ways in which the efficiency of a machine can be increased.

(c) The figure shows a load of 10 N raised slowly by a simple frictionless pulley system.

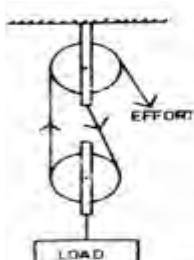


Figure 8.26

- (i) What is the velocity ratio of the system?
 - (ii) Calculate the effort required to lift the load if the mass of the pulley is 0.2 kg.
 - (iii) If the load is raised through a distance of 5 m in 5 s, calculate the efficiency of the system.

- 23.** A smooth wooden board 3.6 m long is used to raise a box of 600 N to a height of 1.2 m.
Calculate: (a) The effort required (b) The M.A of the system.

CHAPTER NINE

PRESSURE

LEARNING OBJECTIVES

By the end of this chapter, you should be able to:

1. (a) Define: - Pressure and state its S.I unit and other units;
(b) State: - The conditions for Pressure in liquids.
(c) Describe: - An experiment to show that liquid pressure depends on depth.
- How to measure liquid and gas pressure using manometer.
(d) State: - The applications of liquid pressure.
(e) Describe: - How to measure Relative Density of liquids using manometer.
2. Solve problems involving pressure:
 - Exerted by solids on a surface and
 - In liquids.
3. (a) State: (i) - Pascal's Principle (The law) of equal transmission of pressure in liquids.
(ii) - Applications of the law of equal transmission of pressure.
(b) Describe: - The structures and the mechanisms of:
 - The Hydraulic Press and
 - The Hydraulic Brake.
(c) Solve problems involving pressure, force and area in the Hydraulic Press.
4. (a) Define: - Atmospheric Pressure.
(b) Describe: (i) - Simple experiment to show the effect of atmospheric pressure.
(ii) - How to measure atmospheric pressure using Mercury Barometer.
(c) State: - The applications of atmospheric pressure.
(d) Describe: - The structures and the mechanisms of:
 - The Lift pump and
 - The force pump.

9.1 Pressure

Pressure is defined as: *force acting normally (perpendicularly) per unit area.*

Mathematically, it is expressed as: Pressure, $P = \frac{\text{Force } (F)}{\text{Area } (A)}$

$$\therefore P = \frac{F}{A} \quad \text{Where area } A \text{ is in } m^2$$

S.I Unit of Pressure

The SI unit of pressure is Newton per square metre (Nm^{-2} or N/m^2). It is a derived unit i.e. it is derived from the SI units of the quantities used to define pressure.

From the definition; Pressure, $P = \frac{\text{Force } (F)}{\text{Area } (A)}$

The SI unit of pressure $= \frac{\text{SI unit of force } (N)}{\text{SI unit of area } (m^2)} = \frac{N}{m^2}$ (N/m^2) or Nm^{-2}

Other units of pressure are:

- (i) Pascal (Pa) is also SI unit of pressure.
 $1 \text{ Pa} = 1 \text{ Nm}^{-2}$ Therefore, Pascal is also the S.I unit of pressure
- (ii) Atmosphere (atm).
- (iii) Millimeter of mercury (mmHg)
 $1 \text{ atm} = 101325 \text{ Pa or } Nm^{-2}$
Also $1 \text{ atm} = 760 \text{ mmHg}$ When measured at a temperature
of
 0°C at sea level.

The larger units of pressure are:

$$\begin{array}{ll} \text{- kiloPascal (kPa)} & 1 \text{ kPa} = 1000 \text{ Nm}^{-2} \\ \text{- Mega Pascal (MPa)} & 1 \text{ MPa} = 1000000 \text{ Nm}^{-2} \end{array}$$

Note that from the formula $P = \frac{F}{A}$, it follows that:

- (i) At constant area, $P \propto F$. i.e. at constant area, the pressure is directly proportional to force (pressure increases with increase in force).
- (ii) At constant force, $P \propto \frac{1}{A}$, i.e. pressure is inversely proportional to area (pressure increases with decreasing area and decreases with increasing area).

Hence;

- Pressure is greatest when area A is smallest and
- Pressure is least when area A is greatest.

Worked Examples

1. A force of 10,000 N is applied to an area of 2 m^2 . Calculate the pressure exerted on the area.

Solution: $F = 10,000 \text{ N}$, $A = 2 \text{ m}^2$, $P = ?$

$$\begin{aligned} P &= \frac{F}{A} \\ &= \frac{10000}{2} \\ &= 5000 \text{ Nm}^{-2} \end{aligned}$$

2. A glass block of mass 60 g exerts a pressure of 1000 Nm^{-2} on a table top. Determine the area of contact between the glass block and the table top. (Take $g = 10 \text{ ms}^{-2}$)

Solution: $m = 60 \text{ g} = \frac{60}{1000} \text{ kg}$, $F = ?$, $g = 10 \text{ ms}^{-2}$, $P = 1000 \text{ Nm}^{-2}$, $A = ?$

Hint: Since the force is not given directly, we first find the force F using the formula:

$$F = mg = \frac{60}{1000} \times 10 = 0.6 \text{ N}$$

Now force F and pressure P are known. We can then use the formula for finding pressure to calculate the area A.

$$\begin{aligned} P &= \frac{F}{A} \\ 1000 &= \frac{0.6}{A} \\ A &= \frac{0.6}{1000} \\ &= 0.0006 \text{ m}^2 \text{ or } 6 \times 10^{-4} \text{ m}^2 \end{aligned}$$

3. A block of wood of mass 1200 g measures by 30 cm by 6 cm by 5 cm. Calculate;
 - (a) The greatest pressure.
 - (b) The least pressure exerted by the wood on a flat surface. (Take $g = 10 \text{ ms}^{-2}$)

Solution: $m = 1200 \text{ g} = \frac{1200}{1000} = 1.2 \text{ kg}$, $F = W = mg = 1.2 \times 10 = 12 \text{ N}$

$$l = 30 \text{ cm} = \frac{30}{100} = 0.3m, w = 6 \text{ cm} = \frac{6}{100} = 0.06 m, h = \frac{5}{100} = 0.05 m$$

First calculate the three possible surface area of the cuboid.

The three possible areas are: $A_{(\text{Largest})} = l \times w = 0.30 \times 0.06 = 0.018 \text{ m}^2$

$$A_{(\text{Medium})} = l \times h = 0.30 \times 0.05 = 0.015 \text{ m}^2,$$

$$A_{(\text{Smallest})} = w \times h = 0.06 \times 0.05 = 0.003 \text{ m}^2$$

(i) *The greatest pressure:*

Since pressure is inversely proportional to area in contact, the greatest area acts on the smallest area. So from the three areas calculated above, we select the smallest.

$$P_{(\text{Greatest})} = \frac{F}{A_{\text{Smallest}}} = \frac{12}{0.003} = 4000 \text{ Nm}^{-2}$$

(ii) *The least pressure:*

The least pressure acts on the largest area. So we select the largest area from the three possible areas.

$$P_{(\text{least})} = \frac{F}{A_{L \arg est}} = \frac{12}{0.0183} = 666.67 \text{ Nm}^{-2}$$

Self-Check 9.0

1. A metal cube of density 3000 kg/m^3 is 4 m high and stands on a square base. What is the pressure exerted by the weight of the block on the surface on which it stands?
A. 120000 N/m^2 B. 7500 N/m^2 C. 60000 N/m^2 D. 15000 N/m^2
2. The rectangular block has a mass of 3600 kg and base area of the base is 9 m^2 . What is the pressure exerted on the ground?
A. 3000 N/m^2 B. 9000 N/m^2 C. 4000 N/m^2 D. 4500 N/m^2
3. A block of concrete weighs 900 N and its base is a square of side of 3 m . What pressure does the block exert on the ground?
A. 50 N/m^2 B. 100 N/m^2 C. 200 N/m^2 D. 300 N/m^2
4. A man of mass 80 kg wears snow shoes with a total area of 0.5 m^2 . What is the pressure exerted by him on the ground?
A. 1200 Pa B. 1400 Pa C. 1600 Pa D. 1800 Pa
5. A book weighing 18 N has 0.06 m^2 surface area and lies on a table. Calculate the pressure exerted by the book on the table.
A. 1.08 Pa B. 0.3 Pa C. 0.3 kPa D. 0.003 Pa

9.2 Pressure in fluids

A liquid in a container exerts pressure at the bottom of the container. The pressure exerted has the following properties:

The pressure in liquids:

- (i) Is independent of the base area.
- (ii) Increases with depth below its surface.
- (iii) Increases with the density of liquid.
- (iv) At the same point (depth), the pressure is the same and acts equally in all directions.

Experiment 9.0 To show that pressure in liquids depends on the depth

Apparatus: A tall can (tin), a small nail, running water from tap.

Procedure:

- Make three holes A, B and C of the same diameter along a vertical line on one side of the can using a small nail.
- Fill the tall can with water from tap up to a level above hole A as shown in the diagram below.
- Observe the jets of water from the holes.

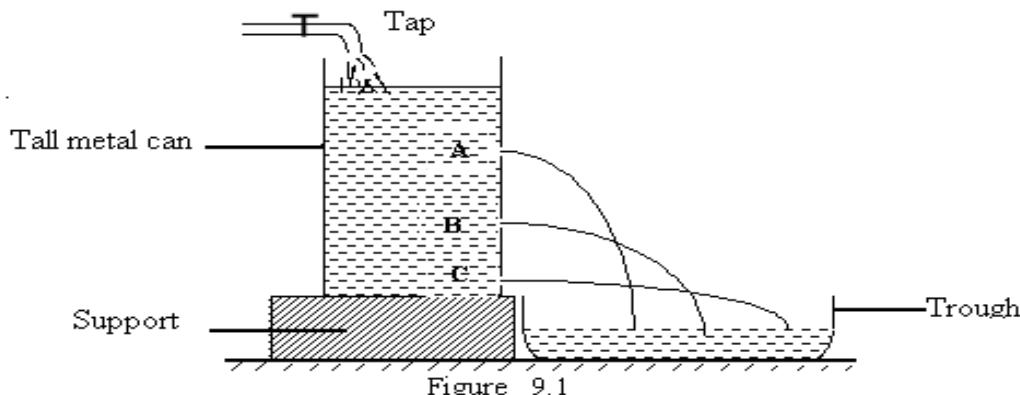


Figure 9.1

Observation

- Water jets through the holes with different speed.
- The lower hole, C throws water farthest and fastest followed by B and lastly hole A.
- Water leaves the holes at right angles to the wall of the can. This shows that the pressure is perpendicular to the wall of the can.

Conclusion: Pressure due to water at hole C is the greatest and at hole A is the least. Therefore, pressure in liquids depends on depth.

(a) To show that pressure in liquids is independent of base area but depends on the depth and density of the liquid

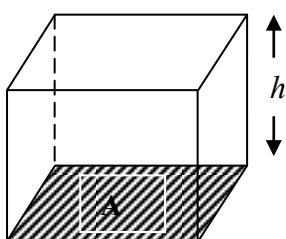


Figure 9.2

Consider a liquid of density mass $m \text{ kg}$ and density, $\rho \text{ kg/m}^3$ filled in a container of base area A to a depth, h (metres) as shown in the diagram below.

The liquid exerts pressure, P , on the bottom of the container as a result of its weight.

$$\begin{aligned} \text{The volume of the liquid} &= \text{Volume of the container} \\ &= \text{Base area} \times \text{Height} \end{aligned}$$

$$= A$$

$$\text{Mass of the liquid} = \text{Volume} \times \text{Density}$$

$$= Ah \times \rho$$

$$\text{Weight of the liquid} = \text{Mass} \times \text{Acceleration due to gravity}$$

$$= mg \quad \text{But } m = Ah\rho$$

$$\therefore \text{Weight of the liquid} = A\rho hg$$

$$\text{From} \quad \text{Pressure} = \frac{\text{Force}}{\text{Area}} \quad \text{we have;}$$

$$= \frac{A\rho hg}{A}$$

\therefore Pressure in liquids is given by the formula, $P = h\rho g$

Note that the final result does not have A. This shows that:
Pressure in liquid is independent of the base area but depends on the depth of the liquid.

That is pressure is directly proportional to the depth, hp of the liquid, since g is a constant.

NB: *The same result will be obtained whatever shape of a container is used.*

(b) Pressure and liquid density

If the pressure is measured at the same depth below the surface of different liquids we find that: *The pressure is proportional to the density of the liquid.*

(c) Liquid levels (A liquid finds its own level)

When a liquid is poured into a set of connected tubes of various shapes the liquid flows round the tubes until all the liquid surfaces are the same level, fig. 9.21. We say that a liquid finds its own level.

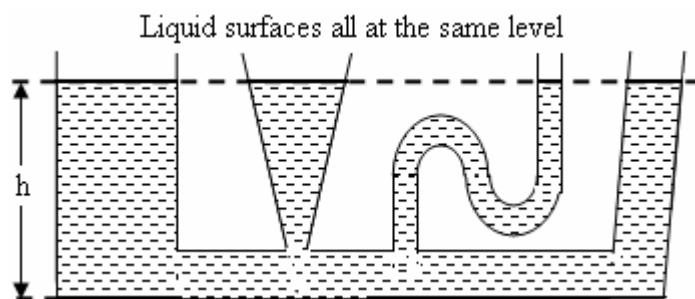


Fig. 9.21

NB: *See the photograph on this book cover.*

(d) Calculation of Liquid Pressure

The pressure exerted by a liquid can be calculated using the formula:

$$P = h\rho g$$

Where: P = Pressure, h = height/depth in metres, ρ = density of liquid in kg/m^3 ,
 g = gravity = 10m/s^2 .

Worked Examples

1. What is the pressure on the bottom of a vessel when it is filled with a liquid of density of 800 kg/m^3 to a depth of 2 m. ($g = 10 \text{ m/s}^2$).

Solution:: $\rho = 800 \text{ kg/m}^3$, $h = 2 \text{ m}$, $g = 10 \text{ m/s}^2$, $P = ?$

$$\begin{aligned} P &= h\rho g \\ &= 2 \times 800 \times 10 \\ &= 16000 \text{ Nm}^{-2} \end{aligned}$$

2. The pressure at the bottom of a column of mercury is 50 Nm^{-2} . Calculate the height of the mercury column. (Density of mercury = 13600 kg/m^3 and $g = 10 \text{ m/s}^2$).

Solution: $\rho = 13600 \text{ kg/m}^3$, $g = 10 \text{ m/s}^2$, $P = 50 \text{ Nm}^{-2}$, $h = ?$

$$\begin{aligned} P &= h\rho g \\ 50 &= 13600 \times 10 \times h \\ h &= \frac{50}{13600 \times 10} \\ &= 3.68 \text{ m} \end{aligned}$$

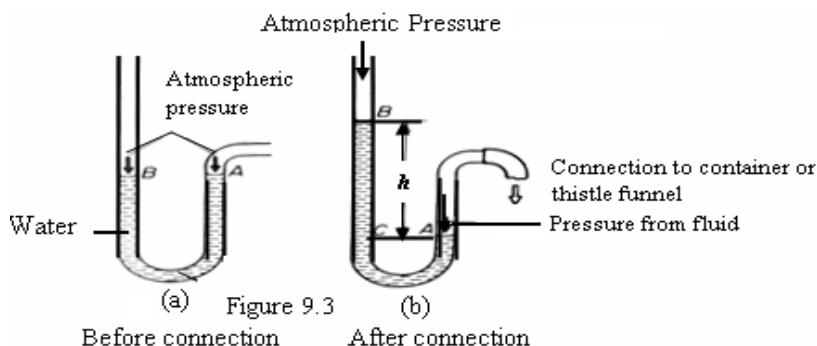
9.21 Measurement of Pressure in Fluids

Fluid pressure is measured using an instrument called *manometer*.

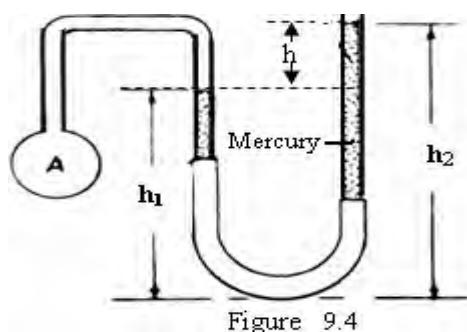
(a) The U-Tube Manometer

A manometer consists of a U-shaped tube with one end connected either directly to the container containing a gas or to a thistle funnel whose base (bottom) is covered with a thin membrane and the other end remains open to the atmosphere. The manometer is filled with a liquid, such as water, oil, or mercury, the difference in the liquid surface levels, h , in the two manometer arms indicates the pressure difference from local atmospheric conditions.

Diagrams showing U-tube manometer



9.22 Measurement of Gas Pressure



One arm of the manometer is connected to the container in which the gas whose pressure to be measured is kept. The difference in the levels of the two arms of the manometer gives the pressure of the gas.

If the actual pressure is required, then it is calculated from the formula:

$$\text{Gas pressure} = \left(\frac{\text{Atmospheric}}{\text{Pressure(PA)}} \right) + \left(\text{Pressure due to liquid column} \right)$$

$$\text{Gas pressure} = P_A + h\rho g$$

Note that: For the case of the above diagram, $h = h_2 - h_1$

Worked Examples

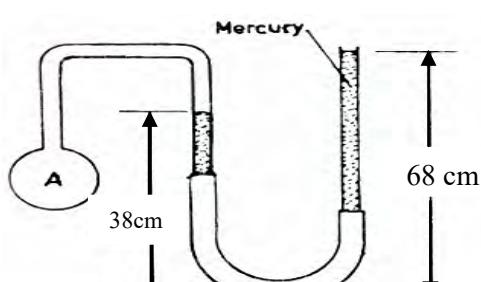
1. (a) In figure 9.5, a fixed mass of dry air is trapped in bulb A. If the atmospheric pressure is 76cm of mercury.

Calculate the total pressure of the air in A,

in:

- (i) mmHg
- (ii) Pa (atm. pressure = 101325 Pa,

$$\rho \text{ of mercury} = 1.36 \times 10^4 \text{ kg m}^{-3}, g = 10 \text{ ms}^{-2}$$



Solution: Atmospheric Pressure = 76 cmHg = $76 \times 10 = 760$ mmHg

$$h_1 = 38 \text{ cm} = 38 \times 10 = 380 \text{ mm}, h_2 = 68 \text{ cm} = 68 \times 10 = 680 \text{ mm}$$

(i) Pressure due to mercury column, $h = h_2 - h_1 = 680 - 380 = 300$ mmHg

$$\begin{aligned}\text{Gas pressure} &= P_A + \text{Pressure due to liquid column} \\ &= 760 + 300 \\ &= \mathbf{1060 \text{ mmHg}}\end{aligned}$$

(ii) Pressure, P , due to mercury column = $h\rho g$

$$\begin{aligned}&= 0.3 \times 13600 \times 10 \\ &= 40,800 \text{ Pa}\end{aligned}$$

$$\begin{aligned}\text{Gas pressure} &= P_A + \text{Pressure due to liquid column} \\ &= 101,325 + 40,800 \\ &= \mathbf{142,125 \text{ Pa}}\end{aligned}$$

2. (a) Figure 9.6 below shows a gas trapped by a mercury column in a J-tube. If the atmospheric pressure is 1.0×10^5 Pa and the density of mercury is $1.36 \times 10^4 \text{ kg m}^{-3}$, find the pressure at which the gas is. ($g = 10 \text{ m s}^{-2}$)

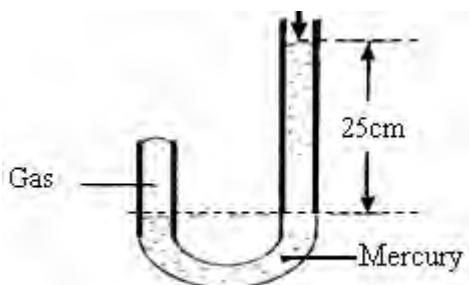


Figure 9.6

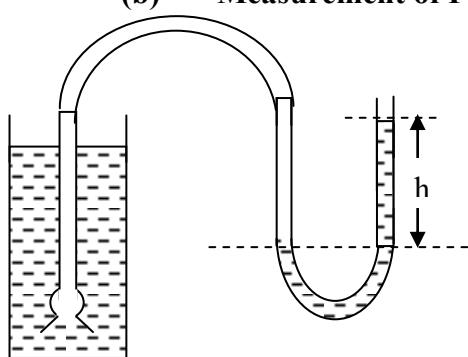
- (b) What would happen if the closed end of the J-tube was opened?
(c) Would it have been better to use water instead of mercury in the J-tube?
Give a reason for your answer.

Solution: Mercury column = 25 cm = 0.25 m, ρ of mercury = $1.36 \times 10^4 \text{ kg m}^{-3}$, $g = 10 \text{ ms}^{-2}$, Atm. pressure = 1×10^5 Pa

(a) Pressure, P , due to mercury column = $h\rho g = 0.25 \times 13600 \times 10 = 34,000$ Pa
Gas pressure = $P_A + \text{Pressure due to liquid column}$
 $= 100,000 + 34,000$
 $= \mathbf{134.000 \text{ Pa}}$

- (b) - The gas trapped would escape. This would reduce the pressure inside the J tube.
- The mercury column on the right arm would fall while the one on the left arm would rise until the two levels become the same level.
(c) - No. **Reason:** Water is less dense than mercury. Therefore, to balance the same pressure, it would require a large volume of water which in turn would need a manometer with a very long arm to hold the higher water column.

(b) Measurement of Pressure in a liquid



In measuring the liquid pressure, one arm of the manometer is connected to a thistle funnel covered with a thin membrane.

The thistle funnel is immersed into the liquid to the point where the pressure is to be measured.

The difference in the levels of the liquid in the two limbs of the manometer gives the pressure at that point. Since the pressure in a liquid is proportional to the depth below the surface, pressures can be measured in terms of the height of a liquid.

Figure 9.7

The diagram above shows how liquid pressure at different points in a liquid can be measured using a manometer.

Note:

- ❖ Manometers can be used to measure pressure both above and below atmospheric pressure.
 - ❖ Mercury is used as manometer liquid unless the pressure being measured is close to the atmospheric pressure, in which case a liquid of lower density (e.g oil or water) is more suitable.
 - ❖ The pressure registered by the manometer, $h\rho g$, is known as the *gauge pressure*. Gauge pressure is the *excess pressure* i.e is the amount by which the pressure measured in a fluid exceeds the atmospheric pressure.
 - ❖ It is often convenient to express the gauge pressure simply in terms of the liquid column, h , of the liquid used in the manometer only.
 - ❖ In this case the units generally used are:
 - mmH₂O and mmHg, read as millimeters of water and
 - millimeters of mercury respectively.
- Where H₂O is a chemical formula of water and Hg is the chemical symbol of mercury.
- ❖ The actual pressure, Pa + hρg, is called the *absolute pressure*?
- $$\begin{aligned}\text{Actual Pressure} &= \text{Atmospheric pressure} + \text{Pressure due to liquid column} \\ &= \text{Pa} + h\rho g\end{aligned}$$

9.23 Pressure due to flow of liquid in a pipe

Liquid flowing in a pipe has kinetic energy due to its speed, potential energy due to its position, and pressure energy because it is under pressure. The sum of these energies is a constant.

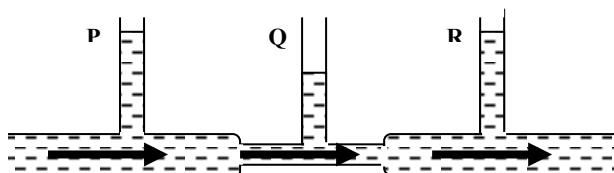


Figure 9.8

Consider water flowing in a pipe a constriction at one point as shown in the diagram.

Facts about the flow of the liquid

- ❖ Pressure of water changes with its rate of flow in the pipe.
- ❖ The speed of water is much greater at the constriction; as a result its kinetic energy is greater.
- ❖ Its pressure energy is less since its potential energy is constant.
- ❖ Pressure is highest in tubes P and R and lowest in Q (i.e. at the constriction).

9.24 Application of Liquid Pressure

Liquid pressure is applied in:

- (i) Measurement of relative density of liquids
- (ii) Water supplies

(a) Measurement of Relative Density of Liquids

(i) Determination of Relative Density of liquids that are Miscible with water

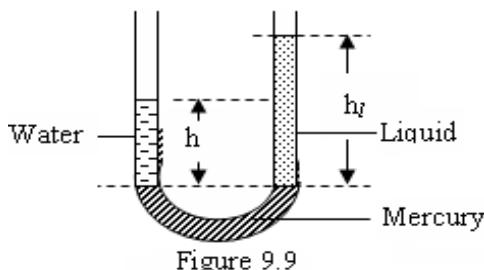


Figure 9.9

The Relative density of a liquid that is miscible with water is determined by balancing a column of small volume of the liquid with water on mercury surface in a manometer until the mercury levels in the two limbs of the manometer are at the same level as shown in figure 9.8 below.

Facts in calculating the Relative Density from the above diagram

- (i) The pressure acting on the two surfaces of the mercury is the same.

(ii) The pressure due to the liquid column is equal to the pressure due to the water column

Calculation: Let pressure, P_l , due to the liquid column $= h_l \rho_l g$ and
Pressure, P_w , due to the water column $= h_w \rho_w g$

$$\text{But } P_l = P_w$$

$$\therefore h_l \rho_l g = h_w \rho_w g$$

$$h_l \rho_l = h_w \rho_w$$

$$\frac{\rho_l}{\rho_w} = \frac{h_w}{h_l} \quad \text{But } \frac{\rho_l}{\rho_w} = \text{R.D (See chapter 3)}$$

$$\therefore \text{R.D of the liquid} = \frac{h_w}{h_l}$$

$$\text{I.e R.D} = \frac{\text{Height of water column}}{\text{Height of liquid column}}$$

(ii) Determination of Relative Density of liquids that are Immiscible with water
E.g. Carbon tetrachloride

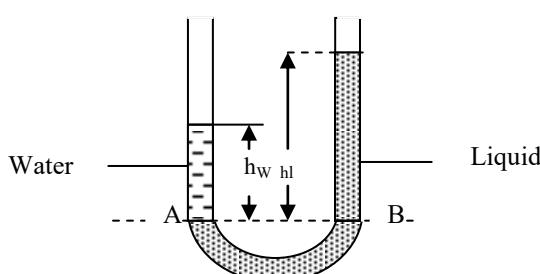


Figure 9.10

The Relative density of liquids that are immiscible with water is determined by balancing the columns of small volume of the liquid and water in a manometer as shown in figure 9.9 below.

By placing a ruler at the position AB, the liquid columns h_l and h_w are measured.

Points to note:

- Point A is called the interface of the two liquids.
- Points A and B are at the same levels so they are at the same pressure.
- The liquid column, h_l , balances the column of water, h_w .

Calculation: Pressure due to liquid column $= h_l \rho_l g$ Pressure due to water column $= h_w \rho_w g$

$$h_l \rho_l = h_w \rho_w$$

$$\frac{\rho_l}{\rho_w} = \frac{h_w}{h_l} \quad \text{But } \frac{\rho_l}{\rho_w} = \text{R.D}$$

$$\therefore \text{R.D of the liquid} = \frac{h_w}{h_l}$$

Worked Example

1. An open U-tube contains columns of water and kerosene over mercury as shown in the figure 9.12 below. Calculate the relative density of kerosene.

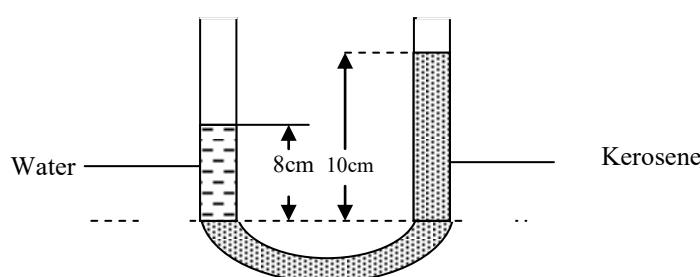


Figure 9.12

Solution: Height, h_w , of water column = 8 cm, Height, h_k , of kerosene column = 10 cm.

$$\text{Relative Density, R.D} = \frac{\text{Height of water column}}{\text{Height of liquid column}} = \frac{h_k}{h_w} = \frac{8}{10} = 0.8$$

(b) Water Supply

Facts about Water Supply

There must be:

- A water pump
- A large reservoir
 - situated near the water source to pump water to;
 - situated on top of a hill or mountain side to create a pressure difference between it and the taps to be supplied in the neighborhood.

In water supply, water is pumped against gravity using a water pump (generator) to a reservoir or water tower high up on a hill or a mountain side. Due to the pressure difference that exists between the water in the reservoir and the taps to be supplied, the water in the reservoir is supplied to houses, factories and other buildings.

Note: *In some large blocks or flats there is/are large water tank(s) on the roof or on a high support. The main reservoir supplies water to this/these tank(s) which then supplies water to the taps in the building.*

9.25 (a) The Law of Equal Transmission of Liquid Pressure (Pascal's Principle)

The law states that:

Pressure applied to a liquid is transmitted equally throughout the liquid in all directions.

Experiment To show that pressure applied to a liquid is transmitted equally throughout the liquid in all directions

Apparatus

A round bottom flask with holes of same size on its surface, a tight fitting plunger and water.

Procedure

- Fill a round bottom flask with holes on the round surface with water.
- Insert a plunger and
- Push the plunger towards the bottom of the flask in the direction shown in figure 9.11.

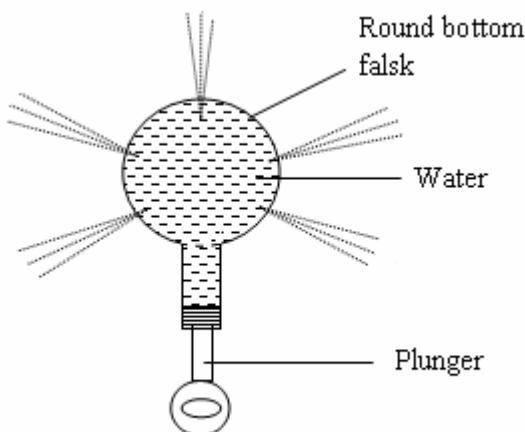


Figure 9.11

(b) Application of the Law of Equal Transmission of Hydraulic Pressure

The principle of equal transmission of pressure in liquids is applied in the following machines:

- (i) The Hydraulic Press (Braham's Press).
- (ii) The Hydraulic brake and
- (iii) The Hydraulic jack.

9.26 The Hydraulic Press

The hydraulic press is a machine which uses the principle of equal transmission of pressure in fluids. It works on the principle that the effort required to move something is the product of the force and the distance through which the object is moved.

(a) The structure of the Hydraulic press

It consists of:

- Two pistons (of different diameters) that move up and down in;

- Two cylinders (pump cylinder and ram cylinder) of different diameters connected by a pipe.
- Incompressible fluid,
- A reservoir and
- Two valves (inlet valve and return valve).

The diagram showing the cross section of a Hydraulic Press

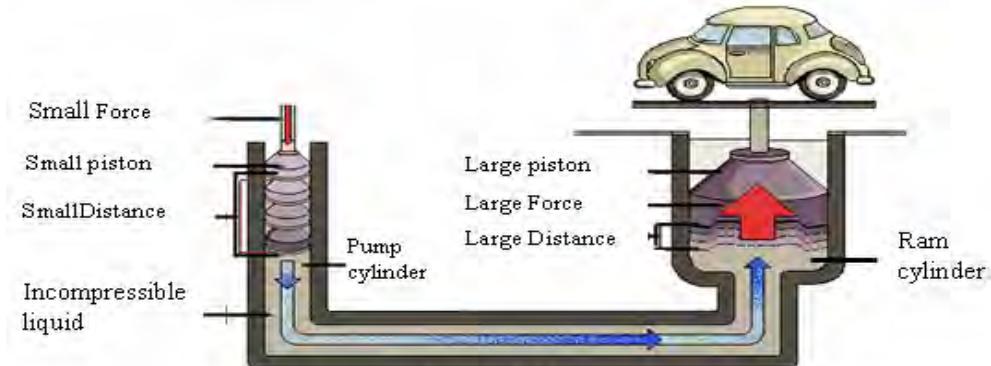


Figure 9.12

(b) How it works

Effort is applied at the smaller piston and moves it through a large distance in the pump cylinder. The hydraulic pressure acting on the liquid surface in the *pump cylinder* is transmitted equally through the liquid to the larger piston in the *ram cylinder* and a large force is applied over a small distance. A heavy load is raised by the force produced by the pressure acting on the ram piston.

Note: *In this way, a small hand pump may be used to lift an automobile. In order to fill the large cylinder under the car with fluid, however, the small pump must be operated many, many times.*

When the return valve is opened, the fluid flows back to the reservoir.

For simplicity, the above cross section is drawn excluding the reservoir.

Problems involving Hydraulic Press are solved by using the following formulae.

$$(i) \text{ Using force: } \frac{f}{a} = \frac{F}{A} \quad \text{Or} \quad \frac{f}{F} = \frac{a}{A}$$

$$(ii) \text{ Using mass: } \frac{m}{a} = \frac{M}{A} \quad \text{Or} \quad \frac{m}{M} = \frac{a}{A}$$

Derivation of the above formulae

- Let:
- the area of the piston in the pump cylinder = a
 - the area of the piston in the ram cylinder = A
 - the mass placed at the pump cylinder = m
 - the mass placed at the ram cylinder = M
 - the acceleration due to gravity = g
 - Force at the pump piston, f = mg
 - Force at the pump piston, F = Mg

$$\text{Pressure, } P_1 \text{ exerted at the pump cylinder} = \frac{\text{Force}}{\text{Area of pump piston}} = \frac{f}{a} = \frac{mg}{a}$$

$$\text{Pressure, } P_2 \text{ exerted at the ram cylinder} = \frac{\text{Force}}{\text{Area of ram piston}} = \frac{F}{A} = \frac{Mg}{A}$$

By the principle of equal transmission of pressure in fluids;

Pressure exerted at the pump cylinder = Pressure exerted at the ram cylinder

$$P_1 = P_2 \quad \text{Or} \quad \frac{m}{M} = \frac{a}{A}$$

$$\frac{mg}{a} = \frac{Mg}{A} \quad \text{Using forces we have:} \quad \frac{f}{a} = \frac{F}{A}$$

$$\therefore \frac{m}{a} = \frac{M}{A} \quad \frac{f}{F} = \frac{a}{A}$$

NB: Using the above formulae,

- (i) The force at the pump piston or ram piston can be calculated when the areas of the pistons are given.
- (ii) The area of the pump piston or ram piston can be calculated when the forces or masses are given.

Worked Examples

- The area of the large piston of a hydraulic press is 10 m^2 and that of the smaller one is 0.25 m^2 . A force of 100 N is applied on the smaller piston. Calculate the force produced at the larger piston.

Solution

Data: $a = 0.25 \text{ m}^2$, $A = 10 \text{ m}^2$, $f = 100 \text{ N}$, $F = ?$

$$\text{From} \quad \frac{f}{F} = \frac{a}{A}$$

$$\begin{aligned} F &= \frac{f \times A}{a} \\ &= \frac{100 \times 10}{0.25} \\ &= 4000 \text{ N} \end{aligned}$$

2. The area of a smaller piston of a hydraulic press is 0.5 m^2 . If an effort of 250 N is applied on the smaller piston and raises a load of 20000 N, calculate the area of the large piston.

Solution: $a = 0.5 \text{ m}^2$, $A = ?$, $f = 250 \text{ N}$, $F = 20000 \text{ N}$

From

$$\frac{f}{F} = \frac{a}{A}$$

$$A = \frac{a \times F}{f} = \frac{0.5 \times 20000}{250} = 40 \text{ m}^2$$

3. In a hydraulic press a force of 400 N is applied to a piston of area 0.1 m^2 . The area of the other piston is 4 m^2 . Calculate:

(i) The pressure transmitted through the liquid.

(ii) The force on the other piston?

Solution: $f = 400 \text{ N}$, $F = ?$, $a = 0.1 \text{ m}^2$, $A = 4 \text{ m}^2$

$$(i) \text{ Pressure} = \frac{F}{A}$$

$$= \frac{400}{0.1}$$

$$= 4000 \text{ N m}^{-2}$$

$$(ii) \frac{f}{a} = \frac{F}{A}$$

$$\frac{400}{0.1} = \frac{F}{4}$$

$$F = \frac{400 \times 4}{0.1}$$

$$= \frac{1600}{0.1}$$

$$\therefore F = 16000 \text{ N}$$

(c) The Hydraulic brake

(i) Structure of Hydraulic Brake

A hydraulic brake system consists of the following features.

- (i) *Master cylinder* Contains two pistons and is connected to wheel cylinders by steel tubes called brake lines.
- (ii) *Wheel cylinders* They are found in the wheels and also contain two pistons.
- (iii) *Return spring* Returns the brake shoe back to its position hence forcing the brake fluid back to the master cylinder.
- (iv) *Brake line* Steel tubes that connect the master cylinder to the wheel cylinders and is filled with the brake fluid.
- (v) *Brake fluid* Special incompressible non-freezing liquid.
- (vi) *Brake lining* A thin, replaceable strip of material attached to a brake shoe. It makes contact with the brake drum thus stopping the rotation of the wheel.

- (vii) *Brake shoes* These are two curved blocks to which the brake linings are attached and they press against the brake drum thus slowing down the rotation of the wheel.
- (viii) *Brake drum* A metal cylinder attached to the wheel of a vehicle. They slow down the rotation of the wheel when the brake is applied.
- (ix) *Brake pedal* Lever operated by the foot that powers the mechanism of brake system.

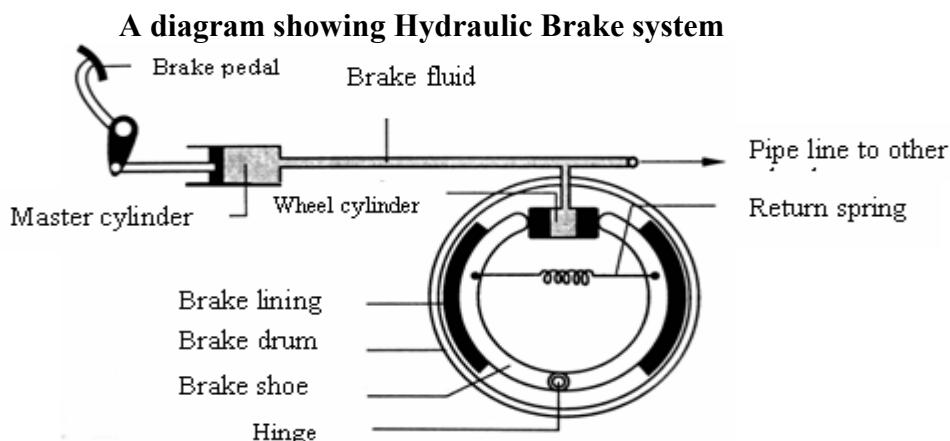


Figure 9.13

(ii) How the Hydraulic Brake System works

When the driver steps on a brake pedal, the pedal pushes a piston inside the master cylinder. This squeezes the fluid inside the master cylinder, creating hydraulic pressure which is transmitted through the brake lines to additional pistons inside each wheel cylinder in each brake. The pistons in the brake cylinder push the hinged brake shoes. The shoes pivot outward pressing the brake linings attached to them against the brake drum. The contact between the brake lining and the brake drum stops the rotation of the wheels and retards the motion of the car and the car slows down.

- NB:**
- (i) *When the pedal is released, the return springs causes the brake fluid to return to the master cylinder.*
 - (ii) *Some braking systems use disc system in which the force resulting from the hydraulic pressure pushes the brake pads in the caliper against the rotor, thus slowing the rotation of the wheel.*

9.3

ATMOSPHERIC PRESSURE

Atmosphere refers to mixture of gases surrounding any celestial object that has a gravitational field strong enough to prevent the gases from escaping; especially the gaseous envelope of Earth.

In reference to the earth, atmosphere refers to the air that surrounds the earth. The atmosphere exerts pressure called atmospheric pressure on the earth surface and the objects found in the pool of the air surrounding the earth. The atmospheric pressure is due to the weight of the air.

Variation of Atmospheric Pressure with altitude

Pressure in fluids depends on the depth or height of the fluid column, the atmospheric pressure therefore, depends on the altitude (height above sea level). As a result of this, at low altitude (high air column), pressure is greatest while at higher altitude (low air column), like mountain peaks, pressure is lower than at low altitude.

Effect of atmospheric pressure on boiling

Boiling takes place when the vapour pressure from a boiling liquid equals the atmospheric pressure. Due to the variation in atmospheric pressure, a liquid will boil at different boiling points. At higher altitudes where atmospheric pressure is low, water boils at low boiling point. Therefore, at higher altitudes, cooking takes longer than at low altitudes where the atmospheric pressure is high.

The large forces which can be produced by atmospheric pressure may be demonstrated by means of a metal can fitted with an airtight stopper.

(a) Crushing can experiment

Apparatus: A metal can with a lid, water and source of heat

Procedure:

- Fill a metal can with some water.
- Heat the water until steam drives out the air from the can.
- Coke the can tightly.
- Remove the can and simultaneously put off the flame.
- Pour cold water on to the can.

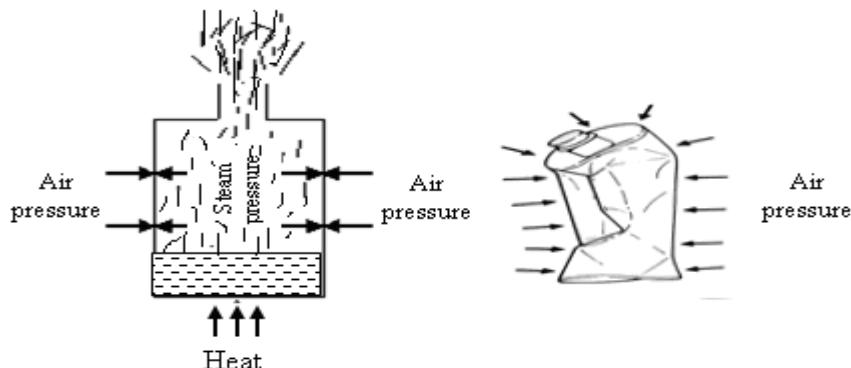


Fig. 9.14 Crashing can experiment

Observation: The metal can crash inwards.

Explanation

The cold water poured caused the steam to condense, producing water and water vapour at a very low pressure. Consequently, the excess atmospheric pressure outside the can causes it to collapse inwards.

(b) Measurement of atmospheric pressure

The atmospheric pressure is measured by using the following instruments

- (i) Barometer (Mercury/water barometer)
- (ii) Bourdon gauge

A simple Barometer

Barometer is an instrument used for measuring atmospheric pressure.

Types of Barometer

Barometers are named according to the type of liquid used in it. The common liquids used are water and mercury. As a result of this we have:

- (i) Water barometer - Not convenient to be used.
- (ii) Mercury barometer - The most convenient to be used.

Mercury barometer

Mercury is 13.6 times as heavy as water, and the column of mercury sustained by normal atmospheric pressure is only about 760 mm (0.76) m high. It is more convenient to use mercury barometer than water barometer which sustains extremely high column of water.

An ordinary mercury barometer consists of:

- A glass tube about 840 mm (0.84 m) high, closed at one end.
- A glass beaker or glass trough and
- A pool of mercury.

How to measure Atmospheric pressure using mercury barometer

- Fill the glass tube with mercury up to brim.
- Cover the open end of the tube with a finger or small glass plate.
- Invert the tube and place it vertically with its end well below the surface of the mercury in the beaker.
- Remove your finger.

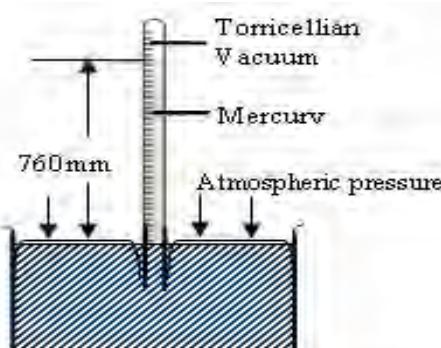


Figure 9.17 Simple mercury barometer

Observation

The mercury level in the tube drops until for some time and then remains constant. The constant level is when the pressure due to the mercury column balances the atmospheric pressure acting on the mercury surface in the beaker.

Read and record the two levels of the mercury (i.e. top in the tube and down in the trough).

The mercury column is given by the formula:

$$\text{Mercury column, } h = \text{Upper reading} - \text{Lower reading}$$

At sea level, the mercury column = 760 mm (76 cm or 0.76 m).

Therefore, the atmospheric pressure is recorded as: 760 mmHg at sea level.

NB:

- (i) *The falling of the mercury level leaves almost a perfect vacuum called Torricellian vacuum. After an Italian scientist who lived in Pisa.*
- (ii) *When the mercury level is read with a form of gradated scale, known as a vernier attachment, and suitable corrections are made for:*
 - Altitude and latitude (because of the change of gravity), and
 - Temperature (because of the expansion or contraction of the mercury).
- (iii) *The vertical height of the mercury column remains constant even when the tube is tilted, unless the top of the tube is less than 760 mm above the level in the beaker, in which case the mercury completely fills the tube.*

Variation of the Mercury column with altitude

When the set up is taken to different places with different atmospheric pressure, the variation in the atmospheric pressure causes the liquid in the tube to rise or fall by small amounts, rarely below 737 mm (0.737 m) or above 775 mm (0.775 m) at sea level.

Bourdon gauge

Bourdon gauge, (named after the French inventor Eugène Bourdon), is an instrument used to measure higher pressures e.g. steam pressure and water pressure.

It consists of a hollow metal tube with an oval cross section, bent in the shape of a hook or question mark. One end of the tube is closed, the other open and is connected to the measurement region. If pressure (above local atmospheric pressure) is applied, the oval cross section becomes circular, and at the same time the tube will straighten out slightly. The resulting motion of the closed end which is proportional to the pressure, can then be measured via a pointer or needle connected to the end through a suitable linkage.

NB: *Gauges used for recording rapidly fluctuating pressures commonly employ piezoelectric or electrostatic sensing elements that can provide an instantaneous response.*

Other instruments for measuring atmospheric pressure are:

- The Fortin Barometer.
- Aneroid barometer and
- Altimeter.

Application of atmospheric pressure

Atmospheric pressure is applied in:

- (i) The lift pump (the common pump) and
- (ii) The force pump.

(a) The lift Pump

The lift pump consists of:

- A handle - which helps to move the piston up and down.
- A piston - which reciprocates (moves back and forth) in a cylinder.
- A pipe - which helps water to flow from under ground.
- Two one-way valves - which regulate the flow of water into and out of the cylinder.

Diagram showing parts of the lift pump

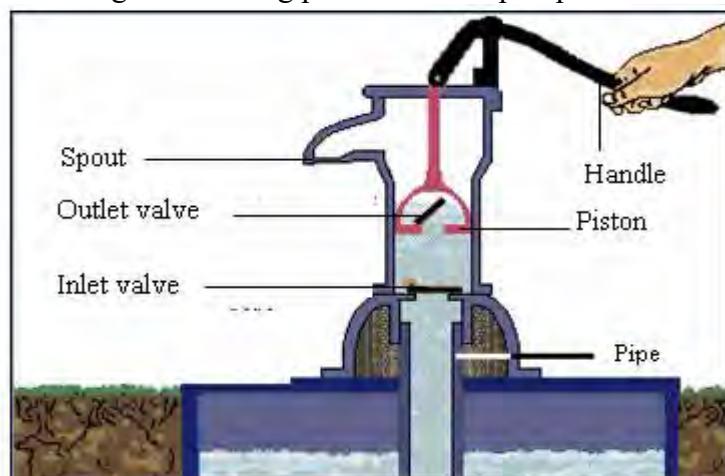
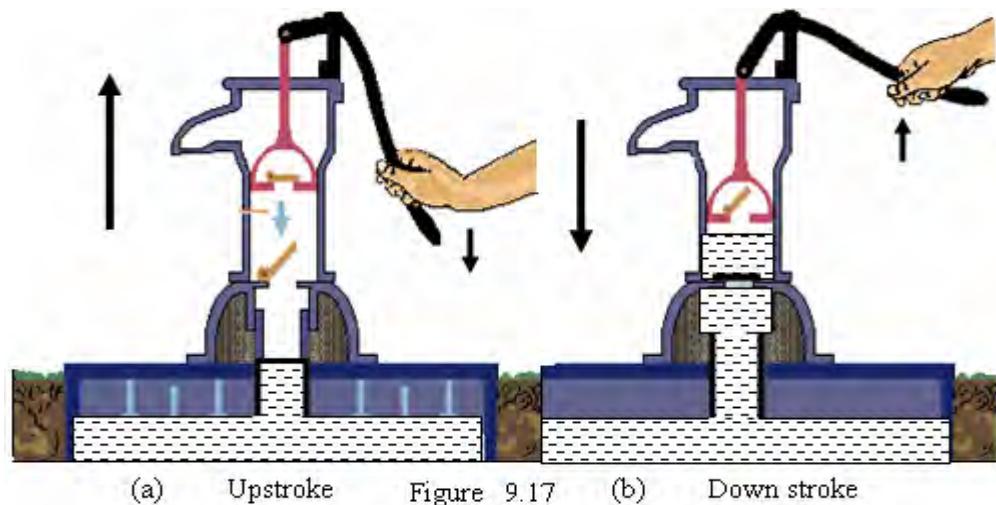


Figure 9.16 Cross section of a Lift pump

A lift pump is reciprocating pump which draws fluid (water) in at one end and discharges or expels it at the other end as described in the mechanism below.



- Points to note:**
- *A stroke refers to the up and down movement.*
 - *The up and down movement considered is of the piston **not** of the handle.*
 - *The handle and the piston move antagonistically. I.e. when the piston moves up, the handle moves down and vice versa.*

Mechanism of Lift Pump (How a Reciprocating Pump Works)

Up-stroke

During the up stroke, the piston moves up reducing the air pressure in the cylinder. A partial vacuum is formed beneath the piston making the outside air having greater pressure than the inside. Atmospheric pressure then pushes water up the pipe. The rising water opens the inlet valve, and the water passes to the space above the inlet valve.

Down-stroke

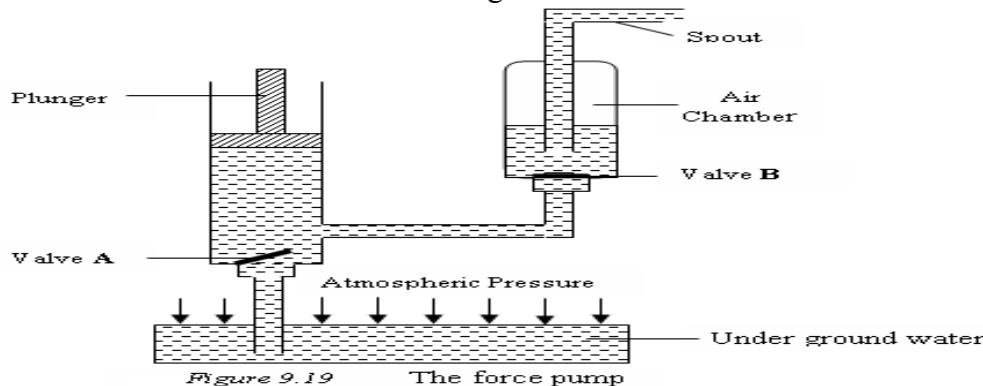
During down stroke, the handle is pulled up, the piston moves down, the outlet valve opens and the inlet valve closes, preventing water from falling back down the pipe. In the next repeated strokes, the water resting on top of the piston pours out of the spout. At the same time, more water is drawn up through the inlet valve.

Limitation of the Lift pump

Water is pushed up into the pump by the pressure of the atmosphere on the water in the well. This limits the distance through which water can be raised using a lift pump to about 8 meters.

The force pump

The force pump barrel contains a tightly fitting piston and two valves as shown in figure 9.18 below.



Mechanism of the Force Pump (How the Force pump Works)

Up stroke

During up stroke, the piston moves up reducing the air pressure in the cylinder. Valve A, opens while valve B, remains closed then atmospheric pressure forces water into the barrel.

Down stroke

During down stroke, the water in the barrel is compressed; valve A closes, B opens and water is forced along the spout into the air chamber compressing the air in the chamber. During the next up stroke, Valve A, opens and valve B, remains closed. The compressed air forces water out of the air chamber along the spout. The result is a continuous delivery of water through the spout.

Other applications of atmospheric pressure include the following.

- (i) The syringe.
- (ii) The drinking straw.
- (iii) The bicycle pump and
- (iv) Siphon.

Self-Check 9.1

1. A tank is filled with water to a depth of 3 m. What is the pressure at the bottom of the tank due to the water alone? ($d_{\text{water}} = 1000 \text{ kg/m}^3$)
A. 30 kPa B. 15 kPa C. 3 000 Pa D. 1 500 Pa
2. A diver is searching for treasure at a depth of 40m below the surface. What is the pressure exerted on the diver. ($P_{\text{atm}} = 100 000 \text{ N/m}^2$; $d_{\text{water}} = 1000 \text{ kg/m}^3$)
A. 400 000 N/m² B. 200 000 N/m² C. 500 000 N/m² D. 50 000 N/m²
3. What is the pressure at the bottom of a 3 km deep oil well filled with oil of density 860kg/m³?
A. 5 400 kPa B. 1 080 kPa C. 10 800 kPa D. 25 800 kPa
4. What is the total pressure on a fish swimming in the sea at a depth of 2 m below the surface? ($d_{\text{sea}} = 1 125 \text{ kg/m}^3$, $P_{\text{atm}} = 101 300 \text{ Pa}$)
A. 22.5 kPa B. 123.8 kPa C. 32.6 kPa D. 132.5 kPa
5. The piston of a hydraulic automobile lift has 0.48 m^2 area. What pressure is required to lift a car of mass 1 200 kg?
A. 25 kPa B. 12 kPa C. 30 kPa D. 60 kPa

6. In the hydraulic lift, the area of the smaller piston is one fourth that of the larger piston. If 40 N force is applied on the smaller piston, what is the force on the bigger piston?
 A. 640 N B. 160 N C. 10 N D. 320 N
7. In a hydraulic press a force of 40 N is applied to a piston of area 0.1m^2 . The area of the other piston is 4m^2 . What is the pressure transmitted through the liquid and the force on the other piston?
 A. 800 N/m^2 ; 3 200 N B. 400 N/m^2 ; 1 600 N
 C. 400 N/m^2 ; 400 N D. 800 N/m^2 ; 1 600 N
8. A hydraulic jack is made with a small piston 12 cm^2 that is used to move a large piston 108 cm^2 . If a man can exert a force of 270 N on the small piston, how heavy a load can he lift with the jack?
 A. 1 215 N B. 2 430 N C. 4 860 N D. 3 645 N
9. A hydraulic press has a large piston with a cross-sectional area of 250 cm^2 and a small piston with a cross-sectional area of 1.25 cm^2 . What is the force on the large piston when a force of 1 250 N is applied to the small piston?
 A. 375 000 N B. 125 000 N C. 500 000 N D. 250 000 N
10. In a liquid, pressure is
 A. Transmitted in a specific direction B. Transmitted in all directions.
 C. Decreased with depth D. Decreased with density
11. Pressure in a liquid is independent of the
 A. density of the liquid
 B. depth below the surface of the liquid
 C. pressure exerted on the surface of the liquid above
 D. cross-sectional area and the shape of the vessel containing the liquid
12. A rectangular block of metal weighs 3N and measures $(2 \times 3 \times 4) \text{ cm}^3$. What is the greatest pressure it can exert on a horizontal surface.
 A. $5.0 \times 10^3 \text{ Nm}^{-2}$ B. $3.75 \times 10^3 \text{ Nm}^{-2}$ C. $2.5 \times 10^3 \text{ Nm}^{-2}$ D. $7.5 \times 10^{-1} \text{ Nm}^{-2}$
13. The mass of a cuboid of dimensions $4 \text{ m} \times 2 \text{ m} \times 3 \text{ m}$ is 48 kg. The minimum pressure it can exert is
 A. 20 Nm^{-2} B. 40 Nm^{-2} C. 60 Nm^{-2} D. 80 Nm^{-2}
14. In a hydraulic machine
 A. an object displaces its own weight of fluid
 B. the pressure transmitted in the fluid is the same in all directions
 C. the volume of fluid compressed is proportional to the applied force
 D. an object experiences an upthrust equal to the weight of fluid displaced
15. Which one of the following is true about a manometer?
 (i) It uses mercury because mercury is a good conductor of heat.
 (ii) It is used for measuring gas pressures.
 (iii) The maximum height of mercury it can support is 760mm.
 A. (i) and (ii) only B. (i) and (iii) only C. (ii) only D. (ii) and (iii) only.
16. What is 730mm Hg in Nm^{-2} ?
 A. $\frac{13600 \times 1000 \times 10}{730}$ B. $\frac{13600 \times 730 \times 10}{1000}$ C. $\frac{13600 \times 730}{1000 \times 10}$ D. $\frac{13600 \times 10}{1000 \times 730}$
17. A metal cylinder contains a liquid of density 1100 kg/m^3 . The area of the base of the cylinder is 0.005 m^2 and the height of liquid is 5m. Calculate the force exerted by the liquid on the base of the cylinder.
 A. 27.5 N B. 55 N C. 220 N D. 275 N

18. A uniform tube with a narrowed middle part has three identical manometers attached to it as in the figure 9.21 below. If a steady flow of a liquid is maintained in the direction indicated by the arrows, the height of the liquid will be

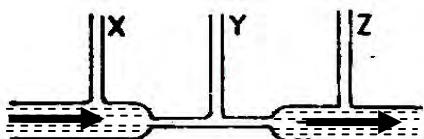


Figure 9.21

- A. greatest in X and Y B. greatest in Y
C. greatest in Z D. equal in X, Y and Z

19. Which one of the following are true about a hydraulic brake?

- (i) It uses water.
 - (ii) The brake pedal is connected to the master cylinder.
 - (iii) The return spring returns the brake drum in position.
 - (iv) The return spring returns the brake shoe in position.
- A. (i) (ii) and (iii) B. (ii) (iii) and (iv) C. (ii) and (iv) D. (iii) and (iv) only.

20. Which one of the following statements is false? The pressure in a liquid

- A. at any one point in a liquid would not change even when more liquid is added.
- B. at any one point depends only on the depth and density.
- C. at any one point acts equally in all directions.
- D. increases with depth.

21. When the handle, H, of the force pump shown in figure 9.22 below is moved upwards, the valves at

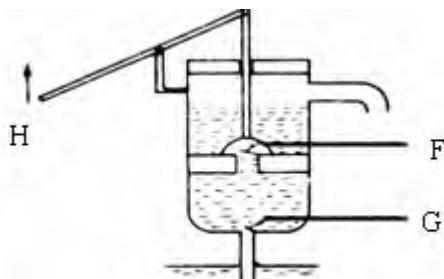


Figure 9.22

- A. F and G will both close
B. F and G will both open
C. F will close, and G will open
D. F will open and G will close

22. A rectangular block of dimensions $4 \text{ cm} \times 2 \text{ cm} \times 1\text{cm}$ exerts a maximum pressure of 200 Nm^{-2} when resting on a table. Calculate the mass of the block

- A. 4 g B. 16 g C. 40 g D. 400 g

23. Calculate the increase in pressure which a diver experience when he descends 30m in sea water of density 1.2×10^3

- A. $3.0 \times 10^2 \text{ Nm}^{-2}$ B. $1.2 \times 10^4 \text{ Nm}^{-2}$ C. $3.6 \times 10^4 \text{ Nm}^{-2}$ D. $3.6 \times 10^5 \text{ Nm}^{-2}$

24. In a hydraulic press, the area of the piston on which the effort is applied is made smaller in order to

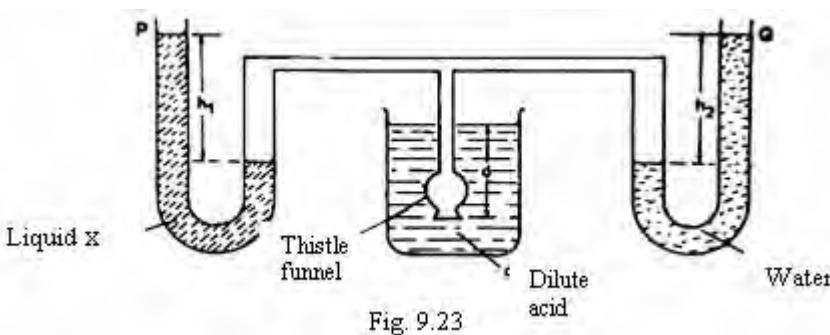
- A. facilitate the movement of the piston downwards
- B. transmit a force as large as possible to the load
- C. transmit pressure equally through out the liquid
- D. obtain a pressure as large as possible.

25. Which of the following is true about pressure in liquids? It

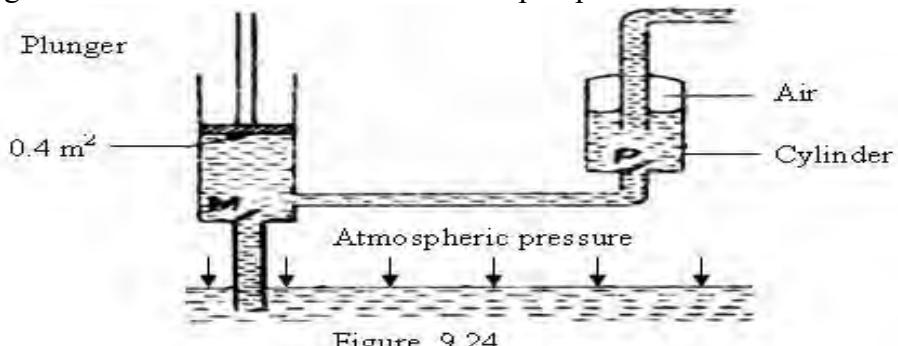
- A. increases with the surface area of the liquid
- B. is directly proportional to the depth
- C. depends on the shape of the container
- D. is the same at equal depths in all liquids

SECTION B

- 26.** (a) (i) Define pressure and state its units.
 (ii) With the aid of a diagram, describe how you would show that the pressure of a liquid is independent of cross-sectional area and shape of a container.
 (b) Two manometers P and Q contain a liquid X, and water respectively at the same level. They are then connected to a thistle funnel covered with a rubber membrane as shown in figure 9.23. When the thistle funnel is lowered into a beaker containing a dilute acid of density 1200 kgm^{-3} , the heights h_1 and h_2 are 15 cm and 12 cm respectively.



- Find the:
- Ratio of the density of liquid X to that of water,
 - Depth d of the thistle funnel below the surface of the dilute acid.
 - Explain why a ship floats in water although it is made mainly of metal.
- 27.** (a) (i) State the principle of transmission of pressure in fluids.
 (ii) Give one assumption on which the principle is based.
 (iii) State two applications of the principle.
 (iv) In a hydraulic press the smaller piston has a diameter of 14 cm while the larger has a diameter of 280 cm. If a force of 77 N is exerted on the smaller piston, calculate the force exerted on the larger piston.
 (b) With the help of diagram, describe how a hydraulic brake works.
- 28.** (a) Explain why large water reservoirs are much wider at the base than at the top.
 (b) Figure 9.24 shows the structure of a force pump.



- (i) Describe the action of the pump.
 (ii) If a downward force of 500 N is exerted on the plunger whose surface area is 0.4 m^2 , calculate the pressure which forces water into cylinder C.
- 29.** (a) Define term pressure and state its unit.
 (b) (i) Describe how a simple mercury barometer can be set up to measure the atmospheric pressure.
 (ii) The difference between the atmospheric pressure at the top and bottom of a mountain is $1 \times 10^4 \text{ N m}^{-2}$. If the density of air is 1.25 kgm^{-3} , calculate the height of the mountain.

CHAPTER TEN

ARCHIMEDES'S PRINCIPLE

LEARNING OBJECTIVES

By the end of this chapter you should be able to:

1. State: - Archimedes's Principle.
 2. Describe an experiment to verify the principle.
 3. State: - Applications of Archimedes's Principle.
 4. Solve problems involving Archimedes's Principle.
 5. State: - The law of Flotation.
 6. Describe an experiment to verify the law of Flotation.
 7. State: - Applications of the law of Flotation.
 8. Solve problems involving the law of Flotation.
 9. Define: - Terminal Velocity
 10. (a) Describe: - What happens to a body released to fall in a liquid in a tall measuring cylinder until it hits the bottom.
(b) Sketch a velocity-time graph for a body falling in a fluid.
-

10.1 Archimedes' Principle

Archimedes' Principle states that:

When a body is wholly or partially immersed in a fluid, it experiences an upthrust equal to the weight of fluid displaced.

Terms Used.

- | | |
|------------------|---|
| Upthrust: | - a force in a fluid that acts upwards. |
| Apparent weight: | - weight on an object in liquid. |

Experiment 10.1 To verify Archimedes's Principle

Apparatus/Requirements

Displacement can, water, Light and thin string, spring balance, A Suitable solid.

Procedure:

- Fill a displacement can with water till water flows through the spout and wait until the water ceases (stops) dripping.
- Suspend a solid object using a light string from a spring balance and weigh it in air.
- Place a beaker of known weight under the spout of the displacement can.
- Immerse the solid object in to the water in the displacement can and wait until water ceases dripping into the beaker.
- Read and record the apparent weight.
- Reweigh the beaker and the displaced water.

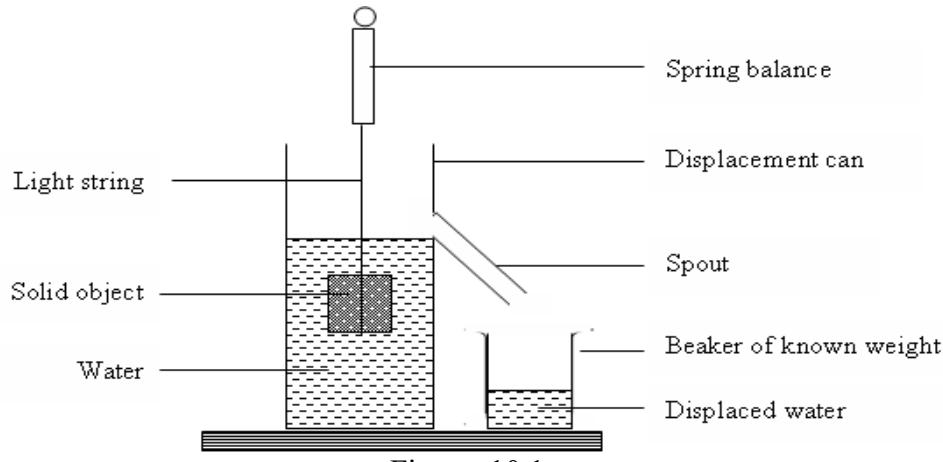


Figure 10.1

Results:

Let:	Weight of solid object in air	$= W_a \text{ N}$
	Weight of solid object in water (Apparent weight)	$= W_w \text{ N}$
	Weight of empty beaker	$= W_b \text{ N}$
	Weight of empty beaker + Displaced water	$= W_{(b+w)} \text{ N}$

Calculation:

$$\begin{aligned} \text{Upthrust (Loss in weight of object)} &= W_a - W_w \text{ N} \\ \text{Weight of water displaced} &= W_{(b+w)} - W_b \text{ N} \end{aligned}$$

Conclusion: If $W_a - W_w = W_{(b+w)} - W_b$,
i.e. Upthrust = Weight of fluid displaced, then Archimedes's principle
is verified.

10.2 Application of Archimedes's Principle

Archimedes's Principle is applied in the measurement of relative density of solid and liquid substances.

Experiment 10.2 To measure the Relative Density of Solid

Apparatus/Requirements

A beaker, water, Light and thin string, spring balance and suitable solid.

Procedure:

- Suspend the solid whose relative is to be determined from a spring balance by means of light string in air and record its weight.
- Immerse the solid wholly in water and record its apparent weight.

Results:

Let:	Weight of solid object in air	$= W_a \text{ N}$
	Weight of solid object in water (Apparent weight)	$= W_w \text{ N}$

Calculation:

$$\begin{aligned} \text{Upthrust (Loss in weight of object)} &= \text{Weight of water displaced} \\ &= W_a - W_w \text{ N} \end{aligned}$$

But Volume of water displaced = Volume of the solid immersed

$$\text{From Relative Density} = \frac{\text{Weight of substance}}{\text{Weight of an equal volume of water}}$$

$$\text{I.e. } \textbf{Relative Density} = \frac{W_a}{W_a - W_w} = \frac{\text{Weight of substance in air}}{\text{Upthrust in water}}$$

Examples

1. A glass stopper weighs 44 N in air and 24N when completely immersed in water. Calculate the relative density of glass.

Solution

$$\begin{aligned}\text{Weight of solid object in air} &= 44 \text{ N} \\ \text{Weight of solid object in water (Apparent weight)} &= 24 \text{ N} \\ \text{Weight of water displaced} &= \text{Upthrust in water} \\ &= 44 - 24 \text{ N} \\ &= 20 \text{ N}\end{aligned}$$

$$\text{Relative Density} = \frac{\text{Weight of substance in air}}{\text{Upthrust in water}} = \frac{44}{20} = 2.2$$

Experiment 10.3 To measure the Relative Density of Liquid

Apparatus/Requirements

A beaker, water, Light and thin string, spring balance and the liquid.

Procedure

- Suspend a solid from a spring balance by means of light string in air and record its weight.
- Immerse the solid wholly in water and record its apparent weight.
- Wipe the surface of the solid with a piece of dry cloth and immerse it wholly in the liquid whose relative density is to be found.
- Read and record its weight.

Results: Let: Weight of solid object in air $= W_a$ N
 Weight of solid object in water (Apparent weight) $= W_w$ N
 Weight of solid object in liquid (Apparent weight) $= W_l$ N

Calculation: Weight of water displaced $= \text{Upthrust in water}$
 $= W_a - W_w$ N
 Weight of liquid displaced $= \text{Upthrust in liquid}$
 $= W_l - W_w$ N

But in each case, the solid displaces its own volume of liquid.

But Volume of water displaced $= \text{Volume of the solid immersed}$
 $= \text{Volume of the liquid displaced.}$

$$\begin{aligned}\text{From } \text{Relative Density} &= \frac{\text{Weight of substance}}{\text{Weight of an equal volume of water}} \\ &= \frac{\text{Weight of liquid}}{\text{Weight of an equal volume of water}} \\ &= \frac{W_a - W_l}{W_a - W_w}\end{aligned}$$

I.e. Relative Density $= \frac{\text{Upthrust in liquid}}{\text{Upthrust in water}}$

Worked Example

1. A piece of iron weighs 145 N in air. When completely immersed in water, it weighs 120 N and weighs 125N when completely immersed in alcohol. Calculate the relative density of alcohol.

Solution:

Weight of solid object in air	= 145 N
Weight of solid object in water (Apparent weight)	= 120 N
Weight of solid object in liquid (Apparent weight)	= 125 N

Calculation:

Weight of water displaced	= Upthrust in water
	= 145 – 120 N
	= 25 N

Weight of alcohol displaced	= Upthrust in liquid
	= 145 – 125 N
	= 20 N

Relative Density	$= \frac{\text{Upthrust in liquid}}{\text{Upthrust in water}} = \frac{20}{25} = 0.8$
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10.3 Flotation

A body floats in a liquid if its density is less than the density of the liquid. A floating body sinks deeper in liquids of less density than in liquids whose densities are high. This is seen when ships move from fresh water to sea or ocean water. The depth to which the ship sinks is shown by lines called *plimsoll line* marked on the side of ship.

The law of Flotation

The law of flotation states that:

A floating body displaces its own weight of fluid in which it floats.

(a) Facts about a floating body

- ❖ The weight of the floating body = the weight of the fluid displaced.
- ❖ The weight of the fluid displaced = Upthrust (Archimedes's Principles)
- ❖ Therefore, the Upthrust = the weight of the floating body
- ❖ The mass of the floating body = the mass of the fluid displaced.

Experiment 10.4 To verify the Law of Flotation

Apparatus: Beaker, water, light string, spring balance, a suitable solid.

Procedure:

- Fill a beaker with water.
- Suspend a solid object in air using a light string from a spring balance and record its weight.
- Immerse the solid object completely in to the water in the beaker.
- Read and record the apparent weight (weight when the solid object is in liquid).

Observation: The string becomes slack (loose).

Results: Let: Weight of solid object in air = W_a N
Weight of solid object in water = 0.0 N

Calculation: Weight of water displaced = Upthrust in water = $W_a - 0.0$ N

Conclusion: If $W_a - 0.0 = W_a$,

I.e. Upthrust = Weight of fluid displaced, then law of flotation is verified.

(b) Relationship between the Density of floating body, Density of liquid and the Fraction submerged

The density of a floating body is related to the density of the liquid and the fraction submerged is by the formula:

$$\text{Density of floating body} = \text{Density of liquid} \times \text{Fraction submerged}$$

Derivation of the formula

Points to note:

- ❖ A floating body is supported by the upthrust of the liquid.
 - ❖ Therefore, in equilibrium,
 - the upthrust = the weight of the floating body.
 - ❖ The mass of the floating body = the mass of the fluid displaced.
 - ❖ The fraction submerged = the volume of the liquid displaced

Now let;

$$\begin{aligned} \text{The mass of the body floating} &= m_b \text{ g} \\ \text{The mass of the liquid displaced} &= \text{The mass of the floating body} \quad (\text{Law of flotation}) \\ &= m_b \text{ g} \end{aligned}$$

$$\text{The density of the floating body} = \rho_b \quad \text{g/cm}^3$$

The density of the liquid	ρ_l	g/cm^3
The volume of the body above the liquid surface	$= v_x$	cm^3
The volume of the body below the liquid surface	$= v_y$	cm^3

The volume of the body floating, $v = (v_x + v_y) \text{ cm}^3$

$$\text{The fraction submerged} = \frac{v_b}{(v_x + v_y)}$$

$$\text{The density of the floating body, } \rho_b = \frac{m_b}{(v_x + v_y)} \quad g/cm^3$$

$$m_b = \rho_b(v_x + v_y) \quad \dots \dots \dots \quad 1$$

$$\text{The density of the liquid, } \rho_l = \frac{m_l}{v_v} \text{ g/cm}^3 \quad \text{But } m_l = m_b$$

$$\rho_l = \frac{m_b}{v_v} \text{ g/cm}^3$$

$$m_b = \rho_l v_y \dots \dots \dots \quad 2$$

Equating equation (1) to (2) we have:

$$\rho_b(v_x + v_y) = \rho_l v_y$$

$$\rho_b = \rho_l \times \left(\frac{v_y}{(v_x + v_y)} \right)$$

$\therefore \boxed{\text{Density of floating body} = \text{Density of liquid} \times \text{Fraction submerged}}$

Note that $\frac{v_y}{(v_x + v_y)}$ = Fraction of the floating body submerged

Rearranging the equation, we have:

$$\boxed{\text{Fraction submerged} = \frac{\text{Density of floating body}}{\text{Density of liquid}}}$$

Worked Examples

1. A piece of wood of volume floats with $\frac{4}{5}$ of its volume under a liquid of density 800 kgm^{-3} . Find the density of the wood in kgm^{-3} .

Solution: Fraction submerged $= \frac{4}{5}$, Density of the liquid $= 800 \text{ kgm}^{-3}$

Using the formula

$$\text{Density of floating body} = \text{Fraction submerged} \times \text{Density of liquid}$$

$$\text{We have: } = \frac{4}{5} \times 800 = \frac{3200}{5} = 640 \text{ kgm}^{-3}$$

2. A piece of wood of volume 240 cm^3 floats with three quarters of its volume under water. Calculate the density of the wood if the density of water is 1000 kgm^{-3} .

Solution: Fraction submerged $= \frac{3}{4}$, Density of the water $= 1000 \text{ kgm}^{-3}$

$$\text{Density of floating body} = \text{Fraction submerged} \times \text{Density of liquid}$$

$$= \frac{3}{4} \times 1000 = \frac{3000}{4} = 750 \text{ kgm}^{-3}$$

10.4 Application of the law of flotation

The practical application of the law of flotation is seen in the following:

(i) Ships

Ships are able to float on water although they are made of metal. This is because their average densities are less than the density of water.

Ships float deeper in fresh water than in salty (sea water). This is because the density of fresh water is less than the density of salty water.

(ii) Submarines

These are ships that float submerged in water. They are equipped with periscope for viewing and tanks which can be filled with air or water to alter the density of the submarine. Thus making the submarine to float afloat, awash or submerged.

(iii) Balloons

Balloons are airships used for recording meteorological measurements.

The balloon is filled with a light gas e.g hydrogen gas until it displaces a weight of air greater than its own weight. The greater upthrust then pushes the balloon upwards.

It continues to rise until the upthrust on it is equal to the weight of the balloon plus its contents and then floats sideways.

(The lifting power of balloon) = Upthrust -

(Weight of balloon + Weight of its contents)

Example

- A balloon has a capacity of 10 m^3 and is filled with hydrogen. The balloon's fabric and the container have a mass of 1.25 kg. Calculate the maximum mass load the balloon can lift. (Density of hydrogen = 0.089 kgm^{-3} and of air = 1.29 kgm^{-3} , gravity, $g = 10 \text{ ms}^{-2}$).

Solution: Volume of balloon, $v = 10 \text{ m}^3$, Density of hydrogen, $\rho_h = 0.089 \text{ kgm}^{-3}$,

Density of air, $\rho_a = 1.29 \text{ kgm}^{-3}$, $g = 10 \text{ ms}^{-2}$,

Volume of air displaced, $v_a = \text{volume of balloon} = 10 \text{ m}^3$

Volume of hydrogen, $v_h = \text{Volume of balloon} = 10 \text{ m}^3$.

Mass of (balloon + container) = 1.25 kg

Let the mass of the load = $x \text{ kg}$

Total mass = Mass of balloon + Mass of Hydrogen + Mass of the load

$$= 1.25 + v_h \rho_h + x$$

$$= 1.25 + 10 \times 0.089 + x$$

$$= (1.25 + 0.89 + x) \text{ kg}$$

Weight of balloon = Total mass x gravity

$$= (2.14 + x)g \text{ N}$$

Weight of displaced air = mg

$$= v \rho g$$

$$= 10 \times 1.29 \times g$$

$$= 12.9g \text{ N}$$

For the balloon just to rise, upward force must be equal to the downward force i.e.

Upthrust = Weight of the load

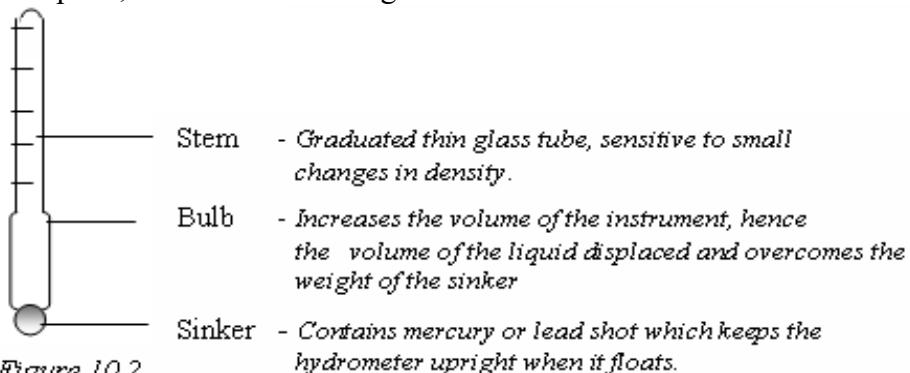
$$12.9g = (2.14 + x)g$$

$$x = 12.9 - 2.14$$

$$\therefore x = \mathbf{10.76 \text{ kg}}$$

5 Hydrometer

A hydrometer is an instrument used to measure relative density of liquids. It consists of three main parts, as shown in the diagram below.



The hydrometer is placed in the liquid whose R.D is to be measured and the scale read at the level of the liquid surface.

NB:

- ❖ Sensitivity of the hydrometer increased by making the stem very thin.
- ❖ The buoyancy is increased by making the bulb large.
- ❖ The smaller scales are at the top and the bigger scales are at the bottom. This is because the hydrometer floats deeper in lighter liquids than in denser liquids.

Common examples of hydrometers are:

- | | |
|--|---|
| - <i>Car hydrometer (battery tester)</i> | - Used to test the state of the charge of a car battery |
| - <i>Lactometer</i> | - Used to test the purity of milk. |

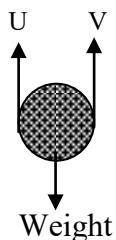
10.6 Terminal Velocity

Terminal velocity – is the constant velocity attained by a body falling through a fluid.

Facts about a body falling in a fluid

- (i) The body first accelerates i.e. its velocity increases with time.
- (ii) After some time, it attains a constant velocity called *terminal velocity* and falls with this velocity until it hits the bottom of the cylinder.

A diagram showing a ball bearing falling through a liquid



Where: U = Uthrust
V = Viscosity (fluid friction)

Explanation

As the ball bearing falls through the liquid, the liquid resistance (viscosity) exerts an upward force opposing the gravity. Since viscosity in fluids increases with velocity (i.e. the higher the velocity the greater the viscosity), the viscosity or viscous drag increases with velocity eventually the combined upward force of upthrust and the viscosity is equal to the weight (force of gravity) on the ball bearing. At this point the resultant force on the ball bearing is zero and its. As no force acts on the ball bearing, it has no acceleration, but it acquires a constant velocity called *terminal velocity*.

When the values of velocity is plotted against time the shape of the graph below is obtained

The graph of velocity against time for a body falling through a fluid

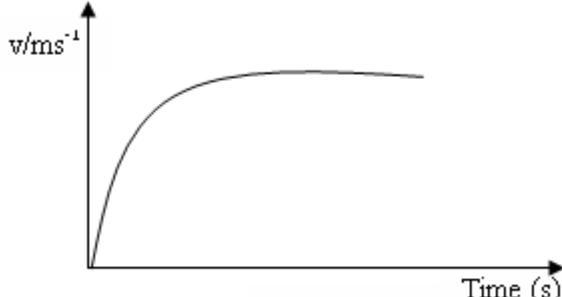


Figure 10.3

Self-Check 10.0

1. A block of metal (density 2700 kg/m^3) has volume 0.09 m^3 . Calculate the up thrust force when it is completely immersed in brine (density 1200 kg/m^3)

A. 600 N	B. 1080 N	C. 180 N	D. 1200 N
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2. An iron box of mass 90 g and density 0.9 g/cm^3 floats on brine (density 1200 kg/m^3). What is the volume immersed in the brine?

A. 40 cm^3	B. 60 cm^3	C. 90 cm^3	D. 75 cm^3
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3. The envelope of a hot air balloon contains 1500 m^3 of hot air of density 0.8 kg/m^3 . The mass of the balloon (not including the hot air) is 420 kg. the density of surrounding air is 1.3 kg/m^3 . What is the lifting force?

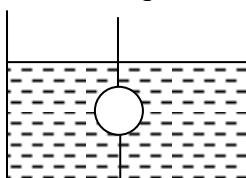
A. 3300 N	B. 4400 N	C. 5500 N	D. 6600 N
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4. What fraction of a wooden cube of one side 10cm will be below the water level if the cube is floating in water? ($d_{\text{water}} = 1 \text{ g/cm}^3$, $d_{\text{wood}} = 0.6 \text{ g/cm}^3$)

A. $\frac{3}{5}$	B. $\frac{2}{5}$	C. $\frac{1}{5}$	D. $\frac{1}{10}$
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5. An ice cube of volume 600 cm^3 floats in water. What is the volume of the part above the water level? ($d_{\text{ice}} = 0.9 \text{ g/cm}^3$, $d_{\text{w}} = 1 \text{ g/cm}^3$)

A. 60 cm^3	B. 80 cm^3	C. 520 cm^3	D. 540 cm^3
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6. A cubical brass block floats in mercury. What fraction of the block lies above the mercury surface? (the densities of brass and mercury are 8600 kg/m^3 and 13600 kg/m^3 respectively)

A. $\frac{86}{136}$	B. $\frac{50}{86}$	C. $\frac{136}{86}$	D. $\frac{50}{136}$
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7. A large, hollow plastic sphere is held below the surface of a fresh water pool by a cable attached to the bottom of the pool. The sphere has a volume of 0.400 m^3 .

Plastic sphere



Calculate the buoyancy force exerted by the water on the sphere.

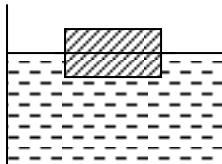
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|-----------|-----------|
| A. 4000 N | B. 800 N |
| C. 3200 N | D. 4800 N |

8. A lead sphere has a total mass of 45.2 kg. If it is put into water, what will be the upthrust force on it? (Density of lead is 11300 kg/m^3)

A. 10 N	B. 20 N	C. 30 N	D. 40 N
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9. A block of wood of volume 80 cm^3 and density 0.5 g/cm^3 floats in water. What is the volume immersed in water (density of water = 1 g/cm^3)

A. 50 cm^3	B. 40 cm^3	C. 30 cm^3	D. 20 cm^3
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10. Figure 2 shows a block of volume 40 cm^{-3} floating in water with only half of its volume submerged. If the density of water is 1000 kg m^{-3} , determine the mass of the wood.



- A. $40 \times 1000 \text{ kg}$.
B. $20 \times 1000 \text{ kg}$.
C. $40 \times 10^{-6} \times 500 \text{ kg}$.
D. $20 \times 10^{-6} \times 500 \text{ kg}$.

SECTION B

11. (a) State Archimedes's Principle.
(b) Describe an experiment to verify Archimedes's Principle.
(c) A piece of iron weighs 355 N in air. When completely immersed in water, it weighs 305 N and weighs 315 N when completely immersed in methylated spirit. Calculate the relative density of methylated spirit.
(d) State the application of Archimedes's principle.
12. (a) State the law of flotation.
(b) Describe an experiment to verify the law of flotation.
(c) A piece of wood of volume 40 cm^3 floats with only half of volume submerged. If the density of water is 1000 kg m^{-3} , calculate the density of wood.
13. A balloon has a capacity of 20 m^3 and is filled with hydrogen. The balloon's fabric and the container have a mass of 2.5 kg . Calculate the maximum mass load the balloon can lift. (Density of hydrogen = 0.089 kg m^{-3} and of air = 1.29 kg m^{-3} , gravity, $g = 10 \text{ ms}^{-2}$).
14. (a) Define terminal velocity.
(b) Explain with a help of velocity-time graph, what happens to a USA soldier parachuted from a war plane flying at a high altitude in an area free of enemies in Iraq from the time he leaves the plane till he lands to the ground.

CHAPTER ELEVEN

MOTION

LEARNING OBJECTIVES

By the end of this chapter, you should be able to:

1. (a) Define: - Speed, Velocity, Uniform velocity, Acceleration and uniform acceleration.
(b) State: - The S.I units of: Speed, Velocity and Acceleration.
- The difference between speed and velocity.
(c) State: - The equations of linear motion.
(d) Solve problems using the equations of linear motion.
2. (a) Represent linear motion using: - Displacement-time graph and
- Velocity-time graph.
(b) Describe from: - Displacement-time graph and
- Velocity-time graph.
3. (a) Calculate: - Average speed/velocity and
- Acceleration from a sample of ticker-tape.
(b) Describe: - Motion from a sample of a ticker tape.
4. (a) Solve problems involving: - Motion under gravity and
- Projectile motion.
(b) State: - The forces acting on a body moving in a circle.

11.1 Speed velocity and Acceleration

(a) Speed

Speed is defined as the rate of change of distance moved with time.

OR *Speed is the distance traveled in a unit time.*

Mathematically, it is expressed as: $\text{Speed} = \frac{\text{Distance}}{\text{Time}}$

S.I unite of speed is **m/s or ms^{-1}** .

(b) Displacement

Displacement is defined as distance moved in a specified direction.

For example if a body moves along a straight line in a given direction such as 100m due east or 50m due north.

(c) Velocity

Velocity is defined as the rate of change of displacement with time.

Or *Velocity is the rate of change of distance moved with time in a specified direction.*

Or *Velocity is defined as speed in a specified direction.*

The S.I unite of velocity is **ms^{-1} or m/s**.

Difference between speed and velocity

Velocity is a vector quantity whereas speed is a scalar quantity.

NB: *Vector quantity is a quantity that has both magnitude and direction.*
Scalar quantity is a quantity that magnitude only.

Uniform Velocity

Uniform velocity is the velocity when the rate of change of displacement is constant.

Non-uniform velocity

Non-uniform velocity is the velocity when the rate of change of displacement is not constant.

Acceleration

Definition *Acceleration is defined as the rate of change of velocity with time.*

$$\begin{aligned}\text{Acceleration} &= \frac{\text{Change of velocity}}{\text{Time Taken}} \\ &= \frac{\text{Final velocity} - \text{Initial velocity}}{\text{Time Taken}}\end{aligned}$$

The S.I unit of acceleration

The SI unit of acceleration = m/s^2 or ms^{-2} . Read as metres per sec squared.

When the velocity of a body is changing, the body is said to be accelerating.

Acceleration is: Positive - if the velocity is increasing and
 Negative - if the velocity is decreasing.

A negative acceleration is called deceleration or retardation.

Uniform Acceleration

Uniform acceleration is the acceleration when the rate of change of velocity is constant.

11.2 The Equations of Linear Motion

The following are the equations for uniformly accelerated body.

$v = u + at$ $s = \frac{1}{2}(u + v)t$ $s = ut + \frac{1}{2}at^2$ $v^2 = u^2 + 2as$	<i>Where:</i> u = Initial velocity i.e velocity when $t = 0$ v = Final velocity i.e velocity at time t a = Constant acceleration s = Distance traveled from the starting
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- Notes:**
- When using the equations, it is necessary to bear in mind that u , v , a , and s are vectors. If, say, the positive direction is taken to be *up*, then:
 - The velocity of a body which is moving *down* (i.e in opposite direction) is negative.
 - Points below the starting point have negative values of s .
 - Downward* directed accelerations are negative.
 - This facts will help a learner to understand a velocity-time graph with negative values of velocity.

Derivation of the Equations of Motion

Suppose that a body is moving with constant acceleration a and that in a time interval t its velocity increases from u to v and its displacement increases from 0 to s . Then, from the definition of acceleration we have:

$$\begin{aligned}\text{Acceleration} &= \text{Rate of change of velocity} \\ \text{Acceleration} &= \frac{\text{Change of velocity}}{\text{Time Taken}} \\ &= \frac{\text{Final Velocity} - \text{Initial Velocity}}{\text{Time Taken}} \\ a &= \frac{v - u}{t} \\ v &= u + at \quad \dots \dots \dots \quad 1\end{aligned}$$

Since the acceleration is uniform,

$$\begin{aligned}\text{Average velocity} &= \frac{\text{Final Velocity} + \text{Initial Velocity}}{2} \\ &= \frac{v - u}{2} \text{ and therefore} \\ \text{Displacement} &= \text{Average velocity} \times \text{Total time} \\ s &= \frac{(v+u)t}{2} \\ s &= \frac{1}{2}(v+u)t \quad \dots \dots \dots \quad 2\end{aligned}$$

Eliminating v from equation gives equation 3. This is done by substituting equation 1 ($v = u + at$) in equation 2.

$$\begin{aligned}s &= \frac{(u + at + u)t}{2} \\ &= \frac{(2u + at)t}{2} \\ &= \frac{(2ut + at^2)}{2} \\ s &= ut + \frac{1}{2}at^2 \quad \dots \dots \dots \quad 3\end{aligned}$$

Eliminating t from equation (2) gives equation (4).

This is done by substituting $t = \left(\frac{v-u}{a}\right)$ from equation (1) in equation (2).

$$\begin{aligned}\text{i.e.} \quad s &= \left(\frac{v+u}{2}\right) \times \left(\frac{v-u}{a}\right) \\ s &= \frac{v^2 - u^2}{2a} \\ 2as &= v^2 - u^2 \\ v^2 &= u^2 + 2as \quad \dots \dots \dots \quad 4\end{aligned}$$

Worked Examples

1. An object starts from rest and moves with an acceleration of 10 m/s^2 for four seconds.

Calculate: (a) The velocity

(b) The distance traveled

Solution: (a) $u = 0, a = 10 \text{ ms}^{-2}, t = 4 \text{ s}, v = ?$

$$\begin{aligned} \text{Using the formula} \quad v &= u + at \\ &= 0 + 10 \times 4 \end{aligned}$$

$$v = 40 \text{ m/s}$$

(b) Using the formula $s = ut + \frac{1}{2}at^2$

$$\begin{aligned} &= 0 \times 4 + \frac{1}{2} \times 10 \times 4 \times 4 \\ &= 0 + 80 \text{ m} \end{aligned}$$

$$\therefore s = 80 \text{ m}$$

2. A car moving with uniform acceleration of 4 m/s^2 increases its velocity from 20 m/s to 60 m/s . Calculate:

(a) the total time taken during this change

(b) the total distance moved

Solution: $a = 4 \text{ m/s}^2, u = 20 \text{ m/s}, v = 60 \text{ m/s}, t = ?, s = ?$

(a) Using the formula $v = u + at$

$$60 = 20 + 4 \times t$$

$$60 = 20 + 4t$$

$$4t^2 = 60 - 20$$

$$4t^2 = 40$$

$$\frac{4t}{4} = \frac{40}{4}$$

$$\therefore t = 10 \text{ s}$$

(b) Using the formula $s = ut + \frac{1}{2}at^2 = 20 \times 10 + \frac{1}{2} \times 4 \times 10 \times 10$

$$= 200 + 200$$

$$\therefore s = 400 \text{ m}$$

3. A body traveling with a velocity of 10 m/s is uniformly retarded to rest in 5 seconds

Find (a) its acceleration.

(b) the distance traveled during the retardation.

Solution: $u = 10 \text{ m/s}, v = 0, t = 5 \text{ s}, a = ?, s = ?$

(a) Using the formula $v = u + at$

$$0 = 10 + 5$$

$$\frac{5a}{5} = \frac{-10}{5}$$

$$\therefore a = -2 \text{ m/s}^2$$

The minus sign means that the body is accelerating in the opposite direction to its initial velocity.

(b) Using the formula: $v^2 = u^2 + 2as$

$$0 = 10^2 + 2 \times 2 \times s$$

$$0 = 100 + 4s$$

$$4s = 100$$

$$\frac{4s}{4} = \frac{100}{4}$$

$$\therefore s = 25 \text{ m}$$

11.21 Changing velocity from km/h to m/s

Velocity given in km/h can be changed to m/s. This is simply done by applying the formula for speed.

$$\text{I.e.} \quad \text{Speed} = \frac{\text{Distance}(km)}{\text{time }(h)}$$

Steps followed

- ❖ Interpret the value of the speed given.
E.g. x km/h means that the body travels x km in 1 hour.
- ❖ Change the numerical value of the velocity or speed to metres and also change 1 hour to seconds.
- ❖ Divide the distance in metres by the time in seconds.

Example

Change the speed 36 km/h to m/s.

The speed 36 km/h, means that the body travels 36 km in 1 hour.

To change the speed from km/h to m/s, we change the 36 km to m and 1 hour to seconds.

Changing 36 km to m: $1 \text{ km} = 1000 \text{ m}$

$$36 \text{ km} = x$$

$$x = \frac{36 \text{ km} \times 1000 \text{ m}}{1 \text{ km}} = 36000 \text{ m}$$

Changing 1 hour to seconds: $1 \text{ h} = 60 \text{ min}$

$$= (60 \times 60) \text{ s}$$

$$= 3600 \text{ s}$$

Now we substitute the distance in m and time in seconds in the formula:

$$\text{Speed} = \frac{\text{Distance}}{\text{Time}} = \frac{36000}{3600} = 10 \text{ m/s}$$

Self-Check 11.1

1. An object starts from rest and moves with an acceleration of 10 m/s^2 for four seconds.
Calculate:
(a) The velocity
(b) The distance traveled .
2. A car moving with uniform acceleration of 4 m/s^2 increases its velocity from 20 m/s to 60 m/s , Calculate:
(a) the total time taken during this change
(b) the total distance moved
3. A body traveling with a velocity of 10 m/s is uniformly retarded to rest in 5 seconds
Find:
(a) its acceleration.
(b) the distance traveled during the retardation.
4. Change the following speeds from km to m/s.
(a) 72 km/h (b) 108 km/h (c) 180 km/h (d) 288 km/h

11.3 Graphical Representation of Linear Motion

Graphs can be used to represent the motion of a body which is moving in a straight line.

(a) Types of Graphs of Linear Motion

There are two types of graphs namely:

- Distance-time graph and
- Velocity-time graph.

(b) Distance-Time graph

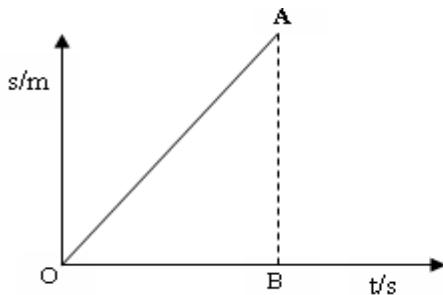
A distance-time graph is the type of graph obtained by plotting distance/displacement travelled against time taken.

The common graphs are for a body:

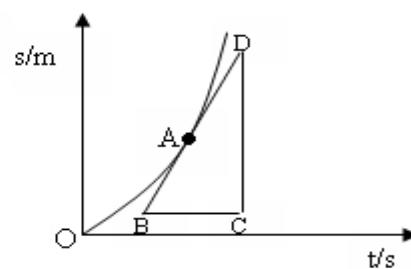
- Moving with a uniform velocity
- Non-uniform velocity and
- At rest.

By definition, velocity is rate of change of displacement and therefore the slope of a graph of displacement against time represents velocity.

(i) Uniform velocity



(ii) Non-uniform velocity



$$\text{Velocity} = \frac{\text{Distance}}{\text{Time taken}}$$

$$\text{Velocity} = \frac{\text{Distance represented by } DC}{\text{Time interval represented by } BC}$$

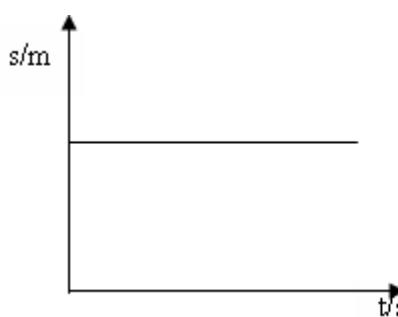
$$= \frac{AB}{OB}$$

$$\text{Velocity at A} = \frac{DC}{BC}$$

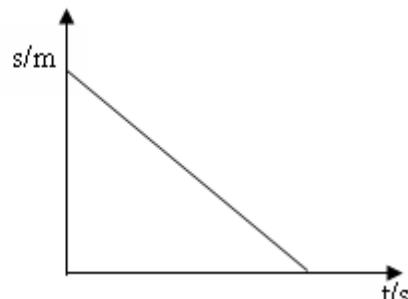
I.e Velocity = Gradient of the line OA

= Gradient at A

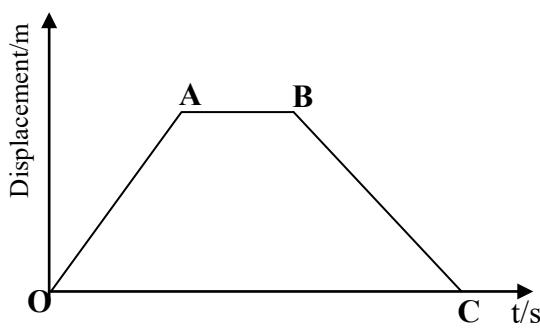
(iii) A body at rest



(iv) A body on return journey



However, these graphs can be combined to form a single graph with the different stages of the motion as shown below.



- OA**
 - The slope is positive
 - The body is moving constant velocity during this period
- AB**
 - The slope is zero i.e the velocity is zero
 - The body is stationary
- BC**
 - The slope is negative
 - The body is moving constant velocity in the opposite direction during this period

Velocity-Time graph

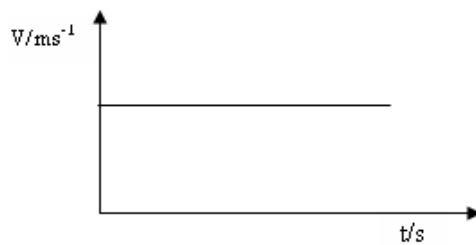
A velocity-time graph is the type of graph obtained by plotting velocity against time.

The common graphs are for a body:

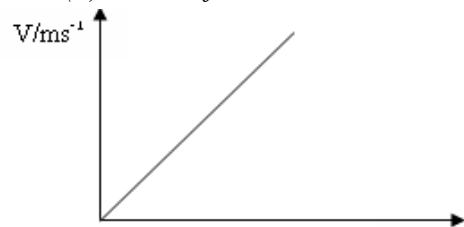
- ❖ moving with uniform velocity (constant velocity)
- ❖ Non-uniform velocity,
- ❖ Uniform acceleration,
- ❖ Non-uniform acceleration and
- ❖ Uniform deceleration

By definition, acceleration is rate of change of velocity and therefore, the slope of a graph of velocity against time represents acceleration.

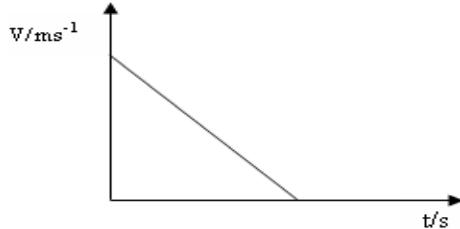
(i) Uniform velocity,



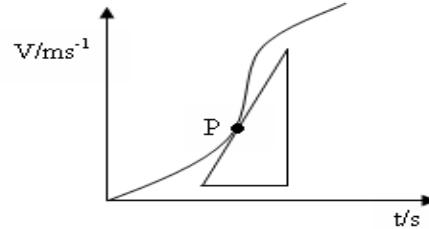
(ii) Uniform acceleration



(iii) Uniform deceleration



(iv) Non-uniform acceleration



$$\text{Acceleration} = \frac{\text{Change in velocity}}{\text{Change in time}}$$

$$\text{Acceleration} =$$

$$\frac{\text{Change in velocity}}{\text{Change in time}}$$

$$= \frac{AB}{OB}$$

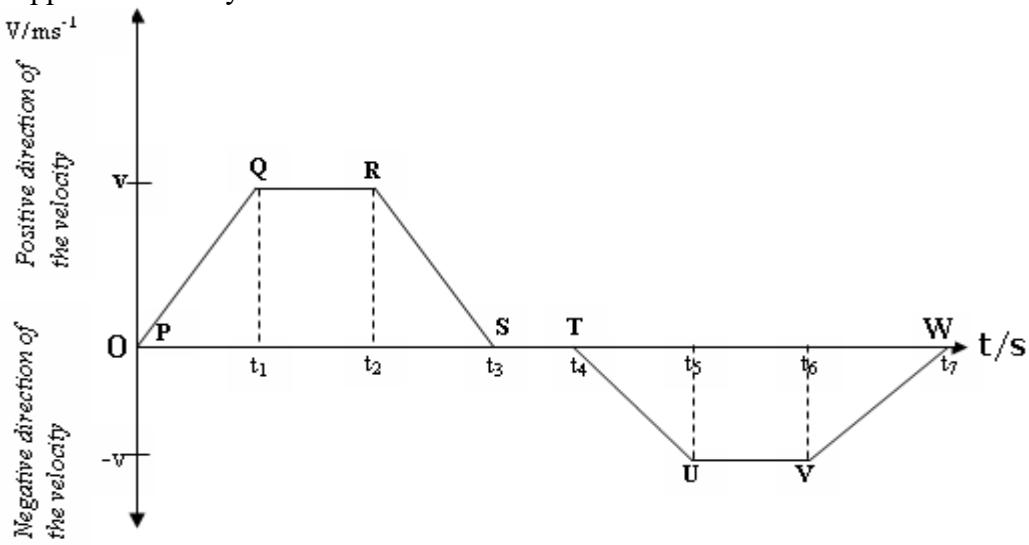
$$\text{Acceleration at A} = \frac{DC}{BC}$$

$$\text{Acceleration} = \text{Gradient of the line OA}$$

$$= \text{Gradient at A}$$

However, the graphs for uniform acceleration, velocity and deceleration can be combined to represent a linear motion for a body starting from rest or at a certain initial velocity. Then the total distance travelled is equal to the area under the graph and can be calculated using equations of motion or using appropriate formulae.

A velocity-time graph for a body that travelled a given distance and returned and stopped on the way.



Notes: 1. When interpreting a graph, it is necessary to bear in mind that u , v , a , and s are vectors.

If, say, one direction is taken to be positive, then:

- (i) The velocity of a body which is moving in the opposite direction is negative.
 - (ii) Points below the starting point have negative values of s .
 - (iii) Downward directed accelerations are negative.
 - (iv) The magnitude and the direction of the slope of the graph give the magnitude and direction of the acceleration.
2. These facts will help you to understand the interpretation of the above velocity-time graph where there are negative values of velocity.

Stage	State of the body	Interpretation
P - Q	The body starts from rest and moves with a uniform acceleration during this period.	<ul style="list-style-type: none"> - The velocity is positive and increasing. - The slope is positive and constant. - The acceleration is positive and constant.
Q - R	The body is moving with a constant velocity during this period.	<ul style="list-style-type: none"> - The velocity is positive and constant. - The slope is zero. - The acceleration is zero.
R - S	At t_2 , the body brakes and is uniformly decelerated to rest at t_3 .	<ul style="list-style-type: none"> - The velocity is positive and decreasing. - The slope is negative and constant. - The acceleration is negative and constant. - The negative acceleration means that it acts in the opposite direction to the direction of velocity.
S - T	The body is stationary at this period	<ul style="list-style-type: none"> - The velocity is zero (the body is stationary) - The slope is zero - The acceleration is zero
T - U	At time t_4 , the body returns and moves with a constant acceleration in the opposite direction.	<ul style="list-style-type: none"> - The velocity is negative and increasing. - The slope is negative and constant. - The acceleration is negative and constant.

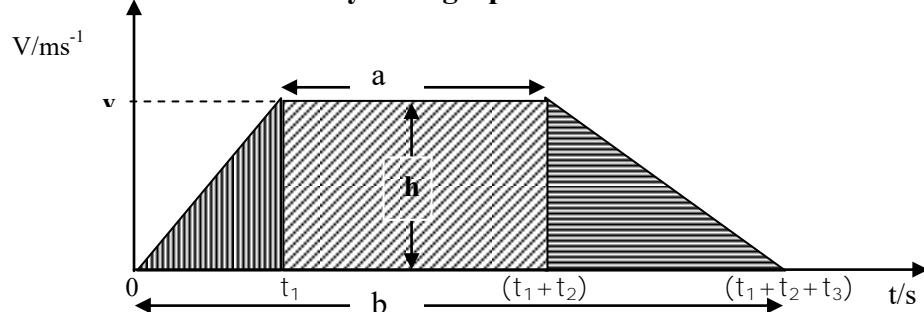
U - V	The body is moving with a constant velocity in the opposite direction during this period.	- The velocity is negative and constant. - The slope is zero. - The acceleration is zero.
V - W	At time t_6 , the body brakes and decelerated uniformly until it comes to rest at time t_7 .	- The velocity is negative and decreasing. - The slope is positive and constant. - The acceleration is positive and constant.

Worked Examples

1. A car starts from rest and accelerates uniformly for time t_1 seconds to attain a maximum velocity $v \text{ ms}^{-1}$. It maintained this velocity for t_2 seconds, then the brakes were applied and the car uniformly retarded to a rest for t_3 seconds.
- Represent the above motion in a velocity-time graph.
 - On your graph show by shading the total distance travelled.

Solution: Initial velocity = 0 (from rest), Final velocity = $v \text{ ms}^{-1}$

The velocity-time graph for the motion



$$\begin{aligned}\text{Total distance travelled} &= \text{Area under the graph} \\ &= \text{Area of the trapezium} \\ &= \frac{1}{2}(a + b)h\end{aligned}$$

$$\begin{aligned}\text{Or } \text{Total distance travelled} &= \text{Area A} + \text{Area B} + \text{Area C} \\ &= \frac{1}{2}bh + lw + \frac{1}{2}bh\end{aligned}$$

2. A car starts from rest and is accelerated uniformly at the rate of 5 ms^{-2} for time 10 seconds to attain a maximum velocity. It then maintained this velocity for 40 seconds. The brakes were then applied and the car uniformly retarded to rest in 5 seconds.

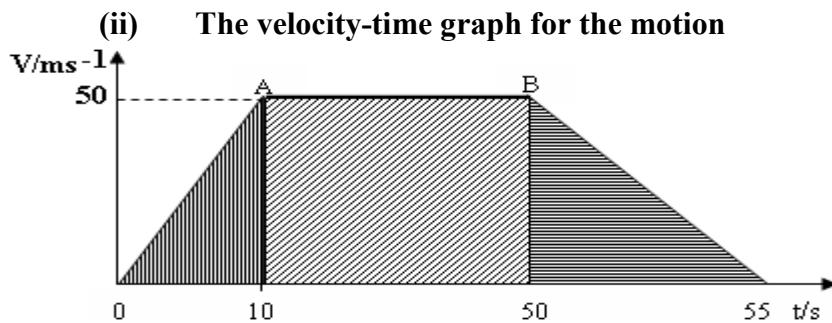
Calculate:

- the maximum velocity attained.
- Represent the motion on velocity-time graph.
- Find the total distance travelled in metres.

Solution

- $\mathbf{(i)} \quad u = 0, v = ?, a = 5 \text{ ms}^{-2}, t = 10 \text{ s}$

$$\begin{aligned}v &= u + at \\ &= 0 + 5 \times 10 \\ \therefore v &= 50 \text{ ms}^{-1}\end{aligned}$$



(iii) Method I $a = 50 - 10 = 40$, $b = 55$, $h = 50$

$$\text{Total area} = \text{Area trapezium OABC}$$

$$= \frac{1}{2}(a + b)h$$

$$= \frac{1}{2}(AB + OC) \times AD$$

$$= \frac{1}{2}(50 - 10 + 55) \times 50$$

$$= \frac{1}{2}(40 + 55) \times 50$$

$$= \frac{1}{2} \times 95 \times 50$$

$$= 2375 \text{ m}$$

\therefore Total distance travelled = 2375 m

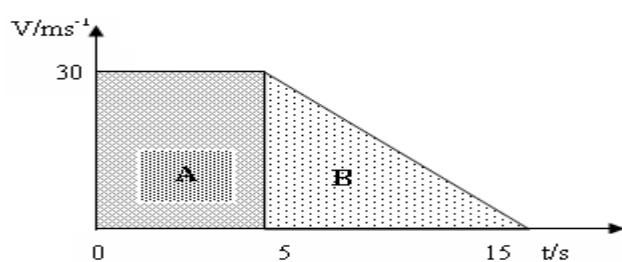
Method II Total distance travelled = Area A + Area B + Area C
 $= \frac{1}{2}bh + lw + \frac{1}{2}bh$
 $= \frac{1}{2} \times 10 \times 50 + (50 - 10) \times 50 + \frac{1}{2} \times (55 - 50) \times 50$
 $= 250 + 40 \times 50 + \frac{1}{2} \times 5 \times 50$
 $= 250 + 2000 + 125$
 $= 2375 \text{ m}$

\therefore Total distance travelled = 2375 m

3. A car travels with a uniform velocity of 30 ms^{-1} for 5 seconds. The brakes are then applied and the car comes to a rest with a uniform retardation in a further 10 seconds.
- Draw a sketch graph of velocity-time graph.
 - Show by shading the total distance travelled by the car.
 - Find the distance travelled by the car after the brakes are applied.

Solution: $u = 30 \text{ ms}^{-1}$, $t_1 = 5 \text{ s}$, $t_2 = 10 \text{ s}$

(i) Velocity-time graph for the motion



(ii) The distance travelled after the brakes were applied

$$= \text{Area B}$$

$$= \frac{1}{2}bh$$

$$= \frac{1}{2}(15 - 5) \times 20$$

$$= \frac{1}{2} \times 10 \times 30$$

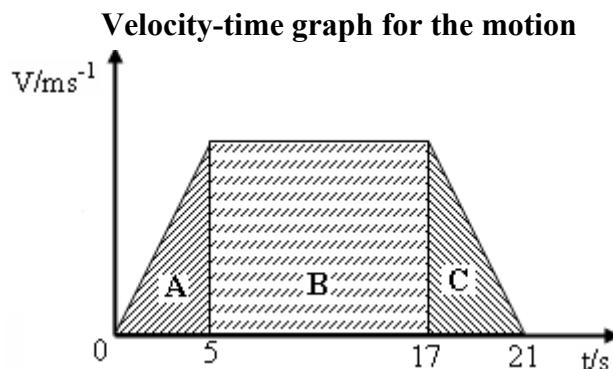
$$= 150 \text{ m}$$

4. A body starts from rest and accelerates at 5 ms^{-2} , for 5 seconds. Its velocity remained constant at the maximum value so reached for 12 seconds and it finally came to a rest with uniform retardation after another 4 seconds.

Find by graphical method:

- The distance travelled during each stage of the motion.
- The average velocity for the whole journey.

Solution $u = 0, v = ?, a = 5 \text{ ms}^{-2}, t_1 = 5 \text{ s}, t_2 = 12 \text{ s}, t_3 = 4 \text{ s}$
 $v = u + at = 0 + 5 \times 5 = 25 \text{ ms}^{-1}$



Dist. travelled at the first stage = Area A
 $= \frac{1}{2}bh$
 $= \frac{1}{2} \times 5 \times 25$
 $= 62.5 \text{ m}$
 $\therefore \text{Distance travelled} = 62.5 \text{ m}$

Distance travelled at the second stage = Area B
 $= lw$
 $= (17 - 5) \times 25$
 $= 12 \times 25$
 $= 300 \text{ m}$

Distance travelled at the third stage = Area C
 $= \frac{1}{2}bh$
 $= \frac{1}{2} \times (21 - 17) \times 25$
 $= \frac{1}{2} \times 4 \times 25$
 $\therefore s = 50 \text{ m}$

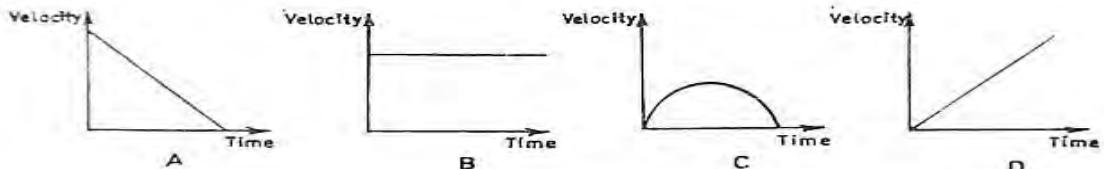
(ii) Average velocity

$$\begin{aligned}
 &= \frac{\text{Total distance travelled}}{\text{Total time taken}} \\
 &= \frac{\text{Area A} + \text{Area B} + \text{Area C}}{t_1 + t_2 + t_3} \\
 &= \frac{62.5 + 300 + 50}{5 + 12 + 4} \\
 &= \frac{412.5}{21} \\
 \therefore \text{Average velocity} &= 19.64 \text{ ms}^{-1}
 \end{aligned}$$

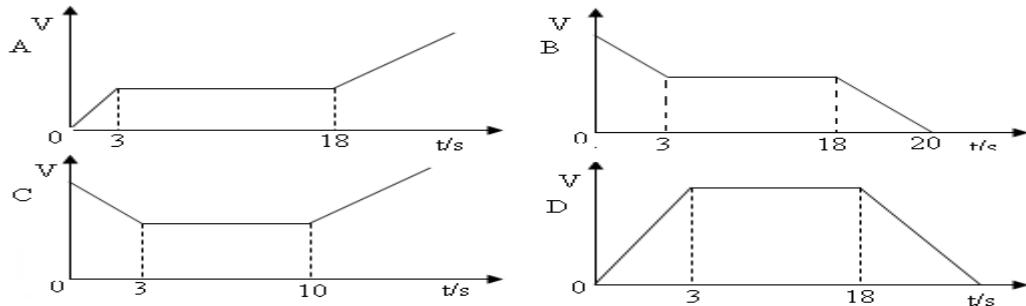
Self-Check 11.2

1. A body moves with uniform acceleration if
 - A. its momentum remains constant
 - B. it covers equal distances in equal times
 - C. the velocity changes by equal amount in equal times
 - D. the net force on the body is zero
2. A cyclist traveling at a constant acceleration of 2ms^{-2} passes through two points A and B in a straight line. If the speed at A is 10ms^{-1} and the points are 75m apart, find the speed at B.
 - A. 15.8ms^{-1}
 - B. 17.3ms^{-1}
 - C. 20.0ms^{-1}
 - D. 400.0ms^{-1}
3. A body moves with a uniform acceleration of $P\text{ms}^{-2}$. If its initial velocity is $x\text{ms}^{-1}$ and it travels for t s to attain a final velocity of $y\text{ms}^{-1}$, find the value of p in terms of x , y and t .
 - A. $x + yt$
 - B. $\frac{y - x}{t}$
 - C. $\frac{y + x}{t}$
 - D. $y + xt$
4. A body is said to be moving with a constant velocity if;
 - (i) Its momentum remains constant
 - (ii) It covers equal distances in equal times
 - (iii) The velocity changes by equal amount in equal times
 - (iv) The net force on the zero
 - A. All
 - B. (i), (ii) and (iv)
 - C. (i) and (ii) only
 - D. (ii) only
5. A car of mass of mass 1200 kg moving with a constant velocity of 60 ms^{-1} is retarded uniformly to rest in 12 sec .Calculate the retarding force.
 - A. $(1200 \times 12)\text{ N}$
 - B. $(1200 \times 5)\text{ N}$
 - C. $(1200 \times 10)\text{ N}$
 - D. $(1200 \times 60)\text{ N}$
6. The gradient of a velocity-time graph represents the

A. Speed of the body	B. Velocity of the body
C. Acceleration of the body	D. The distance covered by the body
7. A body is said to be moving with uniform velocity when the rate of change of

A. acceleration with time is constant	B. velocity with time is constant
C. distance with time is constant	D. displacement with time is constant.
8. Which one of the above sketches represents uniformly accelerated motion?
 

9. A lift accelerates uniformly from rest for 3s. It then moves at uniform velocity for 15s then decelerates uniformly for 2s before coming to rest. Which of the following velocity-time graph represents the motion of the lift.



10. Figure 4 shows a velocity-time graph for a moving body. Which one of the following statements is true about the motion of the body?

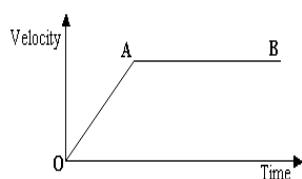


Figure 4

- A. Velocity of the body is constant between O and A.
- B. Velocity of the body is constant between A and B.
- C. The body is accelerating between A and B.
- D. The body is not accelerating between O and A.

11. The graph in figure 1 describes the motion of particle. Between which points is the particle at rest?

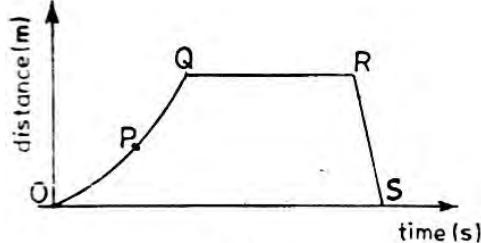


Fig.1

- A. O and P.
- B. P and Q.
- C. Q and R.
- D. R and S.

12. A car starts from rest and accelerates uniformly at the rate of 2ms^{-2} from $\frac{1}{4}$ of a minute. Find the velocity of the car after this time.
 A. 0.5ms^{-1} B. 12ms^{-1} C. 15ms^{-1} D. 30ms^{-1}

13. The in the figure shows a speed-time graph for a body.

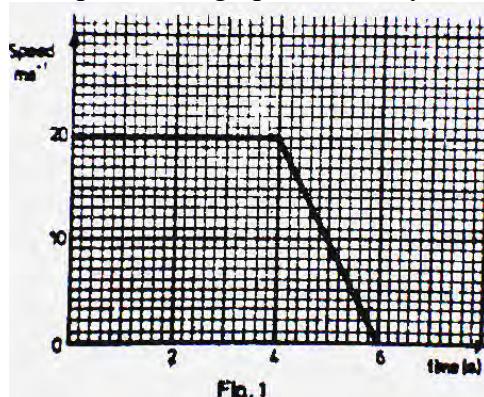
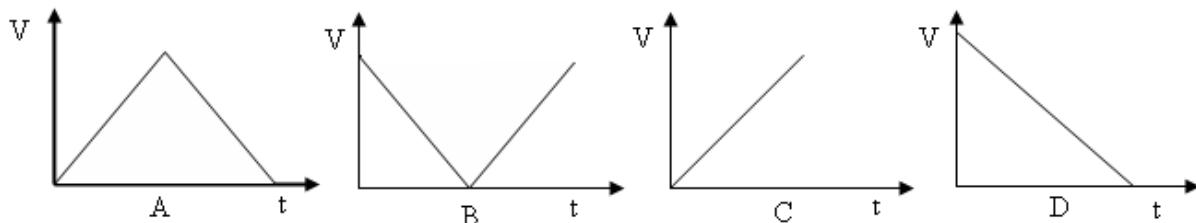


Fig.1

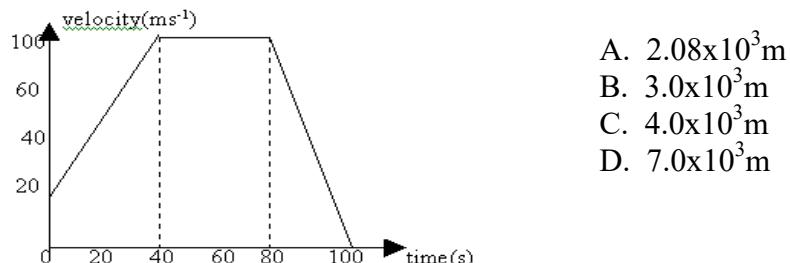
Calculate the distance traveled during retardation

- A. 20m
- B. 40m
- C. 80m
- D. 100m

14. A boy throws a ball in the air and it goes up and falls back to his hand. Which one of the following sketches of velocity-time graph represents the motion of the ball up to the time it is received back?

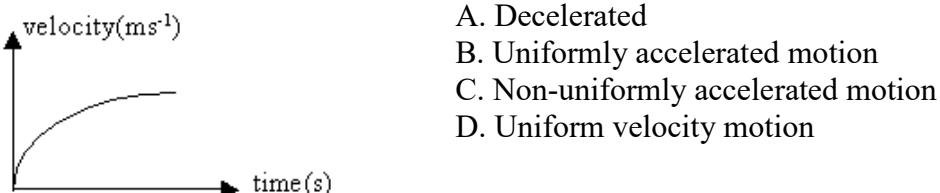


- 15.** The velocity-time graph for a car is as shown in fig. Find the total distance the car travels.



- A. 2.08×10^3 m
 B. 3.0×10^3 m
 C. 4.0×10^3 m
 D. 7.0×10^3 m

- 16.** Which of the following best describes the motion represented by the velocity-time graph shown in the diagram?



- A. Decelerated
 B. Uniformly accelerated motion
 C. Non-uniformly accelerated motion
 D. Uniform velocity motion

- 17.** A car is uniformly accelerated from rest and after 10s acquires a speed of 20ms^{-1} . How far does it move during the eleventh second?

- A. 20m B. 21m C. 100m D. 121m

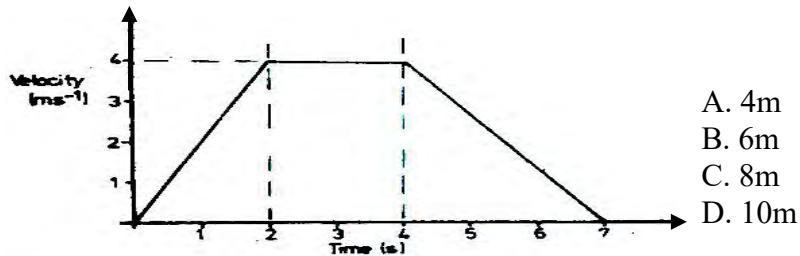
- 18.** Which one of the following is not true about a body moving with a constant velocity?

- A. its acceleration is zero B. Its momentum is constant
 C. Its kinetic energy is constant D. There is a resultant force on it

- 19.** A car travelling at 20ms^{-1} is brought to rest in 10s. Find the distance it travels

- A. 100m B. 200m C. 300m D. 400m

- 20.** Use the velocity-time graph in the figure to find the distance over which there is deceleration.



- A. 4m
 B. 6m
 C. 8m
 D. 10m

Fig. 1

SECTION B

- 21.** (a) What is meant by the following:
 (i) uniform velocity (ii) uniformly accelerated motion ?
 (b) A body starts from rest and reaches a speed of 5m/s after travelling with uniform acceleration in a straight line for 2 seconds. Calculate the acceleration of the body.
- 22.** A body starts from rest and moves with uniform acceleration of 2m/s in a straight line.
 (a) What is its velocity after 5 seconds?
 (b) How far has it travelled in this time?
 (c) How long will the body be after the starting point?

- 23.** (b) The table below shows the variation of velocity with time for a body, which has been thrown vertically upwards from the surface of a planet.

Velocity(ms^{-1})	8	6	4	2	0	-2
Time	0	1	2	3	4	5

- (i) What does the negative velocity mean?
 - (ii) Plot a graph of velocity against time.
 - (iii) Use the graph in b (ii) to find the acceleration due to gravity on the planet.
 - (iv) Use the graph in b (ii) to find the total distance traveled.
- 24.** (a) What is meant by acceleration?
 (b)

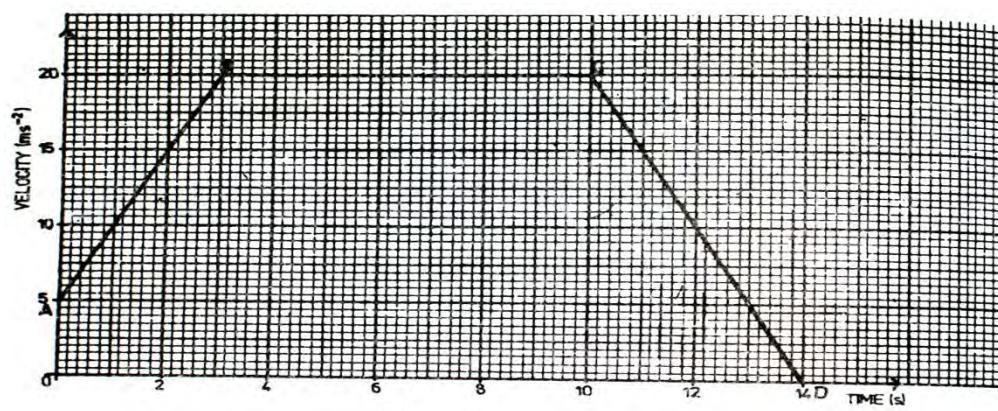
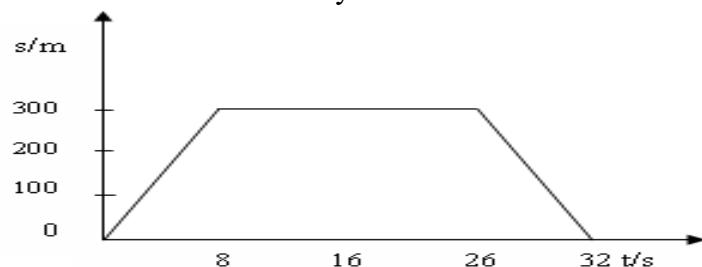


Fig.1

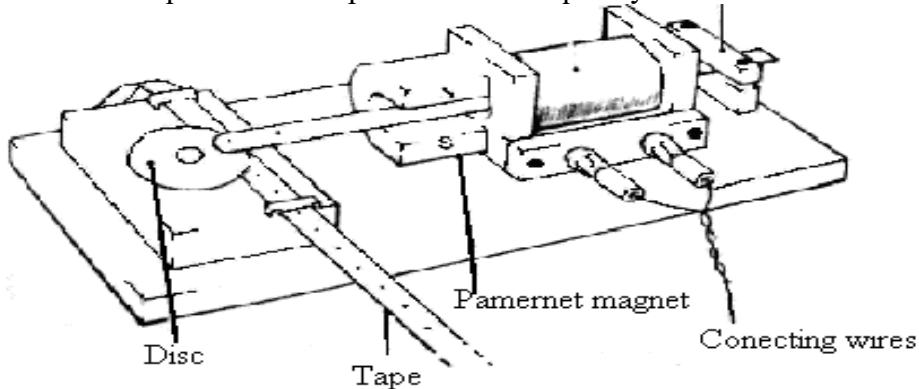
The above figure shows a speed-time graph of a cyclist.

- (i) Find the acceleration of the cyclist between A and B.
 - (ii) Describe the motion of the cyclist between B and C
 - (iii) Explain what is happening along CD.
 - (iv) Calculate the distance travelled by the cyclist during the first 10 seconds
- 26.** (a) What is the difference between speed and velocity?
 (b) The graph in the figure shows the variation of distance with time for a body.
 Describe the motion of the body.



11.4 Ticker-Tape Timer (ticker-tape vibrator)

This is a device used to investigate speed, velocity and acceleration of a moving body. It consists of a steel strip which vibrates at mains frequency, f , making dots on paper tape which is pulled by the body. The time interval between any two successive dots is called a *tick* and is equal to the reciprocal of the frequency in seconds.



Calculations

To calculate speed, velocity or acceleration, the following steps are followed.

First determine:

- (i) The distance between the reference points (dots) on the ticker tape

(ii) The tick using the formula

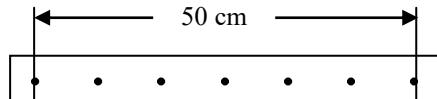
$$\text{One tick} = \frac{1}{\text{Frequency}} \text{ second.}$$

(iii) The time taken to make the dots from the formula

$$\text{Total time taken} = \text{One tick} \times \left(\frac{\text{No. of spaces between}}{\text{reference points}} \right)$$

(a) To calculate velocity

1. The diagram below shows equally spaced dots on a ticker tape.



If the vibrator of the ticker timer has a frequency of 50 Hz, find the average speed of the trolley in m/s.

Solution: Frequency = 50Hz, One Tick = ?

$$\text{One tick} = \frac{1}{f} = \frac{1}{50} = 0.02 \text{ s}$$

$$\text{Total distance covered} = 50 \text{ cm} = \frac{50}{100} \text{ m} = 0.5 \text{ m}$$

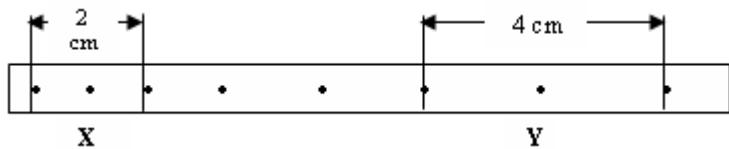
$$\begin{aligned} \text{Total time taken} &= \text{One tick} \times \left(\frac{\text{No. of spaces between}}{\text{reference points}} \right) \\ &= 0.02 \times 6 \end{aligned}$$

$$t = 0.12 \text{ s}$$

$$\text{Using} \quad \text{Speed} = \frac{\text{Distance}}{\text{Time}} = \frac{0.5}{0.12} = 4.166 = 4.2 \text{ ms}^{-1}$$

(b) To calculate the acceleration

1. The tape shown in the diagram below was made by a trolley moving with a constant acceleration. If the frequency of the ticker-timer is 100 Hz, find the acceleration in ms^{-2} .



Solution: $F = 100 \text{ Hz}$ One tick $= \frac{1}{f} = \frac{1}{100} = 0.01 \text{ s}$

Initial Velocity, u , at X: Distance, $s = 2 \text{ cm} = \frac{2}{100} = 0.02 \text{ m}$

$$\begin{aligned} \text{Time taken} &= \text{One tick} \times \text{No. of spaces between the dots} \\ &= 0.01 \times 2 \\ &= 0.02 \text{ s} \end{aligned}$$

$$\text{Initial velocity}, u = \frac{s}{t} = \frac{0.02}{0.02} = 1 \text{ ms}^{-1}$$

Final Velocity, v , at Y: Distance, $s = 4 \text{ cm} = \frac{4}{100} = 0.04 \text{ m}$

$$\begin{aligned} \text{Time taken} &= \text{One tick} \times \text{No. of spaces between the dots} \\ &= 0.01 \times 2 \\ &= 0.02 \text{ s} \end{aligned}$$

$$\text{Initial velocity}, u = \frac{s}{t} = \frac{0.04}{0.02} = 2 \text{ ms}^{-1}$$

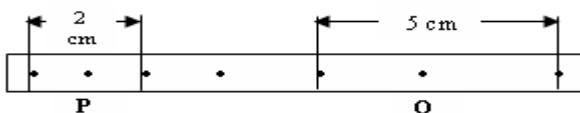
Time taken from X to Y is calculated from the formula

$$\begin{aligned} \text{Time taken} &= \text{One tick} \times \text{No. of spaces between XY} \\ &= 0.01 \times 5 \\ t &= 0.05 \text{ s} \end{aligned}$$

The acceleration is calculated from the formula:

$$\begin{aligned} \text{Acceleration} &= \frac{\text{Velocity at Y} - \text{Velocity at X}}{\text{Time taken}} \\ a &= \frac{v - u}{t} = \frac{4 - 2}{0.05} = \frac{2}{0.05} = 40 \text{ ms}^{-2} \end{aligned}$$

2. Calculate the acceleration, in ms^{-2} , for the motion shown in the diagram below.
(Take frequency = 50Hz)



Solution: $F = 50 \text{ Hz}$ One tick $= \frac{1}{f} = \frac{1}{50} = 0.02 \text{ s}$

Initial Velocity, u , at P: Distance, $s = 2 \text{ cm} = \frac{2}{100} = 0.02 \text{ m}$

$$\begin{aligned} \text{Time taken} &= \text{One tick} \times \text{No. of spaces between the dots} \\ &= 0.02 \times 2 \\ t &= 0.04 \text{ s} \end{aligned}$$

$$\text{Initial velocity}, u = \frac{s}{t} = \frac{0.02}{0.04} = 0.5 \text{ ms}^{-1}$$

$$\text{Final Velocity, } v, \text{ at } Q: \quad \text{Distance, } s = 5 \text{ cm} = \frac{5}{100} = 0.05 \text{ m}$$

$$\begin{aligned}\text{Time taken, } t &= \text{One tick x No. of spaces between the dots} \\ &= 0.02 \times 2 \\ &= 0.04 \text{ s}\end{aligned}$$

Time taken from P to Q is calculated from the formula

$$\begin{aligned}\text{Time taken, } t &= \text{One tick x No. of spaces between } P \text{ and } Q \\ &= 0.02 \text{ s} \times 4 \\ t &= 0.08 \text{ s}\end{aligned}$$

$$\text{Initial velocity, } v = \frac{s}{t} = \frac{0.05}{0.04} = 1.25 \text{ ms}^{-1}$$

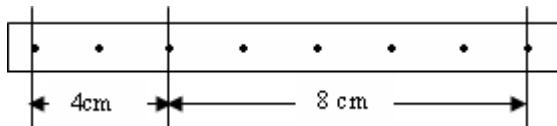
The acceleration is calculated from the formula

$$\begin{aligned}\text{Acceleration} &= \frac{\text{Velocity at } P - \text{Velocity at } Q}{\text{Time taken}} \\ a &= \frac{v - u}{t} = \frac{1.25 - 0.5}{0.08} = \frac{0.75}{0.08} = 9.375 \text{ ms}^{-2}\end{aligned}$$

2

(c) To Describe Motion

The figure below shows dots made on a ticker tape pulled by a trolley through a ticker timer.



Describe the motion of the trolley if the frequency is 50Hz?

To describe motion from a sample of ticker tape, you find the speeds at the two stages of the motion and their respective time taken. Then relate the speeds to the time taken for the two stages as shown below.

Speed at the first stage

$$\text{Frequency, } f = 50 \text{ Hz}, \quad \text{Tick} = \frac{1}{f} = \frac{1}{50} = 0.02 \text{ s}, \quad s = 4 \text{ cm},$$

$$\begin{aligned}\text{Time taken} &= \text{One tick x No. of spaces} \\ &= 0.02 \times 2 \\ &= 0.04 \text{ s}\end{aligned}$$

$$\text{Speed} = \frac{s}{t} = \frac{4}{0.04} = 100 \text{ cms}^{-1}$$

Speed at the second stage

$$\begin{aligned}s = 8 \text{ cm}, \quad \text{time taken} &= \text{One tick x No. of spaces} \\ &= 0.02 \times 5 \\ &= 0.1 \text{ s}\end{aligned}$$

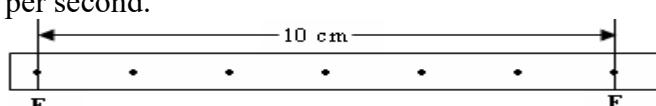
$$\text{Speed} = \frac{s}{t} = \frac{8}{0.1} = 80 \text{ cms}^{-1}$$

Description of the motion

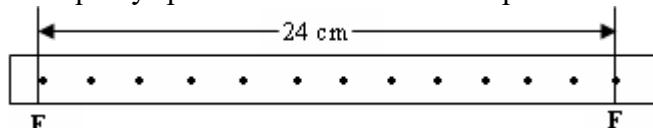
In the first 0.04 s, the body was traveling with a speed of 100 cms^{-1} . The body then decelerated and the speed reduced to 80 cms^{-1} in the next 0.1 s.

Self-Check 11.3

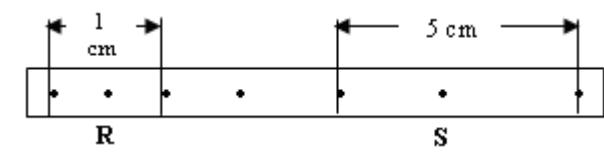
1. A ticker timer is connected to the mains supply of frequency 40Hz. Find the time it takes to print three consecutive dots.
 A. 0.08 s B. 0.25 s C. 0.050 s D. 0.75 s
2. The ticker tape shown in the figure was pulled through a ticker timer, which makes 50 dots per second.



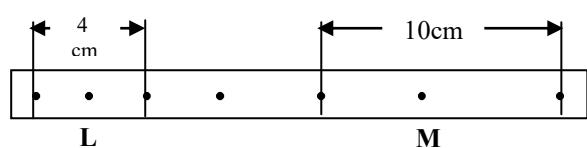
- The speed at which the tape was pulled is
 A. 10 cm s^{-1} B. 25 cm s^{-1} C. 50 cm s^{-1} D. 100 cm s^{-1}
3. A tape is pulled through a ticker-timer, which has a frequency of 50Hz. If the distance between successive dots is 2cm, calculate the speed of the body
 A. 0.01 cms^{-1} B. 50 cms^{-1} C. 100 cms^{-1} D. 250 cms^{-1}
 4. The equally spaced dots on the ticker tape above are made by a vibrator of



- frequency 50 Hz. The speed of the tape in m/s is
 A. 0.1 B. 0.01 C. 0.001 D. 1
5. The tape shown in the diagram below was made by a trolley moving with a constant acceleration. If the frequency of the ticker-timer is 50 Hz, find the acceleration in m/s^2 .



- A. 75 ms^{-2} B. 2 ms^{-2} C. 5 ms^{-2} D. 12.5 ms^{-2}
6. Calculate the acceleration, in ms^{-2} , for the motion shown in the diagram below.
 (Take frequency = 100Hz)



- A. 75 ms^{-2} B. 2 ms^{-2} C. 5 ms^{-2} D. 0.04 ms^{-2}

11.5

Motion under Gravity

Types of Motion

There are different forms of motion under gravity, depending how the motion is started.

- (i) **Free-falling objects** - If an object is released from rest (i.e. when the initial velocity is zero) and allowed to fall.
- (ii) **Projectile motion** - If an object is thrown (projected) at an angle with an initial velocity greater than zero.

(a) Free-falling objects

Objects released from rest at a height above the surface of the earth fall downwards. This is because of force of gravity pulling them downwards.

An object thrown vertically upwards with an initial velocity greater than zero moves with a negative acceleration since the motion is away from the earth surface. The velocity reduces until it becomes zero at the maximum height reached. At this point the object is momentarily at rest and then begins to accelerate downwards with a positive acceleration. The velocity increases until it hits the ground. This acceleration arises from the *force of gravity* acting on the body, and is called *acceleration due to gravity* (symbol g).

If air resistance or friction is neglected, all objects near to the surface of the earth, (regardless of their mass) accelerate at the same rate called *acceleration due to gravity*. The acceleration due to gravity (symbol g) is about 9.81 ms^{-2} . But the value varies slightly from place to place. See chapter five. For simple calculations g is usually rounded up to 10 ms^{-2} . This means that objects falling freely under gravity increase their velocity by about ms^{-1} every second.

Calculations for free-falling objects

The equations of motion, apply to objects moving vertically downwards or upwards under the force of gravity, except that the acceleration a is replaced by the acceleration due to gravity, g .

Equations for Linear Motion

$$v = u + at$$

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

$$v^2 = u^2 + 2as$$

Equations for Motion under gravity

$$v = u + gt$$

$$s = ut + \frac{1}{2}gt^2$$

$$v^2 = u^2 + 2gs$$

Distance moved by a free-falling body

Distance moved by a body falling freely from rest is related to time of fall by the formula:

$$s = \frac{1}{2}gt^2$$

The formula is derived from the third equation of motion

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

Where $u = 0$ (i.e. from rest)

$a = g$ acceleration due to gravity

NB: An object moving vertically upwards has a negative acceleration or retardation. Therefore the acceleration due to gravity, $g = 10 \text{ ms}^{-2}$ while for an body moving downwards, the acceleration due to gravity is positive, $g = 10 \text{ ms}^{-2}$

Worked Examples

1. A coconut fruit falls from the coconut tree and takes 5 seconds to hit the ground.
 Calculate: (a) its velocity.
 (b) the total distance traveled. (Take $g = 10 \text{ m/s}^2$)

Solution (a) $g = 10 \text{ m/s}^2, u = 0 \text{ ms}^{-1}, t = 5 \text{ s}$

$$\begin{aligned} v &= u + at \\ &= 0 + 10 \times 5 \\ \therefore v &= 50 \text{ ms}^{-1} \end{aligned}$$

(b) Using the formula $s = ut + \frac{1}{2}at^2$

$$\begin{aligned} &= (0 \times 5) + \frac{1}{2} \times 10 \times 5^2 \\ &= 0 + 5 \times 25 \\ \therefore s &= 125 \text{ m} \end{aligned}$$

2. A stone is dropped from a top of a cliff. If it takes 8 seconds to hit the ground, calculate: (a) the height of the cliff.
 (b) the velocity at impact. (Take $g = 10 \text{ ms}^{-2}$)

Solution (a) Using the formula $g = 10 \text{ m/s}^2, u = 0 \text{ ms}^{-1}, t = 4 \text{ s}$

$$\begin{aligned} s &= ut + \frac{1}{2}gt^2 \\ &= (0 \times 4) + \frac{1}{2} \times 10 \times 4^2 \\ &= 0 + 5 \times 16 \\ \therefore s &= 80 \text{ m} \end{aligned}$$

(b) $v = u + at$

$$\begin{aligned} &= 0 + 10 \times 4 \\ \therefore v &= 40 \text{ ms}^{-1} \end{aligned}$$

3. A stone is thrown vertically upwards with an initial velocity of 40 ms^{-1} .
 Calculate: (a) the maximum height reached.
 (b) the time taken to reach the maximum height.
 (Take $g = 10 \text{ ms}^{-2}$ and neglect air resistance)

Solution

$u = 40 \text{ ms}^{-1}, v = 0 \text{ ms}^{-1}$ (*At maximum height the stone is momentarily at rest*),
 $a = g = -10 \text{ ms}^{-2}, s = ?$

(a) $\begin{aligned} v^2 &= u^2 + 2as \\ v^2 &= u^2 + 2gs \\ 0^2 &= 40^2 + 2 \times -10 \times s \\ 0 &= 1600 - 20s \\ 20s &= 1600 \\ s &= 80 \text{ m} \end{aligned}$

(b) $u = 40 \text{ ms}^{-1}, v = 0 \text{ ms}^{-1}, a = g = -10 \text{ ms}^{-2}, s = ?$

$$\begin{aligned} v &= u + at \\ v &= u + gt \\ 0 &= 40 + -10 \times t \\ 0 &= 40 - 10t \\ 10t &= 40 \\ \therefore t &= 4 \text{ s} \end{aligned}$$

4. A ball is thrown vertically upwards with an initial velocity of 20 ms^{-1} .

Neglecting air resistance, calculate:

- the maximum height reached,
- the time taken before it reaches the ground. (Take $g = 10 \text{ ms}^{-2}$)

Solution $u = 20 \text{ ms}^{-1}$, $v = 0 \text{ ms}^{-1}$ (*At maximum height the stone is momentarily at rest*),
 $a = g = -10 \text{ ms}^{-2}$, $s = ?$

$$\begin{aligned}(a) \quad & V^2 = u^2 + 2as \\ & V^2 = u^2 + 2gs \\ & 0^2 = 20^2 + 2 \times -10 \times s \\ & 0 = 400 - 20s \\ & 20s = 400 \\ & \therefore s = \underline{\underline{20 \text{ m}}}\end{aligned}$$

$$\begin{aligned}(b) \quad & u = 20 \text{ ms}^{-1}, v = 0 \text{ ms}^{-1}, a = g = -10 \text{ ms}^{-2}, t_1 = ? \\ & v = u + at \\ & v = u + gt \\ & 0 = 20 + -10 \times t_1 \\ & 0 = 20 - 10t_1 \\ & 10t_1 = 20 \\ & t_1 = \underline{\underline{2 \text{ s}}}\end{aligned}$$

Time taken in the return journey, $t_2 = ?$ $u = 0 \text{ ms}^{-1}$, $v = 0 \text{ ms}^{-1}$, $a = g = 10 \text{ ms}^{-2}$, $s = 20 \text{ m}$

$$\begin{aligned}\text{Using the formula} \quad & s = ut + \frac{1}{2}at^2 \\ & 20 = (0 \times t_2) + \frac{1}{2} \times 10 \times t_2^2 \\ & 20 = 5t_2^2 \\ & \sqrt{4} = \sqrt{t_2^2} \\ & t_2 = \underline{\underline{2 \text{ s}}}\end{aligned}$$

Time taken before it reaches the ground $= t_1 + t_2 = 2 + 2 = \underline{\underline{4 \text{ s}}}$

NB: Note that the time taken to reach the maximum height is equal to the time taken to return to the ground.

Further Examples

1. A stone is thrown vertically upwards with an initial velocity of 30 ms^{-1} from a tower 20 m high. Neglecting air resistance, calculate:

- The time taken to reach the maximum height.
- The maximum height reached.
- The total time taken which elapses before it just hits the ground
(Take $g = 10 \text{ ms}^{-2}$)

Solution

(a) $u = 30 \text{ ms}^{-1}$, $v = 0 \text{ ms}^{-1}$ (*At the maximum height the stone is momentarily at rest*),
 $a = g = -10 \text{ ms}^{-2}$, $t = ?$ $s = ?$

$$\begin{aligned}& v = u + gt \\ & 0 = 30 + -10 \times t \\ & 0 = 30 - 10t \\ & 10t = 30 \\ & t_1 = \underline{\underline{3 \text{ s}}}\end{aligned}$$

$$\begin{aligned}
 (b) \quad v^2 &= u^2 + 2as \\
 v^2 &= u^2 + 2gs \\
 0^2 &= 30^2 + 2 \times -10 \times s \\
 0 &= 900 - 20s \\
 20s &= 900 \\
 \therefore s &= 45 \text{ m}
 \end{aligned}$$

$$\begin{aligned}
 (c) \quad \text{Total height} &= \text{Height of cliff} + \text{Maximum height reached} \\
 &= 20 + 45 \\
 \therefore \text{Total height} &= 65 \text{ m}
 \end{aligned}$$

Time to fall from the maximum height to the ground = ?, $g = 10 \text{ ms}^{-2}$

Using the formula: $s = ut + \frac{1}{2}at^2$

$$65 = (0 \times t) + \frac{1}{2} \times 10 \times t^2$$

$$65 = 5t^2$$

$$\sqrt{13} = \sqrt{t^2}$$

$$t = 3.60 \text{ s}$$

$$\begin{aligned}
 \text{Total time taken} &= \left(\begin{array}{l} \text{Time taken from the top} \\ \text{of the cliff to reach the} \\ \text{maximum height} \end{array} \right) + \\
 &\quad \left(\begin{array}{l} \text{Time taken from the top} \\ \text{of the maximum height} \\ \text{to reach the ground} \end{array} \right)
 \end{aligned}$$

$$= 3 + 3.60$$

$$\therefore \text{Total time taken} = 6.60 \text{ s}$$

2. A small marble chip of mass 5 g is dropped from the top of a cliff and takes 2.5 s to reach the sandy beach below it. Calculate:

(a) (i) the velocity with which it strikes the sand.

(ii) the kinetic energy with which it hits the sand.

(b) The height of the cliff.

(c) If the marble chip penetrates the sand to a depth of 12.5 cm, calculate:

(i) its average retardation.

(ii) the retarding force. (Take $g = 10 \text{ ms}^{-2}$)

Solution: (a) $u = 0 \text{ ms}^{-1}$, $v = ?$, $a = g = 10 \text{ ms}^{-2}$, $t = 2.5 \text{ s}$,
 (i) $v = u + at$

$$\begin{aligned}
 v &= u + gt \\
 &= 0 + 10 \times 2.5 \\
 &= 0 + 25 \\
 &= 25 \text{ ms}^{-1}
 \end{aligned}$$

$$\begin{aligned}
 \text{(ii)} \quad v &= 25 \text{ ms}^{-1}, m = 5 \text{ g} = \frac{5}{1000} \text{ kg}, \text{K.E} = ? \\
 \text{K.E} &= \frac{1}{2}mv^2 \\
 &= \frac{1}{2} \times \frac{5}{1000} \times 25^2 \\
 &= \frac{5 \times 625}{2000} \\
 &= \frac{3125}{2000} \\
 \text{K.E} &= \mathbf{1.56 \text{ J}}
 \end{aligned}$$

$$\begin{aligned}
 \text{(b)} \quad g &= 10 \text{ m/s}^2, u = 0 \text{ ms}^{-1}, t = 2.5 \text{ s}, s = ?, v = 25 \text{ ms}^{-1} \\
 s &= ut + \frac{1}{2}gt^2 \\
 &= (0 \times 2.5) + \frac{1}{2} \times 10 \times 2.5^2 \\
 &= 0 + 5 \times 2.5 \times 2.5 \\
 &= \mathbf{31.25 \text{ m}}
 \end{aligned}$$

$$\text{(c) (i)} \quad \text{Depth of penetration, } s = 12.5 \text{ cm} = \frac{12.5}{100} \text{ m, } a = ?$$

u = initial velocity with which the marble starts to penetrate the sand
 $=$ velocity before it just hits the sand
 $= 25 \text{ ms}^{-1}$
 $v = 0$ (after penetration the marble was brought to rest)

$$\begin{aligned}
 \text{Using the formula} \quad v^2 &= u^2 + 2as \\
 v^2 &= u^2 + 2gs \\
 a &= \frac{v^2 - u^2}{2s} \\
 &= \frac{0^2 - 25^2}{2 \times 0.125} \\
 &= \frac{625}{0.25} = \mathbf{2500 \text{ ms}^{-2}} \\
 m &= \frac{5}{1000} \text{ kg, } a = 2500 \text{ ms}^{-2}, F = ? \\
 F &= ma \\
 &= \frac{5}{1000} \times 2500 \\
 &= \frac{5000}{1000} \\
 &= \mathbf{5 \text{ N}}
 \end{aligned}$$

Experiment 5.31

To Determine Acceleration due to Gravity, g , in a place

Apparatus/Requirements

2 G-clamps, a retort stand, 2 m ticker tape, a ticker timer, a standard mass of 100 g, a soft material.

Procedure

- Clamp a ticker timer about 2 m or more at the edge of a table so that there is a clear drop below it as shown in figure 5.1 below.

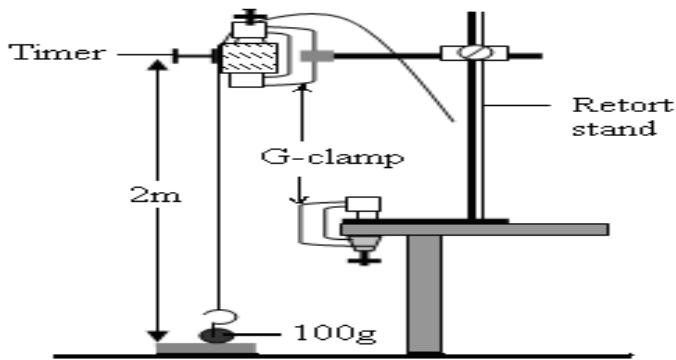


Figure 5.1

- Pass a 2 m ticker tape through the paper guides and under the carbon disc.
- Place a soft material on the floor for a 100 g mass to fall on.
- Attach one end of the tape to 100 g.
- Switch on the ticker timer and allow the 100 g mass to drop to the ground.
- Construct a tap chart using two-tick strips of the tape.

The chart may appear similar to the one shown in figure 5.2 below.

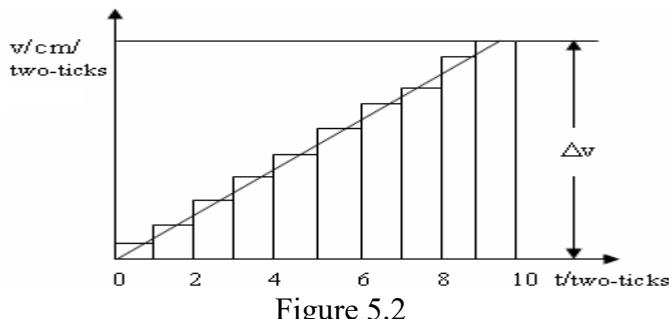


Figure 5.2

Note that: *The steps showing increasing velocity may vary slightly and become rather shorter at higher velocities. This is due to the effect of friction, particularly the drag of the tape through the ticker timer, which increases with speed.*

To overcome these irregularities, draw a straight-line graph which passes through the centre of the tops of the tapes taking more notice of those which best fit a straight line through the origin.

Measure Δv and Δt from your tape or tape chart.

Since initial velocity, $u = 0$, Δv = Final velocity, v and Δt = time taken.

Calculate the acceleration due to gravity from the formula:

$$\text{Acceleration, } g = \frac{\text{Final Velocity}}{\text{Time taken}} = \frac{\Delta v}{\Delta t} \text{ ms}^{-2}$$

How to calculate the value of g from given data.

(The steps may be understood full after covering ticker timer in Chapter 11).

Let: Frequency of vibrator of the ticker timer = 50 Hz
Number of two-tick tapes used to construct the chart = 10 pieces

The main steps in the calculations

Step I: Calculate the time interval for the two-tick tape

$$\begin{aligned}\text{Time interval of a two-tick} &= \text{Number of spaces} \times \text{Tick} \\ &= 2 \times \frac{1}{f} \\ &= 2 \times \frac{1}{50} \\ &= \frac{2}{50} \\ &= \mathbf{0.04 \text{ s}}\end{aligned}$$

Step II: Using the time interval for a two-tick tape and the number of pieces of tapes used calculate the time taken.

$$\begin{aligned}\text{Time taken, } t &= \left(\frac{\text{Number of spaces}}{\text{of tapes used}} \right) \times \left(\text{Time interval for two-tick tape} \right) \\ &= 10 \times 0.04 \\ \therefore t &= \mathbf{0.4 \text{ s}}\end{aligned}$$

Step III: Calculate the velocity, from the ticker tape.

Data: Final velocity, $v = \Delta v = 14 \text{ cm in each } 0.04\text{s}$
 $s = 14 \text{ cm} = 0.14 \text{ m}, t = 0.04 \text{ s}, v = ?$

$$\begin{aligned}\text{Using the formula } v &= \frac{s}{t} \\ &= \frac{0.14}{0.04} \\ &= \mathbf{3.5 \text{ ms}^{-1}}\end{aligned}$$

Step IV: Calculate the acceleration due to gravity, g .

$$\text{Acceleration, } g = \frac{\text{Final velocity}}{\text{Time taken}} = \frac{3.5}{0.4} \text{ ms}^{-1}/\text{s} = \mathbf{8.75 \text{ ms}^{-2}}$$

Note: In the absence of all resisting forces such as the drag of the tape and air resistance, the acceleration of freely falling object at the surface of the earth is about 9.8 ms^{-2} .

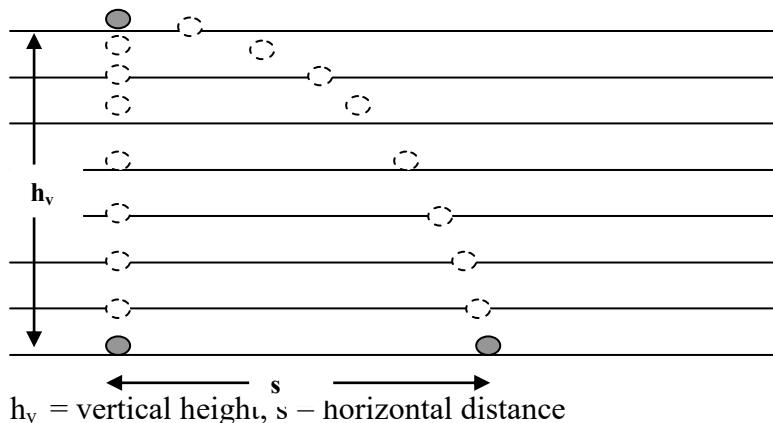
Self-Check 11.4

1. A stone is dropped a deep hole. If it takes 10 seconds to hit the bottom of the hole.
Calculate: (a) its velocity.
(b) the depth of the hole. (Take $g = 10 \text{ m/s}^2$)
2. A stone is dropped from a top of a cliff. If it takes 6 seconds to hit the ground,
calculate: (a) the height of the cliff.
(b) the velocity at impact. (Take $g = 10 \text{ ms}^{-2}$)
3. A tennis ball is thrown vertically upwards with an initial velocity of 40 ms^{-1} .
Calculate: (a) the maximum height reached.
(b) the time taken to reach the maximum height.
(Take $g = 10 \text{ ms}^{-2}$ and neglect air resistance)
4. A bullet is fired vertically upwards with an initial velocity of 300 ms^{-1} . Neglecting air resistance, calculate:
(a) the maximum height reached,
(b) the time taken before it reaches the ground. (Take $g = 10 \text{ ms}^{-2}$)
5. A stone is thrown vertically upwards with an initial velocity of 20 ms^{-1} from a tower 80 m high. Neglecting air resistance, calculate:
(a) the maximum height reached,
(b) the time taken to reach the maximum height,
(c) the total time which elapses before it just hits the ground
(Take $g = 10 \text{ ms}^{-2}$)

11.6 Projectile Motion

A projectile is any body projected through space. When two tennis balls placed at the same height are let to fall under gravity, one dropped vertically downwards and the other projected horizontally, it is noticed that all the balls hit the ground at the same time.

A diagram showing the motion of two tennis balls moving downwards from a table top (one dropped vertically downwards and the other projected horizontally)



Facts about the motion

- (i) The initial velocity of the ball falling vertically is zero.
- (ii) The vertical accelerations (due to gravity) of the two balls are equal.
- (iii) A projectile falls like a body is dropped from rest.
- (iv) The two balls take the same time to reach the ground.
- (v) The horizontal velocity of the projectile is independent of the vertical motion (i.e. does not affect the vertical motion).

The path of a projectile is called *trajectory*. It is (almost) the arc of a parabola from the following reasoning.

Consider a projectile with an initial velocity, u vertical velocity zero, initial horizontal acceleration zero and vertical acceleration downwards, g . After time, t , the horizontal distance, s , and vertical distance, h , traveled by the projectile are obtained by using the equation:

$$s = ut + \frac{1}{2}gt^2$$

$$\text{For horizontal motion, } g = 0 \quad \therefore s = ut \quad \dots \quad 1$$

$$\text{For vertical motion, } = 0 \quad y = \frac{1}{2}gt^2 \quad \dots \quad 2$$

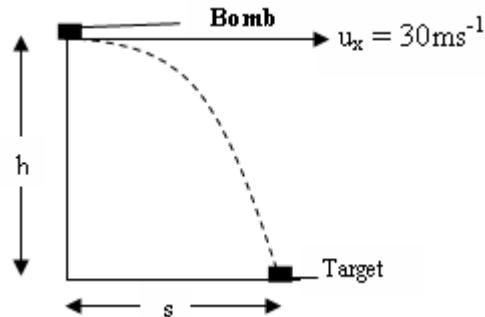
Since $x \propto t$ and $y \propto t^2$, then:
 $y \propto x^2$

When this is plotted on a graph it is a parabola. That is the same as that of the graph in diagram for projectile motion but is inverted because the projectile falls and does not rise.

Worked Examples

- A ball is hit horizontally off a cliff with a velocity of 30 ms^{-1} . If it takes 5 seconds to reach the ground, calculate:
 - The height of the cliff.
 - The horizontal distance from the foot of the cliff to the point where the ball lands.
 - The velocity with which the ball hits the ground.

Solution: $u_y = 0 \quad u_x = 30 \text{ ms}^{-1}$



- To calculate the height of the cliff, we consider the vertical motion.

$$u_y = 0, g = 10 \text{ ms}^{-2}, t = 5 \text{ s}, s = h = ?$$

$$\begin{aligned} \text{Using the formula } s &= u_y t + \frac{1}{2}gt^2 \\ &= (0 \times 5) + \frac{1}{2} \times 10 \times 5^2 \\ &= 0 + 5 \times 25 \end{aligned}$$

$$s = h = 125 \text{ m}$$

- The horizontal distance, s , is got by considering the horizontal motion.

$$u_x = 30, g = 0 \text{ ms}^{-2}, t = 5 \text{ s}, s = ?$$

$$\text{Using the formula } s = u_x t + \frac{1}{2}gt^2 = 30 \times 5 + \frac{1}{2} \times 0 \times 5^2 = 150 + 0 = 150 \text{ m}$$

Therefore, the ball lands 150 m from the foot of the cliff.

- (c) The velocity with which the ball hits the ground is got by considering the vertical motion.
This is because the horizontal velocity of the ball remains unchanged throughout the motion.

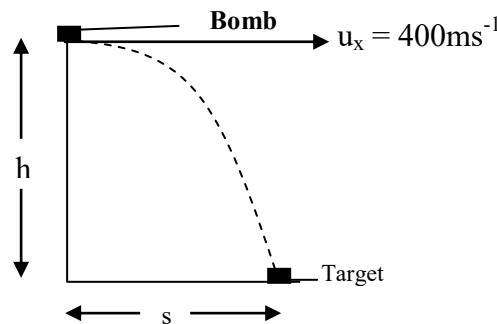
Vertical initial velocity, $u_y = 0$, Vertical final velocity, $v_y = ?$,
 $g = 10 \text{ ms}^{-2}$, $t = 5 \text{ s}$,

Using the formula: $v = u + at$

$$\begin{aligned} v_y &= u_y + at \\ &= 0 + 10 \times 5 \\ &= \mathbf{50 \text{ ms}^{-1}} \end{aligned}$$

2. A bomb is released from a jet fighter plane moving with velocity of 400 ms^{-1} to hit a rebel camp in northern Uganda. If the bomb took 10 seconds to hit the target, calculate:
- The altitude at which the bomb was released.
 - The horizontal distance from the vertical point of the plane to the target.
 - The velocity with which the bomb hits the target. (Take $g = 10 \text{ ms}^{-2}$)

Solution $u_y = 0 \text{ ms}^{-1}$, $g = 10 \text{ ms}^{-2}$, $t = 10 \text{ s}$, $s = h = ?$



- (a) To calculate the altitude of the plane, we consider the vertical motion.

$$\begin{aligned} \text{Using the formula: } s &= u_y t + \frac{1}{2} g t^2 \\ &= (0 \times 5) + \frac{1}{2} \times 10 \times 10^2 \\ &= 0 + 5 \times 100 \\ s &= h = \mathbf{500 \text{ m}} \end{aligned}$$

- (b) The horizontal distance, s , is got by considering the horizontal motion.
 $u_x = 400$, $g = 0 \text{ ms}^{-2}$, $t = 10 \text{ s}$, $s = ?$

$$\begin{aligned} s &= u_x t + \frac{1}{2} g t^2 \\ &= 400 \times 10 + \frac{1}{2} \times 0 \times 10^2 \\ &= 4000 + 0 \\ s &= \mathbf{4000 \text{ m}} \end{aligned}$$

- (c) The horizontal velocity of the bomb remains unchanged throughout the motion (400 ms^{-1}). The vertical velocity increases as the bomb falls.
The velocity with which the bomb hits the ground is got by considering the vertical motion.

$$\begin{aligned} u_y &= 0 \text{ ms}^{-1}, g = 10 \text{ ms}^{-2}, t = 10 \text{ s}, \\ v &= u + at \\ &= u_y + gt \\ &= 0 + 10 \times 10 \\ &= \mathbf{100 \text{ ms}^{-1}} \end{aligned}$$

Self-Check 11.5

1. Which one of the following statements is true when a stone of mass 2 kg and that of 1 kg are released from the same point at the same time?
 - A. both masses will hit the ground at the same time.
 - B. the 2kg mass will hit the ground first.
 - C. the 1 kg mass will hit the ground first.
 - D. they fall with different speeds.
2. A mass is projected upwards with a velocity of 10 m/s. If the acceleration due to gravity is 10 m/s^2 , what is the maximum height reached in meters?
 - A. 1
 - B. 5
 - C. 10
 - D. 20
 - E. 100
3. A stone is hit horizontally off a cliff with a velocity of 50 ms^{-1} . If it takes 10 seconds to reach the ground, calculate:
 - (a) The height of the cliff.
 - (b) The horizontal distance from the foot of the cliff to the point where the ball lands.
 - (c) The velocity with which the ball hits the ground.
4. An Israel jet fighter plane moving with velocity of 300 ms^{-1} released a bomb to hit a Hezbollah base in Southern Lebanon. If the bomb took 20 seconds to hit the target, calculate:
 - (a) The altitude at which the bomb was released.
 - (b) The horizontal distance from the vertical point of the plane.
 - (c) The velocity with which the bomb hits the target. (Take $g = 10 \text{ ms}^{-2}$)
5. A stone falls from rest from the top of a high tower. Ignoring air resistance and taking $g = 10 \text{ m/s}^2$, what is the velocity and distance travelled after:
 - (i) 1 s,
 - (ii) 2s,
 - (iii) 3s
 - (iv) 5s?

11.7 Circular Motion

One of the effects of force is that it keeps bodies moving in a circular path about a fixed point. This kind of motion is described as *Circular Motion*.

Examples of circular motion include:

- a stone/pendulum bob whirled at the end of a string in a vertical or horizontal plane,
- a vehicle negotiating a corner,
- an electron orbiting a nucleus,
- a planet or satellite orbiting the earth.

Facts about a body moving in a circle:

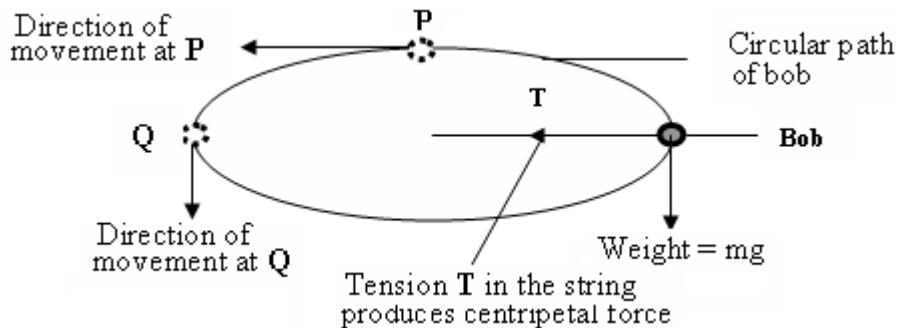
- (i) Its direction changes every second.
- (ii) Its velocity is constantly changing due to the change in direction of the motion.
- (iii) It has an acceleration called *centripetal acceleration* due to the constant change in velocity.
- (iv) It has a force called *Centripetal force*, acting on it producing the acceleration.
- (v) The centripetal force is perpendicular to the direction of the motion.
- (vi) Both the *centripetal force* and the *centripetal acceleration* are acting towards the centre of the circle.

Experimental results show that the centripetal force required to keep a body in a circular path increases with:

- (i) an increase in the mass of the body.
- (ii) an increase in the speed of the body and
- (iii) a decrease in the radius of the circular path.

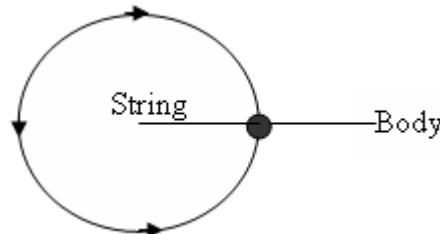
When the object is released, it moves in a straight line. The direction of the motion is along the tangent to the circle as shown in the diagram below.

A diagram showing a bob tied at the end of a string being whirled in a horizontal circle



Self-Check 11.6

1. (a) Define the term acceleration.



- (b) A body attached to a string is swung in a vertical circular path in air as shown in the figure below.

Copy the above diagram and on it indicate and name all the forces acting on the body if the body is moving in an anti-clockwise direction.

- (c) Explain why the weight of an object on the earth's surface may vary from one place to another.

CHAPTER TWELVE

FORCE AND MOTION

LEARNING OBJECTIVES

By the end of this chapter, you should be able to:

1. (a) State: - Newton's laws of motion and give examples for laws 1 and 3.
(b) Define: - Inertia and state the effects of inertia.
2. Define and state the SI unit of momentum.
3. (a) State: (i) - The Principle of Conservation of momentum.
(ii) - The types of collision
(b) Describe: -
Experiments to verify the principle (law) of conservation of momentum.
- (c) State: - Applications of the principle of the principle of conservation.
- (d) Explain: - The mechanism of:
(i) The rocket propulsion
(ii) The jet engine
4. Solve problems involving the principle of conservation of momentum.

12.1 Force and Motion

As we have seen in chapter five that one of the effects of force when it acts on a body is that:

- (i) Make a stationary object to move.
- (ii) Increase the speed of a moving object.
- (iii) Decrease or slow down the speed of a moving object or bring a moving object to a rest.
- (iv) Change the direction of a moving object.
- (v) Deform (change the shape of) an object.

The relationship between force and motion was stated by *Galileo Galilli*, an Italian scientist and died before he finished. Then *Sir Isaac Newton*, an English Scientist, continued the study of moving bodies which was started by *Galileo Galilli*.

Newton carried out series of experiments and through the experimental results; he summed up the basic principles underlining motion in three laws. These laws are known as *Newton's Laws of Motion*.

12.11 Newton's First Law of Motion

Newton's First Law of Motion States that:

Every body continuous in its present state of rest or uniform (un-accelerated) motion in a straight line unless acted on by some external force.

Common experiences have shown that objects at rest do **not** begin to move on their own accord or objects in motion do **not** come to rest instantly on their own. As a result of this, the following are cited as examples of Newton's first law of motion.

(a) A body at rest

If a pile of coins is placed on a table, the one at the bottom can be removed without disturbing the ones on the top.

Explanation: *The force applied only acts on that particular coin at the bottom. Since the rest are not acted upon by the force, they remain undisturbed.*

(b) A body on motion

- (i) A person riding a bicycle along a level road does not come to a rest immediately when he stops pedaling. The bicycle continues to move forward for some time, but eventually comes to a rest.

Explanation

The bicycle continues to move because of inertia and comes to a rest after time as a result of the retarding action of the external forces such as air resistance and frictional force between the tyre and the road surface. These external forces oppose the motion and eventually come to a rest.

- (ii) Collision of two vehicles or when a sharp brake is applied to a car moving at a high velocity.

In the above incidences, passengers who do not fasten their safety belts are often injured when they jack forward and hit the wind screen.

Explanation

An external force acts on the vehicle but not on the passenger who simply continue their motion in a straight line in accordance with Newton's first law of motion.

- (iii) A bullet fired at an angle from a gun.

When a bullet is fired from a gun held at angle to the ground, the bullet travels and eventually falls to the ground.

Explanation

The motion of the bullet is opposed by air resistance and the gravitational force, hence, sooner or later it returns to the ground.

Note: As per Newton's first law of motion, it is supposed that, if the external forces such as friction between solid surfaces in contact, air resistance and gravitational force in the above examples were not there, the bodies would continue to move for ever.

12.12 Inertia

Definition: *Inertia is the tendency of a body to remain at rest or, if moving to continue its motion in a straight line.*

Or *Inertia is the reluctance of a body to start moving or to stop moving once it has started.*

For this reason, Newton's first law is sometimes called "the law of inertia".

A body of large mass requires a large force to change its speed or its direction i.e. the body has a large inertia. Thus, the mass of a body is a measure of its inertia.

12.13 Momentum

Momentum is defined as the product of mass and velocity of a body.

Mathematically, it is expressed as:

$$\text{Momentum} = \text{Mass} \times \text{Velocity}$$

The SI unit of Momentum

The SI unit of momentum is kg ms^{-1}

Since the mass of a body is constant, the momentum of a body is directly proportional to its velocity. I.e. $\text{Momentum} \propto \text{Velocity}$

This fact explains the following observations

A heavy goods vehicle moving at high speed needs more powerful brakes to stop it than a light car moving at the same speed or velocity. This is because the heavier vehicle has greater momentum than the lighter one.

Like wise when the same force acts upon the same vehicles for the same time, the lighter one builds up a higher velocity than the heavy one. But their momenta are the same.

This important connection between force and momentum was recognized by Newton and he expressed it in his second law of motion.

12.12 Newton's Second Law of Motion

Newton's First Law of Motion States that:

The rate of change of momentum of a body is proportional to the applied force and takes place in the direction in which the force acts.

Newton's second law enables us to define the unit of force and establishes the fundamental equation of dynamics, $F = ma$.

Derivation of the formula

Suppose a force, F , acts on a body of mass, m , for time t and causes its initial velocity, u , to change to final velocity, v . The momentum changes uniformly from mu to mv in the time interval, t .

$$\begin{aligned}\text{The rate of change of momentum} &= \frac{\text{Final momentum - Initial momentum}}{\text{Time taken}} \\ &= \frac{mv - mu}{t}\end{aligned}$$

By Newton's second law, the rate of change of momentum is proportional to the applied force and hence, $F \propto \frac{mv - mu}{t} \Rightarrow F \propto \frac{m(v - u)}{t}$ But $\frac{v - u}{t} = a$
 $\therefore F \propto ma$

Introducing a constant to change the sign of proportionality to equal sign, we have:

$$F = \text{Constant} \times ma$$

If $m = 1 \text{ kg}$ and $a = 1 \text{ ms}^{-2}$, the value of the unit of force is chosen so as to make $F = 1$. This implies that the value of the constant = 1.

The SI unit of force is called the *Newton (symbol, N)* and is defined as:

The force which produces an acceleration of 1 ms⁻² when it acts on a mass of 1 kg.

Or A force which give 1 kg mass an acceleration of 1 m ms⁻².

Thus, when F is in Newton, m in kilograms and a in metres per second squared, we have

$$F = ma$$

Worked Examples

1. A force 3 N acts on a body of mass 5 kg. Find the acceleration produced.

Solution: Mass = 5 kg, F = 3 N, a =? $F = ma \Rightarrow a = \frac{F}{m} = \frac{3}{5} = 0.6 \text{ ms}^{-2}$

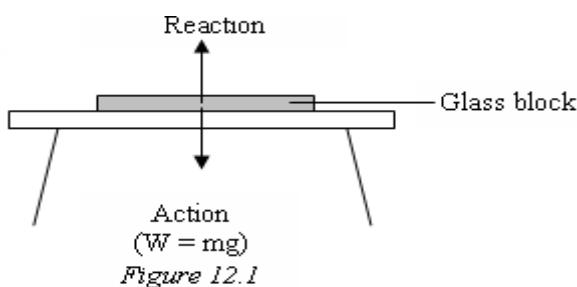
2. Find the force acting on a body of mass 12 kg and making it to produce an acceleration of 6 ms^{-2} .

Solution m = 12 kg, F = ?, a = 6 ms^{-2} $F = ma = 12 \times 6 = 72 \text{ N}$

12.13 Newton's Third Law of Motion

Newton's third law of motion states that:

To every action there is an equal and opposite reaction.



For example, a glass block placed on a table, exerts a force equal to its weight on to the table top. This force is called *action*. At the same time the table top exerts an equal force on to the glass block in the opposite direction. This force acting in the opposite direction is called *reaction*.

Notes:

- Action = Reaction
- Action and reaction react on different bodies.
- The two forces are in opposite directions.
- The net resultant force on the glass block is zero

Examples of Newton's third law include:

(i) A man jumping from a boat

A man jumping from a boat exerts action force on the boat and the boat exerts a reaction force. As he jumps to the river bank, the boat moves backwards.

(ii) Propulsion of a bullet from a gun

When a bullet is fired from a gun, the energy of the explosion of the charge in the cartridge acts on both the bullet and the gun, thus producing equal and opposite forces acting on them. These equal forces act for the same time i.e the time taken by the bullet to travel up the barrel of the gun. The time effect of a force is called **impulse**; thus the bullet and the gun are given equal and opposite impulses. In each case, the impulse is equal to the change in momentum.

To show that Impulse is equal to momentum change of a body

Applying $F = ma$ and substituting $a = \frac{(v - u)}{t}$ in it we have,

$$= \frac{mv - mu}{t}$$

$$= \frac{m(v - u)}{t}$$

$$Ft = mv - mu$$

The product Ft is called *impulse*, p , and is equal to the change in momentum.

I.e. **Impulse of a force on a body = Change in momentum of a body**

As the gun and the bullet were initially at rest, their initial momenta were both zero, hence the final momentum in each case is the change in momentum. Since their impulses were equal and opposite, their momenta will be equal and opposite.

The bullet leaves the gun barrel with a *muzzle velocity* and the gun kicks or reacts in the opposite with a velocity called *recoil velocity*.

Thus; **Mass of bullet x Muzzle velocity = Mass of gun x recoil velocity**

Since the two velocities (muzzle and recoil velocities) and the two momenta are vector quantities and are acting in opposite directions, their sum is zero.

The above observation illustrates an important principle called the *principle of conservation of momentum*.

Worked Example

1. A car of mass 5000 kg initially moving at a velocity of 50 m/s accelerates to 100 m/s in 2 seconds. Calculate the engine force on the car that caused the velocity change.

Solution: Mass of the car = 50 000 kg,

Initial velocity, $u = 50$ m/s, Final velocity, $v = 100$ m/s, Time, $t = 2$ s, $F = ?$

Hint: - Think of a formula of force in this topic.

- See if your data has all the quantities in it.

- If one quantity is missing in the formula, check if the information in the data can

help you to calculate it.

- If yes, solve for the quantity first and then substitute in the formula to get F .

We use the formula $F = ma$

From the data the values of u , v and t can be used to solve for a . Now let us solve for F .

Using the formula $v = u + at$

$$a = \frac{(v - u)}{t} = \frac{(100 - 50)}{2} = 25 \text{ ms}^{-2}$$

Now we can now apply the formula the formula

$$F = ma = 50,000 \times 25 = 1,250,000 = 1.25 \times 10^6 \text{ N}$$

12.2 The Principle of Conservation of Momentum

The principle of conservation of momentum states that:

When two or more bodies act on one another, their total momentum remains constant, provided no external forces act on the colliding bodies.

Or *The total linear momentum of a system of interacting bodies, on which no external forces are acting, remains constant.*

For example, if two bodies of masses m_1 and m_2 , initially moving with velocities u_1 and u_2 respectively collide, and after the collision their velocities change to v_1 and v_2 , then by the principle of conservation of momentum,

The Sum of the Initial Momenta = The Sum of the Final momenta

$$m_1 u_1 + m_2 u_2 = m_1 v_1 + m_2 v_2$$

(a) Collisions

Whenever two or more bodies collide, their total momentum is conserved unless there are external forces acting on them. However, the total kinetic energy usually decreases. This is because some of the kinetic energy is converted by the impact to other forms of energy such as: *heat, sound, and light* or permanently distorts the bodies leaving them with an increased amount of potential energy. The total kinetic energy of the colliding system before and after impact determines the type of collision.

(b) Types of collision

There are three types of collision, namely:

- Elastic collision,
- Inelastic collision and
- Completely inelastic collision.

(i) Elastic collision

Elastic collision is the type of collision in which there is no loss of kinetic energy. I.e. the total kinetic energy remains the same.

(ii) Inelastic collision

Inelastic collision is one in which there is loss of kinetic energy. I.e. the total kinetic energy after collision becomes less than the kinetic energy before collision.

(iii) Completely inelastic collision

Completely inelastic collision is one in which the colliding bodies stick together on impact and move as a single body.

Notes: Using these types of collisions, the principle of conservation of momentum can be investigated.

12.1 Experiments

Experiment 12.1 To investigate the Conservation of Momentum for colliding bodies moving in the same direction.

Inelastic collision of a moving body with one at rest

Apparatus/requirements

2 trolleys, a stout pin, a cork., a ticker timer with a ticker tape, standard masses and a run way.

Procedure:

- Fit trolley 1 with a stout pin and the other with a cork.
- Load trolley 1 with standard masses and weigh them.
- Attach a ticker tape passing through a ticker timer to trolley 1.
- Place the trolleys on a run way as shown in figure below.
- Give a push to trolley 1 so that it moves forward with a uniform velocity u_1 and collides with trolley 2 which is at rest.

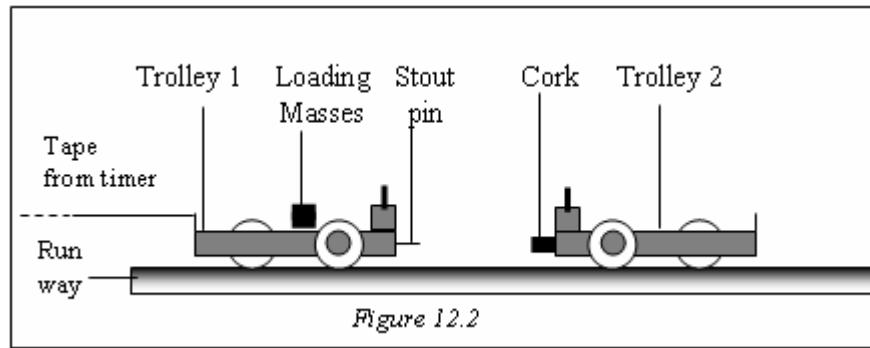


Figure 12.2

Observation:

The stout pin on trolley 1 penetrates the cork on trolley 2 and the two trolleys stick together and move on as a single body, with a common velocity v .

The ticker tape has two successive sets of equally spaced dots from which the velocities u and v are calculated.

Both trolleys after collision

Trolley 1 before collision

Gives common velocity, v Gives initial velocity, u_1 of trolley 1

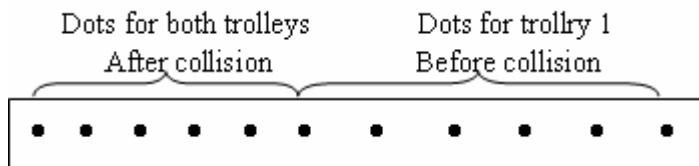


Figure 12 3

Calculation:

Mass of trolley 1 = m₁ kg

Mass of trolley 2 = m₂, kg

Initial velocity of trolley 1 = u_1 ms $^{-1}$

Initial velocity of trolley 2 = u_2 , ms⁻¹

α_2 HIS-1
= 0 (at rest)

Final velocity of both trolleys = v (common velocity since they stick together)

Total momentum before collision $\equiv m_{11} \vec{v}_1 + m_{22} \vec{v}_2$

$$= m_1 \mathbf{u}_1 + m_2 \mathbf{u}_2 \\ = m \mathbf{u} + m \mathbf{0}$$

$$= m_1 u_1 + m_2 v$$

Total momentum after collision = $m_1 u_1 \text{ kg ms}^{-1}$
 \equiv Total mass x common velocity

$$= \text{Total mass} \times \text{velocity}$$

If Momentum before collision \equiv Momentum after collision

$$\text{Elastic collision - Momentum} \\ \text{I.e. } m_1 v_1 = (m_1 + m_2) v$$

Then law of conservation of momentum is verified

Experiment 12.2 *Partially elastic collision of a moving body with one at rest*

Apparatus/requirements

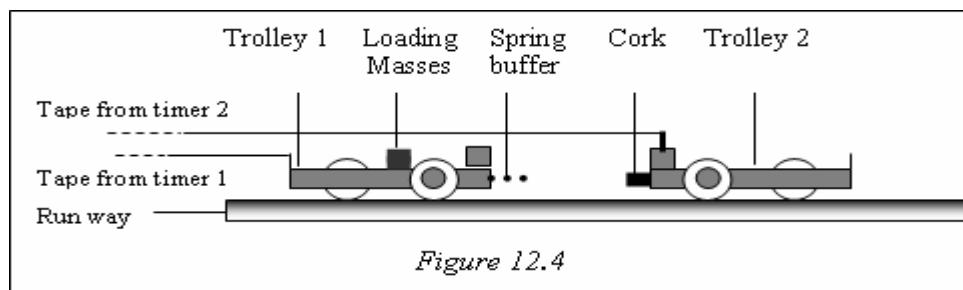
Apparatus/Requirements
2 trolleys, a spring buffer, 2 ticker timers with a ticker tapes, standard masses and a run way.

Procedure

- Procedure**

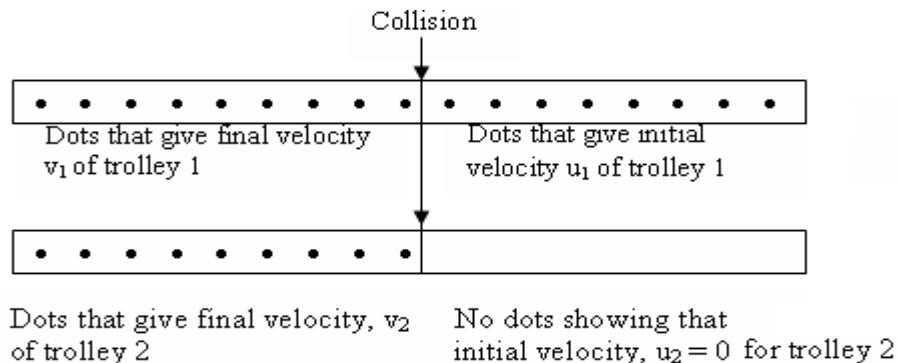
 - Fit trolley 1 with a spring buffer.
 - Load trolley 1 with standard masses and then weigh both trolleys.
 - Attach each trolley to a tape passing through a ticker timer.

- Place the trolleys on a run way as shown in figure below.
- Give a push to trolley 1 so that it moves forward with a uniform velocity u_1 and collides with trolley 2 which is at rest.



Observation:

On collision, trolley 1 is slowed up while trolley 2 moved forward with a greater velocity.



Calculation: Mass of trolley 1

$$= m_1 \text{ kg}$$

$$\text{Mass of trolley 2}$$

$$= m_2 \text{ kg}$$

$$\text{Initial velocity of trolley 1}$$

$$= u_1 \text{ ms}^{-1}$$

$$\text{Initial velocity of trolley 2}$$

$$= u_2 \text{ ms}^{-1}$$

$$= 0 \text{ (at rest)}$$

$$\text{Final velocity of trolley 1}$$

$$= u_1 \text{ ms}^{-1}$$

$$\text{Final velocity of trolley 2}$$

$$= v_2 \text{ ms}^{-1}$$

$$\text{Total momentum before collision}$$

$$= m_1 u_1 + m_2 u_2$$

$$= m_1 u_1 + m_2 0$$

$$= m_1 u_1 \text{ kg ms}^{-1}$$

$$\text{Total momentum after collision}$$

$$= m_1 v_1 + m_2 v_2$$

Conclusion: Momentum before collision = Momentum after collision

$$\text{I.e. } m_1 u_1 = m_1 v_1 + m_2 v_2$$

Then law of conservation of momentum is verified.

Experiment 12.3 Gun and projectile experiment

Apparatus: 2 trolleys, 2 ticker timers with a ticker tapes, standard masses and a runway.

Procedure

- Load trolley 1 with standard masses and then weigh both trolleys.
- Push in the horizontal metal rod in trolley 1 (the “gun”) against a spring held in place by a metal plate.
- Attach each trolley to a tape passing through a ticker timer.

- Place the trolleys on a level run way so that they are in contact as shown in figure below.
- Releases the top trigger on the “gun” to fire the projectile.

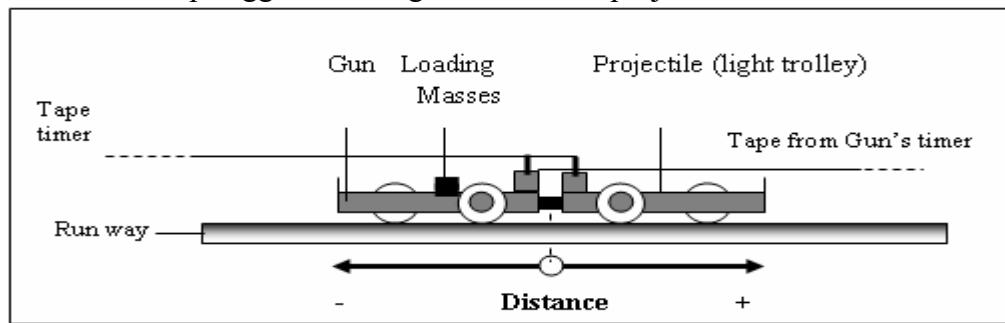


Figure 12.5

Observation:

On releasing the trigger, the projectile (lighter trolley) moved forward and the heavy trolley, the gun, moved backwards.

Note: The total momentum before and after collision is both zero.

Reason: Momentum is a vector quantity. Since the momenta are equal and opposite, then their sum equal to zero.

Calculation:

We represent distances and velocities to the right by a positive sign.

Let:
The velocity of the gun = $-v_g$ (velocity in the opposite direction)
The velocity of the projectile = v_p

$$\begin{aligned} \text{Momentum of the gun after firing} &= m_g \times -v_g \\ &= -(m_g v_g) \text{ kg ms}^{-1} \\ \text{Momentum of the projectile after firing} &= m_p v_p \text{ kg ms}^{-1} \\ \text{The total momentum after firing} &= m_p v_p + -m_g v_g \\ &= (m_p v_p - m_g v_g) \text{ kg ms}^{-1} \\ \text{The total momentum before firing} &= 0 \quad (\text{Both bodies initially were at rest}) \end{aligned}$$

By the law of Conservation of momentum,

$$\begin{aligned} \text{Momentum before collision} &= \text{Momentum after collision} \\ 0 &= m_p v_p - m_g v_g \\ m_g v_g &= m_p v_p \end{aligned}$$

Worked Examples

- Two trolleys of masses 8 kg and 5 kg are traveling on the same truck with speeds 4 ms^{-1} and 2 ms^{-1} respectively in the same direction. They collided and coupled together.
 - State the type of the collision.
 - Calculate the common velocity after collision.

Solution:

- Inelastic collision
- $m_1 = 8 \text{ kg}, u_1 = 4 \text{ ms}^{-1}, m_2 = 5 \text{ kg}, u_2 = 2 \text{ ms}^{-1}$

Total mass	$= m_1 + m_2 = 8 + 5 = 13 \text{ kg}$,
Common velocity	$= v \text{ ms}^{-1}$

$$\begin{aligned} \text{Total momentum before collision} &= m_1 u_1 + m_2 u_2 \text{ kg ms}^{-1} \\ \text{Total momentum after collision} &= (m_1 + m_2) v \text{ kg ms}^{-1} \end{aligned}$$

Applying the principle of conservation of momentum,
 Momentum before collision = momentum after collision

$$\begin{aligned} m_1 u_1 + m_2 u_2 &= (m_1 + m_2)v \\ 8 \times 4 + 5 \times 2 &= (8 + 5) \times v \\ 32 + 10 &= 13v \\ 42 &= 13v \\ v &= \frac{42}{13} \\ \therefore v &= 3.2 \text{ ms}^{-1} \end{aligned}$$

2. A bullet of mass 6 g is fired from a gun of mass 500 g. If the muzzle velocity of the bullet is 300 ms⁻¹, calculate the recoil velocity of the gun.

Solution: Let: Mass of the gun = $m_g = 500 \text{ g} = \frac{500}{1000} \text{ kg}$

Mass of bullet	$= m_b = 6 \text{ g}$	$= \frac{6}{1000} \text{ kg}$
Velocity of gun before explosion	$= u_g = 0$	
Velocity of the bullet before explosion	$= u_b = 0$	
Velocity of gun after explosion	$= v_g = ?$	
Velocity of the bullet after explosion	$= v_b = 300 \text{ ms}^{-1}$	

Applying the principle of conservation of momentum,

$$\begin{aligned} \text{Momentum before firing} &= \text{Momentum after firing} \\ m_1 u_1 + m_2 u_2 &= m_1 v_1 + m_2 v_2 \\ m_b u_b + m_g u_g &= m_b v_b + m_g v_g \\ 0.006 \times 0 + 0.5 \times 0 &= 0.006 \times 300 + 0.5 v_g \\ 0 &= 1.8 + 0.5 v_g \\ 0.5 v_g &= 1.8 \\ v_g &= -3.6 \text{ ms}^{-1} \end{aligned}$$

Since velocity is a vector quantity, the minus sign indicates that the bodies move to the left (i.e. in the original direction of body B) after collision.

Therefore, the gun kicks backwards with a velocity of 3.6 ms⁻¹

Note: To get the same answer but positive at once, we take the velocity of the gun to be negative in the data and then substitute in the same formula as shown below.

$$\begin{aligned} \text{Mass, } m_g, \text{ of the gun} &= \frac{500}{1000} \text{ kg}, \quad \text{Mass, } m_b, \text{ of bullet} = \frac{6}{1000} \text{ kg} \\ \text{Initial velocity, } u_g, \text{ of gun before firing} &= 0 \\ \text{Initial velocity, } u_b, \text{ of the bullet before firing} &= 0 \\ \text{Final velocity, } v_g, \text{ of gun after firing} &= ? \\ \text{Final velocity, } v_b, \text{ of the bullet after firing} &= 300 \text{ ms}^{-1} \end{aligned}$$

Since velocity is a vector quantity, we take the velocity of the bullet to be positive and that of the gun to be negative.

Then apply the principle of Conservation of momentum, we have;

$$\text{Momentum before firing} = \text{Momentum after firing}$$

$$m_1 u_1 + m_2 u_2 = m_1 v_1 + m_2 v_2$$

$$m_b u_b + m_g u_g = m_b v_b + m_g v_g$$

$$0.006 \times 0 + 0.5 \times 0 = 0.006 \times 300 + 0.5 \times v_g$$

$$0 = 1.8 - 0.5 v_g$$

$$0.5 v_g = 1.8$$

$$\therefore v_g = 3.6 \text{ ms}^{-1}$$

Note: - The detailed working is to make you understand the application of the concept

of solving the problem the first principle.

- After understanding the concept, use the shortest method.

3. A gun of mass 5 kg fires a bullet of mass 50 g at a speed of 500 ms^{-1} . Calculate the recoil velocity of the gun.

Solution: Mass of the gun, $m_g = 5 \text{ kg}$, Mass of bullet, $m_b = 50 \text{ g} = \frac{50}{1000} \text{ kg}$

$$\text{Initial velocity, } u_g, \text{ of the gun} = 0$$

$$\text{Initial velocity, } u_b, \text{ of the bullet} = 0$$

$$\text{Final velocity, } v_g, \text{ of gun} = ?$$

$$\text{Final velocity, } v_b, \text{ of the bullet} = 500 \text{ ms}^{-1}$$

We take the direction of the bullet to be positive and that of gun to be negative.
Then we can solve the problem by using any one of the following methods.

Method I Using the first principle

We substitute the values in the data in the formula of the principle of conservation of momentum.

$$\text{Momentum before firing} = \text{Momentum after firing}$$

$$m_1 u_1 + m_2 u_2 = m_1 v_1 + m_2 v_2$$

$$m_b u_b + m_g u_g = m_b v_b + m_g v_g$$

$$0.05 \times 0 + 5 \times 0 = 0.05 \times 500 + 5 v_g$$

$$0 = 25 + 5 v_g$$

$$5 v_g = 25$$

$$v_g = \frac{25}{5}$$

$$\therefore v_g = 5 \text{ ms}^{-1}$$

Method II Using the derived formula for gun and projectile

We substitute the values in the data in the formula:

$$\frac{m_g v_g}{5 \times v_g} = \frac{m_b v_b}{0.05 \times 500}$$

$$v_g = \frac{25}{5} = 5 \text{ ms}^{-1}$$

12.21 Applications of the principle of Conservation of momentum

The principle of conservation of momentum is applied in:

- (i) Rocket propulsion
- (ii) Jet engine

(a) Rocket propulsion

A space rocket carries tanks of liquid fuel and liquid oxygen and some chemicals which react to produce oxygen to enable the fuel to burn.

When the fuel burns inside the rocket engine, it creates a large force which propels a blast of hot gaseous products of the combustion out through the tail nozzle with very high velocity.

By Newton's third law of motion, the reaction to this force propels the rocket forward. Note that although the mass of the gas emitted per second is very small, it has a very large momentum on account of its high velocity. An equal momentum is imparted on to the rocket in the opposite direction, so that in spite of its large mass, it also builds up a high velocity.

(b) Jet engine

A jet engine (used on air crafts) operates on the same principle as rocket propulsion. As the air craft does not leave the earth's atmosphere, oxygen supply is from the air.

The fuel burns to form large quantities of gaseous products. As the blast of hot gas molecules (burnt fuel and excess air or oxygen) is thrown out from the combustion chamber) through the exhaust pipe with high momentum, the jet intern, acquires an equal momentum but in the opposite direction enabling it to move forward.

Self-Check 12.0

1. When a car is suddenly brought to rest, a passenger jerks forward because of
A. inertia B. friction C. gravity D. momentum
2. A boxer while training noticed that a punch bag is difficult to set in motion and difficult to stop. What property accounts for this observation?
A. Size. B. Inertia. C. Friction. D. Weight of the bag.
3. Eggs packed in a soft, shock-absorbing box are placed in a car. When the car suddenly starts or stops moving, the eggs do not crack because
A. no force acts on them
B. the force acts on them for only a short time
C. the force is small and acts for a longer time
D. the force causes fast change of momentum.
4. A body of mass 20 kg moves with a uniform velocity of 4 m/s from rest. Find its momentum.
A. 5 kg m/s B. 80 kg m/s C. 160 kg m/s D. 320 kg m/s
5. An object of mass 2 kg moving at 5 ms^{-1} , collides with another object of mass 3 kg which is at rest. Find the velocity of the two bodies if they stick together after collision
A. 1.0 ms^{-1} B. 2.0 ms^{-1} C. 2.5 ms^{-1} D. 5.0 ms^{-1}
6. A bullet of mass 0.1 kg is fired from a rifle of mass 5 kg. The rifle recoils at a velocity of 16 ms^{-1} . Calculate the velocity with which the bullet is fired
A. 66 ms^{-1} B. 110 ms^{-1} C. 210 ms^{-1} D. 800 ms^{-1}
7. A body of mass 20 kg moves with a uniform velocity of 4 m/s from rest. Find its momentum.
A. 5kgm/s B.80 C.160 D. 320

8. When a person steps forward from rest, one foot pushes backwards on the ground. The ground will as a result push that foot
 A. backwards with an equal force B. forwards with an equal force
 C. backwards with a smaller force D. forwards with a smaller force
9. If the forces acting on a moving body cancel each other out (i.e. are in equilibrium) the body will
 A. Move in straight line to the steady speed B. Slow down to a steady slower speed
 C. Speed up a steady faster speed D. Be brought to a state of rest.
10. A body of mass 20 kg, moving with uniform acceleration, has an initial momentum of 200 kg m/s and after 10s, the momentum is 300 kg m/s. What is the acceleration of the body.
 A. 0.5 m/s² B. 5 m/s² C. 25 m/s² D. 50 m/s²

SECTION B

1. (a) State Newton's laws of motion.
 (b) Define: (i) Inertia of a body (ii) Momentum.
 (d) Explain why a passenger standing on the floor of a lorry jerks backwards when the lorry starts moving forwards.
 (e) A 7-tonne initially moving at a velocity of 50m/s accelerates to 80m/s in 3 seconds. Calculate the force on the truck that caused the velocity change.
2. (a) (i) What is meant by linear momentum?
 (ii) State the law of conservation of linear momentum.
 (b) A bullet of mass 20g is fired into a block of wood of mass 400g lying on a smooth horizontal surface. If the bullet and the wood move together with the speed of 20ms⁻¹, calculate.
 (i) The speed with which the bullet hits the wood, (ii) The kinetic energy lost.
 (c) State the energy changes involved in (b) above.
3. (a) State the law of conservation of linear momentum.
 (b) A water jet directed to a spot on the ground digs a hole in the ground after sometime. Explain.
 (c) A moving ball P of mass 100g collides with a stationary ball Q of mass 200g. After collision, P moves backwards with a velocity of 2ms⁻¹ while Q moves forwards with a velocity of 5ms⁻¹. Calculate
 (i) The initial velocity of P.
 (ii) The force exerted by P on Q if the collision took 0.03s.
 (d) Explain the principle of operation of a rocket engine
4. A sphere of mass 3 kg moving with velocity 4m/s collides head on with a stationary sphere of mass 2kg & imparts to it a velocity of 4.5 m/s. Calculate the velocity of the 3kg sphere after the collision.
5. A railway truck of mass 4×10^4 kg moving at a velocity of 3m/s collides with another truck of mass 2×10^4 kg which is at rest. The couplings join & the trucks move off together.
 (a) State the type of collision.
 (b) Calculate the common velocity after collision.

CHAPTER THIRTEEN

MECHANICAL PROPERTIES OF MATTER

LEARNING OBJECTIVES

By the end of this chapter, you should be able to:

1. State and define: - The following properties of materials
 - Strength, Stiffness, Ductility, Brittleness and Elasticity.
 2. State: (a) - The factors affecting the strength of a material.
(b) - Characteristics of brittle materials.
(c) - The factors which determine the amount of deformation of a material.
 3. (a) State: - Hooke's law.
(b) Describe: - Experiments to verify Hooke's law using
 - A Nuffield spring and
 - A copper wire.
 4. Define: - Stress and Strain.
 5. (a) State: - The factors for stability and safety of structures.
(b) Define: - Ties and strut.
(c) Identify: - Ties and struts in a structure.
 6. (a) Explain: - The effects of compression and tension forces on beams.
(b) State:- The uses of beams.
 7. (a) Describe:- How concrete is made.
(b) State: - The uses of concrete.
(c) Describe:- How concrete is reinforced.
-

13.1 Materials

Materials are used in construction of structures like buildings, communication masts, bridges, dams, tanks, motorcars etc. Before these materials are put to use, their mechanical properties are tested. Some of the properties tested are: *strength, stiffness (toughness) ductility, brittleness and elasticity*.

1. Strength

Strength is the ability of material to withstand stress.

It is the measure of how great an applied force a material can withstand before breaking. Thus strength is a measure of the size of *breaking stress* a sample of a material has.

(a) Breaking Stress

Breaking strength is the force needed to break a piece of material of cross-sectional area of 1m^2 .

It is given by the formula: $\text{Breaking stress} = \frac{\text{Force}}{\text{Cross-sectional area}}$ N/m^2 (Pascal)

The greatest stress (breaking stress), the material can withstand before it can break is its ultimate tensile strength.

(b) Factors affecting the strength of a material

- (i) Cross-sectional area (diameter)

For samples of the same substance, it requires a larger force to brake one of larger cross-sectional area.

- (ii) Nature of the material

It is for example harder to break a steel rod than to break a sisal rod

- (iii) Force applied

The strength of a material may depend on how a force is applied on it. For example concrete is very strong when compressed but very weak when stretched.

2. Stiffness (toughness)

Stiffness is the ability of a material to resist bending. Stiffness tells us about opposition a material sets up when being deformed i.e. having its size or shape changed.

Stiff materials resist forces which try to change their shapes or sizes. They can withstand large compressional forces but stretch by little amount when pulled apart.

3. Ductility

Ductility is the ability of a material to be drawn into wires or worked into any shape without breaking. Examples of ductile materials include all metals except mercury. Metals can be hammered, rolled, cut or stretched into any useful shapes.

4. Brittle materials

Brittle materials are substances which bend very little, then suddenly crack without any warning. Examples of brittle materials are glass, brass, bronze and other alloys.

Characteristics of brittleness

- (i) Undergo very little deformation before finally breaking

- (ii) Can withstand fairly large compressional forces but break when subjected to tension

- (iii) Cracks form easily and are rapidly transmitted through the material once formed

- (iv) When broken, the broken pieces can be fitted together accurately.

5. Elasticity

Elasticity is the ability of a substance to recover its original shape and size after deformation.

Examples of materials which have this property called elasticity are said to elastic.

E.g. all metals except mercury and rubber. While materials which do not have elasticity are said to inelastic. E.g. Wood, paper, etc.

The amount of deformation depends on

- (i) The nature of the material

- (ii) The magnitude (Strength) of the distorting force.

There is a limit to the elasticity of the substance as it will break if the force applied is strong. The elasticity of a material depends on the force of attraction between its molecules. When a substance is stretched, its molecules are pulled apart as the distorting force overcomes the force of attraction between the molecules. On removing the distorting force, the substance will return to its original shape if the elastic limit is not exceeded. The relation between force and extension was investigated by Robert Hooke and stated it in his law called *Hooke's law*.

13.2 Hooke's Law

Hooke's Law states that:

The extension is directly proportional to the load provided the elastic limit is not exceeded.

Robert Hooke illustrated his law by carrying out four different experiments.

- Loading a spiral spring (deformation increases in length)
- Loading a wire (deformation increases in length)
- Loading a horizontal beam fixed at one end (deformation and depression of the free end).
- Tightening a watch spring (deformation = angular rotation)

Experiment 13.1 To verify Hooke's Law, Using a spring

- (a) Arrange the apparatus as shown in figure 13. below.

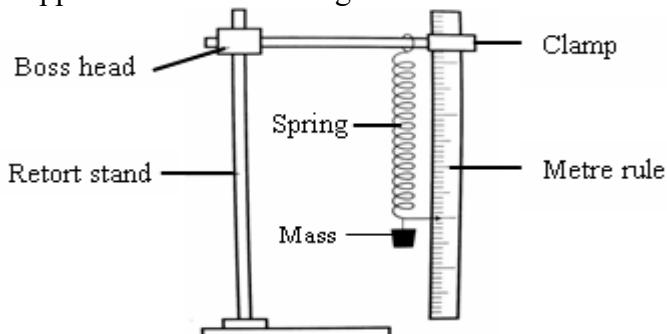


Figure 13.1

- (b) Attach a pointer to a spring and suspend the spring from a support clamped up using a retort stand.
- (c) Read and record the position, P_0 , of the pointer on the meter rule.
- (d) Suspend a mass hunger of 100 g from the spring.
- (e) Read and record the new position, P_1 , of the pointer.
- (f) Determine the extension, e_1 , of the spring.
- (g) Repeat the procedures (d) to (f) for values of slotted masses of 200 g, 300 g, 400 g, 500 g and 600 g.
- (h) Remove the masses in steps of 100 g and each time record the position, P_2 , of the pointer until the spring returns to its original length.
- (i) Determine the extension, e_2 , of the spring.
- (j) Enter your results in the table 13.1 below.

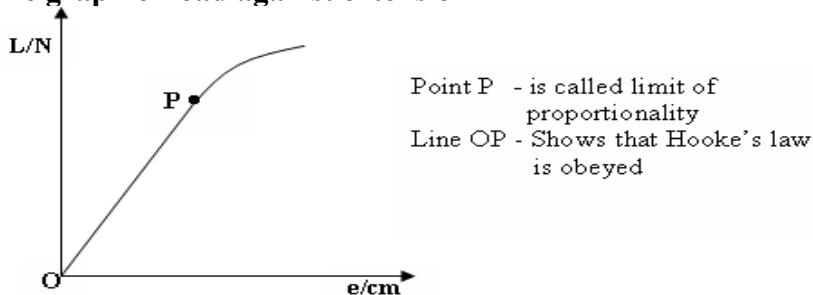
Table of results

M/kg	Load/N	P ₁ /cm	$e_1 = (P_1 - P_0)/cm$	Decreasing Load		Average extension $e = \frac{e_1 + e_2}{2} / cm$
				P ₂ /cm	$e_2 = (P_2 - P_0)/cm$	
0.1						
0.2						
0.3						
0.4						
0.5						

Table 13.1

- (k) Plot a graph of load (N) against extension, e.
 If the experiment is carefully performed, and the graph is accurately drawn, the shape of the graph below is obtained.

The graph of load against extension



Observation: When the load is doubled, the extension is also doubled.

Conclusion: Hooke's law which states that:

The extension of an elastic material is directly proportional to the load provided the elastic limit is not exceeded, is verified.

Experiment 13.2

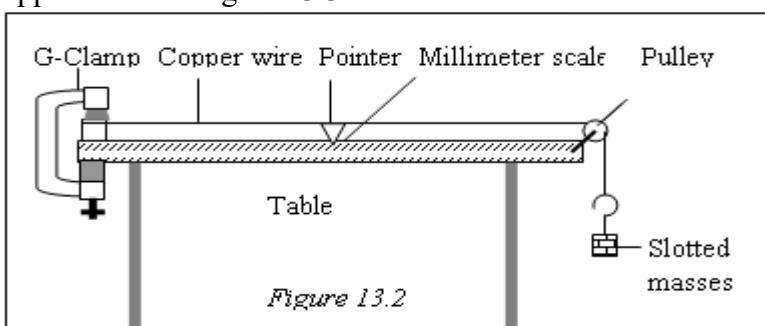
To verify Hooke's Law, Using a Copper wire

Apparatus

A smooth pulley, G-clamp, a mass hanger and slotted masses, a table, a pointer (made of paper) and a millimeter scale.

Procedure

- (a) Set up the apparatus as in figure 13.3 below.



- (b) Add small masses one at a time to the weight hunger and observe the scale reading.
 (c) Determine the extension in millimeters.
 (d) Repeat the procedure (b) to (c) by adding more masses until the wire breaks.
 (e) Enter your results in table 13.2 below.

Mass/kg	Load/N	Extension/cm

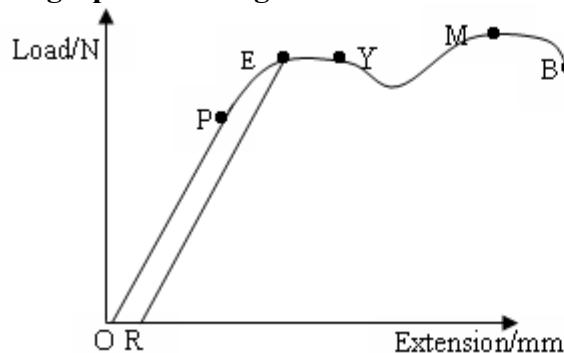
Figure 13.2

- (f) Plot a graph of load/force against extension for the wire.
 If the experiment is carefully performed, and the graph is accurately drawn, the shape of the graph resembles that of a spring except the extension is much smaller for a given force.

Note: The extension for a given load depends on:

- The metal used,
- The length of the wire and
- The diameter or cross sectional area of the wire.

The graph of load against extension for a wire



P	- Limit of proportionality
E	- Elastic limit
Y	- Yield point
OP	- a straight line passing through the origin. - It shows that Hooke's law is obeyed.
YM	- Plastic region
B	- Breaking point

Explanation of the shape of the graph

Line OP: Line OP is a straight line passing through the origin. It shows that the extension is directly proportional to the load. And therefore indicates that Hooke's law is obeyed. When the load is removed from the wire within this range of load, the wire returns to its original unloaded length.

Point E: Point E is called *elastic limit*.

After the elastic limit, the wire does not return to its original length when the load is removed. Some of the extension remains and the wire is deformed permanently giving a *residual extension*, OR, on the diagram.

Point Y: Just after the elastic limit is point Y. It is called *yield point*. Beyond this point, an increase on the load causes the wire to „flow“ thus producing a larger extension than the previous one. After point Y, *plastic deformation* occurs.

Point M: Point M indicates the maximum load the wire can take.

Reducing the load after reaching point M has little effect; the wire forms a waist at its weakest point and breaks on reaching point B called *breaking point*.

Worked Examples

1. A force of 20 N extends a spring by 5 cm. Calculate the force required to extend the same wire by 20 cm.

Solution: Let: $F_1 = 20 \text{ N}$, $e_1 = 5 \text{ cm}$, $e_2 = ? \text{ cm}$, $F_2 = ?$

20 N extends the spring by 5 cm,

1 cm is extended by a force of $\frac{20}{5} \text{ N}$

The force that can extend the spring by 20 cm = $\frac{20 \times 20}{5} = 80 \text{ N}$

2. A force of 10 N extends a wire by 2 cm. Find the extension by a force of 50 N.

Solution: Let: $F_1 = 10 \text{ N}$, $e_1 = 2 \text{ cm}$, $e_2 = ? \text{ cm}$, $F_2 = 50 \text{ N}$

10 N extends the wire by 2 cm,

1 N extends by 10/2

Then the extension by 50 N = $2 \times \frac{50}{10} = 10 \text{ cm}$

13.3 Stress and strain

(a) Stress

Stress is defined as *force per unit area of cross-section*.

$$\text{i.e. } \text{Stress} = \frac{\text{Force (N)}}{\text{Area (m}^2\text{)}}$$

The SI unit of stress is Newton per metre squared, $\text{Nm}^{-2} = \text{Pascal (Pa)}$.

(b) Strain

Strain is defined as *the change in length per unit length*.

$$\text{Strain} = \frac{\text{Change in length}}{\text{Original length}}$$

Strain has no units because it is a ratio of the same quantity.

13.4 Structures

Structures are generally designed and built to carry or support a load (i.e. to withstand a force). A well designed structure must be able to stay in position without collapsing for a long period of time.

13.4.1 Factors for stability and safety of structures

The stability and safety of structures depend on the following.

- (i) The nature of the material.
- (ii) Shapes of the materials.
- (iii) The way of arrangement of the materials.

The behaviour of structures under stress or strain can be investigated by using models made out of straws.

The straws are arranged to give structures of different shapes and a heavy load is then attached to one end of each structure as shown in the diagrams in figure 13.3 below.

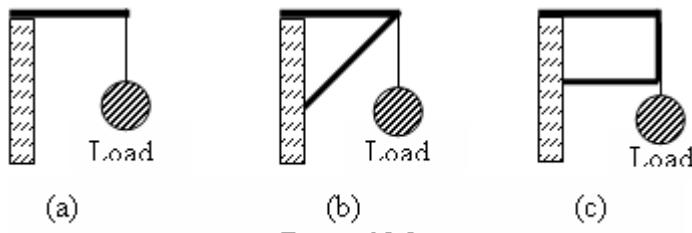


Figure 13.3

Experimental results show that the triangular structure figure 13. (b), provides better support than (a) and the rectangular structure (c) for the same load. However, the rectangular structures can be strengthened by fixing more girders diagonally. Notable examples are seen in door and window frames.

13.42 Beams and Girders

(a) Beams:

A beam refers to a large, straight piece of material with uniform cross section whose width and thickness are small compared to the length. Beams are used as major structural items in a building or structure.

(b) Girders:

These are the smaller pieces of materials used to strengthen a structure.

In any structure, some girders are under tension while others are under compression. Girders under compression bend or buckle and those under tension become thin and may break.

13.43 (a) Ties and Struts

Girders and beams are used to make the frame works of structures such as water tank supports, radio masts, roof trusses, bridges, cranes, electricity pylons etc. In these structures, materials ties and others are struts.

(i) Ties: *A tie is a girder under tension.*

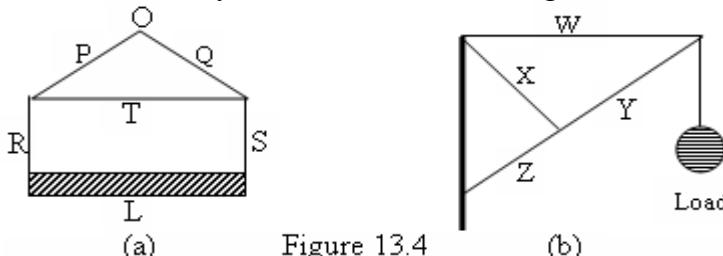
(ii) Struts: *A strut is a girder under compression.*

(b) Identification of Ties and struts in a structure

To identify ties and struts in a structure can be identified by replacing them with strings. If the string is pulled tightly, the girder is in tension and therefore it is a tie. And if it becomes slacked, it is under compression and therefore it is a strut.

Worked Examples

1. The diagram in figure 13.4 (a) and (b) shows a structure supporting a heavy load hanging from a nail at A. Identify ties and struts in the diagrams below.



Answer: (a) P, Q, S and R are ties
Only T is a strut.

(b) Tie: W
Struts: X, Y and Z

(c) Applications of struts and Ties

Ties and struts are applied in:

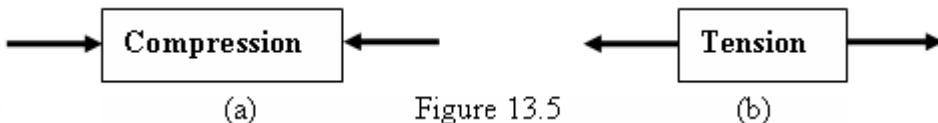
- | | |
|---------------------|------------------------------------|
| (i) Roof supports | (ii) Water tank/reservoir supports |
| (iii) Girder bridge | (iv) Communication masts |

13.5 Effect of Compression and Tension forces in beams

Beams are used to support loads in buildings and bridges.

(a) Effect of Compression forces in a beam

If a beam is acted on by two compression forces (two opposing forces that act toward each other) as shown in figure 13. (a) below, the particles in the body are pushed closer together. The body becomes shorter compared to the original length and the body is said to be in a state of compression.



(b) Effect of Tension forces in a beam

If the beam is acted on by two tension forces (two opposing forces that act away from each other) as shown in figure 13. (b) above, the particles in the body are moved apart. The body becomes slightly longer than the original length and the body is said to be in a state of tension.

(c) Bending of beams

When a beam is subjected to a bending force, as shown in figure 13. below, three things happen to it.

Diagrams showing the behaviour of a beam under a load

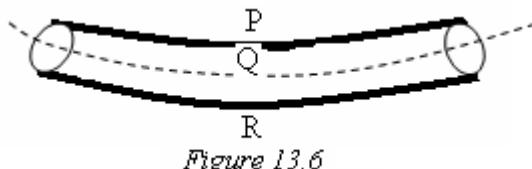
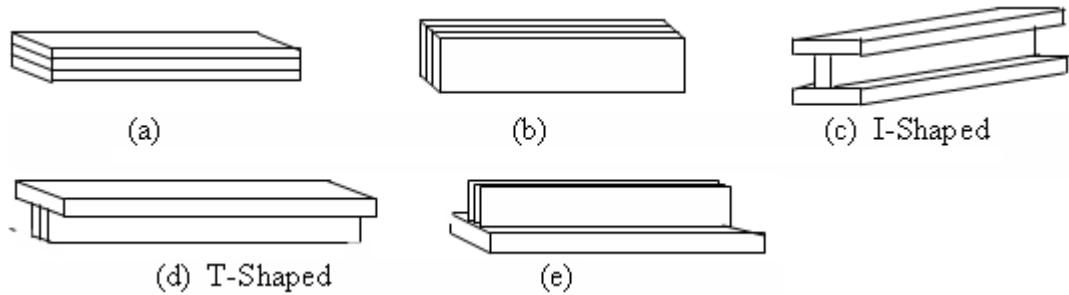


Figure 13.6

- (i) The particles in the upper region marked P become closer and shorter. The part region is under compression.
- (ii) In the lower region, R, the particles become further apart and the region becomes longer. It is under tension.
- (iii) Near the middle point Q, the distance between the particles remains the same. That is the region is neither under compression nor under tension. The length of this surface has not changed. This region is called the *neutral plane* or *neutral surface*.

13.51 (a) Stiffness of *three* wooden beams

Three wooden beams can be arranged in five possible ways to give different shapes as shown in figure 13.7 below. One end of each beam is then subjected to a heavy load.



Experimental results show that the I-shaped beam is the most stiff i.e. the strongest. That is why many beams in structures such as bridges, buildings are I-shaped.

I-shaped beams can be made lighter by removing material along the neutral axis.

(b) Effect of shear force on a body

When a body is acted upon by *shear forces* (two equal and opposite forces whose line of action are parallel to each other) the body becomes twisted and deformed. See the diagrams in figure 13.8 below.

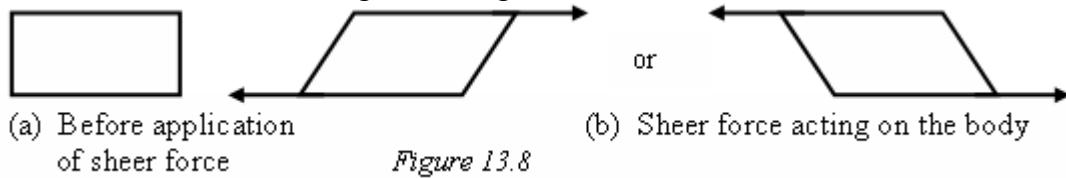


Figure 13.8

(c) Uses of beams

- (i) **I-Shaped beam:** I-Shaped beam resists bending and sagging under load. They are used in building constructions such as buildings, bridges, masts, cranes etc.
- (ii) **Joist.** A joist is a wooden beam which helps to support a floor or ceiling. The joists are laid on their edges since they are then stiffer and bend less.

13.52 Other materials used in construction of structures are the following:

1. **Natural stone:** Stone is an inorganic mineral or soil concretion of the earth. The commonly used types of stones in building, civil engineering, manufacturing and art are: sedimentary, igneous, or metamorphic origin. Some of the building stones are basalt, flint, granite, limestone, marble, porphyry, sandstone, slate, and flagstone.
2. **Bricks:** Brick is block of clay or other ceramic used for construction and decorative facing. They are made by mixing together clay and water. The mixture is molded into different shapes and baked in a kiln (i.e. fired at high temperature) or may be dried in the sun. Well known places for making bricks is Lweza Clays at Kajjansi in Wakiso district.
3. **Mortar:** Mortar is a mixture of sand and cement made into paste by adding water. When dried it produces a hard stony material used for *bonding* bricks. They resist dampness and heat, and can last longer than stone. Some bricks are made of special fireclays for use in fireplaces or ovens.

4. **Concrete:** Concrete is made by mixing gravel or small stones, sand, cement and water in right proportions. The gravel or stones make the concrete very strong; the sand fills up the spaces between the stones.

(a) **Uses of concrete**

It is used where heavy loads have to be supported, e.g. in

- the foundations of tall buildings,
- airport runways,
- dams,
- the piers of bridges
- etc.

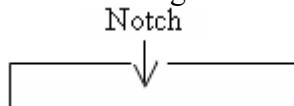
Concrete has great compressive strength but little tensile strength. Its tensile strength is increased by reinforcing it.

(b) **Reinforcement of concrete**

Concrete used in most construction work is reinforced with steel. Steel is embedded in the concrete in the form of a mesh. A bond forms between the steel and the concrete. When reinforced concrete is subjected to extreme tensile stresses, the steel supplies the necessary strength and stresses can be transferred between both components.

13.6 Notches

A notch is an indentation or incision on an edge or surface.

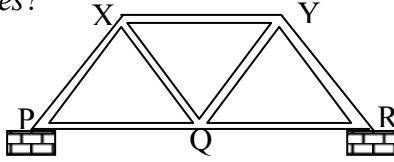


Notches and cracks spread more easily when brittle materials such as glass and concrete are under tension. This effect is applied in cutting glass where a notch is made on the surface of the glass and the glass is subjected to bending from below.

Self-Check 13.0

1. The strength of a material depends on the:
 (i) Nature of the material (ii) Diameter of the material (iii) Length of the material
 A. (i) only B. (i) and (ii) only C. (ii) and (iii) only D. (i), (ii) and (iii)
2. A mass of 0.2 kg produces an extension of 8 cm in a spring. The force required to produce an extension of 6cm is
 A. 0.75 N B. 1.50 N C. 2.70 N D. 24.00 N
3. A ductile material is that which
 A. Is fragile B. Is not elastic
 C. Can be molded into any shape D. Easily breaks under compression.
4. In a wire supporting a load, stress is given by
 A. $\frac{\text{strain}}{\text{area}}$ B. force x area C. $\frac{\text{area}}{\text{force}}$ D. $\frac{\text{force}}{\text{area}}$

5. The diagram in figure below shows a framework of a bridge.
Which of the girders are *ties*?

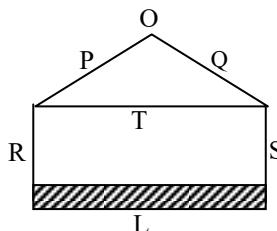


- A. XQ, QY, PX, YR B. PQ, QR, XY C. XQ, QY D. PX, YR

6. Which of the following are all brittle materials?

- A. Leather, rubber, thread. B. Clay, glass, wood.
C. Glass, cast iron, stone. D. Rubber, polyester, copper wire.

7. The diagram below shows a structure of wooden beams P, Q, R, S and T supporting a heavy road L. Which of the beams can be replaced by ropes if the same shape is to be maintained?



- A. P, R, S and T
B. P, Q, S and T
C. Q, R, S and T
D. P, Q, R and S

8. A rod of cross-sectional area 40cm^2 needs a tensile force of 2N to break it. What is its breaking stress?

- A. 0.005Nm^{-2} B. 0.05Nm^{-2} C. 5Nm^{-2} D. 500Nm^{-2}

9. A mass of 0.5kg causes a spiral spring to extend by 4cm . The force that would cause an extension of 6cm would be

- A. 2.0 N B. 3.3 N C. 4.8 N D. 7.5 N

10. If a load 1N extends a spring by 5cm , what extension will a load of 0.6 N produce?

- A. 1.2 cm B. 3.0 cm C. 8.3 cm D. 30.0 cm

11. Which of the following are brittle substances?

- A. Dry clay, steel, chalk, wood B. Chalk, steel, plastic, glass.
C. Glass, chalk, concrete and steel D. Dry clay, glass, chalk and concrete.

12. Reinforced concrete is stronger than ordinary concrete because concrete and the steel are

- A. Both brittle materials. B. Strong in tension and compression respectively.
C. Both ductile materials. D. Strong in compression and tension

respectively.

13. The graph above represents the extension of a wire with increasing load. Where does the yield point occur?

- A. between point P and Q B. between point Q and R
C. between point R and S D. at point S

14. A load of 4 N stretches a spring by 0.5 cm . Calculate the extension when a load of 8 N is applied.

- A. 0.25 cm B. 1.0 cm C. 2.0 cm D. 4.0 cm

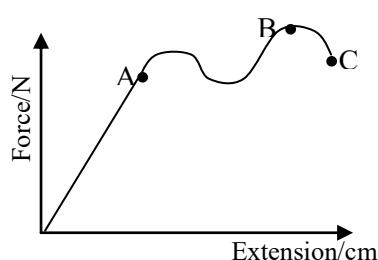
15. A notch on a material spreads more rapidly when the metal is

- A. in tension B. in compression C. pre-stressed D. reinforced

SECTION B

1. (a) With the aid of a diagram, describe the effect of a shear force on a body.
 (b) (i) What is meant by strength as applied on a material?
 (ii) State the factors on which strength on a material depends.
 (c) (i) Describe a simple experiment to describe Hooke's law using a spring.
 (ii) State any three characteristics of concrete which make it a desirable building material.

2. (a) Define the following terms
 (i) Strain. (ii) Stress.
 (b)



The curve in the figure shows the force versus extension graph for a copper wire.
 Describe what is happening between points A and B.

3. (a) Explain with the aid of a sketch diagram, how a notch weakens a beam of a brittle material.
 (b) State two ways in which concrete may be made stronger.
 (c) A force of 100 N stretches an elastic spring by 2 cm. what force would stretch the same spring by 3.5 cm?
 (d) The diagram in the above figure shows a simple bridge on a stream.



- (i) Mark the neutral axis
 (ii) Label the part that will be in tension
 (iii) Indicate on the diagram how the bridge can be strengthened.

CHAPTER FOURTEEN

BEHAVIOUR OF LIGHT

LEARNING OBJECTIVES

By the end of this chapter, you should be able to:

1. Define:
 - (a) A ray and a beam.
 - (b) State and draw the types of beams.
2. (a) State
 - (i) The rectilinear propagation of light.
 - (ii) The types of shadow.
(b) Describe an experiment for the formation of the types of shadows.
(c) State: The types of eclipses.
(d) Describe with a help of diagrams the formation of the types of eclipses.
3. (a) Describe
 - (i) The structure of the Pin-hole camera.
 - (ii) The formation of image in a pin-hole camera.
(b) State:
 - (i) The properties of the image formed in a pin-hole camera.
 - (ii) The effects of the object distance and the size of the pin hole, on the image formed in a pin-hole camera.
4. (a) Define magnification.
(b) Solve problems using the formula of magnification.

14.1 INTRODUCTION

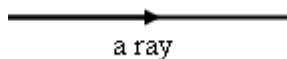
Optics is a branch of physical science dealing with the propagation and behavior of light.

Light is a form of energy that travels in a straight line.

(a) Rays and Beams of Light

(i) **Rays:** A ray is the direction of the path taken by light.

Diagrammatically it is represented by a straight line with an arrow.



(ii) **Beam:** A beam is a stream of light energy.
It is represented by a number of rays.

(b) Types of Beams

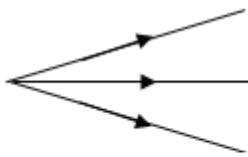
There are three types of beams namely;

- Parallel beam,
- Convergent beam and
- Divergent beam.

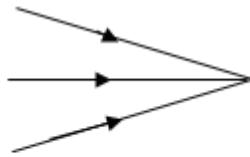
Diagrams showing the three types of beams



(a) Parallel beam
The rays are parallel to each other.



(b) Divergent beam:
The rays start from a common point and separate in different directions.



(c) Convergent beam:
The rays from different directions come together and meet at a common point.

14.11 Rectilinear Propagation of Light

The rectilinear propagation of light states that: *Light travels in a straight line.*

Experiment 14.1 To verify the rectilinear propagation of light

Apparatus:

Source of light, three slits, screen, retort stand

Procedure:

- Stand the slits such that they are in a straight line.
- Place the source of light at one end such that it is at the same level with the three holes.
- View the source of light from the other end as shown figure 14.1 below.

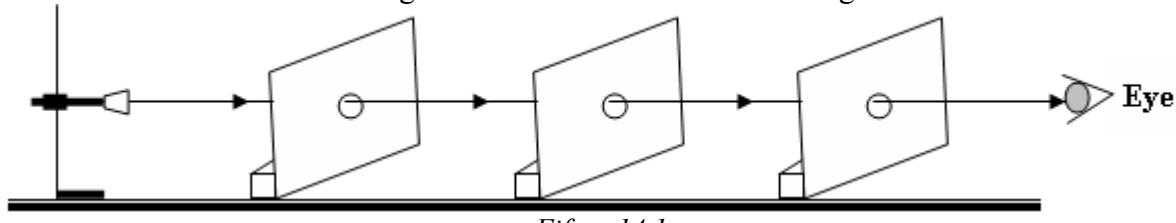


Figure 14.1

Result: The source of the light can be seen.

Procedure continued

- Now displace any one of the slits such that the holes are not in a straight line.
- Observe the source of the light as before.

Result: The source of the light can no longer be seen.

Explanation: Since the holes are no longer in a straight line, therefore the light ray strikes the surface of the displaced slit.

Conclusion: Light travels in a straight line.

14.12 Applications of the Rectilinear Propagation of Light

The rectilinear propagation of light is applied in:

- Shadows
- Eclipses and
- Pinhole camera.

(a) Shadows

A shadow is a dark area caused by an opaque object blocking a ray or a beam of light. A shadow may be described as umbra and penumbra.

(i) Umbra:

The fully shaded inner region of shadow cast by an opaque object, especially the area on the earth or moon experiencing totality in an eclipse.

In the laboratory, it may be obtained when a point source of light is enclosed in a box with very small hole on one its sides and an opaque object is placed in between the source of light and a screen as shown in figure 14.2 on page 213.

A diagram showing the formation of umbra using a point source of light

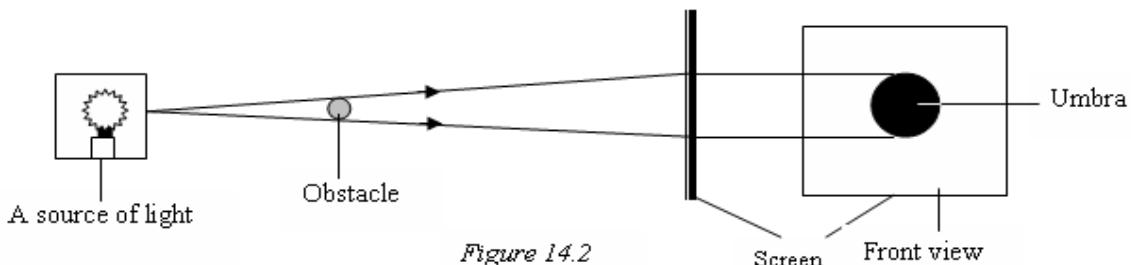


Figure 14.2

(i) **Penumbra:** The partially shaded outer of the shadow cast by an opaque object, especially the area on the earth or moon experiencing totality in an eclipse.

It can be obtained when a source of light is enclosed in a box with extended or larger hole on one its sides and an opaque object is placed in between the source of light and a screen as shown in figure 14.3 below.

A diagram showing the formation of penumbra using an extended source of light

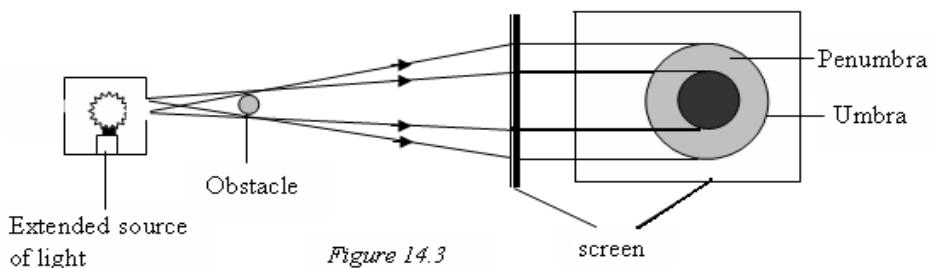


Figure 14.3

(b) Eclipses

Eclipse, in astronomy, is the obscuring or blocking of light from the sun by a celestial body (e.g the moon or the earth).

14.13 Types of Eclipse

Two kinds of eclipses involve the earth. These are:

- (i) Solar eclipse and
- (ii) Lunar eclipse

(a) Solar eclipse

A solar eclipse is an eclipse occurs when the moon is between the sun and the earth and its shadow moves across the face of the earth.

Solar Eclipse is divided into two, namely;

- (i) Total solar eclipse and
- (ii) Annular eclipse

(i) Total solar eclipses

Total solar eclipse occurs when the moon's umbra reaches the earth as shown in the figure 14.4 below.

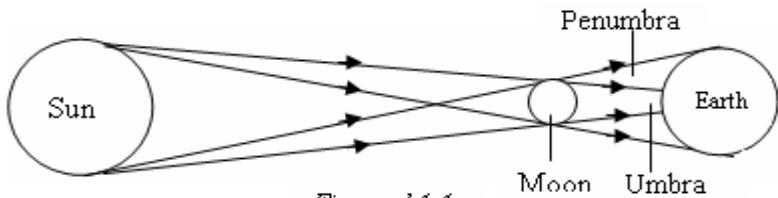


Figure 14.4

(ii) Annular eclipse (Partial Eclipse)

The Moon's orbit around Earth is slightly elliptical, or egg-shaped. Therefore the distance between Earth and the Moon varies slightly as the Moon orbits Earth. When the moon is farther from Earth than usual, it appears smaller and may not cover the entire sun during an eclipse. A cone of umbra forms in upper atmosphere and does not reach the earth surface. As a result the whole area on the earth surface is covered by penumbra. See figure 14.5 below. This type of eclipse produced is called an **annular eclipse**.

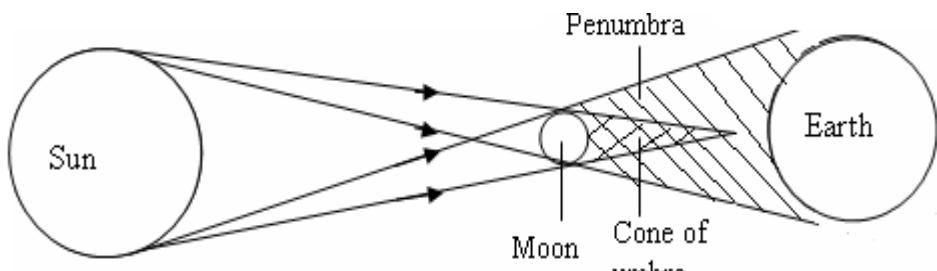
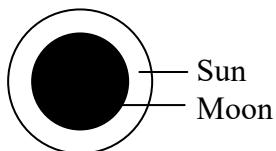


Figure 14.5

Off to the sides of the path of a total eclipse, a partial eclipse, in which the sun is only partly covered, is visible. As such a bright ring of the solar disk appears around the black disk of the moon.

At the beginning of a total eclipse, the moon begins to move across the solar disk about 1 hour before totality.



- Notes:**
- (i) *In areas outside the band swept by the moon's umbra but within the penumbra, the sun is only partly obscured, and a partial eclipse occurs.*
 - (ii) *The illumination from the sun gradually decreases and during totality (and near totality) declines to the intensity of bright moonlight.*
 - (iii) *A total solar eclipse occurs about every 18 months.*

(b) Lunar Eclipse (Partial or total obscuring of the moon by the earth's shadow)

A lunar eclipse occurs when the earth is between the sun and the moon and its shadow is cast on the surface of the moon.

The earth, lit by the sun, casts a long, conical shadow called *umbra* in space. At any point within that cone the light of the sun is wholly obscured. Surrounding the shadow cone, is an area of partial shadow called the *penumbra*. See figure 14.6 below.

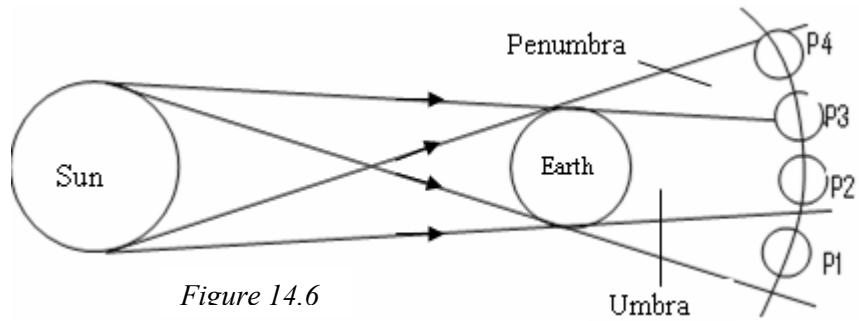


Figure 14.6

Lunar Eclipse is divided into two types namely;

- Partial lunar eclipse and
- Total lunar eclipse.

(i) Partial lunar eclipse

A partial lunar eclipse occurs when only a part of the moon enters the umbra and is obscured. This is the case when the moon is in position P3. Figure 14.1 .

(ii) Total lunar eclipse

A total lunar eclipse occurs when the moon passes completely into the earth's umbra. That is when the moon is in position P2, figure14.1. In positions P1 and P4 there is no eclipse, but the moon is less bright.

Notes:

- ❖ Before the moon enters the umbra in either total or partial eclipse, it is within the penumbra and the surface becomes visibly darker.
- ❖ The portion that enters the umbra seems almost black, but during a total eclipse, the lunar disk is not completely dark; it is faintly illuminated with a red light refracted by the earth's atmosphere, which filters out the blue rays.
- ❖ Occasionally a lunar eclipse occurs when the earth is covered with a heavy layer of clouds that prevent light refraction; the surface of the moon is invisible during totality.

14.14 The Pin hole Camera

(a) Structure

A pinhole camera is made of a light proof box painted black on the inside with a small pinhole in front and a piece of frosted glass or tracing paper placed at the back as the screen.

(b) Mechanism

An illuminated object is placed in front of the camera. Light rays from the object pass through the pin hole and forms an inverted, backwards image of the subject on the screen at the back of the box.

A diagram showing the formation of image in a pinhole camera

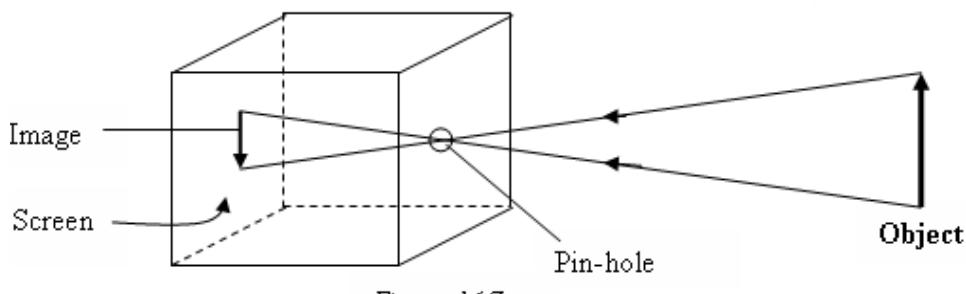
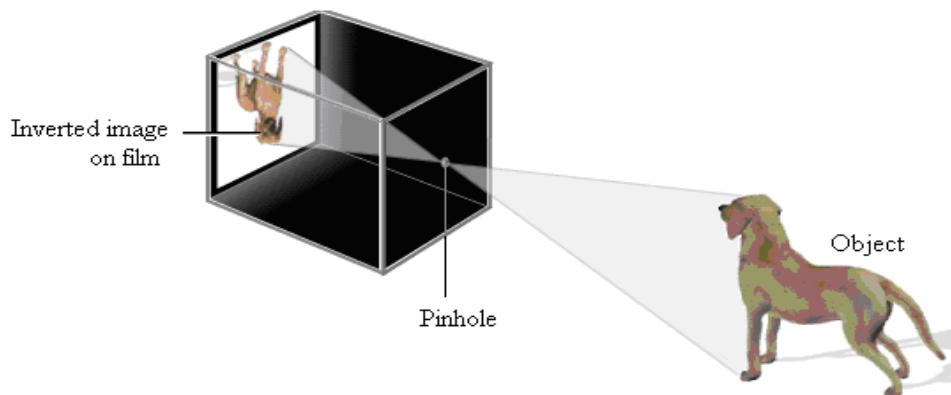


Figure 14.7

A photograph of a dog formed in a pin-hole camera



(c) The Nature of the Image formed by a Pin-hole Camera

The nature of the image formed by a pin-hole camera is described by using the following terms.

- | | |
|------------------|--|
| (i) Real | - Formed by intersection of actual rays and can be obtained on screen. |
| (ii) Inverted | - Upside down |
| (iii) Diminished | - Smaller than the object and |
| (iv) Magnified | - Bigger/larger than the object. |

(d) The effect of the object distance on the size of the image

The size of the image, magnified or diminished, depends on the object distance.

(i) When the object distance is small

When the object is moved towards the pin-hole or when the camera is moved towards the object, such that the object distance is small, the image becomes magnified.

(ii) When the object distance is large

When the object is moved away from the pin-hole, or when the camera is moved away from the object, such that the object distance is large, the image becomes diminished.

(e) The effect of the size of the pin-hole on the nature of the image formed in a pin-hole camera

When the pin-hole is small, the image is sharp or clear and is said to be in focus. But when the hole is bigger, the image is blurred (brighter).

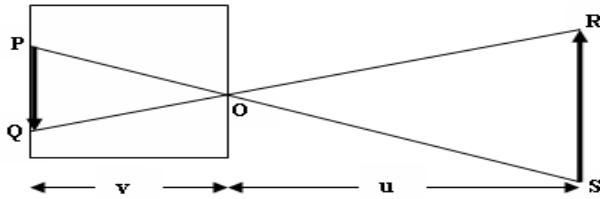
Explanation

The blurred image is explained by the fact that a large hole is believed to be made up of a collection of many small holes, each of which produces an image slightly displaced from the other images. The result is thus a brighter (blurred) image.

(f) Magnification, m, of the pin-hole camera

Magnification, m, is the ratio of the image height to the object height.

Consider the cross section of the pin-hole camera



$$\text{Magnification} = \frac{\text{Image Height}}{\text{Object height}} = \frac{PQ}{RS}$$

$$\therefore m = \frac{h_i}{h_o}$$

$$\text{Or} \quad \text{Magnification} = \frac{\text{Image distance from the pin-hole}}{\text{Object distance from the pin-hole}}$$

$$\therefore m = \frac{v}{u}$$

From the above equations, we have

$$\frac{\text{Image Height}}{\text{Object height}} = \frac{\text{Image distance from the pin-hole}}{\text{Object distance from the pin-hole}}$$

$$\frac{h_i}{h_o} = \frac{v}{u}$$

Example

1. An object of height 5 cm is placed 20 cm from a pin-hole camera which is 5 cm long. If the height of the image formed is 1.25 cm, calculate the magnification

Solution: $u = 20 \text{ cm}$, $v = 5 \text{ cm}$ (length of the camera), $Oh = 5 \text{ cm}$, $Ih = 1.25 \text{ cm}$, $m = ?$

$$\text{Magnification} = \frac{\text{Image Height}}{\text{Object height}} = \frac{IH}{OH} = \frac{1.25}{5} = 0.25$$

$$\text{Or} \quad \text{Magnification} = \frac{\text{Image distance from the pin-hole}}{\text{Object distance from the pin-hole}} = \frac{v}{u} = \frac{5}{20} = 0.25$$

2. A man 1.75 m tall stands at a distance of 7.0 m from the pinhole of pinhole camera. If the film is 0.20 m behind the pinhole, find the length of the image of the man formed on the film.

- A. 8.75 m B. 4.00 m C. 0.80 m D. 0.05 m

Solution: $h_o = 1.75 \text{ m}$, $u = 7.0 \text{ m}$, $v = 0.20 \text{ m}$, $h_i = ?$

Using $\frac{h_i}{h_o} = \frac{v}{u} \Rightarrow \frac{h_i}{1.75} = \frac{0.2}{7.0}$ $h_i = \frac{0.2 \times 1.75}{7.0} = 0.05 \text{ m}$

Therefore the answer is **D**.

Self-Check 14.1

1. When a pin-hole camera is moved nearer an object, the size of the image
 - A. remains the same
 - B. becomes smaller
 - C. becomes larger
 - D. becomes diminished
2. In a pin-hole camera, sharper and taller images are obtained by
 - A. widening the hole and moving the object farther
 - B. narrowing the hole and moving the object nearer
 - C. using a longer camera with a wider hole
 - D. using a shorter camera with a narrower hole
3. (a) Describe an experiment to show that light travels in a straight line.
(b) With the aid of a diagram, illustrate how the shadows are formed when an opaque object is placed between an extended source of light and a screen.
4. (a) An object of height 4 cm is placed 5 cm away from a pin-hole camera. The screen is 7 cm from the pinhole.
 - (i) Draw a scale a ray diagram to show the formation of an image by a pinhole camera.
 - (ii) What's the nature of the image.
 - (iii) Find the magnification.
 - (iv) Explain what happens to the image if the pinhole is made larger.
(b) Draw a diagrams to show the formation of a partial and total solar eclipse.

REFLECTION OF LIGHT

LEARNING OBJECTIVES

By the end of this chapter, you should be able to:

1. (a) Define the term reflection.
(b) State and describe the type of reflection.
2. (a) State the laws of reflection.
(b) Describe an experiment to verify the laws of reflection.
3. (a) Draw the formation images in plane mirror.
(b) State the properties of the images formed in a plane mirror.
4. State the effect of rotating a plane mirror to the angle of reflection.
5. Solve problems involving the number of images in two mirrors inclined at an angle.

14.2 Reflection

Definition: *Reflection is the change in the direction of light ray or a beam of light after impinging on a surface.*

(a) Types of reflecting surfaces

Reflection occurs on two types of reflecting surfaces namely;

- (i) Plane surface e.g. plane mirrors.
- (ii) Curved surfaces e.g. curved mirrors

(b) Reflection on plane surfaces

Terms used

The figure 14.21 below illustrates the terms used in the study of reflection of light.

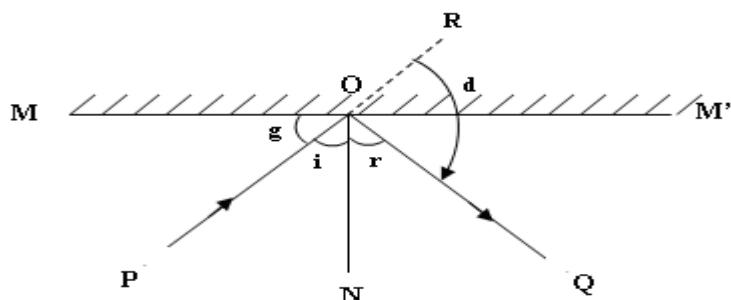


Figure 14.21

MM' - represents the plane mirror

PO - *Incident ray* is the ray of light falling to the reflecting surface.

OQ - *Reflected ray* is the ray of light that leaves the reflecting surface after reflection.

ON (Normal) - is a perpendicular line that meets the reflecting surface.

Point O - *Point of incidence* is the point on the reflecting surface where the incident ray, the reflected ray and the normal all meet.

$\angle PON = \text{Angle of incidence}$ - is the angle made by incident ray and the normal.

$\angle NOQ = \text{Angle of reflection}$ - is the angle made by the normal and the reflected ray.

$\angle MOP = \angle M'OP = \text{Glancing angle, } g$: - is the angle between the incident ray or reflected ray and the reflecting surface.

$\angle ROQ$ - Angle of deviation, d .

The angle of deviation is the angle between the reflected ray and the original path of the incident ray.

14.22 Types of reflection

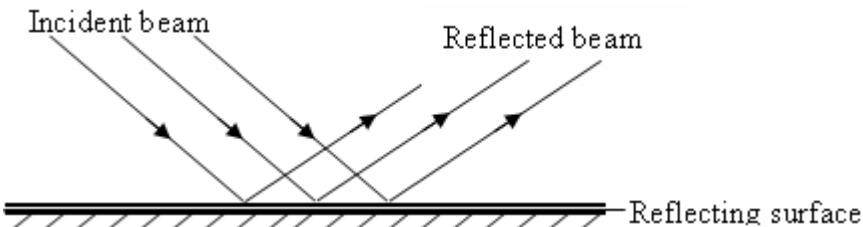
There are two types of reflection namely;

- (i) Regular Reflection
- (ii) Diffuse (Irregular) reflection

(a) Regular Reflection

Regular reflection is the type of reflection in which a parallel beam is reflected parallel.

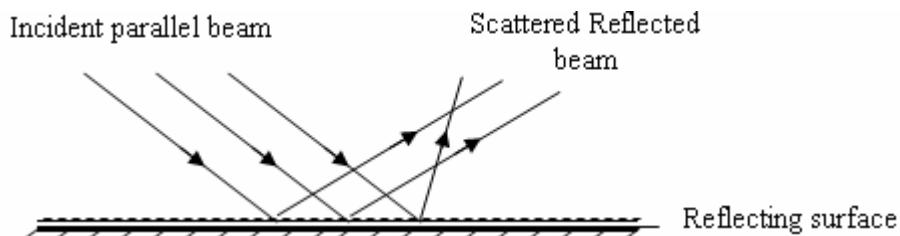
It occurs on smooth reflecting surfaces and gives clear images of objects thus allowing them to be recognized.



(b) Diffuse (Irregular) reflection

Diffuse or Irregular Reflection is the type of reflection in which a parallel beam is scattered after reflection.

It occurs on rough reflecting surfaces. Because the reflected beam is scattered after reflection it does not form clear images of objects.



Difference between Regular and Diffuse Reflections

Regular Reflection	Diffuse Reflection
(i) Parallel incident beam is reflected parallel	- Parallel incident beam is scattered after parallel
(ii) Forms clear images of objects	- Forms blurred image of objects due to the scattering reflected rays
(iii) Occurs on smooth surfaces	- Occurs on rough surfaces
(iv) The angles of incidence and reflection are equal for the incident rays and reflected rays	- The angles of incidence and reflection are not equal for the incident rays and also not equal for the reflected rays
(v) The amount of light intensity after reflection is high since the reflected beam remains parallel	- The amount of light intensity after reflection is low due to the scattering of reflected rays

Note:

- 1. Not all of the light that strikes a mirror is reflected; some of it absorbed by the reflecting object and the object becomes warmer.
- 2. The laws of reflection are obeyed for each ray.

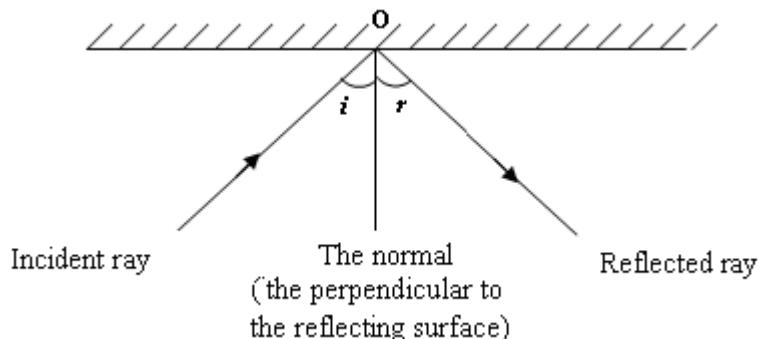
14.23 The Laws of Reflection

The reflection of light from a reflecting surface is governed by two laws. These laws are called *laws of reflection*. They are stated as follows:

LAW 1 *The incident ray, the reflected ray and the normal at the point of incidence all lie in the same plane.*

LAW 2 *The angle of incidence is equal to the angle of reflection.*

The situation is illustrated in the figure below.



Where: $i = \text{Angle of incidence}$, $r = \text{Angle of reflection}$

According to **law 1**, point of incidence, **O**, which lies in the plane formed by the reflecting surface, is a common point for the incident ray, the reflected ray and the normal. That is to say, at that, all the three lie in the same plane.

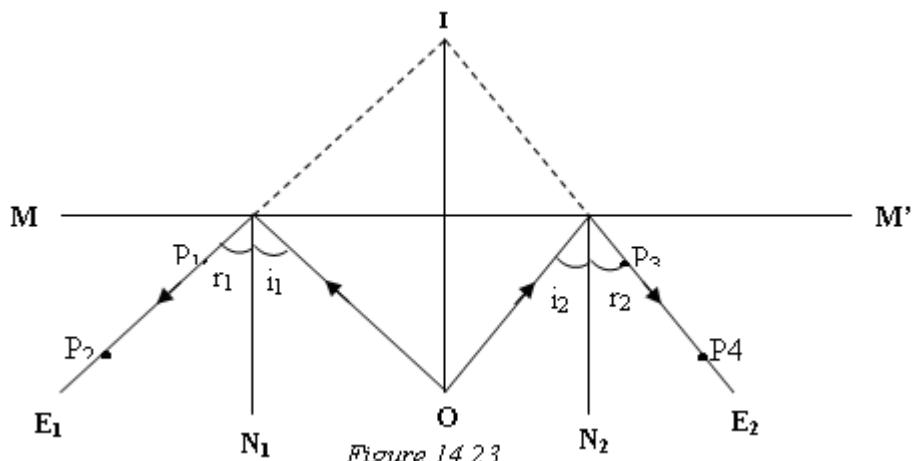
Law 2 is about the angles made by the incident ray and the reflected ray with the normal. That is $\angle i = \angle r$. However, the laws of reflection can be verified experimentally.

Experiment 14.1 To verify the laws of reflection

Apparatus: A strip of a plane mirror, 4 optical pins, 4 office pins, a white piece of paper and drawing board.

Procedure

- Fix the white sheet of paper on the drawing board using the office pins.
- Draw a straight thin pencil line MM'' as shown in figure 14.23.



- Stand a strip of a plane mirror up vertically, with the silvered surface on the line MM'' drawn on the paper.
- Fix object pin **O**, in front of the mirror about 10cm from line MM'' .
- View the image, **I**, of the object, **O**, by placing your eye at position **E₁** and fix two pins **P₁** and **P₂** such that they are collinear (on a straight line) with **I**.

- Remove the two pins P_1 and P_2 .
- Repeat the above procedure with the eye in position E_2 .
- Remove the mirror.
- Join the points P_1 , P_2 , P_3 and P_4 by to meet MM'' at B_1 and B_2 .
- Extrapolate the lines to intersect at I .
- Construct the normals, B_1N_1 and B_2N_2 .
- Measure the angles i_1 and r_1 , i_2 , and r_2 .

Results:

1. The incident rays (OB_1 and OB_2), the reflected rays (B_1E_1 and B_2E_2), and the normals N_1 and N_2 at the points of incidence B_1 and B_2 all lie in the same plane.
2. The angle of incidence, $i_1 = \text{Angle of reflection } r_1$ and
The angle of incidence, $i_2 = \text{Angle of reflection } r_2$

Conclusion: The laws of reflection are verified.

(a) Image Formation by Plane Mirrors

The formation of an image by a plane mirror is illustrated in the figure 14.24 below.

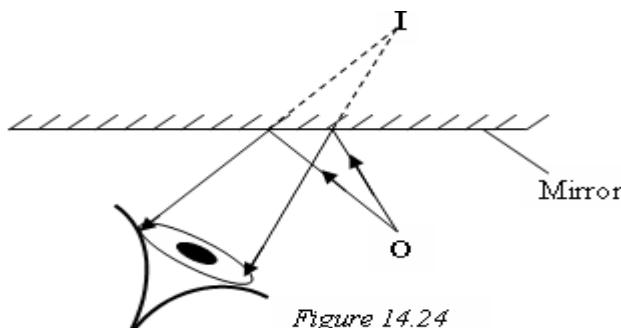


Figure 14.24

Rays of light from a real object O are reflected by the mirror and enter the eye in such a way that they appear to have come from I . It follows that the image of the object is at I . Since the rays appear to have come from I , the image is a *virtual image*.

(b) To show that the Line Joining a Point Object and its Image is Perpendicular to the Mirror

Consider the diagram in figure 14.25 below in which I is the image of point object O , and ON is perpendicular to the mirror.

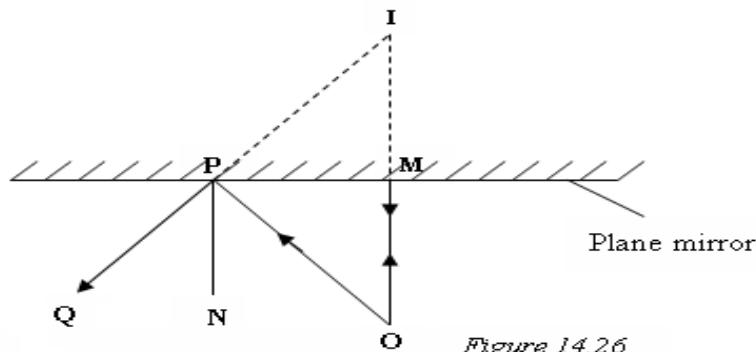


Figure 14.25

It follows from the second law of reflection that a ray incident along OM must be reflected back along MO . Since this reflected ray appears to have come from the image, I , it follows that OMI are collinear (i.e. are on a straight line) and therefore, OI is perpendicular to the mirror. That is to say, the line joining object and image is perpendicular to the mirror (reflecting surface). Also by measurement, $OM = MI$. This shows that the image is as far behind the mirror as the object is in front of it.

(c) Image Location by No-parallax

The method of no-parallax is used in light experiments to locate the images of objects formed in a mirror.

In this method the eye is moved from side to side while viewing a search pin until a position is found for which both the object pin and the image appear to coincide in the same straight line.

(d) Rotation of a Plane Mirror

Consider the diagram below in which a plane mirror M_1M_1'' is rotated through an angle.

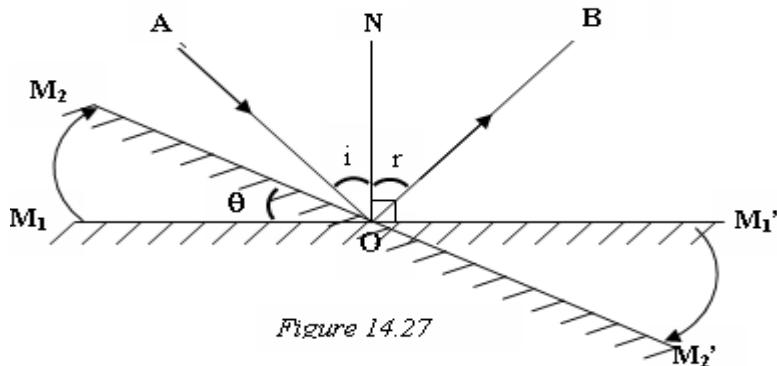


Figure 14.27

M_1M_1' = Position of mirror before rotation

M_2M_2' = Position of mirror after rotation

Angle, θ = Angle of rotation of the mirror

$$= \angle M_1OM_2 = \angle M_1'OM_2'$$

When a plane mirror is rotated through an angle, θ , while keeping the direction of the incident ray along the same path, it can be proved that:

$$\left(\begin{array}{l} \text{Angle of rotation} \\ \text{of the reflected ray} \end{array} \right) = \left(\begin{array}{l} \text{Twice the angle of} \\ \text{rotation of the mirror} \end{array} \right)$$

I.e. *The angle of rotation of the reflected ray = 2θ*

Derivation of the formula

The incident ray, AO, makes an angle, i , with the normal. The angle between the angle of incidence and the angle of reflection, AOB

$$\begin{aligned} &= \text{AON} + \text{NOB} \\ &= i + r \quad \text{But by the second law of reflection } i = r \\ &= i + i \\ &= 2i \quad \dots \dots \dots \quad 1 \end{aligned}$$

If the mirror is rotated through an angle, θ , the normal must also turn through the same angle of rotation, θ . This gives a new angle of incidence ($i + \theta$).

But by the second law of reflection, *the angle of incidence = angle of reflection*.

Therefore, the reflected ray has also turned through an angle ($i + \theta$).

Hence, the new angle between the angle of incidence and the angle of reflection

$$\begin{aligned} &= \text{Angle of incidence} + \text{Angle of reflection} \\ &= (i + \theta) + (i + \theta) \\ &= i + \theta + i + \theta \\ &= 2i + 2\theta \quad \dots \dots \dots \quad 2 \end{aligned}$$

As the incident ray remains in the same path, the angle of rotation of the reflected ray is given by the formula:

$$\begin{aligned}
 (\text{The angle of rotation}) &= \left(\begin{array}{l} \text{Angle between the incident} \\ \text{ray \& the reflected ray} \\ \text{after rotation} \end{array} \right) - \left(\begin{array}{l} \text{Angle between the} \\ \text{incident ray \& the} \\ \text{reflected ray} \end{array} \right) \\
 &= \text{Equation (2)} - \text{Equation (1)} \\
 &= 2i + 2\theta - 2i \\
 &= 2\theta
 \end{aligned}$$

Thus when a mirror is rotated through an angle, θ ,

The angle of rotation of the reflected ray = twice the angle of rotation of the mirror

(e) Properties (Characteristics) of Images formed in Plane Mirrors

The image formed in a plane mirror has the following properties.

- (i) The image is the same size as the object.
- (ii) The image is as far behind the mirror as the object is in front.
- (iii) The image is lateral inverted. See figure 14.28 below.
- (iv) The image is virtual (can not be obtained on film) for a real object.

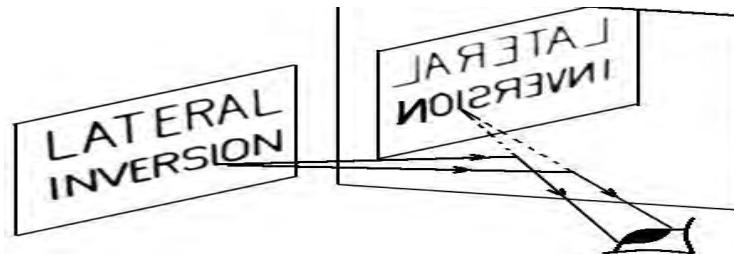


Figure 14.28

(f) Formation of a Real Image from a Virtual Object by a Plane Mirror

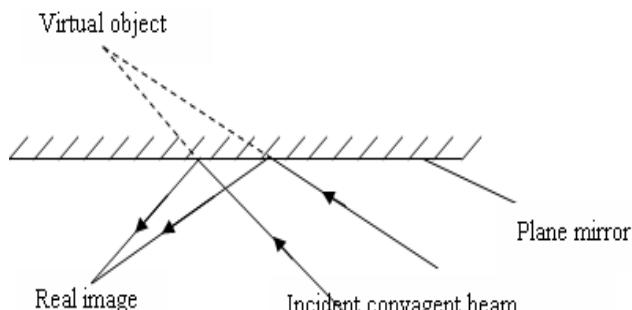


Figure 14.29

We have seen that a plane mirror produces a virtual image of a real object. It follows from the principle of reversibility of light that a plane mirror must produce a real image of a virtual object as shown in the figure 14.29.

(g) The Number of Images formed by Two Mirrors Inclined at an Angle θ

When an object is placed between two mirrors inclined at an angle, θ , a number, n , of images is formed. The value of n is calculated from the formula:

$$n = \left(\frac{360^\circ}{\theta} \right) - 1$$

Examples

Find the number of images of an object placed between two mirrors inclined at:

- (a) 90°
- (b) 60°
- (c) 45°
- (d) 0°

Solution

$$(a) \theta = 90^\circ, n = ?$$

$$(b) \theta = 90^\circ, n = ?$$

$$\text{Using } n = \left(\frac{360^\circ}{\theta} \right) - 1$$

$$n = \left(\frac{360^\circ}{\theta} \right) - 1$$

$$\begin{aligned}
 &= \frac{360^\circ}{90^\circ} - 1 &&= \frac{360^\circ}{60^\circ} - 1 \\
 &= 4 - 1 &&= 6 - 1 \\
 \therefore n &= 3 &\therefore n &= 5
 \end{aligned}$$

(c) $\theta = 45^\circ, n = ?$ (d) $\theta = 0^\circ, n = ?$

$$\begin{aligned}
 n &= \left(\frac{360^\circ}{\theta} \right) - 1 &n &= \left(\frac{360^\circ}{\theta} \right) - 1 \\
 &= \frac{360^\circ}{45^\circ} - 1 &&= \frac{360^\circ}{0^\circ} - 1 \\
 &= 8 - 1 &&= \frac{360}{0} \\
 \therefore n &= 7 &\therefore n &= \infty
 \end{aligned}$$

Formation of Image when the angle of Inclination is zero (i.e. $\theta = 0$)

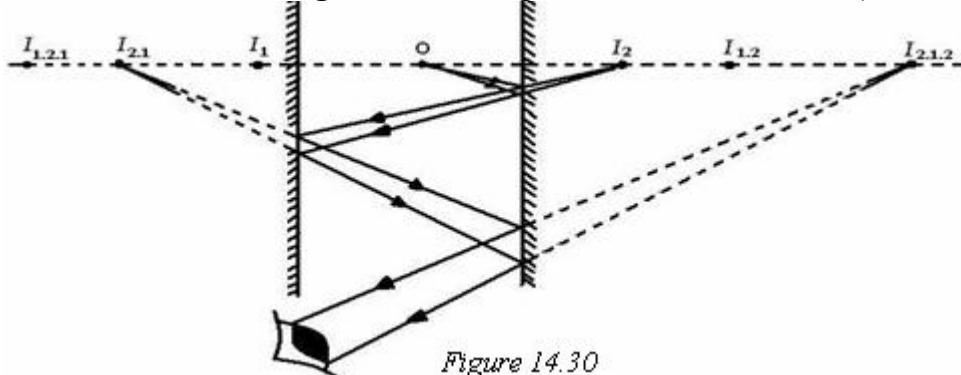


Figure 14.30

14.24 Applications of Reflection in Plane Mirrors

Reflection in plane mirrors is applied in the following:

- (i) Periscope
- (ii) Kaleidoscope
- (iii) Saloons and Dressing rooms for admiration
- (iv) Small vehicles by drivers to see the activities of passengers aboard.
- (v) Bicycles for seeing traffic behind.

(a) **Periscope**, optical instrument for conducting observations from a concealed or protected position.

(i) Structure

A simple periscope consists essentially of reflecting mirrors at opposite ends of a tube with the reflecting surfaces parallel to each other, and at a 45° angle to the axis of the tube.

(ii) Mechanism

A ray of light from an object is successively reflected by the two mirrors inclined at 45° so that the image of an object on the other side of an obstacle is seen by an observer. See figure 14.31 below.

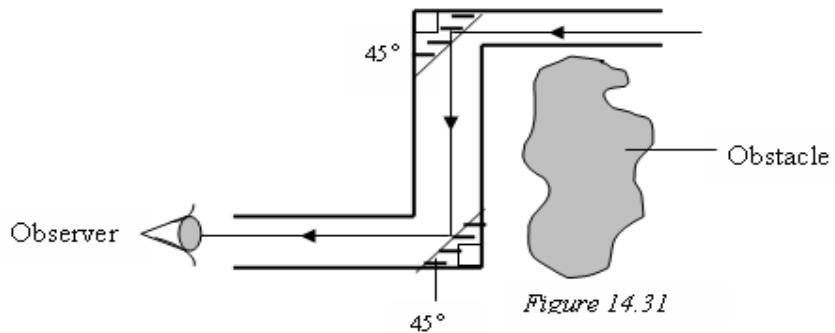


Figure 14.31

Periscopes are commonly used in:

- National theatres,
- Football pitches and
- Submarines

Notes:

- The modern submarine periscope is a larger and more complex instrument.
- It consists of reflecting prisms at the top and bottom of the vertical periscope tube, with two telescopes and several lenses between them, and an eyepiece at the lower end.

Figure 14.32 shows a photograph of a cross section of a submarine periscope

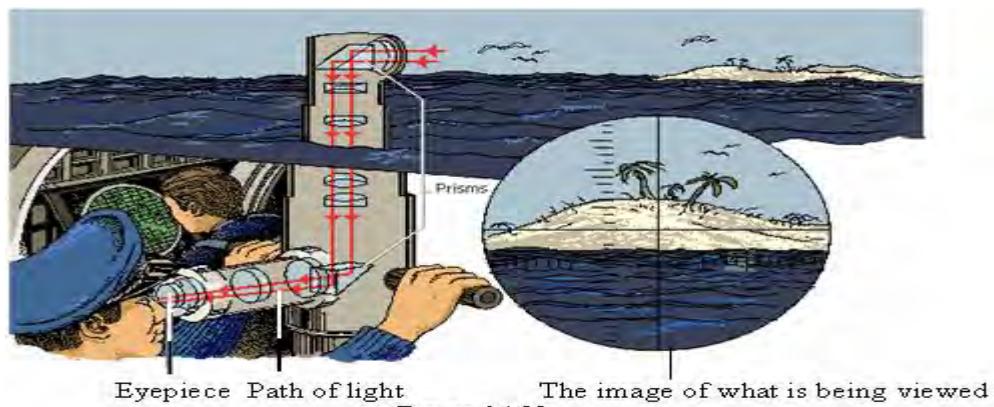


Figure 14.32

(b) **Kaleidoscope**, optical device that uses mirrors and objects to create a variety of colorful patterns.

(i) Structure

The Kaleidoscopes consists of three mirrors inclined at 60-degrees to each other and is fixed inside light proof tube with a small hole in one end. At the bottom of the tube is a ground glass plate to admit light into the tube.

(ii) How it works

Beads, colored glass, pieces of plastic, or mixtures of oil and water contained loosely between two glass or plastic disks is placed at the bottom of the kaleidoscope. Light enters the tube through the translucent glass or plastic, reflecting the images of the mirrors inside the tube giving multiple symmetrical images of objects inside the tube. When the tube is rotated, the tumbling motion of the items inside the compartment changes the patterns seen through the eyepiece.

Self-Check 14.2

1. Light energy is reflected when
 - A. angle of incidence is greater than angle of reflection
 - B. angle of incidence is equal to angle of refraction
 - C. angle of incidence is equal to angle of reflection
 - D. the normal at the point of incidence makes the same angle as the incident ray.

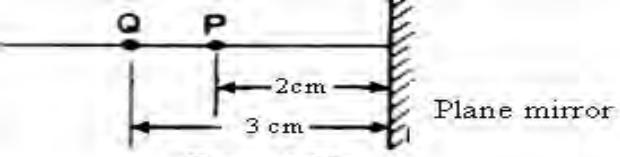
2. When reflection occurs in a plane mirror
 - (i) the image is real, erect and magnified
 - (ii) the angle of reflection is equal to the angle of incidence
 - (iii) the incident ray and reflected ray lie in different planes
 - (iv) the object and the image are at the same distance from the mirror

A. (i), (ii) and (iii) only	B. (ii) and (iv) only
C. (i), (ii) and (iv) only	D. (iv) only

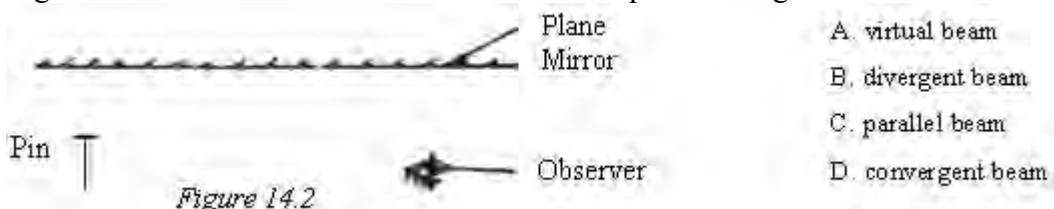
3. An object is placed 30 cm in front of a plane mirror. If the mirror is moved a distance of 6 cm towards the object, find the distance between the object and its image.

A. 24 cm	B. 36 cm	C. 48 cm	D. 60 cm
----------	----------	----------	----------

4. Objects P and Q are placed at distances of 2 m and 3 m respectively from a plane mirror as shown in figure 14.1. Find how far the image of P is from Q.

 <i>Figure 14.1</i>	A. 1 m. B. 4 m. C. 5 m. D. 7 m.
---	--

5. A person observes the image of a pin placed in front of a plane mirror as shown in the figure 14.2 below. The reflected beam from the pin reaching the observer is a



- ### SECTION B
6. a) With the aid of diagrams, distinguish between diffuse and regular reflection.
 - b) (i) State the laws of reflection.
 - (ii) Describe an experiment to verify the laws of reflection of light.

 7. (a) State the applications of reflection in plane mirrors.
 - (b) Describe the structure and the mechanism of the periscope.

REFLECTION IN CURVED MIRRORS

LEARNING OBJECTIVES

By the end of this topic you should be able to:

1. State the types of curved mirrors.
2. Define the terms used in curved mirrors.
3. (i) State the principal rays for constructing ray diagrams.
(ii) Draw and state the properties of images in curved mirrors.
4. Solve problems using the mirror formula.

14.31 Curved Mirrors

Curved mirrors are mirrors whose surfaces are obtained from a hollow transparent sphere or pipe and silvering one of the side.

(a) Types of Curved Mirrors

There are two types of curved mirrors, namely:

- (i) Concave mirror
- (ii) Convex mirror

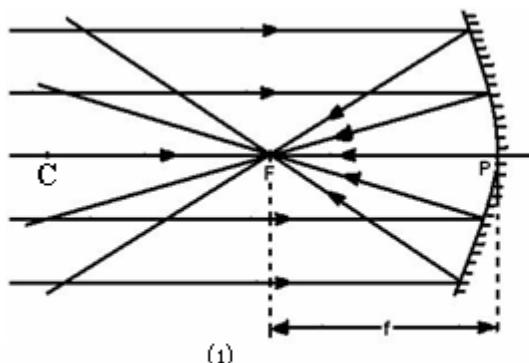


(i) Concave mirror



(ii) Convex mirror

(b) Reflection of parallel beams from curved mirrors



Reflection of parallel beams
from Concave mirrors

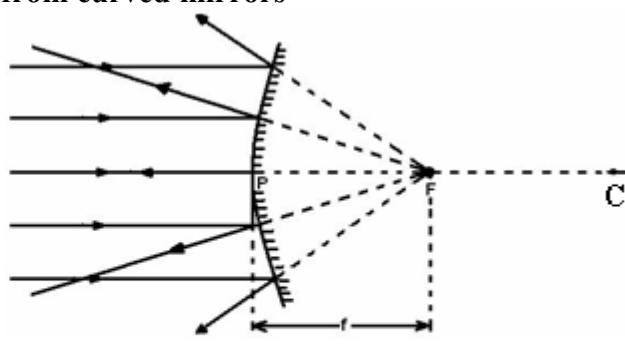


Figure 14.31

Reflection of parallel beams
from Convex

(c) Terms Used

- (i) *The Centre of curvature, C*, is the centre of the sphere of which the mirror is a part.
- (ii) *The radius of curvature, r*, is the radius of the sphere.
- (iii) *The pole, P*, of a mirror is the centre of reflecting surface.
- (iv) *The principal axis* is the imaginary line joining the pole and the centre of curvature produced in each case.
- (v) *The principal focus, F*, is the point on the principal axis through which rays parallel and close to the principal axis pass after reflection (for the case of concave mirror) or from which the rays appear to come (for the case of convex mirror).

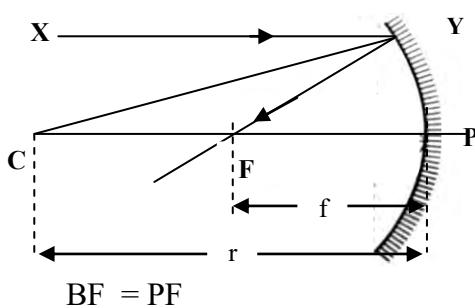
(vi) The focal length, f , is the distance between the principal focus and the pole of the mirror.

Notes:

- C and f of a concave mirror
- C and f of a convex mirror

- are real (i.e. are in front of the mirror).
- are virtual (i.e. are behind the mirror).

(d) The Relation between f and r



From the laws of reflection

$$\angle ABC = \angle CBF$$

But $\angle ABC = \angle BCF$ (alternate angles)

$$\angle CBF = \angle BCF$$

$\therefore BF = FC$ (sides of an isosceles triangle)

Now B is very close to P

$$PF = FC$$

$$\therefore f = \frac{r}{2} \quad \text{or} \quad r = 2f$$

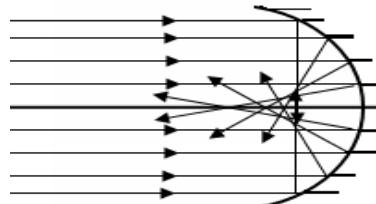
(e) Mirrors of Large aperture

If a parallel beam parallel to the principal axis is incident on to a concave mirror, the rays which are close to the principal axis are reflected to pass through the principal focus. While those which are not close to the principal axis are reflected in such a way that they subsequently cross the axis at points which are closer to the mirror than its principal focus. The reflected rays intersect to form a surface called *caustic surface*.

Examples of bright caustic surface can be seen:

- (i) on surfaces of liquids contained in vessels of circular cross section
e.g. tea surface on tea surface.
- (ii) at the bottom of clean containers such as cups, source pans, basins etc.

Diagram showing formation of Caustic Surface



(i) Parabolic Mirror

A parabolic mirror has the property of reflecting the light source placed at the focal point parallel to the principal axis with undiminished intensity.

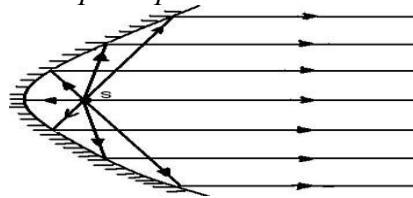


Figure 14.32

(ii) Uses of Parabolic Mirrors

Because of their property of reflecting light rays from a lamp placed at the focus parallel with a diminishing intensity, they are used as search-light reflectors.

14.32 Construction of ray diagrams

The ray diagrams for curved mirrors are drawn by using any two of the principal rays. The images formed are described by using the technical terms.

(a) Terms used to describe images formed in Curved Mirrors

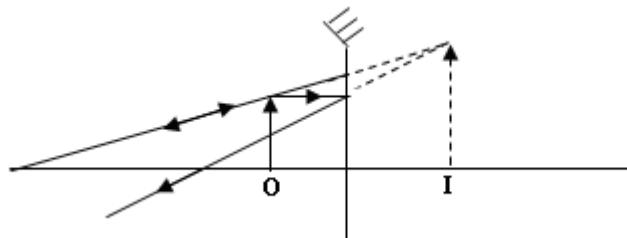
- | | |
|-------------------|---|
| (i) Real obtained | - Formed by intersection of actual rays and can be on screen. |
| (ii) Virtual | - when not actual rays of light intersect after reflection |
| (iii) Inverted | - Upside down |
| (iv) Diminished | - Smaller than the object and |
| (v) Magnified | - Bigger/larger than the object. |
| (vi) Erect | - Upright |

(b) The principal rays for a Concave Mirror

1. A ray parallel to the principal axis is reflected through the focal point.
2. A ray passing through the focal point is reflected parallel to the principal axis.
3. A ray passing through the centre of curvature is reflected back along the same path.

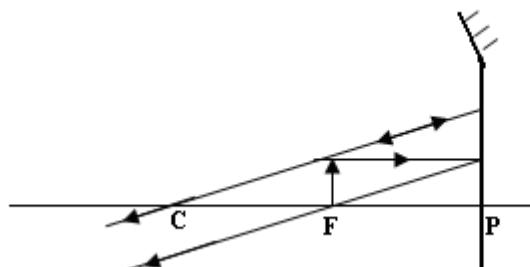
Ray diagrams for concave mirror for various positions of object

(i) Object between F and P



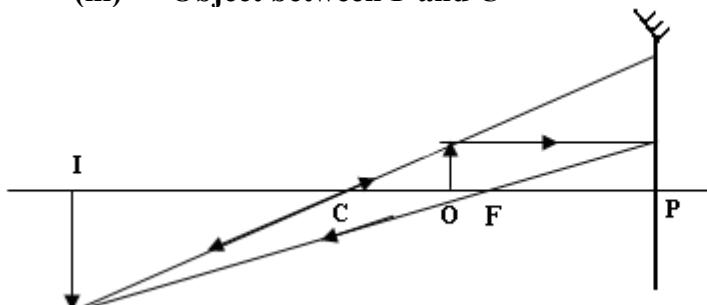
- The nature of the image is
- erect
 - magnified
 - Virtual
 - Behind the mirror

(ii) Object at F



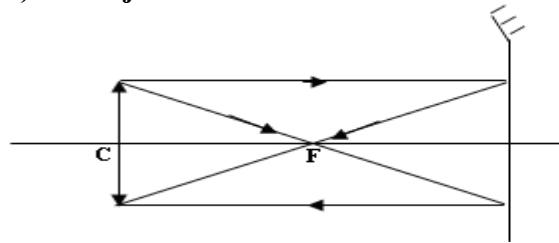
- The nature of the image is
- real
 - at infinite

(iii) Object between F and C



- The nature of the image is
- real
 - magnified
 - Inverted
 - Beyond C

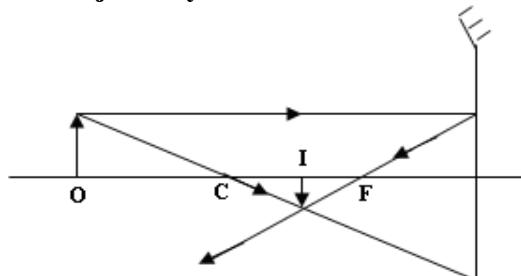
(iv) Object at C



The nature of the image is

- Real
- Same size as object
- Inverted
- At C

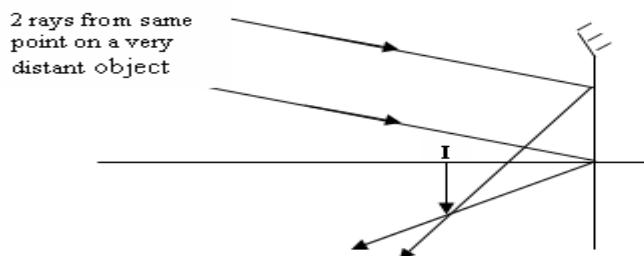
(v) Object beyond C



The nature of the image is

- Real
- Inverted
- Diminished
- Between C and F

(vi) Object at infinite



The nature of the image is

- Real
- Inverted
- Diminished
- At F

(c) The principal rays for a Convex Mirror

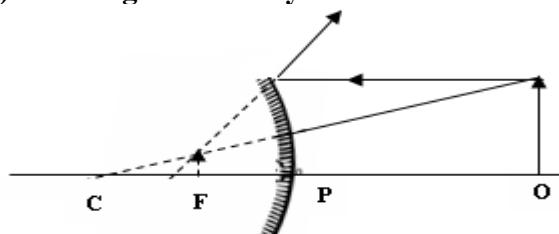
1. A ray parallel to the principal axis is reflected to appear as though it passed through the focal point in other words the reflected ray, if produced, would pass through the focal point.
2. A ray which if produced would pass through the focal point, is reflected parallel to the principal axis.
3. A ray which if produced, would pass through the centre of curvature, is reflected back along the same path.

Ray diagrams for convex mirror

For any position of object in front of the mirror, the nature of the image is:

- Erect
- Virtual
- Diminished
- Between P and F

(d) Image formed by a Convex Mirror



14.33 The Mirror Formula

The mirror formula is given by the relation:

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

Since $r = 2f$, the mirror formula can also be written as:

$$\frac{1}{u} + \frac{1}{v} = \frac{2}{r}$$

Where: $\left. \begin{array}{l} u = \text{object distance} \\ v = \text{image distance} \\ f = \text{focal length} \\ r = \text{radius of curvature} \end{array} \right\} \text{all measured from the pole of the mirror}$

In order to distinguish between real and virtual image and the two types of curved mirrors, it is necessary to employ a *sign convention*.

Sign Convention

Real-is-Positive Convention

1. All distances are measured from the mirror as the origin.
2. Distances of real objects and images are positive.
3. Distances of virtual objects and images are negative.
4. Focal length, f , for concave mirror is positive and negative for convex mirror.

Examples

1. An object 1 cm tall is placed 30 cm in front of a convex mirror of focal length 20 cm. Find (i) the position (ii) the size of the image formed.

Solution: $h_o = 1 \text{ cm}$, $h_i = ?$, $u = 30 \text{ cm}$, $v = ?$, $f = -20 \text{ cm}$ (convex mirror)

$$(i) \quad \frac{1}{u} + \frac{1}{v} = \frac{1}{f}$$

$$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{-20} - \frac{1}{30} = \frac{-3 - 2}{60} = \frac{-5}{60} = -\frac{1}{12} \text{ cm}$$

The minus sign means that virtual image is formed 12 cm behind the mirror

$$(ii) \quad \frac{\text{Image Height}}{\text{Object height}} = \frac{\text{Image distance from the mirror}}{\text{Object distance from the mirror}}$$

$$\frac{h_i}{h_o} = \frac{v}{u} \Rightarrow \frac{h_i}{1} = \frac{12}{30} \quad \therefore h_i = 0.4 \text{ cm}$$

2. A small object is placed on the principal axis of a convex mirror of radius of curvature of 20 cm. Determine the position of the image when the object is 15 cm from the mirror.

Solution: $r = 20 \text{ cm}$, $u = 15 \text{ cm}$, $v = ?$, $f = \frac{r}{2} = \frac{20}{2} = -10 \text{ cm}$ (convex mirror)

$$, \quad \frac{1}{u} + \frac{1}{v} = \frac{1}{f} \Rightarrow \frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{-10} - \frac{1}{15} = \frac{-3 - 2}{30} = \frac{-5}{30} \quad \therefore v = -6$$

cm

The minus sign means that virtual image is formed 6 cm behind the mirror

3. A concave mirror of radius of curvature 20 cm forms an erect image 30 cm from the mirror and 5 cm tall.

- Find (i) Position and
(ii) Size of the object.
(iii) Hence or otherwise, find the magnification

Solution: $h_i = 5 \text{ cm}$, $u = ?$, $h_o = ?$, $v = -30 \text{ cm}$, $m = ?$, $r = 20 \text{ cm}$,

$$f = \frac{r}{2} = \frac{20}{2} = 10 \text{ cm} \text{ (concave mirror)}$$

$$\begin{aligned} \text{(i)} \quad & \frac{1}{u} + \frac{1}{v} = \frac{1}{f} \\ \Rightarrow \quad & \frac{1}{u} = \frac{1}{f} - \frac{1}{v} = \frac{1}{10} - \frac{1}{-30} = \frac{1}{10} + \frac{1}{30} = \frac{3+1}{30} = \frac{4}{30} \therefore u = 7.5 \text{ cm} \\ \text{(ii)} \quad & \frac{\text{Image Height}}{\text{Object height}} = \frac{\text{Image distance from the mirror}}{\text{Object distance from the mirror}} \\ & \frac{h_i}{h_o} = \frac{v}{u} \Rightarrow \frac{5}{h_o} = \frac{30}{7.5} = \frac{5 \times 7.5}{30} \therefore h_o = 1.25 \text{ cm} \\ \text{(iii)} \quad & m = \frac{h_i}{h_o} = \frac{5}{1.25} = 4 \\ \text{or} \quad & m = \frac{v}{u} = \frac{30}{7.5} = 4 \end{aligned}$$

14.34 Applications of Curved Mirrors

Curved mirrors are applied in various fields depending on the type of the mirror.

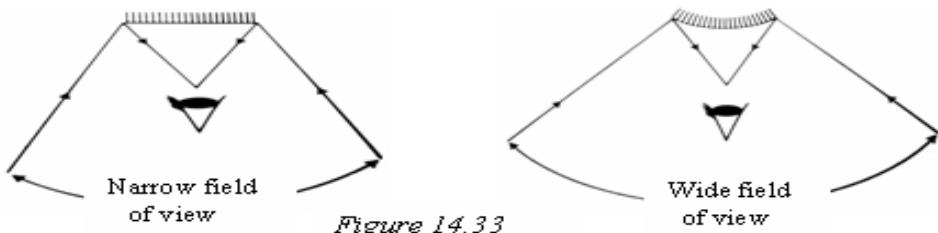
(a) Convex Mirror

Convex mirrors are used in:

- (i) locomotives as driving mirrors for seeing traffic behind.
- (ii) They are used to observe the activities of customers in super markets for.

They are preferred to plane mirrors and concave mirrors for this purpose because of the following advantages.

- (i) They form erect image
- (ii) They have wider field of view.



However, despite the above advantages they have one disadvantage. In that they form diminished images making them to appear as though they are farther than their actual distances from the mirror, hence, leading to accidents.

(b) Concave Mirrors

Concave mirrors are used as:

- (i) dentist's mirror,
- (ii) shaving mirror and

- (iii) Reflectors in - telescopes for seeing far objects such as stars and planets.
 - search lights, car head lights, torch light.

Advantages

For uses (i) and (ii), the image formed is:

- erect and
- magnified.

- Note:** 1. *In uses (i) and (ii), the mirror is held so that the object distance is less than the focal length of the mirror.*
 2. *They are usually made of plastic or metal.*

Self-Check 14.3

1. A concave mirror can be used as a shaving mirror because when an object is placed between the focus and the pole, the image formed is,

A. magnified, virtual and erect	B. magnified, real and inverted
C. diminished, real and inverted	D. diminished, virtual and erect
2. Which of the following information is true about the concave and convex mirrors?

	Concave mirror	Convex mirror
A	Converges light	Diverges light
B	Diverges light	Converges light
C	Refractions light	Reflects light
D	Has a wide field of view	Has a narrow field of view

3. The focal length of a concave mirror is the
 - A. distance between the pole of the mirror and the focal point
 - B. distance between the center of curvature and the mirror
 - C. distance between the object and the image
 - D. diameter of the mirror
4. (a) With the aid of the diagram explain why a parabolic mirror is most suitable for use in car head lights.
 (b) List three uses of a concave mirror.
5. (a) Draw a ray diagram to show the formation of an image of an object O placed in front of a convex mirror shown in the figure below. F is the principal focus of the mirror.
 (b) A convex mirror whose radius of curvature is 30 cm forms an image of a real object which has been 20 cm from the mirror.
 Calculate: (i) The position of the image
 (ii) The magnification produced.
 (c) Give reasons for use of convex mirrors in vehicles.

14.4 REFRACTION OF LIGHT

LEARNING OBJECTIVES

By the end of this topic you should be able to:

1. Define the term refraction.
2. State the laws of refraction.
3. (i) Define refractive index, n of a material.
(ii) Describe an experiment to determine the refractive index of a glass block.
4. (a) (i) Define the term critical angle.
(ii) Explain total internal reflection.
(b) State (i) the applications of internal reflection.
(ii) Some effects due to total internal reflection.

14.4.2 Refraction

Refraction is the change in the direction of light when it travels from one medium to another.

(a) Laws of Refraction

Law I States that:

The incident ray and refracted ray are on the opposite sides of the normal at the point of incidence, and all the three are in the same plane.

Law II States that:

At any boundary between any two given media, the ratio of the sine of the angle of incidence to the sine of the angle of refraction is constant for rays of particular wavelength.

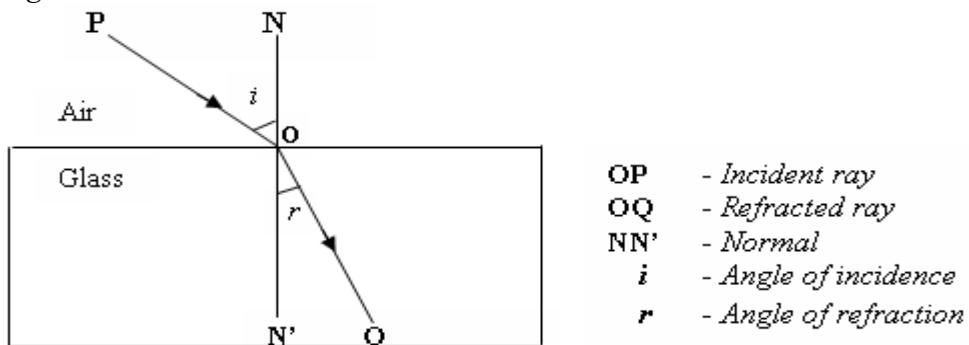


Figure 14.41

(b) (i) Refractive Index, n

It follows from the second law of refraction that:

$$\frac{\sin i}{\sin r} = \text{Constant}$$

The ratio is known as the relative refractive index, ${}_1n_2$, of the two media. Therefore,

$$\text{Snell's law can be written as: } \frac{\sin i}{\sin r} = {}_1n_2$$

(ii) Absolute Refractive Index

The absolute refractive index of a medium is defined as

$$n = \frac{\text{Speed of light in vacuum}}{\text{Speed of light in medium}}$$

By analogy, the absolute refractive index, n , of medium 1 is given by

And the absolute refractive index, n_1 , of medium 2 is given by

Dividing equation 1 by 2 we have: $\frac{n_1}{n_2} = \frac{\text{Speed of light in vacuum 2}}{\text{Speed of light in medium 1}}$

$$\frac{n_2}{n_1} = \frac{\text{Speed of light in vacuum 1}}{\text{Speed of light in medium 2}}$$

$$\frac{n_2}{n_1} = {}_1n_2$$

$$\text{Therefore, } \frac{\sin i}{\sin r} = \frac{n_2}{n_1} \quad \text{Or} \quad n_1 \sin i = n_2 \sin r$$

Note: The absolute refractive index of vacuum is equal to 1 and that of air at normal atmospheric pressure and 20°C is 1.0003. This difference is so small that it is normally ignored; hence the absolute refractive index of air is taken to be 1 as that of vacuum.

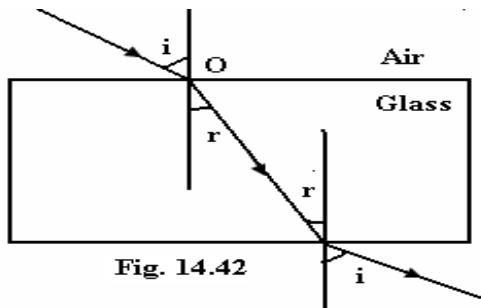
From the equation $n_1 \sin i = n_2 \sin r$

It follows that:

If (i) $n_2 > n_1$, the ray bends towards the normal as it enters the glass and the angle $i > r$.

(ii) $n_1 > n_2$, the ray bends away from the normal as it leaves the glass., then $i < r$.

Thus when light travels from a medium into one which has a greater absolute refractive index, it bends towards the normal as shown in figure 14.42 below.



Note:

- ❖ If the glass block has parallel sides, the emergent ray is parallel to the incident ray, but it is laterally displaced..
 - ❖ This means that the ray is traveling in the same direction but it has been shifted sideways when it emerges.
 - ❖ When the incident ray meets a refracting surface at a right angle, it is not refracted at all.

Experiment 14.41

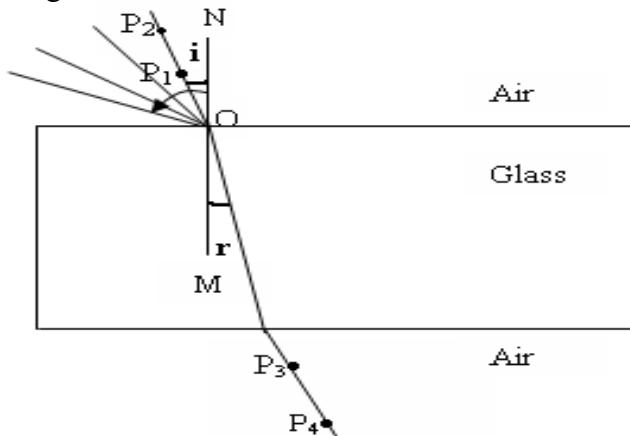
To determine the refractive index, n , of a glass block

Apparatus

A protractor, 4 optical pins, 4 office pins, a white piece of paper and a drawing board

Procedure:

- Fix a white piece of paper on a drawing board using the 4 office pin.
- Trace accurately the outer margin of the glass block on the paper.
- Using a protractor, draw normal NM, in a position shown in figure 14.4, and measure from it several angles of incidence, i.



- Accurately aim the incident ray at O, and for each angle of incidence mark the directions of the emergent ray by fixing 2 pins P_3 and P_4 .
- Remove the glass block.
- Draw in the emergent and refracted rays.
- Measure the angle of refraction, r.
- Replace the glass block.
- Repeat the procedures (d) to (g) for values of $i = 30^\circ, 45^\circ$ and 60° .
- Enter the values of the angles i and r in table 14.41 including the values of $\sin i$ and $\sin r$.

Table 14.41

i/degree	r/degree	$\sin i$	$\sin r$	$\frac{\sin i}{\sin r}$
15		0.26		
30		0.50		
45		0.71		
60		0.87		

- Calculate the mean value of $\frac{\sin i}{\sin r}$.

Note: If the experiment is accurately performed, the mean value for air to glass is about 1.5.

Values of n for some common media

Material	Absolute refractive index n
Air	1 (1.0003)
Glass - Flint	1.65
- Crown	1.52
Water	1.33

Table 14.41

14.43 Total Internal Reflection and Critical Angle

(a) Total Internal Reflection

When light travels from an optically more dense medium to an optically less dense medium (e.g from glass to air), it undergoes both refraction and weak reflection.

Consider a ray PQ incident in glass-air boundary shown in figure 14.43 below.

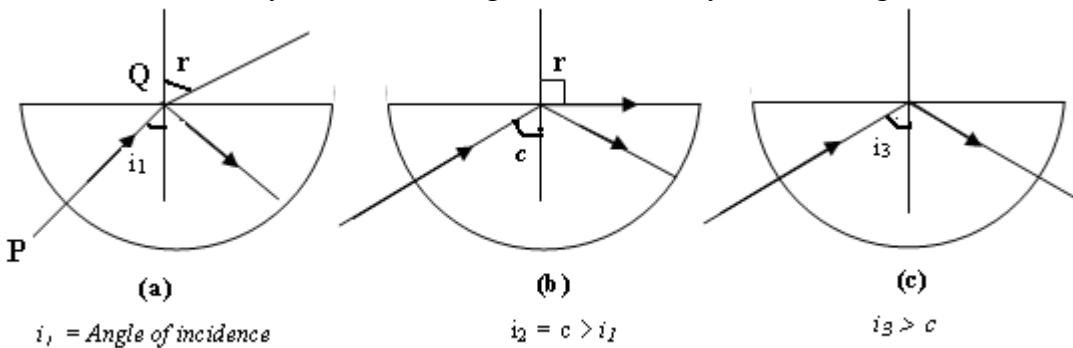


Figure 14.43

When the angle of incidence, i , is gradually increased, the angle of refraction, r , also increases and the weak reflected ray becomes stronger and stronger. A point is reached for which the angle of incidence is such that the angle of refraction is 90° as in diagram (b). The angle of incidence for which the angle of refraction is 90° is called *critical angle*, c .

If the angle of incidence, i , becomes greater than the critical angle ($i > r$), the light ray is totally reflected back into the medium as shown in diagram (c). This is known as **Total Internal Reflection**.

(b) Critical Angle, c

Critical angle of a medium is the angle of incidence when a ray passes from optically denser medium into a less dense optical medium at an angle of refraction of 90° .

(c) The Relationship between c and n

Consider the diagram below.

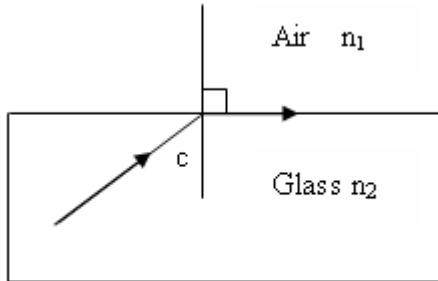


Figure 14.44

Applying $n \sin i = \text{Constant}$

at the glass-air boundary we have :

$$n_1 \sin 90^\circ = n_2 \sin c \quad \text{But } \sin 90^\circ = 1$$

$$n_1 \times 1 = n_2 \sin c$$

$$\sin c = \frac{n_1}{n_2} \quad \text{But } n_1 = 1$$

$$\therefore \sin c = \frac{1}{n_2}$$

Where: c = Critical angle of glass for a glass-air boundary $\approx 42^\circ$

n = the refractive index of the medium in which c is found.

Refractive indices and Critical Angles for Crown glass and Water

Material	Refractive index, n	Critical angle, c
Crown glass	1.5	42°
Water	1.33	49°

Table 14.42

Worked Examples

1. The refractive index of glass is 1.5. Find the critical angle.

Solution: $n = 1.5, c = ?$

$$\text{Substuting in } \sin c = \frac{1}{n} = \frac{1}{1.5} = 0.6667$$

$$c = \sin^{-1} 0.6667$$

$$\therefore c = 41.8^\circ$$

2. A ray of light is incident in air at an angle of 30° . Find the value of angle of refraction, r , if the refractive index is 1.5.

Solution $n_g = 1.5, n_a = 1, i = 30^\circ, r = ?$

Substituting in

$$n \sin i = \text{constant}$$

$$n_a \sin i = n_g \sin r$$

$$1 \times \sin 30^\circ = 1.5 \times \sin r$$

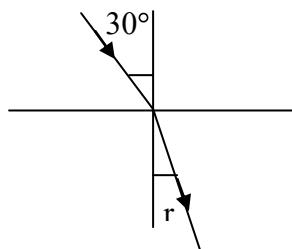
$$1 \times 0.5 = 1.5 \times \sin r$$

$$\sin r = \frac{0.5}{1.5}$$

$$= 0.3333$$

$$r = \sin^{-1} 0.3333$$

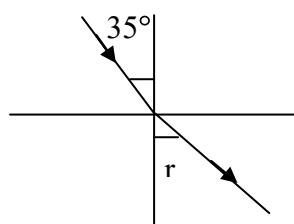
$$\therefore r = 19.47^\circ$$



3. (a) Draw a ray diagram for a yellow light traveling from glass to air at an angle of 35° .
- (b) Find: (i) The angle of refraction.
(ii) The critical angle of the glass.
(iii) The angle of deviation. ($n_g = 1.55$)

Solution:

(a)



(b) (i) $n_g = 1.55, n_a = 1, i = 35^\circ, r = ?$

$$n \sin i = \text{constant}$$

$$n_a \sin i = n_g \sin r$$

$$1.55 \times \sin 35^\circ = 1 \times \sin r$$

$$1.55 \times 0.5736 = \sin r$$

$$\sin r = 0.8891$$

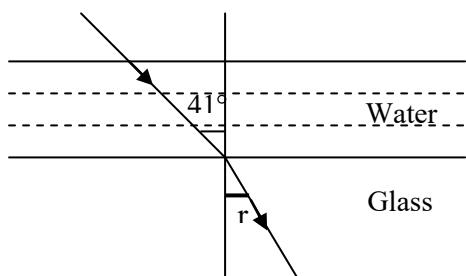
$$r = \sin^{-1} 0.8891$$

$$\therefore r = 62.76^\circ$$

(ii) $n = 1.55, c = ? \quad \sin c = \frac{1}{n} = \frac{1}{1.55} = 0.6452 \Rightarrow c = \sin^{-1} 0.6452 = 40.18^\circ$

(iii) Angle of deviation, $d = r - i = 62.76^\circ - 35^\circ = 27.76^\circ$

4. (a) What is meant by refractive index of a medium?



- (b) A ray of light is incident on a water-glass boundary at an angle of 41° as shown in the diagram below. Calculate the angle of refraction r , if the refractive indices of water and glass are 1.33 and 1.50 respectively.

Solution: (a) *See from the notes.*

(b) $n_g = 1.50, n_w = 1.33, i = 41^\circ, r = ?$
 $n \sin i = \text{constant}$

$$n_w \sin i = n_g \sin r$$

$$1.33 \times \sin 41^\circ = 1.50 \times \sin r$$

$$1.33 \times 0.6561 = 1.5 \sin r$$

$$\sin r = \frac{1.33 \times 0.6561}{1.5}$$

$$= 0.5817$$

$$r = \sin^{-1} 0.5817$$

$$\therefore r = 35.57^\circ$$

14.44 Applications of Total Internal Reflection

(a) The fish's eye view

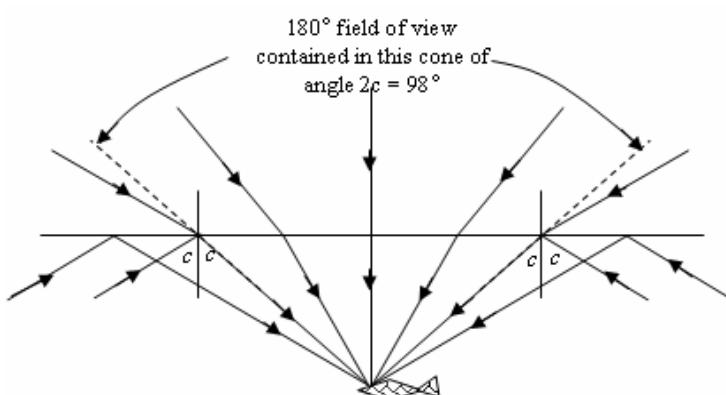


Fig. 14.45 The fish's eye view

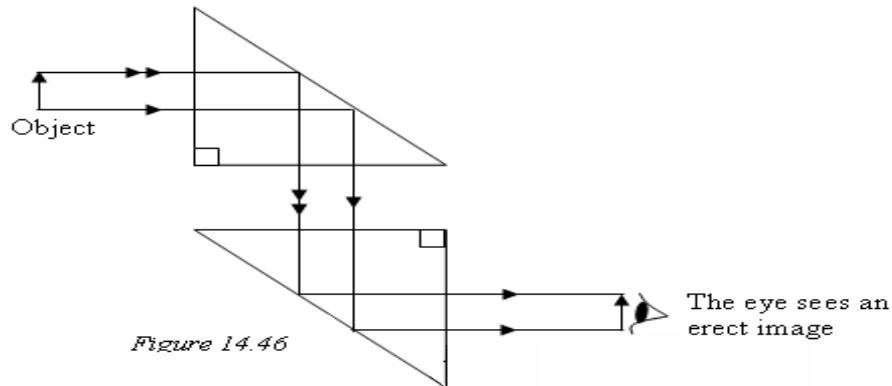
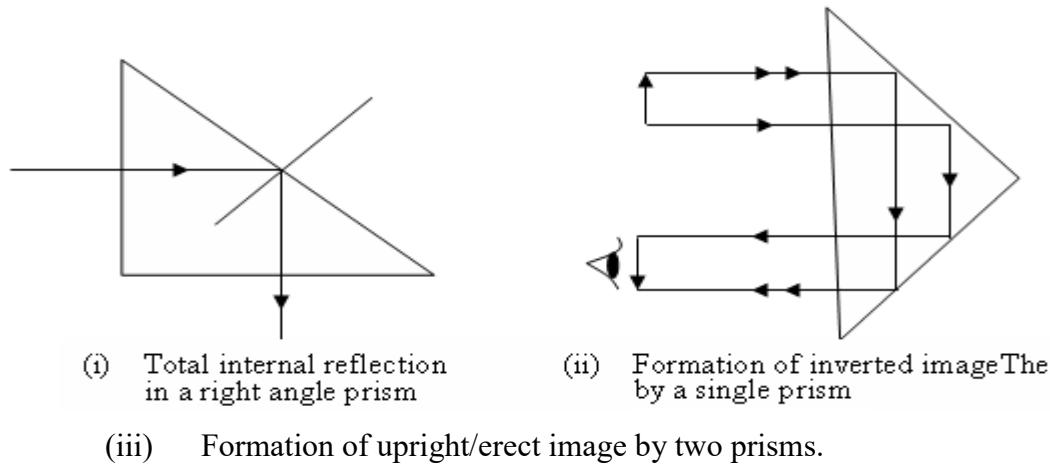
The fish has a full view of everything above or in water at whatever depth, provided that the water surface is unruffled. It enjoys a 180° field of view apparently all squeezed into a cone of angle about 98° (i.e. twice the critical angle for water).

Outside this range the fish sees objects in water and on the bottom which are mirrored in the surface of the water by total internal reflection.

(b) Total Internal Reflection in prisms

The critical angle of glass-air boundary is about 42° . Thus, whenever light which is traveling in glass is incident on such a boundary at an angle greater than 42° , it undergoes total internal reflection leading to formation of upright or inverted image as shown in figure 14.46 below.

Note: That in the diagrams when an incident ray or refracted ray meets the glass at right angle, it is not refracted.



Notes: *Totally reflecting prisms find applications in optical instruments such as binoculars and periscopes used in submarines and opera theaters.*

Figure 14.47 showing arrangement of prisms in a binocular

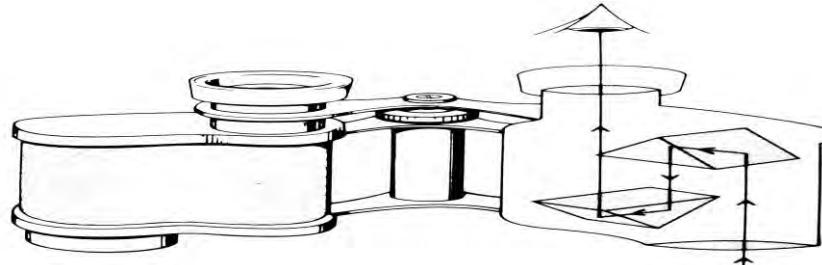


Figure 14.47

They are preferred to plane mirrors in periscopes and binoculars because they have their advantages over plane mirrors.

(c) Advantages of glass prisms over plane mirrors

- (i) All the incident light is reflected when total internal reflection occurs in glass prism whereas mirrors absorb some of the incident light.
- (ii) The finite thickness of glass in front of the reflecting surface produces ghost, blurred, image.

14.45 The Principle of reversibility of light

States that: *The path of light ray is reversible.*

Consider the incident ray PO in figure 14.48. The ray undergoes refraction towards the

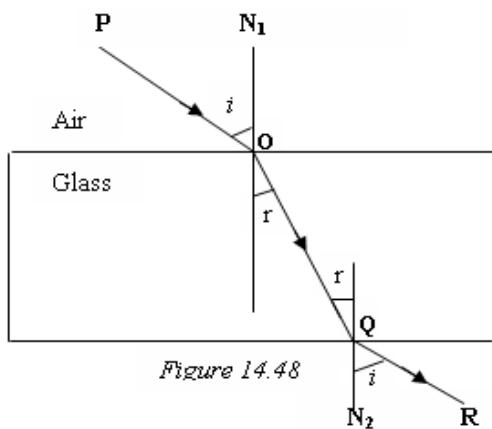


Figure 14.48

Thus for a ray passing from air to glass

3. The ray undergoes refraction towards the normal at O giving a refracted ray OQ. The refracted ray OQ further undergoes refraction at Q giving the second refracted ray QR.

According to the principle of reversibility of light, if the direction of the light ray is reversed, the ray traces the same path in the opposite direction.

The refractive indices for a ray passing from air to glass and from glass to air may be distinguished by using symbols n_g and n_a respectively.

$$\frac{\sin r}{\sin i} = g n_a$$

Equating equation (1) to equation (2), we have: $a \mathbf{n}_g = \frac{1}{\mathbf{n}_a}$ or $\mathbf{g} \mathbf{n}_a = \frac{1}{\mathbf{n}_g}$

(a) Real and apparent depth

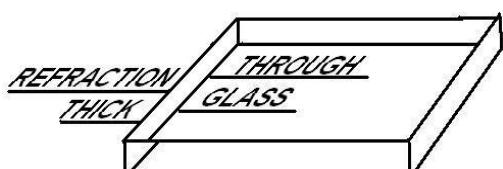


Figure 14.49

Due to refraction, a thick glass block appears to be only two-thirds of its real thickness when viewed vertically above. See figure 14.49

Explanation

Light rays from the object undergo refraction at the medium-air boundary. As the rays from optically more dense medium pass in to a less dense medium they are refracted away from the normal. On entering the eye, the eye automatically assumes the rectilinear propagation of light and then locates the position of the image above the actual point.

(b) Refractive Index related to Real and Apparent depth

Consider the diagram in figure 14.50 (b) on page 242 in which OBC is a ray very close to the normal which enters the eye from a point O at the bottom of the slab. The emergent ray BC appears to be coming from a virtual image I, so that AI is the apparent depth of the slab.

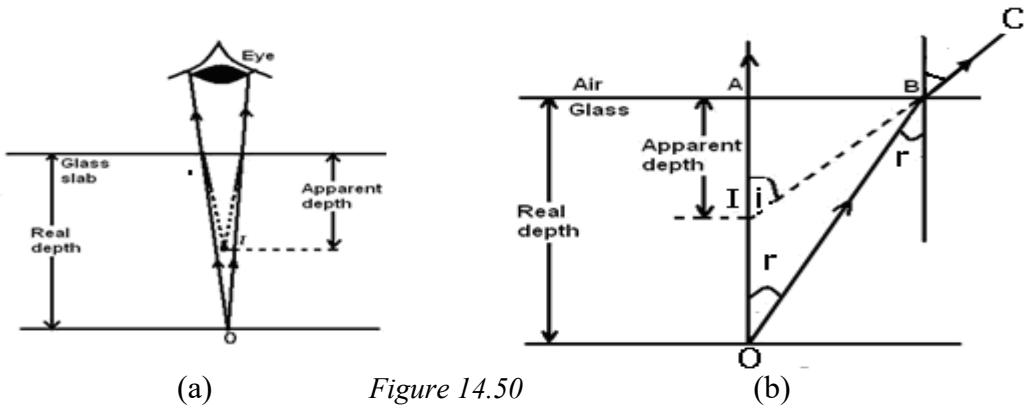


Figure 14.50

By using the principle of reversibility of light the refractive index of glass is given by

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

But $\angle AIB = i$ (corresponding angles) and $\angle AOB = r$ (alternate angles)

Substituting for i and r in the above formula, we have:

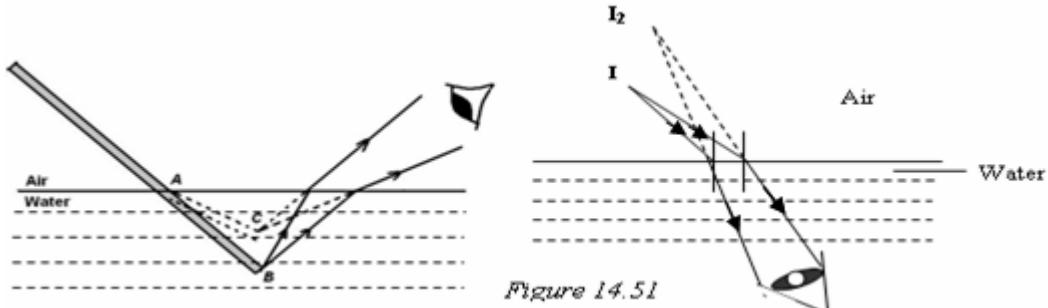
$$n = \frac{\sin \angle AIB}{\sin \angle AOB} = \frac{AB}{BI} \div \frac{AB}{BO} = \frac{BO}{BI} \quad \text{Since B is very close to A,}$$

$$n = \frac{AO}{AI}$$

$$\therefore n = \frac{\text{Real depth}}{\text{Apparent depth}}$$

(c) Some effects of Refraction

- (i) Ponds, pools and liquids in containers appear shallower than their actual depths.
- (ii) A stick or straight object appears bent when partly immersed in a liquid as shown in figure 14.51 below.



Note:

- (i) If an object is viewed from optically denser medium e.g water, the effect described above is reversed, thus the object appears farther than its actual distance.
- (ii) The sun and stars seem to be higher than they really are. This is because light from them is refracted when it leaves the vacuum of the space and enters the atmosphere.
- (iii) The sun and moon appear bigger than their normal sizes when rising or setting.
- (iv) Radio waves: Under total internal reflection in the ionosphere region and are reflected back to the earth surface.

(iv) Mirages

A mirage is a realistic image of an object that is either totally imaginary or that appears to be in a location other than the true one.

Mirages are formed in hot or cold places due to total internal reflection.

Light rays from an object are successively refracted at the boundaries of air layers of different densities until a point is reached when the ray is totally internally reflected. Since the eye interprets that light travels in a straight line, then the image of an object appears upside down. If the rays are from the space above, it appears as a pool of water.

Diagrams showing formation of mirages

Mirage in hot region

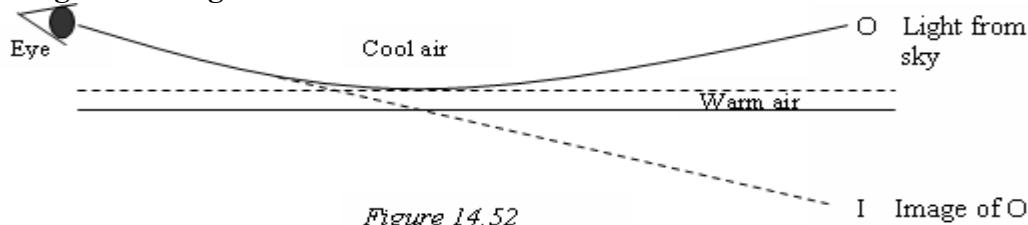


Figure 14.52

Mirage in cold region

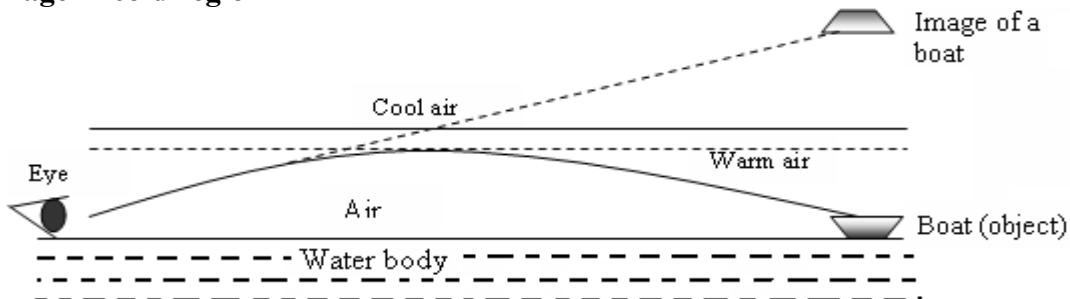
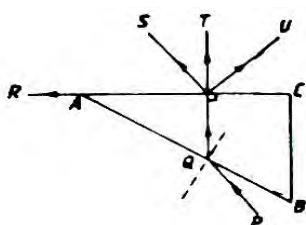


Figure 14.53

In the case of a mirage at sea or ocean during the day, the denser layers of air are next to the cool surface of the water, and the reflection takes place from the upper atmosphere. Thus the object appears distorted, elongated, inverted, and suspended in the air, producing a so-called *looming effect*.

Self-Check 14.4

1. A stick with one end immersed in water appears bent on the water surface because
A. diffraction B. reflection C. interference D. refraction
2. A ray of light PQ is incident on the face AB of a glass prism ABC as shown in the diagram in the figure below.



Which one of the rays R, S, T, U indicates the correct direction of the emergent ray?

- A. R
- B. S
- C. T
- D. U

Figure 14.54

3. Which one of the following is a wrong formula in the study of optics?
A. $m = \frac{u}{v}$ B. $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$ C. $\text{Sine } c = \frac{1}{n}$ D. $m = \frac{v}{u}$
4. A ray of light is incident on a glass block at an angle of incidence of 45° and the angle of refraction 21° . Find the critical angle of the glass
A. 42.0° B. 40.0° C. 33.8° D. 35.0°

5. Total internal reflection occurs when
- the incident angle is equal to the critical angle
 - light travels from a dense to a less dense medium
 - light travels from a less dense to a dense medium
 - the incident angle in a dense medium is greater than the critical angle
- A. (i), (ii) and (iii) only B. (ii) only
 C. (iv) only D. (ii) and (iv) only

SECTION B

6. (a) State the laws of refraction.
 (b) (i) What is meant by refractive index?
 (ii) Describe an experiment you would use to measure the refractive index of glass using a glass block.
 (c) (i) Light traveling in water is incident at a water-air surface at 30° . What is the angle of refraction if the refractive index from air to water is 1.33?
 (3marks)
 (ii) The refractive index of a glass block is 1.62. Calculate its critical angle.
7. (a) Study the diagrams in figure 14.55 (a) and (b) below.

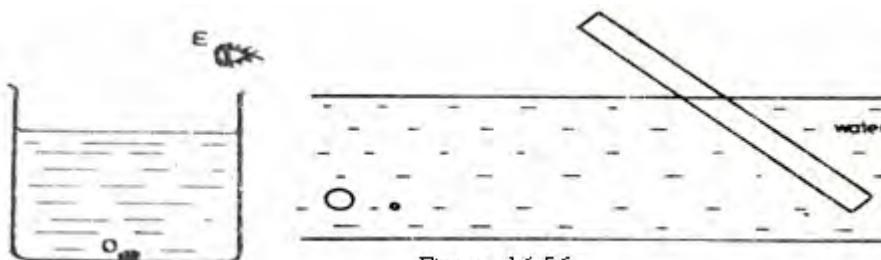


Figure 14.56

Copy and complete by drawing rays to show how the object appears to an observer at E and how the stick will appear to

observer at O.

8. The diagram above shows rays of light in a semi-circular glass block.

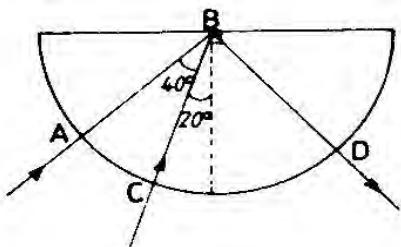


Figure 14.57

- (a) Explain why ray AB:
 (i) is not refracted on entering the block at A.
 (ii) takes path BD on reaching B.
 (b) Ray CB is refracted at B.
 Calculate the angle of refraction. (Refractive index of glass = 1.5)

9. (a) What is meant by the following terms?
 (i) Critical angle (ii) Total internal reflection
 (b) (i) State two conditions for total internal reflection.
 (ii) One application of total internal reflection.
 (c) Draw a diagram to show how a fish in water attains a wide field of view.
10. A ray of light is incident in air on the surface of a glass block. If the angle of incidence is 30° calculate:
 (a) the angle of refraction.
 (b) the amount by which the ray is deviated on entering the glass. (n of glass = 1.5).

LENSES AND OPTICAL INSTRUMENTS

LEARNING OBJECTIVES

By the end of this topic you should be able to:

1. State (a) (i) The types of lenses. (ii) The terms used in lenses.
(b) (i) The principal rays used for drawing ray diagrams.
(ii) Draw ray diagrams using the principal rays.
(c) State the properties of images formed in lenses.
2. Solve problems using the lens formula.
3. Define the power of lens and state its unit.
4. Solve problems using the formula of power of lens.
5. (a) State the application of lenses.
(b) Draw and describe the action of:
(i) The camera. (ii) The projector.
6. Compare the camera and the human eye.

14.51 Lenses

A lens in optical systems refers to a glass or any transparent substance so shaped that it refracts light from any object and forms a real or virtual image of the object.

(a) Types of lenses

Lenses are made with a great variety of shapes and of different kinds. They all belong to two main groups namely: (i) Converging (Convex) lens
(ii) Diverging (Concave) lens

(i) Converging (Convex) lenses

A converging (convex) lens curves outward. It has a thick center and thinner edges.

The different types of converging lenses are bi-convex, plano-convex and converging meniscus.

The diagrams showing the different types/shapes of converging lens.



Bi-convex



Plano-convex



Converging meniscus

(ii) Diverging lenses

Diverging, or concave, lens is curved inward, with a thin center and thicker edges.

The different types of diverging lenses are bi-concave, plano-concave and diverging meniscus.



Bi-concave



Plano-concave

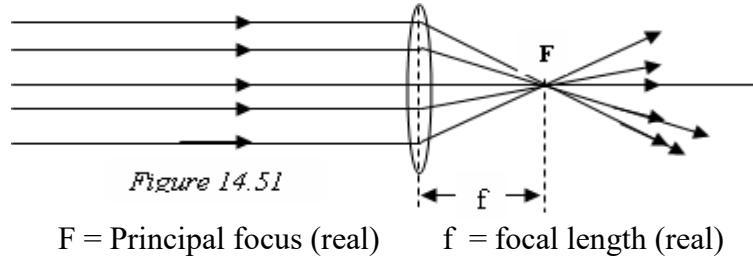


Diverging meniscus

NB: A meniscus lens has both a concave and convex surface and so, to avoid confusion, we shall refer to lenses by their converging and diverging property rather than their shape.

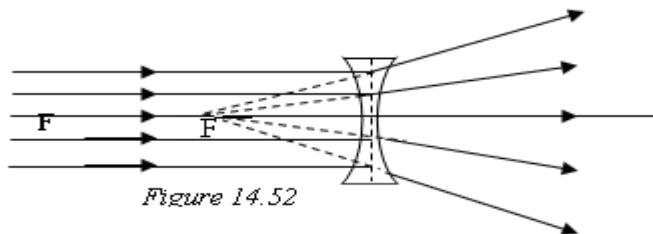
(b) The principal focus and focal length of a converging lens

A parallel beam of light, parallel and close to the principal axis of a converging lens is converged or brought to focus at the principal focus or focal point. See figure 14.51 below.



(c) The principal focus F, and focal length, f, for a diverging lens

A parallel beam of light, parallel and close to the principal axis of a diverging lens is diverged and appear to be coming from the principal focus or focal point as shown in figure 14.52 below.



Lens Definitions

- (i) The *pole*, P, is the centre of the surface of the lens.
- (ii) The *principle axis* of a lens is the imaginary line joining the centers of curvature of its surfaces.
- (iii) The *optical centre*, C, is the point on the principal axis midway between the lens surfaces.
- (iv) The *principal focus, or focal point*, F of a converging lens is the point on the principal axis to which rays parallel to the axis converge after refraction. The principal focus of a converging lens is real.
- (v) The *principal focus, or focal point*, F of a diverging lens is the point on the principal axis from which all rays incident parallel appear to diverge after refraction. The principal focus of diverging lens is virtual.
- (vi) The *focal length*, f, of a lens is the distance between the principal focus and the optical center of the lens.
- (vii) The *focal plane* is the plane through the principal focus F perpendicular to the principal axis.
- (viii) The *aperture* is the width of the lens from one edge to the other.

Notes: - A lens is considered to have two principal foci, depending upon whether light is

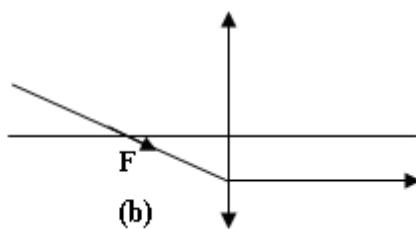
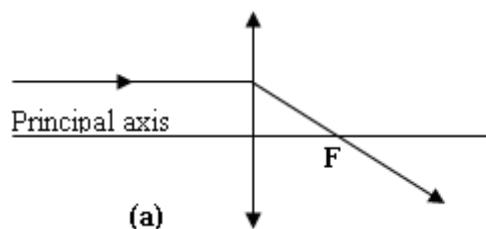
- incident from one direction or the opposite direction.
- For thin lenses, the principal foci are equidistant from the optical centre.
- All work subsequent connected with lenses in this book will assume that thin lenses are used.

14.53 Ray diagrams

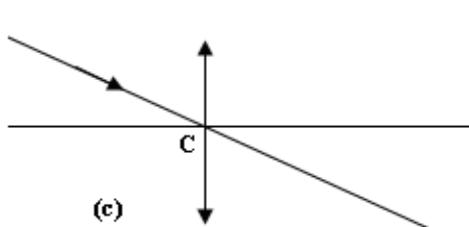
There are three special or particular rays which can be drawn accurately in lens ray diagrams. We choose the most convenient rays called *the principal rays* to find the position of the image formed by a lens.

(a) The principal rays for Converging lens

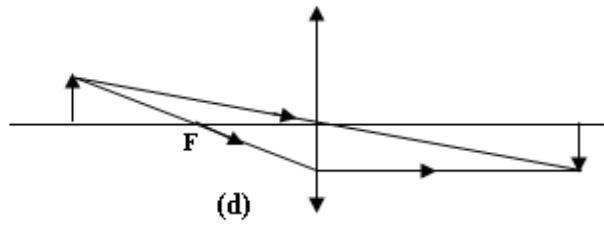
The figures 14. (a) – ((c) show the three principal rays for converging lens.



1. A ray parallel to the principal axis, is refracted (by the lens) to pass through the principal focus F.
2. A ray through the principal focus, F is refracted parallel to the principal axis (i.e. ray 1. reversed)



3. A ray passing through the optical centre is undeviated or is not refracted.



All the principal rays combined

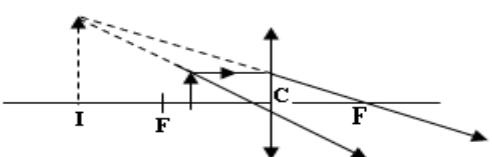
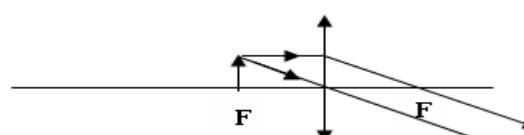
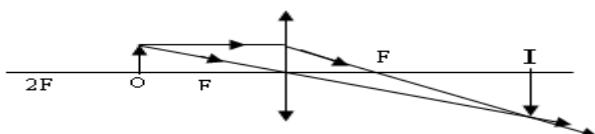
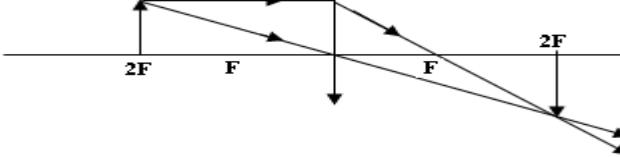
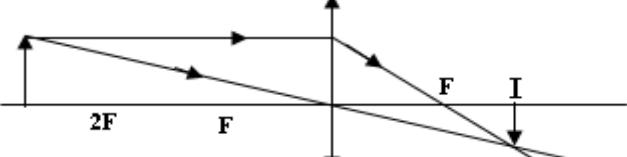
(b) Ray diagrams for Converging lens

In drawing the ray diagrams we choose any two of the principal ray to locate the position of the image formed by a lens. The distance of the object from the lens is critical in deciding the nature, size and position of the image and for this reason it is vital to mark clearly the position of the principal focus of a lens.

Remember, when drawing ray diagrams:

- ❖ All real rays of light are drawn as solid lines with arrows indicating their direction.
- ❖ All virtual rays and images are drawn as broken lines.
- ❖ We draw rays from the tip of an object at a point off the principal axis so that we can find the size or magnification of the image and which way up it is.
- ❖ Images on the same side of a lens as the object are always virtual and erect.
- ❖ Images on the opposite side of a lens to the object are always real and inverted.

Images formed by Converging lenses

Ray diagram	Nature of image I
(a) Object O between F and C	<p>(i) Virtual (ii) Erect (iii) Magnified (iv) On same side of lens as O and further away</p>
	<p>This arrangement is applied in: (i) Magnifying glasses (ii) Microscope eye piece. (iii) Spectacles correction for long sightedness.</p>
(b) Object O at F	At infinity
	<p>Produces parallel beam of light as in a spot light with lamp at O.</p>
(c) Object O between F and 2F	<p>(i) Real (ii) Inverted (iii) Magnified (iv) On opposite side of lens to O, beyond 2F.</p>
	<p>Applied in: (i) Projector (ii) Microscope objective lens</p>
(d) Object O at 2F	<p>(i) Real (ii) Inverted (iii) Same size as O (iv) On opposite side of lens, between F and 2F</p>
	<p>Applied in: (i) Camera (ii) The eye</p>
(e) Object O beyond 2F	<p>(i) Real (ii) Inverted (iii) Diminished (iv) On opposite side of the lens to O, beyond 2F.</p>
	<p>Applied as objective lens in a telescope</p>
(f) Object O at infinity	<p>(i) Real (ii) Inverted (iii) Diminished (iv) On opposite side of lens at F.</p>

(c) The principal rays for Diverging lens

There are two principal rays of a diverging lens; they are:

1. A ray parallel to the principal axis, is refracted (by the lens) to appear to come from principal focus F .
2. A ray passing through the optical centre is undeviated or is not refracted.

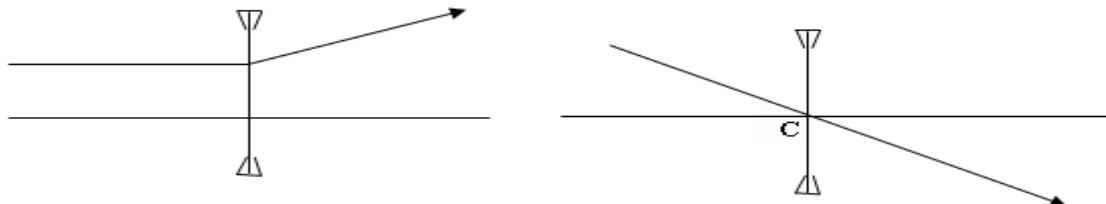


Image formed by Diverging lens

The ray diagram for a diverging lens is the same for all object positions.

Ray diagram	Nature of image I
	<p><i>Image I is:</i></p> <ul style="list-style-type: none"> (i) Virtual (ii) Erect (iii) Diminished (iv) Between F and C (v) On same side of lens as O, but nearer
Applied in: (i) eye piece in some instruments (ii) in spectacles to correct short-sightedness	

Experiment 14.51 To determine the Approximate focal length of a converging lens

- Focusing a distant object on to a screen.
- Move the lens to and fro until a sharp image is formed on a screen.
- The distance from the lens to the screen gives focal length, f .

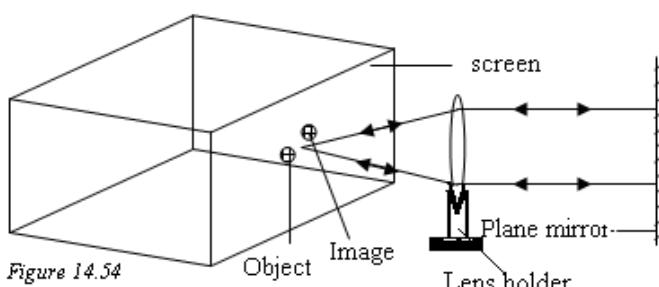
Experiment 14.52 To determine the focal length of a converging lens using an illuminated object and a plane mirror

Apparatus

A ray box with a cross wire on its side, Source of light, a plane mirror, lens holder and a converging lens.

Procedure

- The apparatus are arranged as shown in figure 14.54 below.



- Adjust the position of the lens until a sharp image of the cross wire is formed on the screen.

- NB:** At this position of the sharp image, the rays from the lens emerge as parallel rays and strike the mirror at right angle and they are reflected back along their original path.
The distance between the screen and the lens give the focal length of the converging lens.

(d) Scale drawing of ray diagrams

The ray diagrams can be drawn to scale using squared paper. This provides an accurate method of finding the position, size and nature of the image formed by a lens and may be used to answer lens questions. The following points should be noted:

- (i) The lens is represented by a line at right angles to its principal axis.
- (ii) The scale chosen for the distances from the lens does not necessarily need to be the same as for the object and image heights, if so, both scales should be stated on the diagram.
- (iii) Choose a scale which is simple and convenient to use and that makes the diagram fill most of the sheet of squared paper.

Worked Example

Scale Diagram

1. An object 6 cm high is placed 20 cm from a converging lens of focal length 8 cm. Find by scale drawing the position, size and nature of the image.

Solution Object height = 6 cm, $u = 20$ cm, $f = 8$ cm.
Scale: 1 unit : 4 cm

Steps followed:

Now using the scale: Object height = $\frac{6}{4} = 1.5$ cm, $u = \frac{20}{4} = 5$ cm, $f = \frac{8}{4} = 2$ cm

These values of object height, object distance, and the focal length are measured and drawn on a squared paper.

Measure the image height and the image distances using a ruler.

Multiply the distances by the scale to get the actual image height and the image distance

14.54 The Lens Formula

The lens formula is given by the relation: $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$

Or When rearranged, we have $f = \frac{uv}{u+v}$

(a) The sign convention used in lens calculations

When solving problems on lenses (or curved mirrors), it is necessary to adopt a particular system of giving positive and negative values to distances.

The *real-is-positive* sign convention is used in this book:

- (i) The distances from the lens to real objects, images and principal focus are positive values (i.e. u , v and f) are positive for real objects and images.
- (ii) The distances from the lens to virtual objects, images and principal focus are negative values. (i.e. u , v and f are negative for virtual images).

NB: All distances are measured from the optical centre of the lens.

(b) The Magnification formula

The comparison of image size with object size is called *magnification*. The linear magnification, m , is defined by the formula:

$$\text{Magnification, } m = \frac{\text{Image Height}}{\text{Object height}} \quad \text{Or} \quad \text{Magnification, } m = \frac{v}{u}$$

Note: When using this formula for linear magnification, any negative signs for u and v should be ignored.

Worked Examples

1. An object is placed 20 cm from a converging lens of focal length 15 cm. Find the nature, position and magnification of the image formed.

Solution: $u = +20 \text{ cm}$, $f = +15 \text{ cm}$, $v = ?$

$$(i) \frac{1}{u} + \frac{1}{v} = \frac{1}{f} \Rightarrow \frac{1}{20} + \frac{1}{v} = \frac{1}{15} \Rightarrow \frac{1}{v} = \frac{1}{15} - \frac{1}{20} = \frac{4-3}{60} = \frac{1}{60}$$

$$\therefore v = 60 \text{ cm}$$

$$(ii) m = \frac{v}{u} = \frac{60}{20} = 3$$

Since v = positive, then a real and magnified image of magnification of 3 is formed 60 cm from the lens on side opposite to the object.

2. A four times magnified virtual image is formed of an object placed 12 cm from a converging lens. Calculate the position of the image and the focal length of the lens.

Solution $m = 4$, $v = ?$ Substituting in $m = \frac{v}{u}$
 $v = mu = 4 \times 12 = 48 \text{ cm}$

$u = 12 \text{ cm}$, $v = -48 \text{ cm}$ (virtual image), $f = ?$

$$\text{Substituting in } \frac{1}{u} + \frac{1}{v} = \frac{1}{f} \Rightarrow \frac{1}{12} + \frac{1}{-48} = \frac{1}{f}$$
$$\therefore \frac{1}{f} = \frac{1}{12} - \frac{1}{48} = \frac{-1+4}{48} = \frac{3}{48} \quad \therefore f = 16 \text{ cm}$$

(c) The power of a lens

The power, F , of a lens is defined as the reciprocal of the focal length expressed in metres.

The unit of power of a lens is Dioptres (D).

A diopter (D) is the power of a lens of focal length one metre.

The power of a lens is calculated from the formula:

$$\text{Power} = \frac{1}{\text{focal length in metres}}$$

$$\text{Or} \quad F = \frac{1}{f}$$

NB: The power of converging lens is positive while for a diverging lens is negative.

Worked Examples

A single lens

1. A converging lens has a focal length 15 cm. Calculate the power of the lens.

Solution: $f = 15 \text{ cm} = \frac{15}{100} = 0.15 \text{ m}$, $F = ?$ Substituting in $F = \frac{1}{f} = \frac{1}{0.15} = 6.67 \text{ D}$

2. Find the power of
 (a) a converging lens of focal length 20 cm.
 (b) a diverging lens of focal length 10 cm.

Solution: (a) $f = 20 \text{ cm} = \frac{20}{100} = 0.2 \text{ m}$, $F = ?$ Substituting in $F = \frac{1}{f} = \frac{1}{0.2} = 5 \text{ D}$

(b) $f = -10 \text{ cm} = \frac{-10}{100} = -0.1 \text{ m}$, $F = ?$ Substituting in $F = \frac{1}{f} = \frac{1}{-0.1} = -10 \text{ D}$

D

Combination of two lenses

When two lenses are placed in contact, the power of the combination is obtained by adding or subtracting the powers of the individual lens.

Examples

1. Two converging lenses of focal length 10 cm and 20 cm are placed in contact. Find the power of the combination.

Solution: *Power of the first lens* $f = 10 \text{ cm} = \frac{10}{100} = 0.1 \text{ m}$, $F = ?$
 $F_1 = \frac{1}{f} = \frac{1}{0.1} = 10 \text{ D}$

Power of the second lens $f = 20 \text{ cm} = \frac{20}{100} = 0.2 \text{ m}$, $F = ?$

$$F_2 = \frac{1}{f} = \frac{1}{0.2} = 5 \text{ D}$$

Power of the combination $F = F_1 + F_2 = 10 + 5 = 15 \text{ D}$

2. A converging lens of focal length 10 cm is placed in contact with a diverging lens of focal length 25 cm. Find the power of the combination.

Solution: *Power of the first lens* $f = +10 \text{ cm} = \frac{10}{100} = 0.1 \text{ m}$, $F = ?$

$$F_1 = \frac{1}{f} = \frac{1}{0.1} = 10 \text{ D}$$

Power of the second lens $f = -25 \text{ cm} = \frac{-25}{100} = -0.25 \text{ m}$ (diverging lens), $F = ?$

$$F_2 = \frac{1}{f} = \frac{1}{-0.25} = -4 \text{ D}$$

Power of the combination $F = F_1 + F_2 = 10 + -4 = 6 \text{ D}$

14.55 Applications of lenses

Lenses are of great use in every day life. They are used in the following:

- *the camera, projector, eye glasses, microscope, telescopes and*
- *other optical instruments.*

(a) The lens camera

Structure

The camera consists of light proof box with a converging lens in front and a light sensitive film at the back. The inner surface is painted black in order to prevent the reflection of stray rays of light. The construction of the camera is shown in the figure 14.55 below.

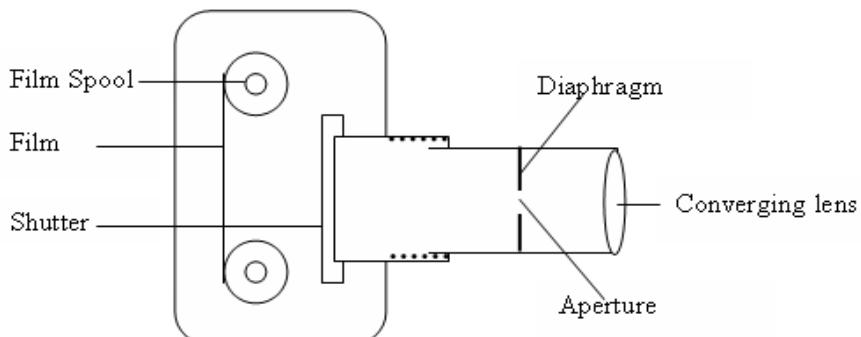


Figure 14.55

The parts of the camera and their functions

- (i) *The converging lens* - focuses the image of the object on to the film.
- (ii) *Diaphragm* - the diaphragm regulates the size of the aperture and thus controls the amount of light energy admitted through the lens.
It operates in conjunction with the shutter.
- (iii) *Aperture* - the opening of a lens through which light enters.
- (iv) *Shutter* - A spring loaded blind which covers the film. It admits or shuts off light from the film. The shutter has a variable speed. It also controls the amount of light entering the camera by length of time for which it is opened.
- (v) *The film* - part of the camera on which images of objects are focused.

Note: *A camera is usually fitted with provision for adjusting the distance between the film and the converging lens.*

14.56 The Human Eye

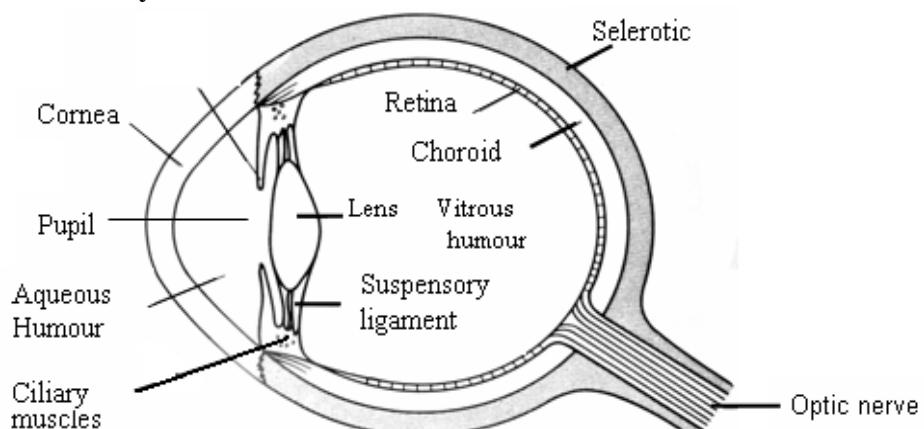


Figure 14.56

The human eye, figure 14.56, in many respects is similar to the camera. The image is formed by the eye lens on a sensitive retina at the back of the eye and transmitted to the brain by means of *optic nerves*.

The amount of light entering the eye is controlled by the *iris*, the coloured portion of the eye which regulates the size of the *pupil* or circular opening in its centre.

In order for the eye to form an image on the retina, the ciliary muscles alter the focal length of the lens by changing its shape. This process by which the eye lens changes its size so that the image is formed on the retina is called accommodation. This process makes the eye to see both near and far objects.

The eye ball has a tough white wall called *sclerotic* and the transparent portion which is in front of the cornea. The cornea serves as a protective covering and also partly focuses light entering the eye. The space between the cornea and the lens contain a transparent liquid called *aqueous humour* and the rest of the eye ball is filled with a jelly like substance known as the *vitreous humour*. The eye lens is suspended by a *suspensory ligament*.

(a) Near point and far point

The closest point at which the eye can focus (comfortably) is called its *near point*; the most distant point is called the *far point*. For a normal eye these are 25 cm and infinity, respectively.

(b) The Eye Defects and Corrections

The eye defects are caused as a result of the eye loosing the ability of its power of accommodation hence resulting to the two defects, namely:

- Short Sighted (Myopia) and
- Long sight (Hypermetropia).

(i) Short Sighted (Myopia)

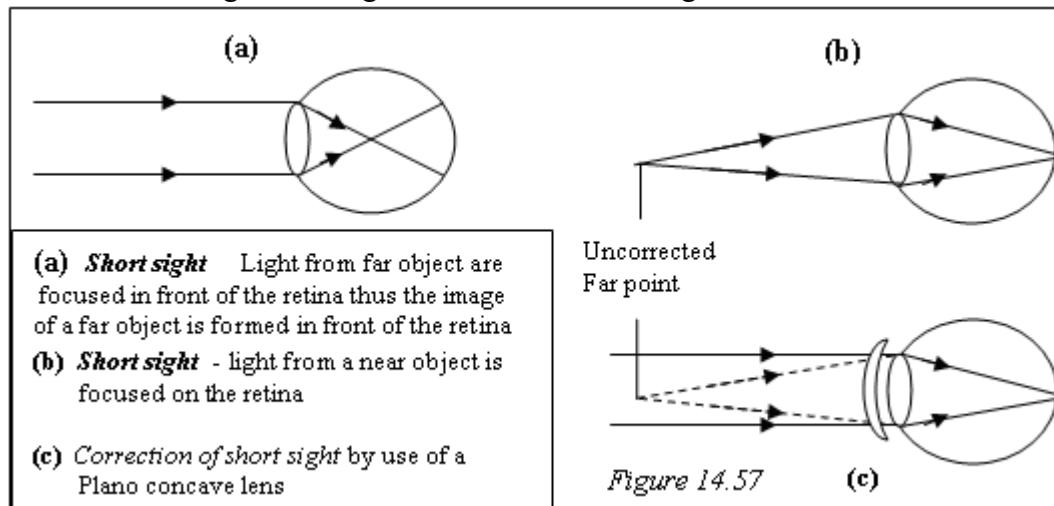
A short sighted person can see near objects clearly but not distant objects. For this person the far point is closer than infinity.

Light from a distant object is brought to focus in front of the retina.

Correction of Short sightedness

Short sightedness is corrected by using a suitable diverging lens. The diverging lens diverges the light rays such that they appear to come from the (uncorrected) far point of the eye.

Diagrams in figure 14.57 show Short sight and its correction



(ii) Long sight (Hypermetropia)

A long sighted person can see distant objects clearly but not those close-by. For this person his or her near point is greater than 25 cm from the eye. Light from near by object focus behind the retina.

Correction of Long sightedness

Long sightedness is corrected by using a suitable converging lens. The lens must produce a virtual image at the (uncorrected) near point of the eye an object which is 25 cm.

Diagrams in figure 14.58 show long sight and its correction

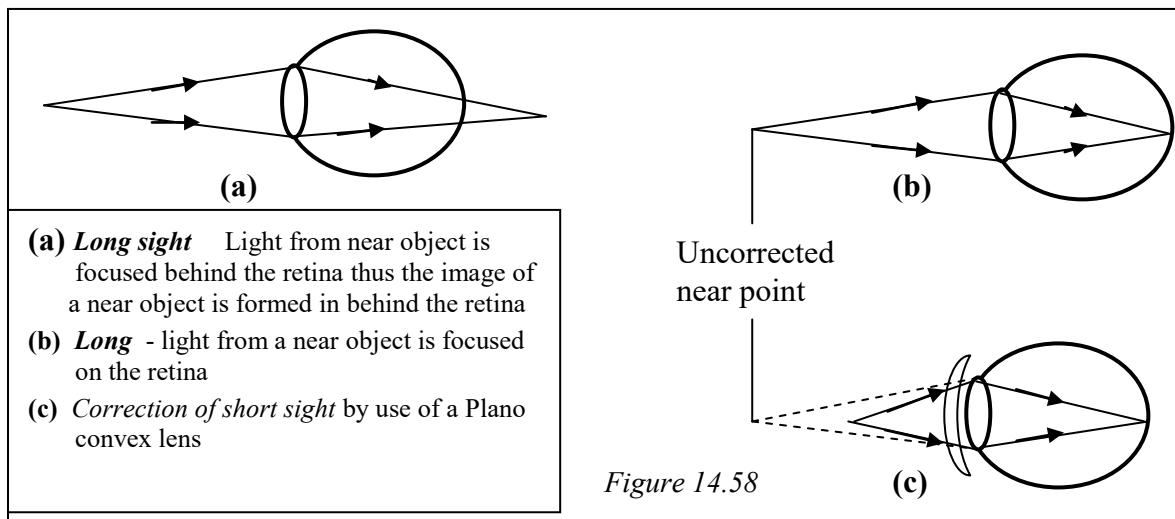


Figure 14.58

Comparison of the camera, the pin-hole and the human eye

	Eye	Pin-hole Camera	Lens Camera
Type of lens	Converging	None	Converging
Method of focusing	Change of lens Shape: thicker for near objects and thinner for far objects.	All distances focused if pin-hole is small.	Lens moves away from the film for near objects and near to the film for far objects.
Light control.	a) Iris. b) Sensitive of retina.	a) Hole size b) Exposure time c) Sensitivity of film.	a) Diaphragm. b) Exposure time or shutter speed. c) Sensitivity of the film.

14.57 The Projector or Enlarger

A projector is an instrument used to project image of a transparent slide on to a screen. It forms a magnified, real and inverted image of a film or slide. It is put in the projector upside, the image appears the right way up. Figure 14.59 show the diagram of the projector.

Structure

It consists of:

- Source of light
- Condenser
- Film or Slide
- Objective Lens

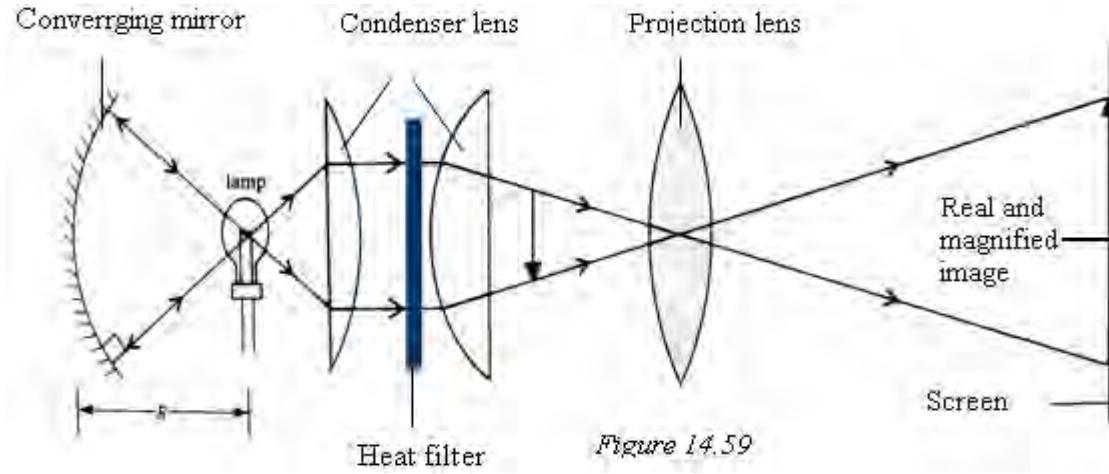


Figure 14.59

Parts of the projector and their functions

(i) Source of light

An electric bulb or electric arc forms a powerful beam of light. A concave mirror behind it reflects back any light rays that travel away from the film.

(ii) Condenser

One or two large convex lenses converge the light rays from the lamp or arc and concentrate them on the film.

(iii) Film or Slide

This is put into the projector both upside down and left to right. The image formed is then the right way up and not laterally inverted (i.e. turned about sideways).

(iv) Objective lens

The image is focused by a converging lens in a moveable tube. The object distance is slightly greater than the focal length of the lens, which therefore forms a real, inverted, magnified image. Moving the lens backwards or forward focuses the image. If it is moved closer to the film, the image is larger and is focused further away.

Self-Check 14.5

- SUMMARY**

1. A pin is placed in front of convex lens at a distance less than the focal length of the lens. What type of image is formed?
A. Real, inverted diminished. B. Virtual, erect, magnified
C. Real, erect, diminished. D. Virtual, inverted, magnified

2. An object 2 cm tall is placed 5 cm in front of a convex lens. A real image is produced 20 cm from the lens. Calculate the magnification of the lens.
A. 4 B. 2 C. 0.5 D. 0.25

3. An object is placed between a converging lens and its principal focus. The image formed is
A. real, magnified, upright B. real, magnified, inverted
C. virtual, diminished, upright D. virtual, magnified, upright

4. An image 5 cm high is formed by a converging lens. If the magnification is 0.4, find the height of the object
A. 2.0cm B. 4.6cm C. 5.4cm D. 12.5cm

5. An object is placed at a distance of 20 m from a convex lens of focal length 15cm. the type of image formed is

 - A. inverted and magnified
 - B. inverted and diminished
 - C. upright and diminished
 - D. upright and magnified

SECTION B

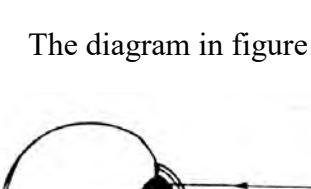
6. (a) State the types of the two common lenses.
(b) Define the following terms as used in the study of lenses.
(i) the principal focus and.
(ii) focal length of a converging lens.
(c) With the help of a ray diagram show how a converging lens can be used as a magnifying glass.

7. (a) Define:(i) real image. (ii) virtual image.
(b) State any two properties of an image of a real object formed in a diverging lens.
(c) An object 8 cm high is placed perpendicularly on the principal axis 12 cm away from the diverging lens. With the aid of a ray diagram, find the focal length of the lens, if the height of the image formed is 2 cm.

8. (a) The focal length of a converging 10.0 cm. What is its power?
(b) State two applications of converging lenses
(c) An object of height 4 cm is placed perpendicularly on the principal axis at a distance of 45 cm from a converging lens of focal length of 15 cm. By graphical construction, determine
(i) the position of the image. (ii) the magnification.

9. (a) Define focal length of a converging lens.
(b) With the aid of a labeled diagram, describe a simple experiment to determine the focal length of a converging lens.
(d) Give one use of converging lenses

10. (a) The diagram in figure 14.60 figure a shows one of the eye defects in human.
(a) (i) State the type of eye defect shown in the diagram.
(ii) Explain with a help of diagram how the defect can be corrected.
(b) What is meant by accommodation?



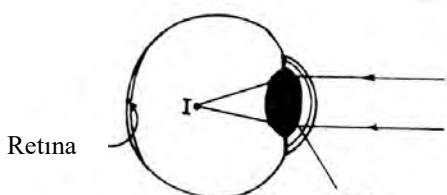


Figure 14.60 Lens

- (b) With a help of ray diagram, describe how a projector is used to project a magnified image on to a giant screen.

(c) With the aid of a labeled diagram, describe how a lens camera works.

REFRACTION OF LIGHT IN PRISMS

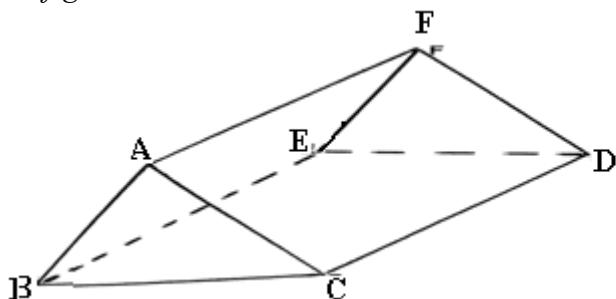
LEARNING OBJECTIVES

By the end of this topic you should be able to:

- (a) Define deviation and minimum deviation.
(b) State the conditions for minimum deviation.
 - Solve problems involving refraction in prisms.

14.61 Prism

Prism, in geometry, is three-dimensional solid with two parallel triangular faces. See figure 14.61 below.



Terms

ABC = DEF - Triangular face

$$\text{ACDF} = \text{ABEF}$$

- Refracting surface

BCDE = The base

/BAC - The angle of prism

Figure 14.6I

Note: For clarity, the triangular face is always considered.

14.62 Deviation by Prism

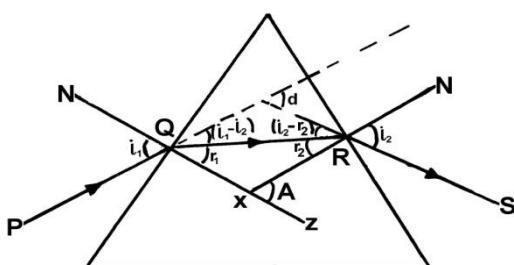


Figure 14.6?

the

When light is passed through a prism, it is refracted at the two refracting surfaces as shown in figure 14.62 above.

The ray PQ is refracted at Q, it then passes along the path QR. It is then refracted again at R, and emerges by the path RS. The direction of the ray has been altered from the initial direction PQ to RS. By producing both lines so that they meet,

angle formed is called *angle of deviation*, d .

(a) Formula of Deviation, d

The deviation, d , is given by the formula: $d = (\mathbf{i}_1 - \mathbf{r}_1) + (\mathbf{i}_2 - \mathbf{r}_2)$
 Or $d = (\mathbf{i}_1 + \mathbf{i}_2) - (\mathbf{r}_1 + \mathbf{r}_2)$

Derivation of the formula of deviation, d

From the diagram. One exterior angle = The sum of two interior angles

From equation 1

$$\begin{aligned}
 \mathbf{d} &= (\mathbf{i}_1 - \mathbf{r}_1) + (\mathbf{i}_2 - \mathbf{r}_2) \\
 &= \mathbf{i}_1 - \mathbf{r}_1 + \mathbf{i}_2 - \mathbf{r}_2 \\
 &= \mathbf{i}_1 + \mathbf{i}_2 - \mathbf{r}_1 - \mathbf{r}_2 \\
 \mathbf{d} &= (\mathbf{i}_1 + \mathbf{i}_2) - (\mathbf{r}_1 + \mathbf{r}_2) \quad \dots \dots \dots \quad 2
 \end{aligned}$$

Also from the diagram,

$$\angle RXZ = \angle XQR + \angle QRX \quad (\text{Sum of two interior angles} = \text{one exterior angle})$$

$$\mathbf{A} = \mathbf{r}_1 + \mathbf{r}_2$$

(b) Minimum Deviation, D

Consider the diagram in figure 14.63 below.

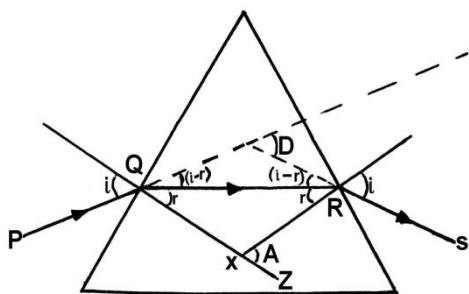


Figure 14.63

Minimum deviation, D , is the deviation that occurs in a prism where the angle of deviation is at its minimum value. It occurs when the conditions of minimum deviation are fulfilled.

(c) Conditions for minimum deviation to occur

1. When the refracted ray in the prism is parallel to the base.
 2. When the light ray passes symmetrically through the prism.
 3. The angle of incident at the first refracting surface is equal to the emergent angle.

(d) The derivation of the formula of Minimum Deviation D

$$\begin{aligned}
 \text{From the diagram, } \mathbf{D} &= (\mathbf{i}_1 - \mathbf{r}_1) + (\mathbf{i}_2 - \mathbf{r}_2) \quad \text{But} \quad \mathbf{i}_1 = \mathbf{i}_2 \text{ and } \mathbf{r}_1 = \mathbf{r}_2 \\
 &= \mathbf{i} - \mathbf{r} + \mathbf{i} - \mathbf{r} \\
 &= \mathbf{i} + \mathbf{i} - \mathbf{r} - \mathbf{r} \\
 &= 2\mathbf{i} - 2\mathbf{r} \\
 \therefore \mathbf{D} &= 2(\mathbf{i} - \mathbf{r})
 \end{aligned}$$

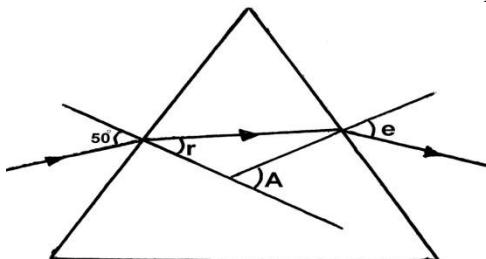
Also from the diagram,

$$\angle RXZ = \angle XQR + \angle QRX \quad (\text{Sum of two interior angles} = \text{one exterior angle})$$

$$\begin{array}{rcl} \mathbf{A} & = & \mathbf{r} + \mathbf{r} \\ \mathbf{A} & = & 2\mathbf{r} \end{array}$$

Worked Examples

1. (a) The diagram in the figure 14.65 shows a ray of yellow light incident at an angle of 50° on one side of an equilateral glass prism of refractive index 1.52.



- (i) Calculate the angles marked r and e.
(ii) State and explain what could be observed if the ray above were of white light.

writing on a piece of paper placed under a glass block appears raised when observed

Figure 14.65

- (c) State (i) the conditions necessary for total internal reflection to occur
(ii) One application of total internal reflection

Solution $n_g = 1.52, n_a = 1$

(i) Applying $n \sin i = \text{Constant}$ at the *first* refracting face, we have

$$n_a \sin i = n_g \sin r$$

$$1 \times \sin 50^\circ = 1.52 \times \sin r$$

$$\sin r = \frac{1 \times \sin 50^\circ}{1.52} = \frac{1 \times 0.766}{1.52} = 0.5040$$

$$r = \sin^{-1} 0.5040$$

$$\therefore r = 30.26^\circ$$

(ii) Applying $n \sin i = \text{Constant}$ at the *second* refracting face, we have

$$n_a \sin i = n_g \sin r$$

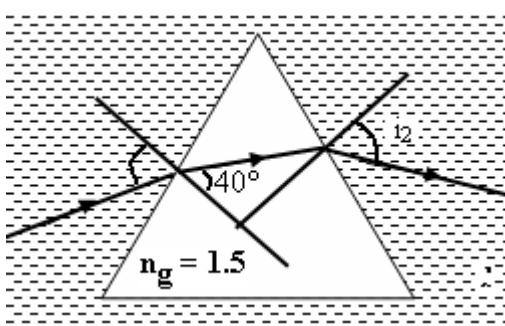
$$1 \times \sin e = 1.52 \times \sin 29.74^\circ$$

$$\sin e = \frac{1.52 \times \sin 29.74^\circ}{1} = \frac{1.52 \times 0.4961}{1} = 0.7540$$

$$e = \sin^{-1} 0.7540$$

$$\therefore e = 48.94^\circ$$

2. The figure 14.66 below shows a ray of light incident at an angle of 46.46° on one side of an equilateral triangular prism immersed in a liquid of refractive index n_l .



Given that the refractive index of the glass is 1.5, and the angle of refraction on the first face is 40° , calculate;

- (i) the value of n_l ,
- (ii) the value of i_2 and
- (iii) the angle of deviation.

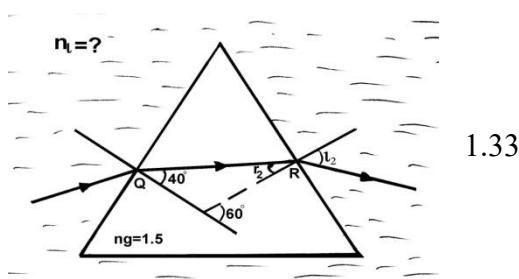
Figure 14.66

Solution:

(i) Applying $n \sin i = \text{Constant}$ at B we have

$$n_l \sin 46.46^\circ = n_g \sin 40^\circ$$

$$n_l = \frac{n_g \sin 40^\circ}{\sin 46.46^\circ} = \frac{1.5 \times 0.6428}{0.7249} = \frac{0.9642}{0.7249} =$$



(ii) Applying $r_1 + r_2 = A$

$$40^\circ + r_2 = 60^\circ$$

$$r_2 = 60^\circ - 40^\circ$$

$$r_2 = 20^\circ$$

Applying

$n \sin i = \text{Constant}$ at C we have

$$n_g \sin r_2 = n_l \sin i_2$$

$$\sin i_2 = \frac{n_g \sin r_2}{n_l} = \frac{1.5 \times \sin 20^\circ}{1.33} = \frac{1.5 \times 0.3420}{1.33} = 0.3857$$

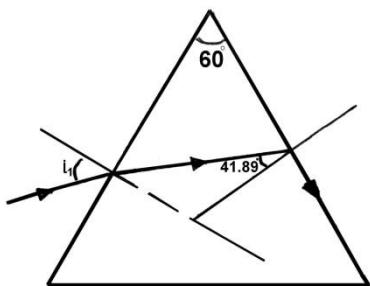
$$i_2 = \sin^{-1} 0.3857 = 22.69^\circ$$

(iii) Applying $d = (i_1 + i_2) - (r_1 + r_2)$

$$= (46.46^\circ + 22.69^\circ) - (40^\circ + 20^\circ) = 69.15^\circ - 60^\circ = 9.15^\circ$$

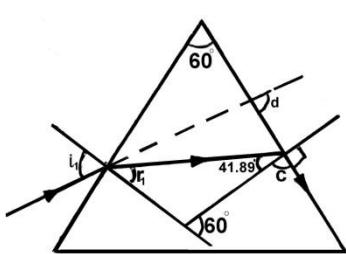
3. Study the diagram below and answer the questions that follow.

glass.



- Calculate;
- the refractive index of the glass.
 - The value of i_1
 - The angle of deviation.

Solution:



- Applying $n = \frac{1}{\sin C}$

$$= \frac{1}{\sin 41.8^\circ} = \frac{1}{0.6665}$$

 $\therefore n = 1.5$
- Applying $r_1 + r_2 = A$
 $r_1 + 41.8^\circ = 60^\circ$
 $r_1 = 60^\circ - 41.8^\circ$
 $\therefore r_1 = 18.2^\circ$

Applying $n \sin i = \text{Constant at B}$ we have

$$n_a \sin i_1 = n_g \sin r_1$$

$$\sin i_1 = \frac{n_g \sin r_1}{n_a} = \frac{1.5 \times \sin 18.2^\circ}{1} = 1.5 \times 0.3123 = 0.4685$$

$$i_1 = \sin^{-1} 0.4685 = 27.94^\circ$$

- Applying $d = (i_1 + i_2) - (r_1 + r_2)$
 $= (27.94^\circ + 90^\circ) - (18.2^\circ + 41.8^\circ)$
 $= 117.94^\circ - 60^\circ$
 $\therefore d = 57.94^\circ$

Self-Check 14.6

- (a) Explain what is meant by minimum deviation in a glass prism.
(b) State the conditions for minimum deviation occur.
- The figure shows a ray of light incident at an angle of i on one side of an equilateral triangular prism of refractive index 1.5. The angle of emergency on the second face is 45° .
Calculate: (i) the value of i . (ii) the angle of deviation..
- (a) Complete the diagram in figure 14.67 to show the path of the light ray PQ through the prism.
(b) (i) State the conditions for total internal reflection to occur.
(ii) State one application of total internal reflection.
(iii) Calculate the critical angle for an air-glass interface if refractive index of glass is 1.5.

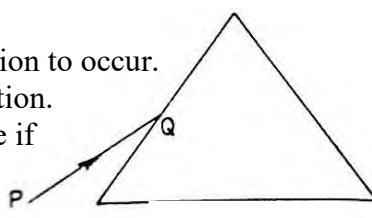


Fig. 14.67

DISPERSION OF WHITE LIGHT AND COLOURS

14.71

LEARNING OBJECTIVES

By the end of this topic you should be able to:

1. (a) Define dispersion of white light by a prism.
(b) Describe an experiment to produce pure spectrum.
2. State the primary and secondary colours.
3. Name the secondary colours formed when primary colours are mixed by addition.
4. (a) Define and state complementary colours.
(b) State the colour of objects in different colours of light.
5. State (i) The effect of filters on colours of light.
(ii) The appearance of colours in electric lamps.

14.72 Dispersion of White light

Dispersion is the separation of white light into its constituent colours. When a narrow beam of white light is passed through a glass prism, it is refracted and spreads into a band of colours of the rainbow as shown in figure 14.71 below. The band of the colours so formed is called *spectrum*.

The diagram showing the formation of a spectrum

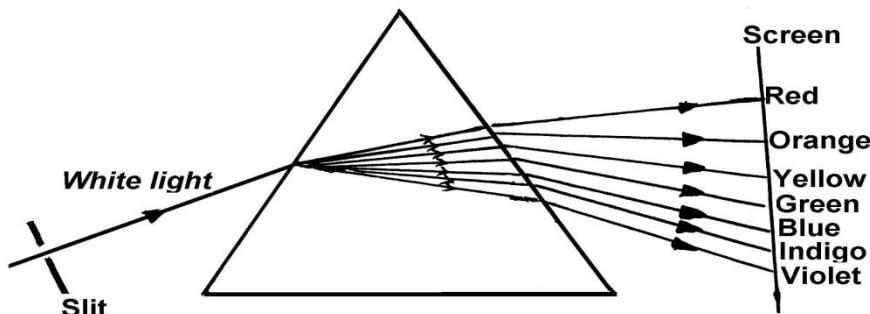


Figure 14.71

Notes: The order of the colours can easily be recalled by the statement:
Richard Of York Gain Battle In Vein.

Conclusion

From the above result, we can conclude that:

- (i) White light is a mixture of seven colours.
- (ii) The prism has different refractive indices for the different colours.
- (iii) The prism separates the colours by deviating red least and the violet light most, and other colours are deviated to varying intermediate extends.

(a) Recombining the Spectrum

The spectrum obtained from a white light can be recombined. This may be done by using the following methods.

Method 1. Using two prisms

The first prism deviates the white light into spectrum. The second prism placed in inverted position reverses the deviation and dispersion of the first prism so that the colours of the spectrum recombine and the emergent ray obtained is white light as shown in figure 14.72 on page 263.

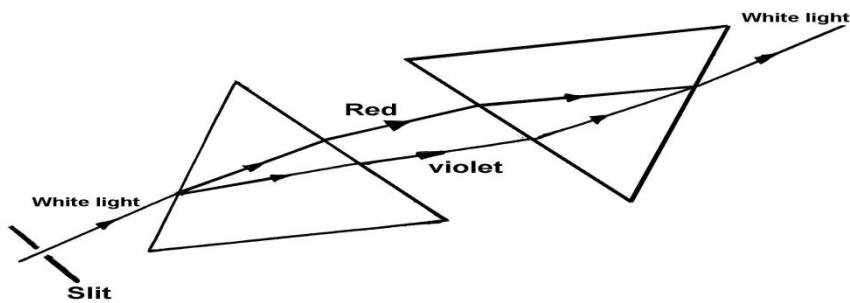


Figure 14.72

Method 2 Using Newton's disc

Newton's disc is a card coloured with all the colours of the spectrum in equal areas. If the card is spun round rapidly the colours of the spectrum are added together and appear as nearly white. The off-white colour is due to the imperfect reflection of colours from the disc.

(b) The Colours of the Spectrum of White Light

The colours of the spectrum of white light are those seen in a rainbow. They are usually named in order from top to bottom as: *Red, Orange, Yellow, Green, Blue, Indigo and Violet*. The colours overlap. That is there are no clear boundaries (no gaps or breaks) between the colours. See figure 14.73 below.

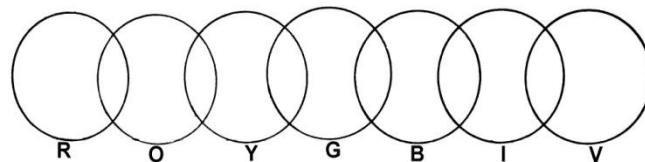


Figure 14.73

Because of the overlapping of the colours, we describe the spectrum of white light as continuous. Which means that there is a complete range of colours from the red end to the violet end of the spectrum. This makes the spectrum impure. However, a pure spectrum can be produced in the laboratory.

(c) Pure Spectrum

A pure spectrum is one in which the colours in it do not overlap. That is to say one colour only forms each part of the image on a screen.

To produce a pure spectrum the following conditions should be fulfilled:

- (i) the source of white light must be restricted by a very narrow slit,
- (ii) The prism is placed such that there is minimum deviation thus making the white light arriving at the glass prism a parallel beam, and
- (iii) The parallel beams of different colours of light emerging from the prism should be focused by a lens onto a screen so that they do not overlap.

Experiment 14.71 To produce a pure spectrum

Apparatus: A source of white light, a slit, two converging lenses, a glass prism and a screen.

Procedure

Place the source of light at the focal length of the first lens, L₁.

Arrange the rest of the apparatus as shown in the figure 14.74 on page 265.

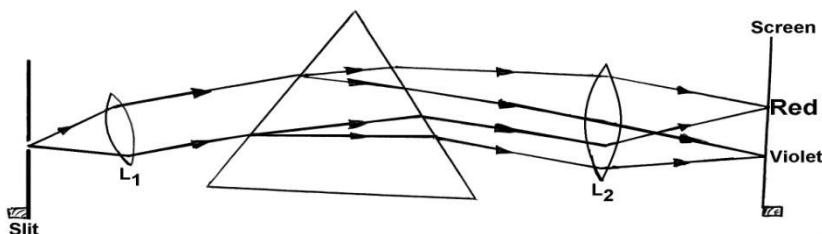


Figure 14.74

This produces parallel emergent beam of white light which is incident on the first refracting surface of the glass prism. The second converging lens, L₂, reverses the effect of the first lens so that the parallel beam of each separate colour is focused at different points on the screen thus forming a pure spectrum.

14.73 Sums with Colours

The human eye has three types of light sensitive cells or colour detectors called cones. Each type of cone detects part of the spectrum of white light.

For example:

The red sensitive cones detect: Red, Orange and Yellow

The green sensitive cones detect: Yellow, Green and Blue

The blue sensitive cones detect: Blue, indigo and Violet.

The simplified plan is shown in figure 14.75 below.

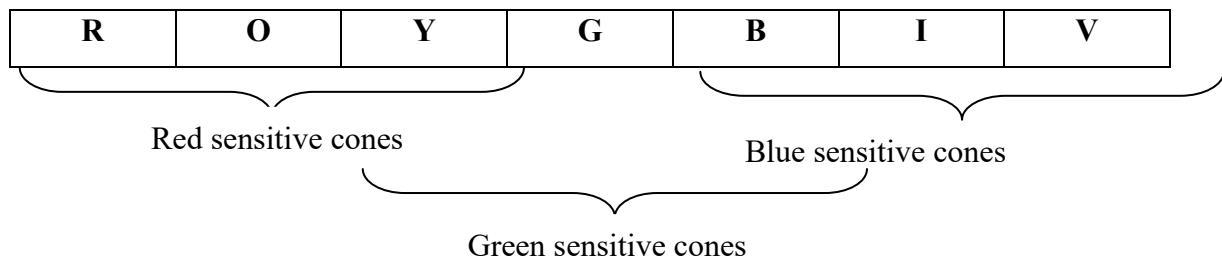


Figure 14.75

As seen from above, there is overlapping of the zones of the spectrum detected by the three types of cones. If the eye receives red light, only the red sensitive cones will be stimulated, but yellow light will stimulate both red and green sensitive cones.

Notes: Although the eye has only three different colour detectors, it can distinguish all the colours of the spectrum from the variety of combinations of responses produced by overlapping of the zones.

(a) Primary and Secondary Colours

Colours of light are grouped in two main categories. These are:

- (i) Primary Colours and
- (ii) Secondary Colours

(i) Primary Colours

Primary colours are colours which cannot be made by adding (or mixing) any other colours of light together. These are: Red, Green and Blue.

Note: With the eye having three types of cones, or colour detectors, it is not surprising to find that the three primary colours can be used to stimulate the other colours in the spectrum.

(ii) Secondary Colours

Secondary colours are colours of light that are made or obtained by adding two primary colours together.

These are: Yellow (Y), Magenta (M) and Cyan (C), (some times called peacock blue).

(b) Addition of Colours of light

Addition of colours of light on white screen can be done by using two or three projectors or light boxes. The colour filters of the colours to be added are placed in each of the window of the projector or light box and are then directed onto a white screen.

(i) Using three projectors or light boxes

An effective way of showing all the possible combinations of primary colours, RGB, on a screen is shown in the figure 14.76 below.

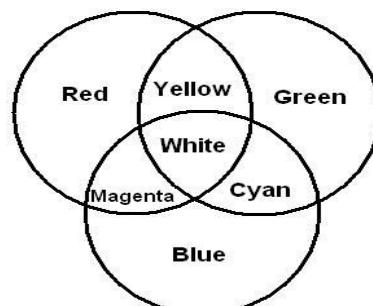


Figure 14.76

Notes:

- ❖ The circles represent the circular images of the projector windows with the three primary colours of light on the screen.
- ❖ All the three colours of light intersect to make white light.
- ❖ Two overlapping primary colours make a secondary colour, CMY. This can also be obtained by using two projectors or light boxes.

(ii) Using two projectors or light boxes

This can be summarized as shown in the table 14.71 below.

Primary Colours of light added	Secondary Colour made
Red + Green	Yellow
Red + Blue	Magenta
Green + Blue	Cyan

Table 14.71

Note:

- ❖ Light of the secondary colour yellow (made of red and green) is indistinguishable to the eye from the true yellow in the spectrum of white light. This is because the red and green sensitive cones in the eye are equally stimulated by a mixture of red and green light or pure yellow light.
- ❖ True yellow light is a single colour and can not be separated by a glass prism.

(c) Complementary Colours

Complementary colours of light are a pair of a primary colour and a secondary colour which when mixed together make white light. Since there are three primary colours of light, then there are three pairs of complementary colours. These are given in the table 14.72 below.

Colours of light mixed		Colour produced
Primary Colour	Secondary Colour	
G + R + B	-	White
R	+ C	White
G	+ M	White
B	+ Y	White

Table 14.72

(d) Mixing colours by subtraction

According to the results of mixing colours by addition, blue and yellow are complementary colours, and when mixed form white. But a student in art lesson learns that blue paint and yellow paint, when mixed together, form green. This would not be possible if the paints were pure blue and pure yellow. The success of this method of making green paint depends on the fact that the pigments in common use are impure colours.

Yellow paint is a compound yellow so that, when illuminated by white light, it reflects red, yellow and green light and absorbs the blue. Similarly, blue paint is not a pure colour: it reflects blue and green and absorbs red and yellow.

When the two paints are mixed, then between them they absorb red, yellow and blue. The only colour they both reflect is green. Consequently, the mixture looks green. This process is called colour mixing by subtraction to distinguish it from the effect of mixing coloured lights by reflection from a white surface which is called *colour mixing by addition*.

14.74 The colour of an object in light

When light is incident on a surface of any object or medium, three things happen to it in varying proportions.

- (i) The light may all be transmitted or reflected by the body and the body appears white,
- (ii) Only some colours of the white light may be reflected while others are absorbed and the object appears coloured,
- (iii) The light may all be absorbed and the body appears black and the energy absorbed is converted into internal energy, the body becomes slightly warm hence, a slight rise in temperature.

The apparent colour of an object is the sum of the colours it is reflecting. Thus:

- (a) A white object appears white in white light because it reflects all the colours of the spectrum which add up to give it a white appearance.
- (b) A black body appears black in any colour of light because it absorbs all the colours of the spectrum and reflects none.
- (c) A white object appears green in green light because it can only reflect the green light that shines on it.

The table 14.73 below summarizes the appearance of the colours of objects.

Colour of object	Colour of object incident on the object	What happens	Appearance of object
White	White	Reflects all colours	White
Black	Any colour of light	Absorbs all colours and reflects none	Black
White	Green	Reflects green light	Green

Table 14.73

Colour of objects can appear to change colour in other colours of light as seen in the following examples.

- ❖ A red object appears red in white or red light because it can reflect red but:
- ❖ A red object illuminated with green light will appear black because it absorbs the green light and reflects none.
- ❖ A yellow object appears yellow in white or yellow light; it reflects yellow light and usually also two primary colours, red and green, which together appear yellow ($R + G = Y$).
- ❖ If however, a yellow object is seen in any colour of light which contains some red, green or yellow light, it can reflect those colours and may appear to change its own colour, for example:
- ❖ A yellow ($R + G$) object seen in cyan ($G + B$) light will appear green because it absorbs the blue light and reflects green.

(a) Colours of light and filters

Filters can be used to produce a particular colour of the spectrum.

When light is passed through filters of various colours; the following happen to the light.

- Very little reflection occurs,
- Some small amounts of colours are transmitted and
- Some colours are absorbed.

For example a red filter absorbs all the other colours of white light. But red light passes through it. The green filter transmits only green light and a blue filter transmits blue. However, yellow filter has a different characteristic. In that it can transmit red and green lights as well as yellow light.

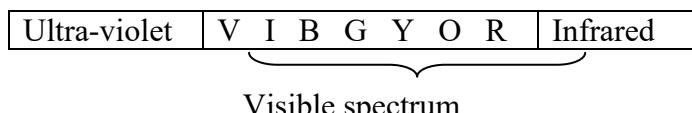
(b) Various Colours from an electric lamp

The source of light of various colours can be obtained from an ordinary electric lamp placed behind gelatine sheets of different colours. By this means the appearance of coloured objects in different colours of light can be examined.

Red objects look red in red light, while blue and green look black because they absorb the red light. Similarly a red object appears black in green light. However, a yellow object appears black only in blue or violet light. It appears yellow only in yellow light or white light. In red light it appears red and in green light green.

14.75 Infrared and Ultra-violet light

The spectrum from the sun has both visible and invisible spectrum.



Both ultra-violet and infrared are detected by a thermopile connected to a galvanometer which shows a deflection. Ultra-violet ray is found at the extreme end of the violet light colour while infrared is found beyond the red light colour. The ultra-violet can also be detected by a photographic paper which darkens when the spectrum falls on it.

Self-Check 14.7

1. A piece of white cloth viewed through a blue glass appears blue because
 - A. Blue light is absorbed by the glass
 - B. the glass adds blue light to the light coming from the cloth
 - C. the glass transmits only blue light and absorbs all other colours
 - D. the colour of the glass is reflected onto the cloth.

2. A student is holding a white paper with green printing on it. If she enters a room with red lights, she will see
 - A. black printing on a red paper
 - B. blue printing on a red paper
 - C. yellow printing on a red paper
 - D. a red printing on a white paper.

3. Which one of the following is correct?
 - (i) green light shone on the green surface is all absorbed
 - (ii) green light added equally to red light appears yellow
 - (iii) green light passes through a red filter
 - A. (ii) only
 - B. (i) and (ii) only
 - C. (ii) and (iii) only
 - D. (i), (ii) and (iii)

4. White light is separated into its component colours due to
 - A. absorption
 - B. dispersion
 - C. reflection
 - D. Transmission

5. Which of the following are secondary colours only?
 - A. Red, green and yellow.
 - B. Blue, yellow and magenta.
 - C. Yellow, cyan and magenta.
 - D. Red, green and blue.

6. Which of the following statements are true?
 - (i) surfaces which reflect all colours of light appear white
 - (ii) red surfaces absorb all colours and reflect only red light
 - (iii) black surfaces appear black because they reflect all colours
 - A. (i) only
 - B. (i) and (ii) only
 - C. (i) and (iii) only
 - D. (ii) and (iii) only

7. The secondary colours of light are cyan, magenta and yellow. Which of the following sets of addition of colours of light will produce white light
 - (i) cyan + blue and magenta + red
 - (ii) cyan + red and magenta + green
 - (iii) yellow + red and magenta + blue
 - (iv) cyan + green and yellow + blue
 - A. (i) only
 - B. (ii) only
 - C. (iii) only
 - D. (iv) only

8. Which of the following statements are true?
- (i) A magenta filter absorbs green light and transmits red and blue lights
 - (ii) A magenta filter absorbs blue light and transmits red and green lights
 - (iii) A cyan filter absorbs red light and transmits blue and green lights
 - (iv) A cyan filter absorbs blue light and transmits red and green lights
- A. (i) only B. (ii) only C. (ii) and (iv) only D. (i) and (iii) only
9. Dispersion of light is
- A. the rectilinear propagation of light.
 - B. the spreading of light around an obstacle.
 - C. the splitting of white light into its constituent colours.
 - D. the changing of direction by light when it moves from one media to another.
10. When a yellow dress with blue dots is placed in a room lit with pure red light, the dress appears
- A. red with black dots
 - B. yellow with blue dots
 - C. green with red dots
 - D. black with yellow dots.

SECTION B

11. (a) Explain the phenomenon of dispersion applied to white light.
(b) Draw a ray diagram to show the dispersion of white light by a glass prism
(c) With the aid of a diagram, explain briefly how a pure spectrum may be produced.
(d) Explain briefly what happens when white light falls on a green body.
12. (a) Distinguish between secondary and primary colours. Give one example of each.
(b) Name the colour that would be obtained when the following coloured lights are mixed.
 - (i) Green and red.
 - (ii) cyan and red.
(c) Explain why an object illuminated by white light appears.
 - (i) coloured
 - (ii) black
(d) State why most hind car registration number plates are printed black on a yellow background.

CHAPTER FIFTEEN

THERMAL PROPERTIES OF MATTER

LEARNING OBJECTIVES

By the end of this chapter, you should be able to:

1.
 - (a) Define: *Expansion and Contraction of a material.*
 - (b) Describe: *The ball & ring/The bar & the gauge experiments to demonstrate expansion and contraction in solids.*
 - (c) State
 - (i) *The applications of expansion in:*
 - (ii) *The problems caused by expansion and their solutions.*
 2.
 - (a) Define:- *Linear expansivity*
 - (b) *Solve problems involving linear expansivity.*
 3.
 - (a) Describe: *Experiments to show expansion in Liquids and Gases.*
 - (b) *Explain the anomalous behaviour of water and give its importance to aquatic animals.*
 4.
 - (a) State:
 - (i) *Any two thermometric liquid.*
 - (ii) *The properties of thermometric liquid.*
 - (iii) *Advantages of mercury over alcohol as used a thermometer.*
 - (b) Define: *The lower and upper fixed points.*
 - (c) *Solve problems involving*
 - (i) *Conversion of temperature from one scale to another.*
 - (ii) *Calculation of temperature for unmarked thermometer.*

15.1 Expansion and Contraction

Expansion is the increase in size of an object when it gets hotter. While contraction is the decrease in size of an object when it becomes colder.

(a) Expansion of solids

All solids expand when heat is applied to them. However, they do so in varying amounts.

Some solids expand very little while others expand greatly.

Expansion in solids can be investigated by using the following experiments.

- (i) The ball and ring.
 - (ii) The bar and gauge

Experiments to investigate the effect of heat on solids

Experiment 15.1 Ball and ring experiment

Apparatus/Requirements A ball and ring, source of heat

Procedure Part II

Pass the ball through the ring when cool as shown in figure 15.1 below.

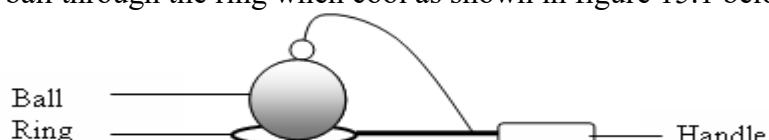


Figure 15.1

Observation: The ball passes through the ring easily.

Part II

- Heat the ball on a Bunsen burner for some time.
 - Try to pass it through the hole again

Observation: The ball does not pass through.

Explanation: When the ball is heated, it expands i.e. the size becomes bigger. As such, it can not pass through the ring.

Expedient 15.2 The bar and gauge experiment

Apparatus/Requirements A bar and gauge, source of heat

Procedure: Part I

- Pass one end of the bar through the hole on the gauge.
- Remove the bar and fix it in between the ends of the gauge as shown in figures 15.2 (a) and (b).

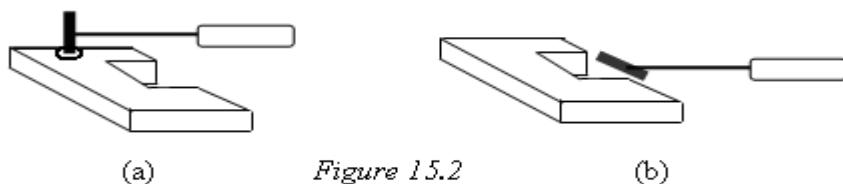


Figure 15.2

Observation: The head of the bar passes through the hole and also fits in the gauge easily.

Part II

- Heat the bar on a Bunsen burner flame for some time.
- Try to pass it through the hole and also try to fix it in the gauge.

Observation:

The head of the bar does not pass through the hole and does not fit in the gauge.

Allow the bar and the ball to cool and repeat the above procedures of passing the ball through the ring and fixing the bar in the hole and the gauge respectively.

Results: When the ball and the bar cool:

- (i) The ball passes easily.
- (ii) The bar fits in the gauge easily.

Explanation

When the bar is heated, it expands both side ways and length ways (i.e. the size becomes bigger and longer). As such, it can not pass through the hole and fit in the gauge.

Note: *The gauge shows that the bar has increased in length, which is called linear expansion. The ring shows that the diameter of the ball has increased in all directions. The expansion in area of a solid is known as superficial expansion and the expansion in volume is called cubical expansion.*

15.11 Applications of expansion in solids

- (a) **Bimetallic strip** A bimetallic strip is a strip made of two different metals welded or riveted together. When cold the double strip is straight as shown in the figure 15.3 below.

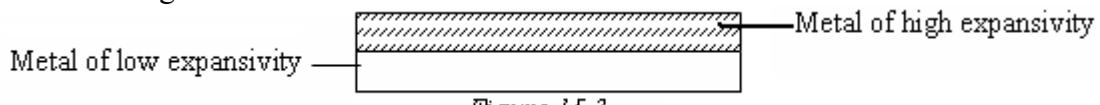


Figure 15.3

(b) Effect of heat on bimetallic strip

When a bimetallic strip is heated, the metals expand with the metal of higher expansivity expanding more than the one of low expansivity. The strip bends to form a curve with the metal of high expansivity on the inside as shown in figure 15.4 below.



Figure 15.4

Examples of a bimetallic strip are;

Brass and iron - Brass having higher expansivity than iron.

Aluminium and iron - Aluminium having higher than iron.

Question: State which metal would be on the out side and inside if the two bimetallic strips in the example above are heated.

(c) Uses of expansion in bimetallic strip

Bimetallic strips are used as electrical switches, in thermostats and many other mechanical switching devices.

Thermostat

A Thermostat is a device that automatically regulates the temperature of a system by maintaining it constant or varying it over a specific range.

A bimetal thermostat uses a special strip of metal to open and close a circuit as temperature fluctuates. Two metals with different expansion rates are bonded to make the strip. The thermostat is arranged so that when the metals are hot, the strip bends upward (toward the metal with the lower expansion rate) and disconnects the circuit. In this particular case, the thermostat will activate a heater when the circuit is closed and electricity is flowing.

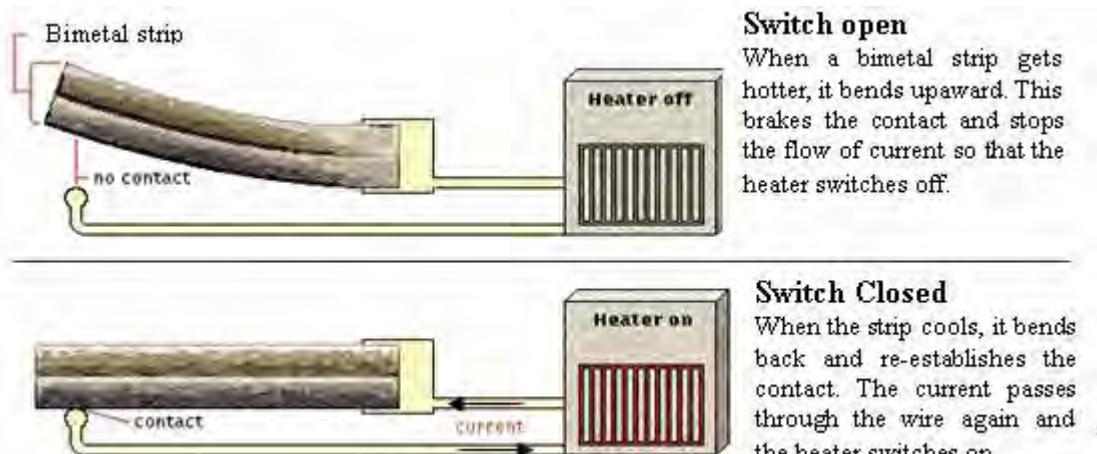


Figure 15.4

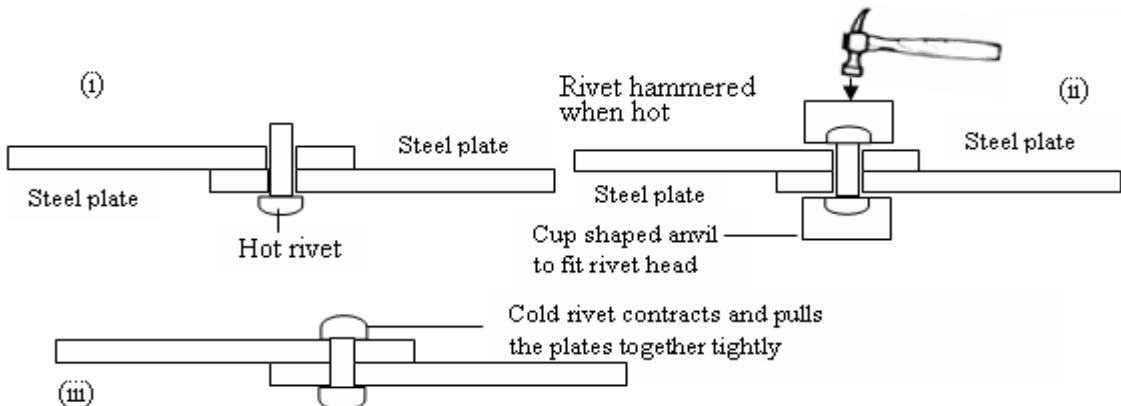
Note: Increasingly, the use of bimetallic strip for this purpose is being replaced by electronic circuits with no moving parts.

(a) Tight fitting of

(i) Riveting

Expansion and contraction is used in riveting to get a tight joint of two or more metal plates.

- A hot rivet (expanded) is pushed through a hole in the two plates or rods to be joined.
- The end of the hot rivet is hammered to form another.



Results: As the rivet cools it contracts and pulls the two plates more tightly.

(ii) Steel tyres onto cart and train wheels

The steel tyre is designed to just fit when it is red hot. As it cools down, it tightens and grips on the wheel.

(iii) Wheel and axles

The same method is also used in fitting wheels on to axles.

(b) Steel bridges

Girder bridges made of steel. During cold weather the bridge contracts and becomes shorter. And during hot weather, it expands and becomes longer. In order to allow for expansion and contraction, one end of the bridge is fixed and the other end is placed on rollers as shown in figure 15.6 below. This enhances the *to* and *fro* movement during expansion and contraction.

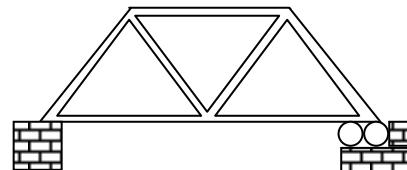


Figure 15.6

(c) Railway lines

Railway tracks have been bent and seriously damaged due to expansion during very hot days where the gap allowed for expansion was too small. Now to allow room for expansion and contraction, fairly large gaps are left between the sections of rails. And the sections are held together by fish plates fixed by bolts in oval shaped holes.

(d) Pipelines

Pipelines carry steam, liquids and gases from one point to another. The pipes contract when cold and expand when hot. To avoid breakage of the pipes due to the force of expansion and contraction, the pipes are fitted with loops or expansion joints. The joints and loops allow the pipes to expand and contract when steam passes through and when it cools down.

(e) Electricity and telephone lines

During cold weather especially at night hours, telephone wires contract and when it is hot during the day, they expand. During cold weather (from evening up to early morning hours) electricity/telephone wires contract. The wires become shorter and taut. And during the hot afternoon hours, the wires become longer and slack.

To avoid the wires from cutting, they are fixed loosely to allow contraction and expansion.

15.2 Linear expansivity

The change in the length of a substance during expansion is called *linear expansion*.

And

the measure of the tendency of a particular material to expand is called its *expansivity*. The lengthways expansivity of a material is called its *linear expansivity* and is given by the symbol α (alpha).

Formula of linear expansivity

Definition:

Linear expansivity is defined as: *The increase in length of a unit length of a material for a degree rise in temperature.*

$$\text{I.e. Linear Expansivity} = \frac{\text{Linear Expansion}}{\text{Original length} \times \text{temperature rise}}$$

S.I Unit of Linear expansivity

The S.I unit of linear expansivity is a derived unit.

$$\begin{aligned} &= \frac{m}{m \times {}^\circ\text{C}} \\ &= {}^\circ\text{C}^{-1} \text{ or } \text{K}^{-1} \end{aligned}$$

By re arranging the formula for linear expansion we obtain a formula which can be used to calculate expansion of things like bridges and railway lines.

$$\text{Linear expansion} = \text{Linear expansivity} \times \text{Original length} \times \text{temperature rise}$$

Factors which determine linear expansivity

The linear expansion or change in length Δl of a material depends on three things:

- The length of the material, l .
- The change (rise) in temperature
- The linear expansivity of the material

Worked example

- Calculate the linear expansion of aluminium cable 50 m between two electric poles when the temperature rises by 40°C . The linear expansivity of aluminium is $2.6 \times 10^{-5}/{}^\circ\text{C}$

Solution $\Delta l = ? \quad \alpha = 2.6 \times 10^{-5}/{}^\circ\text{C}, l = 50\text{m}$

$$\begin{aligned} \Delta l &= \alpha l \Delta \theta \\ &= 2.6 \times 10^{-5} \times 50 \text{ m} \times 40 {}^\circ\text{C} \\ &= 5.2 \times 10^{-2} \text{ m} \end{aligned}$$

Answer: The aluminium will increase in length by 5.2×10^{-2} m or 0.052 m or 5.2 cm.

15.3 Expansion in liquids

All liquids like solids expand with varying amounts. Some expand more than others.

Experiment 15.3 To demonstrate expansion of water

Apparatus: A round bottom flask, capillary tube, source of heat, a cork and a liquid.

Procedure

- Fill a round bottom flask up to the brim with liquid (e.g. water).
- Insert a capillary tube through a cork and cork the flask.
- Mark the level of liquid in the glass tube.

- Set up the apparatus as shown in figure 15.7 below.

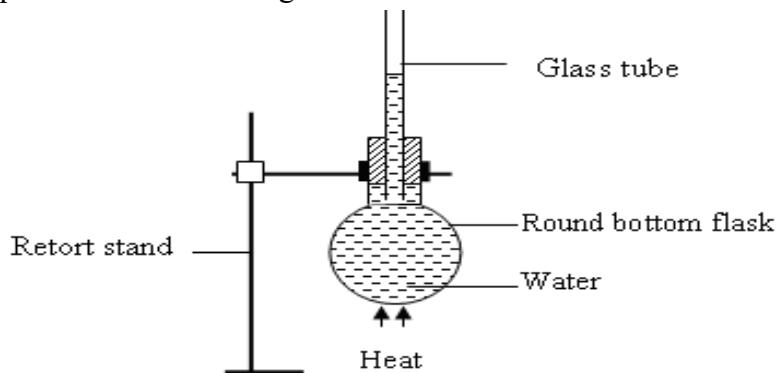


Figure 15.7

- Heat the flask as you observe the level of the water in the tube.

Observation: First the level of the water falls and then starts to rise again.

Explanation

(i) The fall of water level

The initial fall of water level is due to the expansion of the glass flask, which gets heated first and expands. The expansion of the flask results to increased volume of the flask. So water moves in to fill the extra volume.

(ii) The rise of water level

Finally, the heat reaches the water and starts to expand, thus rising up the glass tube.

Note that: Water expands faster than glass.

15.31 Comparison of expansion of different liquids.

Expansion in different liquids can be compared by filling the liquids in different flasks of the same size and type.

Experiment 15.4 To compare the expansion of different liquids e.g. water, alcohol, methylated spirit, ether, benzene

Apparatus: Four identical flasks, trough, water, stirrer, source of heat

Procedure

- Fill the flasks with the liquids to the same height/level and then place them in water in a trough as shown in figure 15.8 on page 276.

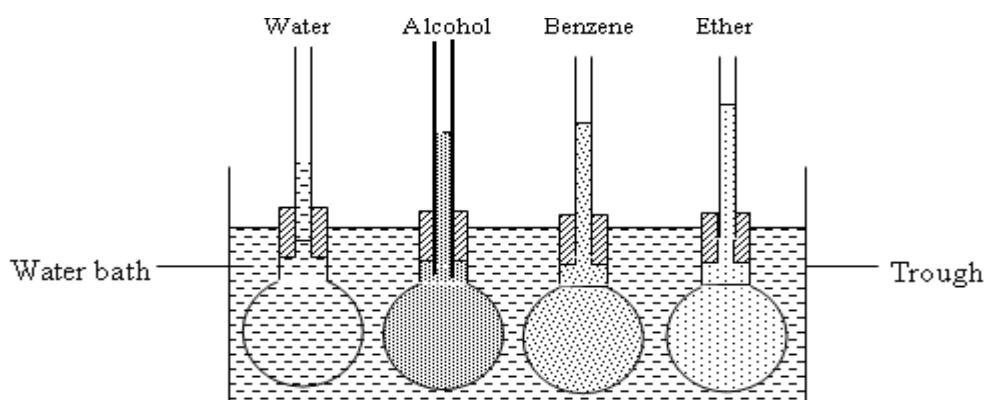


Figure 15.8

- Heat the water bath while stirring.
- Observe the levels of the liquids in the flasks

Observation: The levels of the liquids in the tubes first fall and then rise by different amounts as the heating continues.

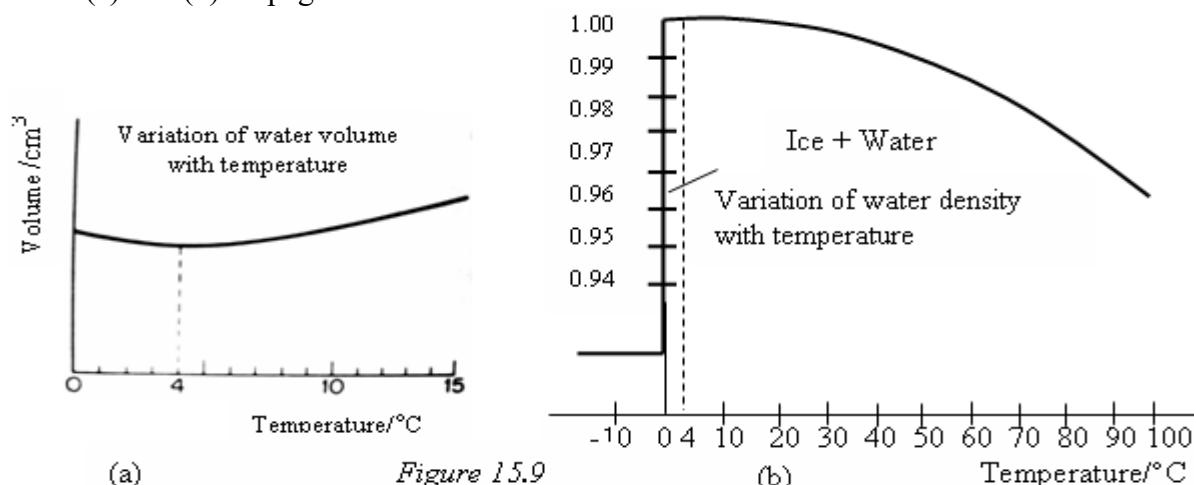
Result: The result shows that ether expands most followed by benzene while water being the least.

Conclusion: The above observation shows that some liquids expand more than others for a given rise in temperature.

15.32 The expansion of water

Most liquids contract steadily as they cool, and contract further on reaching their freezing point. Water contracts as it cools down from 100°C to 4°C. However, between 4°C and 0°C, water behaves unusually in that it expands as it gets cooler with its minimum volume at 4°C. This behaviour of water is described as anomalous (irregular). When water freezes its volume increases by about 8%, which is a much larger increase in volume than occurs between 4°C and 0°C.

The change in volume/density of water with temperature as shown in the figures 15.9 (a) and (b) on page 277.



The importance of the anomalous expansion of water

When a pond is freezing over, density of water at 4°C remains at the bottom of the pond.

The less dense (but lower temperature) water, between 3°C and 0°C, floats in layers above it. The water on the surface is frozen, but floats because it is less dense than the water below it. The different density layers stop convection currents spreading the heat. Ice is a bad conductor of heat so that the layer of ice on the top of a pool acts like an insulating blanket and slows further loss of heat from the water below.

Aquatic animals and plants make use of this phenomenon, by living in the liquid layer when the water freezes over in the winter.

15.4 Expansion in gases

Experiment 15.5 To show expansion in gases

Apparatus: A round bottom flask fitted with glass tube, water, trough and source of heat from Bunsen burner.

Procedure

- Fill a trough with clean water.

- Pass a glass tube through a cork and invert the cork into a round bottom flask.
- Dip the tube in the water in the trough.

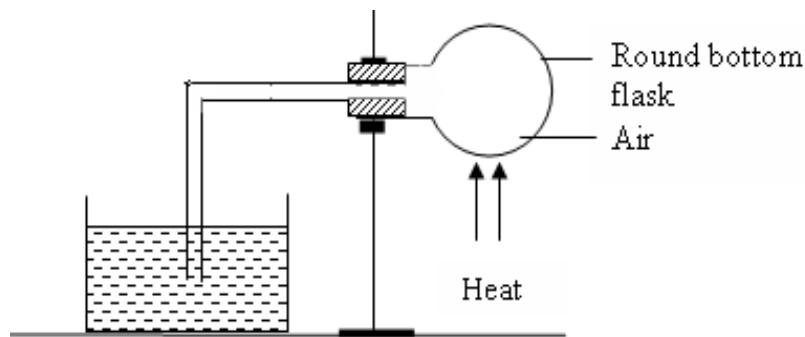


Figure 15.10

- Heat the flask by directing a Bunsen burner flame to it for a short time.
- Observe the water level in the tube.
- Allow the flask to cool while the tube is still in the water. Observe what happens.

Observation: When the flask is hot, the level of the water in the glass tube falls and air bubbles are released.
On cooling, the water level rises up the glass tube.

Explanation

- When the flask is heated the air inside expands. This forces some air out of the flask. Thus bubbles of air are seen as the air escapes.
- As the air in the flask cools, it contracts creating more space and reducing the pressure, then the atmospheric pressure acting on the surface of the water pushes water into the glass tube.

15.5 HEAT AND TEMPERATURE

Heat and measurement of temperature

Heat - is a form of energy which when absorbed by an object makes it hotter and when lost by an object leaves it colder.

Temperature - is the degree of hotness or coldness of a body.

Words such as warm, hot, tepid, cool and cold tell u about the temperature of an object. The words are not very precise, so if we need to be more accurate about the temperature of an object, we use a thermometer graduated with some scales called temperature scales.

NB: Temperature is the measure of how hot or cold a body is and should **not** be confused with the amount of heat the body contains.

(a) Thermometers

Definition: A thermometer is an instrument used to measure temperature.

A number of different types of thermometer are available. Each type of thermometer makes use of a particular thermometric property i.e. a property that changes with temperature. Examples of such properties are:

(i) Change in length of liquid column

- (ii) Increase in electrical resistance

The most common type of thermometer is the liquid-in-glass thermometer. Thermometric liquids used in liquid-in-glass are:

- mercury and alcohol.

(b) Properties of thermometric liquids

A thermometric liquid should have the following properties:

- (i) Should be opaque for easy reading.
- (ii) Good conductor of heat.
- (iii) High and uniform expansivity.
- (iv) High boiling point.
- (v) Low freezing point and
- (vi) Should not wet glass.

Mercury and alcohol compared

Mercury	Alcohol
(i) Opaque and therefore can easily be read	- Not opaque but can be coloured.
(ii) Good conductor of heat therefore sensitive to small temperature changes.	- Poor conductor of heat therefore not so sensitive to small temperature changes
(iii) Has uniform expansivity	- Expansion not so regular
(iv) Has high boiling point (357°C) and therefore can measure high temperatures	- Low boiling point (78°C) and therefore not suitable for measuring high temperatures
(v) Not very low freezing point (-39°C) therefore can not measure temperatures below its freezing point.	- Low freezing point (-115°C)
(vi) Does not wet glass	- Wets glass

(c) Advantages of alcohol over mercury as thermometric liquid

1. It has higher expansivity (about six times) than mercury.
2. It has lower freezing point than mercury. Alcohol freezes at -115°C while mercury freezes at -39°C . The high freezing point of mercury makes the measurement of temperatures lower than -39°C to be impossible.

Apart from the disadvantage, mercury is preferred to alcohol for the following reasons.

- (i) It is a better conductor of heat than alcohol and therefore responds more readily to changes in temperature.
- (ii) It is opaque and makes reading easy.
- (iii) It has a high boiling point, 357°C and whereas alcohol has low boiling point, 78°C , can easily vaporize to fill the upper part with vapour.

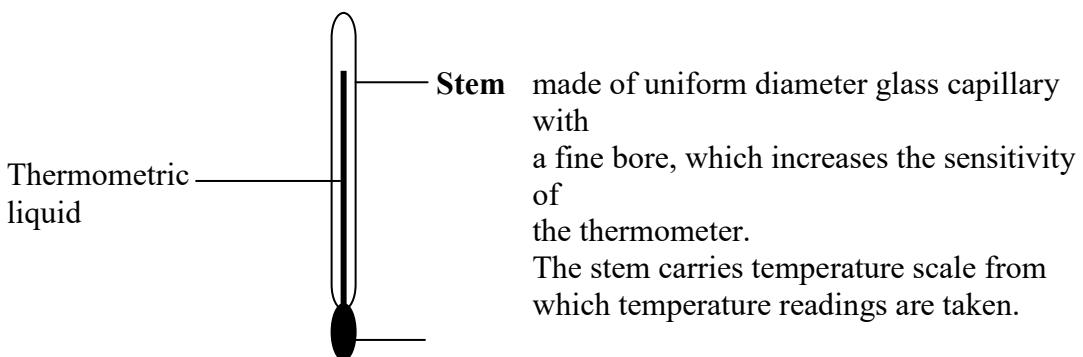
(d) Reasons why water is not used as a thermometric liquid

Water is unsuitable for use in thermometers because of the following reasons.

- (i) It freezes at 0°C .
- (ii) It has irregular expansion.

15.41 Structure of a liquid in glass thermometer

A *liquid-in-glass* thermometer consists of the following features.



Stem made of uniform diameter glass capillary with a fine bore, which increases the sensitivity of the thermometer. The stem carries temperature scale from which temperature readings are taken.

Bulb The bulb contains the bulk of the thermometric liquid.

(f) How to use a thermometer

The bulb is inserted or placed in contact with the object /substance whose temperature is to be measured.

The liquid in the bulb will either:

- (i) Acquire heat energy from the substance and expand making its level rise or
 - (ii) Loses heat energy to the substance making its level to fall.
- The temperature value is then read at the liquid level which directly corresponds on the temperature scale.

15.42 Graduation or Calibration of a thermometer

In order to establish a temperature scale, we choose two *fixed points*. A fixed point is a definite temperature at which a change of state occurs.

The two fixed points chosen are called *lower fixed point* and *upper fixed point*.

(a) Lower fixed point - is the temperature of pure melting ice at standard atmospheric pressure (i.e. at pressure 760mmHg).

(b) Upper fixed point -is the temperature of steam from pure water boiling under standard atmospheric pressure.

NB: The ice and the water must be pure because the presence of impurities lowers melting point of ice and elevate the boiling point of water.

Finding the fixed points of a thermometer

(a) Lower fixed point

- Freeze some pure (distilled) water.
- Crush the ice into small pieces and fill a filter funnel with the pieces and wait for the ice to begin melting.
- When the ice begins to melt (i.e. at 0°C) insert the bulb of the thermometer so that it is covered with ice, figure 15.11 (a). The melting ice cools the mercury to 0°C.
- When the mercury stops shrinking (i.e. when the level becomes constant), mark the stem of the thermometer at the mercury level.
- This point is the lower fixed point, or the ice point on Celsius scale.

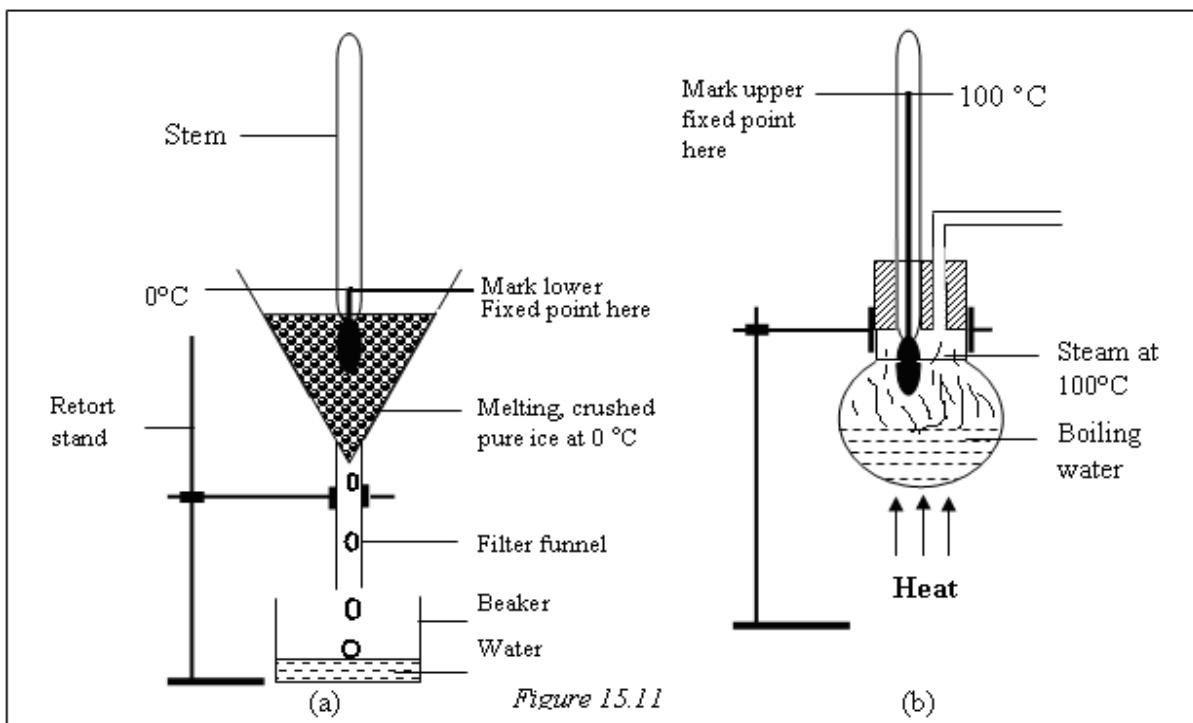
(b) Upper fixed point

- Remove the thermometer and insert it through a two holed cork.
- Fill a flask with pure water and cork it with the cork carrying the thermometer and a delivery tube such that the bulb is just above the water surface, figure 15.11 (b).
- Heat the water in the flask to a boiling point.

- When the mercury stops expanding (i.e. when the level becomes constant) mark its level on the thermometer stem.

This point is the upper fixed point, or steam point (100°C) on the Celsius. Then divide the difference between the two points into 100 equal points. Mark the points as a scale along the stem either in Celsius scale or Kelvin or both.

Finding the fixed points of a thermometer



15.5 Temperature Scales

There are two common scales of temperature, namely:

- Celsius Scale and
- Kelvin Scale

(a) Celsius scale (Centigrade)

The centigrade or Celsius scale assigns a value of 0°C to the freezing point and 100 to the boiling point of pure water. It is defined by dividing the fundamental difference (the difference between the upper and lower fixed points) into 100°C equal degrees. The temperatures on this scale are called “Degree Celsius”.

(b) Kelvin scale (Thermodynamic Scale)

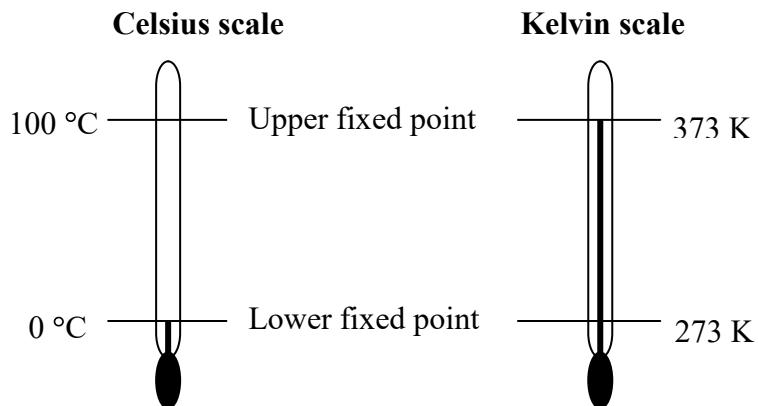
In the Kelvin or absolute scale, the lower fixed point is 273.15 K and the upper fixed point is 373.15 K. The *Kelvin* (K) is the S.I unit of temperature.

- Note:**
- The degree intervals are identical to those measured on the Celsius scale.*
 - Absolute zero is approximately -273.15°C or zero (0 K) degree on the Kelvin scale.*
 - Absolute zero is the lowest possible temperature. It is characterized by complete absence of heat energy.*
 - Temperatures on Kelvin do **not** have degree symbol (°).*
 - One Kelvin is the same as one Celsius. I.e. $1\text{ K} = 1^{\circ}\text{C}$*

15.51 (a) Relationship between Celsius scale and Kelvin scale

The two temperature scales are related to each other as shown below.

Fixed point	Celsius scale	Kelvin scale
Lower fixed point	0	273
Upper fixed point	100	373



(b) Conversion of temperature from one scale to another

The temperature value, θ , on Celsius scale is related to the temperature value, T on Kelvin scale by the formula:

$$\begin{aligned} \theta &= T - 273 \\ \text{Or} \quad T &= \theta + 273 \end{aligned}$$

Worked Examples

1. Convert the following temperature readings to Celsius scale.

$$(a) \quad 1010 \text{ K} \quad (b) \quad 233 \text{ K} \quad (c) \quad 373 \text{ K}$$

2. Convert the following temperature readings to Kelvin scale.

$$(a) \quad 240 \text{ }^{\circ}\text{C} \quad (b) \quad 30 \text{ }^{\circ}\text{C} \quad (c) \quad 120 \text{ }^{\circ}\text{C}$$

Solution

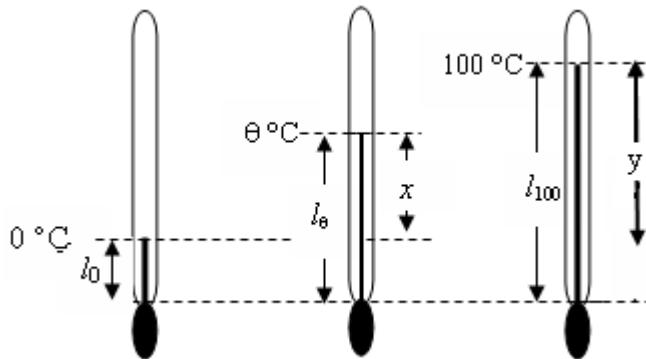
$$(a) \quad \theta = ?, \quad T = 1010 \text{ K}, \quad (b) \quad \theta = ?, \quad T = 233 \text{ K}, \quad (c) \quad \theta = ?, \quad T = 273 \text{ K},$$

$$\begin{array}{lll} \theta = T - 273 & \theta = T - 273 & \theta = T - 273 \\ = 1010 - 273 & = 233 - 273 & = 373 - 273 \\ \therefore \theta = 737 \text{ }^{\circ}\text{C} & \therefore \theta = -40 \text{ }^{\circ}\text{C} & \therefore \theta = 100 \text{ }^{\circ}\text{C} \end{array}$$

2. (a) $\theta = 240 \text{ }^{\circ}\text{C}$, $T = ?$ (b) $\theta = 30 \text{ }^{\circ}\text{C}$, $T = ?$ (c) $\theta = 120 \text{ }^{\circ}\text{C}$, $T = ?$

$$\begin{array}{lll} T = \theta + 273 & T = \theta + 273 & T = \theta + 273 \\ = 240 + 273 & = 30 + 273 & = 120 + 273 \\ \therefore T = 513 \text{ K} & \therefore T = 303 \text{ K} & \therefore T = 393 \text{ K} \end{array}$$

- (c) Calculating the temperature values when the lengths of the thermometric liquid for the lower and upper fixed points are given



From the diagram: l_0 = the length of mercury column at $0\text{ }^{\circ}\text{C}$.

l_{100} = the length of mercury column at $100\text{ }^{\circ}\text{C}$.

l_θ = the length of mercury column at unknown temperature, $\theta\text{ }^{\circ}\text{C}$.

$$x = (l_\theta - l_0)$$

$$y = (l_{100} - l_0)$$

$$\begin{aligned}\text{Temperature, } \theta, \text{ in } ^{\circ}\text{C} &= \frac{\text{Mercury length above}}{\text{Fundamental difference}} \times 100 \\ &= \frac{l_\theta - l_0}{l_{100} - l_0} \times 100 \\ \therefore \theta &= \frac{x}{y} \times 100\end{aligned}$$

Worked Examples

1. A mercury thermometer is calibrated by immersing it in melting pure ice and then in boiling pure water. If the mercury columns are 6 cm and 16 cm respectively, find the temperature when the mercury column is 8 cm long.

Solution $l_0 = 6\text{ cm}$, $l_{100} = 16\text{ cm}$, $l_\theta = 8\text{ cm}$, $\theta = ?$

$$\theta = \frac{l_\theta - l_0}{l_{100} - l_0} \times 100 = \frac{8 - 6}{16 - 6} \times 100 = \frac{2}{10} \times 100 = 20\text{ }^{\circ}\text{C}$$

2. The length of mercury column of a thermometer at ice point and steam point are 2.0 cm and 22.0 cm respectively. The reading of the thermometer when the mercury column is 9.0 cm long is

- A. $45.0\text{ }^{\circ}\text{C}$ B. $40.9\text{ }^{\circ}\text{C}$ C. $35.0\text{ }^{\circ}\text{C}$ D. $31.8\text{ }^{\circ}\text{C}$

Solution $l_0 = 2.0\text{ cm}$, $l_{100} = 22.0\text{ cm}$, $l_\theta = 9.0\text{ cm}$, $\theta = ?$

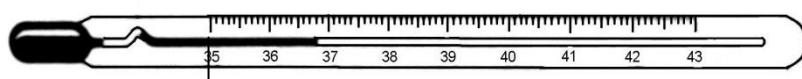
$$\theta = \frac{l_\theta - l_0}{l_{100} - l_0} \times 100 = \frac{9.0 - 2.0}{22.0 - 2.0} \times 100 = \frac{7.0}{20.0} \times 100 = 35\text{ }^{\circ}\text{C}$$

Therefore the answer is C.

Other types of thermometers

Other types of thermometers include:

- (i) Clinical thermometer - Used by doctors in hospitals and clinics.



Constriction

- Causes break to the mercury thread and stops the thread above it from moving back in to the bulb.
- It enables the doctors to take the reading at their own time.

NB: Before use on another patient the thermometer is shaken to let the mercury thread to move in to the bulb.

- (ii) Thermocouple
- (iii) Resistance thermometer
- (iv) Thermister
- (v) The constant-volume gas thermometer
- (vi) The maximum six fixed thermometer

Self-Check 15.0

1. The distance between the fixed points on mercury in glass thermometer is 25cm. What is the temperature in degrees Celsius if the mercury thread is 8cm long?
 A. $\frac{100 \times 25}{8}$ B. $\frac{100 \times 8}{25}$ C. $\frac{25 \times 8}{100}$ D. $\frac{100 \times 25}{10}$
2. Which one of the following fluids is the best conductor of heat?
 A. Air B. alcohol C. water D. mercury
3. The graph in the figure shows water being heated from -10°C to 100°C .

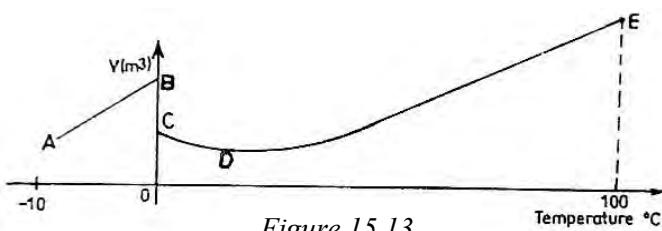


Figure 15.13

At what point does the substance have maximum density?

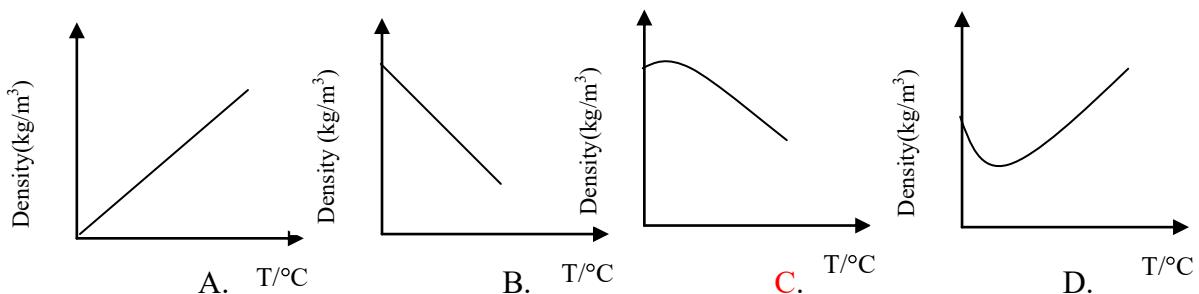
- A. E
- B. C
- C. D
- D. B

4. A bimetallic strip operates on the principle that metals
 - A. are heat controllers.
 - B. are good heat conductors.
 - C. have different rates of expansion.
 - D. have the same rates of expansion.
5. In order to make a mercury thermometer more sensitive, the
 - A. degree markings must be further apart.
 - B. diameter of capillary tube must be reduced.
 - C. volume of the mercury bulb must be reduced.
 - D. capillary tube must be open to air.
6. A tight bottle top becomes easier to unscrew when hot water flows over it because the
 - A. cap expands more than the glass
 - B. glass in the neck of the bottle contracts
 - C. hot water acts as oil between the glass and the bottle
 - D. increased pressure of the air in the bottle causes the cap to expand

7. Which of the following changes occur when a metal block is heated?

	Volume	Mass	Density
A	increases	remains the same	decreases
B	increases	increases	increases
C	remains the same	remains the same	decreases
D	increases	remains the same	increases

8. The distance between the lower and the upper fixed points on the Celsius scale in unmarked mercury-in-glass thermometer is 25cm. If the mercury level is 5cm below the upper fixed point, then the temperature is
 A. 5°C B. 20°C C. 80°C D. 95°C
9. The unusual expansion of water when it is cooled between 4°C and 0°C is due to
 A. water molecules coming closer together to form a compact structure
 B. formation of a new arrangement of molecules which requires a large volume
 C. the increased repulsive forces between the water molecules
 D. differences in the sizes of water and ice molecules
10. Which one of the following graphs shows how the density of water varies with temperature between 0°C and 100°C ?



SECTION B

1. (a) Define the following terms.
 (i) Expansion
 (ii) Contraction of a material.
 (b) Describe an experiment to demonstrate expansion and contraction in solids.
 (c) State any one application of expansion in solids.
2. (a) Define linear expansivity of a material.
 (b) Calculate the linear expansion of concrete bridge of span 100m when the temperature rises by 20°C . The linear expansivity of concrete is $1.2 \times 10^{-5}/^{\circ}\text{C}$
3. (a) Describe an experiments to show expansion in Liquids.
 (b) Explain the anomalous behaviour of water and give its importance to aquatic animals.
4. (a) State: (i) Any two thermometric liquids you know.
 (ii) The properties of a thermometric liquid.
 (iii) Advantages of mercury over alcohol as used a thermometer.
- (d) Define the following terms.
 (i) Lower fixed point.
 (ii) Upper fixed points.
 (c) Describe how the fixed points of a thermometer are determined in the laboratory.

5. The interval between the ice and steam points on a thermometer is 192 mm. Find the temperature when the length of the mercury thread is 67.2 mm from the ice point.
6. The distance between the lower and upper fixed points on the Celsius scale in unmarked mercury-in-glass thermometer is 25 cm. If the mercury level is 5 cm below the upper fixed, calculate the temperature value.
7. Convert the following temperature readings to Celsius scale.
(a) 750 K (b) 400 K (c) 973 K
8. Convert the following temperature readings to Kelvin scale.
(a) 340 °C (b) 130 °C (c) 20 °C
9. (a) Name any two physical properties, which change with temperature.
(b) Explain why gaps are left between rails in a railway line.
(c) Why do gases expand much more than solids for the same temperature change?
(d) Name one application of a bimetallic strip.
(e) Mention any three reasons for not using water as a thermometric liquid.
10. Figure 15.13 shows strips of copper and iron bonded together.



Figure 15.13

- (a) Redraw the diagram to show what happens when the strip is heated.
- (b) Why does the change you have shown in (a) take place?

ANSWERS TO SELF-CHECK QUESTIONS

CHAPTER	SELF-CHECK NUMBER	NEMERICAL ANSWERS
2	2.0	<p>1. (b) 24.8 mm or 2.48 cm or 0.0248 m (c) (i) 4.27 cm or 0.0427 m (ii) 10.63 cm or 0.1063 m</p>
		<p>2. (b) (i) 6.68 mm (ii) 7.47 mm (iii) 9.74 mm</p>
	2.1	<p>1. (a) (i) 10 km (ii) 2 000 cm (b) (i) 25 000 g (ii) 2 kg (c) (i) 43 200 s (ii) 900 s (d) (i) 0.02 m³ (ii) 50 000 000 cm³ Or 5×10^7 cm³</p>
		<p>1. (a) 3 (b) 1 (c) 4 (d) 4 (e) 1 2. 34.1 mm 3. (a) 15 m² (b) 80 m³</p>
	2.3	<p>(a) (i) 2.22×10^{-4} (ii) 2.5×10^{-3} (b) (i) 5.62×10^3 (ii) 7.5×10^4 (c) (i) 1.2×10^{11} (ii) 2×10^1 (d) (i) 5×10^0 (ii) 1.1×10^3 (e) (i) 2.5×10^4m (ii) 2.5 kg (iii) $11 \times 10^{-2}(10^{-2})$</p>
	2.4	<p>1. A. 2. B. 3. D. 4. C. 5. D. 6. B. 7. B. 8. D. 9. D. 10. B. 11. B. 12. B. 13. D. 14. A. 15. B.</p>
3	3.0	<p>1. D. 2. D. 3. C. 4. B. 5. C. 6. C. 7. D. 8. B. 9. A. 10. B. 11. A. 12. A. 13. B. 14. B. 15. B. 16. D. 17. B. 18. D. 19. A. 20. C.</p>

7	7.0	1. B. 2. D. 3. D. 4. D. 5. B. 6. B. 7. D. 8. B. 9. D. 10. C. 11. C. 12. B. 13. C. 14. C. 15. D. 16. C. 17. D. 18. B. 19. B. 20. D. 21. A. 22. C. 23. D. 24. D. 25. C.
	SECTION B 26. (c) (i) 17 500 J (ii) 3 500 W 27. (c) 60 W 28. (c) (i) 3 240 J (ii) 648 W	
8	8.0	1. A. 2. A. 3. C. 4. A. 5. B. 6. B. 7. B. 8. B. 9. B. 10. C. 11. A. 12. C. 13. D. 14. B. 15. B.
		SECTION B 16. (c) (i) 4 (ii) 75% 18. (b) (ii) 3 (iii) 0.8 m (iv) 400 N (v) 80% 20. (a) 4 (b) 75% 21. (i) 2 (ii) 1 N (iii) 100% 22. (a) (i) 4 (ii) 75% (b) (i) 0.25 (ii) 1 200% 23. (a) 200 N (b) 3
9	9.0	1. B. 2. C. 3. B. 4. C. 5. C.
	9.1	1. A. 2. C. 3. D. 4. B. 5. A. 6. B. 7. B. 8. B. 9. D. 10. B. 11. D. 12. A. 13. B. 14. B. 15. C. 16. B. 17. A. 18. A. 19. C. 20. A. 21. D. 22. C. 23. D. 24. B. 25. B.
SECTION B 26. (b) (i) 4 : 5 (ii) 15 cm 27. (a) (iv) 30 800 N 28. (b) (ii) 1 250 N m ⁻² 29. (b) (ii) 800 m		

12	12.0	1. A. 2. B. 3. C. 4. B. 5. B. 6. D. 7. B. 8. A. 9. D. 10. A. SECTION B 1. (e) 70 000 N 2. (b) (i) 420 ms ⁻¹ (ii) 1 760 J 3. (c) (i) 12 ms ⁻¹ (ii) 33.33 N 4. 1 m/s 5. (b) 2 ms ⁻¹ 6. 10m/s
13	13.0	1. D. 2. B. 3. C. 4. D. 5. A. 6. C. 7. D. 8. D. 9. D. 10. B. 11. D. 12. D. 13. C. 14. B. 15. A. SECTION B 3. (c) 175 N
14	14.1	1. C. 2. B. 4. (a) (iii) 1.4
	14.2	1. C. 2. B. 3. C. 4. C. 5. D.
	14.3	1. A. 2. A 3. A. 5. (a) $8\frac{4}{7}$ cm (b) $\frac{3}{7}$
	14.4	1. D. 2. C. 3. A. 4. A. 5. D. SECTION B 6. (c) 38.12° 8. (b) 30.87° 10. (a) 19.47° (b) 10.53°
	14.5	1. B. 2. A. 3. D. 4. D. 5. A. SECTION B 8. (a) 10 D
	14.6	2. (i) 52.37° (ii) 37.37° 3. 41.8°
	14.7	1. C. 2. A. 3. A. 4. B. 5. C. 6. B. 7. B. 8. D. 9. C. 10. A.
15	15.0	1. B. 2. D. 3. C. 4. C. 5. B. 6. A. 7. A 8. B. 9. B. 10. C. SECTION B 2. 2.4×10^{-2} m 5. 35 °C 6. 20 °C 7. (a) 477 °C (b) 127 °C (c) 700 °C 8. (a) 613 K (b) 403 K (c) 293 K

FOREWORD

The idea of publishing this book was born after realising the difficulty involved in establishing a sound library for the school. This is due to the fact that text books are too expensive to afford if every student is to have access to them.

The school administration and the teaching staff have therefore offered to subsidize the cost of text books in terms of service and materials to allow every student to afford these books.

I therefore thank the teachers so much for their unending endeavors in preparing these books with the aim of facilitating our students' learning.

Thank you indeed.

**HEADMASTER
FOR ADMINISTRATION**

MASTER KEY TO 'O' LEVEL PHYSICS S.3 & S.4 EIGHTH EDITION 2017

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PREFACE

Basic knowledge about our world is rapidly increasing as a result of the advancement in all scientific fields. This expansion results in the application of much of this knowledge in our modern society. Therefore, at no other time in our history has it been as important as it is today for students to understand *physical laws* or *principles* and their applications in daily life. It is the laws and concepts of physics that often help us to describe and give scientific explanation to the both naturally and artificially phenomenon that occur around us and deep in the space beyond our planet.

Secondary School is the starting point for students who select scientific careers in later life. The “*Master Key to Physics*” presents a modern and easy approach to the teaching of physical science at secondary level with specific emphasis on fundamental principles and concepts.

This book helps students to know the *what*, *why* and *how* of physics at secondary level. The contents of the book are based on students’ common activities, interests, and experiences. All the concepts and principles dealt with in each unit relate to the central theme of the unit. They offer the student an opportunity to explore the field in depth, and to experience some of the excitement that comes with the discovery of new ideas.

Mathematical problems are one of the more serious difficulties encountered in a course in physics. They always tend to make the subject difficult to students. In this book, as each new kind of problem appears, a detailed example is given. Some of the examples begin with *Steps in solving problems*, which help to the student to develop sense of direction. The steps in these examples are explained into detail. The examples are immediately followed by Self-Check questions to confirm the understanding of the problem. The questions range from simple ones to more difficult ones. Throughout the book there are many simple experiments with plenty of guidance on the results of these experiments.

Every important definition or formula is highlighted or *italicized*.

In calculations, simple numbers have been used to keep the arithmetic as straight-forward as possible. There is orderly flow of information in solving example.

Finally, it is my sincere hope that the users of this will find this it useful and be forced to agree that indeed it is a “*Master Key*” to Physics which is widely believed to be “*unlockable*”.

ACKNOWLEDGEMENT

I am grateful to all the people who helped either directly or indirectly in writing of this book. I would like to thank the administration of Light Academy for the encouragement and financial support towards the printing of the book.

I also wish to express my gratitude to my colligues Mr. Hakan Ulus and Mr. Enos for proof reading the book.

Finally, I would like to thank the director Mr. Ilihan Edogan for supporting the idea of writing the book to up lift the standard of the school.

DEDICATION

I dedicate this book to my late parents, Late Dega Nassur and Late Odaya Jenner, may the Almighty Allah rest their souls in eternal peace, my guardian Mr. Yasin Mustafa who has been the driving force behind my education, brothers, sisters and finally to friends who missed my company during the period of compiling the book. May Almighty Allah bless us all!!

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HOW TO USE THIS BOOK

The “**Master Key to Physics**” aims at giving you the opportunity to understand the basic principles of Physics and practice your Physics by giving detailed examples and self-check questions on topics that form the core of all „O“ level syllabuses. Each chapter begins with *chapter outline* and *learning objectives*. The learning objectives tell you about the most important ideas and areas in that chapter. These will help you to have the idea of what you should cover in any topic and prepare for the work on that chapter. And help you to remain focused when revising that chapter. And once you have an idea of what you should cover in any topic, you can start on the self-questions. There are two types of questions:

- Worked examples and Self-Check questions.

The examples and the questions are either from **UNEB** examination papers or are specially devised to fill in gaps and avoid unnecessary repetition. They are all of „O“ level standard, but some are of course easier than others. They are worked a little more detailed than those we would expect from a good candidate. This is to ensure clarity.

With each example you should gain confidence and improve your technique. Once you have studied the examples, try the self-check questions before checking the answers.

Note: The examples can be used in a variety of ways, but a suggested routine is:

- Read the question carefully. So many marks are lost by careless reading which leads to misfiring of the question.
- Without looking at the answer, have a go at answering it in note form with sketch diagrams where necessary. Consult the start of the chapter and your text book at this stage. Try the numerical problems.
- Consult the answer to find out if and where you have gone wrong and go through it very carefully. Follow any algebra through stage by stage. But **do not** just find your mistakes- learn from them.

A common question that an „O“ level student will ask is: Many people say that Mathematics is the mother of Science. What if my mathematics is **not** strong?

If you are having trouble with the mathematics, read through the working very carefully ask someone to explain for you the steps you do not understand. If you consult a mathematics text book remember that it may go into much more detail than you need. But do not worry too much since the examination board is aware of the problem and try to make sure that they are testing mainly your physics and not your mathematics. But of course you do not have to relax, rather work hard to develop your mathematics strongly.

Abbreviations/Symbols

Physics all over the world use a consistent set of symbols and abbreviations. You should be familiar with them. Most of the symbols used in physics are Roman and Greek letters. Some of which are: α - Alpha, β - Beta, γ - gamma, λ - lambda, μ - mu, θ - theta, η - eta, ϕ - phi, ρ - rho, and π - pi.

Study Skills

What kind of learner Are you?

To get the most out of your studies, you should find out how you learn best – that is, what kind of learner you are.

Types of learners

There are three types of learners, namely:

- auditory learner
- visual learner
- kinesthetic learner

- An *auditory learner* learns by listening. If you are an auditory learner, you should find friends to study with, so you can ask questions and discuss the text. If you have to study alone, you can reinforce your learning by reciting the key concepts out loud.
- A *visual learner* learns by reading. If you learn best this way, you should concentrate on finding a quiet place where you can focus on material you are reading.
- A *kinesthetic learner* learns by doing. If you learn best by doing something, you have to be creative in the way in which you study. For example, highlight your text or take notes as you read. Think about practical ways to apply what you are reading about.

LEARNING SKILLS

In this final section, you are going to examine some specific suggestions on how you can make your study time more valuable. Not every method will be appropriate for your study habits. Choose what you think will help you, or adapt some to fit your needs. Ignore those that you feel won't contribute to your understanding of the materials.

SQ3R method

The SQ3R stands for: Survey, Question, Read, Recite, and Review

SQ3R was developed in 1941 by Francis P. Robinson of Ohio State University. It's an old system, but it still works. Millions of students have successfully used this system, or a variation of it, to improve their reading and studying. SQ3R stands for Survey, Questions, Read, Recite, and Review. Let's take a look at each one of these elements in SQ3R.

Survey

You first survey the material you are going to study. The purpose of the survey step in SQ3R is to help you become familiar with your text book organization. To survey material you are about to read, look quickly at the following types of features:

- Titles and other headings.
- Illustration, diagrams, charts, maps and graphs.
- Text printed in highlighted boxes.
- Boldface and italic type.
- Self-check questions.
- Summary, if appropriate.

Scanning these features will give you a good idea of what topics you are about to study.

Questions

The next step in the **SQ3R** method is question. This step requires you to go through the pages you are about to read and turn the headings into questions. Doing this helps direct your reading and your thinking. Then as you read and study the material, you can look for the answers to your questions. For example, look at the first few headings at the beginning of this book. Here is how you can turn them into questions:

- What is physics?
- How important is physics to us or why is physics taught in Secondary Schools?
- What are the meanings of the following words?
 - Hypothesis
 - Scientific law or Scientific Principle
 - Scientific theory

Note: *The better your questions are, the better will be your understanding of the material.*

The 1st R Read

Begin to read the material slowly and carefully, one section at a time. Don't worry about how long it takes. As you read, look for answers to the questions you have just formed under „Q“ above. Make brief notes, and look up any words you don't understand. If you have completed the first two steps (*Survey and questions*), the material should seem familiar to you. You are prepared to read the new material more efficiently. You have an idea of the information you are required to learn and you are able to read with clearer intent. You know why you are reading a section and what to focus on. Specifically, mark definitions, formulae, examples, names, principles, rules, and characteristics.

The 2nd R Recite

Every time you come to a new heading in the text, stop and repeat, either silently or loud, the main point is to help you to remember what you have just read. Recite it from memory or refer to your marginal notes or the information you have highlighted. If you have trouble with this step, reread the section until it becomes clear to you. Reciting the material in your own words is a tremendous aid to learning .It makes it easier to retain the information.

The 3rd R Review

Review any material you read as soon as you can. Review it again before you complete a self-check and gain confidence before you prepare for an examination .This part of **SQ3R** helps to keep information fresh in your mind. I believe by now you should be able to agree that; the SQ3R method is real helping to make your revisions effective.

- Note:**
- (i) One way to review is to resurvey the material you have read. Or go over the notes you have made to see if they still make sense. Reread any passages and that you have underlined or highlighted.
 - (ii) Another method you can use in the review step is to go back over the questions you developed for each heading. See if you can answer them. If not, look back and refresh your memory about that particular topic. Then continue with your review until you are satisfied that you know the material well.

PREPARING FOR EXAMINATION

Revision

Literally, revision means „seeing again“ and it is a vital part of learning, though the word often gets used simply to mean preparation for an examination or a test. It is found out that the amount that can be recalled drops dramatically unless the new ideas are revised or reviewed. If one reviews his notes most often, it is possible to get the stage where nearly 100% recall is achievable long after the last review. It is also possible that one can forget every thing after **not** reviewing for a long period of time. The explanations to these facts lie in the changes that take place in the cells of the brain and in the connections between them.

If you follow the suggestions in this study unit, you should have no difficulty when reviewing in preparation for an examination. Use these tools, along with answers to the “self – checks,” to prepare for the examination. Don’t just “read” physics. Make your revision effective by involving the hands in going over the examples, drawing and labeling diagrams, trying to answer the questions on examination past papers. Familiarity with and understanding of the text material, diagrams, examples past paper questions will make *taking the examination* much easier.

TAKING EXAMINATIONS

Begin by surveying the examination questions. Read the directions/instructions carefully and be sure to follow them exactly. Do the easy questions first. Skip any you are unsure of. While taking the examination, maintain a positive attitude. If you feel negative thoughts creeping in, say to yourself, “I’ve studied hard.”

Types of questions

There are two types of questions:

- Multiple Choice
- Structured and semi-structure

Multiple Choice questions

Before you do anything on the question paper,

- First write your name and then read the instructions carefully.
- Read the questions very carefully. Careless reading of the instructions and the questions often leads to loss of marks. Carefully reading of the instructions and the questions help you to know exactly what you are to do and how to do it.

For multiple type questions, try to answer from your mind before you look at the answers.

- Read each answer thoroughly even if you think you have already spotted the correct one. Note that some answers may be correct. But the question always requires you to choose the most correct answer. Be aware the wrong answers are always plausible.
- Be active: sketch a diagram; write down a relationship, do anything that helps you think clearly.
- Do not be worried by too many of one letter since they are random.
- Be absolutely sure to get the easier questions right, by not rushing them. The questions carry the same marks.
- Finally if in doubt guess, illuminate the patently wrong answers first. If you can whittle the choice down to two you have a 50% chance of being right.

For Structured and semi-structured questions:

- Use simple straightforward English.
- Use clear-labeled diagrams.
- Where necessary leave space so you can add answers that occur to you later.
- Explain all your working and put in correct **units**. Remember wrong units led to loss of marks.
- Round off your final answers to a sensible number of significant figures.
- Check your work as you continue.
- Look at the marks given besides the question to gauge how much detail is likely to be expected and, in the case of papers where you answer on the question paper, look at the space available. For example, six marks probably mean six important ideas are needed in the answer.

Terms used in setting examination questions

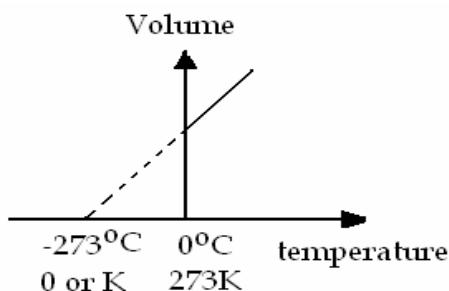
For getting high marks in structured and semi-structured questions, you have to understand the meanings of the following common terms used in setting the questions.

- Define:** State precisely the meaning of terms or words. E.g. define the term density.
- State:** Name, mention or give the condition of a thing. E.g. state the S.I unit of pressure.
- Describe:** Give a detailed account or representation of something in words, e.g. describe an experiment to verify Hooke's law.
- Identify:** Recognize or prove something as being a certain. E.g. the factors that affect density of a substance.
- Name:** Write down, mention or state. E.g. name the parts labeled in a diagram.
- Determine:** Ascertain something after some observation, solve a problem or find out. E.g. determine the refractive index of a glass block.
- Explain:** Give a detailed account of something. E.g. explain what happens to a ball bearing released in a viscous fluid in a tall cylinder.
- Discuss:** Give points and general description in writing either for or against a statement. E.g. discuss the effect of temperature on density of water.
- Suggest:** Put forward an idea. E.g. suggest what would happen to pressure of a gas if the volume of the gas is reduced.
- Calculate:** Work out a problem mathematically. E.g. calculate the focal length of a converging lens.
- Outline:** Give the main points. E.g. outline the steps followed in determining the relative density of a substance.
- Distinguish:** Make, show or recognize differences. E.g. distinguish between density and relative density of a substance.

CHAPTER ONE

GAS LAWS

Absolute Zero: A volume-temperature graph shows that decreasing temperature decreases the volume of gas and at a certain temperature the volume becomes zero. This is called the **absolute zero**.



Absolute zero is the temperature at which the volume of gas becomes zero.

- ❖ $1^{\circ}\text{C} = 1 \text{ K}$.
- ❖ Since $-273^{\circ}\text{C} = 0 \text{ K}$,
- ❖ Conversions from ${}^{\circ}\text{C}$ to K are made by adding 273.

Examples;

- ❖ $0^{\circ}\text{C} = 273\text{K}$
- ❖ $15^{\circ}\text{C} = 273 + 15 = 288 \text{ K}$
- ❖ $100^{\circ}\text{C} = 273 + 100 = 373 \text{ K}$

Kelvin or absolute temperature is represented by letter T and if t stands for a Celsius scale temperature then,

$$\triangleright T = 273 + t$$

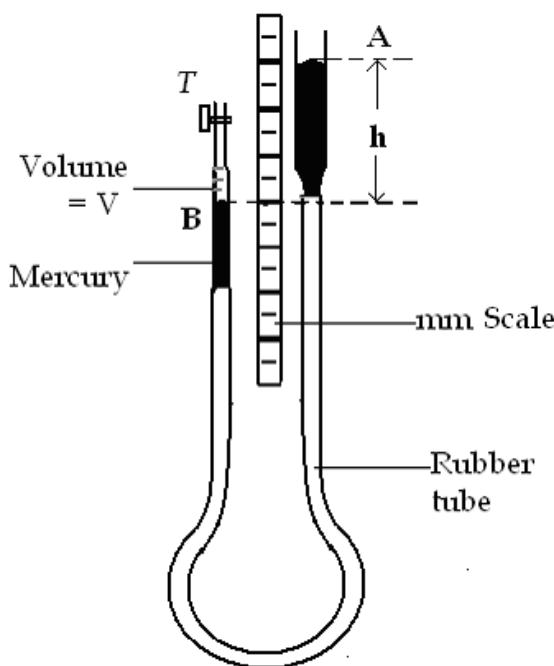
In order to make a full study of the behavior of a gas as regards volume, temperature and pressure, three separate experiments have been carried out to investigate respectively;

1. The relation between volume and pressure at constant temperature (Boyle's law)
2. The relation between volume and temperature at constant pressure (Charles law)
3. The relation between pressure and temperature at constant volume (Pressure law)

Boyle's law

Boyle's law states that the volume of a fixed mass of gas is inversely proportional to the pressure at constant temperature.

This may be verified using an arrangement in the figure below.



- Starting with the reservoir A in its lowest position, the volume V , in cm^3 , together with the readings of the mercury levels A and B on a vertical millimeter scale. The reservoir is then raised a few centimeters at a time and a series of such readings obtained.
- Now, if the volume of a gas is altered, the temperature will change. It is therefore necessary to wait a short while after each adjustment of the reservoir in order to give the air time to revert to room temperature.
- The atmospheric pressure H , in mmHg , is read from a Fortin barometer.
- If the difference in the mercury levels is h in mm, then the absolute pressure of the enclosed air is given by:

$$p = (H + h) \text{ when } A \text{ is above } B \text{ and}$$

$$p = (H - h) \text{ when } A \text{ is below } B.$$

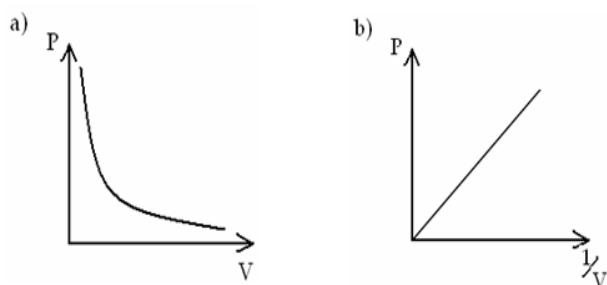
All measurement made should be entered in a table as shown below.

Volume V (cm^3)	h (mm)	$P = H \pm h$ (mmHg)	$\frac{1}{V}$

If a graph of P against V is plotted, a curve similar to figure a below is obtained.

However, a graph of P against $\frac{1}{V}$ is a straight line which passes through the origin as shown in figure b below. This shows that P is proportional to $\frac{1}{V}$.

Thus Boyle's law is verified.



Boyle's law can be stated mathematically as;

$$p \propto \frac{1}{V} \quad \text{or} \quad P = \frac{k}{V}$$

Where k is a constant

In general, this is written as;

$$PV = k \quad \text{or} \quad P_1V_1 = P_2V_2$$

- P_1 and V_1 are initial values of pressure and volume while P_2 and V_2 are final values of pressure and volume respectively.

Example:

The volume of a fixed mass of gas at constant temperature is 20 cm^3 when the pressure is 75 cmHg . Find the new pressure when the volume increases to 50 cm^3 .

Solution:

By Boyle's law $PV = \text{constant}$

$$P_1V_1 = P_2V_2$$

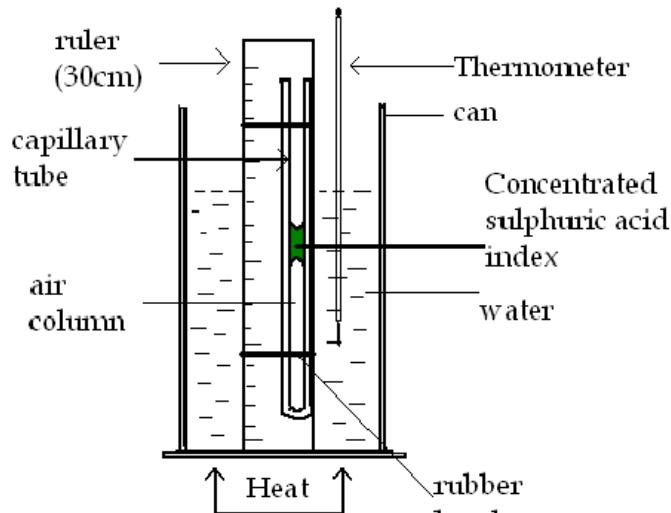
$$75 \times 20 = P_2 \times 50$$

$$P_2 = 30 \text{ cmHg}$$

Charles's law

It states that the volume of a fixed mass of gas at constant pressure is directly proportional to the absolute temperature.

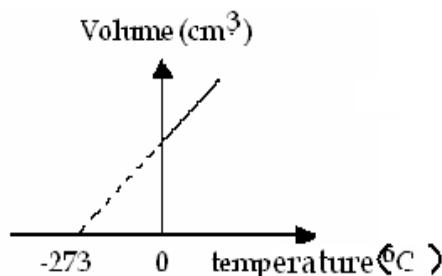
This is about the variation of volume with temperature at constant pressure. The apparatus shown in the diagram below is used to find how the volume of the same air varies with its temperature.



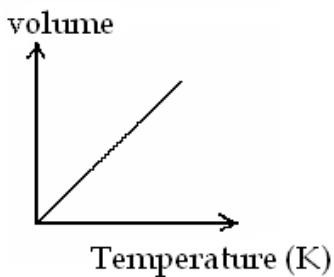
The pressure of the air column is constant and equals atmospheric pressure plus the pressure of the acid index. The volume of air is measured on the scale and water bath is used to vary with the temperature. It is found that the volume of the gas increases in steps with absolute temperature, the volume is proportional to the absolute temperature. This can be expressed mathematically as:

$$\frac{\text{Volume}}{\text{Absolute temperature}} = \text{constant}$$

If a graph of V is plotted against temperature T $^{\circ}\text{C}$ a straight line is obtained as shown in the fig. below showing that volume increases by equal amounts for the same temperature.



When the graph above is redrawn with temperature converted to the absolute scale, the graph now passes through origin.



From the graph above it follows that $\frac{V_1}{T_1} = \frac{V_2}{T_2}$,

Where V_1, V_2 are volumes at absolute temperature T_1 and T_2 respectively.

Example:

The volume of a fixed mass of gas at constant pressure is 50 cm³ at a temperature of 27 °C. What will the volume be at 42 °C?

Solution:

$$27 \text{ } ^\circ\text{C} = 273 + 27 = 300 \text{ K}$$

$$42 \text{ } ^\circ\text{C} = 273 + 42 = 315 \text{ K}$$

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \Rightarrow V_2 = \frac{V_1 \times T_2}{T_1}$$

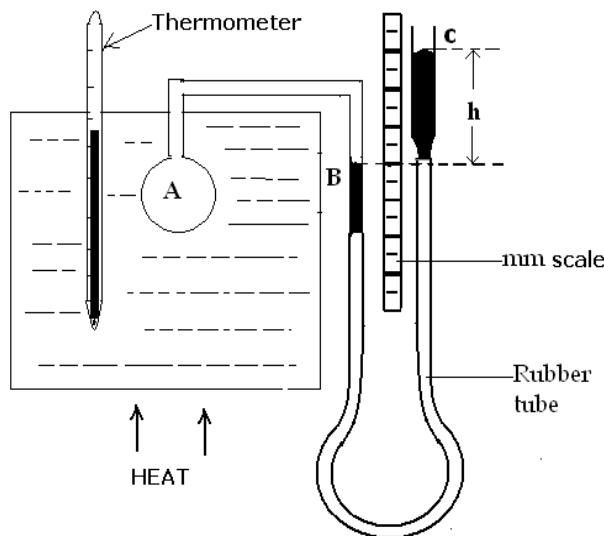
$$V_2 = \frac{50 \times 315}{300}$$

$$V_2 = 52.5 \text{ cm}^3$$

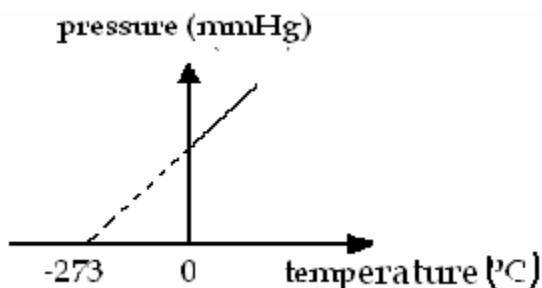
Pressure Law

It states that the pressure of a fixed mass of a gas is directly proportional to its absolute temperature if the volume is kept constant.

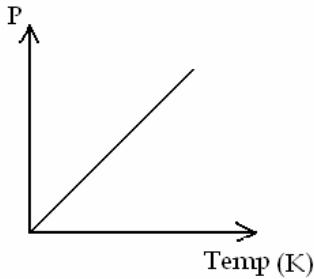
The pressure law gives a relation between pressure and temperature of a given mass of gas at constant volume.



- Bulb A contains dry air and is completely surrounded by water inside a large beaker. The dry gas is trapped in A by mercury and it is heated when the beaker is in water. The pressure and temperature of the gas are only read when the manometer is adjusted until the mercury surface coincides with the fixed mark B.
- The fixed mark is used to ensure that the volume of the gas is the same throughout the experiment.
- The difference between the mercury level in C and B i.e. "h" is read from the scale.
- The pressure of the gas is $H + h$ when C is above B and the pressure is $H - h$ when C is below B, where H is atmospheric pressure.
- The pressure of the gas is obtained for different temperatures.
- A graph of pressure against temperature is plotted.



A graph obtained is a straight line showing that pressure increases by equal amounts for equal increases in temperature. When the graph above is re-drawn with temperature converted to absolute scale, the graph now passes through the origin.



From the graph above it follows that $\frac{P_1}{T_1} = \frac{P_2}{T_2}$,

Example: The pressure of a given mass of gas at constant volume at a temperature of 100 °C is 300 mm Hg. What will the pressure be if the temperature falls to 27 °C?

Solution:

$$T_1 = 273 + 100 = 373\text{K},$$

$$T_2 = 273 + 27 = 300\text{K}$$

$$P_1 = 300 \text{ mm Hg},$$

$$P_2 = ?$$

$$\frac{P_1}{T_1} = \frac{P_2}{T_2} \Rightarrow P_2 = \frac{P_1 \times T_2}{T_1}$$

$$P_2 = \frac{300 \times 300}{373}$$

$$P_2 = 241.3 \text{ mmHg}$$

Equation of state

The three gas laws can be summarized by one equation:

1. Boyle's law; $PV = \text{constant}$ when temperature is constant.
2. Charles' law; $\frac{V}{T} = \text{constant}$ when the pressure is constant
3. Pressure law; $\frac{P}{V} = \text{constant}$ when volume is constant

The three equations can be combined into one equation as:

$$\frac{PV}{T} = \text{constant} \quad \text{or} \quad \frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

- Where P_1 , V_1 and T_1 are initial values of pressure, volume and temperature while P_2 , V_2 and T_2 are final values of pressure, volume and temperature respectively.
- ❖ This equation holds for ideal gases under all conditions.

Note:

- ✓ All temperature must be in Kelvin
- ✓ In some calculations the volume of the gas has to be found at s.t.p (standard temperature and pressure). This is 0 °C and 760 mm Hg.
- ✓ Any units can be used for P and V so long as they are the same on both sides of the equation.

Example:

Air in a 2.5 litres vessel at 127 °C exerts a pressure of 3 atm. Calculate the pressure that the same mass of air would exert if contained in a 4 liters vessel at - 43°C.

Solution-3:

$$T_1 = 273 + 127 = 400\text{K}, \quad T_2 = 273 - 43 = 230\text{K}$$

$$P_1 = 3 \text{ atm}, \quad P_2 = ? \text{ atm}$$

$$V_1 = 2.5 \text{ L} \quad V_2 = 4 \text{ L}$$

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

$$P_2 = \frac{3 \times 2.5 \times 230}{400 \times 4}$$

$$P_2 = \frac{P_1 \times V_1 \times T_2}{V_2 \times T_1}$$

$$P_2 = 1.078 \text{ atm}$$

Example-4: The volume of a gas is 90cm³ at 25 °C and 780mm Hg pressure. Calculate the volume of the gas at s.t.p.

Solution-4:

$$T_2 = 0 \text{ °C} = 273\text{K}$$

$$T_1 = 250\text{°C} = 25+273 = 298\text{K}$$

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2},$$

$$\frac{780 \times 90}{298} = \frac{760 \times V_2}{273} \Rightarrow V_2 = 84.6\text{cm}^3$$

Example-5: Calculate the volume at s.t.p of a gas whose volume is 100cm³ at -5°C and 746 mmHg

Solution

$$T_1 = -250 \text{ C} = -25+273 = 248\text{K}$$

$$T_2 = 00 \text{ C} = 273\text{K}$$

$$V_1 = 100 \text{ cm}^3$$

$$V_2 = ?$$

$$P_1 = 746 \text{ mmHg},$$

$$P_2 = 760 \text{ mmHg}$$

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2},$$

$$V_2 = \frac{P_1 \times V_1 \times T_2}{T_1 \times P_2}$$

$$\frac{746 \times 100 \times 273}{248 \times 760}$$

$$V_2 = 108 \text{ cm}^3$$

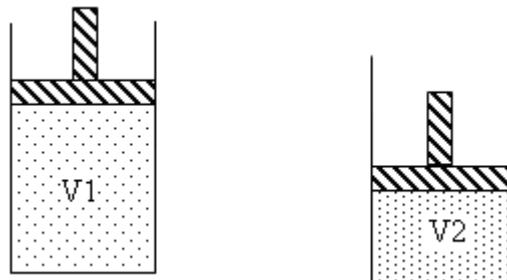
Gases and the kinetic theory

The kinetic theory can explain the behavior of gases.

(a) Cause of gas pressure:

The pressure exerted by a gas is due to the molecules bombarding the wall of the container.

(b) Boyle's Law:



If the volume of a fixed mass of a gas is halved by halving the volume of the container, figure above, the number of molecules per cm^3 will be doubled. There will be twice as many collisions per second with the wall i.e. the pressure is doubled. This is Boyle's Law.

(c) Temperature:

When a gas is heated and its temperature rises, the average speed of its molecules increases. If the volume of the gas is to remain constant, its pressure increases due to more frequent and more violent collisions of the molecules with the walls. (*Pressure law*)

If the pressure of a gas is to remain constant, the volume must increase so that the number of collisions does not. (*Charles' law*)

(d) Absolute Zero:

This is the temperature at which the molecules have their lowest possible kinetic energy.

TEST ONE

SECTION A

1. When air is pumped in a tube at constant temperature, the pressure increases because

- (a) the molecules are large
- (b) the molecules are moving faster
- (c) the molecules are closer together
- (d) more molecules are hitting the tube.

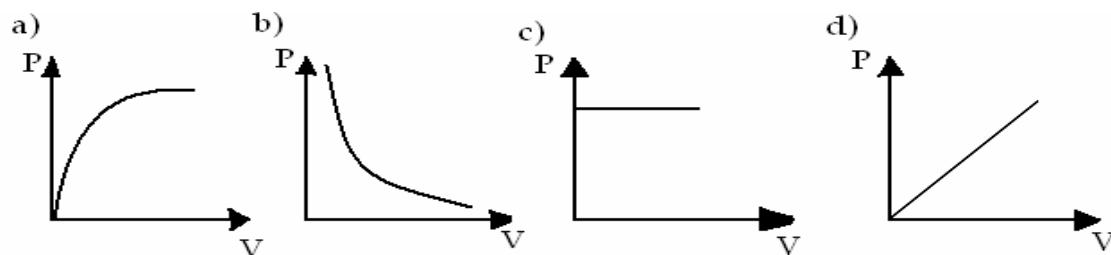
2. The volume of a fixed mass of gas at 27.0°C and a pressure of 750mm of mercury is 300cm^3 . What is its volume when the pressure is raised to 900mm mercury and the temperature is 327°C ?

- (a) 125cm^3
- (b) 180cm^3
- (c) 500cm^3
- (d) 720cm^3

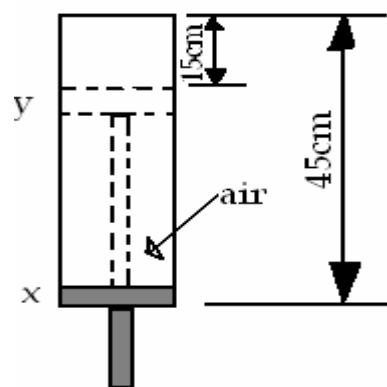
3. When the pressure of a mixed mass of a gas is reduced by half, its volume
a) doubles at constant temperature.
b) is halved at constant temperature.

- c) is halved if the temperature is also halved.
 - d) remains the same at constant temperature

4. Which of the following graphs shows the variation of the pressure of a gas as the volume changes at a constant temperature?



5.



In figure above the piston is moved from X to Y at constant temperature. The air pressure is

- a) trebled
 - b) doubled
 - c) reduced by a third
 - d) unchanged

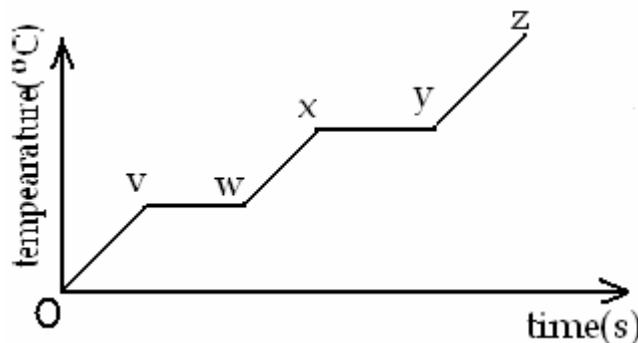
6. The pressure of a fixed mass of a gas at 17°C is 10^5Pa . Find its pressure at 27°C if the volume remains constant.

$$\text{a) } \frac{27}{17} \times 10^5 \text{ Pa} \quad \text{b) } \frac{17}{27} \times 10^5 \text{ Pa}$$

c) $\frac{300}{290} x 10^5 Pa$ d) $\frac{290}{300} x 10^5 Pa$

7. The pressure exerted by a gas decreases when its volume is increased at a constant temperature because the molecules
a) move faster

- b) move closer to one another.
c) hit the walls more often.
d) hit the walls less frequently.
8. Which of the following statements is incorrect when a tin containing air tightly sealed is heated?
- a) the average speed of molecules increases
b) the molecules of air hit the walls of the tin harder
c) The molecules of the air strike the walls of the tin less often.
d) The pressure inside the tin increases.
9. The particles in a solid at room temperature are
- A. close together and vibrating.
B. close together and stationary.
C. far apart and moving at random.
D. close together and moving at random.
10. The temperature at which all the heat energy is removed from the substance is called
- (a) Kelvin temperature (b) Celsius temperature
(c) Freezing temperature (d) Absolute zero temperature
11. Which one of the following statements is true?
- A) The average kinetic energy of the molecules of a gas depends on temperature
B) Each molecule of a gas at a given temperature has a different speed
C) The pressure of a fixed mass of gas decreases as the temperature increases
D) The volume of a fixed mass of gas increases as the temperature decreases
12. The graph in the figure is that of the temperature against time for a substance, which is heated at a constant rate temperature



Which part of the graph corresponds to the situation when the molecules of the substance have the highest average kinetic energy?

13. At room temperature, air is less dense than water because air molecules

- (a) move faster
 - (b) are smaller
 - (c) have greater force of attraction
 - (d) are more widely separated from each other.

14. When a liquid is heated

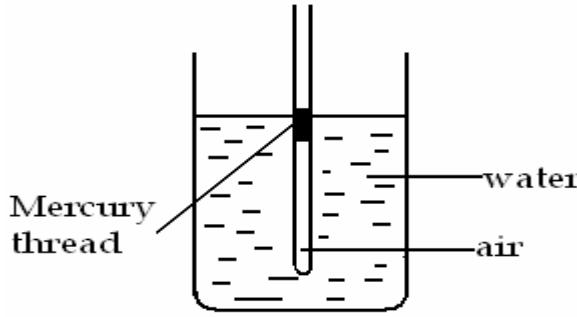
- a) its density decreases
 - b) boiling occurs at all temperatures
 - c) its molecules move with the same speed
 - d) evaporation takes place throughout the liquid

15. It is more difficult to compress a liquid than a gas because

- (a) the speed of liquid molecules is lower than that of gas molecules
 - (b) liquid particles attract one another when compressed while gas particles repel each other
 - (c) the distances between liquid particles are less than those between gas particles
 - (d) liquid molecules repel one another when compressed while gas molecules repel one another

SECTION B

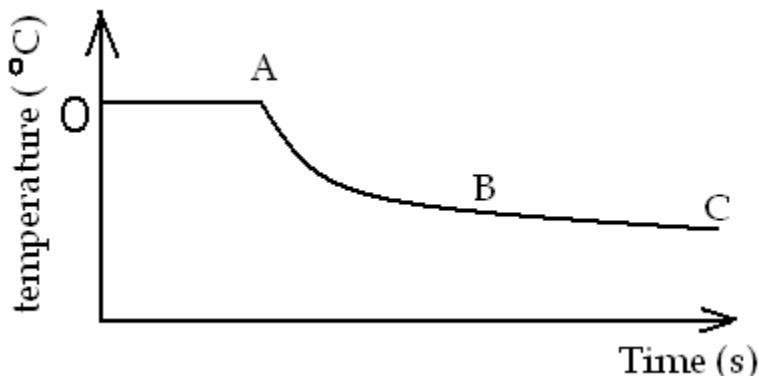
1. a) State Boyle's Law and verify the law.
b) State Charles' Law and verify the law.
c) State Pressure Law and verify the law.
 2. a) What is an equation of state of a gas?
b) (i) With the aid of a sketch graph, describe how absolute zero of temperature can be defined.

- (ii) Use the kinetic theory of gases to explain the existence of absolute zero of temperature.
3. A gas of volume 1000cm^3 at a pressure of $4.0 \times 10^5 \text{ Pa}$ and temperature 17°C is heated to 89.5°C at constant pressure. Find the new volume of the glass.
(Ans: 1250 cm^3)
4. A cylinder with a movable piston contains 0.35 m^3 of air at a temperature of 73°C . Calculate the volume of the gas if it is cooled to 27°C at constant pressure.
(Ans: 0.3 cm^3)
- 5.
- 
- A graduated glass-tube containing air trapped below a mercury thread is immersed in a beaker of water and the water is heated as shown in the figure above.
- i) Sketch a graph showing how the volume of the trapped air varies with absolute temperature.
- (ii) When the temperature of the water is 27°C , the volume of the trapped air is $1.2 \times 10^{-1} \text{ cm}^3$. Calculate the volume of air when its temperature is 77°C .
(Ans: 0.14 cm^3)
6. With aid of labeled diagram, describe an experiment to show how the volume of a gas varies with pressure at constant temperature.
7. With the aid of a labeled diagram, describe an experiment to show the relationship between the volume and temperature of a fixed mass of gas at atmospheric pressure.
8. A volume of a fixed mass of a gas increases from 300 cm^3 to 500 cm^3 at a constant temperature. Find the new pressure if the initial pressure is 70 cm Hg .
(Ans: 116.7 cmHg)

9. A volume of 2500 cm^3 of hydrogen gas is collected at 77°C at a pressure of 730 mmHg . Calculate the volume of the gas at s.t.p.

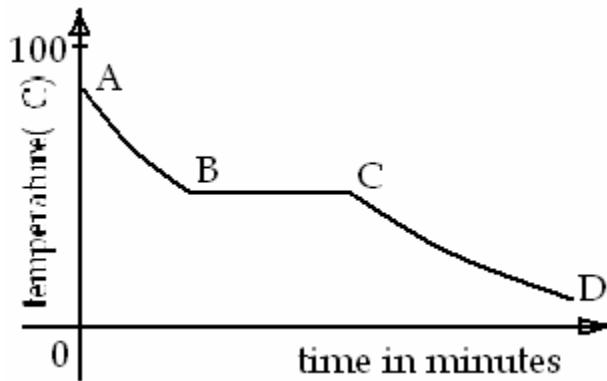
(Ans: 1873 cm^3)

10.



- (a) The figure shows temperature versus time curve for a liquid. State what is happening along BC
 - (b) Use the kinetic theory of matter to explain what is happening along OA.
11. (a) Sketch the variation of volume with temperature in Kelvin, for a gas at constant pressure.
 (b) State any two advantages of mercury as a thermometric substance.
12. Explain the following observations;
 (a) the increase in temperature of the gas
 (b) the increases in the pressure of the gas
13. (a) State the kinetic theory of matter.

14.



The figure shows a cooling curve for a substance, which is in liquid form at 100°C .

- i. In what stages is the substance over the regions AB, BC and CD of the curve?

- ii. Use the kinetic theory of matter to explain the difference between the stages of the substance over the regions AB and CD.

CHAPTER TWO

HEAT CAPACITY

Heat:

The term heat is used to describe the energy transferred through the heating process.

- Its unit is *joules*

Heat capacity

The *heat capacity* of a substance is the quantity of heat required to rise its temperature by 1°C or 1K.

- Its symbol is C and its unit is Joule per degree Celsius ($J/^{\circ}C$) or Joule per Kelvin (J/K)
- *Heat capacity = mass x specific heat capacity*
- In symbols: $C = mc$

Specific heat capacity

Specific heat capacity is the quantity of heat required to raise the temperature of 1kg by 1°C or 1K.

- Its symbol is c.
- Its unit is joule per kilogram degree Celsius ($J/Kg^{\circ}C$) or joule per kilogram Kelvin (J/KgK) or ($JKg^{-1} K^{-1}$).
- When the temperature of a substance rises; heat gained = mass × specific heat capacity × temperature rises,

In symbols:

$$Q_{gained} = m.c (\theta_2 - \theta_1) = m.c.\theta$$

Where temperature rises (θ) is $(\theta_2 - \theta_1)$, final temperature minus initial temperature.

Example-1:

Find the amount of heat required to raise the temperature of 2kg of iron from 20°C to 70°C (specific heat capacity of iron is 460J/kg°C)

Solution:

Mass, $m = 2\text{kg}$

Initial temperature, $\theta_1 = 20^\circ\text{C}$

Final temperature, $\theta_2 = 70^\circ\text{C}$

Temperature rises, $\theta = \theta_2 - \theta_1$

$$70 - 20$$

$$= 50^\circ\text{C}$$

Specific heat capacity of iron, $c = 460\text{J/kg°C}$

Heat gained, $Q = ?$

$$\begin{aligned} Q_{\text{gained}} &= m.c.\theta \\ &= 2 \times 460 \times 50 \\ &= 46000 \text{ joules} \end{aligned}$$

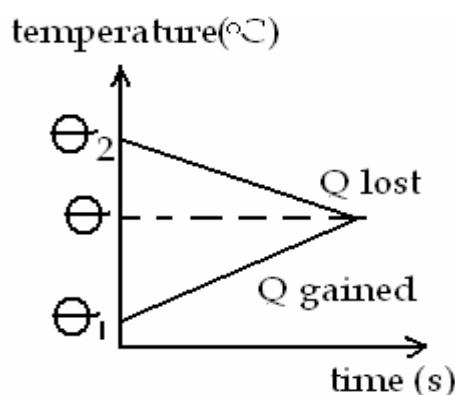
Hence, the amount of heat required is 46000 joules.

Calorimeter and method of mixtures

The term calorimeter means the science of heat measurements and any piece of apparatus with which heat measurements may be made is called a **calorimeter**. In this method hot substances are mixed with cold substances until they reach the same temperature.

Assuming that no heat is lost to the surroundings then. The following equation is used;

$$\text{heat gained by cold substances} = \text{heat lost by hot substances}$$



- Where θ is the temperature of the mixture.
- θ_1 is the temperature of cold substance
- θ_2 is the temperature of hot substance
- m_1 is the mass of cold substance
- m_2 is the temperature of hot substance
- c_1 is the specific heat capacity of cold substances
- c_2 is the specific heat capacity of hot substances

- ❖ $Q_{gained} = Q_{lost}$
- $m_1 \cdot c_1 \cdot (\theta - \theta_1) = m_2 \cdot c_2 \cdot (\theta_2 - \theta)$

Example-2: A 15kg of water at 20°C is added to 5kg of water at 40°C; find the temperature of the mixture?

(Ans: $\theta = 25^\circ\text{C}$)

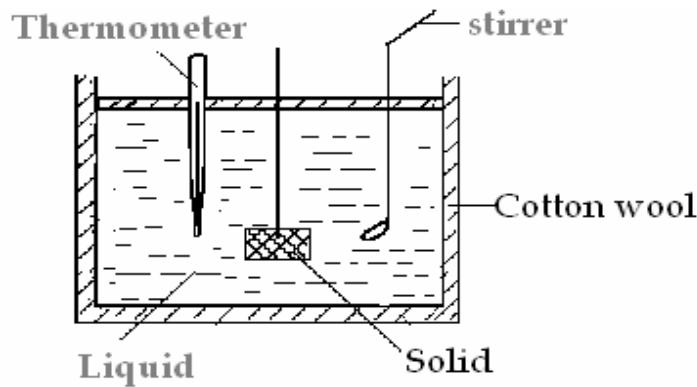
Example-3: 600g of water at 50°C is to be cooled to 25 °C by addition of cold water at 10°C how much cold water is to be added?

(Ans: 1 kg)

- ❖ During the experiment, heat can be lost by conduction, convection, radiation and evaporation. Heat lost by radiation can be reduced by:
 - Using a bright polished calorimeter.
 - By insulating the calorimeter with a poor conductor such as cotton wool. Heat lost by convection and radiation can be reduced by covering the container with a lid. Heat lost by conduction can be reduced by insulating the calorimeter. This process is called **Lagging**.

Measuring of specific heat capacity of liquid by method of mixture

If a solid of known mass m_2 is heated in water to a known temperature say θ_2 . Then it is transferred very quickly into a liquid of mass m_1 which is at a temperature θ_1 . The mixture is stirred gently until a common temperature θ is reached as in figure below.



Assuming that no heat is lost to the surrounding then

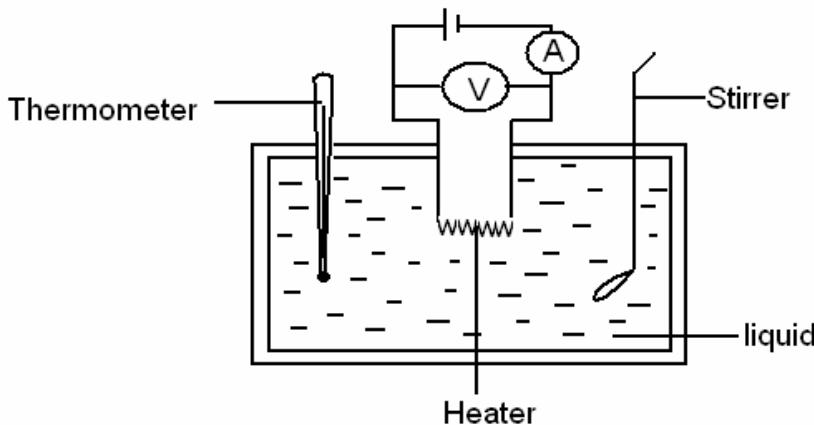
$$\text{heat lost by solid} = \text{Heat gained by liquid} + \text{Heat gained by the calorimeter}$$

$$\begin{aligned} m_2.c_1 (\theta_2 - \theta) &= m_1.c_2 (\theta - \theta_1) + m_3.c_3 (\theta - \theta_1) \\ &= (m_2.c_2 + m_3.c_3) (\theta - \theta_1) \end{aligned}$$

If other terms are known then c_1 can be calculated .Where m_3 and c_3 are mass and specific heat capacity of the calorimeter, c_1 and c_2 are specific heat capacity of the liquid and solid respectively.

Measuring of specific heat capacity of liquid by electrical method

In this method a liquid is in a well lagged calorimeter is electrically heated when current flows through a heater which is completely immersed in it as shown in the fig below.



The temperature of the liquid before current flows though the heater (θ_1) and at the end of the experiment (θ_2) is recorded.

The current I in the circuit and potential difference V across the heater must remain constant throughout the time (t) over which the temperature changes are recorded. Assuming no heat lost to the surrounding then

electrical energy supplied = heat gained by the liquid and the calorimeter.

$$\begin{aligned} \text{Electrical energy supplied} &= VI t \\ &= P \times t \end{aligned}$$

$$VI t = m_1 c_1 (\theta_2 - \theta_1) + m_2 c_2 (\theta_2 - \theta_1)$$

$$VI t = (m_1 c_1 + m_2 c_2) (\theta_2 - \theta_1)$$

m_1 = mass of the liquid

m_2 = mass of the calorimeter

c_1 = specific heat capacity of liquid

c_2 = specific heat capacity of calorimeter

θ_1 = original temperature

θ_2 = temperature after heating.

Note: If heat gained by the calorimeter is negligible, it does not need to induce in the formula.

LATENT HEAT

When a solid is heated, its temperature rises until its melting point is reached when it begins to melt. The solid melts as more heat is absorbed by the solid but the temperature remains unchanged until the entire solid has melted then the temperature rises again.

When a liquid cools its temperature also remains constant at freezing point. At this temperature liquid gives off heat energy and changes into solid. This phenomenon always occurs during a change of state of substance without change of temperature at melting point is called **Latent heat of fusion**. Latent means hidden or concealed.

Specific Latent heat of fusion of a substance is the quantity of heat required to change unit mass from solid to liquid at constant temperature.

The specific latent heat of vaporization of a substance is the quantity of heat required to change unit mass from liquid to vapor at constant temperature.

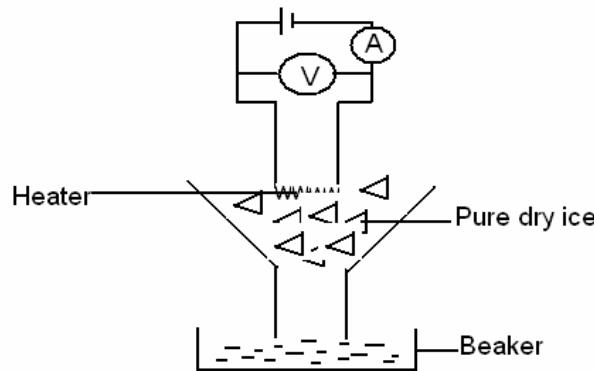
$$Q = m.L$$

Where L is specific latent heat and its unit is J/kg

Example:- Calculate the heat required to convert 2kg of water at 100°C to steam (specific latent heat of vaporization of water = 2.26×10^6 J/kg)

(Ans: 4.52×10^6 J)

An experiment to determine specific latent heat of fusion of ice



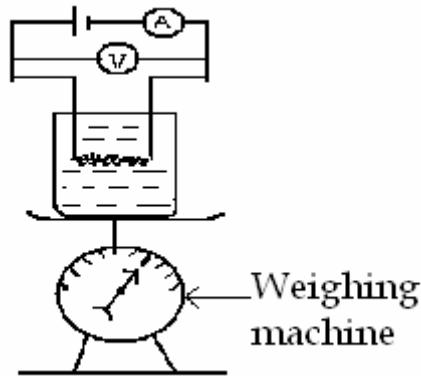
- The circuit in which the battery, ammeter and heater are in series and voltmeter is parallel to the heater is connected as shown.
- The heater is completely immersed in pure dry ice (assuming no heat is lost to the surrounding).
- The switch is closed and a stop clock is started at the same time. The mass 'm' of water collected in a known time, t, is noted, by weighing the beaker before and after the experiment.
- The voltmeter and ammeter readings V and I respectively are noted.

$$mL = Vit$$

$$L = \frac{VIt}{m}$$

Where: L is the specific latent heat of fusion of ice.

Determination of specific latent of vaporization



- The liquid is poured in a beaker and the mass (m_1) of the beaker is noted.
- The beaker is placed on top of a weighing balance.
- A heater is connected in series with an ammeter and parallel with a voltmeter.
- The heater is totally immersed in the liquid.
- The heater is switched on and left until the liquid boils thoroughly and the time t_1 is noted.
- Boiling is allowed to continue for some time and time t_2 is noted again.
- The reading of the weighing balance (m_2) is noted, when sufficient liquid has vaporized.

$$\text{Time taken for vaporization, } t = t_2 - t_1$$

$$\text{Difference in weight balance, } m = m_1 - m_2$$

$$\text{Ammeter reading} \quad = I$$

$$\text{Voltmeter reading} \quad = V$$

$$mL = VIt$$

$$L = \frac{VIt}{m}$$

L can be calculated from expression.

Effects of Heat on matter

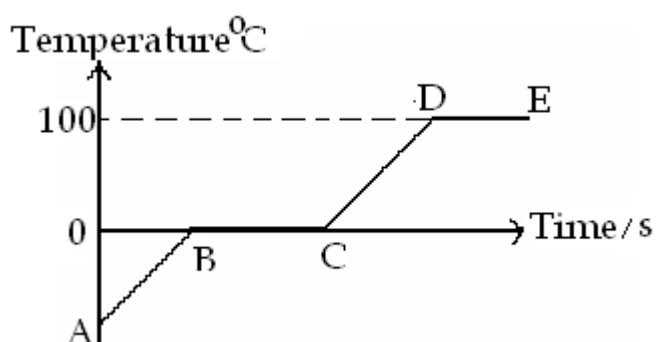
Melting point is the temperature at which a solid changes to a liquid.

When all the solid has melted and more heat is supplied the temperature of the liquid rises again, the heat gained by the liquid decreases the cohesion force in a liquid considerably and

the speed of motion of the molecules increases steadily until the liquid changes into a gas .

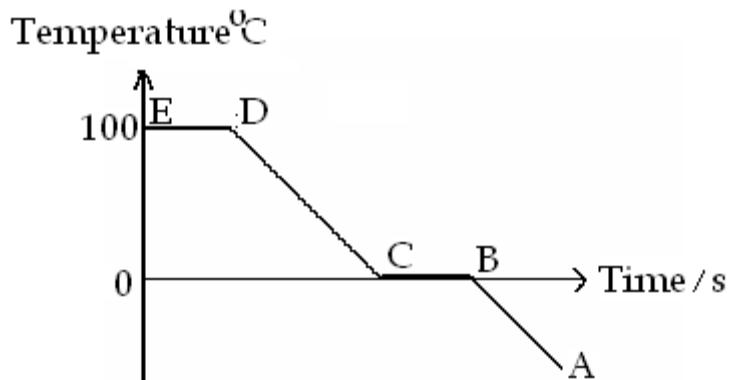
Boiling point is the temperature at which a liquid changes to gas (vapour). During boiling the temperature remains constant.

If water is heated, then its temperature varies with time as shown in the figure below.



- Along AB the temperature of ice rises from A to B.
- Along BC the temperature remains constant when the ice melts at 0°C.
- Along CD the temperature of melted ice rises from C to D.
- Along DE the temperature remains constant at 100 °C.

The reverse of the above process takes place when the water cools or when heat extracted from it.



- The temperature remains constant along ED at 100°C when steam condenses. When all of it has condensed the temperature falls from D to C.
- At 0°C the temperature remains constant along CB as water changes to ice.
- The temperature again falls along BA when all water has frozen.

Effects of impurities on boiling and melting points

When a substance contains impurities the boiling point of substance is raised and the melting point is lowered. However, when the substance is pure then its boiling point and melting point remains the same provided the pressure of the surrounding does not change.

Cooking food at a very high altitude

At a high altitude, atmospheric pressure is lower, so the boiling point of water is also lower. So water would vaporize before food is properly cooked, because of decreased boiling points hence it will take a long time for the food to be ready.

EVAPORATION

When a liquid is exposed to the atmosphere, some of the molecules gradually escape from its surface, causing the liquid to change its vapour form. This process is known as **evaporation**. During evaporation, molecules which have enough kinetic energy are able to escape from the attraction of other molecules and the process takes place at all temperatures.

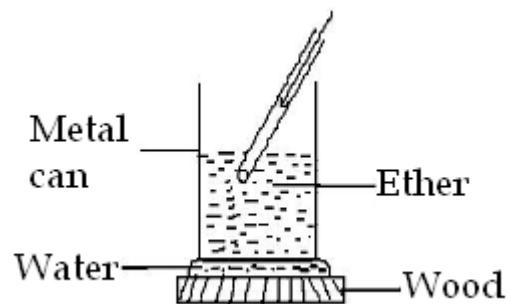
The rate of evaporation is influenced by temperature, pressure, surface area of the liquid, wind and dryness of air.

Differences between Boiling and Evaporation

BOILING	EVAPORATION
1.Takes place throughout the liquid	-Takes place only on the surface of the liquid
2. Takes place at a fixed temperature for a given liquid.	-Takes place at any temperature
3.Doesn't cause cooling	-Cause cooling for the liquid

To make ice by the evaporation the ether

Air is blown into liquid ether of low boiling point as shown in the figure below.



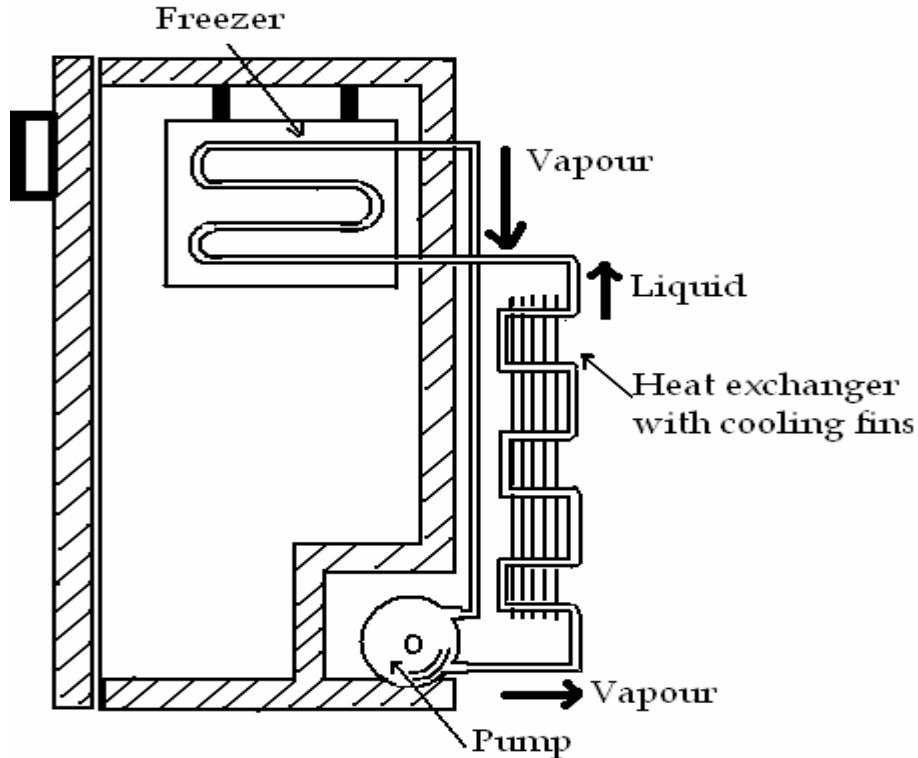
Observation after longtime

The water under the metallic can froze to ice.

Explanation

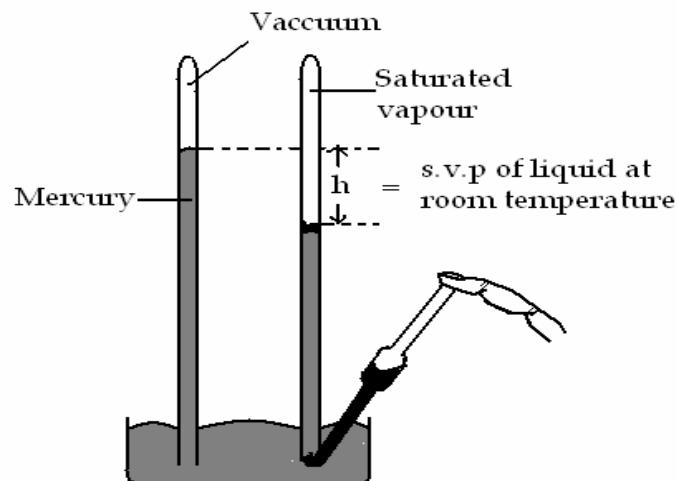
The liquid in the can evaporates and it obtains heat of evaporation from water so water loses heat and becomes cool and freezes.

REFRIGERATOR



- In a refrigerator heat is taken in at one place and given out at another by the refrigerating substance as it is pumped round a circuit.
- The coiled pipe round the freezer contain Freon a volatile liquid which evaporates and takes latent heat of vaporization from surroundings causing cooling.
- The pump removes the vapour reducing pressure so lowering boiling point and increasing evaporation forces it into heat exchanger (pipe with cooling fins outside the rear of the refrigerator).
- The vapor is compressed (in heat exchanger) liquefies giving out its latent heat of vaporization to the surroundings.
- Liquid returns to the freezer and the cycle is repeated with continuous extraction of heat from freezer.

To measure the saturated vapour pressure of a liquid



A very small quantity of the chosen liquid is introduced into the lower end of the tube by means of a special bent pipette. In this way a small drop of liquid is allowed to rise up the mercury column. On reaching the top it evaporates and the pressure exerted by the vapour depresses the column.

If sufficient liquid is added so that a small quantity remains on top of the mercury the space above will become saturated and the saturated vapour pressure may be measured by the total depression, h , of the column.

- ❖ **Saturated vapour pressure** is the pressure of vapour which is in equilibrium with its liquid state of the same substance. In this case there is a state of dynamic equilibrium between the vapour and liquid state.
- ❖ A **saturated vapour** is one which is in a state of dynamic equilibrium with its own liquid or solid.
- ❖ Before water appeared on top of the mercury column the vapour pressure could be increased by introducing more water and we say that the vapour above mercury is **unsaturated vapour**.

TEST 2

SECTION A

1.

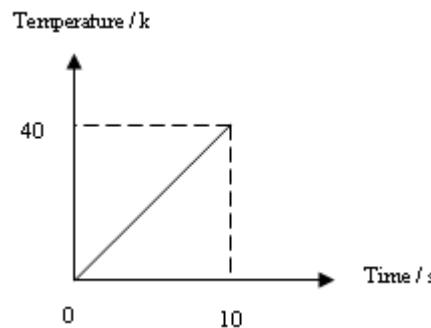


Figure above shows a graph of the temperature rise with time when a body of mass 4kg is heated using a 2000W heater. Find its specific heat capacity in $\text{Jkg}^{-1}\text{K}^{-1}$.

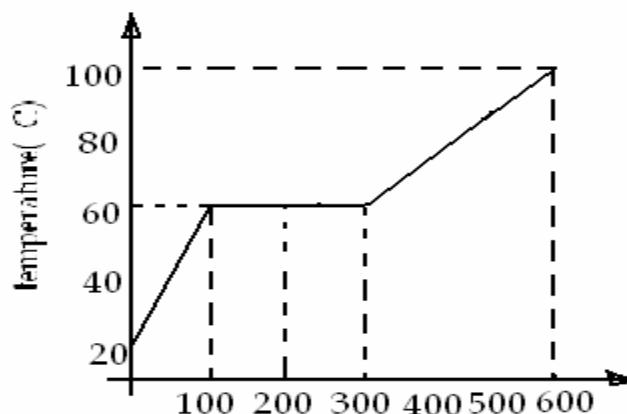
- a. $40 \times 10 / 2000 \times 4$ b. $2000 \times 10 / 40 \times 4$
 c. $2000 \times 4 / 40 \times 10$ d. $40 \times 4 / 2000 \times 10$
2. The specific heat capacity of a substance
- A. Heat required to raise it through 1°C
 B. Heat required to raise the temperature of 1kg mass of the substance through 1°C
 C. Heat required to change 1kg mass of the substance into liquid at the same temperature
 D. Heat required raising its temperature the specific no of degrees
3. The amount of heat required to raise the temperature of a 0.5kg mass from -5°C to 15°C is (specific heat capacity of salt solution is $4000 \text{ J kg}^{-1}\text{K}^{-1}$)
- a). 8000J b) 20000J
 c) 40000J d) 160000J
4. A 100g quantity of water at 24°C is added to 50g of water at 36°C . The temperature of the mixture is
- a) 28°C b) 32°C
 c) 30°C d) 34°C
5. The amount of heat required to raise the temperature of 0.5kg of iron from 25°C to 50°C is (specific heat capacity of iron is $460 \text{ joules kg}^{-1}\text{ K}^{-1}$)
- (a) $0.5 \times 460 / 25$ (b) $460 \times 25 / 0.5$
 (c) $0.5 \times 25 \times 460$ (d) $0.5 \times 25 / 460$

6. A block of lead of mass 1000g hits a hard surface without rebounding with a velocity of 23 ms^{-1} . if the temperature rises from 25°C to 27°C . Calculate the specific heat capacity of lead.
- (a) $5.75 \text{ J kg}^{-1} {}^{\circ}\text{C}^{-1}$ (b) $9.79 \text{ J kg}^{-1} {}^{\circ}\text{C}^{-1}$
(c) $132.25 \text{ J kg}^{-1} {}^{\circ}\text{C}^{-1}$ (d) $264.50 \text{ J kg}^{-1} {}^{\circ}\text{C}$
7. 450g of water at 60°C is to be cooled to be 35°C by addition of cold water at 20°C . How much cold water is to be added?
- (a) 0.169kg (b) 0.270kg
(c) 0.281kg (d) 0.75kg
8. Calculate the time required for a kettle taking 10 A from a 240 V supply, to heat 5kg of water through 80°C , assuming no heat is lost.
- (a) 700s (b) 292s
(c) 8.8s (d) 1.7s
9. When 1kg of a certain liquid is heated for 10s, its temperature rises by 25°C . If the power supplied is 1000 watts, find the specific heat capacity of the liquid.
- (a) $40 \text{ J kg}^{-1}\text{K}^{-1}$ (b) $400 \text{ J kg}^{-1}\text{K}^{-1}$
(c) $1000 \text{ J kg}^{-1}\text{K}^{-1}$ (d) $2500 \text{ J kg}^{-1}\text{K}^{-1}$
10. An electric heater is rated 240V, 400W. If the efficiency of the heater is 80% find the amount of energy wasted per second.
A. 48J. B. 80J.
C. 192J. D. 320J.
11. Calculate the specific heat capacity of paraffin if 22000 J of heat are required to raise the temperature of 2.0 kg of paraffin to 30°C from 20°C .
- (a) $1100 \text{ J kg}^{-1}\text{K}^{-1}$ (b) $1200 \text{ J kg}^{-1}\text{K}^{-1}$
(c) $2200 \text{ J kg}^{-1}\text{K}^{-1}$ (d) $2100 \text{ J kg}^{-1}\text{K}^{-1}$.
12. An electric heater is immersed in 0.05kg of oil in a calorimeter of negligible heat capacity. The temperature of the oil rose from 20°C to 50°C in 100 s. If the specific

heat capacity of the oil is 2000 J kg^{-1} , calculate the power supplied by the heater, assuming that there is no heat loss

- | | |
|---------|---------|
| a) 30W | b) 50W |
| c) 140W | d) 600W |

13. When 100W heater is used to heat 1kg of solid wax, the temperature of the wax is observed to change with time as shown below.



Find the specific latent heat of fusion of the wax

- | | |
|---|---|
| (a) $1.0 \times 10^4 \text{ J kg}^{-1}$ | (b) $2.0 \times 10^4 \text{ J kg}^{-1}$ |
| (c) $3.0 \times 10^4 \text{ J kg}^{-1}$ | (d) $6.0 \times 10^4 \text{ J kg}^{-1}$ |

14. A heater with a power rating of 100W is placed in 0.5kg of ice at 0°C . How long will it take the heater to melt all the ice? (Specific latent heat of fusion of ice = $3.34 \times 10^5 \text{ J kg}^{-1}$)

- | | |
|-------------------------------------|-------------------------------------|
| (a) $1.67 \times 10^{-3} \text{ s}$ | (b) $1.67 \times 10^3 \text{ s}$ |
| (c) $3.34 \times 10^{-3} \text{ s}$ | (d) $3.34 \times 10^{-3} \text{ s}$ |

15. How much heat is required to raise the temperature of 20g of water from 30°C to 60°C ?

- | | |
|-----------|-------------|
| (a) 2520J | (b) 6300J |
| (c) 8400J | (d) 126000J |

SECTION B

1. (a) What is meant by specific latent heat of vaporization?
(b) State two factors, which affect boiling points of water.
(c) Calculate the heat required to convert 0.8 kg of water at 100 °C to steam.
[Specific latent heat of vaporization of water = $2.26 \times 10^6 \text{ J/kg}$]
(Ans: $1.808 \times 10^6 \text{ J}$)

2. (a) What is meant by latent heat of vaporization?
(b) With the aid of a labeled diagram, describe how a refrigerator works.

3. (a) What is meant by specific heat capacity of a substance? And state its SI unit
(b) When a block of iron of mass 2 kg absorbs 19 kJ of heat, its temperature rises by 10°C. Find the specific heat capacity of the iron.
(Ans: $950 \text{ J kg}^{-1} \text{ K}^{-1}$)

4. The specific heat capacity of water is $4200 \text{ J kg}^{-1} \text{ K}^{-1}$.
What is meant by the above statement?

5. (a) Define the term specific latent heat of vaporization.
(b) Describe an experiment to determine the specific latent heat of vaporization of steam.

6. (a) Define the term specific latent heat of fusion.
(b) A copper can of mass 0.2kg contains 0.20kg of water at 10 °C. The can and its contents are placed in a refrigerator. Calculate the quantity of heat given out if the temperature of the can and its contents falls to -2 °C. ($c_{copper} = 400 \text{ J kg}^{-1} \text{ K}^{-1}$, $c_{ice} = 2100 \text{ J kg}^{-1} \text{ K}^{-1}$, $L_{fusion} = 340000 \text{ J kg}^{-1}$)
(Ans: 78200 J)

7. An immersion heater rated 1000 W, 250 V supplies heat to 80kg of liquid in a tank. If the temperature of the liquid rises by 40°C in 48 minutes, what is the specific heat capacity of the liquid?

(Ans: $900 \text{ J kg}^{-1} \text{ K}^{-1}$)

8. Distinguish between specific heat capacity and specific latent heat of a substance.

9. A copper block of mass 250g is heated to a temperature of 145°C and then dropped into a copper calorimeter of mass 250g, which contains 250 cm^3 of water at 20°C .

- (i) Calculate the maximum temperature attained by the water (specific heat capacity of copper = $400 \text{ J kg}^{-1}\text{K}^{-1}$)

(Ans: 30°C)

- (ii) Sketch a graph to show the variation of water with time.

10. (a) What is meant by saturated vapor pressure?

- (b) Explain what may happen when one is to cook food from a very high altitude.

11. (a) The cooling system of a refrigerator extracts 0.07kW of heat. How long will it take to convert 500g of water at 20°C into ice? ($L_f = 0.336 \times 10^6 \text{ J kg}^{-1}$)

(Ans: 300 s)

- (b) Explain how evaporation takes place.

12. A copper container of heat capacity $60 \text{ J kg}^{-1} \text{ K}^{-1}$ contains 0.5kg of water at 20°C . Dry steam is passed into the water until the temperature of the container and water reaches 50°C . Calculate the mass of steam condensed. ($L_v = 2.26 \times 10^6 \text{ J kg}^{-1}$)

(Ans: 0.02867 kg)

13. Equal volumes of water at the same temperature are poured in a basin and in a jug. State, giving a reason, which water will evaporate faster.

CHAPTER THREE

TRANSFER OF HEAT

Heat can travel in three ways:

1. Conduction
2. Convection
3. Radiation

Conduction: It is the flow of heat through matter from place of higher temperature to place of lower temperature without movement of matter as a whole.

The transfer of heat requires a material medium.

Convection: It is flow of heat through a fluid from places of higher temperature to places of lower temperature by movement of the fluid itself.

Radiation: It is the flow of heat from one place to another by means of electromagnetic waves.

The transfer of heat does not require a material medium.

Conduction in Solids

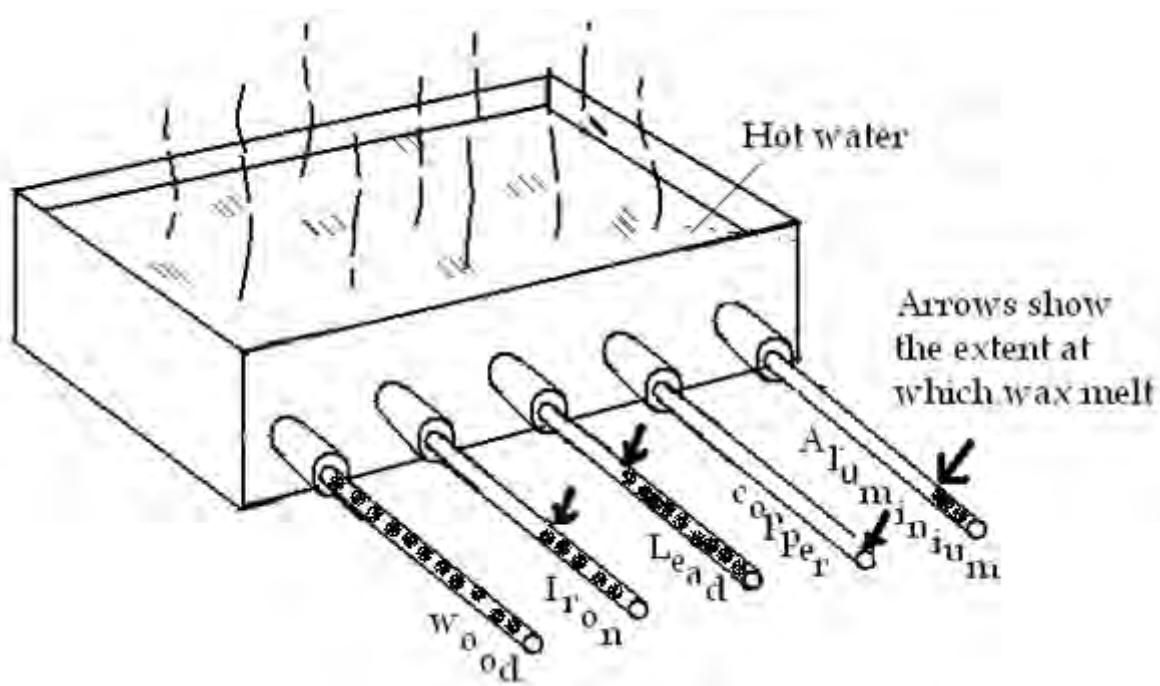
Heat transfer in solids can occur as an excess energy of the vibration being passed along from atom to atom and this happens in all solids. Metals are made of atoms which have free electrons. As a result metals allow heat to pass through them easily and they are called **good conductors of heat**.

On the other hand, non-metals do not have free electrons and they don't allow heat to pass through them. Non-metals are classified as **poor conductor or insulators**.

Good conductors of Heat: Copper, Iron, Aluminum, Silver, Mercury etc.

Poor conductors of Heat: Plastic, Rubber, Wood, Grass, Gases, liquids, etc

Comparison of thermal conductivities



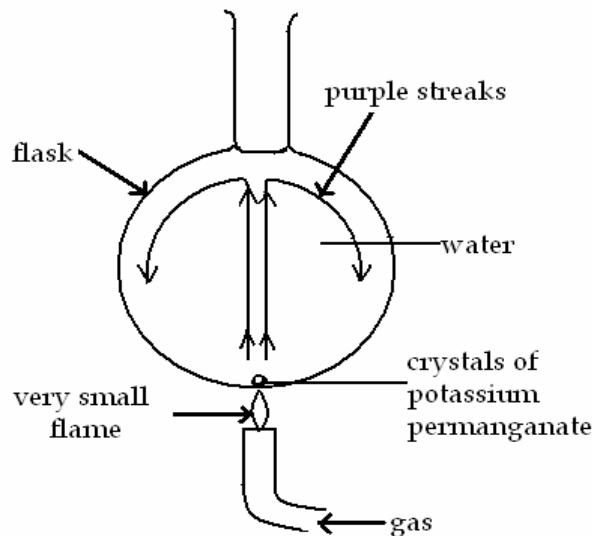
Rods of different materials having the same length and diameter are passed through corks inserted inside of a metal trough as shown in the figure above. These rods are first dipped into molten paraffin wax then passed through corks attached to a water tight containing hot water. Small lengths of the rods rest in the water, while the long portions just out. It is realized after a short time that wax begins to melt along the rods. It melts fastest along copper rod and slowest along wood.

This shows that copper is the best conductor of all these rods and wood is the poorest of them.

Convection in liquids

The transfer of heat by convection can be demonstrated by using simple experiment as seen in the figure below. A crystal of potassium permanganate is placed at the bottom of a beaker full of water.

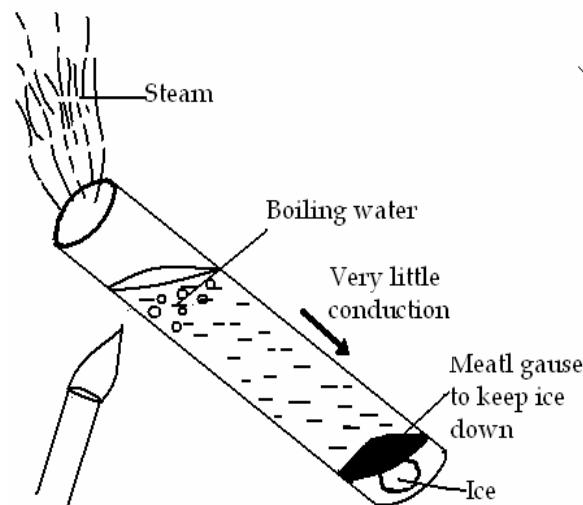
When the beaker is heated gently from the bottom, potassium permanganate spreads out and then descends to the bottom in a cyclic manner. In the course of heating the water on top becomes hot. This shows that heat has been transferred from the bottom to upwards.



The transfer of heat in this case can be explained as: When the liquid is heated, the liquid expands and becomes less dense. The less dense liquid rises and carries the heat it absorbed with it, thus transferring the heat upwards. The cold water sinks to the bottom in order to take up the position of the warm liquid. At the bottom of the beaker, the cold liquid also becomes less dense as it absorbs heat and it rises. This cyclic process is repeated on and on until the liquid boils. The movement of the liquid from the bottom upwards then downwards from the top of the liquid forms what is called **convection current**.

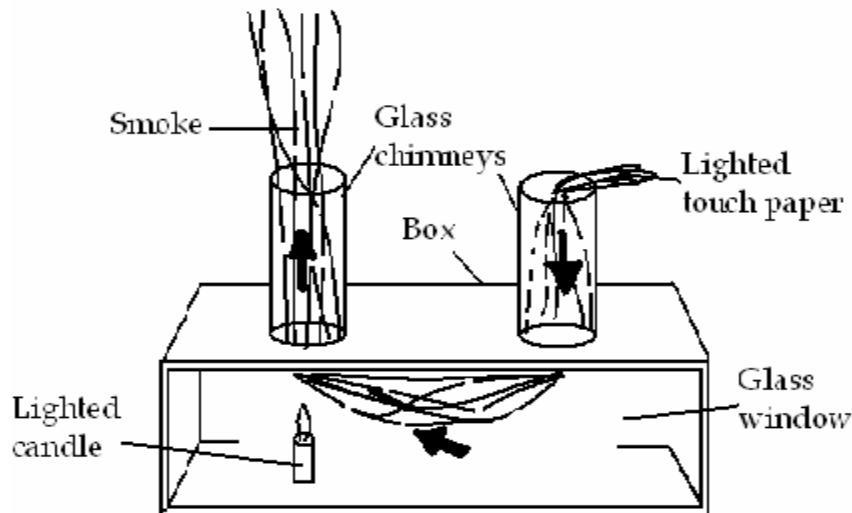
When a liquid is heated from the top as in the figure below, no convection is setup. This is because the warm liquids remain on top as it is already less dense than the liquid at the bottom.

However, after a long time, ice placed at the bottom of the tube may be seen to melt as some heat transfer down by conduction.



Convection in Gases (in Air)

Convection is much faster in gases than in liquids. This is due to much greater change in density when the gas is heated. Convection current in gases can be demonstrated by using the arrangement in the figure below.

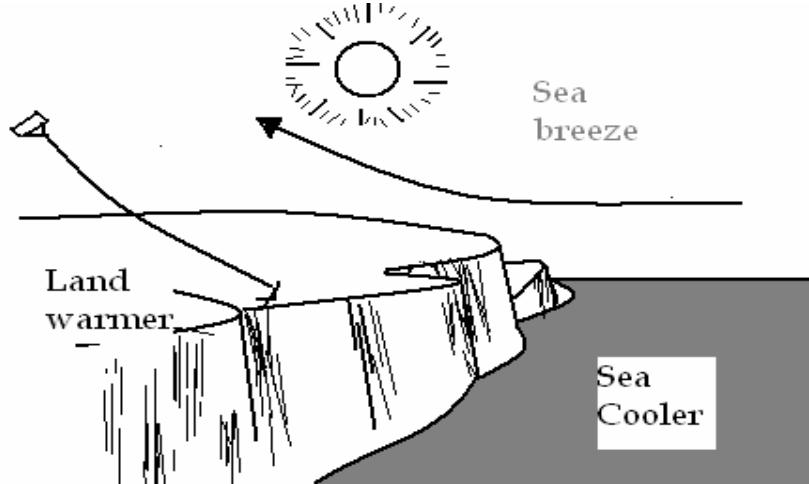


The direction of the convection current created by the candle is made visible by the smoke from the touch paper.

Application of air convection

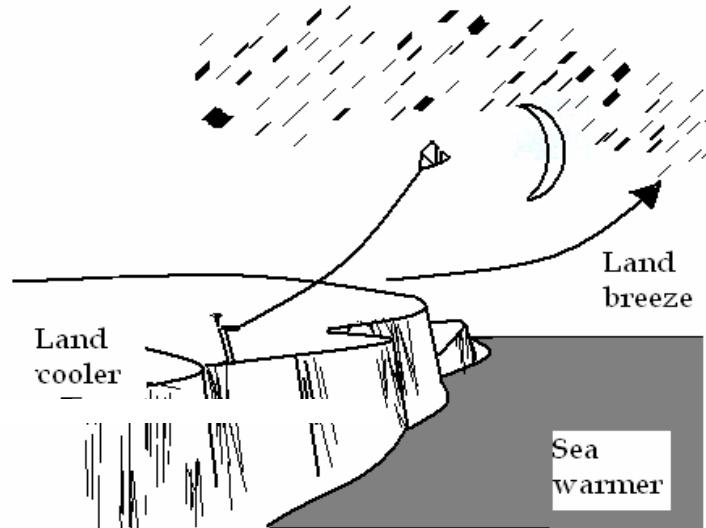
Sea and Land Breezes: During the day the temperature of the land increases more quickly than that of the sea (because the specific heat capacity of the land is much smaller). The hot air above the land rises and is replaced by colder air from the sea. Breeze from the sea results figure (a)

a)



At night the opposite happens. The sea has more heat to lose and cools more slowly. The air above the sea is warmer than that over the land and a breeze blows from the land figure(b).

b)

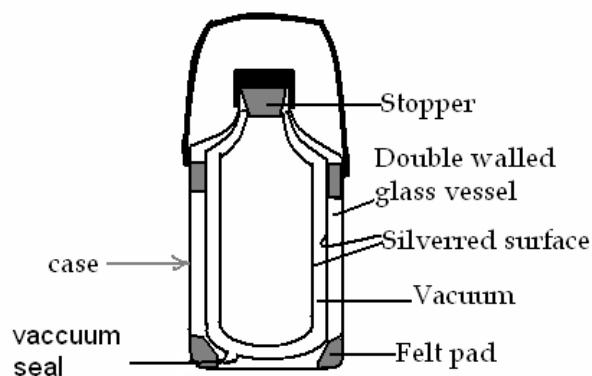


Laws of Radiation

1. Bodies only radiate heat if their temperature is higher than the surrounding and they absorb heat from the surrounding if their temperature is lower.
2. Radiate heat travels in a straight line.
3. Good absorbers of heat radiations are also good emitters of heat radiation.

Application of Heat Radiation

Vacuum Flask



A vacuum or Thermos flask keeps hot liquids hot and cold liquids cold.

The thermos consists of double walled glass vessel having a vacuum between walls. Both walls are silvered on the vacuum side. The liquid can be kept hot or cold because heat loss by;

- Conduction and convection are eliminated by the vacuum space between the double walled glass vessel.
- Convection from the hot liquid upwards to the outside is reduced by the cork or plastic stopper.
- Radiation is prevented by the silvered glass wall. In this case, any heat when tries to escape through vacuum is reflected back.

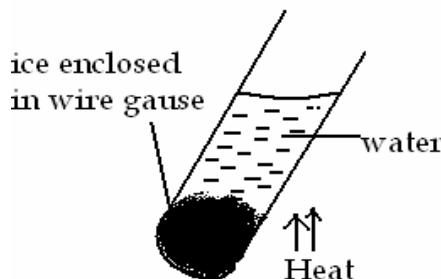
NB: *A thermos flask can be considered useless when the vacuum seal breaks. This is because the vacuum will no longer be there and heat can be lost by radiation, convection or conduction through the broken seal.*

TEST 3

SECTION A

1. The transfer of heat by the actual movement of molecules matter takes place
 - A. Only in liquids.
 - B. Only in gasses
 - C. In solids and liquids
 - D. In liquids and gasses
2. The process of using a material of low thermal conductivity to prevent heat loss is called
 - a) cooling
 - b) lagging
 - c) absorption
 - d) contraction
3. A domestic refrigerator uses a volatile liquid. Which of the following represents the order of the process the liquid undergoes?
 - a) Evaporation compression condensation evaporation.
 - b) Cooling condensation evaporation compression evaporation.
 - c) Compression evaporation condensation cooling evaporation.
 - d) Condensation cooling evaporation compression evaporation.
4. The rate of evaporation from a body is increased by
 - (i) temperature
 - (ii) pressure
 - (iii) liquid with greater cohesive forces
 - (iv) dryness of air around the body
 - (a) (i) and (ii) only
 - (b) (ii) and (iii) only
 - (c) (i) and (iv) only
 - (d) (iii) only.
5. A dull black surface feels hotter even though it is at the same temperature as a shiny surface because it
 - (a) Has more heat than the shiny surface
 - (b) Emits more heat than a shiny surface
 - (c) Reflects more heat than a shiny surface
 - (d) Conducts more heat than a shiny surface.
6. A sea breeze occurs
 - (a) when cool air blows towards the land
 - (b) when warm air blows towards the land
 - (c) during the night
 - (d) when cool air blows towards the sea.

7



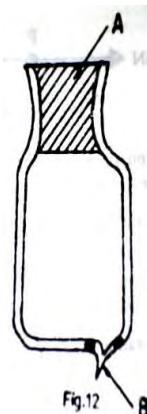
Which of the following is/are true about the experimental set up in the above figure?

1. The ice takes long to melt because of the gauze.
 2. The wire gauze keeps the ice at the bottom of the test tube. .
 3. The ice does not melt because the heating is from above.
 4. The ice takes long to melt because water is a poor conductor.
- | | |
|-----------|-----------------|
| A. 1 only | B. 2 and 3 only |
| C. 4 only | D. All |
8. Which one of the following statements is/are true about heat radiation?
1. A cold body emits invisible radiation of long wave length
 2. Very hot objects emit radiations of short wave lengths
 3. All good radiators of heat are good absorbers
 4. All radiations emitted by hot objects are invisible.
- | | |
|-----------|-----------------|
| A. 1 only | B. 2 and 4 only |
| C. 4 only | D. All |
9. Metals are good conductors of heat because
- | | |
|----------------------------------|---|
| (a) they are ductile | (b) they contain free protons |
| (c) they contain loose electrons | (d) their atoms can be easily displaced |
10. On a cool day, a metal feels cold to the touch because
- a) metals contain less heat
 - b) the temperature of the metal is the same as that of the surroundings
 - c) the temperature of the metal is less than that of the surroundings
 - d) the metal conducts the heat away from the hand.

SECTION B

1. (a) Explain why the sea remains cooler than land during daytime and warmer than land at night.
(b) State any one factor on which the rate of heat transfer along a metal bar depends.

2.



The above figure shows a thermos flask.

- (a) Name the parts labelled A and B
(b) State the use of part labelled A
(c) Why do the contents of the flask ultimately get cold?
3. a) Name two main features of a vacuum flask, which enable it to keep a liquid warm.
b) What is the use of a vacuum in a thermos flask?
 4. What are the functions of the following in a refrigerator.
 - i) Compressor
 - ii) Cooling fins?
 5. (a) Differentiate between conduction and convection.
(b) Describe an experiment which can be performed to show convection in a liquid
 6. (a) What is meant by conduction?
(b) Draw a diagram of a thermos flask and explain how it is able to keep a liquid cool for a long time.
 7. Explain the following observation
A bare cement floor feels colder than a carpeted one.

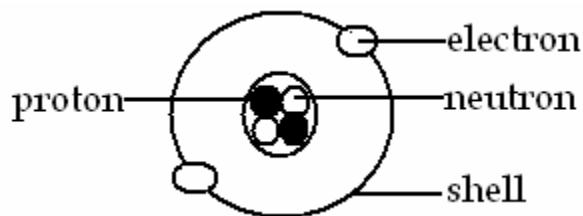
CHAPTER FOUR

ELECTROSTATICS

* Electrostatics is simply the study of electric charges at rest.

The structure of an Atom

- ✓ A substance is made up of tiny atoms which consist of electrons, protons and neutrons.
- ✓ The electrons are found in the shell while protons and neutrons are found in the nucleus, the central part of the atom.



- ✓ An electron carries a negative charge while a proton carries a positive charge.
- ✓ The magnitude of the negative charge on an electron and positive charge on a proton are equal.
- ✓ The number of electrons and protons in an atom is always equal, thus the atom is electrically neutral.

Conductors and insulators

A **conductor** is a substance which has atoms in which electrons can move from one part of the conductor to another. These electrons are called *free electrons* i.e. electrons are loosely bound to atoms. Electrons therefore are able to transfer charges from one part of a conductor to another.

The transfer of charge in this way is called **conduction**.

Examples are any metal such as copper, aluminum, brass and electrolytes.

*An **insulator** is a substance which has its electrons tightly bound to the atoms, that is, the electrons are not free to move about. Insulators are therefore poor conductors.

Examples are glass, fur, silk, ebonite, polythene etc.

Charging an Insulator by friction

- ✓ When glass and silk are rubbed together, glass atoms tend to lose electrons faster than the atoms of silk.
- ✓ The electrons lost by the atoms of glass are acquired by the atoms of silk.
- ✓ The exchange of electrons makes the atoms of glass to have more protons than electrons and the atoms of silk to have more electrons than protons. Thus glass and silk become positively and negatively charged respectively.

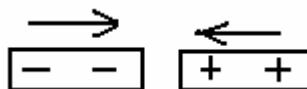
- ✓ **Note!** In all cases, a substance is charged when it has more protons than electrons or vice-versa.
- ✓ E.g.: When ebonite is rubbed with fur electrons are transferred from fur to ebonite, therefore making the fur positive and ebonite negative.

Laws of electrostatics

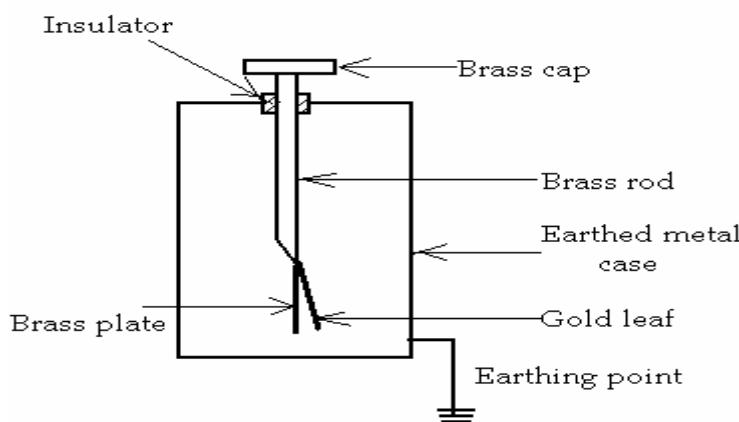
i) Like poles repel each other.



ii) Unlike poles attract each other.



Gold leaf electroscope



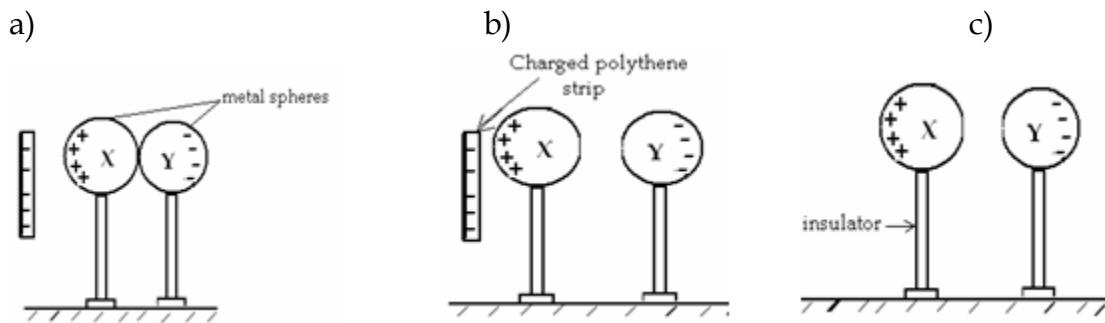
A gold leaf electroscope is a device used in electrostatics for the detection and testing of small electric charges.

The uses of gold leaf electroscope are as follows:

1. To detect the presence of charge on a body.
2. To charge a gold leaf electroscope by conduct.
3. To test for the sign of the charge on a body.
4. To test the insulating properties of various materials

Electrostatic induction

The diagram is shown by bringing a negatively charged polythene strip near to an insulated sphere X which is touching a similar sphere, figure a. Electrons in the spheres are repelled to the far side of Y.



If X and Y are separated, with the charged strip still in position, X is left with a positive charge and Y with a negative charge, figure b. The signs of charges can be tested by removing the charged strip and taking X up to the cap of a positively charged electroscope and Y to a negatively charged electroscope, figure c.

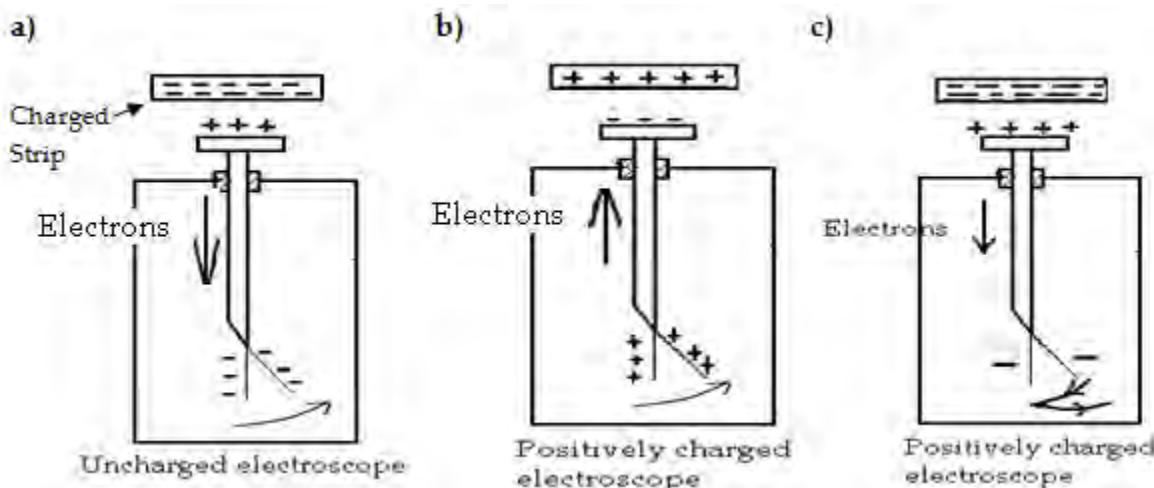
If the whole experiment is carried out again using a positively charged strip as the inducing charge, the induced charges on X and Y are reversed.

Induction and Electroscope

- ✓ Electrostatic induction occurs when a charged strip is brought near an electroscope. In figure a, electrons in the cap of the uncharged electroscope are repelled down to the plate and leaf which both become negatively charged, causing the leaf to rise due to repulsion by the plate.

- ✓ In figure b, electrons are attracted from the plate and leaf of the positively charged electroscope up to the cap. The positive charge on the plate and leaf increases and the leaf raises more.

- ✓ In figure c, if a large charge is brought too near the cap of an oppositely charged electroscope, the leaf rises after first collapsing.

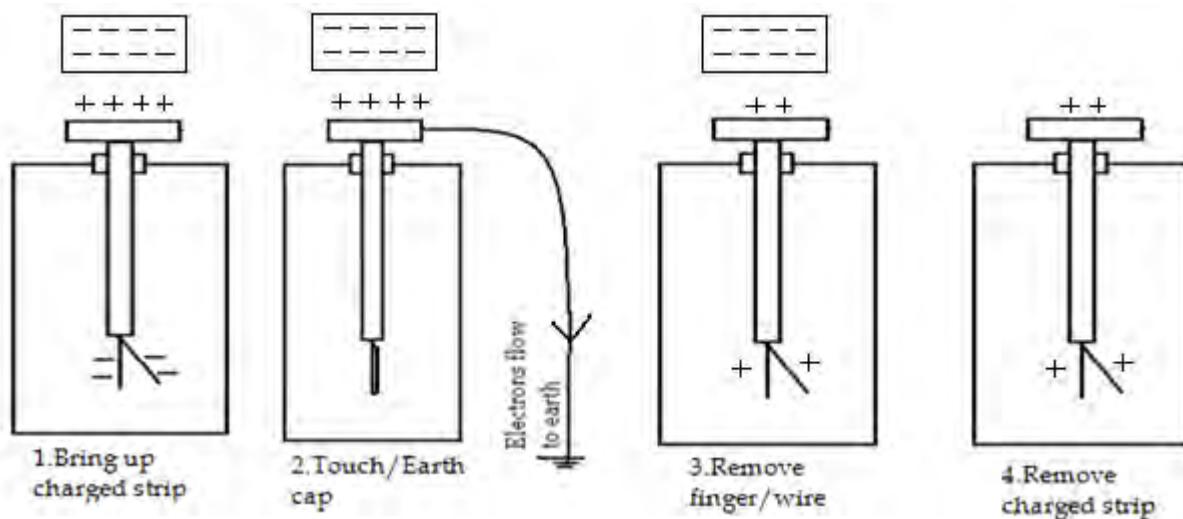


Charge on electroscope	Charge brought near cap	Effect on leaf divergence
+	+	Increases
-	-	Increases
+	-	Decreases
-	+	Decreases
+ or -	Uncharged body	Decreases

Charging by induction

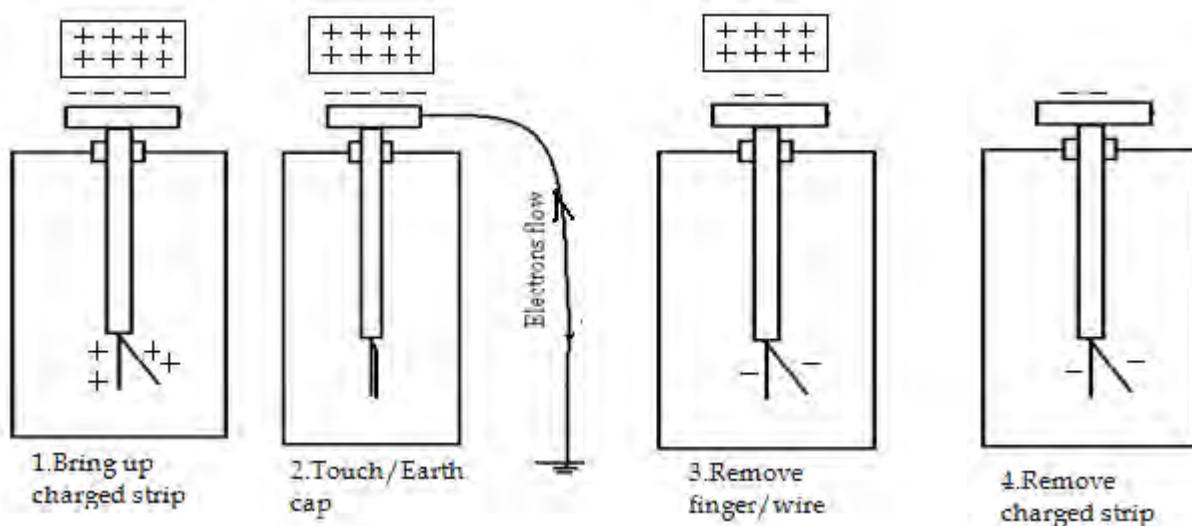
A strip is used with a charge of opposite sign to that required on the electroscope.

a) Charging a gold - leaf electroscope positively by induction



When the cap is “earthing” by touching it with a finger or a wire, electrons flow from the electroscope to the earth through the body or a wire as shown in figure above 2.

b) Charging a gold - leaf electroscope negatively by induction



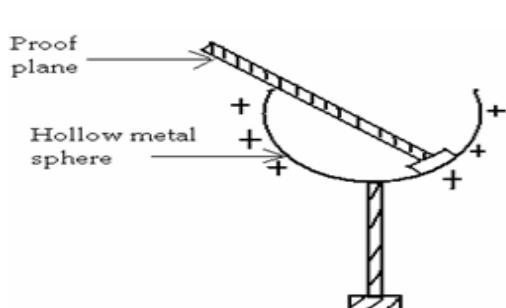
To charge the electroscope negatively by induction, a positively charged strip is used. In this case, when the cap is “earthing” by touching it with a finger or a wire, electrons flow from the earth to the electroscope through the body or a wire as shown in figure above 2.

Distribution of charge on a conductor

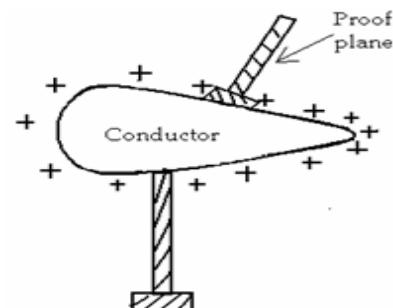
The charge on a conductor is only on its outside surface.

This may be shown by charging a hollow metal sphere with an electrophorus and touching its inside and outside with a proof plane (a small metal disc on an insulating handle), figure a. Any charge on the proof plane can be detected by an electroscope.

a)



b)



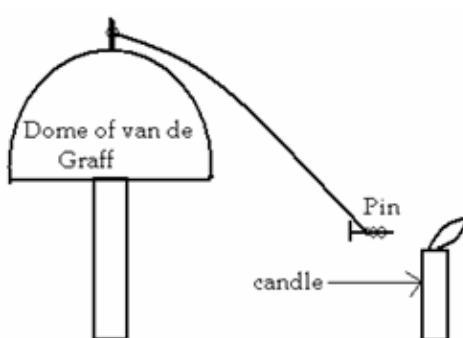
In general the charge on the outside of a conductor is not evenly spread over it. The charge per unit area, called the *charge density*, is greatest where the surface is most curved.

In the conductor of figure b, this is at the pointed end, as a proof plane will show.

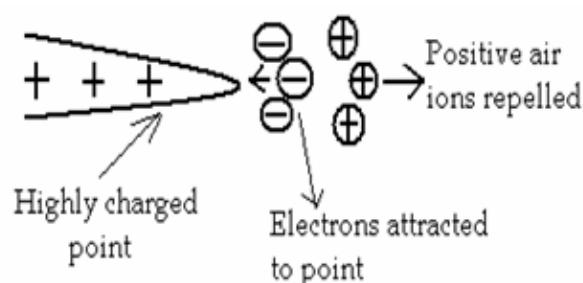
Action of points

A lighted candle placed near the point of a pin which is connected to the dome of a van-de-Graaff generator is blown aside when the generator is working, figure below.

a)



b)

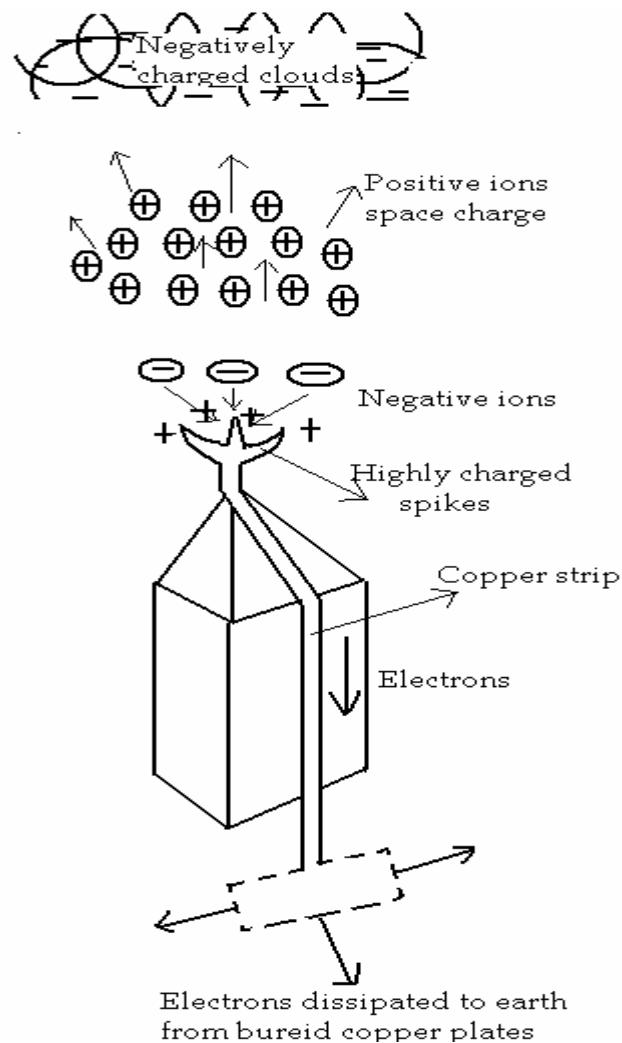


Charge concentrates on the sharply curved point of the pin and the force it exerts on air molecules nearby may be large enough to remove some electrons from them. These air molecules will be left positively charged and are called positive ions. If the pin is positively charged, it attracts the negative electrons and repels the positive ions which stream away from the point as an "electric wind". As shown in the figure above-b.

- ◆ Van der Graff generator produces a continuous supply of charge on a large metal dome. Large versions are used in nuclear research.

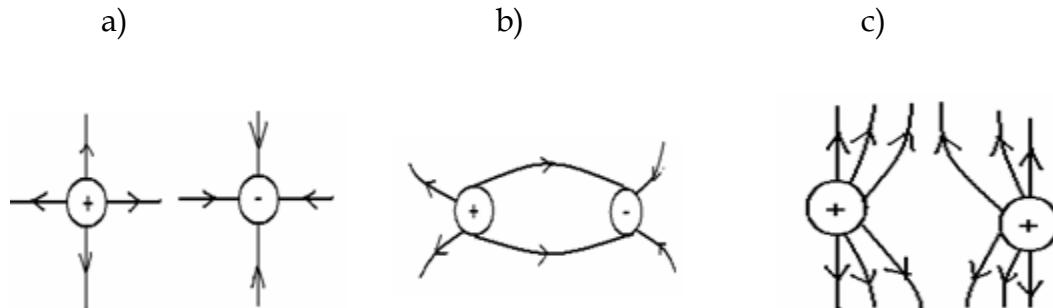
Lightning conductor

- A lightning conductor uses the action of points to protect tall buildings from lightning. The conductor is a copper strip on the outside of the building connecting spikes that stick at the top to a metal plate in the ground.
- Thunder clouds, a negatively charged one passing overhead, repels electrons from the spikes to the earth, leaving the points positively charged.
- An electric wind of positive air ions streams upwards to cancel out some of the charge on the cloud
- If a flash does occur it is less violent and the conductor gives it an easy path to the ground.



Electric Field

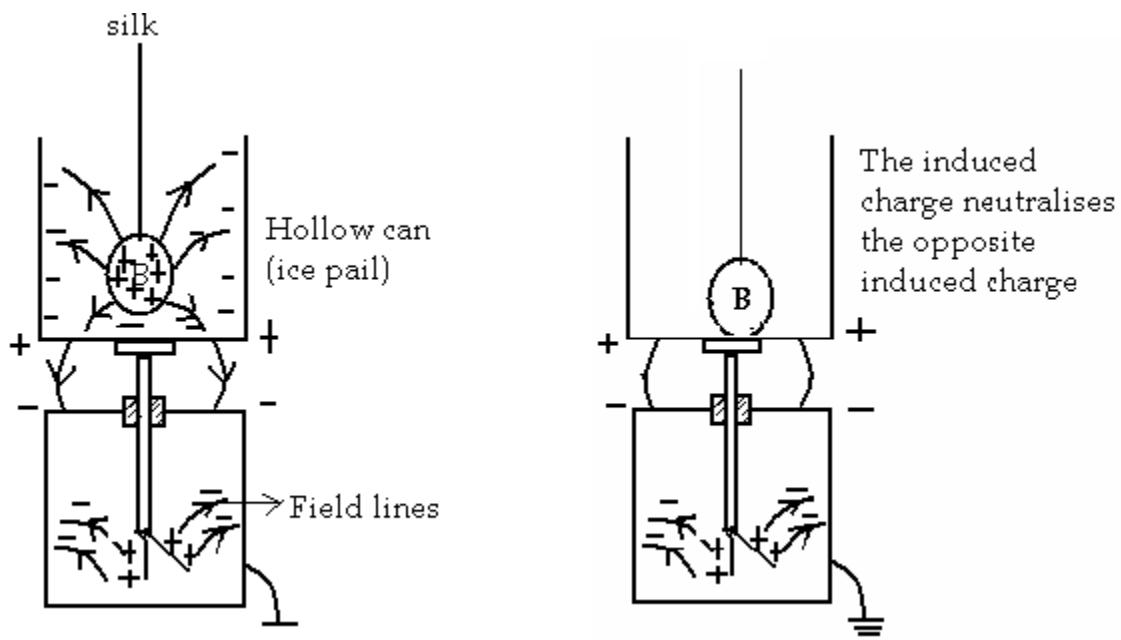
- The space around an electric charge where it exerts a force on another charge is called an electric field. It is represented by field lines or lines of force.
- The direction of the field at any point is taken as the direction of the force on a positive charge at the point.
- It is shown by arrows on the lines which we therefore image as starting on a positive charge and ending on a negative one.



The ice-pail experiment

- In this experiment a positively charged brass sphere B, supported by an insulating silk thread, is lowered inside a hollow can standing on the cap of a gold leaf electroscope. A negative charge becomes induced on the inside of the can and a positive charge on the outside of the can, and the leaf , figure a.
- So long as the sphere is well down inside the can and is not allowed to touch the can, it may be moved about inside without causing any alteration in divergence of the leaf.
- When the charged sphere is allowed to touch the bottom of the can, no change occurs in leaf divergence, figure b.
- On removing the sphere, it is found to be completely discharged, and also there is no longer any charge on the inside of the can.
- It is therefore concluded that the inducing charge on the sphere has exactly neutralized the opposite induced charge on the inside of the can, and hence the two are equal in magnitude.

a) b)



TEST 4

SECTION A

1. A charged conductor usually loses charge gradually by a process called
 - a. induction
 - b. insulation
 - c. conduction
 - d. leakage

2. The result of rubbing a glass rod with silk and separating them is
 - a. a negative charge on the rod and an equal positive charge on the silk.
 - b. equal amounts of negative charge on both
 - c. a positive charge on the rod and an equal negative charge on the silk.
 - d. no charge on both the rod and the silk.

3. A metal rod gains a positive charge when rubbed with fabric. The fabric acquires
 - A. No charge.
 - B. A negative charge equal to that of the rod.
 - C. A positive charge equal to that on the rod
 - D. A positive charge greater than that on the rod.

4. In the diagram below, an electron beam XY enters an electric field between plates A and B as shown in the figure.

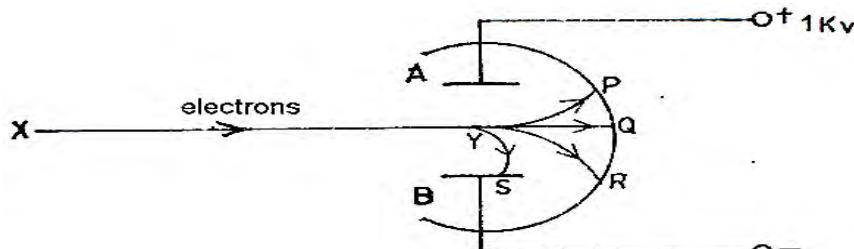


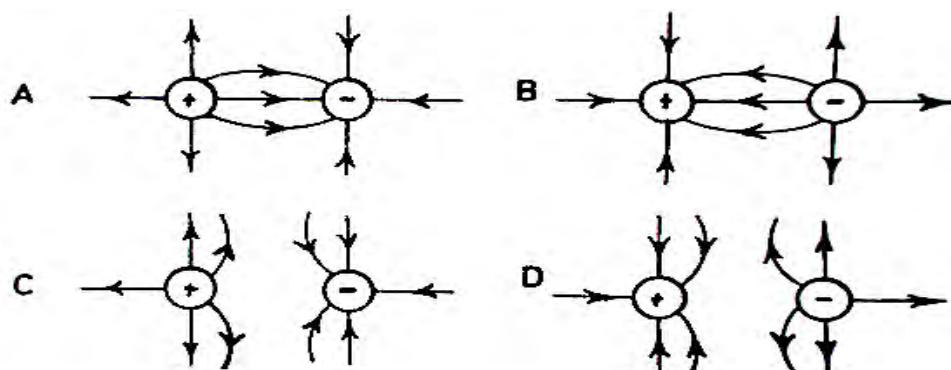
Fig. 3

Which one is the possible route of movement of the electrons?

- a) YS
 - b) YR
 - c) YQ
 - d) YP
5. When a rod is brought close to the cap of a negatively charged gold leaf electroscope and its leaf diverges, it shows that the rod is

- a) Negatively charged
 - b) positively charged
 - c) neutral
 - d) partially charged.

6. Which one of the following diagrams represents the correct electric field pattern for two oppositely charged points?



7. The laws of electrostatic induction states that

- (a) like poles repel and unlike poles attract
 - (b) like poles attract and unlike poles repel
 - (c) like charges repel and unlike charges attract
 - (d) like charges attract and unlike charges repel.

8. Which one of the following actions will cause the leaf of a negatively charged electroscope to fall?

- (i) Bringing a positively charged rod near the cap.
 - (ii) Bringing a negatively charged rod near the cap.
 - (iii) Connecting the can to the earth.

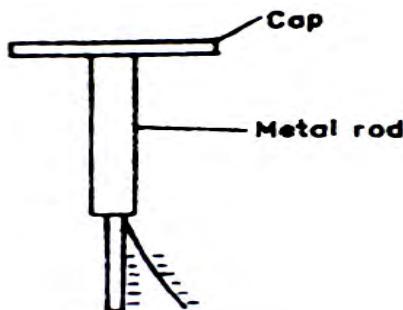
A. (i) and (ii) only
 C. (ii) and (iii) only

B. (i) and (iii) only
D. (i), (ii) and (iii)

9. When polythene and wool are rubbed against each other and then separated, they acquire

- A. no charge.
 - B. equal amount of same type of charge.
 - C. equal and opposite charges.
 - D. both acquire positive and negative charges.

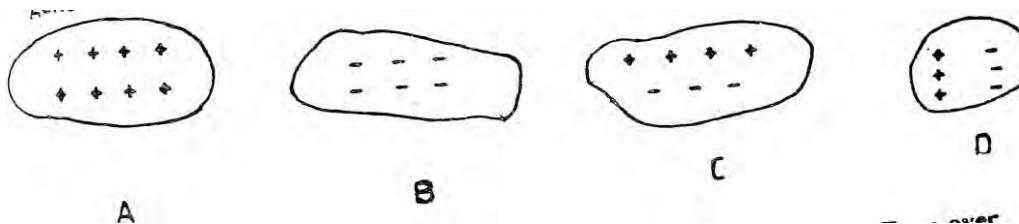
10. A body can only be confirmed to be electrically charged when
- another charged body attracts it.
 - it does not affect the leaf of a charged electroscope.
 - it is repelled by another charged body.
 - it is found to have less protons than electrons.
11. It is recommended that buildings should have earthed conductors in order to
- reduce heat intensity on hot days
 - remove excess electrons from the building
 - stabilise the current electricity to the building
 - provide more charges to electrical appliances in the building.
12. It is easier to charge insulators than conductors because
- the insulators don't allow the charge to flow away but the conductors allow the charge to flow away
 - the conductor retain the charge by conduction but the insulators release it to the atmosphere
 - it is impossible to charge conductors under any condition
 - insulators just receive the charge from the atmosphere without being rubbed
13. The diagram below shows a part of the gold leaf electroscope.



What will happen to the leaf if a positively charged rod is brought near the cap of electroscope? It will

- increase in deflection
- remain in the same position
- reduce in deflection
- break off from the plate.

- 14.** Which of the following statements is true about a good insulator?
- it acquires electric charge when rubbed with suitable materials
 - all its electrons are loosely bound to its atoms
 - electric charge easily flows on its surface
 - some of its electrons are free to move about
- 15.** An electroscope becomes negatively charged when it
- loses electrons
 - gains protons
 - gains electrons
 - loses proton
- 16.** An insulating rod that can be charged positively by rubbing with a piece of fabric is rubbed with fabric and left in contact for a long time and then separated. What will you expect each of them to have?
- no charge
 - equal number of opposite charges
 - more positive charge on the rod than on the fabric
 - more negative charge on the fabric than on the rod
- 17.** When a plastic rod is brought near a charged electroscope, the gold leaf is seen to diverge more. The possible charges on the rod and the electroscope are
- | <u>Electroscope</u> | <u>Plastic rod</u> |
|---------------------|--------------------|
| A. positive | negative |
| B. negative | positive |
| C. negative | negative |
| D. positive | un charged |
- 18.** Which one of the following shows the correct distribution of electric charges generated in clouds due to violent movements within the thunder clouds?



- 19.** Which of the following statements are true
- protons and neutrons are found in the nucleus of an atom
 - electrons and beta particles are the same
 - protons and electrons occur in equal numbers in all neutral atoms
 - alpha particles and beta particles are both positively charged.

- | | | | |
|----|---------------------|----|--------------------|
| a) | (i), (ii) and (iii) | b) | (i) and (iii) only |
| c) | (ii) and (iv) only | d) | (iv) only |

20. The leaf of a charged electroscope gradually collapses with time due to

- (a) leakage to the surroundings
- (b) surrounding magnetic field
- (c) pressure variations in the surroundings
- (d) similar charges from the surroundings

SECTION B

1. A positively charged rod is brought near two conducting spheres A and B in contact as shown in the figure.

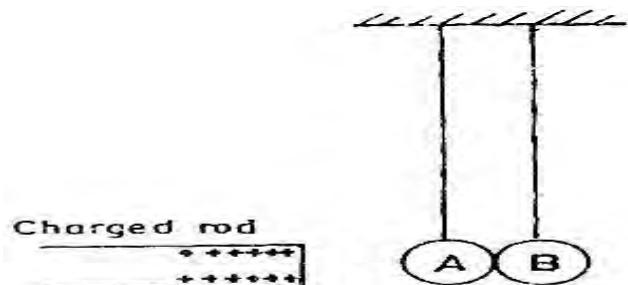
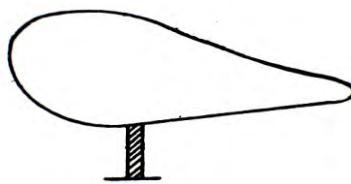


Fig. 9

- a) Show the charges on the spheres.
 - b) Describe how the spheres can be given a permanent charge
2. Explain how leakage of charge occurs at the ends of sharp conductors.
3. (a) What happens when a glass rod is rubbed with:
 - (i) silk
 - (ii) an identical glass rod?
 (b) Describe how a gold leaf electroscope may be used to test the nature of the charge on an object.
4. (a) State the laws of electrostatics.
 (b) Two insulating materials are rubbed together describe what is observed if

- (i) the two are brought near the cap of a gold leaf electroscope.
(ii) only one of them is brought near the cap.
5. (a) What happens to an insulator when it is rubbed by another insulator of different material?
(b)

**Fig. 15**

The above figure shows a conductor supported on an electrical insulator. The conductor is given some positive charge. Show how the charge is distributed on the conductor.

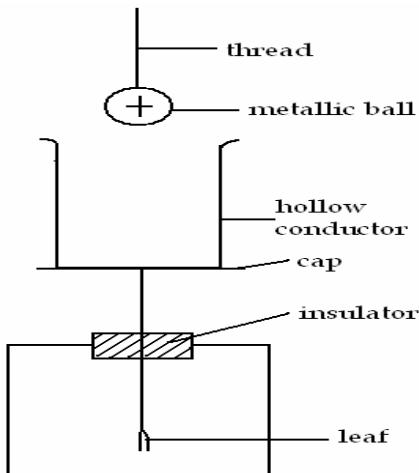
- (c) Sketch the electric field pattern due to two unlike charges P and Q below.



6. (a) Distinguish between a conductor and an insulator.
(b) Describe, stating the observation made, how a gold leaf electroscope can be charged positively
7. (a) Explain why it is not advisable to touch the copper strip of a lightning conductor when it is raining.
(b) Why is it difficult to perform experiments in electrostatics under damp conditions?
8. A gold leaf electroscope is positively charged. State what happens when each of the following is brought near the cap
(i) a neutral metal
(ii) a positively charged body
9. Draw the electric field patterns for:
(i) an insulated negative charge.
(ii) two oppositely charged parallel plates at a small distance apart.
10. (a) Explain why a pen rubbed with a piece of cloth attracts pieces of

paper

- (b) A positively charged metallic ball is held above a hollow conductor resting on the cape of a gold leaf electroscope as shown in the figure below.



Explain what happens to the leaf of the electroscope as the ball is lowered into the conductor.

CHAPTER FIVE

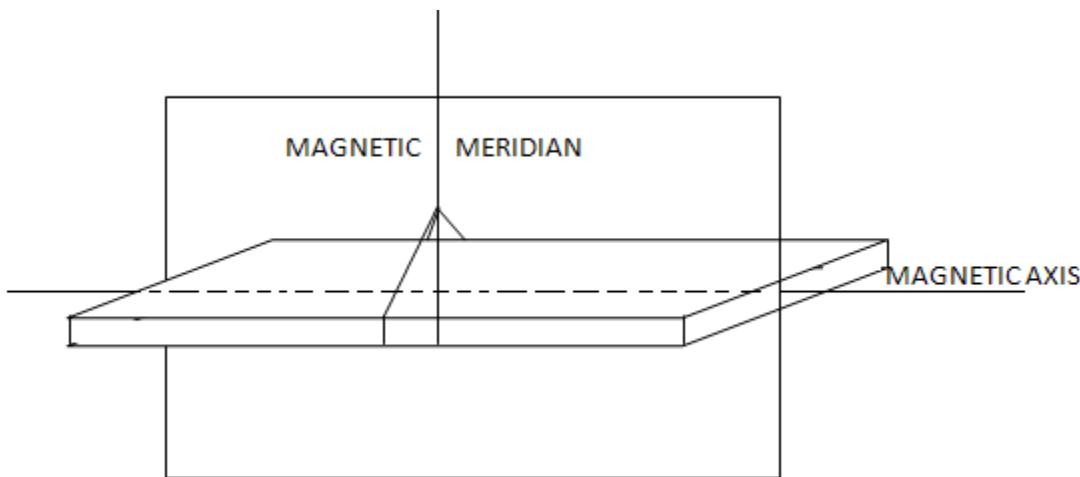
MAGNETISM

Magnets

- A magnet is a piece of metal/material which can attract other materials.
- A substance which is attracted by a magnet is known as a magnetic material or *ferromagnetic* material.
Examples of magnetic material are iron, cobalt, Nickel and Steel.
- A substance which is not attracted by a magnet is known as a *non-magnetic material*.
Examples include: wood, copper, brass, lead and so on.
- A form of iron ore called magnetite or loadstone which has a property of coming to rest while pointing in the North-south direction when freely suspended was the first naturally occurring magnet.
- All substances show some kind of magnetic effect even if it is very small. The apparently non-magnetic substances are classified as either **diamagnetic** or **paramagnetic** respectively.
- Magnets are used in Electric motors, cycle dynamos, loud speakers and telephones.

Magnetic meridian and Magnetic axis

- When a magnet is freely suspended so that it can swing in a horizontal plane it oscillates to and fro for a short time and then comes to rest in N-S direction.
- The magnet may be regarded as having a *magnetic axis* about which its magnetism is symmetrical, and it comes to rest with this axis in a vertical plane called the *magnetic meridian*, as shown in fig below.
- *Magnetic meridian* is a vertical plane containing the magnetic axis of a freely suspended magnet at rest under the action of the earth's magnetic field.
- The pole which points towards the north is called the north-seeking or N pole; the other is called the south-seeking or S pole.



Properties of magnets

1. Magnetic materials

Magnets can only attract strongly certain materials such as iron, steel, nickel, cobalt which are called ferromagnetic.

2. Magnetic poles

These are places in a magnet to which magnetic materials are attracted e.g. iron filings.

3. North and south poles

If a magnet is supported so that it can swing in a horizontal plane, it comes to rest so with one pole, the North-seeking or N pole, always pointing roughly towards the earth's north pole. A magnet can therefore be used as a compass.

4. Law of magnetic poles

Unlike poles of a magnet attract each other, that is a north pole and a south pole.

Like poles repel each other, that is north pole and north pole or south pole and south pole.

In summary: *Like poles repel, unlike poles attract.*

Test for a magnet

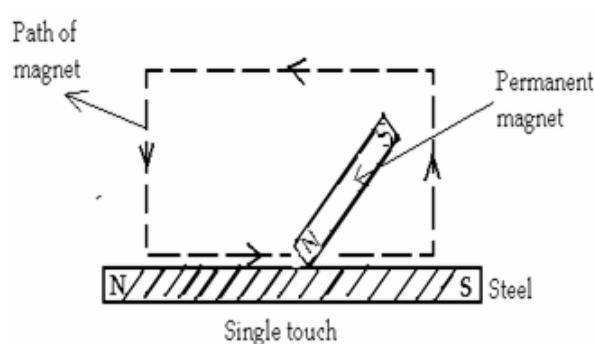
- ❖ A magnet causes repulsion with one pole when both poles are, in turn, brought near to a suspended magnet. An unmagnetised magnetic material would give attraction with both poles of the suspended magnet.

- ❖ Repulsion is, therefore, the only sure test for a magnet.

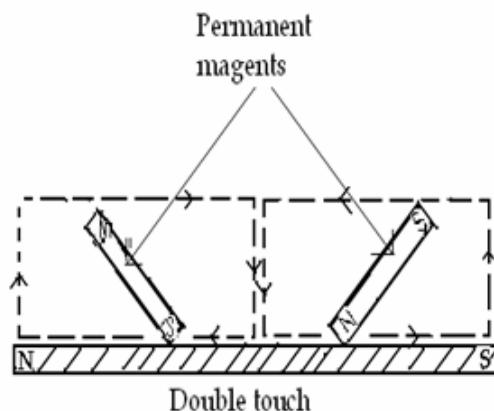
Making a magnet

a) By stroking

a) Single touch



b) Double (Divided) touch



The methods of single and double touch are shown in figures a, b; Steel knitting needles, hair grips or pieces of clock spring can be magnetized. In single touch method, the steel is stroked from end to end about 20 times in the same direction by the same pole of a magnet.

In the better method of double touch, stroking is done from the centre outwards with unlike poles of the magnet at the same time. The magnets must be lifted high above the steel at the end of each stroke in both methods. The pole produced at the end of the steel where the stroke ends is of the opposite kind to the striking pole.

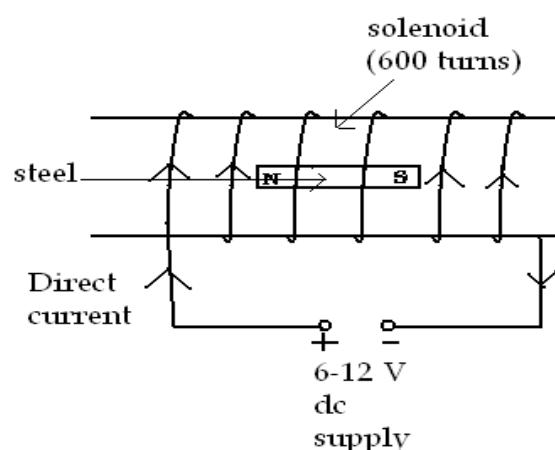
b) Electrically

The magnetic material is placed inside a cylindrical coil called a solenoid, having several hundred turns of insulated copper wire, which is connected to a 6-12V direct current (dc) supply, figure a. If the current is switched on for a second and then off, the material is found to be a magnet when removed from the solenoid.

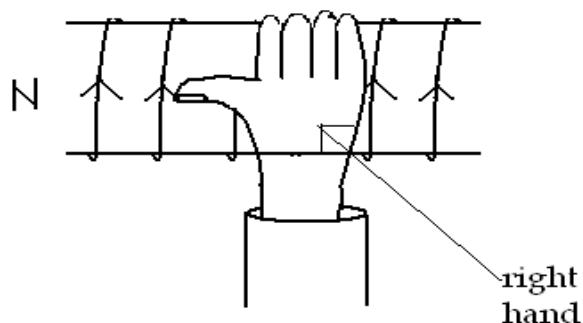
The polarity of the magnet depends on the direction of the current and is given by the right-hand grip rule. It states that if the fingers of the right hand grip the solenoid in

the direction of the current (i.e. from the positive of the supply), the thumb nails points to the North pole ,figure b

a)

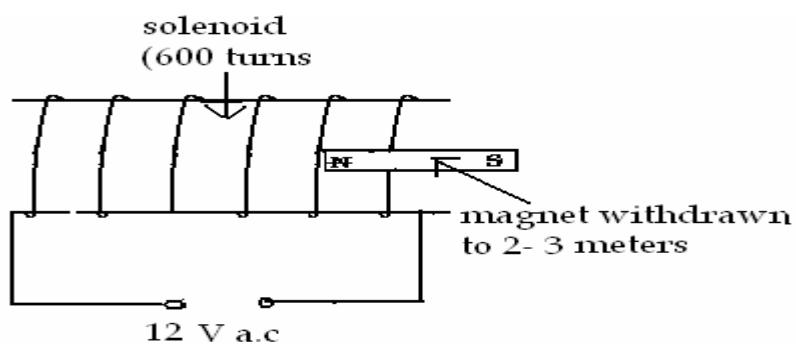


b)



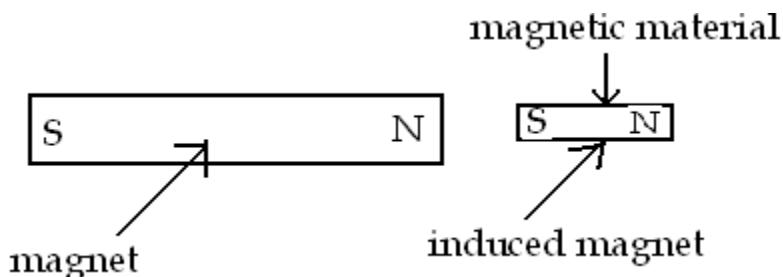
Demagnetizing a magnet

The magnet is placed inside a solenoid through which alternating current (a.c.) is flowing, figure below. With the current still passing, the magnet is slowly removed to a distance from the solenoid.

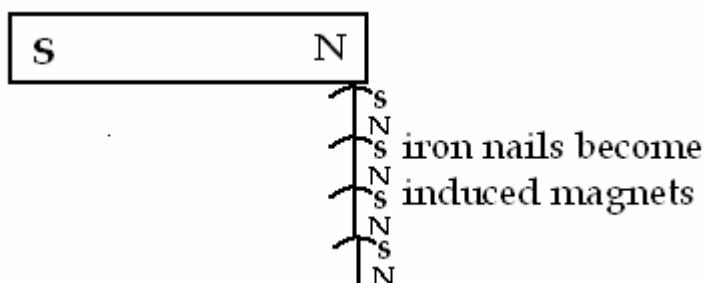


Induced magnetism

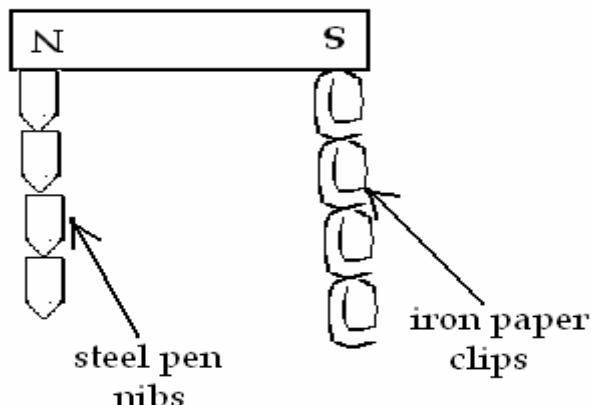
When a piece of unmagnetised magnetic material touches or is brought near to the pole of a magnet, it becomes a magnet itself. The figure below shows that a North pole induces a North pole in the far end.



Induced magnetism can be used to form a “magnetic chain” as shown in the figure below. Each nail added to the chain magnetizes the next one by induction and attraction occurs between their adjacent unlike poles.



Magnetic properties of iron and steel



- Chains of small iron paper clips and steel pen nibs can be hung from a magnet, figure above. Each clip or nib magnetises the one below it by induction and the unlike poles so formed attract.

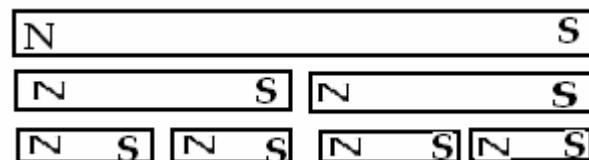
- If the iron chain is removed by pulling the top clip away from the magnet, the chain collapses, showing that magnetism induced in iron is temporary . When the same is done with the steel chain, it does not collapse; magnetism induced in steel is permanent.
- Magnetic materials like iron which magnetise easily but do not keep their magnetism are said to be “soft”. Those like steel which are harder to magnetise but stay magnetised, are “hard”.
- Both types have their uses; very hard ones are used to make permanent magnets.

Theory of magnetism

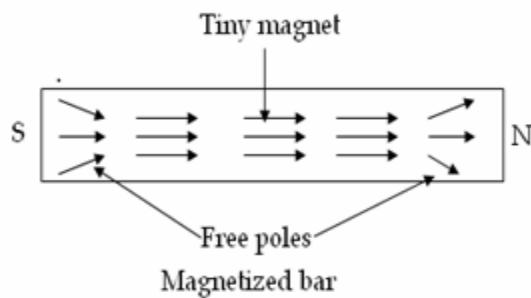
If a magnetised piece of steel rod is cut into smaller pieces, each piece is a magnet with a N and S pole, figure a. It is therefore reasonable to suppose that a magnet is made up of lots of ‘tiny’ magnets all lined up with their N poles pointing in the same direction, figure b.

At the ends, the free poles of ‘tiny’ magnets repel each other and fan out so that the poles of the magnet are round the ends.

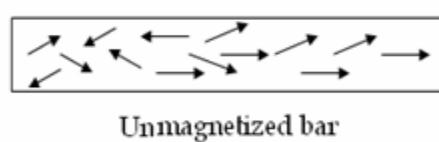
a)



b)



c)



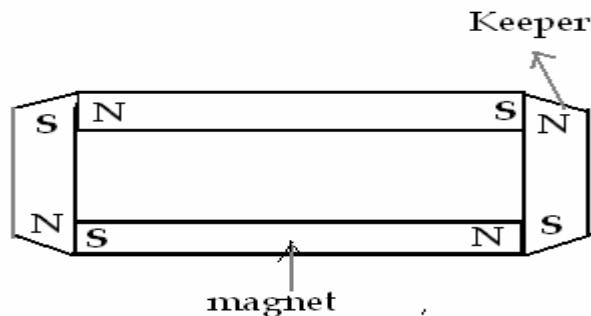
In an unmagnetised bar we can imagine the ‘tiny’ magnets pointing in all directions, the N pole of one being neutralized by the S pole of another. Their magnetic effects cancel out and there are no ‘free’ poles near the ends, as shown in figure (c) above

Breaking of a magnet

- **Magnetic saturation:** There is a hint to the strength of a magnet. It occurs when all the ‘tiny’ magnets are lined up
- **Demagnetization by heating or hammering:** Both processes cause the atoms in the magnet to vibrate more vigorously and disturb the alignment of the ‘tiny’ magnets.
- There is evidence to show that the ‘tiny’ magnets are groups of millions of atoms called **domains**. In a ferromagnetic material, each atom is a magnet and the magnetic effect of every atom in a particular domain acts in the same direction.

Storing magnets

A magnet tends to become weaker with time due to the ‘free’ poles near the ends repelling each other and upsetting the alignment of the domains. To prevent this, bar magnets are stored in pairs with unlike poles opposite and pieces of soft iron called keepers, across the ends, figure below.



The keepers become induced magnets and their poles neutralize the poles of the bar magnets. The domains in both magnets and keepers form closed chains with no “free” poles.

Magnetic Fields

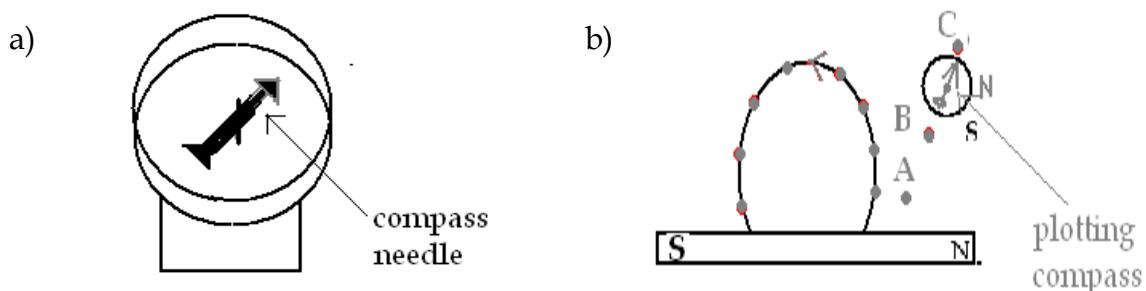
The space surrounding a magnet where it produces magnetic force is called magnetic field.

It is useful to consider that a magnetic field has a direction and to represent the field by lines of force. It has been decided that the direction of the field at any point should be the direction of the force on a north pole. To show the direction, arrows are put on the lines of force and point away from the north pole to the south pole.

Plotting the lines of force

a) Plotting compass method

A plotting compass is a small pivoted magnet in a glass case with brass walls, figure a.

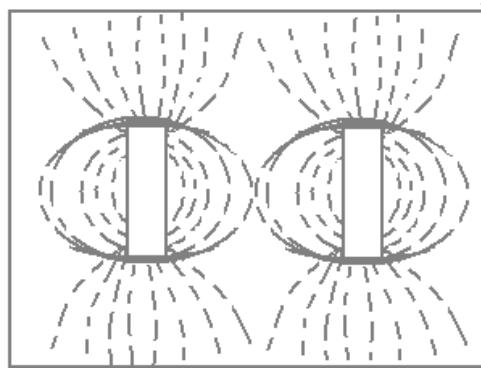


- Lay a bar magnet NS on a sheet of paper, figure b. Place the plotting compass at a point such as A near one pole of the magnet.
- Mark the position of the poles N,S of the compass by pencil dots A,B. Move the compass so that pole is exactly over B. Mark the new position of N by dot C.
- Continue this process until the south pole of the bar magnet is reached.
- Join the dots to give a line of force and show its direction by putting an arrow on it.
- Plot other lines by starting at difficult points around the magnet.
- This method is slow but suitable for weak fields.

b) Iron filings method

- Place a sheet of paper on top of a bar magnet and sprinkle iron filings thinly and evenly on to the paper from a “pepper pot”.

- Tap the paper gently with a pencil and the filings should form patterns of the lines of force. Each filing is magnetized by induction and turns in the direction of the field when the paper is tapped.
- The method is quick but no use to weak magnetic fields. Figure below shows typical patterns with two magnets.



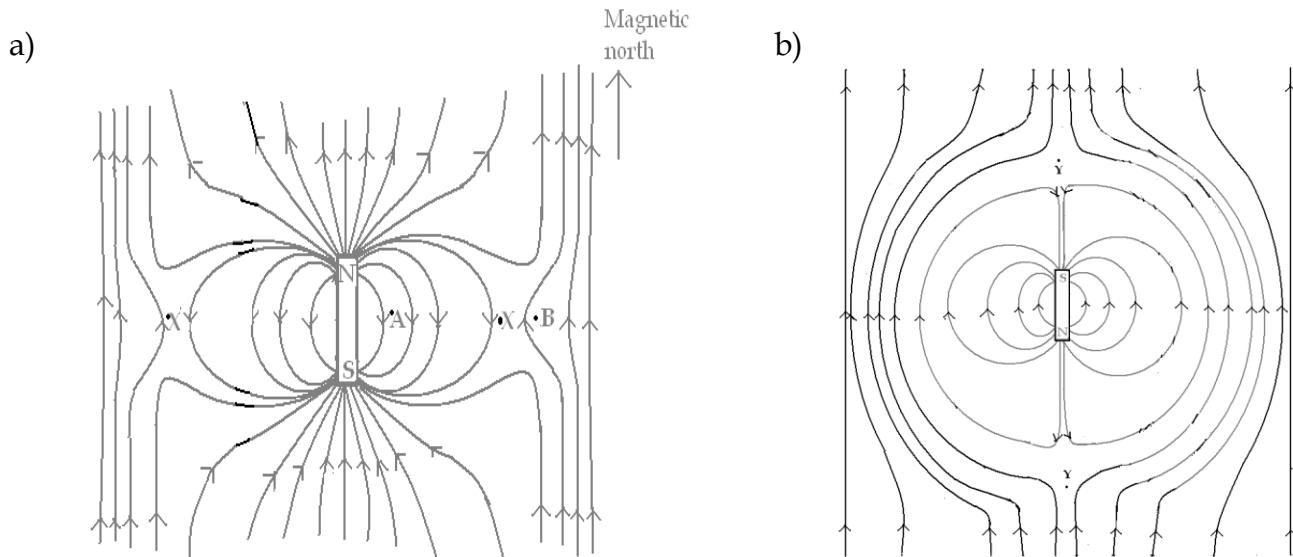
Earth's magnetic field

If lines of force are plotted on a sheet of paper with no magnet near, a set of parallel straight lines are obtained. They can run roughly from S to N geographically, figure below and represent a small part of the earth's magnetic field in a horizontal plane.

The combined field due to the earth and a bar magnet with its N pole pointing N is shown in figure a: it is obtained by the plotting compass method. At the points marked X,



the fields of the earth and the magnet are equal and opposite to the resultant force passing through them. At A, the magnet's field is stronger than the earth's field; at B it is weaker. When the north pole of the magnet points S, the neutral points Y are along the axis of the magnet , figure b.



Neutral point:

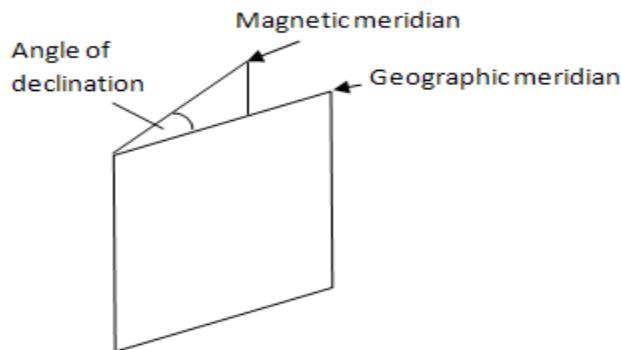
This is the point in a magnetic field at which the resultant magnetic force/flux is zero.

Magnetic Declination

The *magnetic meridian* at any place is a vertical plane containing the magnetic axis of a freely suspended magnet at rest under the action of the earth's field.

The *geographic meridian* at a place is a plane containing the place and the earth's axis of rotation.

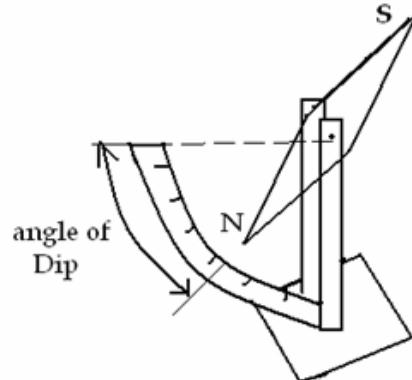
The angle between the magnetic and geographic meridians is called the *magnetic declination* (Fig. below).



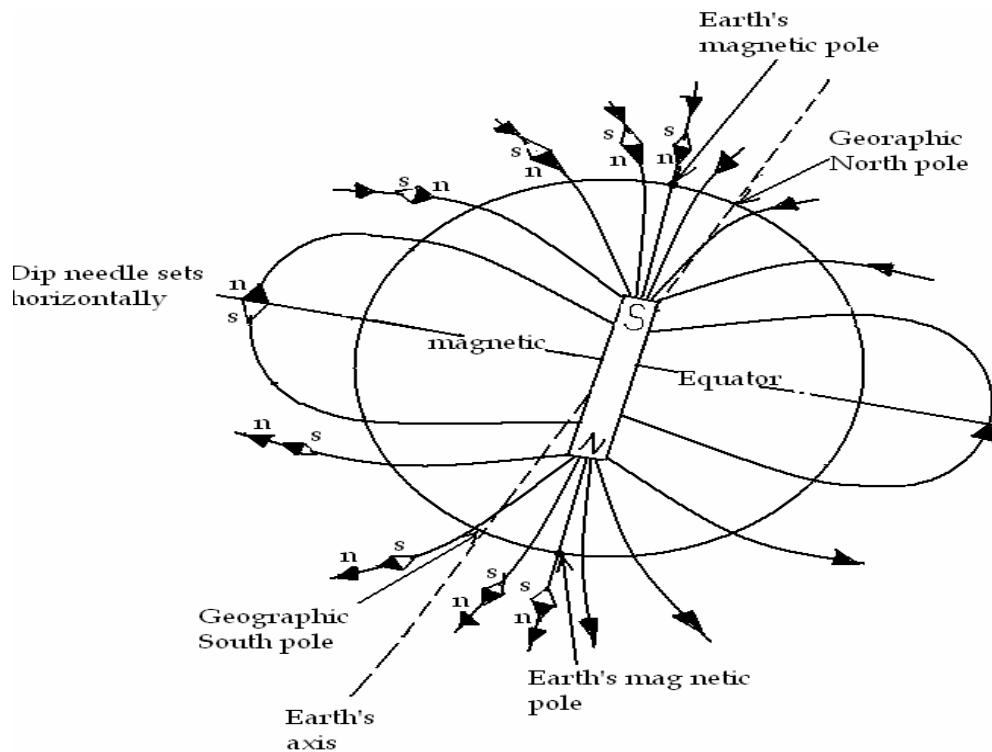
Dip or inclination

- ❖ A magnet pivoted at its centre of gravity so that it can rotate in a vertical plane is called a dip needle, figure below. When placed in the magnetic meridian, i.e. in the

vertical plane containing magnetic N and S, it comes to rest with the North Pole pointing downwards at an angle.



- ❖ The angle a dip needle makes with the horizontal in the magnetic meridian is called the angle of dip or inclination. *Or Angle of dip* is the angle between the direction of the setting compass and the horizontal axis.
- ❖ The angle of dip varies over the earth's surface from 0° at the earth's magnetic equator to 90° at its magnetic poles.
- ❖ This can be explained if we consider the earth behaves as though it had, at its centre, a strong bar magnet whose South Pole points to the magnetic N, figure below.
- ❖ The cause of the earth's magnetism may be electric currents in the liquid core at its centre but there is no generally acceptance for this theory.



TEST 5

SECTION A

1.

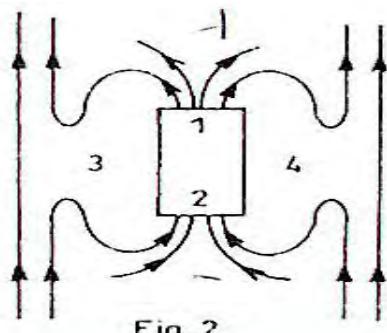


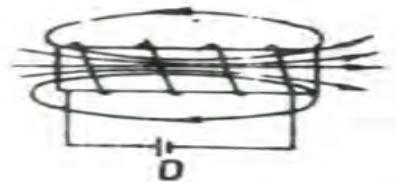
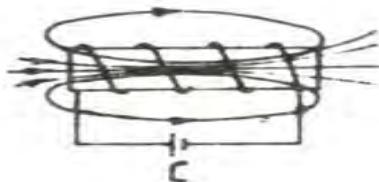
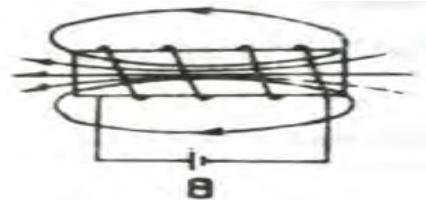
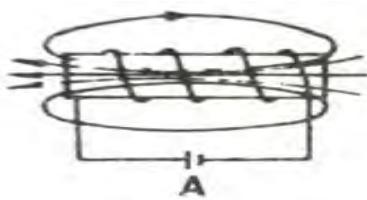
Fig. 2

Figure two shows the super position of the earth's magnetic field and the field due to a magnet. Identify point marked 1, 2, 3 and 4.

	1	2	3	4
A.	South pole	North pole	Neutral point	Neutral point
B.	North pole	South pole	Neutral point	Neutral point
C.	Neutral point	Neutral point	North pole	South pole
D.	Neutral point	Neutral point	South pole	North pole

- 2.** Which of these factors affect the magnitude of force on a current-carrying conductor in a magnetic field.
- (i) The direction of current
 - (ii) the amount of current
 - (iii) the direction of the magnetic field
 - (iv) the strength of the magnetic field
- | | | | |
|----|---------------|----|----------------|
| a) | (i) and (ii) | b) | (ii) and (iii) |
| c) | (i) and (iii) | d) | (ii) and (iv) |
- 3.** A magnetic material can be magnetized by
- (i) stroking with a permanent magnet
 - (ii) using a direct current
 - (iii) by induction
- | | | | |
|-----|---------------------|-----|---------------------|
| (a) | (i) only | (b) | (i) and (ii) only |
| (c) | (ii) and (iii) only | (d) | (i), (ii) and (iii) |

4. Which of the following statements isn't true about a magnet?
- Magnetic poles can't be separated
 - A paramagnetic material is a material from which strong magnets can be made
 - The neutral in a magnetic field is a point where there is no force experienced
 - Heating a magnet can reduce its magnetism
5. Four metals P, Q, R and S are tested for magnetism. Q attracts both P and R but not S. S does not attract P, Q or R. P and R sometimes attract one another and sometimes repel each other. Which of the following statements is correct about P, Q, R and S?
- P, Q, R are magnets, S is magnetic
 - P and Q are magnets, S and R are magnetic.
 - P and R are magnets, Q is magnetic, S is non-magnetic.
 - P and R are magnets, Q and S are non-magnetic.
6. Which of the following statements are correct?
- the particles of magnetic materials are tiny magnets. (ii) the particles in un magnetised iron arrange themselves in closed chains
 - the particles in a magnet are arranged in open chains with N pole of one particle against the S pole of its neighbouring particle
 - groups of atoms form a magnetic domain
- | | |
|-----------------------------|------------------------------|
| (a) (i), (ii) and (iii)only | (b) (i), (iii) and (iv) only |
| (c) (ii) and (iv)only | (d) (iv) only |
7. Which one of the following diagrams shows a correct magnetic field due to a current flowing in a solenoid?



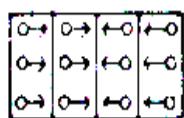
8. Which of the following statements are true about magnets

1. magnets always have opposite polarities
 2. A magnet can be used as a compass
 3. Repulsion is the only sure test for a magnet
 4. Magnets attract all metals
-
- | | |
|--------------------|-----------------|
| A. 1 only | B. 2 and 3 only |
| C. 1, 2 and 3 only | D. All |

9. Permanent magnets are made from

- | | |
|----------------------------|------------------------------|
| (a) diamagnetic materials | (b) Ferro magnetic materials |
| (c) paramagnetic materials | (d) dielectric materials |

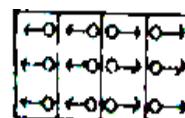
10. Which one of the following diagrams shows the correct arrangement of the magnetic domains in a magnetised material?



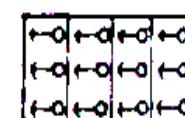
A



B



C



D

11. Which of the following sentences is/are true about molecular theory of magnetism

1. Breaking a magnet into two results into the formation of two magnets
 2. Heating and rough treatment destroys magnetism
 3. The poles of a magnet are of equal strength
 4. The lines of force travel from a north pole towards a south pole
-
- | | |
|-----------|-----------------|
| A. 1 only | B. 1 and 3 only |
| C. 2 only | D. All |

SECTION B

1. (a) What is a soft magnetic material?
(b) State two ways in which a bar magnet can be demagnetized.
2. a) (i) What is a magnetic field?
(ii) State the law of magnetism
3. What is a neutral point in a magnetic field?
4. (a) What happens when a magnet is
i) Dipped in iron filings
ii) Freely suspended in air

(b) A powerful magnet Q is placed on a soft board. Plastic pins are firmly stuck in the soft board around the magnet. An identical magnet P is held in the space surrounded by the pins above the magnet Q. When the magnet P is released, it floats above the magnet Q as shown in figure 3.

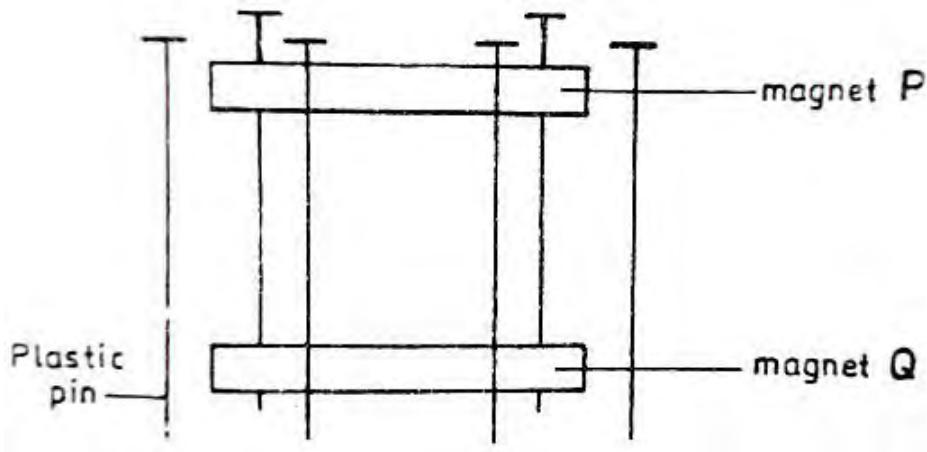


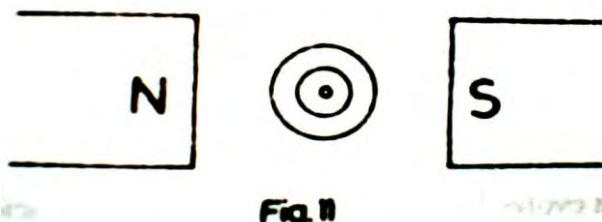
Fig.3

- (i) Explain why P floats above Q.
(ii) Why are plastic pins used instead of steel pins?
(iii) What would happen to magnet P if all the pins were removed at the same time?

5. (a) What is meant by the following;
- Magnetic meridian
 - Geographic meridian
- (b) Describe briefly how a steel bar may be magnetized.

6. (a) What is meant by
- Magnetic saturation
 - Demagnetisation by heating or hammering.

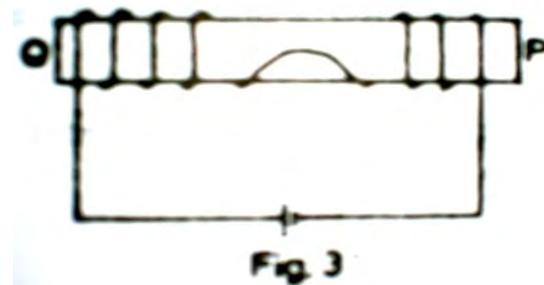
(b)



An iron ring is placed between two poles of two permanent magnets as shown in the figure above. Draw the magnetic field pattern set up between the two poles.

7. (a) (i) Describe an experiment to distinguish between soft and hard magnetic materials.
(ii) State one instance in which each of these materials is used.

(b)



The figure above shows how a magnetic material can be magnetised by electrical method

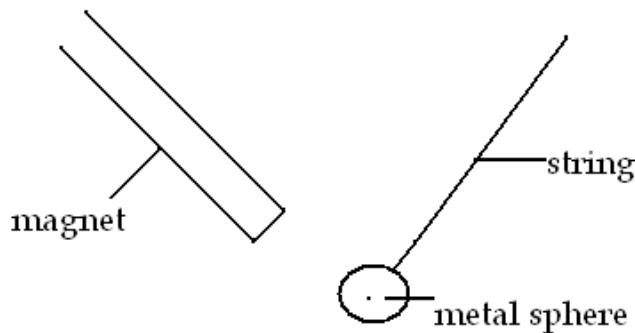
- Indicate the direction of current in the coil.
- Name the polarities P and Q.

8. A bar magnet is placed in the earth's magnetic field with its north pole pointing to the geographical west as shown below.



- (i) On the diagram, draw the lines of the resultant magnetic field around a magnet.
(ii) Mark the neutral point X
9. (a) Explain how a piece of iron can be magnetised by a single touch method illustrate your answer with a diagram
(b) How can you determine the polarity of a magnet?
10. With the aid of a diagram, explain the use of keepers to store magnets.

11. (a) The diagram in the figure shows a metal sphere of weight W in equilibrium. Complete the diagram to show the forces acting on the metal sphere.



- (b) State two effects that a force can have on a body.
12. (a) Explain why a magnet loses its magnetism when placed in a coil of a wire carrying alternating current

- (b) Describe the motion of a beam of electrons directed midway between the north and the south poles of a permanent magnet.
- 13.** (a) Explain with the aid of diagrams how a steel bar can be magnetized by Double/divided touch method
- (b) Sketch the magnetic field pattern of two bar magnets whose north poles face each other
- 14.** (a) What is meant by
(i) Magnetic declination.
(ii) Angle of dip.

CHAPTER SIX

ELECTRIC CURRENT AND RESISTANCE

Electric current is defined as the rate of flow of charge round a circuit.

If Q represents the quantity of charge passing through a point in a time t seconds (s), then the current represented by I is given by

$$I = \frac{Q}{t} \dots \dots \dots \quad (i)$$

The quantity of charge Q is measured in coulombs (C) and the current I is measured in amperes (A).

From (i) it flows that

$$IA = \frac{1C}{1s} \text{ or } 1 \text{ coulomb} = 1 \text{ ampere} \times 1 \text{ second}$$

One coulomb is the charge passing any point in a circuit when a steady current of 1 ampere flows for 1 second.

Its given by $Q = I x t$

The charge on about 6 million million (6×10^{18}) electrons equals 1C.

$1\text{C} = 6 \times 10^{18}$ electrons.

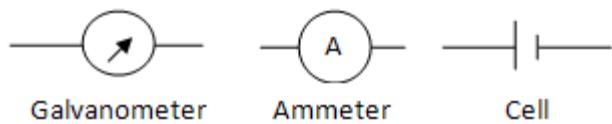
$1\text{A} = 10^3 \text{mA}$ (miliampere).

$1\text{A} = 10^6 \mu\text{A}$ (microampere).

Current measuring instruments

Electric current is measured using a sensitive instrument called an *ammeter*. The ammeter is used for large current; for smaller current a *milliammeter* or *micro ammeter* is used. *Galvanometers* are also used for detecting electric current.

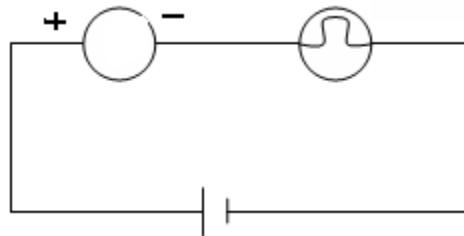
The circuit symbols for galvanometer, ammeter and a cell are shown below.



For a cell, the long bar is for the positive terminal and the short bar for the negative terminal.

An ammeter is always connected in a circuit such that:

- i) its positive terminal is connected to the positive terminal of the cell.
- ii) the current flows directly through it, that is in series with the cell.



Potential difference (p.d)

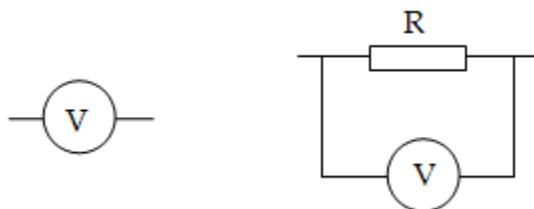
- When an electric current flows through a wire a potential difference is said to exist between ends of wire.
- *The potential difference between any two points is defined as the work done, in joules, when one coulomb of electricity (charge) moves from one point to another.*
- Electrons flow from a lower to a higher potential.
- The unit of p.d is the *volt*.
- Other units of p.d are millivolt (mV) and kilo volts (kV)
 $1V = 10^3 mV$
 $1kV = 10^3 V$
- *Volt defined as the potential difference between two points when 1 J of work is done in moving 1 C of charge between the points.*

Electromotive force (e.m.f)

The electromotive force of a cell is regarded as the sum total of the potential differences which it can produce across all the various components of a circuit in which it is connected.

The electromotive force of a cell is defined as the total work done in joules per coulomb of electricity conveyed in a circuit in which the cell is connected. Its unit is volt (V)

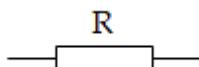
The p.d is measured by an instrument called a voltmeter. See diagrams for the symbol and connection.



The voltmeter is connected across or in parallel with any section of where p.d is to be measured.

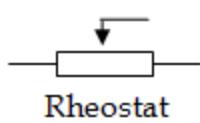
Resistance

- *Electric resistance is opposition to the flow of electric charges in a circuit.*
- A good conductor has a low resistance, while a good insulator has a very high resistance.
- Generally, metals such as silver and copper have very low resistances and they are used in connecting wires and cables in electric circuits.
- A substance which resists the flow of electric current is called a **resistor**.
- Its symbol is



Rheostat

- The amount of current that flows through a resistance wire can be reduced if the length of the wire is increased. This can be reduced by a variable resistor called a rheostat.
- A rheostat consists of a coil of constant wire wound on an insulated iron former. The length of the resistance wire through which the current passes is determined by the position of the slider which provides an alternative path of very low resistance. The circuit symbol for the rheostat is shown below.



OHM'S LAW

This law gives a relationship between the current flowing through a given conductor and the p.d across it.

- It states that the current passing through a metallic conductor at constant temperature is proportional to the potential difference between its ends.

In symbols, it can be written

$$\frac{V}{I} = R \quad \text{or}$$

$$I = \frac{V}{R} \quad \text{or}$$

$$V = I \times R$$

	<i>Symbol</i>	<i>Unit</i>	<i>Symbol of unit</i>
Resistance	R	ohm	Ω
Potential difference(p.d.)	V	volts	V
Current	I	ampere	A

- The ohm is defined as the resistance of a conductor such that when a potential difference of 1 volt is applied to its end, a current of 1A flows through it.

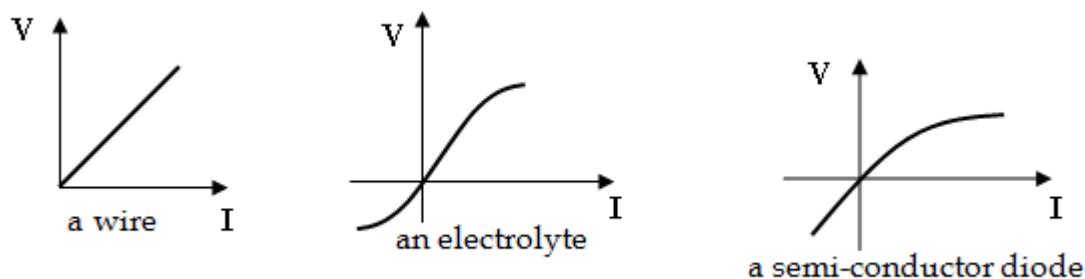
The substances which obey ohm's law are called **ohmic conductors**.

Limitation of Ohm's law

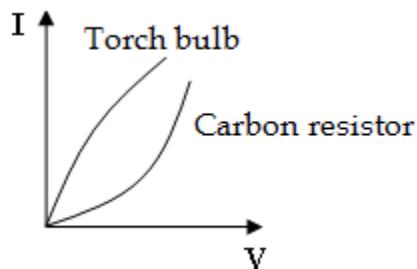
Ohm's law is obeyed only when physical conditions of the conductor such as temperature, length and cross-sectional area remain constant.

Ohm's law doesn't apply to semi conductors such as diodes, transistors and electrolytes. These are called non- ohmic conductors

Graphs of p.d (V) against current (I) for ohmic and non-ohmic conductors are shown below.

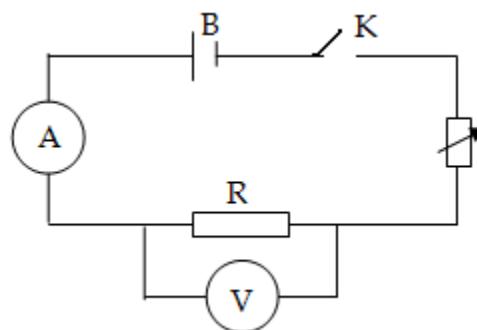


Graph of current (I) against p.d (V) for torch bulb and carbon resistor is shown below.

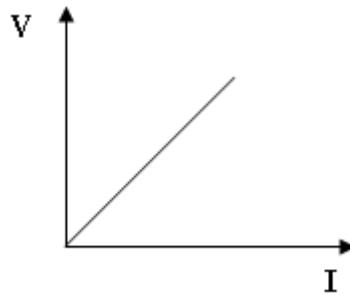


Verification of Ohm's law

In order to verify Ohm's law, the circuit below is used. The circuit consists of a battery B, a resistor R, rheostat, ammeter A, voltmeter V. At the start, the rheostat is adjusted to a maximum value, then key K is switched on and the voltmeter and ammeter readings V and I are noted. The settings of the rheostat are gradually reduced and a series of readings of V and I are noted and tabulated.



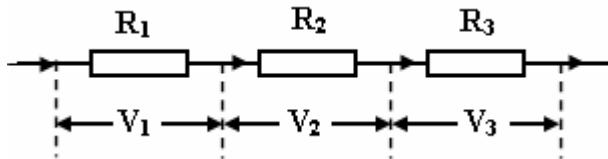
When a graph of V is plotted against current I, a straight line which passes through the origin is produced hence verifying Ohm's law.



The slope of the graph gives resistance to the resistor R.

Resistors in series

Resistors R_1 , R_2 and R_3 are said to be connected in series when they are connected end to end in such a way that the same current I, passes through each of them when they are connected to a source of e.m.f.

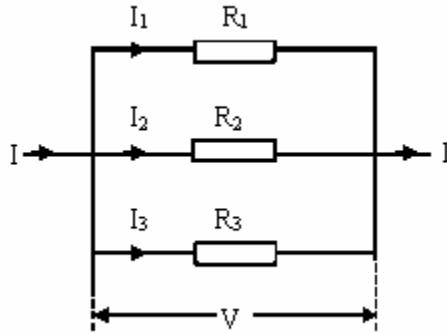


If R is the combined or effective resistance of R_1 , R_2 and R_3 and V is the total p.d across them, then

- $V = V_1 + V_2 + V_3$
where V_1 , V_2 and V_3 are individual p.d.s across
- $V = IR_1 + IR_2 + IR_3 = IR$
the resistor R_1 , R_2 and R_3 . Dividing through by I
- $R = R_1 + R_2 + R_3$
This relation is true for any number of resistors in series.

Resistors in parallel

Resistors R_1 , R_2 and R_3 are said to be in parallel when they are connected side by side with their ends joined together such that they have two common points as shown below.



The p.d V between the ends of each is the same and the total current I equals to the sum of the current in separate branches.

$$I = I_1 + I_2 + I_3 \quad \text{But} \quad I_1 = \frac{V}{R_1}, \quad I_2 = \frac{V}{R_2}, \quad I_3 = \frac{V}{R_3}$$

Also if R is the combined resistance,

$$V = IR \text{ and so}$$

$$\frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} \quad \text{Dividing both sides by } V$$

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

For the case of two resistors in parallel;

$$\frac{1}{R} = \frac{1}{R} + \frac{1}{R_2} \Rightarrow \frac{R_2}{R_1 \cdot R_2} + \frac{R_1}{R_1 \cdot R_2}$$

Inverting both sides,

$$R = \frac{R_1 \cdot R_2}{R_1 + R_2} =$$

$$\frac{\text{product of resistors}}{\text{sum of resistors}}$$

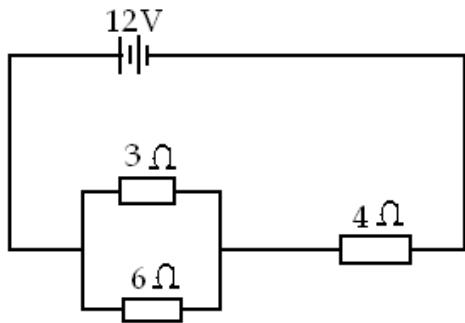
Example-1:

A p.d. of 24V from a battery is applied to the network of resistors in figure a.

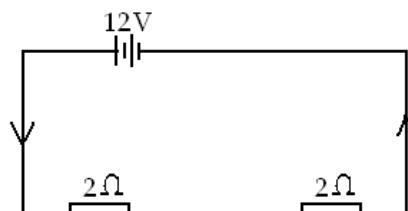
- a) What is the combined resistance of the 6Ω and 12Ω resistors in parallel?

- b) What is the current in the 8Ω resistor?
- c) What is the pd across the parallel network?
- d) What is the current in the 6Ω resistor?

a)



b)

**Solution:**

- a) Let R_1 = resistance 3Ω and 6Ω in parallel.

$$\begin{aligned}\frac{1}{R_1} &= \frac{1}{3} + \frac{1}{6} \\ &= \frac{2+1}{6} = \frac{3}{6} = \frac{1}{2} \\ R_1 &= 2\Omega\end{aligned}$$

- b) Let R total resistance of circuit

$$R = 2+4 = 6\Omega$$

The equivalent circuit is shown in figure b above and if I is the current in it then since $V = 12\text{ V}$

$$\begin{aligned}I &= \frac{V}{R} \\ &= \frac{12}{6} = 2A\end{aligned}$$

\therefore Current in 4Ω resistor is 2 A

- c) Let V_1 = p.d. across parallel network.

$$\begin{aligned}V_1 &= IR_1 \\ &= 2 \times 2 = 4\text{ V}\end{aligned}$$

- d) Let I_1 = current in 3Ω ,
then since $V_1 = 4\text{ V}$

$$\begin{aligned} I_1 &= \frac{V_1}{3} \\ &= \frac{4}{3} = 1.33\text{A} \end{aligned}$$

Effects of physical properties of conductors

1. Length:

The resistance of a wire increases when the length of the wire increases

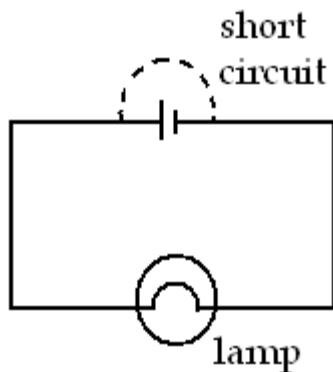
2. Cross-sectional area:

The resistance of a wire decreases when its cross-sectional area increases

3. Temperature:

The resistance of a pure metal increases when the temperature increases. For certain conducting materials such as carbon and semi -conductors such as silicon, germanium, the resistance decreases as the temperature increases. However, the resistance of the alloys which are used for making standard resistors show very small resistance changes in tempo under normal laboratory conditions.

Short Circuit



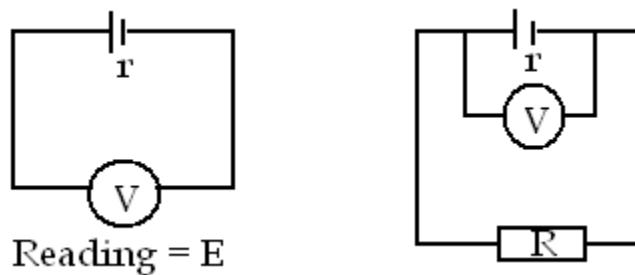
In figure above, if a short length of copper wire is connected across the battery (the dotted line), the lamp goes out. A large current flows in the wire which gets very hot. It acts as a “short circuit” and provides an easy path for the current because of its low resistance.

Internal resistance of a cell (r)

Internal resistance is the resistance of a cell.

To obtain internal resistance of a cell:

A voltmeter is connected to the terminals of a cell directly, and a reading E of the voltmeter is noted.



- A standard resistor R is connected in series with the cell and the voltmeter reading, V is noted.

In the first part e.m.f $E = I(R+r)$,

$$r = \frac{E - IR}{I}$$

But $V = IR$,

$$r = \frac{(E - V)}{I}$$

Since $I = \frac{V}{R}$

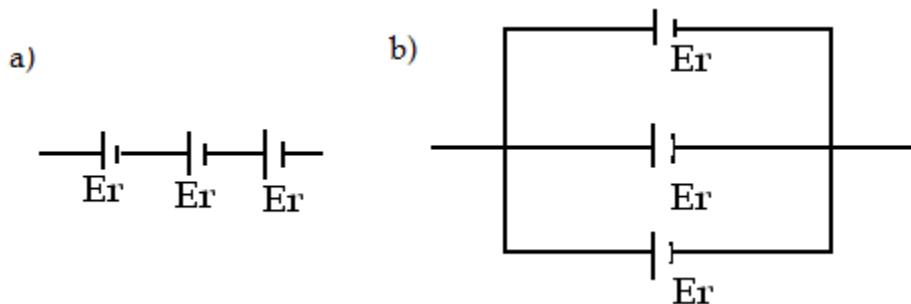
$$r = \frac{(E - V)R}{V}$$

- So the values of E, V and R are substitute in the expression and r is obtained.

Note: If the cell has no internal resistance, then the terminal p.d. equals to the e.m.f of the cell.

Series and parallel of cell

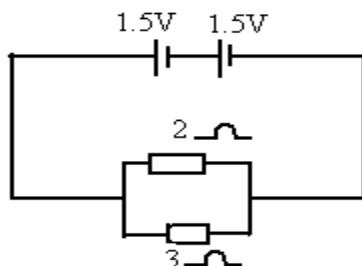
A group of cells connected together is called a battery. If n identical cells each of e.m.f E and internal resistance r are connected in series as shown in the figure below (a), then the combined e.m.f is the sum of all e.m.f's that is nE .



- The combined internal resistance is the sum of all internal resistances of individual cells, that is nr .
- When three cells are connected in parallel as shown in b, the combined e.m.f is E , since all the cells have two common points and the combined resistance = $\frac{r}{n}$

Example-2:

Two cells each of e.m.f 1.5V and negligible internal resistance are connected across resistors of 2 ohms and 3 ohms



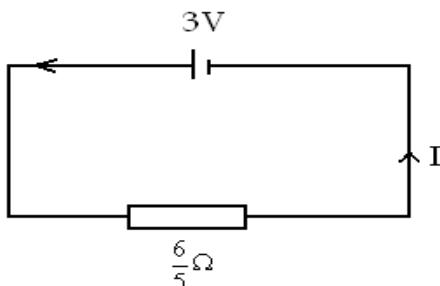
Calculate:

- the total current in the circuit
- the current that passes through
 - the 2Ω resistor
 - the 3Ω resistor

Solution:

$$\text{Total resistance, } R = \frac{R_1 \cdot R_2}{R_1 + R_2} = \frac{2 \times 3}{5} = \frac{6}{5} \Omega$$

Equivalent circuit,



a) Total current, $I = \frac{V}{R} = \frac{3}{\cancel{6}/5} = \frac{3 \times 5}{6} = 2.5A$

b) (i) Current through 2Ω = $I_1 = \frac{3}{2} = 1.5A$

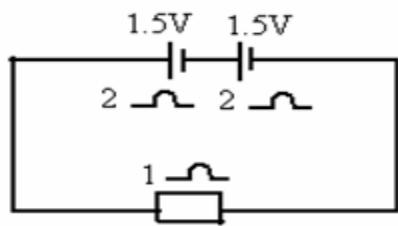
(ii) current through 3Ω = $I_2 = \frac{3}{3} = 1.0A$

Example-3:

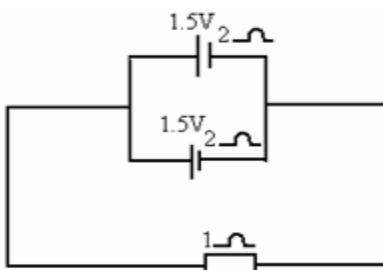
Two cells each having an emf of 1.5V and an internal resistance of 2Ω are connected a) in series, and b) in parallel.

Find the current in each case when the cells are connected to a 1Ω resistor.

a)



b)



Solution:

a) Total resistance $R = R_1 + R_2 + R_3$ (in series)
 $= 2 + 2 + 1 = 5\Omega$

current flowing $I = \frac{V}{R} = \frac{3.0}{5} = 0.6A$

b) Total resistance in parallel $R_3 = \frac{R_1 \cdot R_2}{R_1 + R_2} = \frac{2 \times 2}{2 + 2} = \frac{4}{4} = 1\Omega$

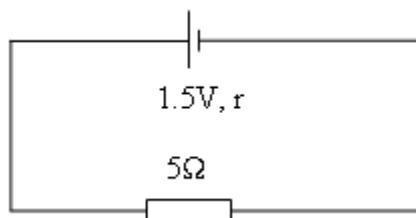
total resistance = $R = R + R_3 = 1 + 1 = 2\Omega$

$$\text{current flowing} = \frac{V}{R} = \frac{1.5}{2} = 0.75\text{A}$$

TEST 6

SECTION A

1.



A cell of e.m.f 1.5V and internal resistance, r , is connected in series with a 5Ω resistor as shown in Figure 1. If the current in the circuit is 0.25A, find r .

- a. 1Ω
c. 11Ω

- b. 6Ω
d. 16Ω

2. If each cell shown in figure 1 has an internal resistance of 0.5Ω finds the effective resistance in the circuit.

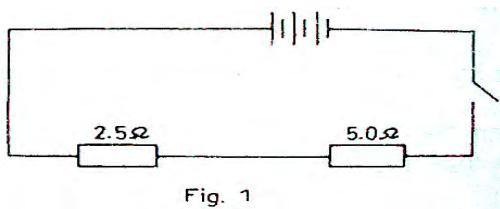


Fig. 1

- A. 1.25 B. 7.50 C. 8.00 D. 9.00

3. Two resistors of 2 ohms and 3 ohms are connected in series with a 10 volt battery of negligible internal resistance. The potential difference across a 3 ohm resistor is

a) 2V

b) 5V

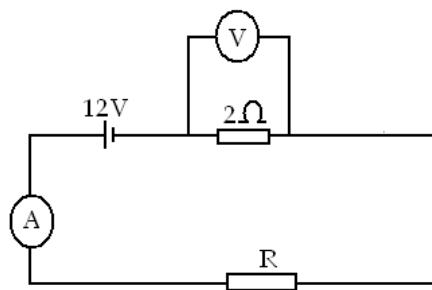
c) 6V

d) 10V

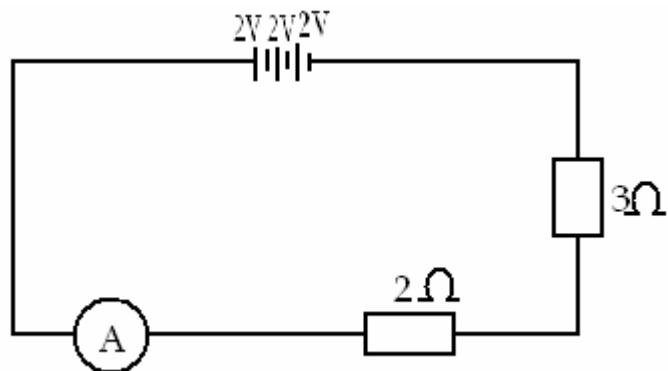
4. A bulb is rated 40V, 60W. Find its resistance

a) 26.7Ω b) 410Ω c) 120Ω d) 960Ω

5. In figure below, the ammeter A reads 4A and the voltmeter V reads 4V. find the value of R.

A. 1Ω B. 2Ω C. 3Ω D. 4Ω

6. Three cells each of e.m.f 2V and negligible internal resistance are connected to two resistors as shown in the circuit in the figure. The reading of the ammeter is



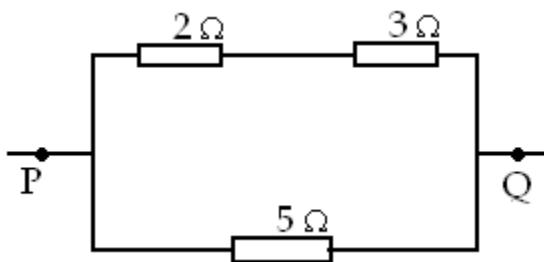
(a) 0.40 A

(b) 0.83 A

(c) 1.20 A

(d) 7.20 A

7. Figure below shows a network of resistors. The effective resistance between points P and Q is



A. 0.97Ω .

B. 1.2Ω .

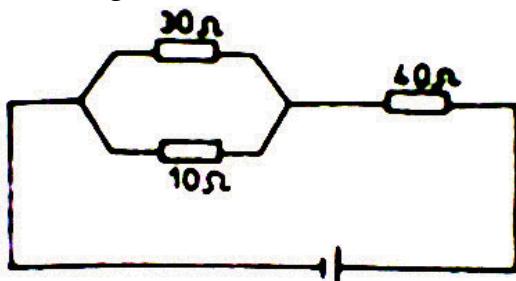
C. 2.5Ω .

D. 10Ω .

8. The resistance of a metal in the form of a wire increases with

- (a) decrease in length
- (b) increase in temperature
- (c) decrease in temperature
- (d) increase in cross-sectional area

9. The diagram in the below figure shows three resistors connected in a circuit.



What is the effective resistance of the current

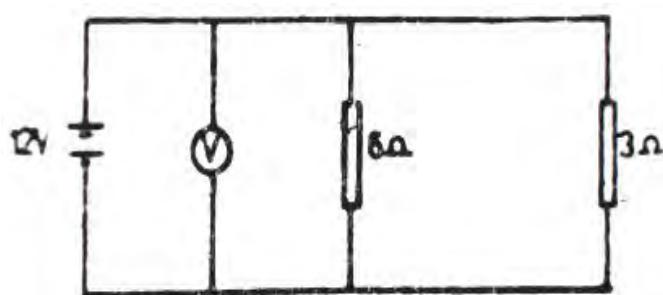
A. 20.0Ω

B. 47.5Ω

C. 60.0Ω

D. 90.0Ω

10. A battery of e. m. f. 12 V is connected across two resistors of 6Ω and 3Ω as shown in the figure.



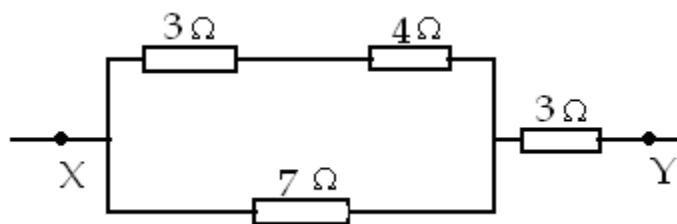
Which of the following statements is true about the circuit? The

- a) p.d across 6Ω is half the p.d across 3Ω
- b) p.d across 6Ω is twice the p.d across 3Ω
- c) p.d across 6Ω is equal to p.d across 3Ω
- d) reading of the voltmeter V is greater than 12V

11. Two coils of wire of resistances 2Ω and 3Ω are connected in series to a 10V battery of negligible internal resistance. The current through the 2Ω resistor is

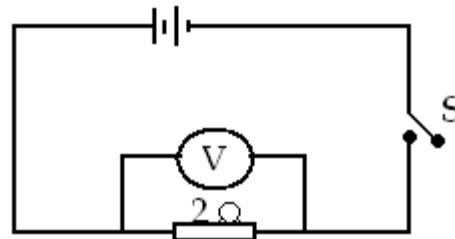
- a) 0.5 A
- b) 2 A
- c) 5 A
- d) 50 A

12. The total resistance between X and Y in the figure below is



- (a) 20.0Ω
- (b) 9.50Ω
- (c) 6.50Ω
- (d) 4.20Ω

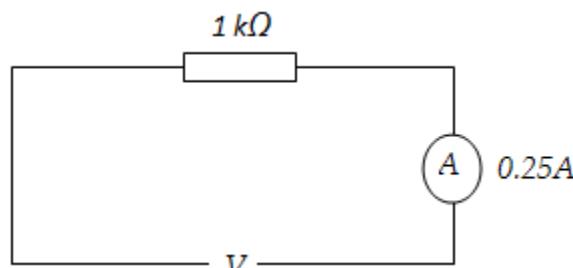
13. Two cells each of e.m.f 1.5V and internal resistance 0.5Ω are connected in series with a resistor of 2Ω as in the figure below.



The reading of the voltmeter V when S is closed is

- (a) 1.0V
- (b) 1.5V
- (c) 2.0V
- (d) 3.0V

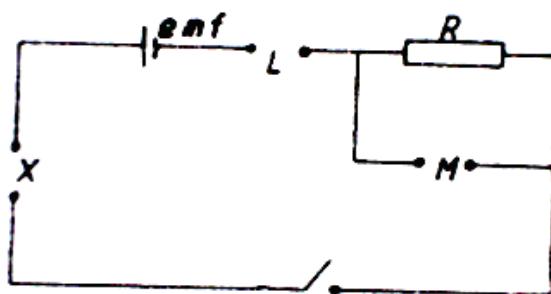
14.



The voltage supply in the circuit in the above figure is

- (a) 0.25V (b) 4.0V (c) 25V (d) 250V

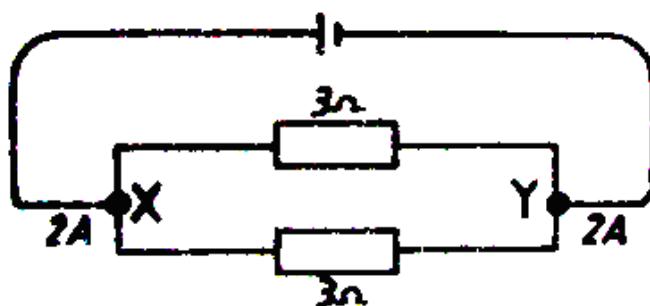
15. To determine the value of resistor R, a voltmeter, a rheostat and an ammeter must be connected in the gaps X, L and M as shown in the figure below



Which one of the following arrangements gives the correct circuit ?

X	L	M
A. Voltmeter	rheostat	ammeter
B. Ammeter	voltmeter	rheostat
C. rheostat	voltmeter	ammeter
D. Ammeter	rheostat	voltmeter

16. A current of 2A flows in a circuit in which two resistors each of 3Ω , are connected as shown in figure below calculate p.d across XY.

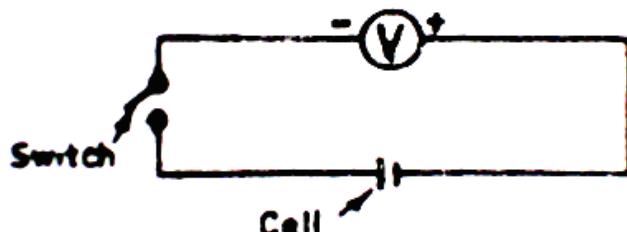


- (a) 1.5V (b) 3.0V (c) 6.0V (d) 12

17. Which of the following is true about both alternating current and direct current

- (i) Cause heating
 - (ii) can be stepped up or down with transformer
 - (iii) Can be used to charge a battery
-
- | | | | |
|----|----------------|----|------------------|
| a) | (i) only | b) | (i) and (ii) |
| c) | (ii) and (iii) | d) | (i), (ii), (iii) |

18.



When the circuit in the above figure is switched on, the voltmeter.

- A. shows no deflection.
- B. deflects in the wrong direction.
- C. reads e.m.f of the cell.
- D. reads the terminal difference across the cell.

SECTION B

1. (a) Define the volt.

- (b) (i) What is the effective resistance in the circuit in the figure.
(The cell has negligible resistance).

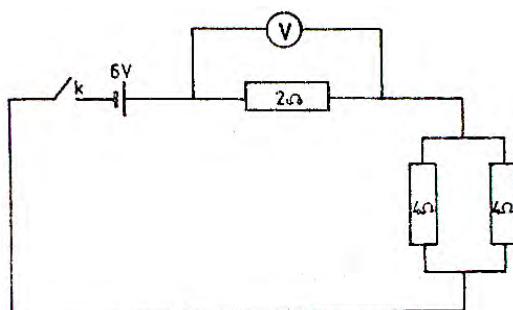
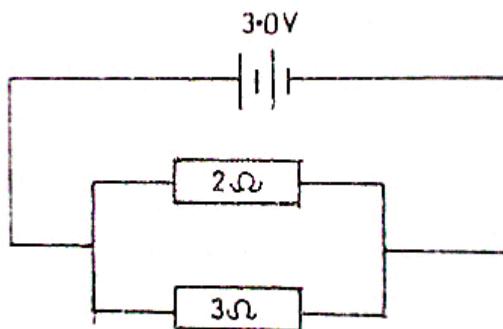


Fig.9

- (ii) What will be the reading of the voltmeter when the key K is closed?

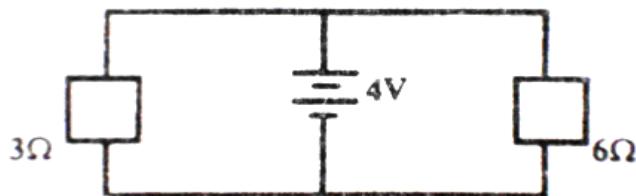
2. When two identical heating elements of a kettle are connected in series to a 240V supply, the power developed is 400W. Find;
- the resistance of the either element
 - the power developed when the elements are connected in parallel to the same supply
3. (a) Draw sketch graphs of p.d, V against current, I, for the following
- a wire
 - an electrolyte
 - a semi conductor diode
4. a) Explain the differences between a voltmeter and an ammeter in terms of their
- construction
 - use
- b) State three physical properties that affect the resistance of a solid conductor
- 5.



Two cells each of e.m.f 1.5V and negligible internal resistance are connected in series across two resistors of 2Ω and 3Ω as shown in the above figure. Calculate the current

- supplied by the cells
 - that passes through the 3Ω resistor
6. (a) State ohm's law?
- (b) Describe a simple experiment to measure the internal resistance of a Cell.

7.

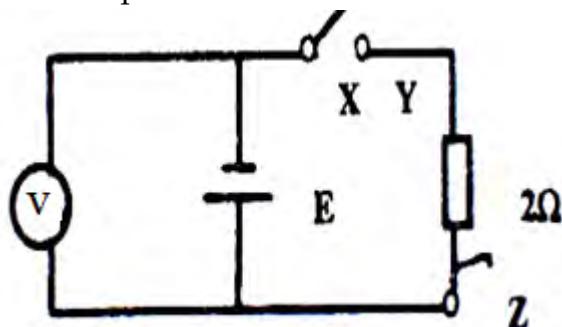


Two resistors of resistances 3Ω and 6Ω are connected across a battery of $4V$ of negligible internal resistance as shown in the above figure.

Find the

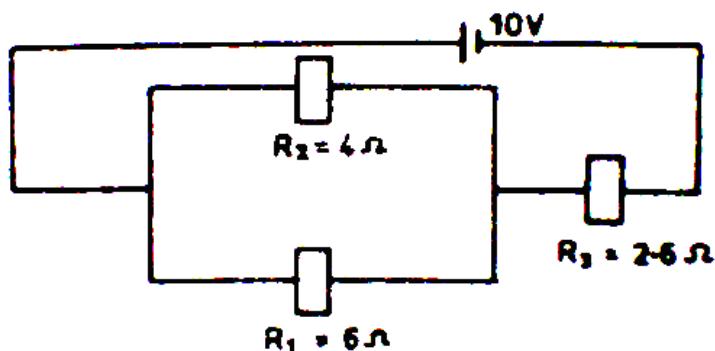
- (i) combined resistance
- (ii) current supplied by the battery

8. (a) A cell of e.m.f , E and internal resistance 1.0Ω is connected in series with a 2Ω resistor as shown in the figure below. The voltmeter reads $1.5V$ when the switch is open. V



- (i) What is meant by e.m.f of a cell
- (ii) Find the value of E
- (iii) What will the voltmeter read when the switch is closed
- (iv) What will the voltmeter read if X is connected to Z ? Give reasons for your answer?

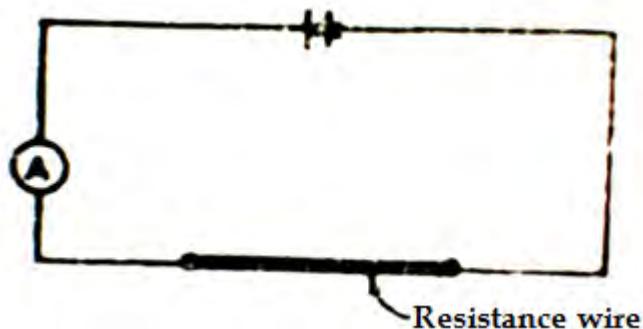
9.



A battery of e.m.f 10V and negligible internal resistance is connected to resistors R_1 , R_2 and R_3 of resistances 6Ω , 4Ω and 2.6Ω respectively as shown in the above figure.

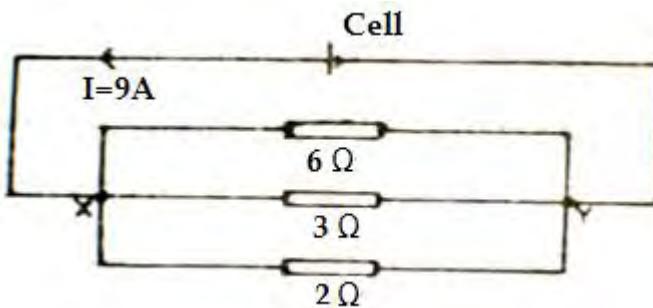
- (i) Calculate the effective resistance of the circuit
- (ii) Find the rate at which the electrical energy is converted to heat energy in R_3 .

10. (a) Draw diagrams to show two ways in which two resistors can be arranged in an electrical circuit.
 (b) State what happens to the reading of the ammeter in the circuit in the figure below if one cell is removed



11. (a) Sketch the current versus p.d variation for.
 (i) metal wire
 (ii) semi-conductor diode

12. (a)



The above figure shows a cell of negligible internal resistance connected to a system of resistors. Calculate

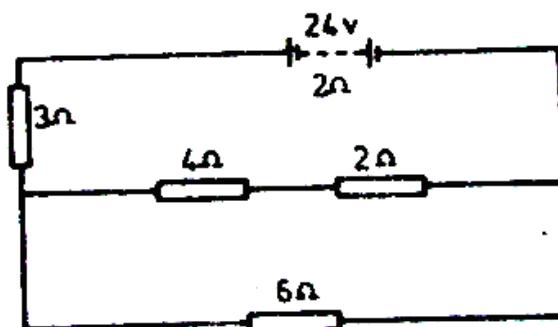
- (i) e.m.f of the cell.
- (ii) the current through 3Ω resistor
- (iii) power dissipation in the 3Ω resistor.

13. Describe the energy changes which occur from the time an electric bulb is switched on.

14. (a) Draw a circuit diagram which can be used to investigate the p.d-current relationship for a wire

- (b) Sketch a graph of current against p.d for
 - (i) carbon resistor
 - (ii) a semi-conductor diode

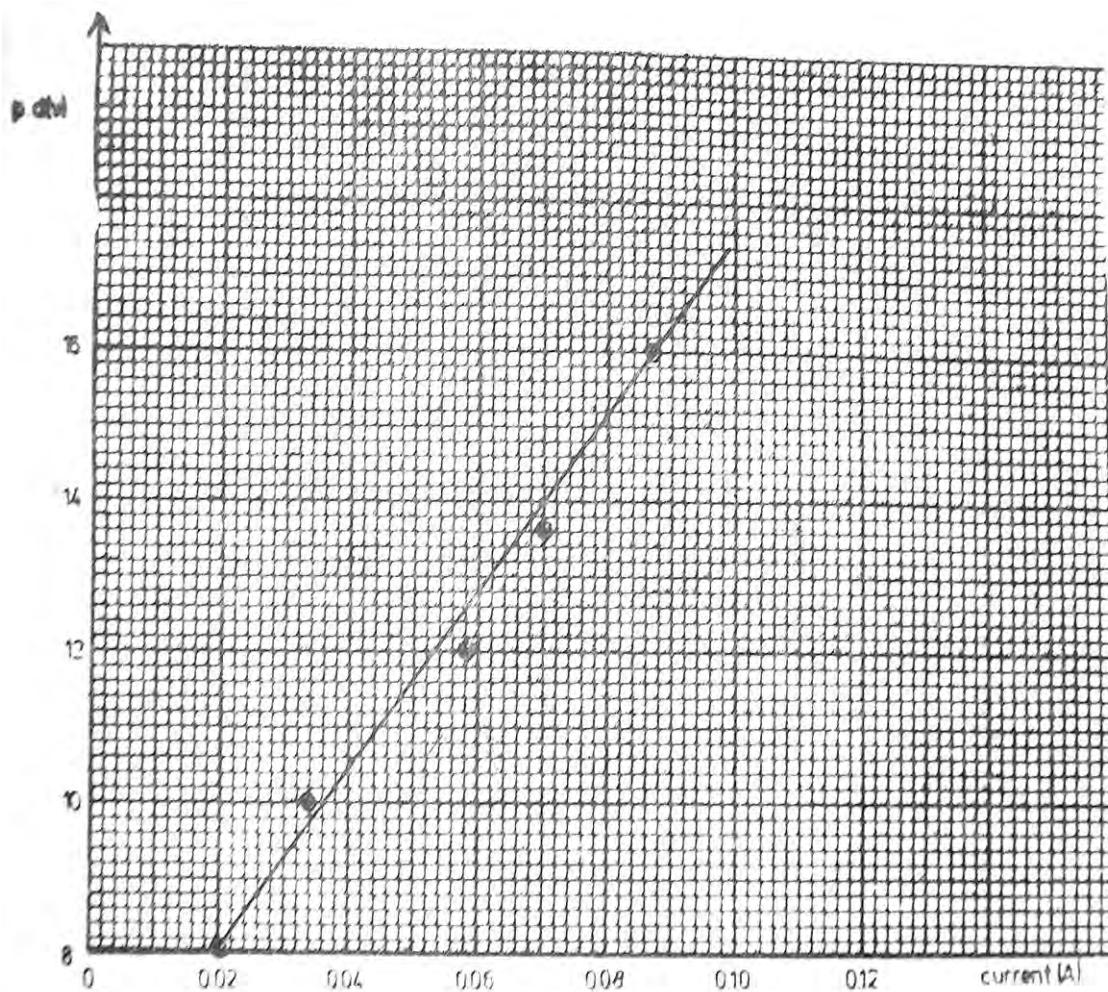
15. An accumulator of e.m.f 24V and internal resistance of 2Ω is connected to 3Ω , 4Ω , 2Ω and 6Ω as shown in the figure below.



Calculate;

- (i) the current through the 6Ω resistor
- (ii) the total power expended

16. What is meant by Internal resistance of a cell?
17. (a) Sketch a p.d versus current graph for an ohmic resistor.
(b) State one example of a non- ohmic conductor.
(c) Find the voltage across a 3Ω resistor if a current of $4A$ passes through it.
18. (a) What is meant by short circuit as applied to electricity?
(b) The electric appliance is marked "240V 4Kw".
(i) What does this statement mean?
(ii) Calculate the current drawn by the appliance in normal use.
19. Four resistors are connected across a 12V battery of negligible internal resistance as shown in the below figure. Determine
-
- (i) the reading of the ammeter A
(ii) the p.d across the parallel combination of resistors
- 20.



The above graph shows the variation of current with p.d across a device. Use the graph to find the resistance of the device

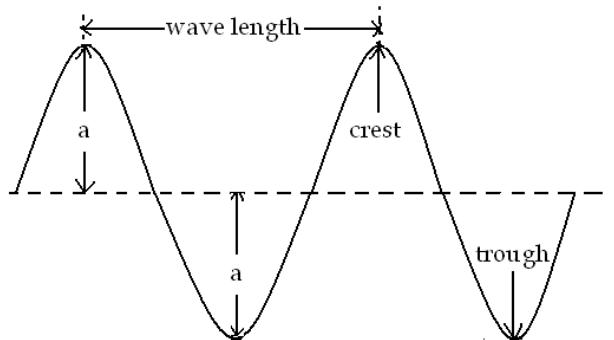
CHAPTER SEVEN

WATER WAVES

- ❖ Waves carry energy from one place to another.
- ❖ **Transverse wave** is seen at the end of a piece of rope or string is moved up and down in a direction perpendicular to its length.

Describing waves

The figure below helps to explain the terms used

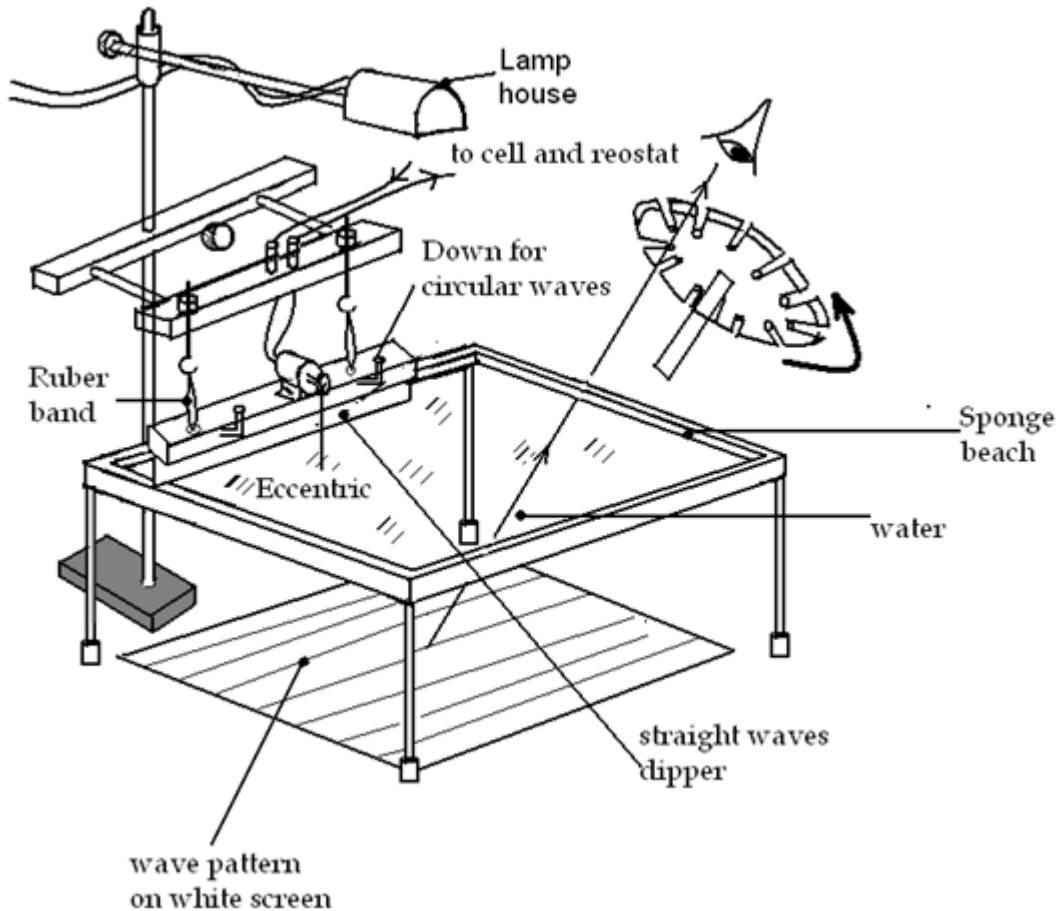


- **Wavelength (λ)** represented by the Greek letter λ (lambda), is the distance between successive crests.
- **Wavefront** is any line or section taken through an advancing wave in which all the particles are in the same phase.
- **The Phase** of an oscillation is the timing of it in comparison with another oscillation.
- **Speed (V)** of the wave is the distance moved by a crest or any point on the wave in 1 second.
- **Amplitude (a)** is the height of a crest or depth of a trough measured from undisturbed position of what is carrying the wave e.g. a rope.
- **Frequency (f)** is the number of complete waves generated per second. Its SI unit is hertz (Hz).
- In the time it takes the particles to make one complete oscillation the whole wave moves forward one wavelength.
- Hence in 1 second the wave moves forward a distance $f\lambda$.
- But the distance moved per second is the velocity, v .
- Hence

$$v = f\lambda,$$

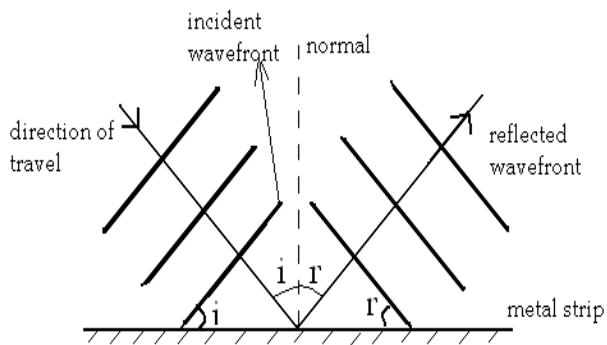
$$\text{frequency} = \frac{1}{\text{period}}$$

Experiment: The ripple tank

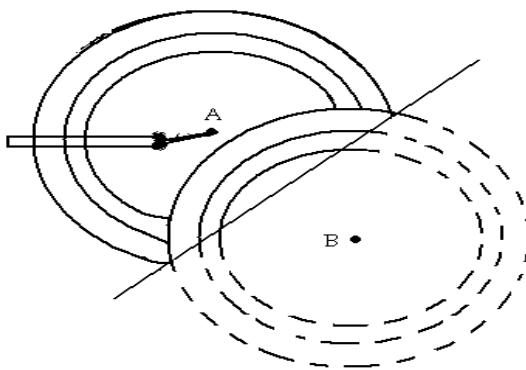


- The behaviour of water waves can be studied in a ripple tank.
- This consists of a transparent tray containing water, having a lamp above and a screen below, figure above.
- Pulses (i.e. short bursts) of ripples are obtained by dipping a finger in the water for the circular ones and a ruler for the straight ones.
- Continuous ripples are generated by an electric motor on a bar which gives straight ripples if it just touches the water and circular ripples if the bar is raised and a small ball fitted so as to be in the water.

Reflection



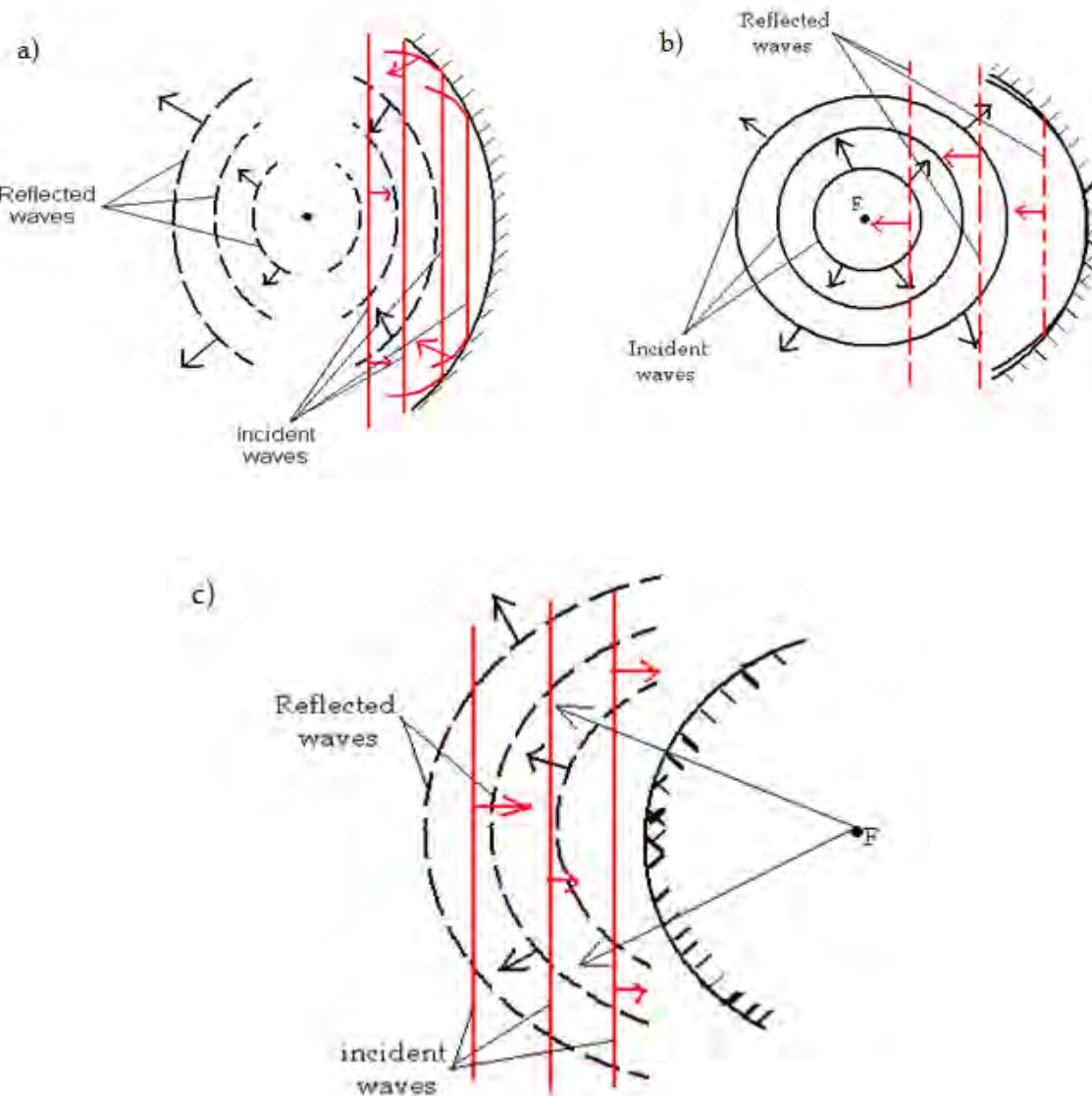
In the figure above straight water waves are represented falling on a metal strip placed in a ripple tank at an angle. The angles of reflection and incidence are always equal ($r = i$)



A pattern given by a circular pulse starting at A and falling on a straight strip is shown in the figure above. The reflected pulse seems to come from B which is as far behind the strip as A is in front.

Reflection at spherical surfaces is shown in the figure a, b, c.

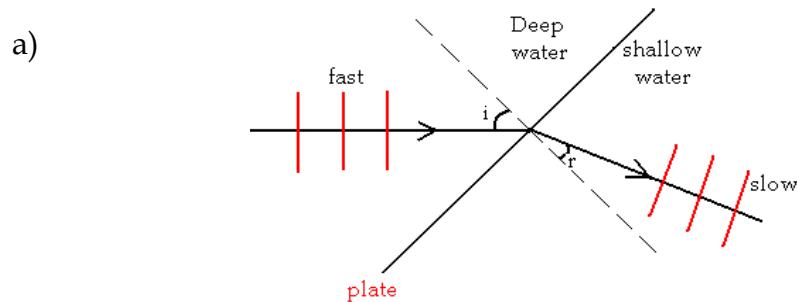
- In a (below), the incident straight wave, which is another way of representing a parallel beam is converged after reflection to the principal focus F as a circular wave.
- In b (below), the incident circular wave from F is reflected as a straight wave.
- In c (below), the incident straight wave produces a reflected circular wave which appears to come from a virtual principal focus F behind the reflector.



- Water waves are evidently reflected in the same way as light when reflected

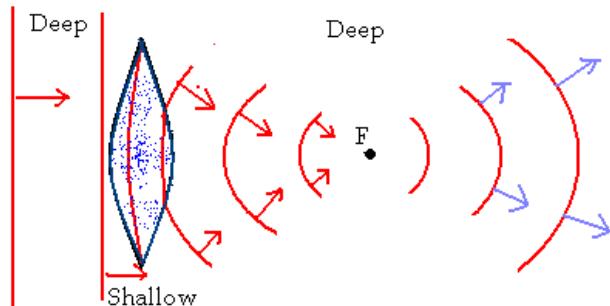
Refraction

Waves travel more slowly in shallow water.



When a wave enters shallow water its speed and wavelength decreases, and frequency remain constant. When the plate is at an angle to the waves, their direction of travel in the shallow water is bent towards the normal, figure above. i.e. refraction occurs. This is due to change of speed.

b)

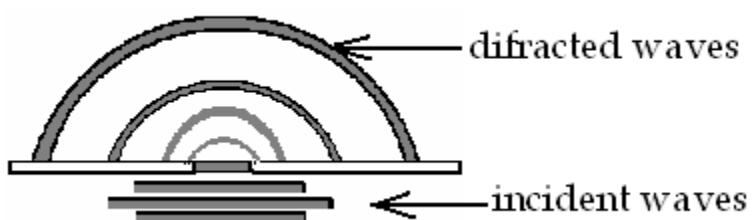


Refraction of a straight wave at a curved surface can be shown by the focusing action of a lens-shaped area of shallow water formed by having a convex piece of Perspex in the tank, figure above.

Diffraction

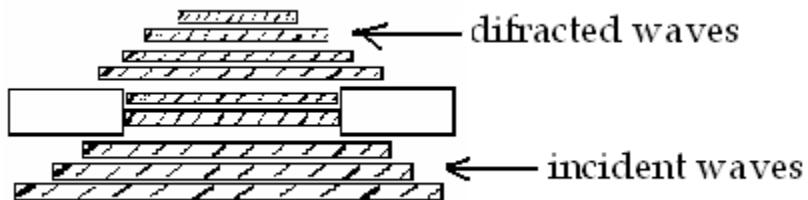
The spreading of the waves at the edges of obstacles is called diffraction

In figures a, b, straight waves in a ripple tank are falling on gaps formed by obstacles.
a)



In a, the gap width is about the same as the wave-length of the waves (1cm): these passing through are circular and spread out in all directions.

b)

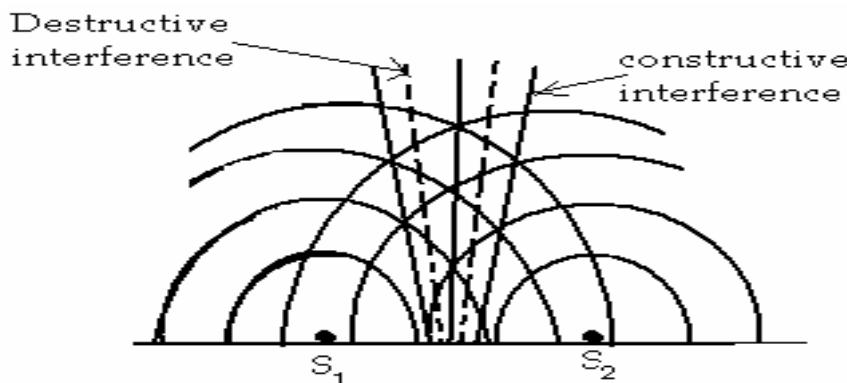


In b, the gap is wide (10cm) compared with the wave-length and the waves continue straight on; some spreading occurs but it is less obvious.

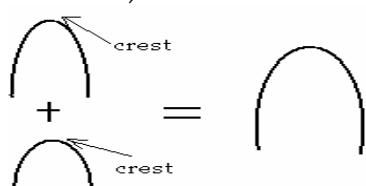
Interference

Interference is the combination of waves to give a larger or smaller wave.

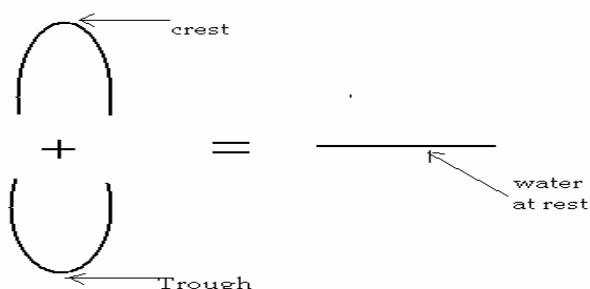
a)



b)



c)



- When two sets of continuous circular waves cross in a ripple tank, a pattern like that in the figure above a. is obtained.
- At points where a crest from S_1 arrives at the same time with a crest from S_2 , a bigger crest is formed and the waves are said to be in phase (*constructive interference*) as shown in figure b.
- At points where a crest and a trough arrive together, they cancel out (if their amplitudes are equal); the waves are exactly out of phase (*destructive interference*) (due to traveling different distances from S_1 and S_2) and the water is undisturbed, figure c.

Red Sunset and Blue sky

- The wave-length of red light is about twice that of blue light. The longer the wave-length, the more penetrating is the light, while the shorter the wave-length, the more easily it is scattered.

- When the sun is setting, the light from it has to travel through greater thickness of the earth's atmosphere and only the longer wave-length red light is able to get through.
- Sunsets are therefore red
- The shorter wave-lengths, like blue light are scattered in all directions by the atmosphere, which is why the sky looks blue.

TEST 7.1

SECTION A

1.

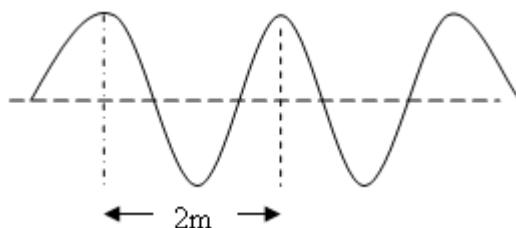


Figure above shows a wave produced in a string. If the frequency is 2Hz, at what speed do the waves travel along the string?

- a. 0.5ms^{-1} b. 1.0ms^{-1} c. 2.0ms^{-1} d. 4.0ms^{-1}

2. A longitudinal wave is one in which the

- a) direction of propagation is parallel to that of the vibration producing it.
- b) particles of the medium through which it travels move opposite to the direction of propagation.
- c) direction of propagation is perpendicular to that of the vibration producing it.
- d) particles of the medium through which it travels move together with it.

3. The number of complete oscillations made per second is referred to as

- | | |
|-------------------|---------------|
| (a) periodic time | (b) amplitude |
| (c) wave length | (d) frequency |

4. A source producing waves which travel a distance of 140cm in 0.08 s. If the distance between successive crests is 20cm, find the frequency of the source.

- | | |
|--------------|-------------|
| (a) 0.875Hz | (b) 8.750Hz |
| (c) 87.500Hz | (d) 8750Hz |

5.

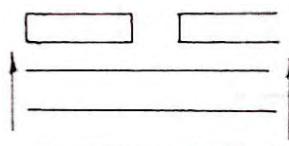


Fig.6

The diagram in the figure shows parallel wavefronts approaching a narrow gap. Waves passing through the gap are likely to undergo

- | | |
|-----------------|------------------|
| (a) Reflection | (b) refraction |
| (c) diffraction | (d) interference |

6. Figure 3 shows waves spreading out from a point. The wavelength of the waves is

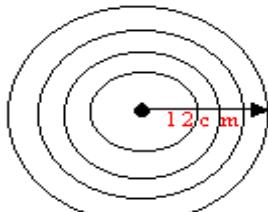


Figure 3

- A. 3cm B. 6cm C. 9cm D. 12cm

- 7.

Vibrator	Wave Length	Frequency
Wave P	1,500 m	0.2 MHz
Wave Q	500 m

The table above shows readings obtained by using a vibrator which produces waves of a constant velocity. Find the frequency of the wave Q.

- A. 0.07MHz. B. 0.3 MHz. C. 0.6 MHz. D. 1.2 MHz.

8. Which of the following statements is true about the wave traveling from one medium to another

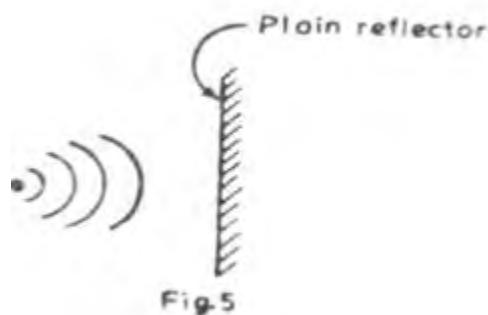
- (i) its frequency and wave length change
- (ii) its frequency and velocity change
- (iii) its velocity and wave length change
- (iv) only the frequency remains unchanged

- A. (i) only B. (i) and (ii) only
C. (i) and (iii) only D. (iii) and (iv) only

9. Water waves travel a distance of 36cm in 6s and the separation of successive troughs is 3.0cm. Calculate the frequency of the waves

- A. 2Hz B. 12Hz. C. 18Hz D. 72Hz

10. The figure below shows circular waves incident on a plane reflector. Which of the following patterns represents the reflected waves.



11. Which one of the following does not change when water waves travel through deep to shallow water

 - a) frequency
 - b) amplitude
 - c) velocity
 - d) wave length

12. Which of the following statements are true about refraction of waves

 - (i) the speed of waves changes
 - (ii) the wave-length changes
 - (iii) the direction of travel changes
 - (iv) the frequency changes
 - (a) (i) only
 - (b) (i) and (iii) only
 - (c) (ii) and (iv)
 - (d) (i), (ii) and (iii) only

13. Water waves are produced at a frequency of 5Hz and the distance between 10 successive crests is 18cm. calculate the velocity of the waves in ms^{-1}

 - (a) 9ms^{-1}
 - (b) 0.09ms^{-1}
 - (c) 0.1ms^{-1}
 - (d) 1ms^{-1}

14. Which of the following change(s) when water waves travel from a deep to a shallow region

 - 1. Velocity
 - 2. Amplitude
 - 3. Wavelength

4. Frequency
- 1 only
 - 2 and 3 only
 - 1, 2 and 3 only
 - All
15. A vibrator produces waves which travel a distance of 12m in 4s. If the frequency of the vibrator is 2Hz, what is the wavelength of the waves?
- 1.5m
 - 3m
 - 6m
 - 24m
16. A vibrator produces waves which travel a distance of 35cm in 2s. If the distance between successive wave crests is 5cm, what is the frequency of the vibrator
- 3.5Hz
 - 7.0Hz
 - 14.0Hz
 - 8.7Hz

SECTION B

1. (a) (i) Describe how the speed of waves in a ripple tank can be decreased
(ii) Explain the effect of decreasing the speed of the wave in (a) (i) on frequency
(b) With the aid of sketch diagrams, explain the effect of size of a gap on diffraction of waves
2. (a) With the aid of a diagram, explain the terms amplitude and wavelength as applied to wave motion.
(b) Derive an equation relating velocity, V, frequency, F and wave length of a wave.
3. (a) What is meant by a standing wave?
(b) Figure 11 shows plane waves approaching a gap in a barrier.

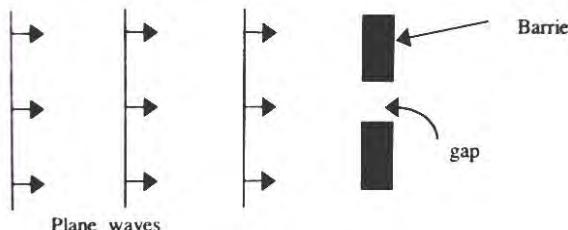
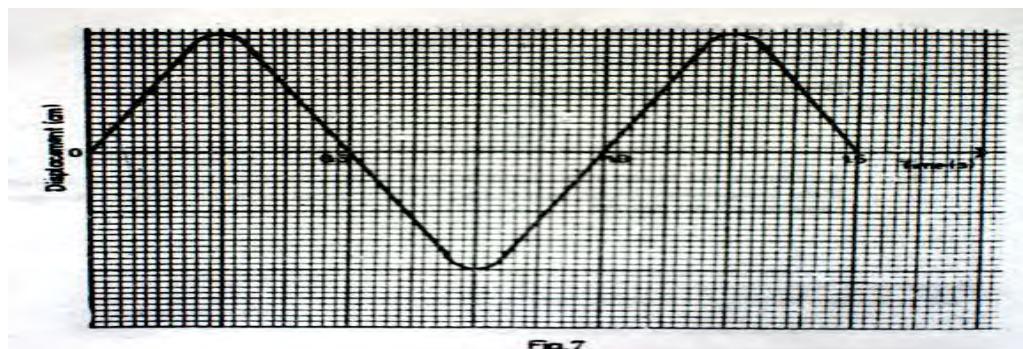


Fig. 11

- (i) Show the diagram, the appearance of the waves after the barrier.
(ii) What is the effect of reducing the size of the gap?

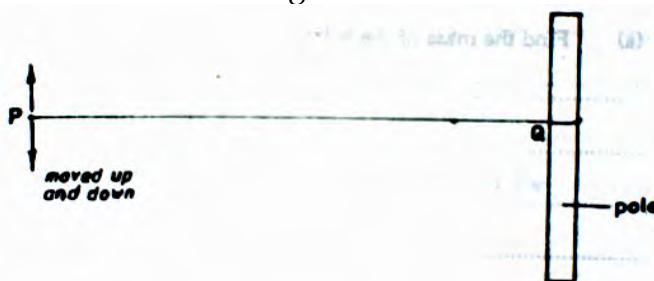
4.



The diagram in the figure shows a section of a transverse wave of wave-length 4.0cm. find its

- (i) frequency (ii) amplitude (iii) velocity

5. (a) The end Q of a rope is tied to a pole while the end P is moved up and down as shown in the figure below.

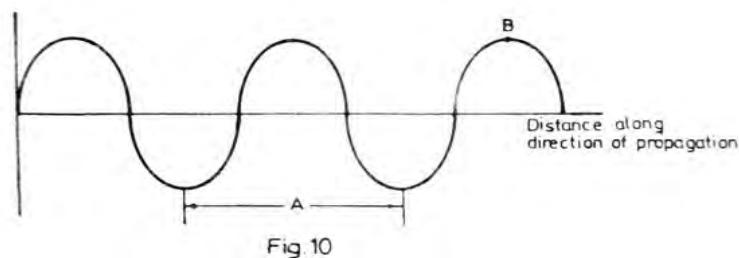


Sketch the resultant wave pattern between P and Q

- (b) (i) Name the type of wave produced in (a) above.
 (ii) Name one musical instrument which produces this type of wave.

6. (a) Describe how a straight wave is produced in a ripple tank.
 (b) State the conditions of the occurrence of destructive interference of waves.

7. (a) What is a *transverse wave*?
 (b) The diagram in figure 10 represents a wave traveling in water.



- (i) Name the part labeled B .

- (ii) If the distance represented by A is 20cm and the speed of the wave is 8.0 ms^{-1} , what is the frequency of the wave?
8. (a) Explain the difference between transverse and longitudinal waves.
Give one example of each
(b)

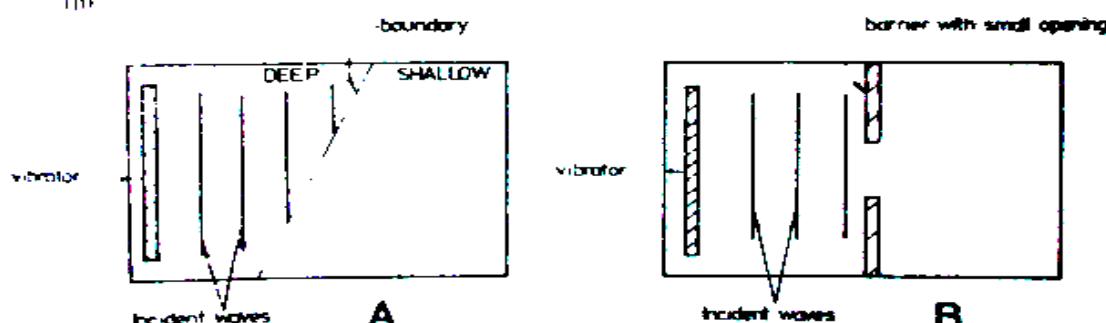


Fig. 3

The diagram in the above figure represents a place view of horizontal ripple tanks set up to study characteristics of water waves. The vibrators were set up to produce plane waves

- (i) Draw diagrams to show the wave patterns in A and B
(ii) Explain what happens to the plane waves in each case.
9. A vibrator in a ripple tank vibrates at 5Hz. If the distance between 10 successive crests is 37.8cm, calculate
(i) the wavelength of the waves
(ii) the velocity of the waves
10. The figure shows waves propagating towards a concave reflector.

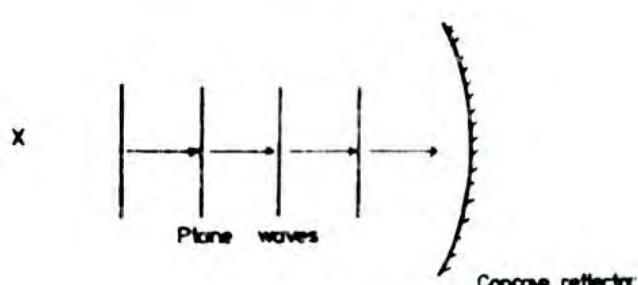


Fig. 2

- (i) Draw a diagram to show how the waves will be reflected.
(ii) If the velocity of the waves is 320 ms^{-1} and the distance between two successive crests is 10cm, find the period of the waves.

- (b) Straight water waves travel from deep to shallow water as shown in the figure below

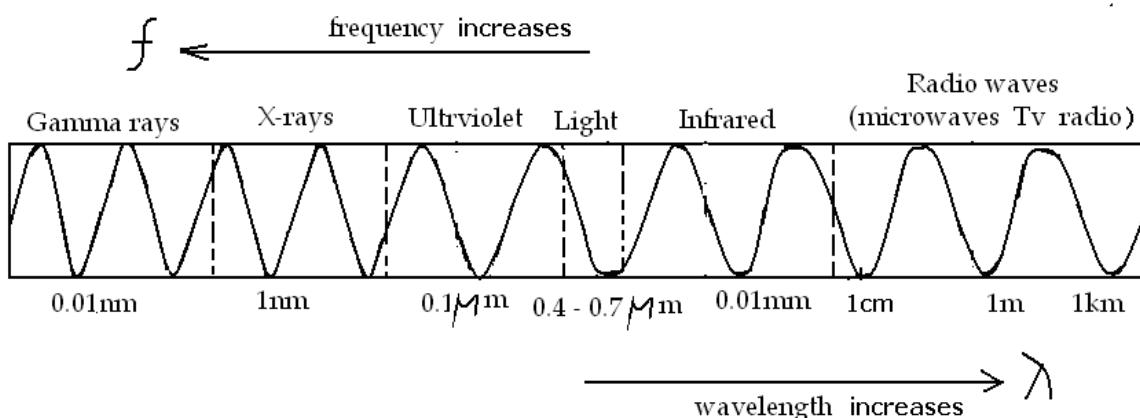


Copy and complete the wave front pattern in the shallow water.

ELECTROMAGNETIC SPECTRUM

This is a family of waves which are made up of electric and magnetic vibrations of very high frequency. An electromagnetic wave such as light from the sun travels most places of its journey through a vacuum before it reaches the earth. This implies that, an electromagnetic wave does not need a material medium for its transmission.

The table below shows the whole range of an electromagnetic wave. Any electromagnetic range of wave length is referred to as a band.



Typical wavelength:

$$\begin{array}{ll} 1\text{nm} & =10^{-9}\text{m} \\ 1\text{Mm} & =10^{-6}\text{m} \end{array}$$

Properties of electromagnetic waves

- Can travel through a vacuum
- Posses energy
- Travel with a speed of $3.0 \times 10^8\text{ms}^{-1}$ in a vacuum
- Are transverse
- Undergo interference.
- Do not need a material medium for its transmission.

Effects of each band of the spectrum on matter

Gamma rays:

- Gamma rays destroy the body tissue especially when the body is exposed to it for a long time or many times.

- Gamma rays cause rubber solution to harden and lubricating oil to thicken when the rubber solution and lubricating oil are exposed to it.

X-rays:

- It destroys body tissue especially when they are exposed to it for a long time.
- X-rays may cause certain metals to emit electrons.

Ultra Violet

- It causes;
- Certain metals to emit electrons
- Sun burn
- Blindness when too much of it falls into the eye
- Photosynthesis in green plants to take place.
- It can penetrate and kill certain bacteria and it is used in bacteriology.

Visible Spectrum

- The visible spectrum;
- May change the apparent colour of an object
- Enable one to see
- May make an object appear bent

Infrared

- It is produced by all hot bodies such as the sun, red-hot or white-hot metals, furnace, electric fires and so on.....
- The eye does not respond to this radiation but sense organs in the skin detect it as heat.
- It can cause the body temperature to rise.

Radio Waves

- They are used in radar and in new methods of cooking food right through quickly VHF (very high frequency).
- Radio waves are transmitted due to electric and magnetic fields oscillating perpendicular to direction of the wave propagation. It is sent into space, and the wave is refracted away from the normal, until the critical angle is reached, when the wave undergoes total internal refraction, only to be received on the other side of the earth.

Origin and source of electromagnetic waves

WAVE - BAND	ORIGIN	SOURCES
GAMMA RADIATION	Energy changes in nuclei of atoms	Radioactive substances
X - RADIATION	a. High energy changes in electron structure of atoms b. Decelereted electrons	X-ray tubes
ULTRAVIOLET RADIATION	Fairly high energy changes in electron structure of atoms	a. Very hot bodies, e.g., electric arc b. Electric discharge through gases, e.g., mercury vapur
VISIBLE RADIATION	Energy changes in electron structure of atoms	Various lamps, flames and anything at or above the temperature at which it begins to emit red light
INFRARED RADIATION	Low energy changes in electron structure of atoms	All matter over a wide range of temperature from absolute zero upwards
RADIO WAVES	a. High-frequency oscillatory electric currents b. Very low energy changes in electron structure of atoms	Radio transmitting circuits and associated aerial equipment

TEST 7.2

SECTION A

1. Which of the following can be detected by an ordinary antenna?
A. Microwaves B. Infrared rays
C. Ultra violent rays D. Gamma rays

2. Which of the following are transverse waves only?
A. Radio, sound, ultra-violet.
B. ultra-violet, x-rays, water waves.
C. Infrared, gamma rays, sound wave.
D. Sound waves, ultra-violet, x-rays.

3. Which of the following are not electromagnetic waves?
A. X-rays B. radar waves
C. Microwaves D. Sound waves

4. Which of the following radiations has the longest wave-length?
(a) Gamma rays (b) Radio waves
(c) visible light (d) X-rays

5. The components of electromagnetic spectrum have
1. the same velocity
2. different wavelength
3. different frequencies
4. the same refractive index for a given media
A. 2 only B. 1 and 3 only
C. 1, 2 and 3 only D. All

6. Which of the following shows the order in increasing wave length of the members of the electro-magnetic spectrum.
(a) Ultra-violet, X-ray, radio waves, infra-red.
(b) radio waves, infra-red, X-rays, Ultra-violet

- (c) X-rays, ultra-violet, infra-red, radio waves
- (d) Gamma rays, ultra-violet, radio waves, radio waves

7. X-rays are

- (a) electrons of high velocity.
- (b) particles of negative charge
- (c) neutrons of high velocity
- (d) electromagnetic waves.

SECTION B

1. a) List 4 properties of electromagnetic waves
b) State two properties of electromagnetic radiation
2. a) state two similarities between water waves and electromagnetic waves
b) Describe a simple method of detecting ultra violet radiations.
3. A radio station broadcasts on 49m band.
 - (i) What is meant by the above statement?
 - (ii) Calculate the frequency of the broadcast.
 - (iii) Explain how radio waves are transmitted
 - (iv) Explain what happens to the plane waves in each case.
4. A vibrator in a ripple tank vibrates at 5Hz. If the distance between 10 successive crests is 37.8cm, calculate
 - (i) the wavelength of the wave
 - (ii) the velocity of the waves
5. Increasing wave-length
→

A	B	C	D
---	---	---	---

The above figure shows part of the electromagnetic spectrum consisting of gamma rays, radio waves, infrared and visible light.

- (a) Identify the bands to which the radiations A, B, C and D belong?
- (b) State one application of the radiation in
 - (i) B and A
 - (ii) B and B

CHAPTER EIGHT

SOUND WAVES

- ❖ *Sound is a form of energy which vibrates as longitudinal wave through media.*
- ❖ The speed of sound in air is about 330m/s in air at 0oC and increases at higher temperatures. And it is much higher in water and solid media. In steel, it is 6000m/s. In water, it is 1500 m/s.
- ❖ Changes in pressure have no effect on the velocity of sound in air
- ❖ Sound does not travel through a vacuum.
- ❖ Sound travels by longitudinal waves which consist of compressions and rarefactions.
- ❖ Sound is produced by a vibrating body.
- ❖ It is transmitted by longitudinal vibrations.
- ❖ It is a form of energy.

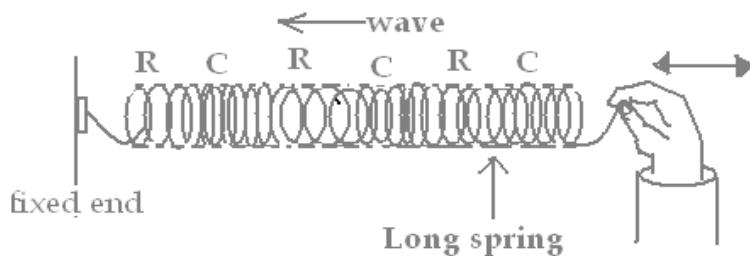
Sound waves require a material medium

The figure below shows that sound waves need a material medium for its transmission. When an electric bell is switched on, a loud sound is heard, but when air inside the bell jar is gradually removed by means of a vacuum pump, the loudness of sound heard gradually dies away. No sound is heard when all the air is completely removed from the jar, even though the hammer is still seen hitting the gong. When air is allowed into the jar the bell is heard to ring once more. This shows that sound waves need a material medium such as air, liquid or solid for its transmission.

Longitudinal waves

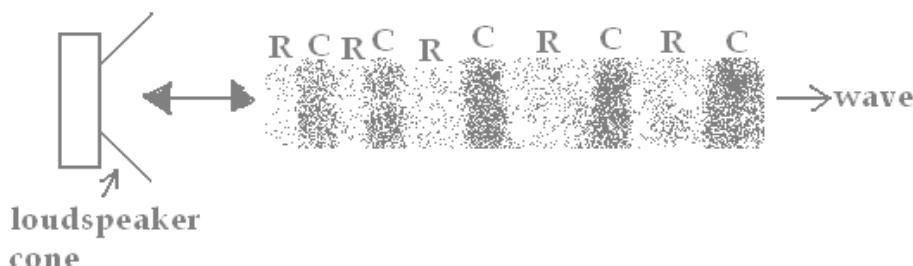
In transverse wave the plane of oscillation of the particles is perpendicular to the direction of the wave, while in a longitudinal wave the plane of oscillation of the particles is parallel to the direction of the wave propagation.

A longitudinal wave can be sent along a spring, stretched out on a bench and fixed at one end if the free end is repeatedly pushed and pulled sharply. Compressions C (where the coils are closer together) and rarefactions R (where the coils are further apart) figure a travel along the spring.



A sound wave produced by for example a loud speaker consists of a train of compressions and rarefactions in the air, figure b. The speaker has a cone which is made to vibrate in and out by an electric current. When the cone moves out the air in front is compressed; when it moves in the air is rarefied (goes "thinner")

b)



Frequency of sound:

It is the number of compressions produced per second.

Wavelength of sound:

It is the distance between successive compressions.

- * As for the transverse waves,
- * speed, $V = f\lambda$
- Human beings hear only sounds with frequencies from about 20Hz to 20000Hz (20 kHz). These are the limits of audibility; they decrease with age.

Reflection:

Sound waves are reflected well from hard, flat surfaces such as walls or cliffs and obey the same way laws of reflection as light.

Echo:

The reflected sound is called an echo.

Reverberation:

Reverberation is when the reflecting surface is so near to the sound source that, the sound appears more prolonged, because the echo is heard at almost at the same time as the sound produced.

Diffraction:

A doorway has a width of 1m which is comparable with the wave-length of much speech and music. It is therefore not surprising that sound is diffracted around such openings and we hear it round corners.

Interference

Two loudspeakers of the same power are placed fairly nearby. They are made to send out sounds of equal intensity. An observer then walks across, along a line parallel to that joining the two loudspeakers. The observer hears loud and soft sounds alternately. The observer will hear loud sound where constructive interference has occurred and soft sound where destructive interference has taken place.

- At night there is less interference than during day, so sound is louder at night than during day time.

Speed of sound

A person with two pieces of wood in the hands stands X metres away from a high wall. He claps the pieces of wood n times and notes the time. Each clap should coincide with the arrival of the echo of the previous clap. He notes the time taken to make n claps, say time t .

$$\text{Then, the velocity of sound} = \frac{\frac{2X}{t}}{\frac{n}{n}} = \frac{2nX}{t}$$

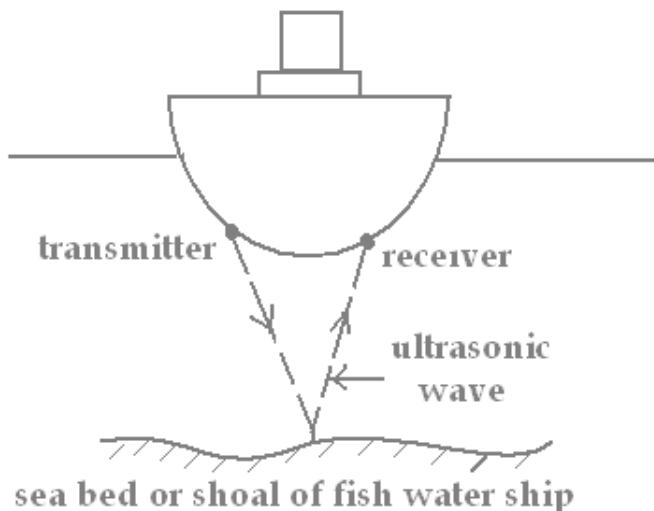
Factors that affect the speed of sound in air:

- Wind direction. It increases if the sound travels in the same direction as the wind and decreases if the sound travels in the opposite direction.

- Temperature of air. It increases when temperature increases and vice-versa.

Ultrasonic

- Sound waves with frequencies above 20 kHz are called *ultrasonic waves*.
- They cannot be heard by human ears
- In the echo-sounding system called sonar, ships use ultrasonic waves to measure the depth of the sea and to detect shoals of fish.



- Velocity of sound in water, V .

$$V = \frac{2 \times \text{depth of water}(m)}{\text{time}(s)} \quad \text{In symbols, } V = \frac{2h}{t}$$

Example: An echo sounder ship received reflected waves from a sea bed after 0.20s. What is the depth of the sea bed, if the velocity of sound in water is 1450m/s.

Solution:

$$\begin{aligned} \Rightarrow h &= \frac{Vt}{2} \\ V &= \frac{2h}{t} \\ &= \frac{1450 \times 0.20}{2} \\ &= 145 \text{ m} \end{aligned}$$

MUSICAL NOTES

Irregular vibrations cause noise, regular vibrations such as those which occur in the instruments of an orchestra produce *musical notes* which have three properties namely pitch, loudness and quality

Pitch

It is highness and lowness of sound.

The pitch of a musical note depends on the frequency of the sound wave reaching the ear. A high pitched note has a high frequency and a low pitched note has a low frequency

Loudness

A note is louder when more sound energy enters our ears per second than before and is caused by the source vibrating with larger amplitude.

Quality

The characteristic of a note that distinguishes it from another note of the same pitch and loudness is known as quality of a musical scale. The notes obtained from any instrument are made of several different frequencies blended together. The strongest audible frequency present is known as the fundamental frequency, f_0 . Other notes obtained above this, are called over tones or harmonies.

Beats

If two notes of almost the same pitch are produced or played together, there is rhythmic rise and fall in the loudness of sound. These alterations in sound are called beats.

Natural frequency

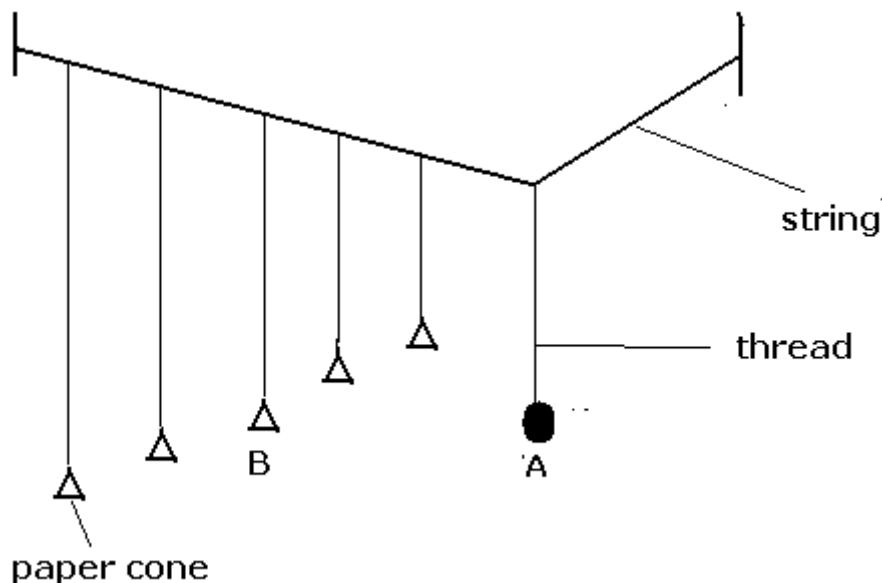
An object vibrates at a particular frequency when suspended so that friction does not stop its vibrations readily. This is called natural frequency.

Resonance

Resonance is a phenomenon in which the energy of one vibrating object is transferred through a medium to another and causes the latter to vibrate. It occurs when the system is made to vibrate at its natural frequency as a result of the vibrations received from another source of the same frequency. Vibrations due to resonance are called resonant.

Example:

When the heavy pendulum A in figure below is set swinging, it forces all the light ones to swing at the same frequency, but B, which has the same length as A, does so with a much larger amplitude, i.e. B resonates with A.



Vibrating Strings

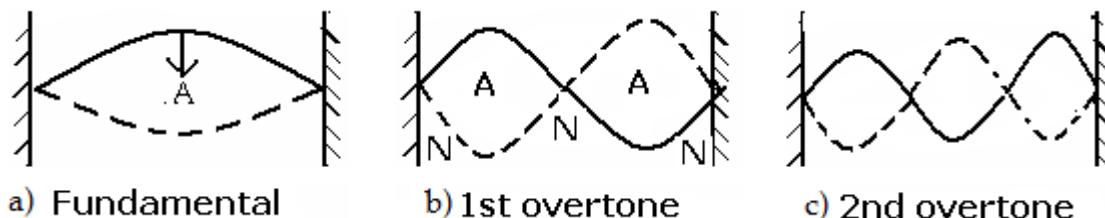
Stationary Waves

- ❖ When two equal progressive waves moving in opposite directions interfere they form a **stationary wave**.
- ❖ On a stationary wave, there are certain points which are permanently at rest. These points are called **nodes (N)**.
- ❖ Some other points are vibrating with maximum amplitude. These points are called **antinodes (A)**, (the central point of the amplitude).

- The distance between the two successive nodes or antinodes equals to half of the wavelength.

Main characteristics of stationary waves:

- Have region of maximum displacement and zero displacement called antinodes and nodes respectively.
 - Neighbouring particles are always in phase.
 - Wave profile is stationary.
- A string can vibrate in various ways. If the standing wave has one loop, figure a, the fundamental note is emitted. If there is more than one loop, figures b, c, overtones are produced.



Frequency of a vibrating string

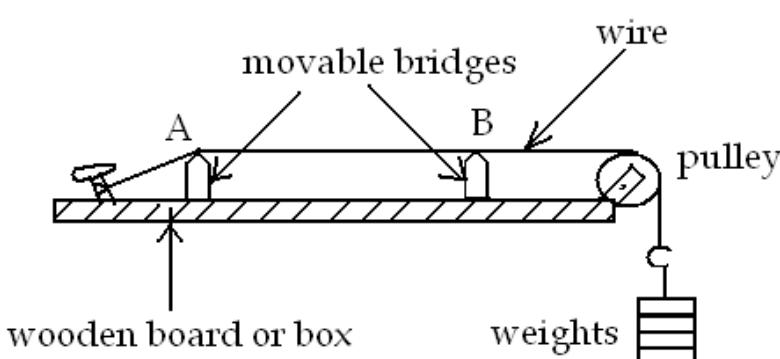
The frequency of a string depends on;

- Length of the string
- Tension
- Mass per unit length.
- The frequency of the fundamental note emitted by a vibrating string of length l , mass per unit length m and under tension T is given by

$$f = \frac{1}{2l} \sqrt{\frac{T}{m}}$$

Hence f increases if l is reduced or T increased or m reduced ; short, thin, tightly stretched wires therefore emit high notes.

This
verified
using a



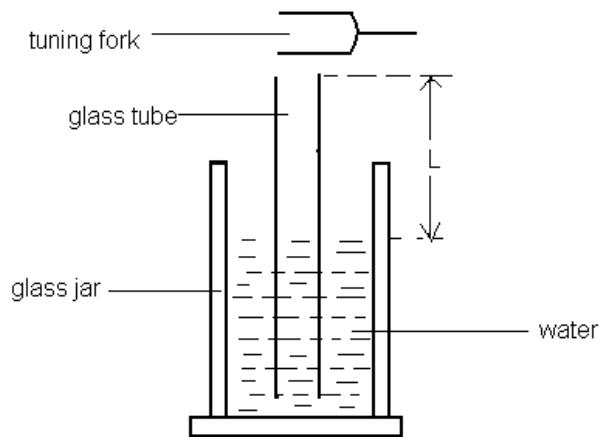
*relationship can be
experimentally
sonometer.*

For example to see how l affects f , a tuning fork is struck and, keeping A fixed, B is moved until the note given by plucking the centre of the wire is the same as that of the fork. When the wire is tuned to the fork the rider jumps off. With the same wire under the same tension the lengths for other forks are found and if $f \propto 1/l$ then $f \propto l$ should be constant.

Vibrating air columns

If a vibrator e.g. a tuning fork is placed at the open end of a glass tube, a stationary wave is set up in the air column. This is the result of waves traveling along the tube combining with reflected waves traveling in the opposite direction. The air column has a natural frequency at which it vibrates. If the frequency of a vibrator matches with the natural frequency, resonance occurs and a loud note is heard.

If the length of the tube is varied by adding water, several positions can be found where resonance is possible (figure below)

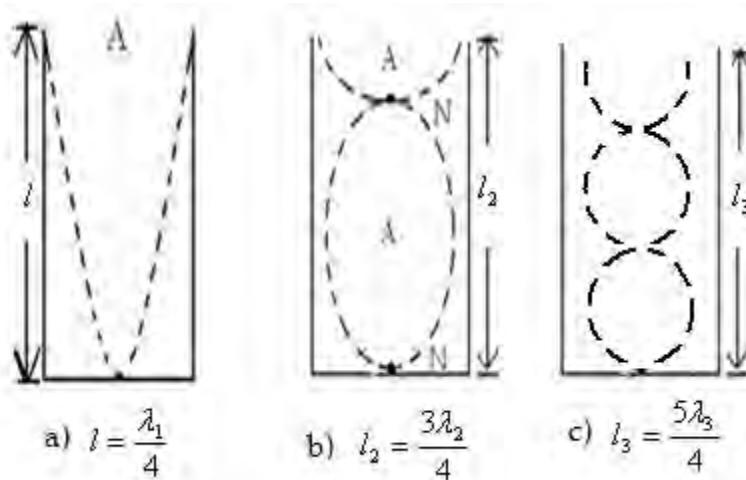


Vibration in closed pipes

A closed pipe is one which is closed at one end only. A node is produced when a stationary wave is produced at the closed end of the tube.

The wave-length of the node is then $4l$ where l is the length of the tube. If one end of the tube is closed by placing a hand over it, then $l = \frac{\lambda}{4}$ or $\lambda = 4l$ (figure a)

If the length of the tube is further increased, resonance again occurs when the length is approximately three times long. Then $l_2 = \frac{3\lambda}{4}$ (figure b)



Vibrations in open pipes

An open pipe is one which can open at both ends.

A stationary wave can be set in an open pipe when a vibrating tuning fork is placed at the mouth of one end. The stationary wave for the first three harmonies as shown in the figure below. In all cases, the antinodes are at both ends.

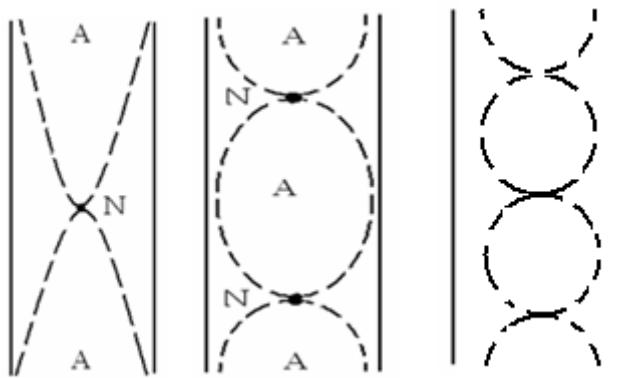
For the fundamental note, the air column l equals to half a wave-length, that is

$$l = \frac{\lambda}{2} \text{ or } \lambda = 2l$$

If V is the speed of sound in air, then $f = \frac{V}{\lambda} = \frac{V}{2l}$

For the first overtone $f_1 = \lambda$ and $f_1 = \frac{V}{\lambda} = 2 \frac{V}{l} = 2f$

For the second overtone $f_2 = \frac{3\lambda}{2} = f$, $f_2 = \frac{V}{\lambda} = \frac{3V}{2l} = f$

**Example -1:**

The frequency of the third harmonic in an open pipe is 590Hz. Find the length of the air column, if the speed of sound in air is 330m/s

$$\text{Solution-1: For third harmonic } l = \frac{3\lambda}{2} \Rightarrow \lambda = \frac{2l}{3}$$

$$f = \frac{V}{\lambda} = \frac{3V}{2l}$$

$$590 = \frac{3 \times 330}{2xl}$$

$$l = 0.84m$$

Example-2.

A tube, closed at one end, resonates first at a length 28.5cm and again at 88.5cm when a tuning fork of frequency 275Hz is held close to the open end. Find the velocity of sound.

Solution-2: Difference between the two lengths, l

$$\begin{aligned} l &= 98.5 - 38.5 \\ &= 60 \text{ cm} \\ &= 0.6 \text{ m} \end{aligned}$$

This is equal to half of a wavelength.

Wave length of the note, $\lambda = 120 \text{ cm} = 1.2 \text{ m}$ ($\lambda = 2l$)

$$\begin{aligned} \text{Velocity of sound} &= f \times \lambda \\ &= 275 \times 1.2 \\ &= 330 \text{ ms}^{-1} \end{aligned}$$

TEST 8

SECTION A

1. A vibrator produces a sound wave that travels 900m in 3s. If the wavelength of the wave is 10m, find the frequency of the vibrator.
- a. 30Hz b. 270Hz c. 300Hz d. 3000Hz
2. A man standing in front of a tall wall makes a loud sound and hears the echo after one and half a sec. How far is he from the wall if the velocity of the sound in air is 330m/s?
- A.110m B.247.5m C.440m D.990m
3. The number of vibrations a wave makes in 1s is the
- A. Frequency B. Wave length
C. period D. amplitudes
4. Which of the following are longitudinal waves?
- A. water waves B. light waves
C. sound waves D. radio waves
5. Points on a stationary wave which are permanently at rest are called
- (a) crests (b) trough (c) nodes (d) anti-nodes

6. Sound is produced by a source vibrating at a frequency of 50Hz. Given that speed is 330ms^{-1} in air its wavelength is
- a) 0.15m b) 6.6m c) 380m d) 16500m
7. The velocity of sound in air at a constant pressure, A
- (a) increases with loudness
(b) decreases with loudness
(c) increases with temperature
(d) decreases with temperature
8. A man sees the flash from a gun fired 1020m away and then later he has a bang. How long does the bang take to reach him. (Take speed of sound as 340ms^{-1})
- A. $\frac{1020}{340 \times 10}\text{s}$ B. $\frac{340}{1020}\text{s}$ C. $\frac{1020}{340}\text{s}$ D. $(340 \times 1020)\text{s}$
9. The effect produced when many echoes merge into one prolonged sound is known as
- A. noise. B. harmonics.
C. reverberation. D. pitch.
11. What occurs when a body is made to vibrate with its natural frequency due to external vibration?
- A. Echo B. Resonance
C. Refraction D. Reverberation
12. A man standing 85 m from a tall wall fires a gun and hears the echo from the wall after 0.5 s. calculate the speed of sound in air.
- A. 340ms^{-1} B. 170 ms^{-1} C. 85 ms^{-1} D. 43 ms^{-1}
13. A boy standing 150 m from a vertical cliff claps his hands and hears an echo 0.85 seconds later. Find the speed of sound in air.

- A. 128 m s^{-1} B. 176 m s^{-1} C. 255 m s^{-1} D. 353 m s^{-1}

- 14.** In a sound wave the particles of the medium
- A. are stationary.
B. move along with the wave.
C. vibrate in the same direction as the wave.
D. vibrate at right angles to the direction of the wave.
- 15.** Which of the following statements are true about sound waves?
- (i) they are longitudinal
(ii) they are transverse
(iii) they are produced by vibrations
(iv) they can travel through empty space
- A. (ii) and (iv) only
B. (i) and (iii) only
C. (i), (ii) and (iii) only
D. (ii), (iii) and (iv) only
- 16.** A girl stands in between two tall cliffs and claps her hands. She hears the first echo after 1s and the second echo after 2s. If the speed of the sound is 300ms^{-1} , the distance between cliffs is
- a) 300m b) 450m c) 900m d) 1200ms
- 17.** Which of the following statements is true?
- a) light waves, radio waves and sound waves will travel through a vacuum
b) light waves and radio waves will travel through a vacuum, sound waves will not.
c) light waves and sound waves will travel through a vacuum, radio waves will not.
d) sound waves and radio waves will travel through a vacuum, light waves will not.
- 18.** Sound waves
- a) do not pass through a vacuum

- b) travel through solids at lower speed than in air
- c) do not travel through liquids
- d) travel at highest speed in air.

19. Sound travels much greater through

- | | |
|-----------|------------------|
| (a) steel | (b) wood |
| (c) water | (d) nitrogen gas |

20. An echo is produced as a result of sound waves being

- (a) absorbed by objects
- (b) transmitted by objects
- (c) deflected by objects
- (d) bent around corners by objects

21. The particles of the medium through which a longitudinal wave travels

- (a) vibrate parallel to the direction of the propagation of the wave
- (b) vibrate perpendicular to the direction of the propagation of the wave
- (c) move along with the wave
- (d) move in the opposite direction to the wave.

22. A girl standing 300m away from a high vertical wall makes a loud sound of frequency 600Hz. Calculate the wave length of the sound wave if the girl hears the echo after 2s.

- (a) 0.2m
- (b) 2.5m
- (c) 5m
- (d) 10m

23. In forced vibrations, resonance occurs when the forcing

- a) Frequency is equal to the natural wavelength
- b) velocity is equal to the natural velocity
- c) frequency is equal to the natural frequency
- d) frequency exceeds the natural frequency.

24. Loudness of a musical note depends on

- | | |
|--------------|--------------|
| 1. pitch | 2. velocity |
| 3. frequency | 4. amplitude |

- | | |
|--------------------|-----------------|
| A. 1, 2 and 3 only | B. 1 and 3 only |
| C. 2 and 4 only | D. 4 only |

SECTION B

1. Two identical loud speakers A and B are placed near each other as shown in the figure. The speakers vibrate with same frequency

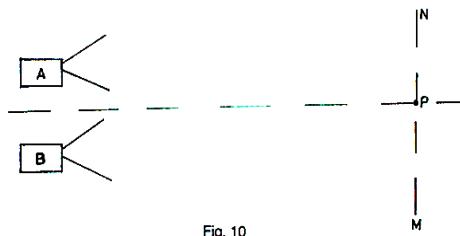


Fig. 10

Explain what will be observed on a sound detector moved from N to M

2. a) What is meant by sound?
b) Describe an experiment to show that sound waves require a material medium for transmission.

3. a) Explain briefly the following:
 (i) a dog is more able than a human being to detect the presence of a thief tip-toeing at night.
 (ii) An approaching train can easily be detected by human ears placed close to the rails.

4. A sound of frequency 250Hz is produced 120m away from a high wall.
Calculate the:
 (a) wave-length,
 (b) Time it takes the sound wave to travel to and from the wall. (Speed of sound in air = 330ms^{-1})

5. a) What is an echo?
b) State any two factors which determine the frequency of a note produced when a guitar string vibrates.

6. (a) Give two reasons why sound is louder at night than during the day.

- (b) An echo sounding equipment on a ship receives sound pulses from the sea bed 0.02 after they were sent out from it. If the speed of sound in water is 1500ms^{-1} , calculate the depth of water under the ship.
7. A long open tube is partially immersed in water and a tuning fork of frequency 425 Hz is sounded and held above it. If the tube is gradually raised, find the length of the air column when resonance first occurs. (Neglect the end correction, Speed of sound in air = 340ms^{-1})
8. (a) State three difference between sound and light waves.
(b) (i) Explain how stationary waves are formed.
(ii) State three main characteristics of stationary waves.
9. (a) Two identical sources are made to produce circular waves in a ripple tank. With the aid of a diagram, explain how interference fringes may be obtained
10. a) (i) Describe an experiment to measure the speed of sound in air.
(ii) State any two likely sources of error in the experiment.
(b) Describe an experiment to determine how frequency of a vibrating string depends on the length of the string.
11. (a) The velocity and frequency of sound in air at a certain time were 320ms^{-1} and 200Hz respectively. At a later time, the air temperature changed and the velocity of sound in air was found to be 340ms^{-1} . determine the change in wavelength of the sound.
(b) List three differences between sound waves and radio waves.
12. a) A girl stands at a distance of 600m from a high cliff and blows a whistle. She hears the sound of the whistle again after 4 seconds. Calculate the speed of the sound.
13. a) A girl at a distance of 165m from a high wall, clapped her hands once but heard two claps
(i) Explain why the girl heard two claps
(ii) Find how long it took her to hear the second clap. (The speed of sound on air is 330ms^{-1})
(b) Give one practical application in which the principle in (a) is used.

14. a) Explain each of the following observations
- (i) Sound from a distant source is louder at night than during day
 - (ii) an observer can hear sound from a source which is behind a building
- (b) Describe an experiment to show interference of sound waves
15. (a) (i) What is meant by reverberation?
(ii) How does complete absence of reverberation affect speech in a concert hall?
- (b) A girl produces sound waves near a series of regularly spaced reflecting surfaces. If the reflected are 15cm apart and the velocity of sound in air is 330ms^{-1} , calculate the frequency of the echo.
16. (a) An echo sounder on a boat sends down a pulse through the water and receive its echo 0.9 s later. If the velocity of sound in the water is 1450ms^{-1} , calculate the water depth.
(b) Identify two differences between water and sound waves.
17. (a) Define the terms *frequency* and *wavelength* as applied to sound.
(b) Describe an experiment to demonstrate resonance in sound.
18. a) A man stands between two cliffs and makes a loud sound. He hears the first echo after one second and a second echo after a further one second. Find the distance between the cliffs

CHAPTER NINE

ELECTRICAL POWER AND ENERGY

Electrical Energy

- When a potential difference is applied to the ends of a conductor, some of the electrons inside it are set in motion by the electrical forces. Work is therefore done and the electrons acquire energy. The moving electrons form an electric current.
 - If a potential difference of 1 volt is applied to the ends of a conductor and 1 coulomb of electricity passes through it, the work done is 1 joule (J).
 - Hence if the pd is in volts (V) and the quantity of electricity which passes is Q coulombs(C), then the
 - Work done, $W = QV$

$$\text{Also } V = IR \quad \text{or} \quad I = \frac{V}{R}$$

Electrical power

Power is the rate of doing work. If electrical work done in a time t seconds is W, then

$$\text{power} = \frac{\text{work}}{\text{time}} = \frac{w}{t}$$

But electrical work done is given by

$$W = VIt \text{ or } W = I^2Rt \text{ or } W = \frac{V^2}{R}t$$

Therefore Power is given by

$$P = \frac{W}{t} = \frac{IVt}{t} = IV \quad (1)$$

$$P = \frac{I^2R}{t}t = I^2R \quad (2)$$

$$P = \frac{V^2t}{Rt} = \frac{V^2}{R} \quad (3)$$

The unit of power is the watt.

It follows that a **watt** = $\frac{1\text{ joule}(J)}{1\text{ second}(s)}$

A **watt** is defined as the rate of working of 1 joule per second.

An appliance rated 240V, 75W gives out energy at a rate of 75J every second when connected to a 240V supply.

Commercial electrical energy

The commercial unit of energy is the kilowatt hour (kWh). The kWh is the energy supplied by a rate of working of 1000 watts for 1 hour, that is

$$\begin{aligned} 1\text{ kWh} &= 1000 \text{ watts for 1 hour} \\ &= 1000 \times 60 \times 60 \text{ joules} \\ 1\text{ kWh} &= 3600000 \text{ joules} = 3.6MJ \end{aligned}$$

Unit consumed = Power(kW) x time(hour)

Example :1 Find the cost of running three 50W lamps and five 75W lamps for 6 hours if electrical energy costs shs 50 per unit.

Solution:

$$\text{Unit consumed} = \left(3x\frac{50}{1000} + 5x\frac{75}{1000}\right)x6 = 3.15 \text{ units}$$

If one unit costs shs 50, then 3.15 units will cost: $3.15 \times 50 = 157.5$
Thus total cost will be shs 157.5

Example :2 Find the cost of running five 60W lamps and four 100W lamps for 8 hours if electric energy costs 40 shs per unit.

Solution:

$$\text{Unit consumed} = \left(5x\frac{60}{1000} + 4x\frac{100}{1000}\right)x8 = 5.6 \text{ units}$$

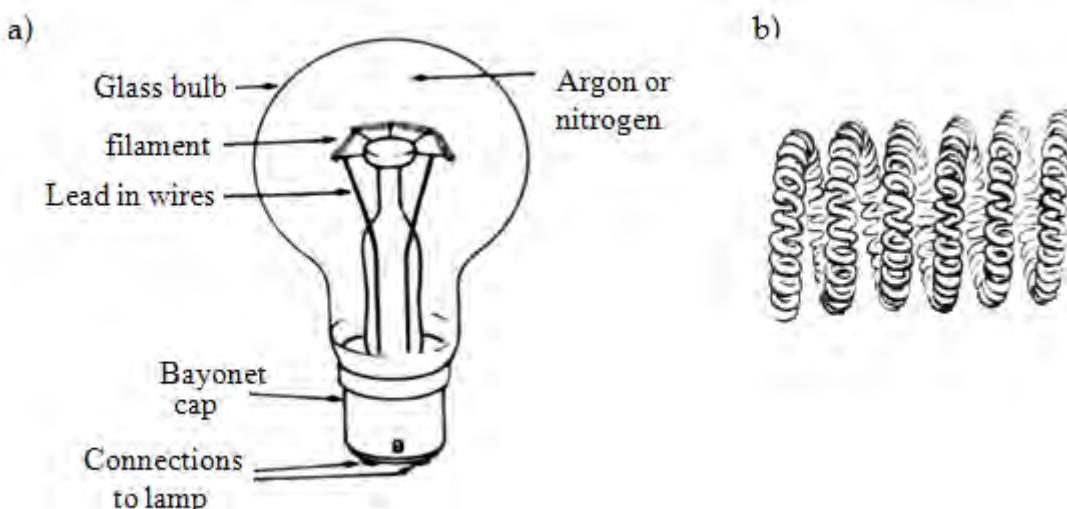
If one unit costs shs 40, then 5.6 units will cost: $5.6 \times 40 = 224$
Thus total cost will be shs 224

Electric lighting

a) Filament lamps:

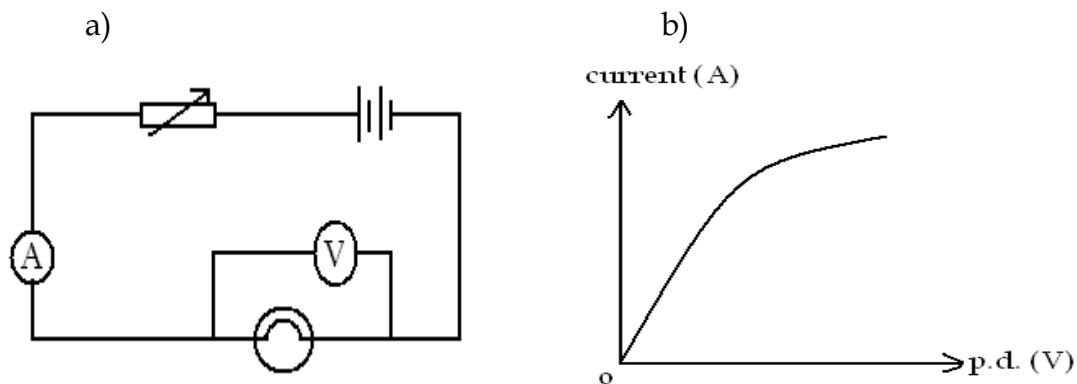
The filament is a small coiled coil of tungsten wire as in the figure below, which becomes white when current flows through it.

The higher the temperature of the filament, the greater is the proportion of electric energy changed to light and for this reason it is made of tungsten, a metal with a high melting point(3400°C).

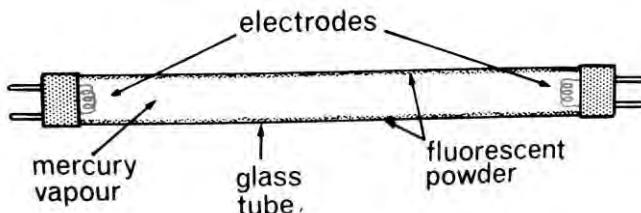


Most lamps are gas filled and containing nitrogen or argon not air. This reduces evaporation of the tungsten which would otherwise condense on the bulb and blacken it.

The circuit figure below(a) and graph below (figure b) shows the variation of current through a tungsten filament with the p.d. across it.



b) Fluorescent lamps

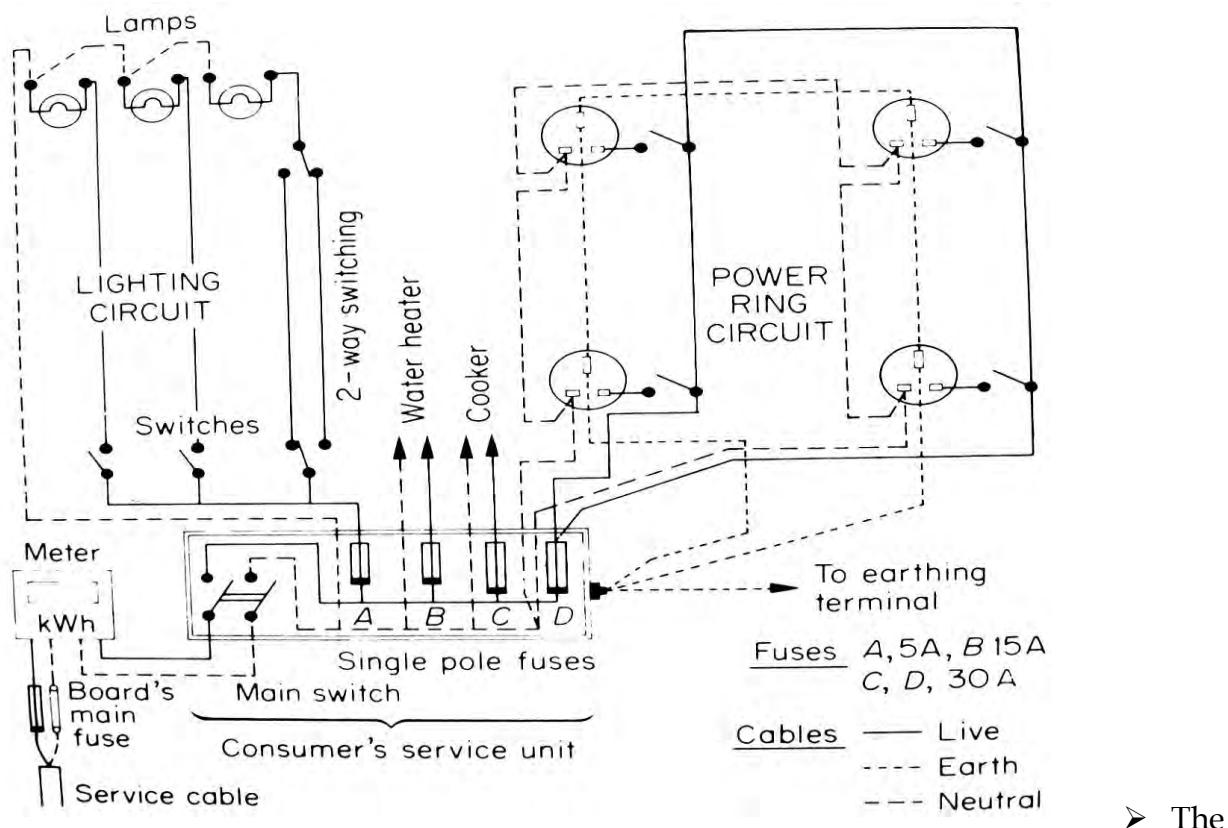


- A simplified diagram of a fluorescent lamp is shown in the figure above. When the lamp is switched on current passes until the tungsten filaments are hot enough to emit electrons. The electrons collide with the mercury atoms, causing the mercury vapour to emit ultra violet radiation (invisible) which makes the powder on the inside of the tube fluoresce (glow), i.e. light (visible) is emitted. Different powders give different colours.
- A filament lamp changes only 10% of the electrical energy supplied into light, the other 90% becomes heat.

Advantage of a fluorescent tube over a filament lamp

- Fluorescent lamps are more energy saving than normal bulbs.
- Fluorescent lamps don't give a lot of heat like filament lamps.
- Fluorescent lamps cost more to install but running costs are less than filament.

Domestic Electrical Installation



cable bringing the mains electricity supply into a house contains two wires, the live and the neutral. The neutral is earthed at the local sub-station and so is at zero potential. And live wire is alternatively positive and negative.

- Within a house, the supply cable which is carrying a.c. enters a sealed box where the live wire is joined to the Electricity Board's fuse.
- *A fuse is a device containing a short length of a thin wire which melts and breaks the circuit if the current exceeds a safe value.*
- From the box, the cables are passed to the consumers service unit in which there is a large main double pole switch combined with a single pole fuse for each of the lighting circuits, cookers, water heater circuit and ring circuit.
- Normally the lighting fuse is 5A, the water heater fuse is 15A, the cooker circuit fuse is 30A and other ring circuit fuse is 30A.
- In wiring the lighting circuit, two wires are used, these are the live and the neutral wire. In wiring the power ring circuit , heater circuit and cooker circuit, a third wire is introduced. This wire is called the **earth wire**. This is done so that one does not get a shock as sometimes the live wire may touch the metal frame of the appliance.
- In wiring an electric circuit, all the switches and fuses are placed on the live side of the supply.

TEST 9

SECTION A

1. A current of 10A flows through an electric heater for 1hour. If 7.2×10^6 J of electrical energy is converted to heat, find the p.d across the heater.
a. 2.0×10^2 V b. 2.0×10^3 V c. 1.2×10^4 V d. 7.2×10^5 V

2. If the cost of one unit of electrical energy is sh.150, find the cost of using two 75W lamps for 2 hours.
a. Sh. 0.30 b. Sh. 4.00 c. Sh. 22.50 d. Sh. 45.00

3. An electric lamp is marked 120 W, 240V. What does 120W mean?
 - A. Total energy consumed by the lamp.
 - B. Rate at which energy is consumed.
 - C. Total current flowing through the lamp.
 - D. Potentional difference across the lamp.

4. A transformer connected to 240V a.c mains is used to light a 12V 36W lamp. What current does the lamp draw?
- a) 20.0 A b) 6.7 A c) 3.0 A d) 0.33A
5. Uganda electricity board charges sh.90 per Kilowatt-hour of electrical energy consumed. What is the total cost of operating 4 light bulbs rated at 100W for 5 hours.
- a) sh.11.25 b) sh.45 c) sh.180 d) sh.180,000
6. What is the cost of running five 200 W lamps for 8 hours if electrical energy costs sh.140 per unit?
- (a) Sh.1120 (b) sh. 700 (c) 224 (d) sh.28
7. The device which disconnects the mains when there is a sudden increase in voltage is
- (a) fuse (b) switch
(c) earth wire (d) circuit breaker
8. An electric heater is connected to a 200 V supply. The heating element has a resistance of 10Ω . The cost of using the heater for 4 hours if each unit of energy costs Sh.35 is
- (a) Sh.5600 (b) Sh.1400 (c) Sh.560 (d) sh.140
9. How many kilowatt hours are used to run
- (i) 8 kW cooker for 1 hour
(ii) 3 kW immersion heater for 40 minutes
(iii) 960W hair dryer for 20 minutes
- (a) 10.32kWh (b) 147.20kWh
(c) 768.00kWh (d) 971.00kWh
10. For safety in house, a fuse and a switch are connected to

- | | |
|--------------|---------------|
| <u>Fuse</u> | <u>Switch</u> |
| A. Live wire | Neutral wire |

- B. Neutral wire Earth wire
C. Live wire Live wire
D. Earth wire Neutral wire

11. An electric appliance having 4 heating elements, each rated at 0.75kW, is used on a 240 V mains. What is the power rating of the appliance?
- A. 80 kW B. 60 kW C. 3 kW D. 3W
12. A car head lamp bulb is marked 12V, 48W. This means that when a
- A. voltage of 12V is applied, a current of $\frac{1}{4}$ A flows.
B. power of 48W is developed, the resistance is 4Ω .
C. voltage of 12 V is applied, resistance is Ω .
D. voltage of 12 V is applied; energy used in every second is 48J.
13. Which of the following statements are true about electric wiring?
(i) The fuse is always connected into the live wire leading to circuit.
(ii) The fuse is connected into the neutral wire leading to a circuit.
(iii) When a fault develops in the circuit, it is the neutral wire which has to be disconnected.
- A. (i) only. B. (iii) only.
C. (i) and (iii) only. D. (i), (ii) and (iii).
14. An electricity board charges shs 10 per kilowatt-hour of electrical energy supplied. What is the total cost in shs. Of operating 4 light bulbs, each rated at 100W for 5 hours?
- A. Sh2. B. Sh.20. C. Sh 4,000 D. Sh 20,000
15. What is the most suitable fuse for an electric heater rated 2.5KW when connected to a voltage of 240V
- A. 5A B. 10A C.13A D.30A
16. An electric heater is rated 240V, 400W. if the efficiency of the heater is 80% find the amount of energy wasted per second.

A. 48J.

B. 80J.

C. 192J.

D. 320J.

17. An electric heater which operates from 240V mains draws 15A for 40 minutes. Calculate the cost of electricity, given that electricity costs 9.00 per kilowatt hour
 a) Sh.1.44 b) sh.21.60 c) sh.960 d) sh.1296
18. A bulb of resistance 1.5Ω is connected to a cell of e.m.f. 2.0V. Find the energy dissipated in 45 seconds.
 a) 60J b) 67.5J c) 90J d) 120J
19. Calculate the amount of current taken by an electric flat iron marked 250 V. 1000W.
 (a) 0.25A (b) 0.40A (c) 2.50A (d) 4.00A

20.

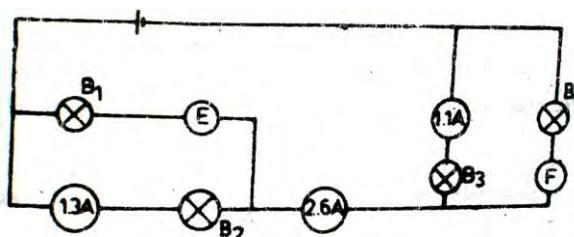
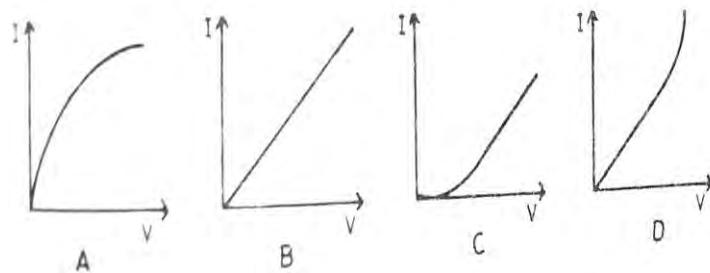


Fig 6

In the above circuit, B_1 , B_2 , B_3 and B_4 are bulbs. The readings of ammeters E and F are respectively

- | | |
|----------------|----------------|
| (a) 1.5A, 1.3A | (b) 1.3A, 1.5A |
| (c) 1.3A, 1.1A | (d) 1.3A, 2.6A |

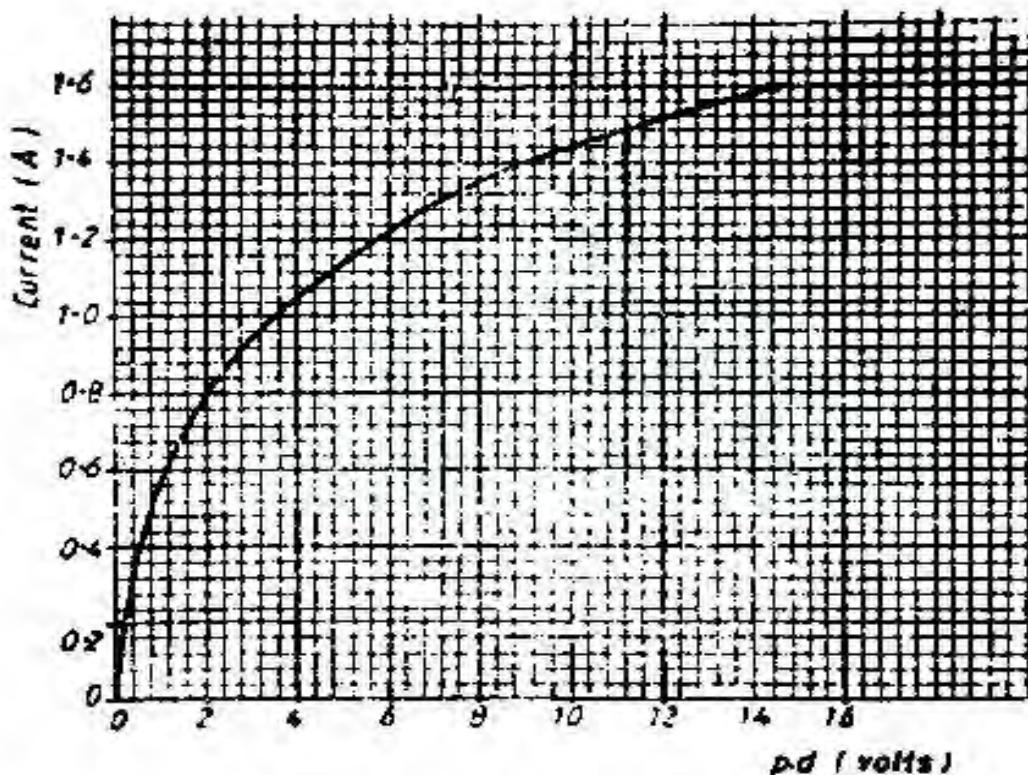
21. 4 bulbs each rated at 75 W operate for 120 hours. If the cost of electricity is sh.100 per unit, the total cost in shillings will be
 (a) 150 (b) 900 (c) 3600 (d) 7500
22. Which one of the following graphs represents the current voltage variation for a tungsten filament wire lamp?



23. A house has four 75 W lamps and five 100 W lamps. What will be the cost of running the lamps for 10 hours if the cost per kWh is sh.50.
- (a) sh.2500.00 (b) sh. 400.00 (c) sh. 500.00 (d) sh. 787.50
24. An electric heater is used to heat 0.2kg of water for 200 seconds. Find the p.d across the heater if the current through it is 0.5A and the temperature of the water rises by 25°C
- (a) 145V (b) 175V (c) 210V (d) 240V
25. Which of the following circuit diagrams shows the correct positions for a lamp and a switch in a lighting circuit?
-
26. A current of 2 A flows through a coil of resistance 3 ohms for one minute. How much energy is converted into heat?
- a) 6J b) 12J c) 360J d) 720J
27. When a 240V supply is connected across an electric appliance, a current of 200mA flows in the circuit. What is the electric power supplied to the appliance
- (a) 1.2W (b) 48.0W (c) 48000.0W (d) 120000.0W

SECTION B

1. A 240 V, 600W water heater is used to boil water for 5 min.
 - (a) By what means does heat spread through the water?
 - (b) Calculate:
 - (i) The current that flows in the heater.
 - (ii) The electrical energy converted into heat.
2. A bulb is rated 12.0volts, 36 watts when used on a 12.0 volts supply.
 - (a) How much current does it draw from the supply?
 - (b) What is its resistance?
3. (a) Describe the structure and action of a fluorescent tube.
(b) Give one advantage of a fluorescent tube over a filament lamp.
4. Find the cost of running two 75 W lamps for 10 hours if the cost of each unit is sh.50.
5. A bulb is rated 6V, 12W. Calculate;
 - (a) the current it takes.
 - (b) the energy it supplies in 30 seconds.
6. Describe the functions of:
 - (i) a fuse
 - (ii) an earth wire.
7. An electric heater which operates from 240V mains draws 12A for 30 minutes. Calculate the cost of electricity, given that electricity costs 8.00 per kilowatt hour.
8. Find the cost of running two 60 W lamps for 20 hours if the cost of each unit is sh.40.
9. An electric heater of resistance 40Ω is connected to a 240 V mains. How long will it take to raise the temperature of 4kg of water from 40°C to 100°C ?
10. The graph below shows the variations of current through a tungsten filament with the p.d across it.



- (a) Draw a suitable circuit diagram to show how the results in the graph can be obtained.
- (b) State what happens to the resistance of the filament as the current increases
- (c) Using the graph, determine the resistance of the filament when the current is 0.7A.

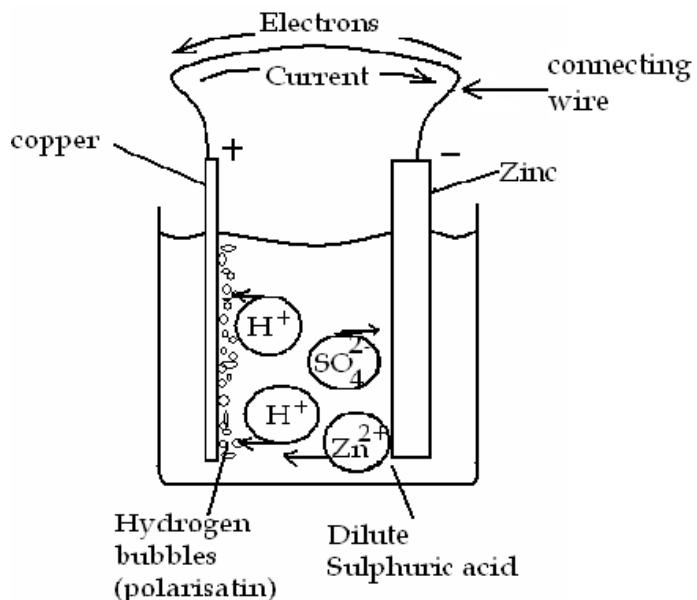
CHAPTER TEN

ELECTRIC CELLS

In a cell chemical energy becomes electrical energy. The process is the reverse of electrolysis where an electric current causes chemical change.

a) A Simple Cell

A simple cell or voltaic cell is made of two electrodes of different metal plates dipped in an electrolyte. The electrodes normally used are copper for positive plate and zinc for negative plate. While the electrolyte used is dilute sulphuric acid, H_2SO_4 .



When the copper plate is connected to the zinc plate by a connected wire, zinc slowly dissolves such that each atom leaves two electrons on the plate and goes into solution as zinc ions, Zn^{2+} . In the solution, zinc ions displace an equivalent amount of hydrogen ions and form zinc sulphate. The hydrogen ions which are displaced move to the copper plate and gain electrons from copper and become neutral atoms. Two of these atoms then combine and form hydrogen gas and this appears as bubbles on the copper plate. When the copper plate loses electrons to hydrogen ions, it becomes positively charged and it attracts the electrons from the zinc plate through the connecting wire. Thus electrons flow from zinc plate to the copper plate through a conductor. This movement of electrons through the wire is called an *electric current*.

Defects of a simple cell

There are two major defects of a simple cell polarization and local action.

1. Polarization.

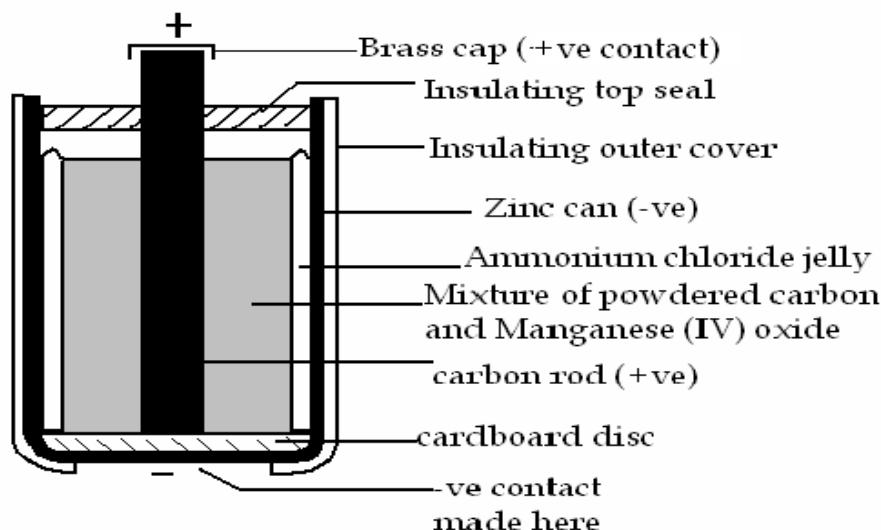
- The working of a cell involves the release of hydrogen bubbles at the positive electrode. These bubbles partially insulate the electrode from the electrolyte. This slows down and eventually stops the working of the cell.
- This effect is called polarization.
- Polarization can be reduced by;
- Use of a depolarizer such as manganese dioxide which oxidizes hydrogen to form water and so removes the hydrogen bubbles.
- By occasionally brushing the plates which are very inconvenient.

2. Local action.

- When zinc plate contains some impurities, some reactions occur between the impurities and the acid electrolyte and bubbles of hydrogen are seen coming off the zinc. This results in the gradual wearing of the zinc plate and the defect is known as *local action*.
- This can be prevented by cleaning zinc with sulphuric acid and then rubbing it with some mercury. The plate is said to be amalgamated. The mercury amalgam covers up the impurities and prevents their contact with the acid electrolyte.

b) Dry (Leclanche) Cell

- In a dry cell, the electrolyte is ammonium jelly, and the electrodes are carbon rod and zinc can. When the terminals are connected in a circuit, chemical reaction take place, and charges flow between the electrodes.
- Zinc can becomes negatively charged and carbon rod becomes positively charged. Manganese (iv) oxide depolarizes the cell to make its life time longer.



Primary and Secondary cell

- There are two main kinds of cells, namely primary cells and secondary cells.
- **A primary cell** is one in which current is produced as a result of an irreversible chemical change. Whenever the cell runs out, the electrolyte and the electrodes have to be replaced.
- e.g.: Simple cell, the wet leclanche cell, and dry leclanche cell.

- A secondary cell is one which can be recharged when it runs down by passing current backwards through them. A secondary cell is known as a storage cell or an accumulator.
- There are two main kinds of secondary cells, the lead acid accumulator, and the nickel-cadmium alkaline or Nife accumulator.

The lead-acid accumulator

It consists of lead oxide as the positive electrode, lead as the negative electrode and dilute sulphuric acid as the electrolyte. When the cell is working, both the plates(electrodes) gradually change to lead sulphate while the acid becomes more dilute and its density decreases. When the cell is fully charged, the relative density of the acid is about 1.25 and the emf of the cell is 2.2V, but when the cell is discharged, the relative density of the acid is about 1.15 and e.m.f is less than 2.0V. The relative density should not drop below 1.15 before the cell is recharged. The lead acid accumulators are more common than the Nife cell and are extensively used for ignition and lighting in motor cars. This is because they have very low internal resistance and hence can give a large current with very little drop in internal p.d.

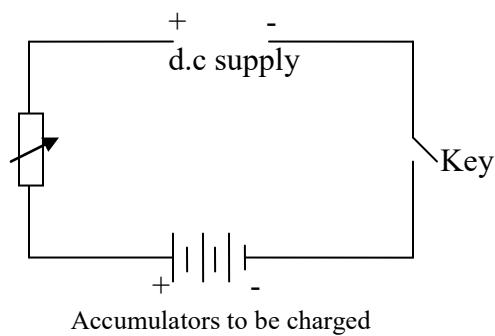
The Nickel-Cadmium Alkaline accumulator or Nife accumulator

- The electrolyte is an alkaline such as potassium hydroxide dissolved in water. The positive electrode is nickel hydroxide while the negative electrode is made of cadmium or iron.
- Many large ships, hospitals and public buildings are provided with alkaline battery installations for emergency lighting.
- The alkaline accumulators have the following advantages over lead-acid:
 - (i) They keep their charges longer
 - (ii) They last much longer

Disadvantages of alkaline accumulators

- (i) Very expensive compared to lead acid
- (ii) Its emf is only about 1.25V and tends to fall continuously on discharge.

Charging an accumulator



The positive terminal of the accumulator is connected to the positive terminal of the battery charge so that current is passed through it in the reverse direction.
In series with the accumulator should be a rheostat to regulate current. The lids of the cells should be removed. Then the battery charger which is in series with the accumulator is switched on and left until the e.m.f. of the cell rises to 2.2V

TEST 10

SECTION A

1. In a simple cell, the source of electron which constitute the electron currents is

- A. the zinc plate
- B. the copper plate
- C. dilute sulphuric acid
- D. potassium dichromate.

2. In a simple cell

- (a) polarisation is caused by impure zinc
- (b) potassium dichromate is used to prevent polarisation
- (c) the formation of hydrogen bubbles on the copper plate causes local action.
- (d) hydrogen is produced on the zinc plate and causes polarisation

3. When brass is to be copper plated, the suitable electrolyte used is

- A. distilled water
- B. sulphuric acid
- C. lead(IV) oxide
- D. copper sulphate

4. The negative plate of a simple cell gradually goes into solution because of

- (a) Polarization
- (b) local action
- (c) charging
- (d) gassing

5. Which one of the following sets of substances can be used when electroplating an iron ring with silver?

- | | Cathode | Anode | Electrolyte |
|----|---------|--------|---------------------|
| A. | Silver | ring | copper(II) sulphate |
| B. | Ring | silver | copper(II) sulphate |
| C. | Ring | silver | silver nitrate |
| D. | Silver | ring | silver nitrate |

SECTION B

1. (a) State two advantages of a nickel iron accumulator over a lead acid accumulator
(b) Name the gases evolved during the charging of lead acid accumulator
(c) Why is a dry cell called a primary cell?

2. (a) Explain why a current does not flow between the electrodes in dilute sulphuric acid until a certain value of p.d is exceeded
(b) Using the same axes, sketch a graph of current against p.d for
(i) A torch bulb
(ii) A carbon resistor

3. (a) List four different sources of e.m.f .
(b) State two advantages of a secondary cell over a primary cell

4. (a) Draw a diagram to show the structure of a simple cell
(b) Give one defect of a simple cell and state how it is minimised
(c) Explain how a lead acid accumulator can be recharged when it has run down.

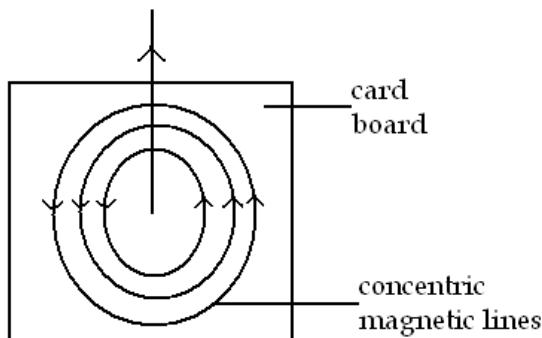
5. With the aid of a labelled diagram, explain how a dry cell works.

6. (a) Draw a labeled diagram of a lead acid accumulator.
(b) List three precautions necessary to prolong the life of an accumulator.
(c) State two disadvantages of a Nife cell over a lead acid cell.

CHAPTER ELEVEN

MAGNETIC EFFECT OF AN ELECTRIC CURRENT

When electric current flows in a wire, magnetic field is created around the wire.

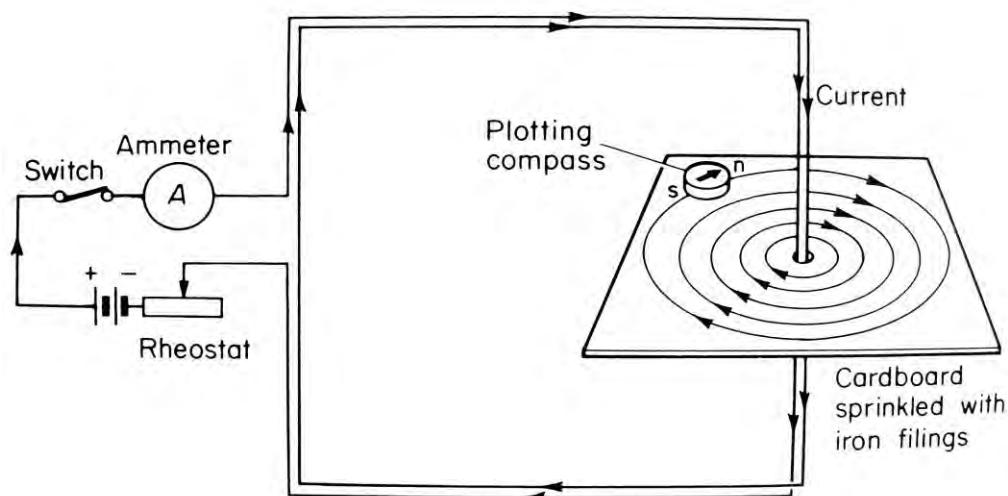


The direction of the magnetic field (flux) depends on the direction of the current in the wire.

Ampere's Swimming Rule

Imagine an observer to be swimming along the wire in the direction of the current and facing the needle, and then the north pole of the needle will be deflected towards his left hand.

Magnetic flux pattern due to a current in a long straight wire



- A large rectangular coil consisting of about twenty turns of insulated copper wire is set up vertically with one of its vertical sides passing through a hole in the centre of a piece of a cardboard supported horizontally as shown in the figure above.
- A current of about 3A may be passed though the coil from a 6V battery in series with a rheostat, an ammeter and a switch.
- A fine layer of iron fillings is then sprinkled on the cardboard; the current is switched on and the card tapped gently.
- The fillings set in series of concentric circles about the wire as center.
- A small plotting compass placed on the card indicates the direction of the flux.
- If the current is reversed by changing over the battery connections, the compass needle will swing round and point in the opposite direction, but the pattern of the flux remain unchanged.

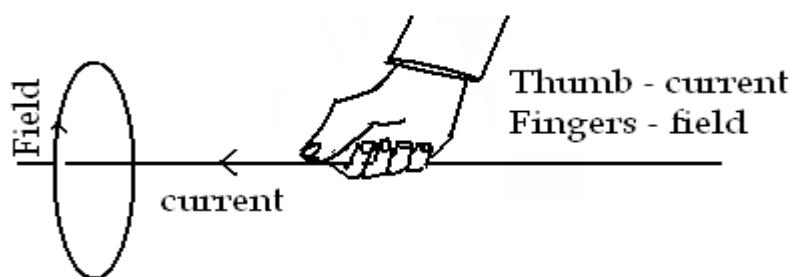
The direction of the magnetic field can be predicted by Maxwell's screw rule and the right hand grip rule.

Maxwell's screw rule

Imagine a screw being screwed along the wire in the direction of the current. The direction of rotation of the screw gives the direction of magnetic field.

Right hand grip rule

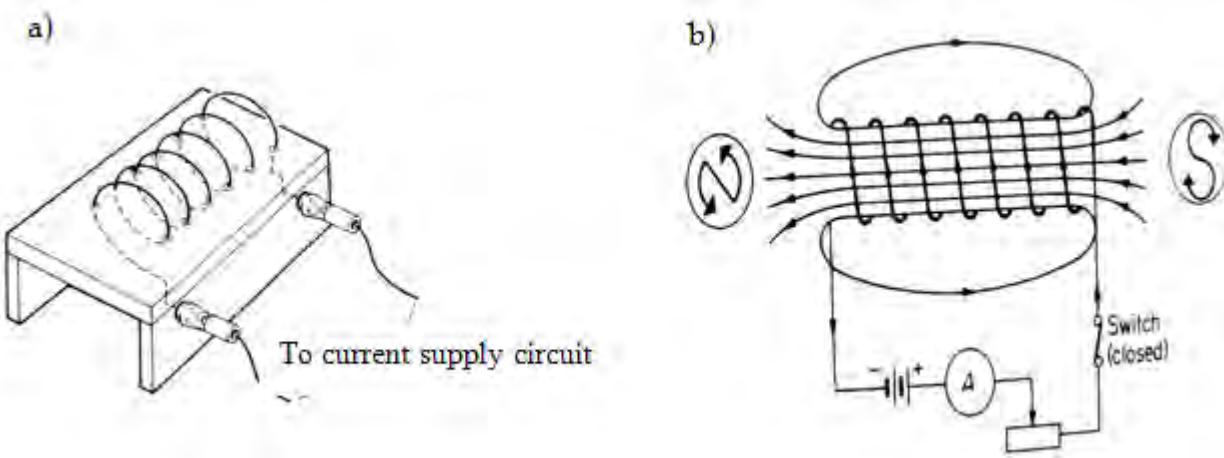
Imagine the wire to be grasped in the right hand with the thumb pointing along the wire in the direction of the current. The direction of the fingers will give the direction of the magnetic flux as shown below.



Magnetic field due to solenoid

The solenoid produces a magnetic flux when an electric current is passed through it. One end of the solenoid acts as a N pole and the other the S pole. A coil is connected in series

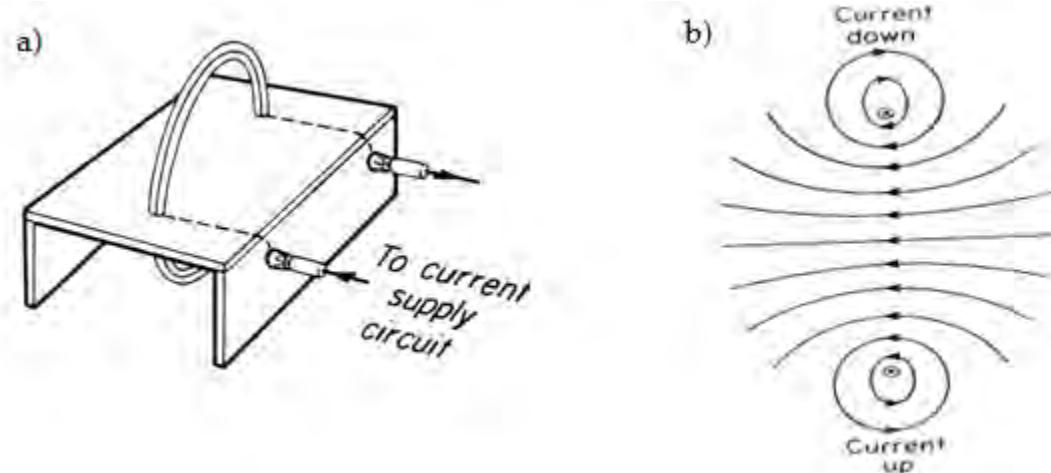
with a battery, ammeter, a rheostat and a switch. The current should be adjusted to at least 20A as it is not possible to multiply the effect.



Rule for the polarity of a coil carrying a current

- When viewing one end of the coil, it will be of N polarity if the current is flowing in an anticlockwise direction, and of S polarity if the current is flowing in the clockwise direction. b)
- Then figure above illustrates an easy way of remembering this rule, by attaching arrows to the letters N and S.

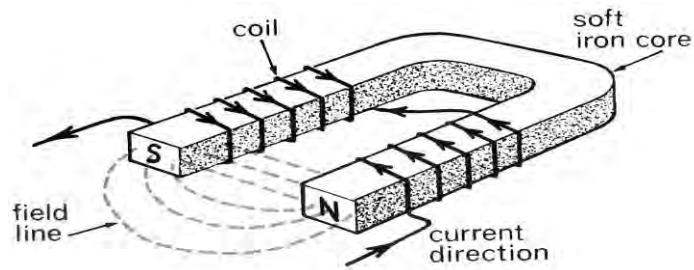
Magnetic flux due to a short circular coil



- When the current is passed through a short circuit coil, the pattern of the magnetic flux is show in the figure (b).
- The magnetic flux at the centre of the coil is straight and is perpendicular to the plane of the coil.

ELECTROMAGNETS

An electromagnet is a temporary magnet made by winding an insulated copper wire round soft iron core. Soft iron is used for making temporary magnets because it is easily magnetized and easily demagnetized.



Factors affecting the strength of electromagnet

1. Increase in the number of turns.
2. Increase the current i.e. its magnitude.
3. Placing an iron core inside a coil.
4. Increase the surface area of the electromagnets.
5. Using soft iron instead of steel.

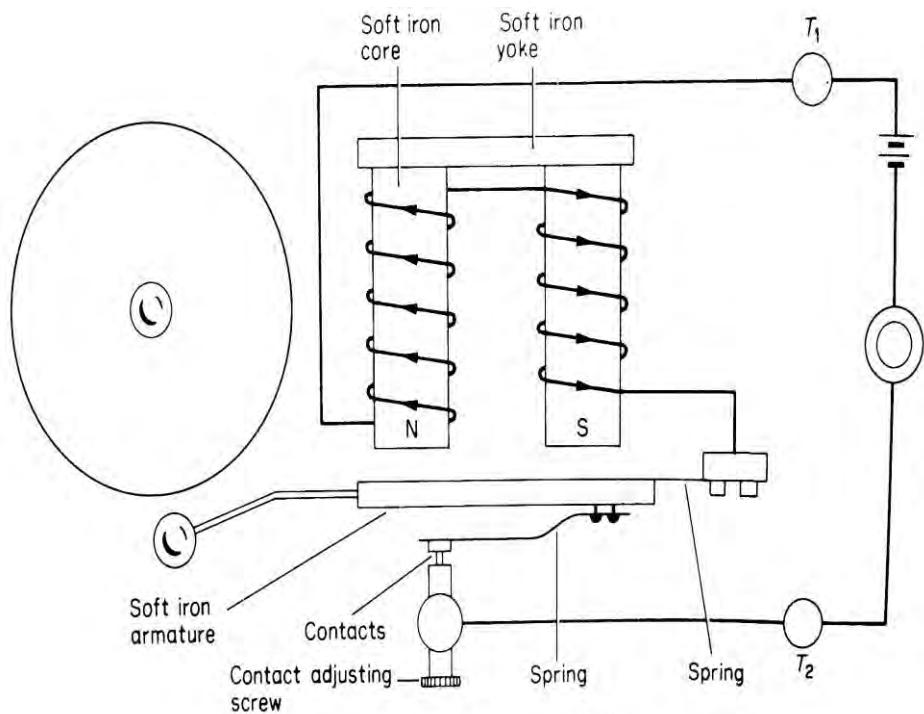
Application for electromagnetism

- Electric bell,
- Telephone system(microphone),
- Loud speakers,
- Electric motors,
- Galvanometers.

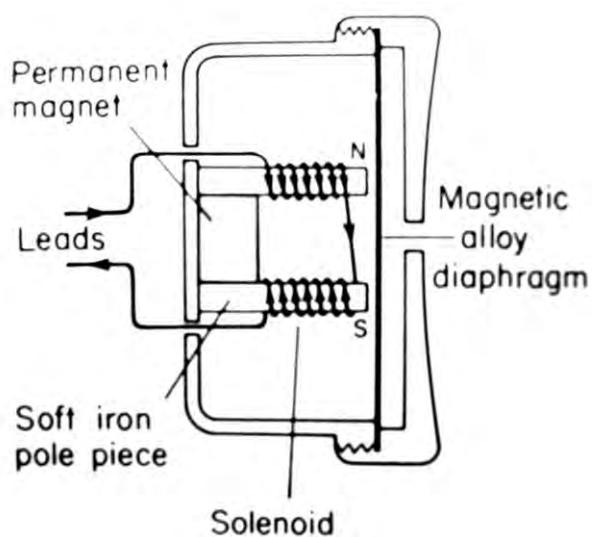
Electric Bell

- An electric bell consists of a hummer, a gong soft iron armature, contact adjusting screw, a bell push which is the switch, steel spring and an electromagnet which is made of two coils wound in opposite direction on two iron cores.
- When the current flows in the circuit, it causes iron core to be electromagnetized.

- It attracts the soft iron armature and the circuit breaks at the contact point causing the electromagnet to lose its magnetism.
- The spring of steel which holds the armature back so that the points are in contact again, thus the process is repeated with the continued striking of the gong by the hummer.



Telephone receiver (ear piece)

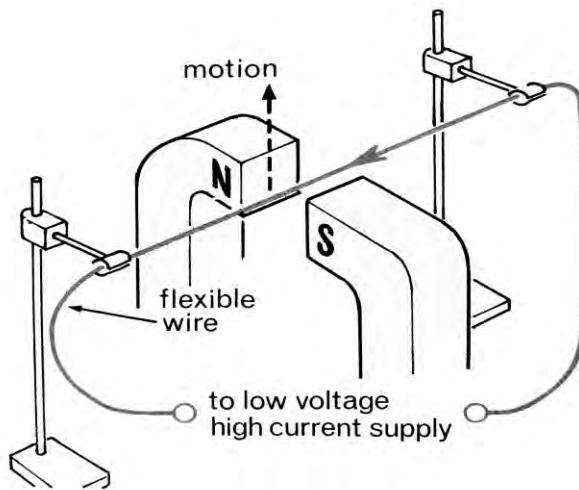


- A microphone changes sound energy into electrical energy which travels along the telephone cables and is changed back into sound by the receiver.
- The varying current from the microphone passes through the coils of an electromagnet. This pulls the diaphragm towards it, by a distance which depends on the current.
- When a person speaks into the microphone at the other end of the line a varying electric current is set up having the same frequency as the sound waves. A similar electric current is caused to pass through the solenoids in the earpiece.
- As a result, the diaphragm moves in and out and produces sound waves that are a copy of those that entered the microphone.

ELECTRIC MOTORS

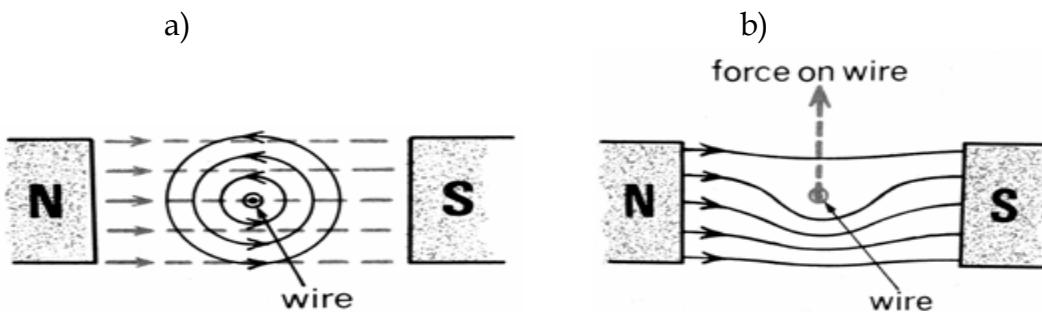
The motor effect

A wire carrying a current in a magnetic field experiences a force. If the wire can move it does.

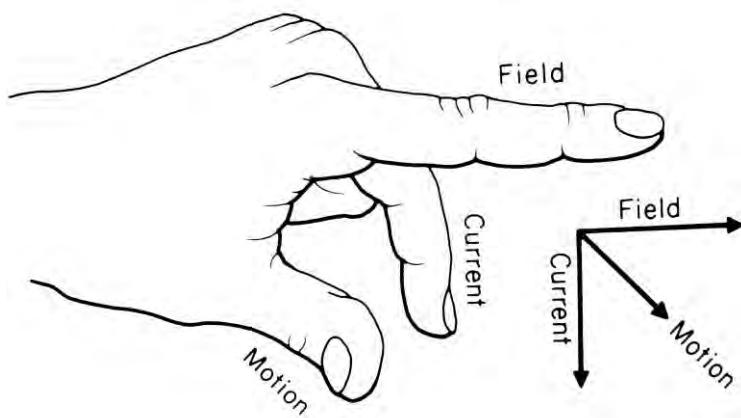


- **Demonstration:** In the figure above, the flexible wire is loosely supported in the strong magnetic field of a C-shaped magnet. When the switch is pressed, current flows in the wire which jumps up as shown. If either the direction of the current or the direction of the field is reversed, the wire moves downwards.

- **Explanation:** In the figure a. below, is a side view of a magnetic field lines due to the wire and the magnet. Those due to the wire are circles and we will suppose their directions are as shown. The dotted lines represent the field lines of the magnet and their direction of to the right.
- The resultant field obtained by combining both fields is shown in the figure (b) below. There are more lines shown below the wire since both fields act in the same direction below but in opposite above.



Fleming's left-hand rule (motor rule)



- Hold the thumb and first two fingers of the left hand at right angle to each other with the First finger pointing in the direction of the field. And the seCond one in the direction of the current, then the thumb points the direction of the Thrust (motion or force).

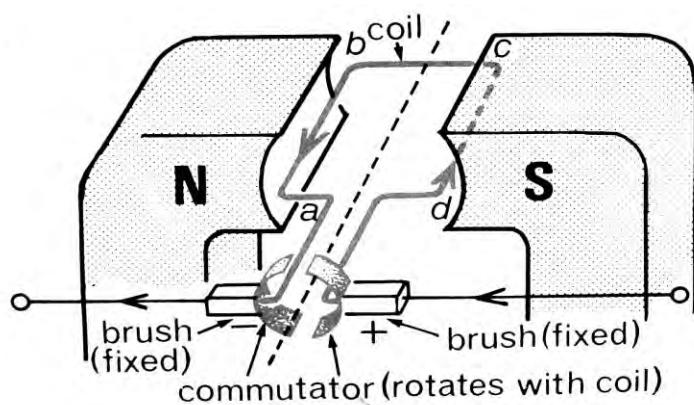
- If the wire is not at right angles to the fields, the force is smaller and is zero if it is parallel to the fields.

Force exerted on the wire carrying a current in a magnetic field depends on:

1. The strength of the magnetic field.
2. The amount of the current in the conductor.
3. The length of the wire in the magnetic field.

Simple d.c electric motor

- A simple motor to work from direct current (d.c) consists of a rectangular coil of wire mounted on an axel which can rotate between the poles of a C-shaped magnet, as shown in figure below.
- Each end of the coil is connected to half of the split ring of copper, called *commutator*, which rotates with the coil.
- Two carbon blocks, the *brushes*, are pressed lightly against the commutator by springs. The brushes are connected to an electrical supply.
- If Fleming's left hand rule is applied to the coil in the position shown, we find that side *ab* experiences the upward force and the side *cd* a downward force. (No forces act on *ad* and *bc* since they are parallel to the field.) These two forces form a *couple* which rotates the coil in a clockwise direction until it is vertical.
- The brushes are then in line with the gaps in the commutator and the current stops.
- However, because of its inertia, the coil overshoots the vertical and the commutator halves change contact from one brush to the other.
- This reverses the current through the coil and so also the directions of the forces on its sides. Side *ab* is on the right now, acted on by the downward force, whilst *cd* is on the left with an upward force. The coil thus carries on rotating clockwise.



- **Back emf** is the emf set up in opposition to the emf applied to a motor as a result of rotation of a coil in a magnetic field.
- The direction of rotation depends on the following:
 1. Direction of current.
 2. Magnetic field.
- **Note:** The speed of rotation increases if;
 1. The amount of current increases.
 2. The magnetic field is strong.
 3. Bigger number of turns.
 4. Large area of the coil.

Moving coil Galvanometer

- A galvanometer detects small currents or small p.d.s, often of the order of milliamperes (mA) or millivolts (mV). Some are even more sensitive.
- Current enters and leaves the coil by hair springs above and below it. When current flows, a couple acts on the coil (as in an electric motor), causing it to rotate until stopped by the springs.
- The greater the current the greater the deflection which is shown by a pointer attached to the coil.

The sensitivity of a galvanometer is increased by having:

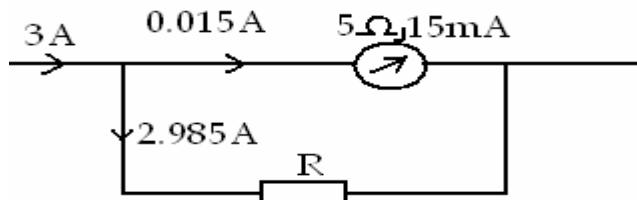
- More turns on the coil
- A stronger magnet
- Weak hair springs or a wire suspension

Conversion of a Galvanometer to ammeter or voltmeter

A galvanometer is a sensitive instrument and usually measures current in milliamperes. The instrument can be converted to an ammeter or voltmeter. To measure big current by connecting a very small resistance (ammeter) in parallel with the instrument. This is called shunting resistance and is very small compared to a galvanometer resistance.

Example-1: A galvanometer has a resistance of 5Ω and gives a full scale deflection (f.s.d) when a current of 15 mA flows through it. Find the shunting resistance to convert it into ammeter which reads 3 A as maximum current.

Solution: For full scale deflection, the current through the galvanometer,
 $= 15 \text{ mA} = 0.015 \text{ A}$



The current that passes through the shunt,

$$3 - 0.015 = 2.985 \text{ A}$$

By ohm's law, $V = IR$

the p.d. across the galvanometer = p.d. across R

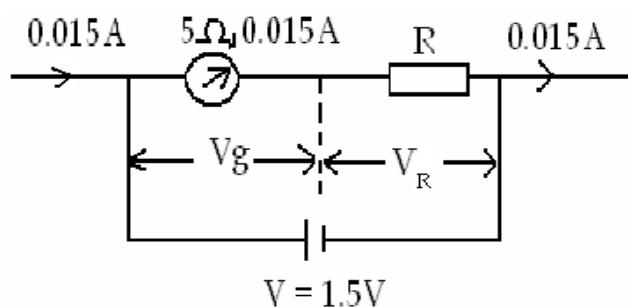
$$0.015 \times 5 = 2.985 \times R$$

$$R = 0.025 \Omega$$

Voltmeter

A voltmeter is constructed such that it has a very high internal resistance so that no current should pass through it. In order to convert a galvanometer into a voltmeter a high resistance called a multiplier is connected in series with it.

Example-2: A galvanometer has a resistance of 5Ω and gives a full scale deflection when a current of 15 mA flow through it. Suppose a maximum p.d of 1.5 V is to be measured using a galvanometer, find the value of the multiplier R required.



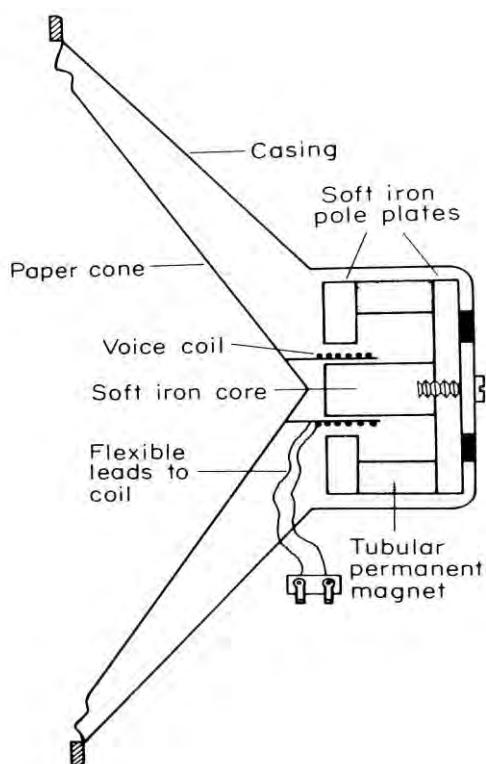
Solution :

For full scale deflection, the current through the galvanometer and $R = 0.015 \text{ A}$.

The p.d. across the galvanometer + p.d. across R = Voltage V being measured

$$\begin{aligned}\text{The p.d.} &= V_g + V_R \\ 1.5 &= 0.015 \times 5 + 0.015 \times R \\ R &= 95 \Omega\end{aligned}$$

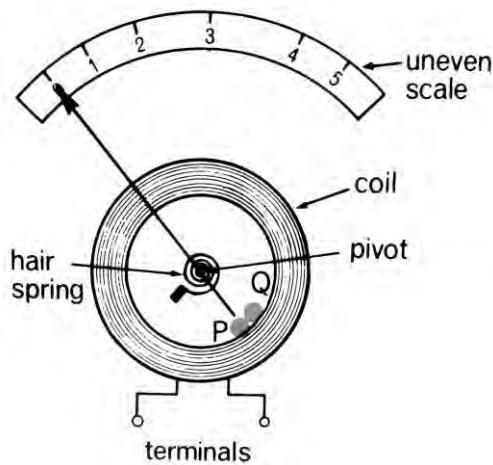
Moving coil loud speaker



- Electric pulses corresponding to sound enter through the leads, and end up in the voice coil.
- A force acts on the voice coil which then vibrates in accordance with Flemings left hand rule.
- The paper cone to which the voice coil is connected also ends up vibrating, and this sets the surrounding air in vibration, producing the required sound.

Moving iron meter (galvanometer)

- When current flows in the coil the two small soft iron rods P and Q are magnetized in the same direction.
- They repel. Q is fixed but P is attached to the pivoted pointer and moves away from Q until stopped by the hair spring.
- The larger the current the greater the repulsion.

**Advantages of moving iron galvanometer:**

1. It can measure both d.c and a.c.
2. It is simple and cheap to make.
3. It is light.

Disadvantages of a moving coil galvanometer:

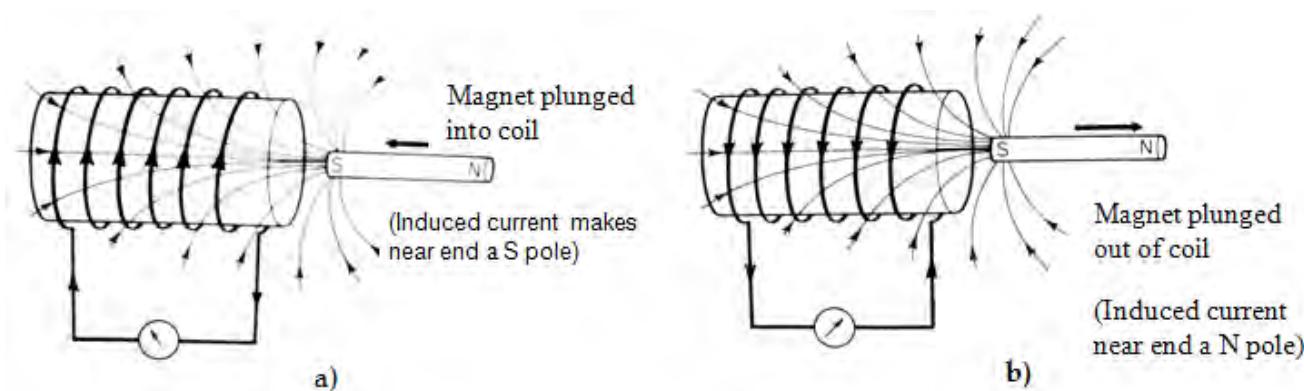
1. It is less accurate than a moving coil galvanometer.
2. Its current is non uniform.

ELECTROMAGNETIC INDUCTION

This is the effect of producing electric current from magnetism. This principle of electromagnetic induction is demonstrated in the dynamo or electric generators.

Faraday's experiment on electromagnetic induction

- Ends of cylindrical coil are connected to the galvanometer and then a magnet is plunged into the coil.
- It is noticed that the galvanometer needle gives momentary deflection showing that a current has been induced in the coil.
- On removal of the magnet from the coil, the galvanometer gives another deflection but in an opposite direction as shown in the figure below. This effect is called electromagnetic induction.
- No current (deflection) is induced simply by allowing the magnet to remain at rest inside or outside the coil.
- Current is induced in the circuit as a result of the wire being cut by magnetic flux (magnetic field lines) when the magnet is removed.
- Alternatively, we say that the electromotive force is induced whenever there is change in the magnetic flux linked with the coil.



Induced current depends on:

1. The number of turns in the coil
2. The strength of the magnet
3. The speed with which the magnet is plunged into the coil.

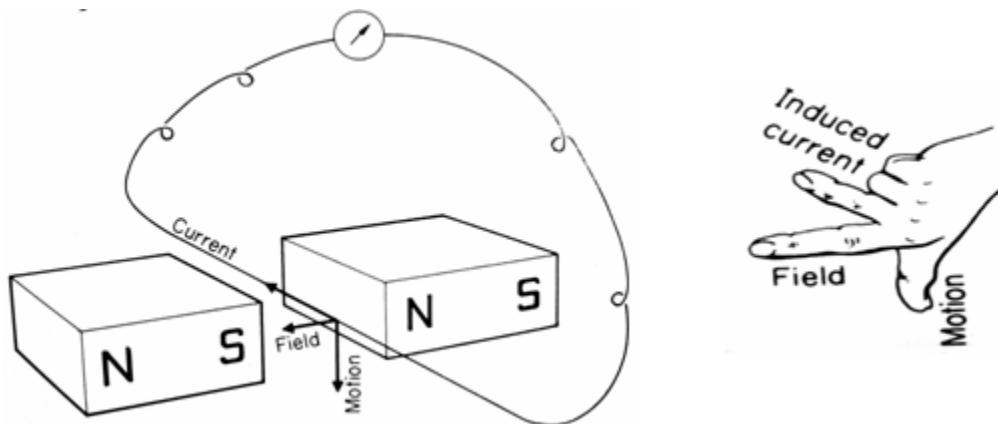
Faraday's law of electromagnetic induction

- Whenever there is a change in the magnetic flux linked with a circuit, an electromotive force is induced, the strength of which is proportional to the rate of change of the flux linked with the circuit.

Lenz's law of electromagnetic induction

- The direction of the induced current is such as to oppose the change producing.
- Figure above illustrates that application of this law in the case of a magnet plunged into a coil.
- When the S pole of the magnet is plunged into the coil the induced current must flow in such a direction as to give S polarity to the end of the coil facing the magnet.
- Thus, since like poles repel, the motion of the magnet is opposed by the induced current.
- On the other hand when the S pole of the magnet is pulled away from the coil the direction of the induced current is reversed. The near end of the coil becomes a N pole and, since unlike poles attract, the motion of the magnet is again opposed.

Direction of the induced current in a straight wire



- A current is induced in a straight wire when it is moved at right angles to the magnetic flux near a bar magnet.
- If the wire is moved downwards, the galvanometer indicates that an induced current flows in the direction as shown in the figure above.
- When the wire is moved upwards, the induced current is reversed. This is shown by the direction of the galvanometer needle in the opposite direction.

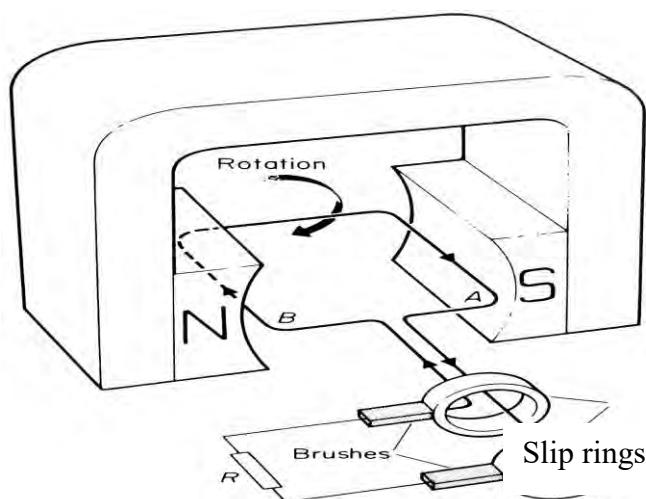
Fleming's right hand rule (dynamo rule)

- Hold the thumb and the first two fingers of the right hand at right angles to each other with the First finger pointing in the direction of the Field and the thumb in the direction of the Motion of the wire, then the second finger points in the direction of the induced Current.

Aid to memory:

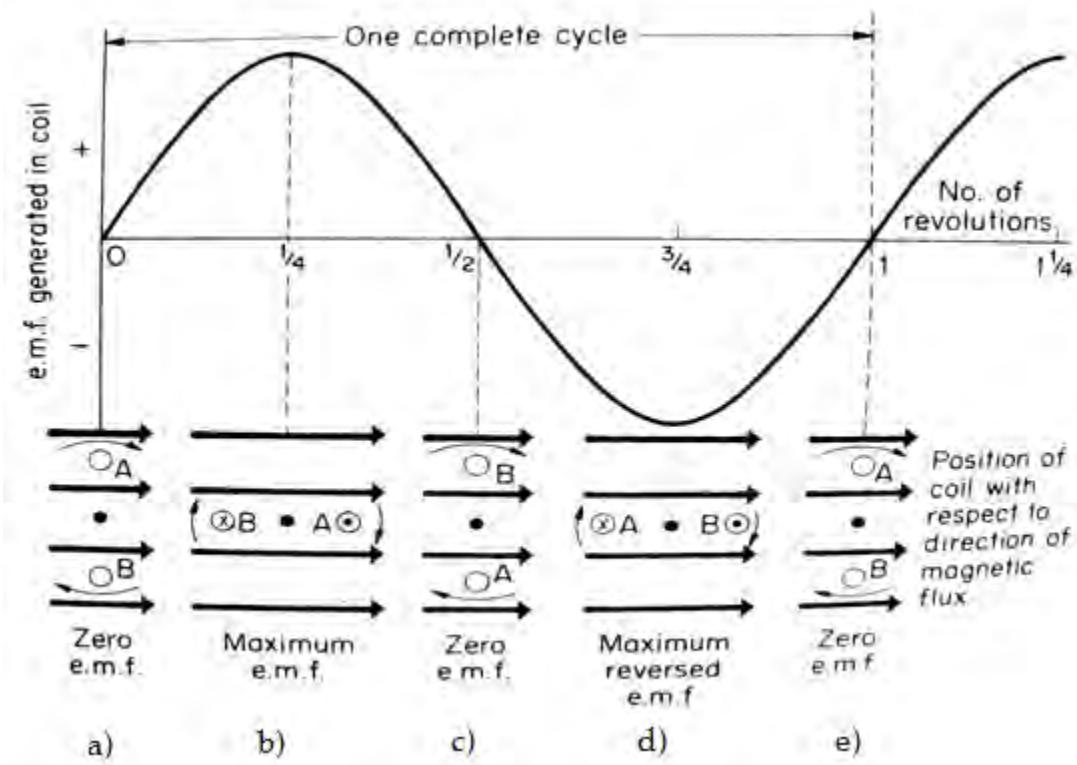
1. thumb → Motion
2. First finger → Field
3. second finger → Current

The simple alternating current (a.c) generator



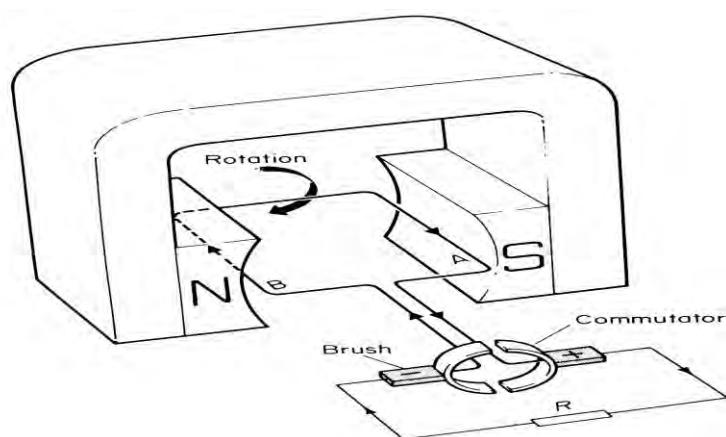
- An a.c generator has a rectangular coil of wire which is rotated in the magnetic field between the poles of the U-shaped permanent magnet. This magnet is called **field magnet**.
- The ends of the coil are connected to two slip rings mounted on the coil spindle. Current can be obtained from the coil through two carbon brushes which are made to press tightly against the slip rings.
- As the coil rotates its sides cut the magnetic flux, and therefore a current is induced in it.
- Application of Fleming's right hand rule indicates that the current flows from back to front along side A and from front to back along side B.
- When viewed from above the current therefore flows in a clockwise direction around the coil.

- The figure below shows how the e.m.f generated in the coil varies over a complete rotation:



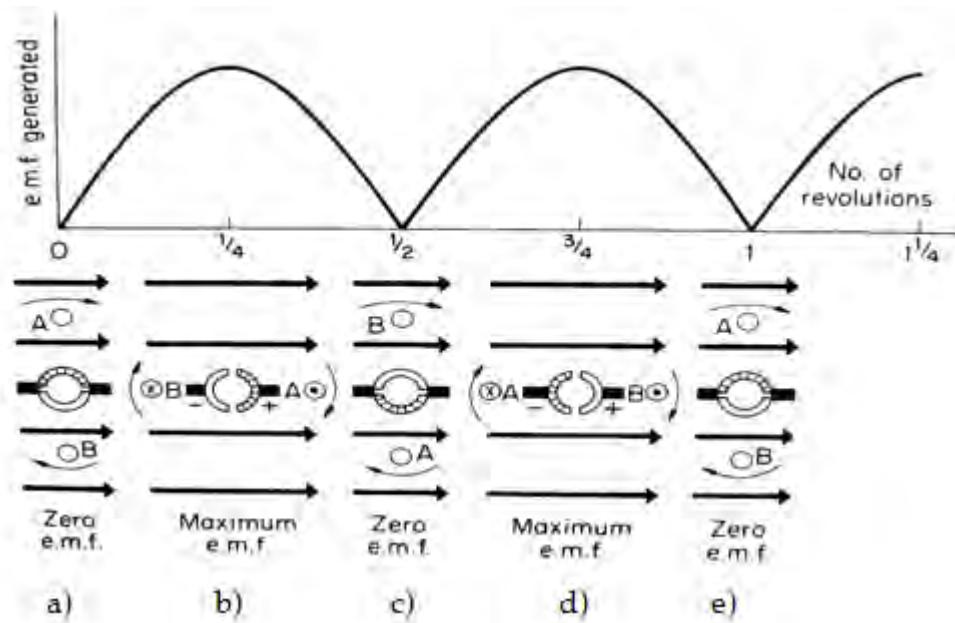
- (a) zero emf coil vertical, side A: down, side B: up.
- (b) maximum emf coil horizontal, side A: left, side B: right.
- (c) zero emf coil vertical, side A: up, side B: down.
- (d) maximum emf reversed coil horizontal, side A: right, side B: left.
- (e) zero emf coil again vertical, side A: down, side B: up.

The simple direct current (d.c) generator



- A direct current is obtained when the slip rings are replaced with a split ring commutator.
- The working of a d.c generator is similar to that of an a.c generator.
- The difference between the two is that the coil rotates about an axis, the two halves of the commutators change contact from one brush to the other and the direction of current is reversed in the coil itself when the coil reaches a vertical point.
- The change over between brushes and commutator halves ensures that the right hand brush remains positive and the left hand brush remains negative.
- Thus after change over, the e.m.f of the brushes remain identical with that before change over and the current through external resistor R continues flowing in the same direction.

- *The emf generated by the d.c generator is shown below:*



- the emf = zero, coil in vertical position. Side A; down, side B: up. a
- maximum emf, coil in horizontal position. Current flows through out side A
- zero emf, coil in vertical position. Side A up, side B down.
- maximum emf, coil in horizontal position, current flows throughout side B
- zero emf, coil in vertical position, side B up, side A down.

D.C. dynamo compared with an electric motor

- If a simple d.c. dynamo connected to a battery it will run as a motor. Conversely, if a simple electric motor is made to rotate it will behave as a dynamo and deliver current at the brushes.
- When, therefore, an electric motor is running it acts as a dynamo and so produces an e.m.f. in opposition to that applied to it. This is called a *back e.m.f.*

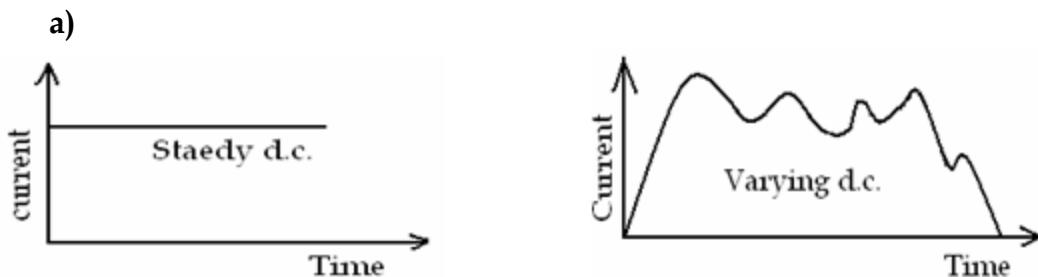
How to increase the e.m.f. obtained from a simple dynamo

- Anything which increases the rate of cutting of magnetic flux in a dynamo will increase the e.m.f. obtained from it. Some ways are made:
 1. by increasing the number of turns in the coil.
 2. by winding the coil on the soft-iron armature so as to increase the magnetic flux through the coil.
 3. by increasing the speed of rotation.
 4. by making the field magnet as strong as possible.

ALTERNATING CURRENT

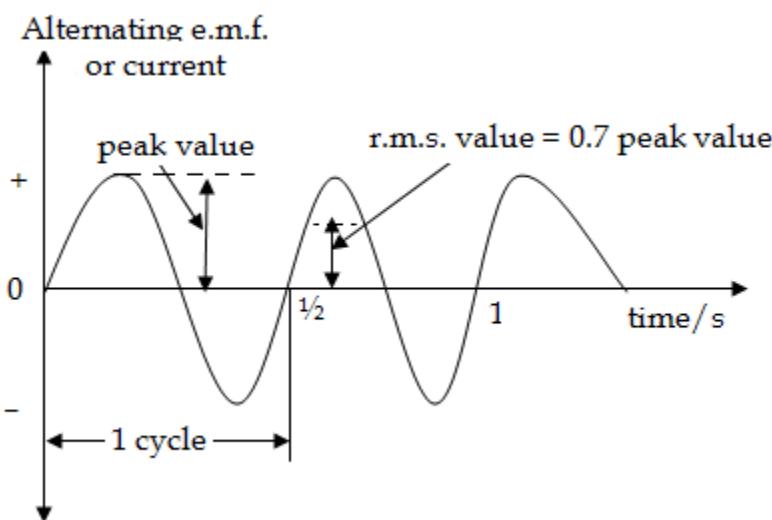
Difference between d.c and a.c

- In a direct current (d.c) the electrons flow in one direction only. Graphs for steady and varying direct currents are shown in figure (a) below.



- In an a.c the direction of flow reverses regularly, fig. (b) below. The sign for a.c is ~

b)

**Peak value:**

Peak value E_0 of an e.m.f. is the maximum e.m.f. of the a.c.

Peak voltage is the maximum voltage produced by the a.c. generator.

Frequency of an a.c. is the number of cycles per second. The unit is hertz. (Hz)

- Batteries give d.c.; generators can produce either d.c or a.c. The main supply is a.c.
- For heating and lighting a.c and d.c. are equally satisfactory but radio and television sets need d.c, as do processes such battery charging and electroplating.
- a.c. can be rectified to give d.c.

Root mean square (r.m.s.)

Its is defined as that direct current or steady current which produces the same heating effect per second in a given resistance.

$$\triangleright \text{ r.m.s value} = 0.7 \times \text{peak value}$$

Example: The r.m.s voltage of the mains supply is 240V;

The peak value is therefore

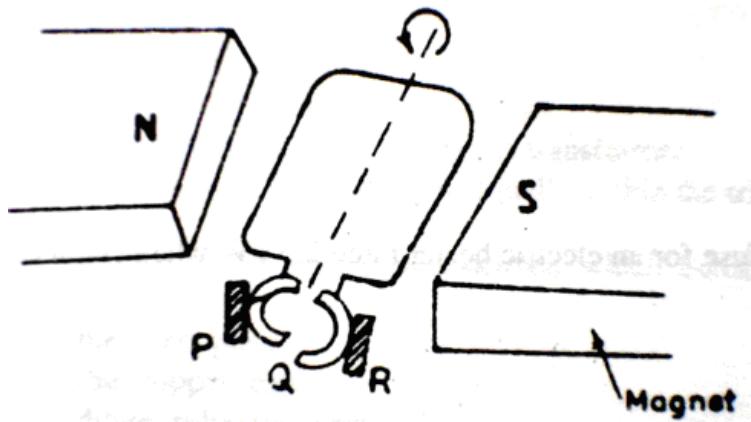
$$= \frac{240}{0.7} = 340V$$

TEST 11.1**SECTION A**

1. moving coil galvanometer can be used to
 - A. measure direct current.
 - B. converting alternating current into direct current
 - C. convert direct current to alternating current.
 - D. to measure the peak value of an alternating current.

2. The sensitivity of a moving coil galvanometer can be increased by using
 - (a) smaller coil
 - (b) weaker magnet
 - (c) weaker hairspring
 - (d) fewer turns of wire on the coil.

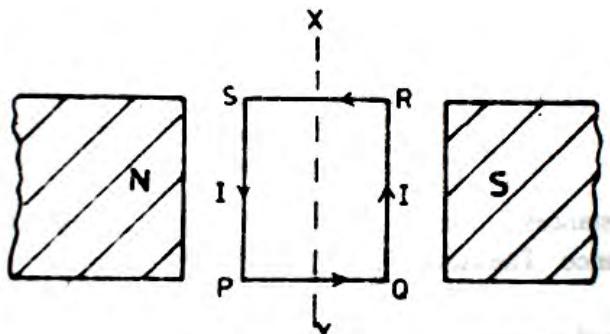
3. The diagram in the figure below shows a simple electric motor.



The coil continues to turn in the same direction because the commutator Q and brushes P and R

- A. reverse current in the coil every half a revolution
- B. reverse current in the coil every quarter of the revolution
- C. reverse polarity of the field produced by the magnet
- D. carry the coil past its vertical position every half a revolution

4.



The diagram in the figure above shows a current carrying coil PQRS pivoted at about XY between two magnets. Which of the statements are true about the coil?

- (i) the sides PQ and QR shall experience force
 - (ii) as seen from X, the coil will rotate anticlockwise
 - (iii) the force on the coil can be increased by increasing the number of turns
 - (iv) the coil will come to rest with PQ at right angles to magnetic field.
- | | |
|------------------------|-----------------------|
| a) (i), (ii) and (iii) | b) (i) and (iii) only |
| c) (ii) and (iv) only | d) (iv) only |

5. A moving iron meter

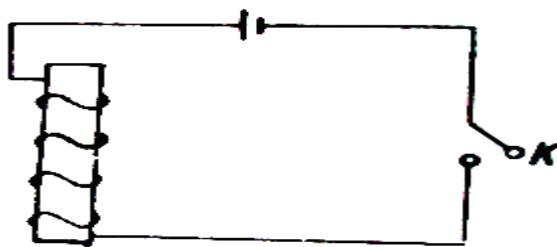
- (a) measures only direct current
- (b) has a permanent magnet
- (c) measures only alternating current
- (d) has the pointer attached to the soft iron.

6. The magnitude of the force on the coil of a d.c motor depends on

1. the strength of the magnetic field
 2. the number of turns on the coil
 3. the current through the coil
 4. the mass of the coil support
- | | |
|----------------|---------------|
| A. 1 only | B. 1 & 2 only |
| C. 1,2 &3 only | D. All |

SECTION B

1. A galvanometer has resistance of 5Ω and a range of 0-40mA. Find the resistance of the resistor which must be connected in parallel with the galvanometer if a maximum current of 10 A is to be measured.
2. Sketch the magnetic field pattern around a straight conductor carrying a current in the plane of paper
3. (a) State three factors on which the magnitude of the force exerted on a wire carrying a current in a magnetic field depends.
(b) With the aid of a labelled diagram, describe the action of a moving coil loud speaker.
4. (a) State two factors which affect the strength of an electromagnet.
(b)



The diagram above shows a small magnet placed near an electromagnet. Describe what happens to it when the key K is closed.

5. A moving coil galvanometer has a coil of resistance 4Ω and gives a full scale deflection when a current of 25mA passes through it. Calculate the value of the resistance required to convert to an ammeter which reads 15A at full scale deflection
6. A milliammeter has an internal resistance of 4Ω and a full scale deflection of 0.015 A. calculate the value of the resistor that must be connected to the milliammeter so that a maximum current of 5A can be measured.

TEST 11.2

SECTION A

1. The induced current in a generator
 - (a) is a maximum when the coil is vertical
 - (b) is a minimum when the coil is horizontal
 - (c) changes direction when the coil is horizontal
 - (d) increases when the speed of rotation increases
2. The arrangement in figure 1 is used to produce an e.m.f. What causes the e.m.f.?

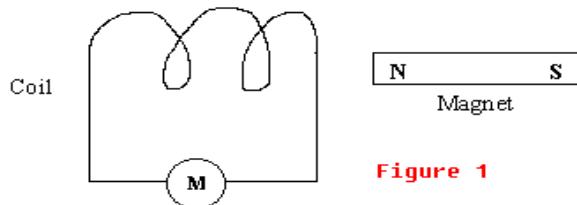
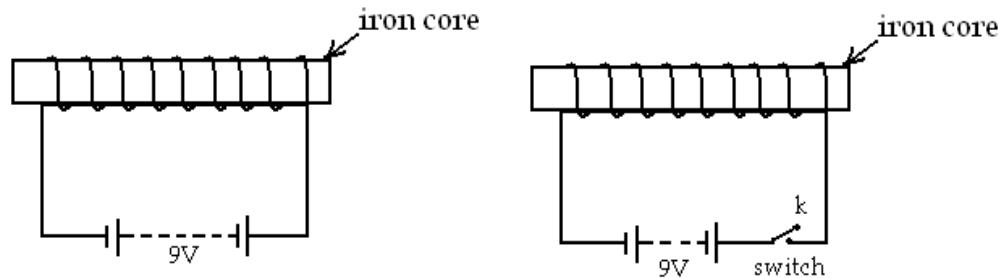


Figure 1

- A. The attraction between the coil and magnet.
 - B. The magnetic field outside the coil.
 - C. The magnet placed close to the coil.
 - D. The variation of magnetic lines linking the coil.
3. Which of the following only works with a direct current?

A. Electric lamp.	B. Transformer.
C. Electroplating.	D. Electric bell.
 4. In figure below, when switch K is closed, the two soft iron cores will



- A. repel each other all the time.
B. attract each other all the time.
C. attract each other for just a brief moment.
D. have no force attraction or repulsion between them

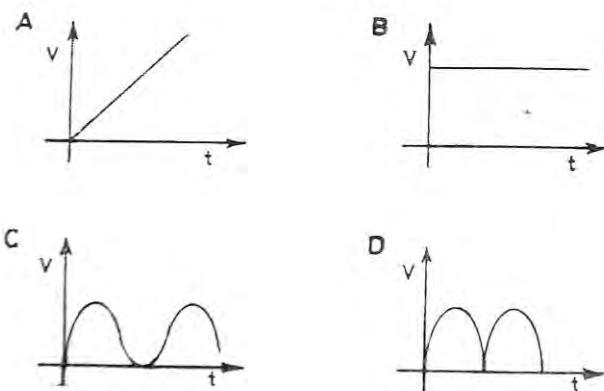
5. A rectifier is used to

A. step up an a.c voltage.
B. amplify an a.c current.
C. change an a.c voltage to a.d.c voltage.
D. change a.d.c. voltage to an a.c. voltage.

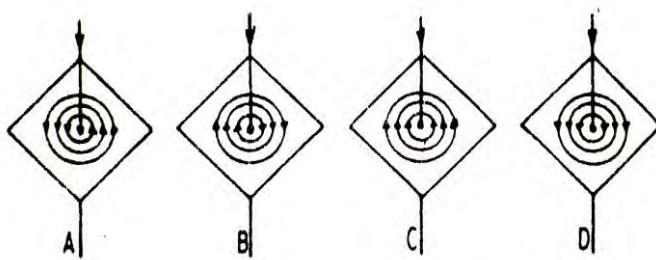
6. Which of the following will increase the force on a current carrying wire?
(i) Using a large current.
(ii) Using a stronger magnetic field.
(iii) Using a shorter length of wire in the field.

A. (i) only. B. (i) and (ii) only.
C. (i) and (iii) only. D. (ii) and (iii) only.

7. Which of the following graphs represents the output voltage from a d.c. dynamo?



8. An alternating current can be changed to a direct current by a
- | | |
|----------------|-----------------------------|
| A. transformer | B. moving coil galvanometer |
| C. dynamo | D. diode |
- 9.
-
- A bar magnet is moved near a coil as shown in the above figure. Which of the following ways can be used to increase the size of the induced e.m.f in the coil?
- (i) using a stronger magnet
 - (ii) moving the magnet at a higher speed
 - (iii) reducing the number of turns in the coil
- | | |
|-------------------|-----------------------|
| A. (i) and (ii) | B. (i) and (iii) only |
| C. (ii) and (iii) | D. (i),(ii) and(iii) |
10. The strength of the magnetic field between the poles of an electro-magnet remains the same if the
- (i) current in the electro-magnetic windings is doubled
 - (ii) direction of the current in the electro-magnet winding are reserved.
 - (iii) The number of turns are halved.
- | | |
|-----------------------|--------------------------|
| (a) (i) only | (b) (ii) only |
| (c) (i) and (ii) only | (d) (ii) and (iii) only. |
11. Which of the following factors affect the strength of an electro magnet?
- (i) change magnitude of the current
 - (ii) change direction of the current
 - (iii) double number of turns
- | | |
|------------------------|-------------------------|
| (a) (ii) only | (b) (i) and (ii) only |
| (c) (i) and (iii) only | (d) (ii) and (iii) only |
12. Which one of the following diagrams represents the correct magnetic field around a straight wire carrying a current?



SECTION B

1. (a) State one advantage of a.c over d.c in a mains supply.
 (b) In the figure 11 shows the variation of an a.c with time.

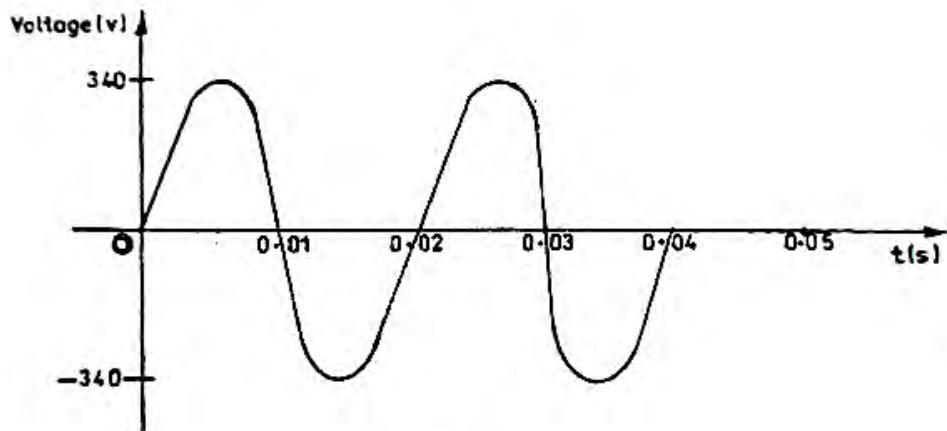
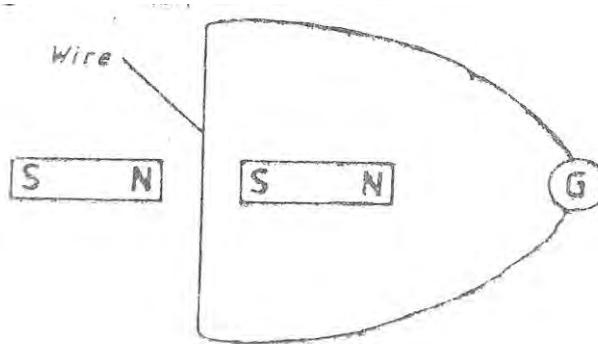


Fig. 11

Find (i) the peak value.
 (ii) the frequency.

2. (a) State any two factors which determines the magnitude the e.m.f. induced in a coil rotating in a magnetic field.
 (b) Explain why soft iron is preferred to steel in making electromagnets.
3. When the wire is moved vertically upwards out of the plane of the paper, the galvanometer deflects
 (i) In which direction does the galvanometer deflect
 (ii) Why does the galvanometer deflect

- (iii) State one way by which the deflection of the galvanometer can be reversed?
4. With the aid of a labeled diagram, explain how a simple a.c generator works
5. Draw the magnetic field pattern due to an electric current in;
- a circular coil.
 - a solenoid.
6. The diagram in the figure below shows a straight wire connected to the terminals of a centre zero galvanometer



When the wire is moved vertically upwards out of the plane of the paper, the galvanometer deflects

- In which direction does the galvanometer deflect
 - Why does the galvanometer deflect
 - State one way by which the deflection of the galvanometer can be reversed?
7. Sketch the magnetic field pattern around a straight conductor carrying a current in the plane of paper
8. State three factors on which the magnitude of the force exerted on a wire carrying a current in a magnetic field depends
9. (a) Describe using a labeled diagram how a telephone receiver works.
 (b) State two ways by which the strength of an electro magnet can be increased.
10. With the aid of a labeled diagram, describe briefly the action of an electric bell.

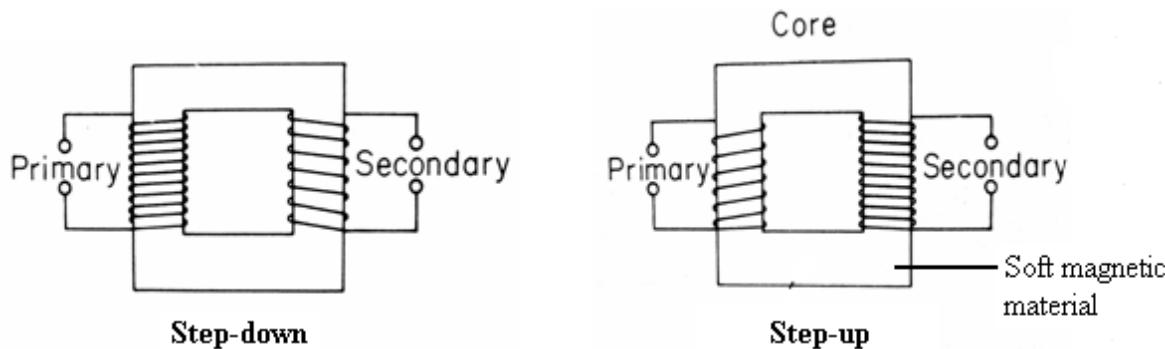
TRANSFORMER

Mutual induction

When the current in a coil is switched on or off or changed an e.m.f. and current are induced in a neighboring coil. The effect is called *mutual induction*.

Transformer

- A transformer is a device which steps up or down the voltage of an alternating current.
- It consists of two coils called the primary and the secondary coils, wound around the soft iron core that is made of soft iron pieces insulated from each other to reduce heat loses.
- Such a soft iron core is said to be laminated, see simple construction of transformer.



Action of a transformer

- When a.c is fed into the primary circuit, it steps up alternating flux in the soft iron core.
- This flux links up the secondary coil and it induces an emf in the secondary coil.
- The emf induced is proportional to:
 1. the number of turns on the secondary coil.
 2. the rate at which flux in the core changes.
- *If the coils are closely wound so that all the flux from the primary links the secondary, then,*

$$\frac{\text{secondary output voltage}(Vs)}{\text{primary input voltage}(Vp)} = \frac{\text{number of turns on secondary}(Ns)}{\text{number of turns on primary}(Np)}$$

In symbols; $\frac{V_s}{V_p} = \frac{N_s}{N_p}$

- It follows that if the transformer is 100% efficient, we can write:

$$\frac{I_s}{I_p} = \frac{N_s}{N_p}$$

I_s: Current in the output or secondary circuit.

I_p: Current in the input or primary circuit.

- Under this condition power transferred in the transformer is a constant, that is;

Input power = output power or

$$I_p V_p = I_s V_s$$

- When a transformer has more turns in the secondary coil than in the primary, then output voltage is higher than input voltage. A transformer of this type is called a ***STEP-UP transformer*** as shown in the figure-a above.
- When the number of turns in the secondary coil are less than those in the primary, the output voltage is less than input voltage. The transformer is called a ***STEP-DOWN transformer*** as shown in figure-b above.
- Step-up transformers are used in power stations to increase the e.m.f. before it is fed into power transmission lines.
- Step-down transformers are used in reducing the higher voltage to a lower voltage that is usable in homes.

In practical transformers, energy loses usually occur in the following ways:

1. Resistance of windings (coils).

Low resistance copper wires are used to reduce loses in windings.

2. Eddy currents induced in soft iron core.

The iron core is laminated to reduce loses due to eddy currents.

3. Leakage of field lines.

The core should be designed efficiently by avoiding air gaps to minimize leakage of field lines.

Advantages of a.c over d.c transmission

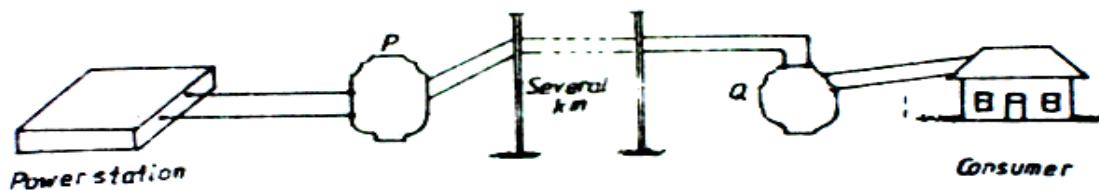
1. a.c. can be easily and cheaply changed from one voltage to another by a transformer with very little loss of energy.
2. Since the a.c. is transmitted at very high voltage, it follows that the cables carry small current. These thinner cables can be used with high voltage transmission.
3. a.c. is more suitable for heating than d.c.

TEST FIFTEEN

SECTION A

1. A 240 V mains transformer has 1000 turns in the primary. The number in the secondary if it is used to supply a 12V, 24W lamp is
 - (a) 2.0×10^4
 - (b) 500.
 - (c) 50
 - (d) 20

2. A transformer is used to step down an alternating voltage from 240V to 12V. Calculate the number of turns on the secondary coil if the primary coil has 1200 turns.
- A. 3 B. 5 C. 60 D. 100
3. The transformer cores are laminated to
- A. Reduce eddy currents
 B. decreases the resistance of the coils.
 C. determine the energy lost by the transformer
 D. Distribute the voltage out put equally with in the transformer.
4. A transformer cannot function normally with d.c. because a d.c
- (a) has extremely high heating effect
 (b) reduces the efficiency of the transformer
 (c) cannot produce a changing magnetic field
 (d) cannot provide high voltage required for power transmission.
5. A transformer has twice as many turns in the secondary coil as in the primary coil. The a.c input to the primary is 4V. Find the output
- (a) 2V (b) 4V (c) 8V (d) 16V
6. The figure below shows a transmission line from a power station to a consumer several kilometres away.



Which one of the following is the correct type of transformers at P and Q

- | | |
|--------------|-----------|
| P | Q |
| A. step-up | step-up |
| B. step-down | step-down |
| C. step-up | step-down |

D. step-down step-up

7. Rectification of alternating current means

- (a) stepping up alternating current by a transformer
- (b) converting alternating current into direct current
- (c) stepping down alternating current by a transformer
- (d) generating alternating current from a dynamo

8. What device could be connected to the secondary of a transformer in order to get a d.c in the output?

- | | |
|--------------|----------------|
| (a) Diode | (b) resistor |
| (c) Rheostat | (d) Thermostat |

9. Which one of the following is the most economical means of transmitting electricity over long distances?

- (a) At a high voltage and a low current
- (b) At a high voltage and a high current
- (c) At a low voltage and a low current
- (d) At a low voltage and a high current

10. When transmitting energy, electrical power over long distances, the voltage is stepped up in order to

- (a) transmit it
- (b) reduce power loss
- (c) increase current for transmission
- (d) prevent electric shocks

SECTION B

1. (a) Describe briefly the structure and action of an a.c transformer.

- (b) (i) State any three causes of energy loss in a transformer
(ii) How are these losses reduced in a practical transformer.

2. (a) What is a transformer?
- (b) A transformer whose efficiency is 80% has an output of 12W. Calculate the input current if the input voltage is 240V.
- (c) Explain briefly why bulbs in a building are connected in parallel.

3.

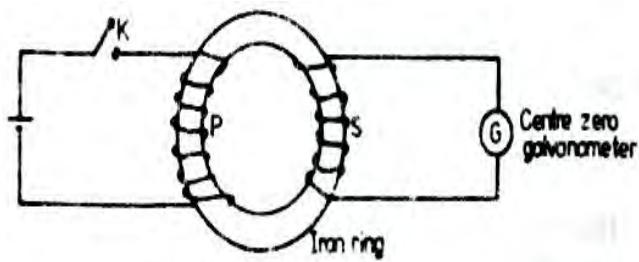


Fig.5

The diagram in the figure above shows a model of a transformer in which the primary coil, P is connected to d.c and the secondary coil, S is connected to a galvanometer.

- What is observed just as the switch K is closed?
- What would be the effect of closing switch K very fast in (i) above?
- What is observed when the switch K is left closed?
- What is observed just as switch K is opened?
- What would be observed if the d.c. source is replaced by an a.c. source of low frequency?

4. When two identical heating elements of a kettle are connected in series to a 240V supply, the power developed is 400W. Find;
- the resistance of the either element
 - the power developed when the elements are connected in parallel to the same supply
5. The figure below shows a charging circuit.

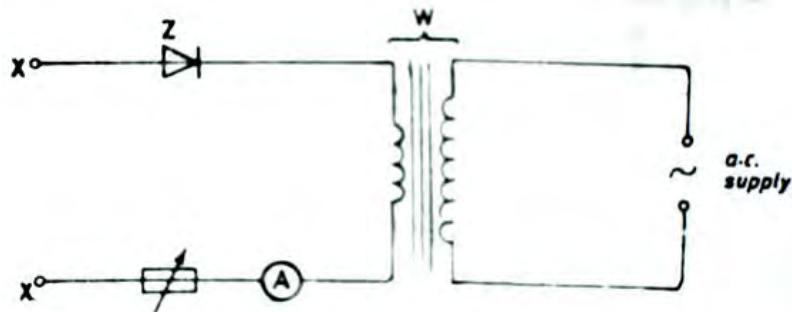
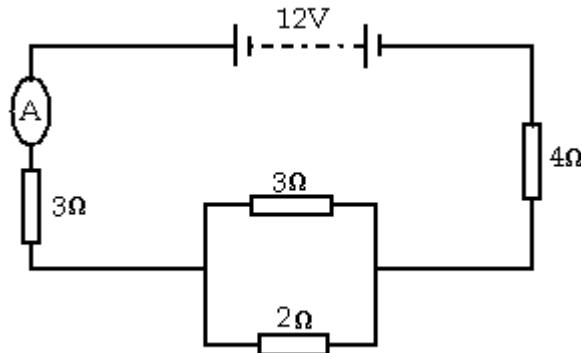


Fig. 10.

- a) Name and state the use of each of the parts labelled
- W : ?
 - Z : ?
- b) Sketch the waveform that is obtained from terminals XX.
6. Four resistors are connected across a 12V battery of negligible internal resistance as shown in the above figure. Determine



- the reading of the ammeter A
 - the p.d across the parallel combination of resistors
7. (a) State two sources of energy loss in a transformer.
- (b) Explain why it is an advantage to transmit electrical power at high voltage.
8. Explain briefly how a calculator which operates on a 6.0 V d.c can draw power from a 240 volts main supply.
9. (a) State three sources of energy loss in a transformer.

- (b) Electric power is generated at 11Kv. Transformers are used to raise the voltage to 440kv for transmission over large distances using cables. The output of the transformers is 19.8 Mw and they are 90% efficient.
Find: (i) the input current to the transformer.
(ii) the output current to the cables.
10. A transformer of efficiency 80% is connected to 240V a.c. supply to operate a heater of resistance 240Ω . If the current flowing in the primary circuit is 5A,
- (i) calculate the potential difference (p.d) across the heater.
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11. Explain briefly what is meant by mutual induction.
(i) mention the causes of energy loss by a transformer and state how the loss can be minimised
(ii) A transformer has 200 turns on the primary coil. Calculate the number of turns on the secondary coil if 240V is to be stepped to 415 V.

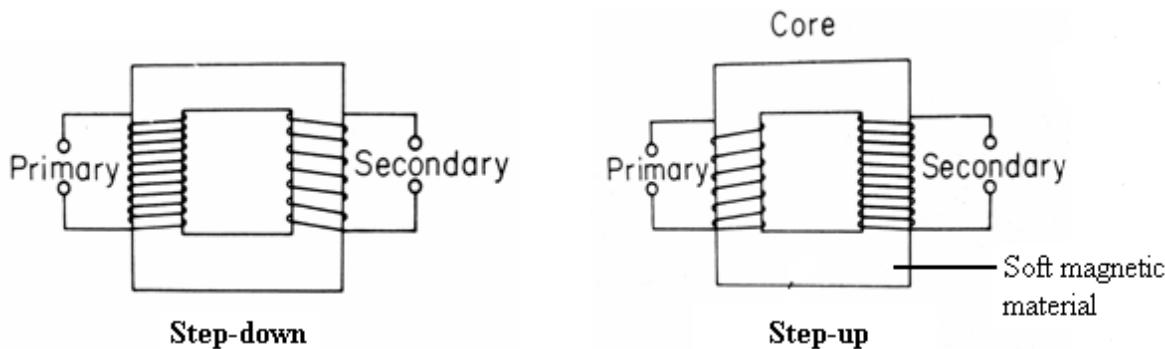
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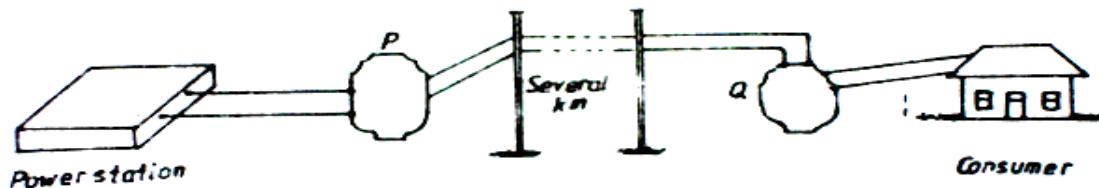
Transmission of power from station to House

- Electricity is generated by power stations.
- It is stepped up by transformers, then fed into grid (high voltage overhead power lines)
- It is stepped down into successive stages at substations.
- In neighborhood of homes, it is then stepped down further to 240V by transformers for domestic use.

TEST 11.4

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P

Q

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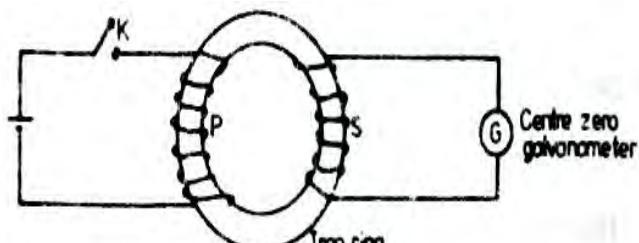


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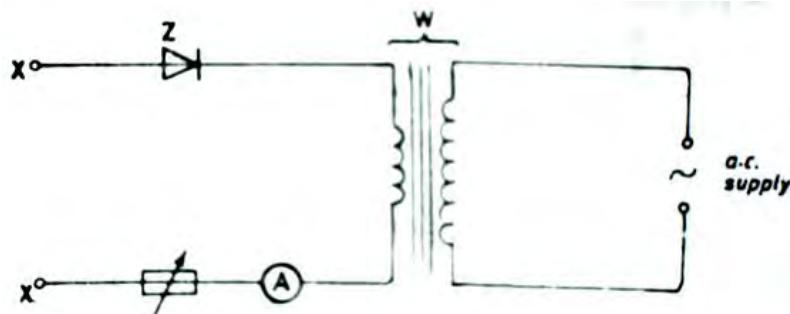


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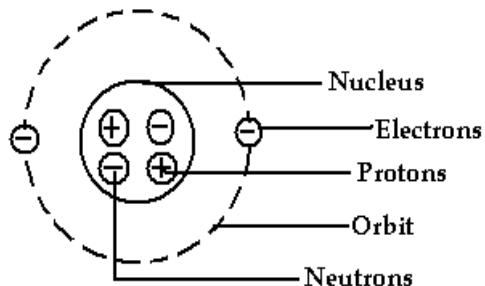
- (ii) A transformer has 200 turns on the primary coil. Calculate the number of turns on the secondary coil if 240V is to be stepped to 415 V.

CHAPTER TWELVE

MODERN PHYSICS

ELECTRONS

Atomic structure



An atom consists of a nucleus at its centre where its mass is concentrated. The nucleus consists of neutrons and protons and is surrounded by electrons which move around it in circular paths called orbits or shells.

In an atom, there are equal numbers of electrons and protons. Electrons carry a negative charge and protons and electrons in an atom form an electrically neutral combination.

Thermionic emission

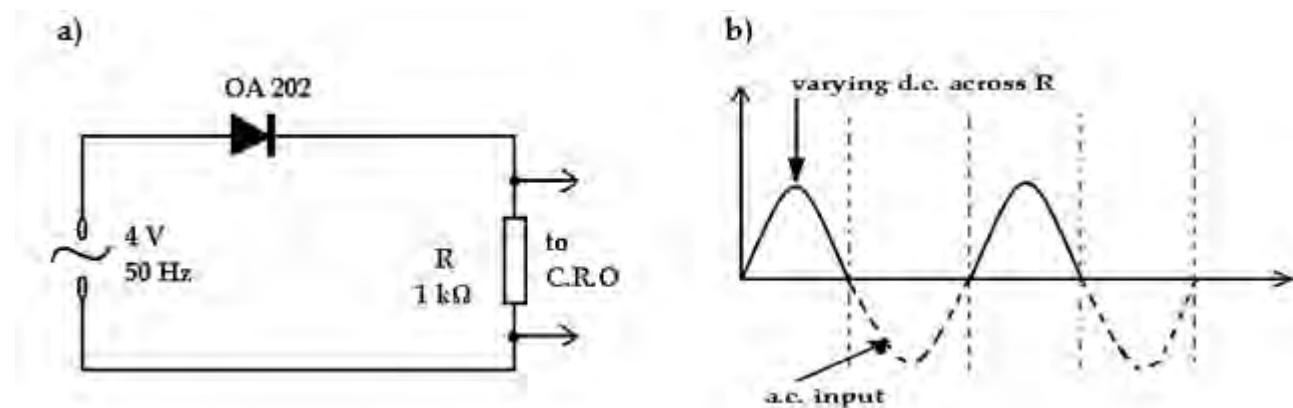
When a metal is heated, the free electrons in it gain an extra energy which enables them to break through the surface of the metal and become free electrons.

The process by which electrons are emitted from hot metal surface is called **thermionic emission**.

Rectification

A semiconductor diode rectifies, i.e. converts a.c. to d.c.

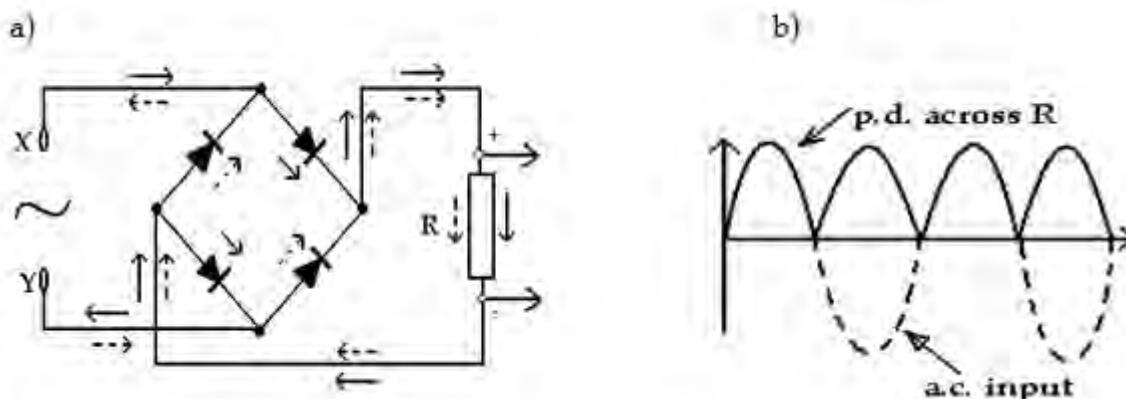
a) Half wave rectification



The diode removes the negative half-cycles of a.c. to give a varying but one-way (direct) p.d. across R, the 'load' requiring a d.c. supply, Figure b above.

Full wave rectification

Both the half-cycles of the a.c to be rectified are used. In the bridge circuit of fig. a, the current flows the solid arrows when X is positive and Y negative and the broken arrows on the negative half-cycles when the positive of X and Y are reversed. During both half-cycles, current flows in R and in the same direction giving a p.d. as shown below,



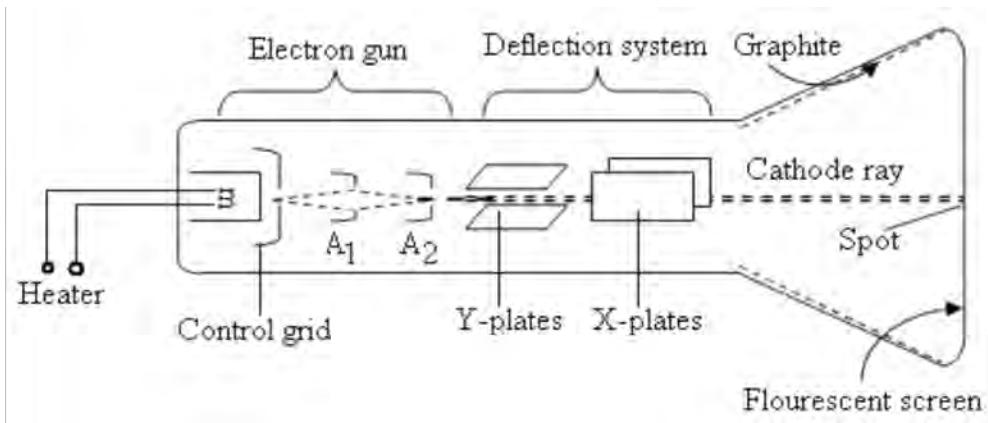
Cathode rays

Streams of electrons moving at high speed are called cathode rays.

CATHODE RAY OSCILLOSCOPE (C.R.O)

The C.R.O is one of the most important scientific instruments ever to be developed. It consists, like a television set.

A cathode ray tube has three main parts, as in figure below.



a) Electron gun

This consists of a heater, a cathode C, another electrode called the grid G, and two or three anodes A₁, A₂. G is at negative potential with respect to C and controls the number of electrons passing through its central hole from C to A; it's the brightness control. The anodes are at high positive potential relative to C; they accelerate the electrons along the highly evacuated tube and also focus them into a narrow beam.

b) Deflecting system

Beyond anode are two pairs of deflecting plates to which p.d.s can be applied. The Y-plates are horizontal but create a vertical electric field which deflects the beam vertically. The X-plates are vertical and deflect the beam horizontally.

c) Fluorescent screen

A bright spot of light is produced on the screen where the beam hits it. The C.R.O. is often used as a graph-plotter to display a wave form showing how a p.d. changes with time. The p.d. is applied to the Y-plates and a circuit is switched on in the C.R.O., called the *time base*, which generates a p.d. across the X-plates. This sweeps the spot steadily and horizontally across the screen until it *flies back* very rapidly to the left of the screen and repeats the motion.

The time-base is an electrical circuit which generates a saw-tooth type of voltage shown below:

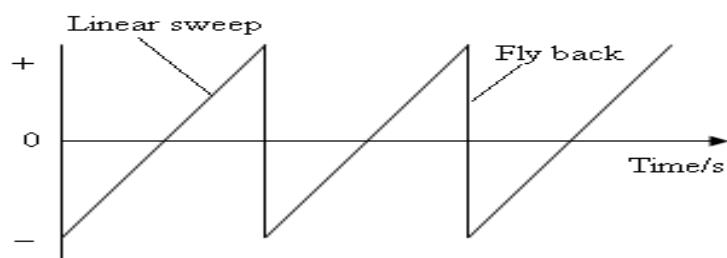
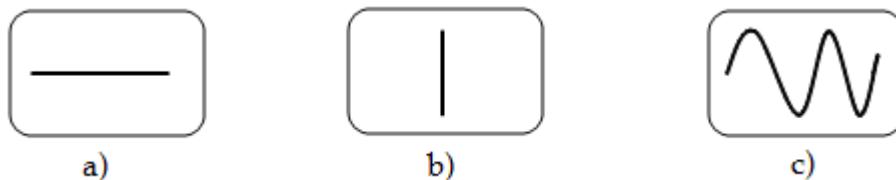


Figure below shows traces for

- (a) Time base on X only,
- (b) a.c. on Y only and
- (c) a.c. on Y and time base on X.



The time-base is an electrical circuit which generates a saw-tooth type of voltage shown below:

Properties of cathode rays

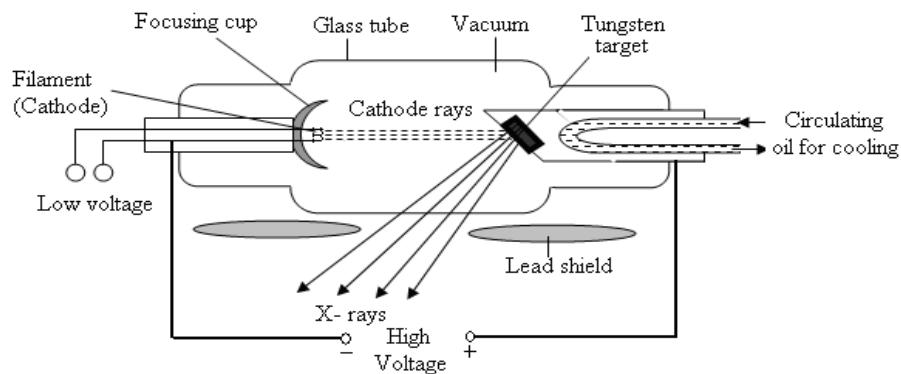
1. They heat objects onto which they fall. This shows that they have considerable energy.
2. They have momentum and therefore have mass.
3. They are deflected by magnetic fields according to Fleming's left hand rule.
4. They are negatively charged.
5. They are deflected by electric field.
6. They cause glass and other materials to fluorescent.
7. They travel in straight lines.

Uses of C.R.O

1. Measure voltage.
2. Measure frequency.
3. Measure phase difference.
4. Measure small time interval.
5. Measure drawing pictures on TV set.

X-RAYS

An X-ray tube consists of a cathode filament focusing cup, a metal target which is usually made of tungsten which has a high melting point all enclosed in an evacuated tube, cooling fins (circulating oil for cooling), a low voltage supply and a high voltage supply.



The cathode filament is heated by a low voltage supply (p.d.) and the electrons are emitted by thermionic emission. These electrons are directed onto a metal target by the focusing cup. When a high voltage (20000V) is applied across the anode and the cathode, the electrons are accelerated to a very high speed towards the target. On striking the target, the electrons are instantly brought to rest. Because of this, they give up all their energy to the target. About 99% of the energy appears as heat and about less than 1% of the energy appears as electromagnetic radiations called **X-rays**.

The heat produced in the target is removed by means of cooling fins.

There are two types of X-rays; soft and Hard.

- a) Soft X-rays are produced at low voltage and they have low penetrating power, energy and long wave lengths.
- b) Hard X-rays are produced at high voltage and they have a high penetrating power, high energy and short wave length.

Properties of X-rays:

They are electromagnetic radiations. I.e. they can pass through flesh but not bones.

- 1. They really penetrate matter up to 1mm of lead.
- 2. They ionize gas.
- 3. They give interference and diffraction effects.
- 4. They are not deflected in an electric or magnetic field.
- 5. They carry no electric charge.
- 6. They travel in straight lines.
- 7. They cause fluorescence.
- 8. They affect a photographic film.

Uses of X-rays

In hospitals, X-rays are used to:

- 1. Investigate the Lungs to detect tuberculosis.
- 2. Investigate the broken bones in x-ray photography.
- 3. Treat cancerous diseases and other malignant growth in human body.

Industrial uses of X-rays

- 1. They are used to detect defects in motor tyres.
- 2. Study the structure of crystals.
- 3. To detect cracks which are invisible to the eye, in metal casting and welding joints.

Health hazards of X-rays

- 1. They damage blood and eye sight.

2. They can cause serious diseases which may appear sometimes many years after the time of irradiation.
3. They destroy living cells in our bodies.
4. They can produce genetic changes which appear in subsequent generation.

Safety precautions of X-rays

1. Unnecessary exposure to X-ray must be avoided.
2. If exposure is necessary, it should be for a very short time.
3. Repeated exposure of X-rays to a patient must be avoided.
4. There should be no X-ray exposure for babies, born or unborn.
5. The technicians in X-ray laboratories should wear lead coated overcoats.
6. Exposure should be for the part affected only.
7. If necessary at all, the other parts of the body must be covered with layer of lead material.

RADIOACTIVITY

Introduction:

Some naturally occurring elements are unstable. They slowly and spontaneously decompose to gain stability by throwing away sub-atomic particles (portions of their nuclei). Such elements are called radioactive elements.

Examples of radioactive elements are:

Uranium (U), radium (Ra), polonium (Po), protactinium (Pa).

The emission of the sub-atomic particles to gain stability is called radioactivity.

Definition:

Radioactivity is the spontaneous disintegration of unstable radioactive element with emission of radiations (sub-atomic particles) and energy.

Examples of radiation detectors are;

- (i) The spark counter
- (ii) The Geiger- muller (G-M) tube.

Types of radiations:

There are three types of radiations, namely:

- (i) Alpha particle (α).
- (ii) Beta particle (β)
- (iii) Gamma ray (γ).

Radiations and their properties

a) Alpha particles (α)

Alpha particles are high speed helium nuclei. The symbol for an alpha particle is ${}^4_2 \text{He}$. Where the superscript (4) is the nucleon (mass) number and the subscript (2) is the proton number. They are called particles as a result of their appreciable mass.

Properties:

- (i) They are positively charged and the magnitude of the charge is double that of an electron.
- (ii) They cause intense ionization in gas.
- (iii) They have very short range in air of a few cm (5-8cm).
- (iv) They are stopped by a thick sheet of paper.
- (v) They have a speed less than that of light.
- (vi) They are deflected by electric and strong magnetic fields.
- (vii) They affect photographic films.
- (viii) They produce flashes when incident on fluorescent substances.

Note:

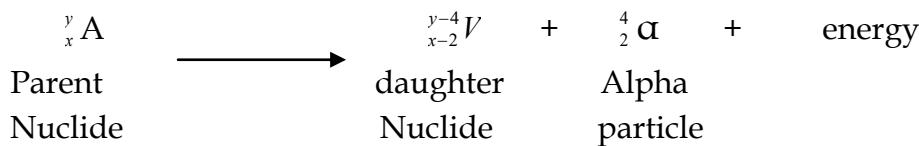
When a nuclide undergoes alpha decay:

It loses two protons and neutrons hence its nucleon (mass) number reduces by four.

Its atomic number reduces by two and

The daughter nuclide (new element formed) is two steps to the left in the periodic table.
A nuclide is an atomic species of an element which emits radiations, particles and energy spontaneously from its nucleus

General Nuclear Reaction Equation for a- particle decay



E.g. Uranium decays by emitting alpha particles to become thorium.



The thorium and the lead formed are stable.

This change of one element to another is called transmutation.

b) Beta (β) particles or rays (${}^0_{-1}\beta$)

Beta particles or rays are high speed electrons emitted from radioactive element.

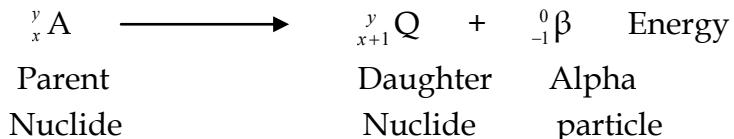
These electrons result from the decay of a neutron to a proton according to the equation:



Properties:

- (i) They are negatively charged.
- (ii) They are more penetrative than alpha particles. This is because of their high speed.
- (iii) They are more easily deflected in both electric and magnetic fields.
- (iv) Their ionizing power is much less than that of α - particles.
- (v) They are stopped by a thin sheet of aluminium.
- (vi) They have a range in air of several metres.
- (vii) They produce flashes when incident on fluorescent substances.

General Nuclear Reaction Equation for beta (β) decay



Note: When a nuclide undergoes beta decay:

Its atomic number increases by one.

Its nucleon (mass) number remains the same and

The daughter nuclide (new element formed) is one step to the right in the periodic table.

c) Gamma ray (γ).

A *gamma ray* is a very-high -energy form of electromagnetic radiation with very short wavelength. The wave lengths range from 10^{-10} m below as such their wavelengths are shorter than those of X-rays.

Properties

They travel at speed of light ($3.0 \times 10^8 \text{ ms}^{-1}$) since they are electromagnetic radiations.

They have neither mass nor charge.

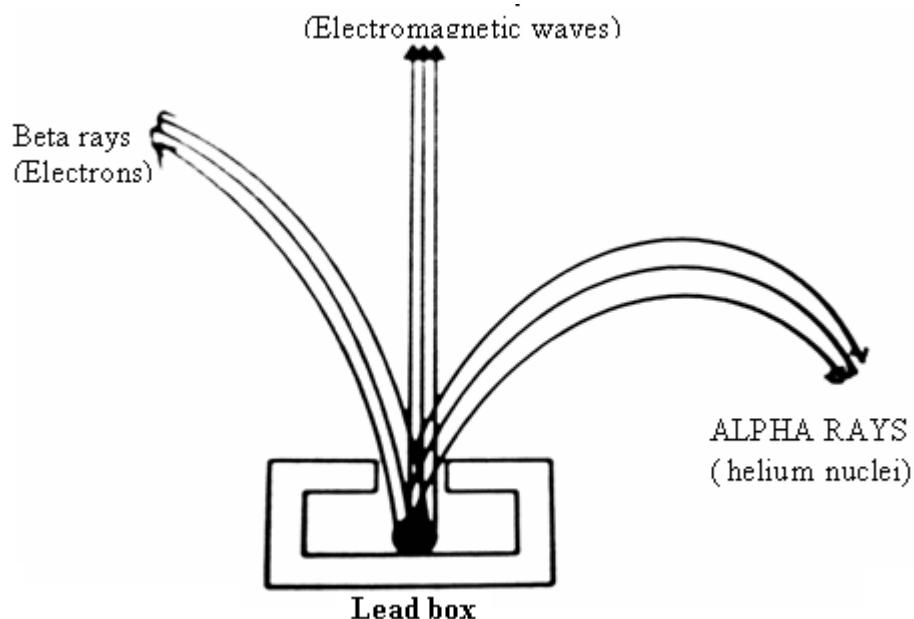
They are not deflected by both electric and magnetic fields.

Their have much more penetrating power than both α -particles.
 They have ionization effect less than beta particles.
 They have interference and diffraction effects.
 They are absorbed by thick block of lead.
 They cause fluorescence when incident on fluorescent substances.

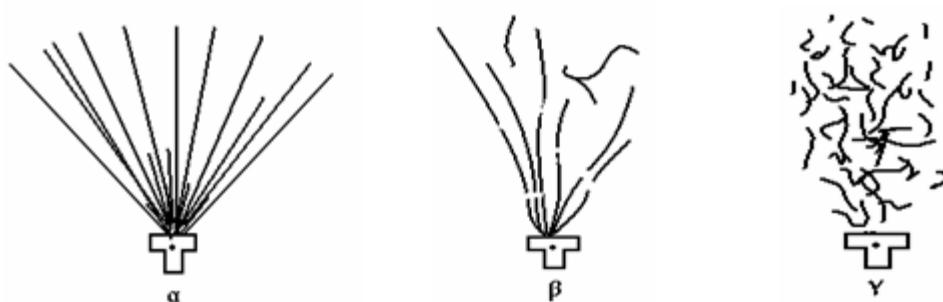
Laws of radioactive decay

- When an element disintegrates by the emission of an α -particle it turns into an element with chemical properties similar to those of an element two places earlier in the periodic table.
- When an element disintegrates by the emission of a β -particle it turns into an element with properties similar to those of an element one place later in the periodic table.

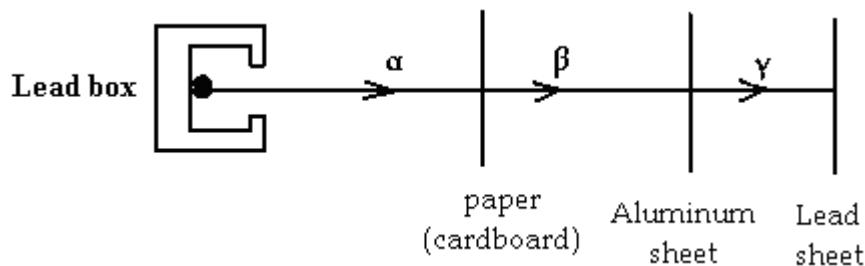
The diagram of radioactivity showing the three radiations



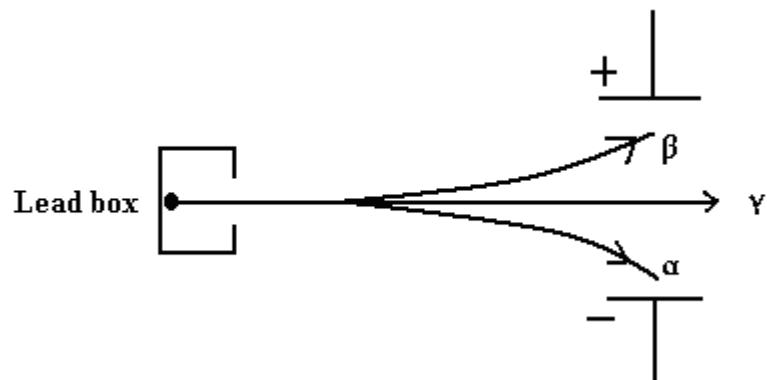
The diagram showing the tracks of the three radiations



The diagram showing the three radiations passing through paper, aluminum Sheet and lead



The diagram showing the three radiations passing through an electric field



Differences between α and β particles

An alpha particle (α) is a helium ion with a positive charge while a Beta particle is an electron with negative charge

An alpha particle can penetrate thin paper (low penetrating power) while a beta particle can penetrate thin metal foil (high penetrating power).

An alpha particle has mass of 4 units while a beta particle has negligible mass.

Comparison between Gamma rays and X- rays

X-Rays differ from gamma rays in two ways.

Gamma rays have much shorter wavelength than X-rays.

Gamma rays originate from the nuclei of atoms while X-rays are as a result of orbital electron transitions or jumps.

Health Hazards of Radioactive Radiations

Radioactive radiations are dangerous to life. This is because they damage body cells.

a) Alpha particles:

The danger from alpha particles is small unless the source enters the body.

b) Beta and gamma radiations

They cause:

Radiation burns (i.e. redness and sore on the skin),

Leukemia, (blood cancer),

Sterility (inability to produce children),

Low body resistance to normal diseases as a result of damage to blood corpuscles.

Mutation, a genetic change, occurring during DNA replication and protein synthesis.

The effects appear in the subsequent generations. E.g. a child may be born with one arm both with one arm shorter than the other.

Safety Precautions:

Radioactive sources should be handled with care.

They should always be handled with forceps and never be touched with bare hand.

No eating, drinking or smoking must be done where radioactive sources are in use.

Hands should be washed thoroughly after exposure to any radioactive material.

Any cuts in the body should be covered before using radioactive source.

During experiments the sources of radioactive elements should be arranged such that the radiation window point away from your body.

Radioactive sources should always be kept in lead boxes when not in use.

Applications of Radioactivity

Despite the dangers associated with radioactivity, there are many useful applications as seen in the following fields.

Medical, Agriculture, Industry, and Archaeology.

Uses of Radioactivity

(i) Medical

In medical they are used

- as tracers in medicine.
- to treat cancerous cells (radiotherapy).

(ii) Agriculture

In agriculture they are used to produce varieties of plants with new characteristics e.g. Resistance to plant diseases.

(iii) Industry

Industrially, radioactivity is used

- to provide source of energy.
- to measure the thickness of metal sheets.
- in food preservation.

(iv) Archaeology

- Radioisotopes of carbon is used to date archaeological remains dead living organisms. This is referred to as carbon dating.
- Determining the age of fossils (remains of old plants and animals) every living thing (plant or animal) has a certain constant quantity of carbon -14 elements (isotope). When the plant or animal dies this isotope begins decaying and the rate of disintegration decreases with time. So when a fossil is obtained the rate of disintegration is determined, and this is used to calculate the age of the fossil. i.e. when the plant or animal died, which would show when that type of plant or animal existed.

Definitions

Atomic number is the number of protons or electrons in an electrically neutral atom.

Mass number is the total number of protons and neutrons in the nucleus of an atom.

N.B: An atom of an element X of mass number A and atomic number Z and neutron number N is represented as:

$$A = N + Z$$

Isotopes are atoms of the same element with the same atomic number but different mass numbers.

e.g: $^{35}_{17}\text{Cl}$ and $^{37}_{17}\text{Cl}$, ^1_1H and ^2_1H .

Radioisotope is an isotope which undergoes spontaneous decay (radioactivity) with emission of radiations.

- **Industrial application of radioisotope:** sodium -24($^{24}_{11}\text{Na}$) is used as tracer in pipelines of water or sewage to study the progress of flow, so can detect blockage or leakage.

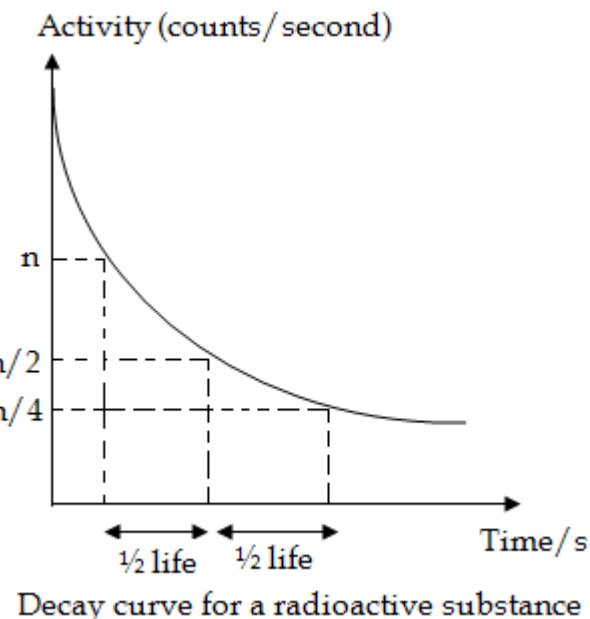
HALF LIFE

Half life is the time taken for a radioactive substance to decay to half of its original mass.

T. half life can be in seconds, minutes, hours, days, months and years.

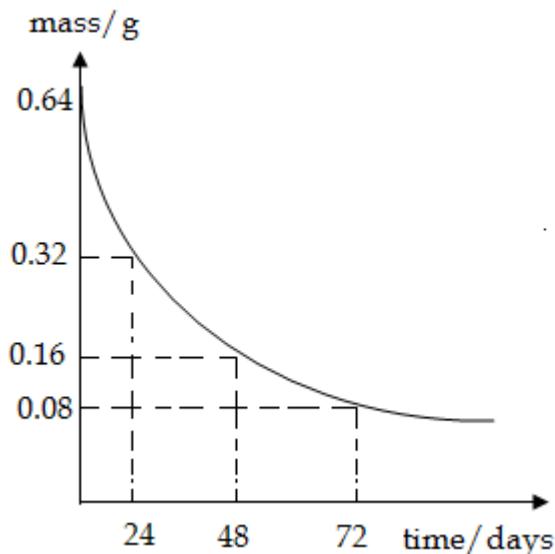
Figure below shows a typical decay curve for a radioisotope obtained by plotting the readings of a rate meter which is used to measure the activity over a period of about three half lives. From such a graph the half life may be found as follows.

If the count rate is n at some time t_1 and has fallen to $n/2$ at time t_2 , then the half life is (t_2-t_1) . Similarly, if the count rate has fallen to $n/4$ at time t_3 , the half life is (t_3-t_2) .



Example: The half life of a radioactive substance is 24 days. Calculate the mass of the substance which decayed after 72 days if the original mass is 0.64g.

Solution:	$\text{Half Life } T$	$= 24 \text{ days}$
	Time of decay	$= 72 \text{ days}$
	Original mass	$= 0.64\text{g}$



$$\text{Mass left after 72 days} = 0.08 \text{g}$$

$$\begin{aligned}\text{Mass that has decayed after 72 days} &= 0.64 - 0.08 \\ &= 0.56 \text{g}\end{aligned}$$

Example: The half life of a sample is 14 days, starting with activity 32g, calculate how long it will take for the mass to drop to 2g.

Solution :

$$\begin{array}{ccccccc} 32g & \xrightarrow{T} & 16g & \xrightarrow{T} & 8g & \xrightarrow{T} & 4g & \xrightarrow{T} & 2g \\ & 14\text{days} & & 14\text{days} & & 14\text{days} & & 14\text{days} \end{array}$$

The mass will drop to 2g after 4 half lives

$$\text{Now } T = 14 \text{ days}$$

$$4T = x \Rightarrow x = \frac{14 \text{ days} \times 4T}{T} = 56 \text{ days}$$

Example: A 40g sample of a radioactive substance reduced to 2.5g in 96 days.

- (i) What was its half life
- (ii) How much will it remain after another 96 days

Solution

$$\begin{array}{ccccccc} 40g & \xrightarrow{T} & 20g & \xrightarrow{T} & 10g & \xrightarrow{T} & 5g & \xrightarrow{T} & 2.5g \\ & & & & & & & & \end{array}$$

The mass dropped from 40g to 2.5g after 4 half lives

$$\text{Now } 4T_{1/2} = 96 \Rightarrow T_{1/2} = 24 \text{ days}$$

$$(ii) \quad (1/2)^4 \times 2.5 = 1/16 \times 2.5 = 0.15625 \text{ g} \quad \text{or}$$

$$2.5 \text{ g} \xrightarrow{T} 1.25 \text{ g} \xrightarrow{T} 0.625 \text{ g} \xrightarrow{T} 0.3125 \text{ g} \xrightarrow{T} 0.15625 \text{ g}$$

Example: The following figures were obtained from the reading of a counter source. Plot a graph of the count rate against time and deduce the half life of the source.

Time s)	0	20	40	60	80	100	120
Corrected counts	120	74	48	30	20	12	8

NUCLEAR REACTIONS

There are two types of nuclear reactions;

- (i) Nuclear fusion
- (ii) Nuclear fission

(a) **Nuclear fission:**

It is the splitting of a nucleus into two or more nuclei releasing radioactive particles (α, β, γ) and energy.

Conditions for nuclear fission

- Nuclear fission takes place in the presence of slow moving neutrons
- Low temperature

Example of Nuclear fission is the bombardment of $^{235}_{92}\text{U}$ by slow neutrons.



- The energy released by nuclear fission of a single atom of uranium is about 200meV.
- Nuclear reactors make use of controlled fission to provide energy while nuclear the atom bomb makes use of uncontrolled fission reaction.

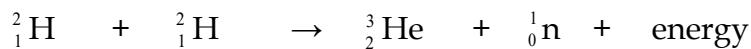
(b) **Nuclear fusion:**

It is the joining together of two or more nuclei to form one nucleus releasing energy and radioactive particles.

Conditions for nuclear fusion

Nuclear fusion takes place at very high temperature about 10^8 K. The high temperature provides the nuclei which are fuse with the energy needed to overcome their mutual electrostatic repulsion.

E.g. The fusion of two deuterium nuclei to produce helium 3



Reactions of this type occur in the sun & stars and the source of the sun's/ stars' energy.

Difference between

Nuclear fission	Nuclear fusion
Is the disintegration of a heavy nucleus into two lighter nuclei	Is the combining of two light nuclei to form a heavy nucleus
Requires low temperature/energy	Requires high temperature/energy
Requires low neutrons for bombardment	Neutron are not required but are a product of fusion
Result into four products	Results into three products
Energy released is high	Energy released is low

- ❖ In both fission and fusion energy is released and this energy is called nuclear energy. This energy can be used to generate electricity or in atomic bombs.

Similarities

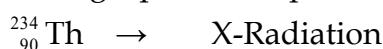
Both processes release energy

The energy provided per unit mass of reactant by the two processes are much the same.

TEST 12

SECTION A

1. The following equations represent the part of radioactivity series.



Substance x and the radiation in the equation above are

- | | |
|-------------------------------------|------------------------------------|
| A. $^{234}_{91}\text{Pa}$ and gamma | B. $^{230}_{90}\text{Th}$ and beta |
| C. $^{230}_{90}\text{Th}$ and gamma | D. $^{234}_{91}\text{Pa}$ and beta |

2.

Element	Neutrons	Protons	Electrons
P	6	6	6
Q	8	6	6
R	2	2	2
S	2	3	3

The table above shows the structure of four atoms P, Q, R, and S. Which ones are isotopes of the same elements?

- | | |
|------------|------------|
| A. P and Q | B. Q and R |
| C. P and S | D. P and S |
3. Streams of electrons moving at a high speed are called
- | | |
|-----------------|--------------------|
| A. x-rays | B. gamma rays |
| C. cathode rays | D. alpha particles |
4. An atom contains 3 electrons, 3 protons and 4 neutrons. Its nucleon number is
- | | | | |
|-----|------|-----|-----|
| A.3 | B. 4 | C.6 | D.7 |
|-----|------|-----|-----|

5. The process by which electrons are emitted from the surface of a metal by application of heat is known as:

- A. photoelectric emission
 - B. Electromagnetic emission
 - C. thermionic emission
 - D. Heat emission

6. Radium nucleus $^{226}_{98}\text{Ra}$ decays to Radon (Rn) by α -particle emission. What is the nuclear equation for this reaction?

- a) $^{226}_{88}\text{Ra} \rightarrow {}^3_2\text{He} + {}^{223}_{86}\text{Rn}$

b) $^{226}_{88}\text{Ra} \rightarrow {}^4_2\text{He} + {}^{222}_{86}\text{Re}$

c) ${}^4_2\text{He} + {}^{222}_{86}\text{Rn} \rightarrow {}^{226}_{88}\text{Ra}$

d) $^{226}_{88}\text{Ra} \rightarrow {}^{225}_{88}\text{Rn} + {}^1_0\text{N}$

7. Which of the following are properties of X-rays? They

- (i) carry no charge
 - (ii) are longitudinal waves
 - (iii) are not deflected by the magnetic and electric fields
 - (iv) travel in straight lines.

8. State the radiations that may be emitted by a radioactive substance

- (a) Alpha, gamma and x-rays
 - (b) Cathode rays, x-rays and beta
 - (c) gamma, alpha and Beta
 - (d) Cathode rays, x-rays and alpha

9. When Uranium 235 is bombarded with a neutron, it splits according to the equation



M and N on P represent

M	N	M	N		
A.	56	141	B.	141	56
C.	199	36	D.	107	128

10. The brightness on the screen of a T.V is determined by

 - (a) darkness in the room
 - (b) the size of the screen
 - (c) the number of electrons reaching the screen
 - (d) direction of the aerial

11. Which one of the following relations is from the nucleus of an atom?

 - A. Cathode rays
 - B. Gamma rays.
 - C. Infra red rays.
 - D. Ultra violet rays.

12. In the atomic bomb, energy is produced by

 - A. fusion.
 - B. fission.
 - C. radioactivity.
 - D. thermionic emission.

13. Which of the following are attracted towards the negative plate in an electric field?

 - A. Beta particles.
 - B. Alpha particles
 - C. Gamma rays.
 - D. Neutron.

14. Which one of the following are properties of Cathode rays?

 - (i) They travel in straight lines.
 - (ii) They can penetrate a thick sheet of paper.
 - (iii) They darken a photographic plate.
 - (iv) They are deflected by a magnetic field.
 - A. (i), (iii) and (iv) only.
 - B. (i), (ii) and (iv) only.
 - C. (i), (ii) and (iii) only.
 - D. (iv) only.

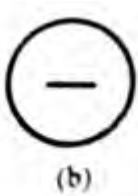
15. The cathode ray oscilloscope may be used to

 - (i) measure energy.
 - (ii) measure potential difference.
 - (iii) display wave forms.
 - A. (i) only.
 - B. (i) and (ii) only.
 - C. (ii) and (iii) only.
 - D. (i), (ii) and (iii).

16. Which of the following represents an appearance on the screen of a cathode ray oscilloscope when a. d.c. voltage is connected across the Y-plates with the time-base switches on?



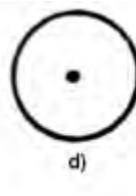
(a)



(b)



c)



d)

17. Which one of the following is a properties of X-rays?

- A. They can deflected by magnetic field.
- B. They can ionize matter.
- C. They can cause photo-electric emission.
- D. They can electrically charged particles.

18.



(a)



(b)

Fig. 3

The above figure shows a spot on the screen of a cathode ray oscilloscope. The spot can be turned in an horizontal straight line as shown in (b) by

- A. switching off the time base
- B. switching on the time base
- C. making one of the plates positive
- D. connecting an a.c voltage to the Y-plates

19. A possible isotope of ${}^3\text{Li}$ has

- A. two protons and three neutrons
- B. two protons and four neutrons
- C. three protons and four neutrons
- D. four protons and three neutrons



The above equation represents an activity in which thorium decays and emits an alpha particle. Find the value of Z.

A. 88

B. 89

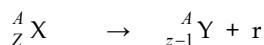
C. 91

D. 92

21. What is the process by which electrons are emitted from a hot filament?

- | | | | |
|----|---------------------|----|------------------------|
| a) | radioactivity | b) | nuclear reaction |
| c) | thermionic emission | d) | thermo-electric effect |

22. Element X emits radiation R and forms element Y as given in the equation



While A and Z are mass and atomic members respectively radiation R is

- | | | | |
|----|-----------------|----|----------------|
| a) | alpha particles | b) | beta particles |
| c) | gamma rays | d) | X-rays |

23. The atomic number of an element is the number of

- (a) protons in its atom
 - (b) neutrons in its atom
 - (c) electrons and protons in its atom
 - (d) neutrons and protons in its atom

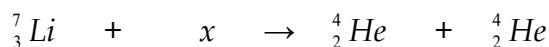
24. Nuclear fission occurs when

- (a) Uranium is heated to a very high temperature
 - (b) Two deuterium (heavy hydrogen) atoms come together
 - (c) A hydrogen molecule splits into two atoms
 - (d) Nuclei of Uranium atoms split into lighter nuclides.

25. Background radiation is due to

- (i) cosmic rays from the sun
 - (ii) microwaves
 - (iii) radioactive fall out
 - (iv) radiations from T.V set

26. Two alpha particles are produced when an unknown particle x is used to bombard lithium 7_3Li as shown in the equation



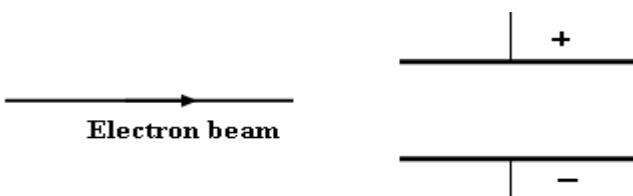
What is x ?

- B. A photographic film
C. A fluorescent paint
D. A thermometer with a blackened bulb.

33. Which one of the following parts of the cathode ray tube form the electron gun?

a) Cathode, metal anode, heater, grid
b) Grid, metal anode, cathode, Y-plates
c) Cathode, grid, heater, X-plates
d) Cathode, metal anode, grid, heater, X-plates, Y-plates.

34. The brightness of the spot of the C.R.O. screen is controlled by
(a) X-plates (b) Anode (c) grid (d) cathode



A beam of electrons is incident midway between two charged plates as shown above. The beam will

- (a) deflect upwards
 - (b) deflect downwards
 - (c) move perpendicular to the plates
 - (d) pass through the plates un deflected.

38. Isotopes are nuclides with the same number of protons but different number of electrons.

- (b) protons but different number of neutrons
 (c) neutrons but different number of protons
 (d) electrons but the same number of neutrons

39.

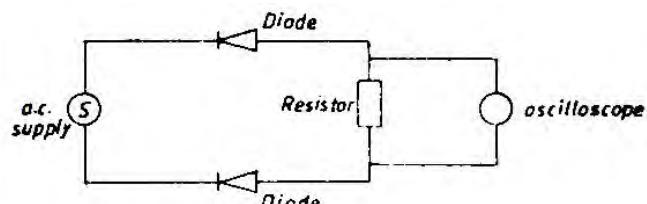
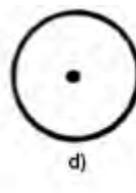


Fig.1

In the above circuit, what is observed on the oscilloscope when the time base is on ?



40. Which one of the following is the correct order in which some energy changes occur in the electron gun of the cathode ray tube?

- A. light → heat → K.E
 B. electric → light → heat
 C. Electric → heat → K.E
 D. sound → electric → heat

41. The phenomenon by which electrons are released from a metal surface when radiation falls on it is known as

- | | |
|-------------------------|--------------------------|
| (a) radio activity | (b) photoelectric effect |
| (c) thermionic emission | (d) reflection |

42. A radioactive element may emit

1. alpha particles
2. gamma rays
3. beta particles
4. protons.

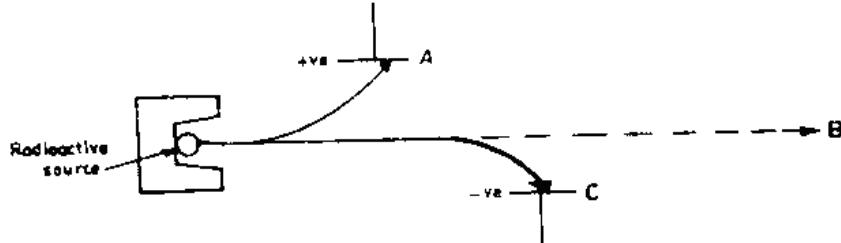
- | | |
|---------------|-------------|
| A. 1,2,3 only | B. 1,3 only |
| C. 2,4 only | D. 4 only |

43. A sinusoidal wave is observed on a cathode ray oscilloscope when
- A cell is connected to the Y plates with a time base off
 - a low frequency alternating voltage is connected to the Y plates with the time base on
 - a high frequency alternating voltage is connected to the Y plates with the time base on.
 - a cell is connected to the Y plates with the time base on

SECTION B

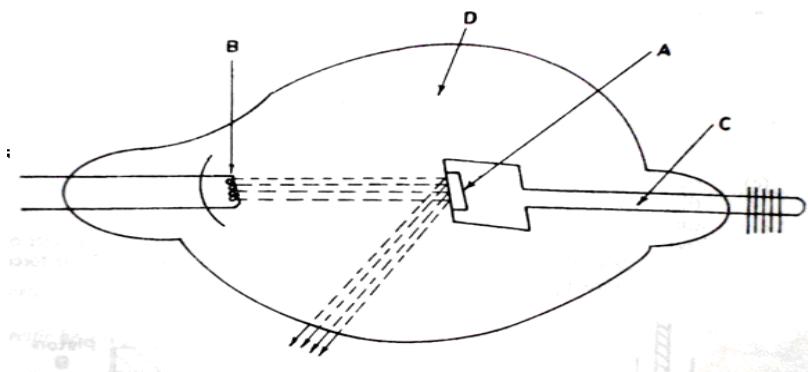
- (a) Describe a simple model of the atom.
(b) What is meant by radioactivity?
- a) (i) What is meant by nuclear fission?
(ii) Give one method of starting the process in (a) (i).
(b) (i) Account for the energy released in nuclear fission?
(ii) State one use of nuclear energy.

3.

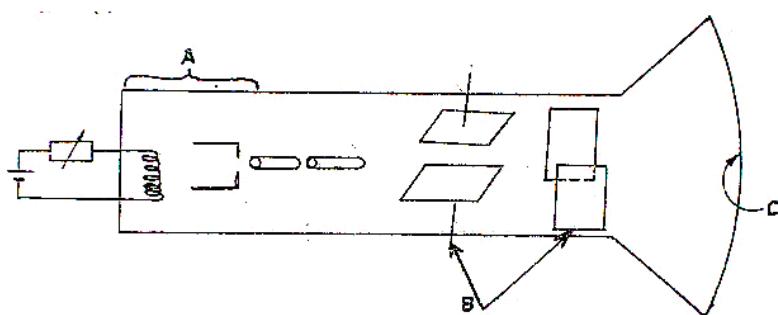


A radioactive source emits radiation, which are directed between two positively charged metal plates as shown in the figure above.

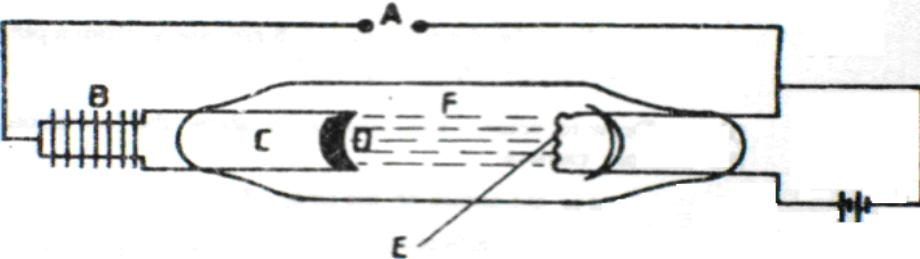
- (a) Name the radiation labeled A, B and C.
(b) What happens when the radioactive source is completely covered with an ordinary sheet of paper.
- (a) Define the following;
(i) atomic number
(ii) isotopes of an element
(b) State two differences between an α - and a β -particle
(c) (i) What is meant by nuclear fission and nuclear fusion.
(ii) Give one example where each one occurs
- Figure below shows the main parts of an x-ray tube.



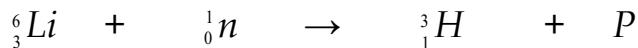
- (a) Name the parts labelled A, B, C and D.
- (b) List in order the energy changes, which occur in the x-ray tube.
- (c) Describe one industrial use of x-rays.
6. Name the electromagnetic radiation which
- causes sensation of heat.
 - passes though a thin sheet of lead.
 - is used in satellite communication.
 - is used for remote control of a television receiver.
7. The symbol $^{235}_{92}\text{U}$ denotes a uranium nucleus.
- What is the meaning of?
 - 235?
 - 92? - Write down a balanced nuclear equation showing the decay of $^{235}_{92}\text{U}$ to a nuclide X by emission of an alpha particle.
8. a)



The above diagram shows the main parts of a cathode ray oscilloscope(C.R.O)

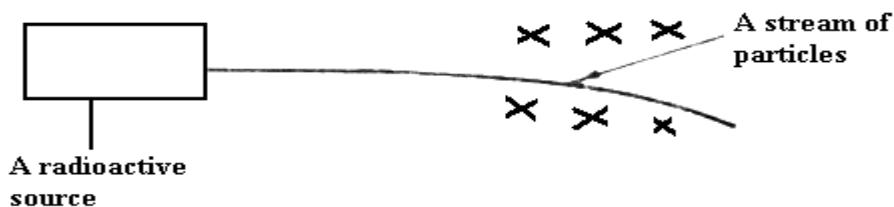
- (i) Name the parts labelled A,B and C
 (ii) Why is the C.R.O evacuated?
 (b) (i) Describe briefly the principals of operation of C.R.O
 (ii) How is the bright spot formed on the screen?
 (c) Use diagrams to show what is observed on the screen of a C.R.O when
 (i) the C.R.O is switched on and no signal is applied on the Y-plates
 (ii) the time base is switched on and no signal is applied on the Y-plates
 (iii) an alternating signal is applied on the Y-plates while the time base is switched off
 (d) Give two uses of the C.R.O
9. (a) What is meant by the atomic number of an element?
 (b) One isotope of neon is denoted by $^{20}_{10}\text{Ne}$. how many neutrons does the isotope have?
 (c) $^{60}_{70}\text{Co}$ is a radioactive isotope of cobalt which emits a beta particle and very high energy gamma rays to form an element X. Write a balanced equation for the nuclear reaction.
10. (a) (i) What is meant by a radio isotope?
 (ii) State one industrial application of radio isotopes.
 (b) Describe what happens when a beam of radiation consisting of α -, β - and γ -rays is incident on a thin sheet of lead.
 (c) The diagram above shows the essential parts of an X-ray tube.
- 
- (i) Name the parts labelled A, B, C, D, E and F.
 (ii) State the function of each part.
 (iii) Describe how X-rays are produced.
 (d) What safety precautions must be taken in an X-ray laboratory?
11. (a) What is a radioactive nuclide?

- (b) A radioactive element X decays by emitting an alpha particle and gamma rays.
Write a balanced equation for the decay.
- (c) State what happens to a beta particle as it passes in between two oppositely charged plates.
12. a) What is an alpha particle?
-
- (b) A radioactive source decays by emission of all the three radiations. The radiation centre normally moves into an electric field as shown in the figure above. Which radiations are most likely to be detected at
- position A
 - position B
 - position C
- (c) A radioactive source which emits all three radiations is placed in front of a cardboard, aluminium and lead sheets as shown in the figure above. Name the radiations likely to be between the:
- cardboard and the aluminium sheet,
 - aluminium and lead sheets
- (d) Name any three precautions, which must be taken by one working with ionising radiation.
- (e) name one:
- industrial use,
 - biological use, of radioactivity.
13. (a) What is meant by the terms
- Isotopes
 - Radioisotope
- (b) (i) Name and state the nature of the emissions from radioactive nuclides
(ii) What effect does each of the emissions have on the parent nuclide?
- (c) Give two uses of radioactivity.
14. (a) Define the terms atomic number and mass number
(b) When lithium is bombarded by neutrons, a nuclear reaction occurs which is represented by the following equation



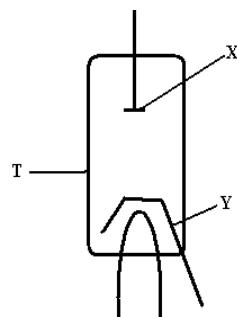
Complete the equation and name P.

- (c) Describe the application of radioactivity in determining the age of fossils (remains of old plants and animals)
 - (d) Give two harmful effects of radioactivity
 - (e) State three differences between cathode rays and x-rays.
15. (a) (i) Name the particles emitted by radioactive nuclides.
(ii) Give one property common to the particles named in (i).
- (b)



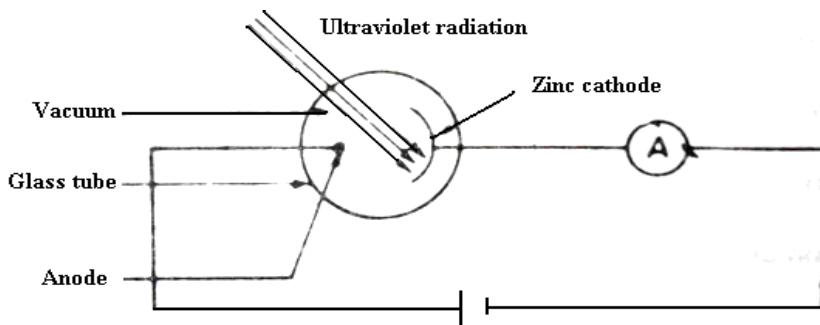
A stream of particles from a radioactive source passes through a magnetic field directed into the plane of the paper as shown in the above figure.

- (i) Identify the particles in the stream.
 - (ii) Sketch a diagram to show the path of the particles in an electric field.
 - (c) Distinguish between the terms fusion and fission.
State two conditions necessary for each to occur.
16. (a) What is meant by the following?
photo-electric effect?
- (b) (i) State the conditions necessary for photo-electric effect to take place?
(ii) With aid of a labeled diagram, describe how an alternating current can be fully rectified.
- (c) (i) State the function of the fluorescent screen in a cathode ray oscilloscope.
(ii) Give two applications of cathode ray oscilloscope.
17. (a) What is thermionic emission?
(b)



The diagram above shows a thermionic diode. Name the parts labelled X,Y.

- (c) Describe briefly how electrons are made to move across the tube T.
 - (d) State two differences between cathode rays and x-rays.
 - (e) In the production of x-rays tube, why must be target be cooled?
18. (a) (i) Name the particles emitted by the radioactive materials.
 (ii) Draw diagrams to show the path of the particles named in (a) (i) and in a cloud chamber
- (b) A Zinc cathode was enclosed in an evacuated glass tube as shown in the figure below.



When the cathode was irradiated with ultra violet radiations, the ammeter gave a reading

- (i) Explain why the ammeter gave a reading.
- (ii) A gas was gradually introduced into the glass tube. Explain what happened?

TEST 12.1

SECTION A

1. The half life of a radioactive substance is 10s. How long will it take for a mass of 16g of that substance to reduce to 2g
- | | |
|---------|---------|
| (a) 40s | (b) 30s |
| (c) 20s | (d) 10s |

- 2.** The count rate from a radioactive source is 138 counts per minute when the background rate is 10 counts per minute. If the half-life of the source is 6 days, find the count rate after 18 days.
A. 16.0 B. 17.25
C. 26 D. 42

3. Thorium has a half-life of 24 days. How many days would it take 8 kg of thorium to disintegrate to 1g?
A. 3 B. 24
C. 72 D. 96

4. The half-life of a radioactive element is 4 hours. Find the mass of the element that decays after 24 hours if the initial mass is 9.6g
a) 0.15g b) 1.6g
c) 9.45g d) 4.8g

5. The half-life of a radioactive element is 10 days. Find the mass left after 40 days if the initial mass is 16g
(a) 1g (b) 2g
(c) 4g (d) 8g

6. A radioactive metal decays to $1/16$ of its original quantity in 2 hours. What is its half life?
(a) 15 min (b) 24min
(c) 30min (d) 40min

7. The count rate of a radioactive isotope falls from 600 counts per second to 75 counts per second in 75 minutes. The half-life of the radioactive isotope is
(a) 8 min (b) 19 min
(c) 25 min (d) 75 min

8. The half life of a radioactive material is 20 days. Find the initial mass of the material if 2g of it remains after 80 days
a). 4g b). 8g
c). 16g d). 32g

SECTION B

1. A radioactive material takes 50 hours for 93.75% of its mass to decay. Find its half-life.

2. The half-life of a radioactive substance is 24 days. Calculate the mass of the substance which has decayed after 72 days if the original mass is 0.64g.
3. (a) What is meant by the *half-life of a radioactive material*?
(b) The activity of a radioactive source decreases from 4000 counts per minute to 250 counts per minute in 40 minutes. What is the half-life of the source?
4. A radioactive material of mass 8g has a half -life of 20 days. Find how much of it will decay after 60days?
5. A radioactive sample has a half-life of 3×10^3 years
(a) What does the statement half-life of 3×10^3 years mean?
(b) How long does it take for three-quarters of the sample to decay?
6. The half-life of Uranium is 24days. Calculate the mass of Uranium, which remains after 120days if the initial mass is 64g
7. (a) Define half life.
(b) x grams of a radioactive material of half life of 3 weeks, decays and 5.12g remains after 15 weeks. Determine the value of x .

TEST ONE

1.D 2.C 3.A 4.B 5.A 6.C 7.D 8.C 9.A 10.D 11.A 12.D 13.D 14.A
15.C

TEST 2

1.A 2.B 3.C 4.A 5.C 6.C 7.D 8.A 9.B 10.B 11.A 12.A 13.B
14.B 15.A

TEST 3

1. D 2. B 3.A 4.C 5. B 6.A 7.C 8. B 9.C 10.D

TEST 4

1. D 2. B 3.A 4.C 5. B 6.A 7.C 8. B 9.C 10.D

TEST 5

1.B 2.D 3. D 4.B 5.C 6.B 7.D 8.C 9.B 10.D 11.D

TEST 6

1.A 2.D 3.C 4.A 5.B 6.C 7.C 8.B 9.B 10.C 11.B 12.C 13.C 14.D
15.D 16.B 17.A 18.B

TEST 7.1

1.D 2.A 3.D 4.C 5.C 6.A 7.C 8.D 9.A 10.A 11.A 12.D 13.C 14.C
15.A 16.A

TEST 7.2

1. A 2.B 3.D 4.B 5.C 6.C 7.D

TEST 8

1.A 2.B 3.A 4.C 5.C 6.B 7.C 8.C 9.C 10.D 11.B 12.A 13.D 14.C
15.B 16.B 17.B 18.A 19.A 20.C 21.A 22.C 23.C 24.D

TEST 9

1.A 2.D 3.B 4.C 5.C 6.A 7.A 8.C 9.A 10.C 11.C 12.D 13.A 14.B 15.C
16.B 17.B 18.D 19.D 20.B 21.C 22.A 23.B 24.C 25.D 26.D 27.B

TEST 10

1.A 2.B 3.D 4.B 5.C

TEST 11.1

1.A 2.C 3.A 4.C 5.D 6.C

TEST 11.2

1. D 2. D 3. C 4.B 5. C 6. B 7. D 8. D 9. A 10.B 11.C 12.B

TEST 11.3

1. C 2. C 3. A 4. C 5. C 6. C 7. B 8. A 9. A 10. B

TEST 11.4

1. C 2. C 3. A 4. C 5. C 6. C 7. B 8. A 9. A 10. B

TEST 12

1.D 2.A 3.C 4.D 5.C 6.B 7.C 8.C 9.B 10.C
11.B 12.C 13.B 14.B 15.C 16.A 17.C 18.B 19.C 20.A
21.C 22.B 23.A 24.D 25.C 26.D 27.B 28.A 29.D 30.B
31.C 32.A 33.A. 34.C 35.C 36.B 37.A 38.B 39.B 40. C 41.B 42.A 43.B

TEST 12.1 half life

1.B 2.B 3.C 4.C 5.A 6.C 7.C 8.D