O

Table of Contents

O

Chapter one: properties of matter 4

1.0 Introduction 5

1.1 The particular nature of the matter 5

Matter 5

Exercise 7

Brownian motion 7

The kinetic theory of matter 9

Change of States: 9

Diffusion 10

Adhesive and cohesive force 12

Surface tension 15

1.2 Properties of Materials 18

Chapter Two Heat and temperature 19

1.0 introduction 20

2.1 Thermal expansion 20

Linear expansion 21

Area expansion 23

Volume expansion 24

2.2 Thermal expansion of liquids 28

Unusual expansion of water (Anomalous expansion of water) 29

2.3 Heat transfer 31

Conduction 31

Convection 34

Radiation 36

Application of thermal radiation 37

2.4 Temperature 40

Heat and temperature 40

Temperature scales 40

Types of thermometers 42

CHAPTER THRE: Magnetism 44

3.0.Introduction 45

3.1 Properties of magnet 45

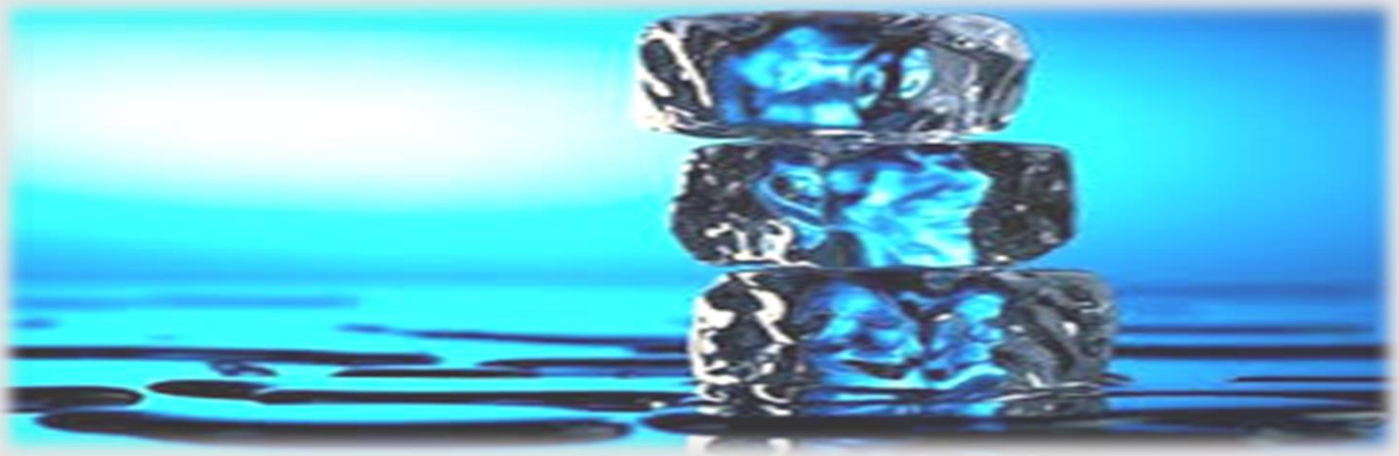
Magnetic and non-magnetic materials 45

3.2 Types of magnet 48
Law of magnetic poles 49
3.3 Magnetic field 50
Magnetic field pattern due to bar magnets 51
Direction of magnetic field 53
Earth's Magnetic Field 54
Magnetic force 55
3.4 Making magnets (Magnetization) 56
Demagnetization 60
Storing magnets 61
3.5 Magnetic Effect of Electric Current (Or Electromagnetism) 62
Magnetic Field due to a Solenoid 66
Electromagnet 68
Applications such of electromagnets 72
3.6 Magnetic Force on Current Carrying Conductor Placed in a Magnetic Field 74
Electric motor 77
Moving coil Load speaker 79
Moving- Coil Meter 80
Chapter four: Oscillation and introduction of waves 90
4.1 Oscillation 91
Common characteristics of oscillation 91
Simple pendulum 93
4.2 Spring oscillation 95
4.3 introduction of waves 98
Waves: 98
Types of waves 98
Chapter five:Reflection of light 103
5.0 Introduction 104
5.1Propagation of Light 104
Speed of Light 105
Transparent, Translucent and Opaque objects 105
5.2 Reflection of light 107
Real and virtual images 110
Applications of plane mirrors 114
5.4 Uses of Spherical Mirrors 120
mirror formula 121

Chapter six: More about forces 124
6.0 Introduction 125
6.1 Newton's law of motion 125
Newton's first law of motion 125
Inertia 125
Resultant force 127
Newton's second law of motion 129
Friction and air resistance 130
6.2 Moment and levers 137
Moment of a force 137
Levers 142
Equilibrium and stability 149
Stability 149
6.3 Pressure 153
Pressure in liquid 156
Hydraulic machines 163
Hydraulic brake system 165
Atmospheric pressure 168
Fluids in motion 186
Equation of continuity 188
Bernoulli's principle 190
Glossary 193
Index 199
References 200

O

Chapter one: properties of matter



Chapter Objectives

By the end of each topic, the learner should be able to:

- explain that matter is composed of particles in order to describe the three states of matter (solids, liquids and gases) in terms of particles (molecules)
- state the kinetic theory of matter (with appropriate models)
- use the kinetic theory of matter to describe the processes of changing state, diffusion and give an idea of Brownian motion
- explain that solids have a definite shape where as gases take the shape of the container.
- explain the difference between cohesion and adhesion forces
- give examples of surface tension and give an explanation in terms of intermolecular forces
- describe experiments to illustrate cohesion, adhesion and surface tension.
- state the factors affecting surface tension, its consequences and importance.
- describe and explain the effect of capillarity using water and mercury thermometer as examples
- show that the use of a material for a particular job depends on the properties of a material (strength, ductility, elasticity, brittleness, and stiffness)

O

1.0 Introduction

Before the 19th century no one could agree what would happen if a piece of matter was cut into smaller and smaller parts. Would there be a time when, however fine the knife, the fragments could not be cut anymore? Or was matter forever divisible? Some people thought one thing, and some another.

Nearly 2500 years ago, a Greek thinker called *Demokritos* said that matter was made of particles which could be separated but not split up. A little later the same idea arose in India, and later still in the Arab world. Eventually, in Western Europe, science and technology developed until gathering real evidence and forming hypotheses became possible. Robert Boyle and Sir Isaac Newton believed in particles.

About 200 years ago, an English schoolteacher called John Dalton also believed in particles. But he went further. He used the idea of a chemical element, saying that all the particles of one element were exactly the same. With that idea and crude but effective chemical weighing scales (balances) our modern particle theory was born. The particles, people thought, were indivisible - they could not be subdivided. The Greek word for 'indivisible' is '*atomos*' so the particles were called *atoms.*

Since then we have learned a great deal about atoms and the way they combine together. That is the story of chemistry. But also, we have learned how atoms and the combinations of atoms, which we call molecules, behave when they exist together without any chemical change. That is the story of physics. It is also what this chapter is about

1.1 The particular nature of the matter

Matter

Matter is anything that has mass, weight and can occupies an empty space. All matter consists of *tiny particles* which are called ***atoms.*** The movement and the arrangement of these tiny particles determine the properties of material such as; *temperature, density, shape and strength,* for example the movement of particles determines temperature and the arrangement of particles determine shape, density and strength of the material. Matter exists in five different states.

1.*Solid*
2.*Liquid*
3. *Gas*
4. *Plasma*
5. *Liquid crystals*

These five different states of matter are caused by the way of their particles are arranged

Solid state

In a solid, the particles are held tightly together and cannot move relative to each other, but they can vibrate. This means that solids cannot flow: a solid has a definite shape, size and volume. Because of this, solids cannot be compressed very much. Because the particles in a solid are close together, the solid has a high density.

The molecules of a solid have *fixed* positions and are closely packed in an orderly manner. These molecules are not at rest but continuously moving to and fro in their fixed positions, there is a large ***attraction force*** holding them together. The force of attraction between same kinds of particles is called cohesive force. We need a large force to change the size or shape of a solid. This is why a wire of a lift can carry load without snapping, the particles vibrate to and fro such that increasing the temperature of the solid increases this vibratory motion. At a certain temperature for a particular solid, the particles break away from this knit structure and the solid is said to have melted.

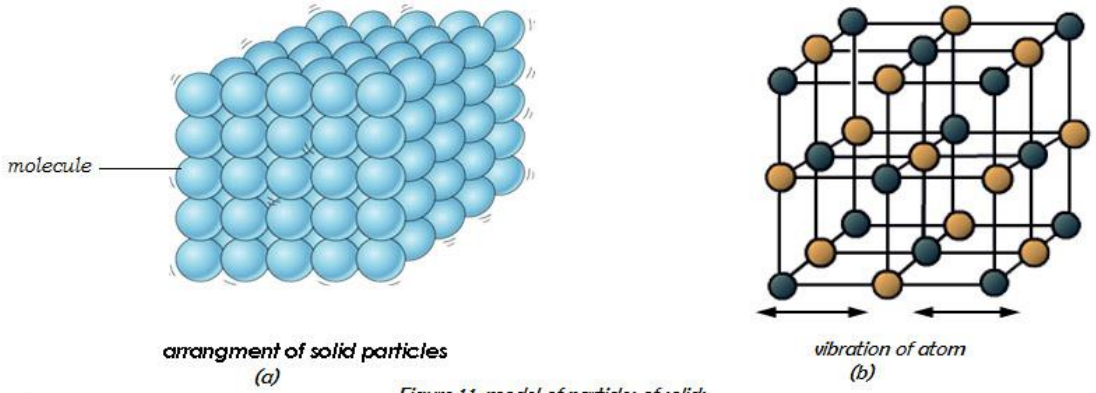


Figure 1.1: model of particles of solids

Liquid state

In a liquid, the particles are a little further apart than in a solid. As well as vibrating, the particles are free to move about each other and are in constant motion. Liquids cannot be compressed very much. They have no definite shape and they can flow. Liquids take the shape of the container which they are in. There are forces of attraction between the particles of a liquid but they are weaker than those between the particles of a solid. the density of a liquid is a little less than the density of the same substance when it is solid. Solid materials therefore sink in their own liquids. An important exception is water. Ice floats on water, because as ice forms, hydrogen bonds hold the water molecules in a structure which is very open.

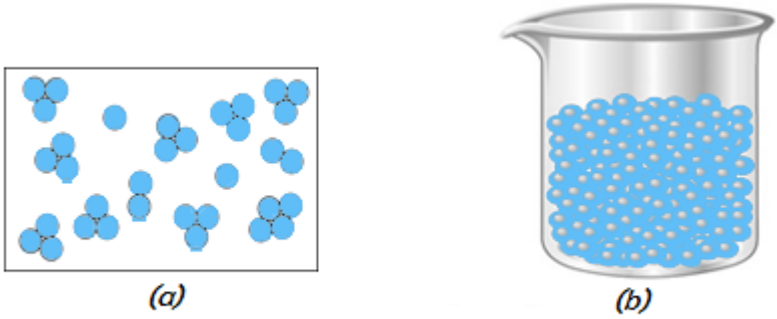


Figure 1.2: model of liquid state of matter

Gas state

The particles are further apart and have increased random motion compared to those in the liquid state. The cohesive force between the particles is extremely small and as the particles move, they collide with each other and with the walls of the container in which they are trapped. This produces gas pressure. Collisions between particles do happen but there is no loss of kinetic energy - we say that the collisions are elastic. If a gas is released into a room, the particles will spread out to fill the room. Gases have density very much less than that of solids or liquids. The fact that it is easier to compress gas than liquids indicates that there exists a large inter-molecular distance in gases than in liquids. Gas molecules or particles can lose some of their energy and fall back into the liquid state by a process known as condensation**.** The particles in a gas are widely separated and can move independently of one another. Gases have no particular shape and no particular volume. The particles in a gas move faster than the particles in a liquid and solid.Other properties of gases, include: *colour, smell and density.*

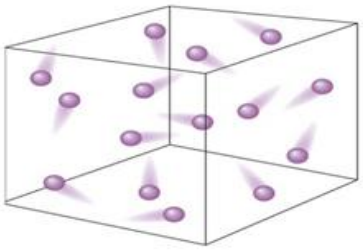


Figure **1.3**: State of gas

Exercise

1. State whether each of these is describing a **solid**, a **liquid** or a **gas**:

a) A fixed size and shape ----------

b) No definite size or shape ----------

c) Particles vibrate about fixed position ----------

d) A fixed volume but no definite shape ----------

e) The particles move at high speed ----------

f) All most no attraction b/w particles ----------

Brownian motion

Robert Brown (1827). Brown was investigating the fertilization process in a newly discovered species of flower, when he noticed a "random motion" of the pollen grains suspended in water under the microscope.

The zigzag motion of the particle of gas is called Brownian motion. A simple modern version of Brown's experiment is the smoke cell. A small cell of air is placed under a microscope and illuminated strongly from the side. Some smoke is then blown into it. Through the microscope the particles of smoke can be seen to be in zigzag random motion just like Brown's pollen grains. This motion is due to the collisions of the (invisible) air molecules with the much larger particles of smoke.

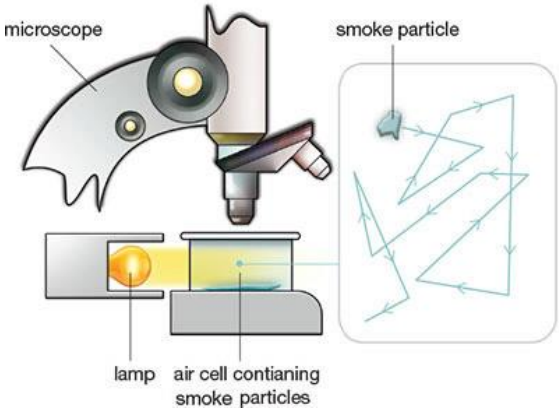
Figure *Robert Boyle (1627–1691) was an Anglo-Irish chemist and philosopher. As well as discovering the law that bears his name, he worked with Robert Hooke at Oxford developing the air pump.*

Experiment: To demonstrate the Brownian motion in air

Apparatus

Drinking straw, smoke cell, microscope and bright light source

Procedure



- Collect some smoke particles (from a smoldering wick or by lighting the top end of a drinking straw) in a small glass container (called the cell).
- Put a cover plate on top to seal the smoke and air in the cell.
- Now, set up the apparatus as shown in figure on the right
- Illuminate the cell with bright light. Use a converging lens to focus the light to the smoke cell.
- Adjust the microscope until you can see very bright specks against the grey background. View the cell through the microscope, what do you observe?

Observation

We see tiny illuminated particles rapidly moving or dancing randomly in different directions with different speeds (Figure)

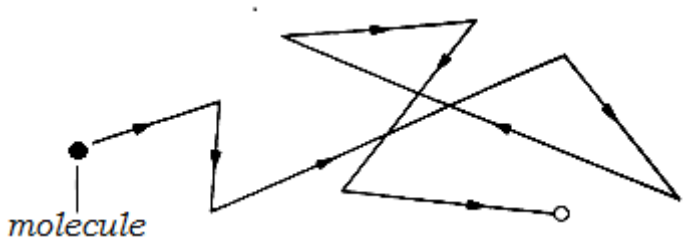


Figure 1.5: Molecules moving at random in different directions.

Explanation

These tiny, bright specks are the illuminated smoke particles moving in a *zig-zag* or *random* path. The density of smoke is less than air and the greyish smoke particles tend to rise up inside the cell. The particles are being hit by the dense colourless air molecules. The smoke particles are forced to move in a zig-zag manner. As we cannot see the air molecules, we can only conclude that the *air molecules are also moving at random in different directions* making the tiny smoke particles to

Conclusion.

From the experiments above, it can be deduced that matter is made up of very small particles which are in constant random motion. This is called the kinetic theory of matter.

The kinetic theory of matter

As we have suggested, matter is thought to be made up of particles which are in constant motion. This is a model which we use to explain observations which we make. If the results of an experiment did not fit in with this model we would have to think again. If someone thought of different, better model to explain the facts which we already know, we would use that model instead. But so far, the 'moving particle model' is the best that has been thought of. We call it the kinetic theory of matter. The way the particles of matter are arranged and move determines the state of a substance that is, whether it is a solid, a liquid, or a gas. Also, the kinetic theory gives us a model for such phenomena as Brownian motion and diffusion, and the different densities of solids, liquids and gases. The kinetic theory explains the behavior of solids, liquids, gases in terms of moving particles.

The Kinetic theory of matter states that:

- All matter is made up of very tiny particles
- The particles of matter are in constant random motion
- There are force of attraction between the particles

Change of States:

Change of state is the physical change from one state of matter to another. Matter can change from one state to another when ***thermal energy*** is taken in or released.

As you noted earlier, particles in a solid just vibrate. These vibrations become faster and the forces of attraction between them weaken when the temperature increases. A stage is reached when the vibrations are so violent that the solid changes into a liquid. In a liquid the forces of attraction are weaker and the particles can move freely from one place to another.

This change in state from solid to liquid is called *melting.* The constant temperature at which this change takes place is called *melting point.*

In liquids, the particles in the surface are only attracted by the particles below them in the liquids. Therefore, they feel a net force acting downwards.

When the liquid is heated, the average kinetic energy of the particles increases, the particles do not all has the same kinetic energy, and some have more than others. Put another way, some are hotter than others.

- **Melting:** The change of state from a solid to a liquid. At a substances melting point, the particles of a solid are vibrating so fast that they break free of their fixed position.
- **Freezing:** the change of state from a liquid to solid. At a substances freezing point, the particles of a liquid are moving so slowly that the particles freeze into place.
- **Evaporation:** the change of state from liquid to gas, evaporation takes place AT THE SURFACE OF A LIQUID.
- **Condensation:** A change from a gas state to a liquid state.

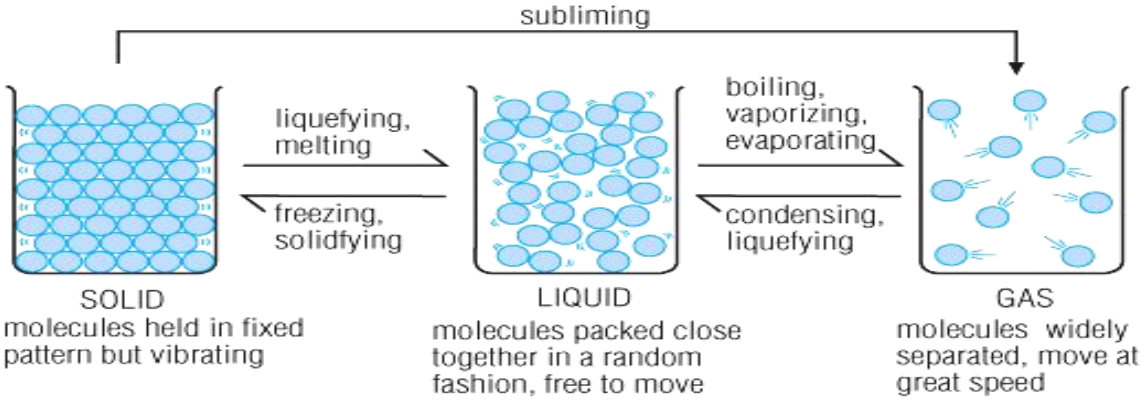


Figure 1.6: Changes of state

Boiling and Evaporation

Evaporation is a change of state from liquid to gas with no bubbles and its reverse process (from gas liquid) is called condensation.

Evaporation occurs because when the liquid is heated the particles of the above get enough kinetic energy to overcome down ward force of other particles of the liquid and escape

The table below shows the main difference between evaporation and boiling

Evaporation	Boiling
♦ Evaporation takes place at all temperature ♦ No bubbles appear ♦ Occurs at the surface	♦ Boiling takes a place at a definite temperature and this is when the pressure inside the liquids equal the atmospheric pressure ♦ Bubbles appear ♦ Occurs within the liquid

Diffusion

Diffusion is the spreading out and mixing process seen mainly gasses and liquids. The molecules diffuse from a region where they are more concentrated to the regions where they are low concentration.

For example, if a bottle of perfume is opened in one corner of a room, it spreads in the whole room by diffusion. If you drop a little ink in a beaker of water it will spread by itself in the beaker of water and the color spreads uniformly.

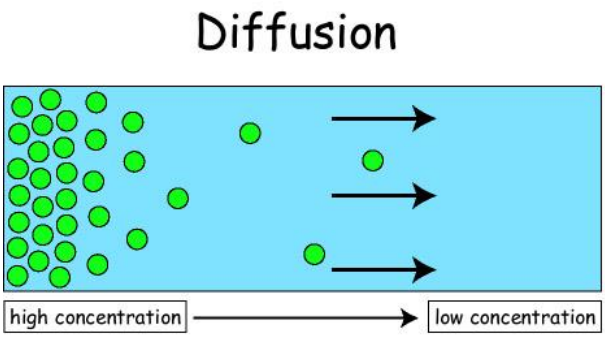


Figure 1.7

The rate of diffusion in gases is inversely proportional to the square root of their densities.

Experiment: To investigate diffusion in liquids

Apparatus

Funnel, beaker, copper (II) sulphate solution.

Procedure

Pour water into the beaker until it is half full

Pour saturated copper **(II)** sulphate solution down the funnel slowly

and notice how the two liquids settle.

Remove the funnel carefully so that the liquids are not disturbed.

Repeat the same steps for another set of apparatus, but using warm liquids. Make observations several times over a period of, say, two days.

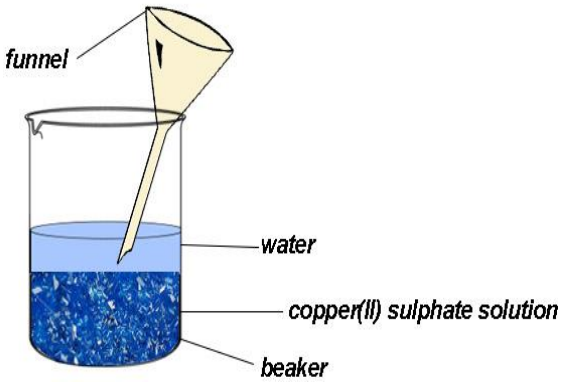


Figure 1.8

Observation and Explanation

Initially, the water layer floats on top of the saturated copper (II) sulphate solution because it is less dense. After sometime, the boundary disappears and the two liquids form a homogeneous pale blue mixture. Formation of the mixture is faster with hot liquids because the movement of particles is faster due to increased energy. There is greater movement of water particles (molecules) from the water layer into copper sulphate layer because it has greater concentration of water molecules than copper (II) sulphate particles.

Similarly, there is a greater movement of particles from copper (II) sulphate layer into the water layer because of greater concentration of copper (II) sulphate particles than water molecules.

Experiment: To demonstrate the diffusion in gases.

Apparatus

Two gas jars, carbon dioxide gas

Procedure

(a) Take two jars, one filled with carbon dioxide gas and the other with air. Introduce lime water into these jars and observe what happens. The lime water turns *milky* in the jar containing carbon dioxide. There is no effect in the other jar. This is the test for the presence of carbon dioxide which will be used in part (b).

(b) Take two jars, one filled with carbon dioxide gas and the other with air. Arrange the two jars with a glass plate separating them as shown in Figure. Leave the set-up undisturbed for a few minutes, and then remove the glass plate carefully. Introduce a few drops of limewater into the jar that contained only air. What happens to the limewater? — The lime water turns *milky.*

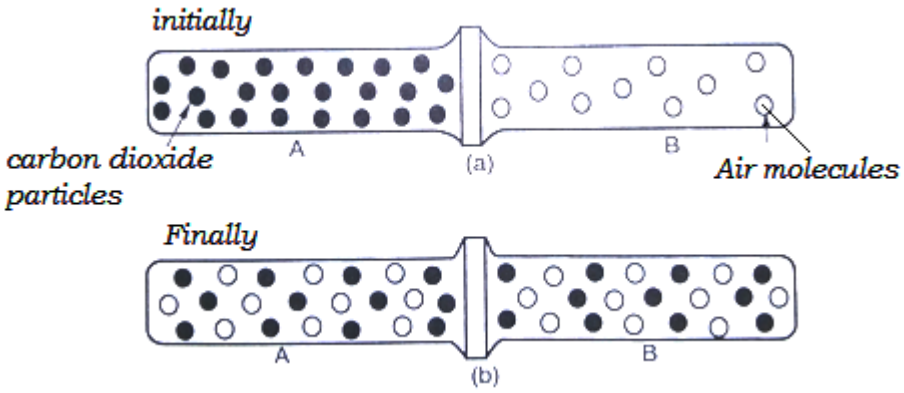


Figure: 1.9, above shows diffusion in gases

The above effect shows the presence of carbon dioxide gas in the top jar, which contained only air. What has happened?

Observation and explanation

As soon as the glass plate is removed, the dense molecules of carbon dioxide gas rise upwards and spread to the region of air of low density.

The molecules of the two **gases inter-mix** with each other. The spreading continues until the mixture acquires uniform density. This shows that molecules in a gas move from a region of ***higher*** *concentration* **to the region of** *lower concentration.* From the above experiments, we can now define the process of diffusion.

Diffusion *is a process where the molecules of a fluid spread from regions of higher concentration to those of lower concentration.*

Diffusion in gases takes place more quickly than in liquids. The molecules of a gas move more freely than those of a liquid. In a solid, the molecules can only move to and fro in their fixed positions.

Adhesive and cohesive force

Molecules liquid state experience strong intermolecular attractive forces. When those forces are between like molecules, they are called cohesive forces. For example, the molecules of a water droplet are held together by cohesive forces, and the especially strong cohesive forces at the surface constitute surface tension. When the attractive forces are between unlike molecules, they are said to be **adhesive forces**. The adhesive forces between water molecules and the walls of a glass tube are stronger than the cohesive forces lead to an upward turning meniscus at the walls of the vessel and contribute to capillary action.

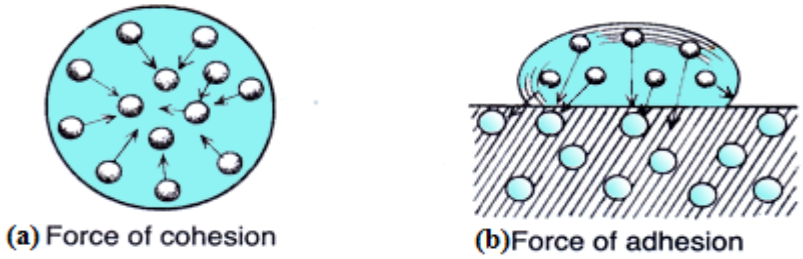


Figure 1.10: adhesion and cohesion

Experiment: To demonstrate the force of cohesion and adhesion.

Place some drops of water on a clean glass plate and on a waxed surface. Observe the shapes of drops. The diagram below shows the shapes of large and small drops of the water. (Figure1.11)

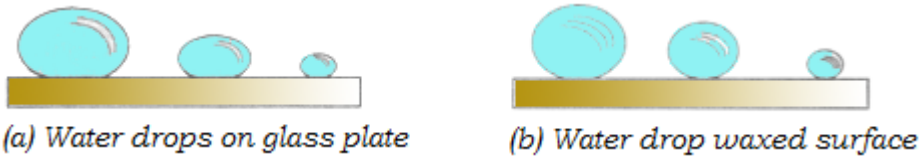


Figure 1.11: Shapes of large and small drops of water.

Matter is made up of small particles called *molecules.* These particles are held together by force of attraction between them. The force of attraction between molecules of the same substance is called the *force of cohesion.* A free liquid drop is almost spherical. When a drop of water is placed on a glass plate, the glass molecules attract the water molecules strongly. The drop spreads out over the glass and hence its shape changes.

When a drop of water is placed on waxed surface (figure), the drop is almost spherical. the force of adhesion between water molecules ***and the wax molecules*** is less than the force of cohesion between water MOLECULES. When a drop of mercury is placed on a glass plate the force **cohesion is so** greater, then the drop is almost spherical. (Figure) the shape of the drops described above is true for small drops. The large one tends to spread a bit more due to their heaviness.

The forces of cohesion and adhesion may be used to explain the liquid *meniscus* and the *capillary* action.

Liquid meniscus

When liquids are poured into containers, their surfaces are curved. in the case of water, the curved surface forms a concave shape (figure a). This is because the adhesive force between water molecule and glass molecules is more than the force of cohesion between the water molecules. For mercury the shape is convex (figure b). This is because cohesive force between the mercury molecules is greater than the adhesive forces between mercury molecules and glass molecules.

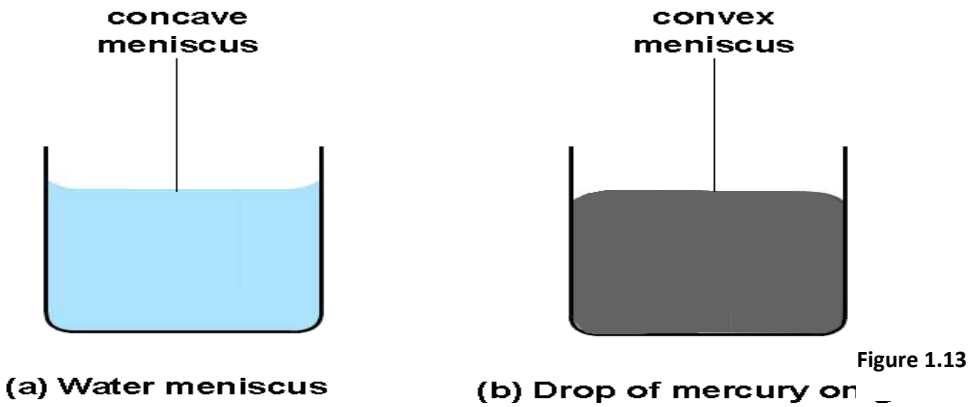
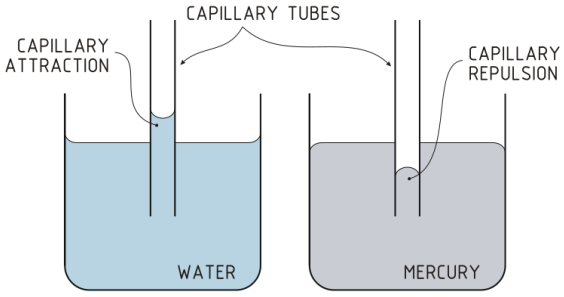


Figure 1.13

Figure 1.12

Capillary action

Capillary is the process by which a liquid rises or falls in tube of small diameter the surface tension causes a water to rise in a tube (capillary) tube above the level outside. Capillary action, also known as capillarity, is a result of the intermolecular attraction within the liquid and solid materials. A familiar example of capillary action is the tendency of a dry paper towel to absorb a liquid by drawing it into the narrow openings between the fibers.



When a glass tube with a narrow bore in its centre (capillary tube) is dipped in a liquid, the liquid level rises or drops depending on the liquid used. The rise or fall of a liquid level in a tube is called ***capillary action.***

Experiment: To demonstrate capillary action using capillary tubes.

Dip three long tubes, open on both ends in a beaker containing water and mercury as shown in Figure 3.19. One of the tubes should be a capillary tube. Observe what happens.

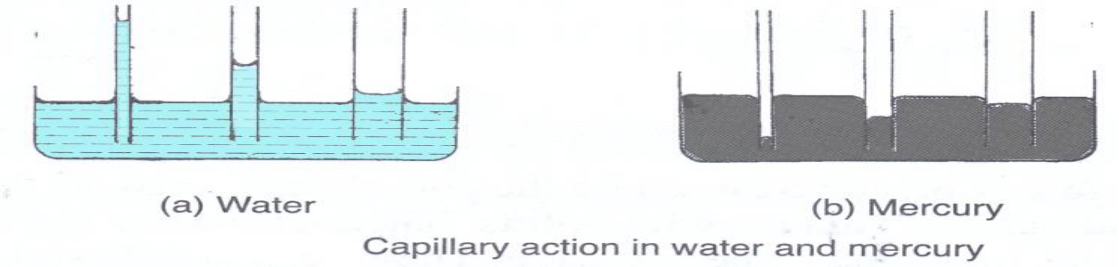


Figure 1.14: Capillary action in water and mercury

The level of water rises in the tubes. The greatest rise is observed in the capillary tube. (Figure(a)). If mercury is used instead of water, the levels fall as shown in Figure (b)). The greatest fall is observed in the capillary tube.

Experiment: To demonstrate capillary action using glass plates.

Use a rubber band and a match stick in between the two glass plates to form a wedge as shown in Figure 3.20. Dip the wedge into water. Examine the level of the water surface between the plates and draw a sketch of what you observe.

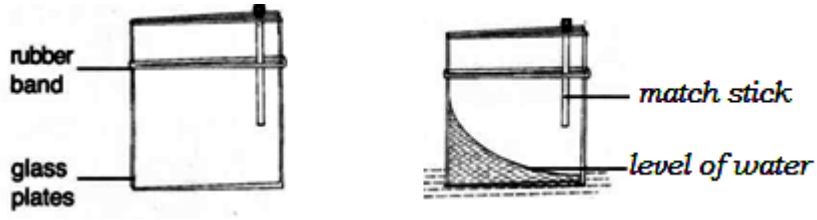
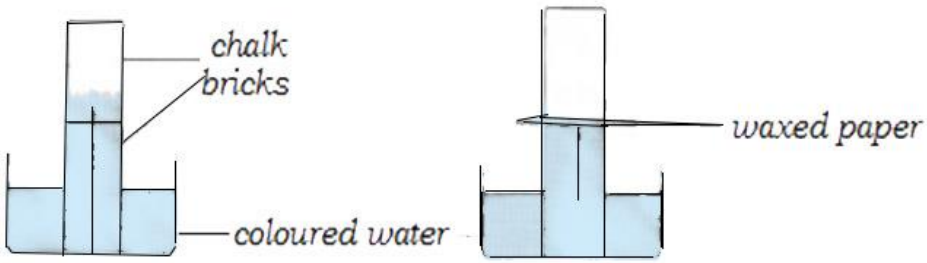


Fig 1.15: Capillary action in glass plates

The level of the water rises most when the plates are nearest to each other. Observe that in Experiments above, the rise is most when there is least liquid to be pulled up.

Experiment: To demonstrate capillary action using chalk bricks.

Pour a little coloured water into a shallow tray so that it half submerges one of the chalk bricks (Figure (a)). Place a second chalk brick on top of the first and observe what happens. Repeat the experiment but with a piece of waxed paper between the two chalk bricks.(Figure (b))



(a) Capillary action takes place (b) No capillary action

Fig1.16: Capillary action on chalk bricks

Chalk is a porous substance. The tiny air spaces in it form the capillary tube needed for the capillary action to take place. The coloured water rises up into the top brick (Figure (a)). However, when waxed paper is used, Figure (b), the adhesive force between the water molecules and the wax is small. The coloured water is therefore not able to cross over to the other chalk brick on top.

Applications of capillary action

Capillary action is applied in many situations. Here are some of the situations.

1. *The spreading of ink over a blotting paper*: the air spaces provide fine tubes.
2. *Kerosene rises up the wick of a lamp*: The fibres act like capillary tubes of fine bore.
3. *The rise of sap from soil in the plants:* tissues of plants provide narrow tubes.
4. *Towels used for drying:* the air space in a towel provides fine tubes. Capillary action might also become a nuisance. It causes dampness through the walls and floors of houses. To prevent this, a waterproof sheet of polythene is laid in the concretes base as shown as shown in figure

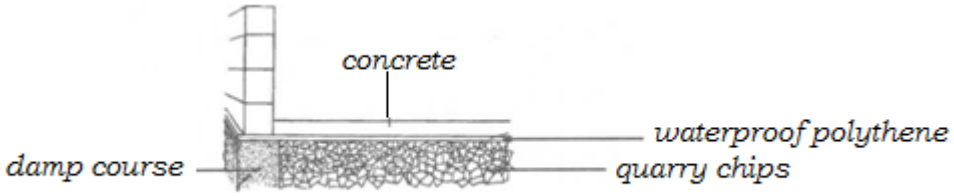
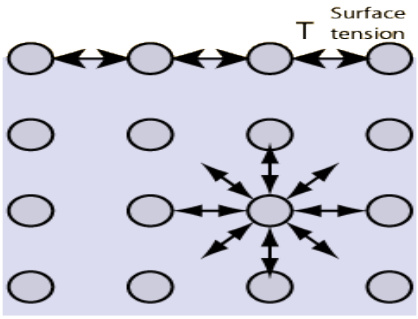


Fig:1.17: *Water proof material prevents dampness*

Surface tension



The cohesive forces between liquid molecules are responsible for the phenomenon known as surface tension. The molecules at the surface attract one another this forms a surface "film".
The cohesive forces between molecules down into a liquid are shared with all neighboring atoms. Those on the surface have no neighboring atoms above and exhibit stronger attractive forces upon their nearest neighbors on the surface. This enhancement of the intermolecular attractive forces at the surface is called surface tension

Explaining surface tension

Molecules in a liquid attract each other (cohesion). Figure (a) Molecules that are inside the liquid are attracted equally in all directions. The net force on a molecule inside a liquid is therefore zero. Figure (b). However those on the liquid surface have no liquid molecules above them. The attractive force is therefore due to the molecules that are inside the liquid. Consequently the molecules on the surface layer experiences an *inward pull* from the molecules below them (Figure (c)). The free surface of a liquid is therefore under tension which tends to stretch it.

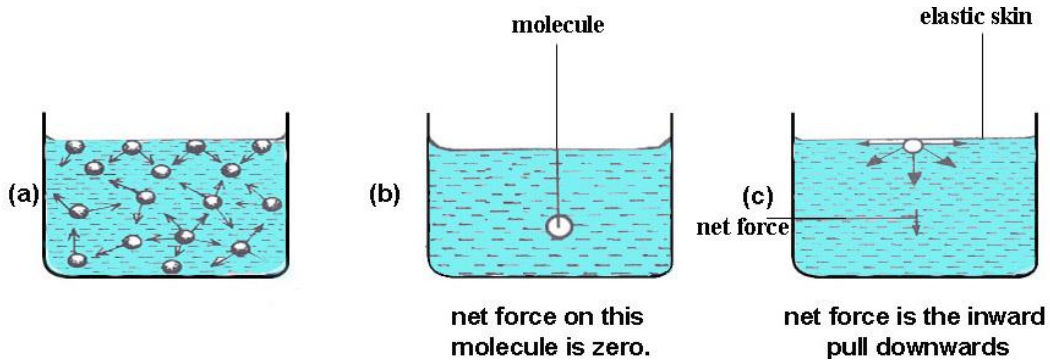


Figure 1.18

Experiment: To demonstrate surface tension.

Place a tissue paper on the surface of a clean water contained in a beaker. Carefully place a greased steel pin on top of the tissue paper. Take care not to touch the water. Observe what happens

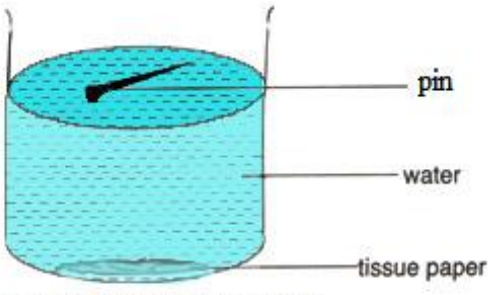


Figure.1.19: surface tension

The tissue paper absorbs water and sinks to the bottom, leaving the steel pin *floating* on the surface of the water. Use a hand lens to observe the surface under the steel pin. How does the steel pin which is denser than water float? The surface of water behaves like a stretched; thin elastic skin that is under tension. The force that causes a liquid to behave this way is called *surface tension.*

Put a drop of oil near the steel pin and note what happens. The steel pin immediately sinks. The oil has reduced the surface tension of water which supported the steel pin and hence the pin sinks, this shows that surface tension of a liquid is reduced by impurities introduced. It is also reduced by raising the temperature of the liquid.

Surface tension enables insects to walk on water surface. It provides a force which supports them.

Experiment: To show that a liquid will tend to have its surface as small as possible.

Dip an inverted filter funnel in a liquid soap or detergent solution. Take it out and blow a soap bubble on the wider end as shown in Figure (a). Observe closely what happens to the bubble.

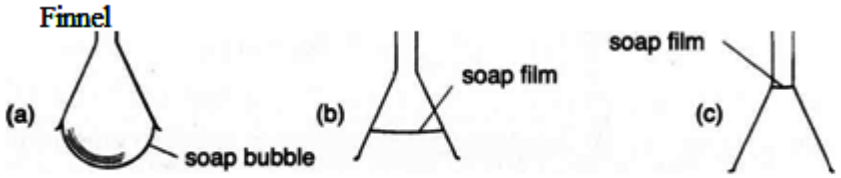


Figure: 1.20

The bubble flattens to a film and slowly moves up the funnel Figure (b) until it reaches the narrower end of the funnel Figure (c). The soap film acts as an elastic skin in forming the soap bubble. By moving up it tries to make its surface as small as possible.

Experiment: To show surface tension in soap film.

Tie a loose loop of cotton thread onto the wire frame. Slowly dip the wire frame into a liquid soap or detergent solution. Withdraw it slowly so that a film is formed across the wire frame as shown in Figure (a). Break the film inside the loop. Observe what happens.

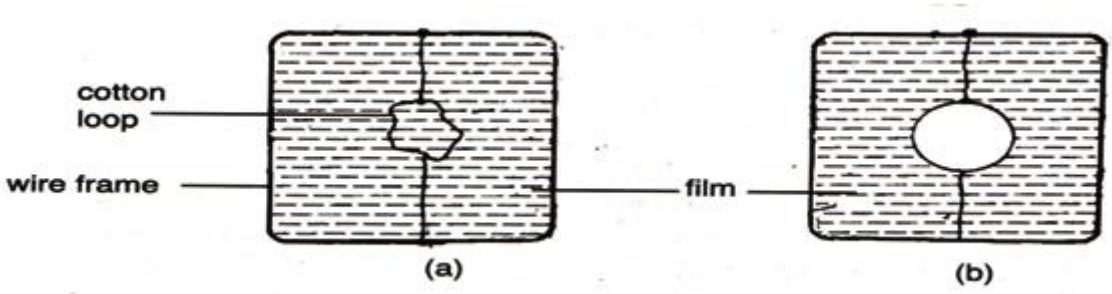


Fig.1.21: Film on a wire loop

Once the film is broken from the inside of the loop, it forms a perfect circle, Figure (b). The film tries to make its surface as small as possible by pulling the thread into a circle.

Experiment: To show surface tension in clean water

Fill a tumbler with clean water. Figure (a). Add a few more drops of water slowly in the tumbler as shown in figure (b). What happens to the water surface?

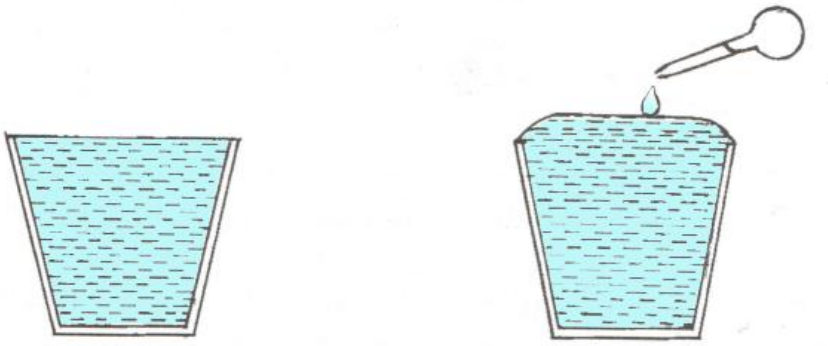


Figure 1.22: Surface of water behaves like an elastic skin

The water forms a concave shape. The surface of the liquid behaves. As if it was an elastic skin. However if more water is added the skin breaks and the water overflows

Factors Affecting Surface Tension

1. **Impurities**

Impurities reduce the surface tension of a liquid. Detergents, for instance, weaken the cohesive forces between liquid molecules.

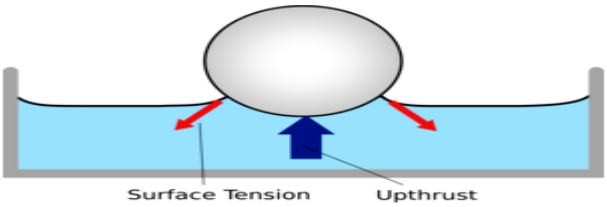
2. **Temperature**

With rise in temperature, the kinetic energy of the molecules of a liquid is increased. The inter-molecular distance increases and the force of cohesion is decreased. Hence, the surface tension is lowered.

Consequences of Surface Tension

1. Water insects can rest on the surface of water without breaking the surface. The insects also skate across the surface of water at high speed.
2. Mosquito larvae float on water surface. Oiling the water surface using kerosene lowers surface tension, thus making the larvae sink. Oiling still water therefore controls the breeding of mosquitoes.

3. Floating a needle on water If a steel needle is placed gently on the surface of water the needle does not sink, despite its greater density.



4. Spherical water drops Small liquid drops are nearly spherical, because surface tension always tends to reduce the surface area.

1.2 Properties of Materials

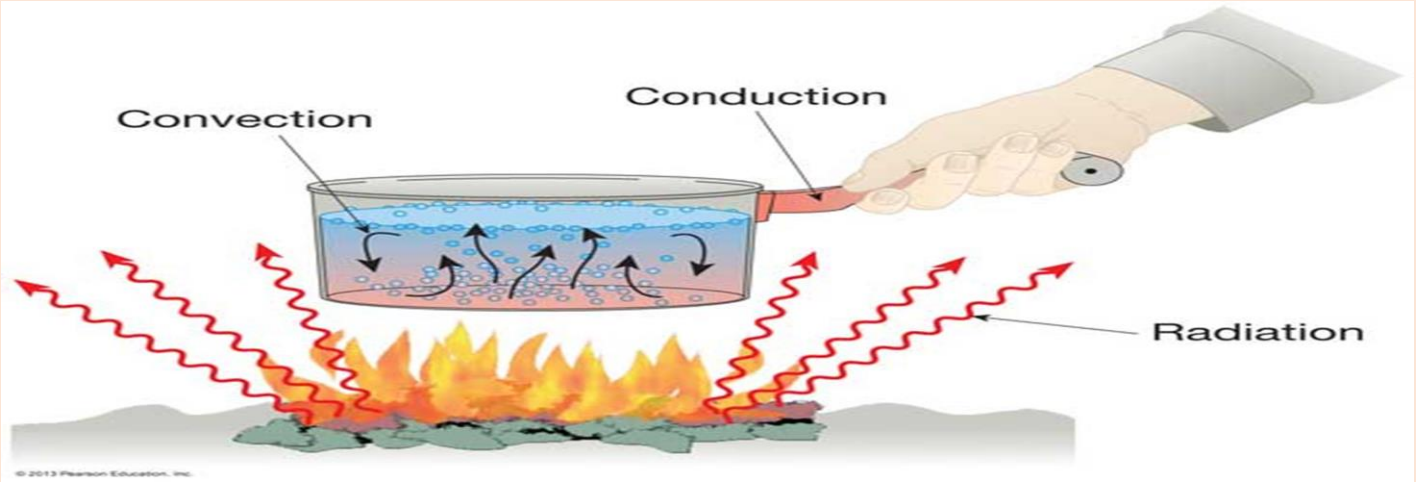
The properties of materials are a way of describing what a material is capable of and how it will behave under certain conditions. This is important when choosing materials for certain jobs, for instance choosing building materials or finding a good electrical insulator for the handle of an electrician's screwdriver!

Properties and Definitions

Here is a quick reference list of the main definitions. They include definitions that would be acceptable if given in an exam. Where units are given they are SI units.

Mass	The amount of matter in a body measured in *kg* - or more properly, mass is a measure of an object's resistance to changing its velocity
Volume	The space taken up by a material in m^3
Density	The amount of mass per unit volume measured in kg/ m^3
Young's modulus	A constant for a material given by stress/strain in $N\ nr^2$ or *Pa*
(Tensile) Stress	The force per unit cross-sectional area of a material that is being stretched or compressed (hence the 'tensile') in N /m^2 or *Pa*
(Tensile) Strain	The change in length/original length for a stretched/compressed material (which has no units as it is a ratio)
Elasticity	An elastic material will return to its original shape when stressing forces are removed.
Ductility	A ductile material is one that can be stretched but does not return to its original shape when the stress is removed
Hardness	How difficult it is to cut, dent or mark a material
Softness	A measure of how easily a material deforms without breaking
Brittleness	A brittle material will not stretch far beyond its elastic limit without breaking
Toughness	The amount of energy a material can absorb before it breaks.
Strength	How much force a material can withstand before it breaks
Malleability	How easily a material can be pressed, bent, hammered or rolled
Stiffness	The amount of resistance to being bent
Electrical conductivity	A material's ability to conduct electricity - dependent on the availability of free electrons
Thermal conductivity	A material's ability allow heat to flow through it
Sonorous	A sonorous material will make a ringing sound when struck
Lustrous	A lustrous material can be polished to a high shine
Melting point	The temperature at which a material changes from a solid to liquid, or a liquid to a solid (freezing)
Boiling point	The temperature at which a material will turn from a fluid to a gas, or gas to a fluid (condensing)
Latent heat	The energy needed to change the phase of a material
Heat capacity	The energy needed to raise the temperature of a material
Viscosity	A measure of how slowly a fluid will flow

Chapter Two Heat and temperature



Chapter objectives

By the end of this chapter learners will be able to:

- define heat and state that Joules are the units of heat
- State the difference between heat and temperature.
- discuss heat and its effects (heat sources eg sun, fire, gas, nuclear, geothermal
- explain the expansion and contraction in solids, liquids and gases
- demonstrate expansions in solids and liquids
- explain forces due to expansion and contraction
- explain the applications of expansion and contraction in solids and liquids
- describe the anomalous expansion of water and its effects.
- describe conduction, convection and radiation as processes of heat transfer
- explain the factors that affect conduction
- describe the properties of, and know which are, good and bad conductors of heat
- demonstrate convection in liquids.
- explain the molecular application of convection in fluids.
- explain the working of hot water systems, car engine, cooling system and land and sea breezes
- compare absorption and emission of radiant heat.
- explain the working of solar concentrators, heat traps and solar heaters.
- explain the working of a thermos flask
- state that temperature is a measure of the degree of hotness or coldness of an object
- show that temperature can be measured using alcohol, mercury and a thermocouple and a bi metallic strip
- be familiar with the Celsius and Kelvin scales
- state the fixed points for a thermometer (Celsius and Kelvin scales)
- describe the structure and action of liquid-in-glass thermometers

-

1.0 introduction

Heat or **thermal** energy is a form of energy that is possessed by hot matter. In other words; **Heat** is the energy which passes from a body at higher temperature to a body at lower temperature because of the difference between the temperatures of the two objects. Heat is scalar quantity and its unit is Joule (J). Heat energy can be used for: *Cooking food, ironing clothes, cutting metals and welding.* Heating has the following effects: can change body's *temperature*, *state* or *expand* it.

If a body gains heat energy, its temperature increases whereas the temperature of the body that gives away heat energy decreases. If two bodies at same temperature are in contact, there is no net heat flow from one body to the other. This condition is known as **thermal equilibrium**.

2.1 Thermal expansion

In general, when matter is heated it expands and when cooled it contracts. The atoms themselves do not expand, but the *volume*, they take up expands and contracts. If the changes are resisted, large forces are created which are sometimes useful, but at other times are nuisance.

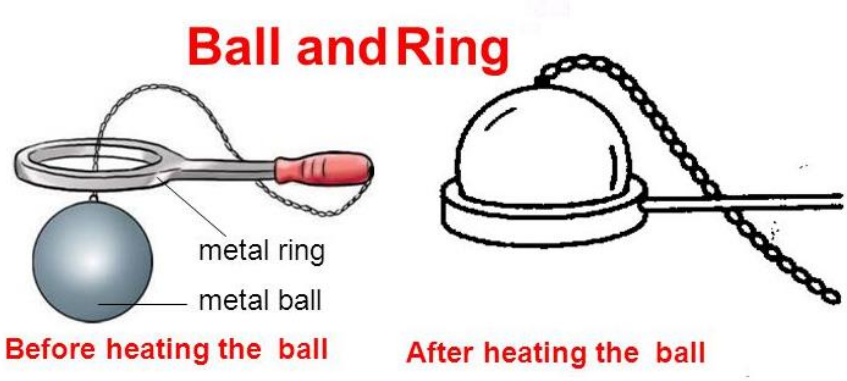
Thermal expansion of solids

When a solid is heated, its atoms vibrate faster about their fixed points. The relative increase in the size of solids when heated is therefore small. Metal railway tracks have small gaps so that when the sun heats them, the tracks expand into these gaps and don't buckle. Solids expand when heated and contract when cooled.

Experiment: To demonstrate expansion of solids using ball and ring experiment

Apparatus

The ball should be such that it just passes through the ring when both are at room temperature.



Procedure

- Heat the ball and try to pass it through the ring. Observe what happens.
- Leave it there for some time. Observe what happens.

Observation

When both the ball and the ring are at room temperature, the ball just passes through the ring. When the ball is heated, it does not go through the ring, but when left there for some time, it goes through.

-

Explanation

When heated, the ball expands so that it cannot go through the ring when left on the ring for some time, the temperature of the ball decreases and it contracts. At the same time, the temperature of the ball increases and expands so that the ball goes through.

Linear expansion

When the solid is heated its original length increases, and when cooled its original length decreases.

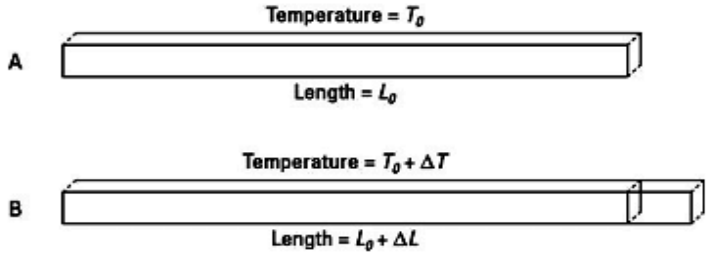


figure: 2.2 shows expansion of solid

Figure 1.2 shows a piece of metal that length increases as its temperature increases.

The change in unit length of a solid when its temperature is changed through one degree is called its **coefficient of linear expansion** or **linear expansivity** (**α**) .

The table below shows some substances and their coefficient of linear expansion.

Material	Average coefficient of linear expansion (α)
Aluminum	**2.6 x10^{-5} / C^0**
Brass	**1.9 x10^{-5} / C^0**
Copper	**1.7 x10^{-5} / C^0**
Iron	**1.2 x10^{-5} / C^0**
Concrete	**1.1 x10^{-5} / C^0**
Steel	**1.2x10^{-5} / C^0**

The linear expansivity α of a substance is the increase in length of 1 m for a 1 °C rise in temperature.

The linear expansivity of a material is found by experiment. For steel it is 0.000 012 per °C. This means that 1 m will become 1.000 012 m for a temperature rise of 1 °C. A steel bridge 100 m long will expand by 0.000 012 × 100 m for each 1 °C rise in temperature. If the maximum **temperature change** expected is 60 °C (e.g. from −15 °C to +45 °C), the expansion will be 0.000 012 per °C × 100 m × 60 °C = 0.072 m, or 7.2 cm. In general,

expansion = linear expansivity × original length × temperature rise

- **Change in original length (ΔL_1) is given by**

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

Where:
ΔL_1 *= change in original length,* L_1 *= original length*
α *= linear expansivity,* ΔT *= change in temperature*
L_2 *= New length*

-

- **New length (L_2) is given by**

$L_2 = L_1 + \alpha L_1 \Delta T$ or $L_2 = L_1 + \Delta L_1$ or $L_2 = L_1 (1 + \alpha \Delta T)$

Example-1

A piece of a steel 20m long in a building is heated **($\alpha = 1.2 \times 10^{-5} / C^0$).** When the temperature changes from $0C^0$ to $30C^0$, calculate:

a- increase in length

b- New length of the metal

Given

$L_1 = 20m$

$\Delta T = 30C^0 - 0C^0 = 30C^0$

$\alpha = 1.2 \times 10^{-5} / C^0$

$\Delta L_1 = ?$

Solution

a) $\Delta L_1 = \alpha L_1 \Delta T$

$\Delta L_1 = (1.2 \times 10^{-5} / C^0)(20m)(30C^0)$

$\Delta L_1 = 720 \times 10^{-5}$

$\Delta L_1 = 7.2 \times 10^{-3} m = \mathbf{0.0072m}$

b- $L_2 = L_1 + \Delta L_1$

Example-2

A piece of copper wire is 15m long at 10 C^0. What will be its length at 25 C^0? ($\alpha = 1.7 \times 10^{-5} / C^0$)

given

$L_1 = 15m$

$\Delta T = 25C^0 - 10C^0 = 15C^0$

$\alpha = 1.7 \times 10^{-5} / C^0$

$L_2 = ?$

Solution

$L_2 = L_1 + \alpha L_1 \Delta T$

$L_2 = 15m + (1.7 \times 10^{-5} / C^0)(15m)(15C^0)$

$L_2 = 15m + 382.5 \times 10^{-5} m$

$L_2 = 15m + 0.003825 m$

$L_2 = 15.0038 m$

Exercise

1- 100m copper pipe is heated through 50 C^0, ($\alpha = 1.7 \times 10^{-5} / C^0$). Calculate:

a- increase in length

b- the new length of the pipe

2- 50 m of aluminum metal is cooled from $30C^0$ to $10C^0$, ($\alpha = 2.3 \times 10^{-5} / C^0$). What is the new length?

-

Area expansion

When the solid is heated its original area increases, and when cooled its original area decreases.

The change in unit area of a solid when its temperature is changed through one degree is called its **coefficient of area expansion or superficial expansion (β)**

- **Change in or original area (ΔA_1) is given by**

$$\Delta A_1 = \beta A_1 \Delta T$$

- **New area (A_2) is given by**

$$A_2 = A_1 + \beta A_1 \Delta T \quad \text{Or} \quad A_2 = A_1 + \Delta A_1 \quad \text{or} \quad A_2 = A_1 (1 + \beta \Delta T)$$

Where:

ΔA_1= change in original area, β = area expansivity ($\beta = 2\alpha$)

ΔT = change in temperature, A_1= original area

A_2 = New area

Example-1

A brass cube has each edge 10cm at $15C^0$, ($\alpha = 1.9 \times 10^{-5} / C^0$). What will be the area of each face at $60C^0$?

given

$A_1 = 10cm \times 10cm = 100cm^2$

$\Delta T = 60C^0 - 15C^0 = 45C^0$

$\beta = 2\alpha = 2(1.9 \times 10^{-5} / C^0)$

$= 3.8 \times 10^{-5}/C^0$

$A_2 = ?$

Solution

$$A_2 = A_1 + \beta A_1 \Delta T$$

$A_2 = 100cm^2 + (3.8 \times 10^{-5}/C^0)(100cm^2)(45C^0)$

$A_2 = 100cm^2 + 17100 \times 10^{-5}cm^2$

$A_2 = 100cm^2 + 0.171cm^2$

$A_2 = 100.171cm^2$

Exercise

A 200 cm^2copper sheet is heated from $20C^0$ to $70C^0$, ($\alpha = 1.7 \times 10^{-5} / C^0$). Calculate:

a- Change in area

b- The new area

-

Volume expansion

When the solid is heated its original volume increases, and when cooled its original volume decreases. The change in unit volume of a solid when its temperature is changed through one degree is called its **coefficient of volume expansion or cubical expansion** (γ)

- **Change in original volume (V_1) is given by**

$$\Delta V_1 = \gamma V_1 \Delta T$$

- **New volume (V_2) is given by**

$$V_2 = V_1 + \gamma V_1 \Delta T \qquad V_2 = V_1(1+\gamma \Delta T) \qquad V_2 = V_1 + \Delta V_1$$

Where:
ΔV_1 = change in original volume, γ = volume expansion ($\gamma = 3\alpha$)
ΔT = change in temperature , V_1= original volume
V_2 = New volume

Example-1

A brass cube has sides of 12cm each side is heated from $20C^0$ to $50C^0$. ($\alpha = 1.9 \times 10^{-5} / C^0$). Calculate:

a- Increase in volume
b- - The new volume of the metal.

Given	***Solution***
$V_1 = 12cm \times 12cm \times 12cm = 1728cm^3$ $\Delta T = 50C^0 - 20C^0 = 30C^0$ $\gamma = 3\alpha = 3(1.9 \times 10^{-5} / C^0)$ $= 5.7 \times 10^{-5}/C^0$ ***a-*** $\Delta V_1 = ?$ ***b-*** $V_2 = ?$	***a-*** $\Delta V_1 = \gamma V_1 \Delta T$ $\Delta V_1 = (5.7 \times 10^{-5}/C^0)(1728cm^3)(30C^0)$ $\Delta V_1 = 295488 \times 10^{-5}\ cm^3$ $\Delta V_1 = 2.95 \times 10^{-5} cm^3$ ***(2dp)*** ***b-*** $V_2 = V_1 + \Delta V_1$ $V_2 = 1728\ cm^3 + 2.95 \times 10^{-5}\ cm^3 =$ ***$1730.95cm^3$***

Exercise

1- A block of iron with a volume of 40 cm^3 is heated from $10C^0$ to $60C^0$, ($1.2 \times 10^{-5}/C^0$). Calculate:

a- Increase in volume
b- New volume of the metal ‘
c- Decrease in volume *if it is cooled* from $10C^0$ to $0C^0$

-

Uses of expansion and contraction of solids

Expansion and contraction of solids have essential applications.

I. Bimetallic strip

If equal lengths of two different metals, such as copper and iron are riveted together, so that they cannot move separately they form **bimetallic strip**. When heated copper expands more than iron and this allows the strip bends with copper on the outside. If they had expanded equally, the strip would have strayed straight. Bimetallic strip itself has many uses.

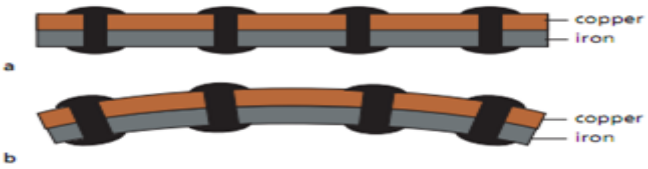
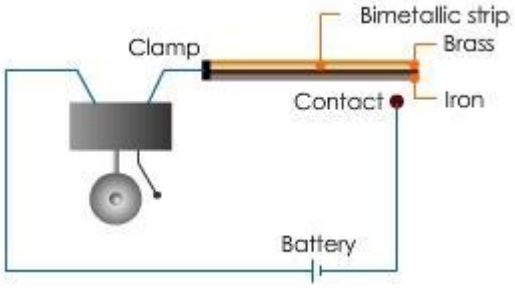


figure: 2.3 shows the expansion of bimetalic strip before and after heating

Application of bimetallic strip

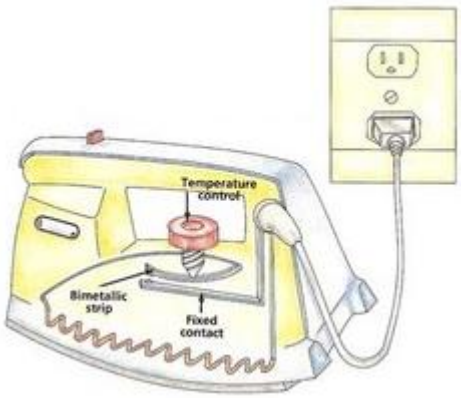
Fire alarm

A bimetallic strip is used to make or break an electric circuit at a preset temperature. When the heat from the fire reaches the bimetallic strip rises the electric circuit is made to completer, which makes the bell to ring.



Thermostat

A thermostat is a device made of a bimetallic strip that can be used to maintain a steady temperature in electrical appliances with heating element, such as electric iron, refrigerators and others.



-

As thermometer

Bimetallic strip thermometer is mechanical thermometer which makes use of thermal expansion of the strip that contains two metals with different linear expansions like **iron** and **brass**.

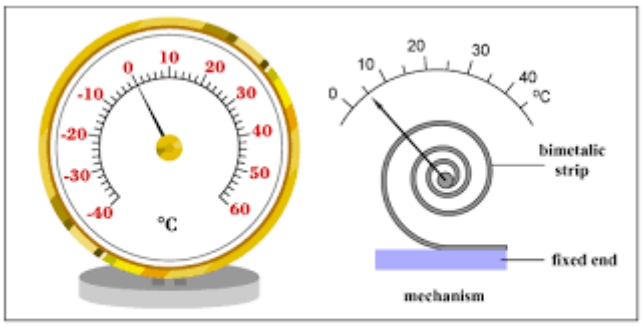


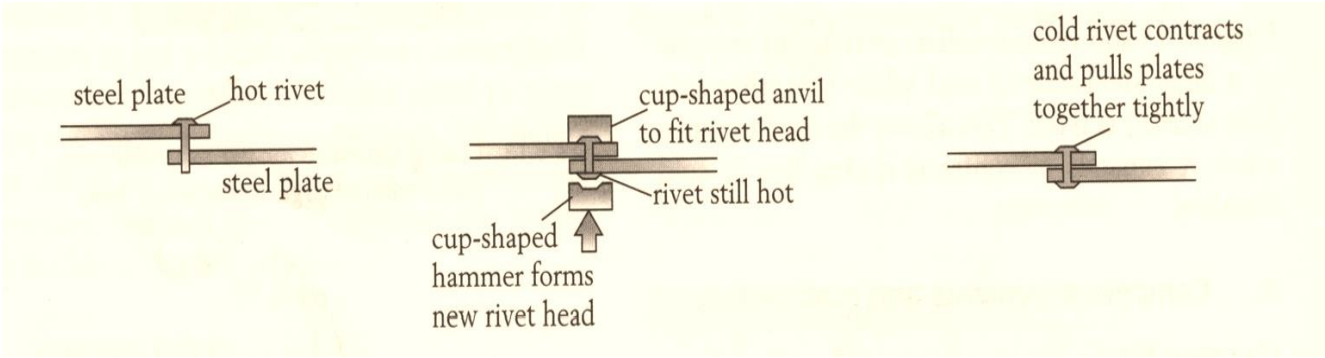
figure: 2.6 shows a bimetalic strip thermometer

Rivets

In industries, steel plates are joined together by means of rivets. Hot rivets are placed in the rivet holes and the ends hammered flat. On cooling, the force of contraction pulls the plates firmly together.

III-Fitting an axel in to wheel

An axle has been shrunk by cooling in liquid nitrogen until the wheel can be slipped on to it On regaining normal temperature the axle expand to give a very tight fit.



-

IV- Rail way lines

While laying railway tracks, a small gap is left between adjacent rails. This is because the iron rails expand in summer, and the gap allows space for the expansion.

Exercise

1. A man wants to fit a brass ring tightly onto a steel rod of diameter equal to the inner diameter of the ring. Explain how this can be achieved.
2. State and explain the disadvantages of anomalous expansion of water.
3. State two advantages of thermal expansion.
4. A bimetallic is made of aluminium and copper riveted together. Which metal expand the most when the strip is heated? Draw a sketch the way the strip will bend.
5. Explain (a) why a metal lid of a glass jar can be unscrewed easily if the jar is placed in very hot water (b) railway tracks were once laid with gaps between adjacent lengths.
6. Rods of platinum, copper and steel are the same length at 0^0C. Which of them will be the longest at 200^0C?
7. A man wants to fit a brass ring tightly onto a steel rod of diameter equal to the inner diameter of the ring. Explain how this can be achieved?

-

2.2 Thermal expansion of liquids

Almost all liquids expand when heated and contract when cooled. Some liquids expand more than others.

In liquids, the molecules are loosely packed together; the force of attraction between molecules is weaker than those in solids. The molecules move freely in the liquid. On heating, the speed and the collision among the molecules increase and so the distance between them increases causing the liquid expand.

Experiment

To demonstrate expansion of water

Apparatus

A round-bottomed flask filled with colored water and a Bunsen burner.

Procedure

- Fill the flask with a colored water and arrange the apparatus as shown in the figure
- Mark the level of the water in the glass tube
- Heat the flask with the burner flame as you observe the level of the water in the tube.

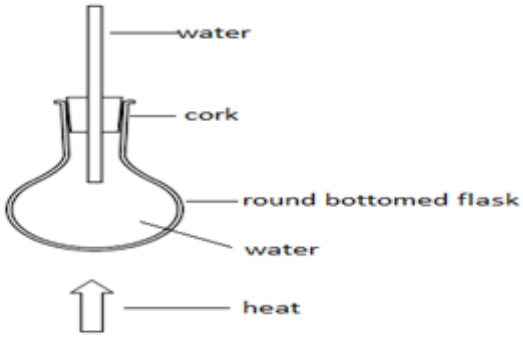


figure: 2.10 round bottomed flask

Observations

The level of the water in the glass tube falls slightly at first and then starts rising.

Explanation

The initial fall of the level of the water is due to the expansion of the glass flask, which gets heated first. The water starts expanding when heat finally reaches it, and it rises up the tube.

Note: The water expands faster than the glass.

The table below shows some liquids and their coefficient of volume expansivity.

Average coefficient of volume expansivity	
Alcohol, ethyl	1.12×10^{-4}
Benzene	1.24×10^{-4}
Acetone	1.5×10^{-4}
Glycerin	4.85×10^{-4}
Mercury	1.82×10^{-4}
Turpentine	9.0×10^{-4}
Gasoline	9.6×10^{-4}

-

Example-1

A motorist purchases 10 liter of gasoline on a cold day when the temperature is -20 ^{0}C. What is the volume of this gasoline after it has warmed up to 20 ^{0}C? **($\gamma = 9.6 \times 10^{-4} /C^0$)**

Given	*Solution*
$V_1 = 10$ liter $\Delta T = 20C^0 - (-20C^0) = 40C^0$ $\gamma = 9.6 \times 10^{-4} /C^0$ **V_2 =?**	*$V_2 = V_1 (1+ \gamma \Delta T)$* *$V_2 = 10L(1+9.6 \times 10^{-4} /C^0(40C^0)$* *$V_2 = 10\ L\ (1+ 384x10^{-4})$* *$V_2 = 10\ L(1+ 0.0384)$* *$V_2 = 10\ L(1.0384)$* *$V_2 = 10.384$ liters*

Exercise-1

Calculate the increase in volume of 100ml of mercury when its temperature changes from 10^{0}C to 35^{0}C. ($\gamma = 9.6 \times 10^{-4} /C^0$)

Unusual expansion of water (Anomalous expansion of water)

When talking about expansion of liquids, water shows anomalous (unusual) behavior. That is, it contracts when its temperature is raised from **0^{0}C**to about **4 ^{0}C.**

When ice is heated from, say, **-20^{0}C**it expands until its temperature reaches **0^{0}C**and melts with no change in temperature. The melting is accompanied by contraction. The water formed will still contract as its temperature rises from **0^{0}C**up to **4^{0}C**as shown in the graph below.

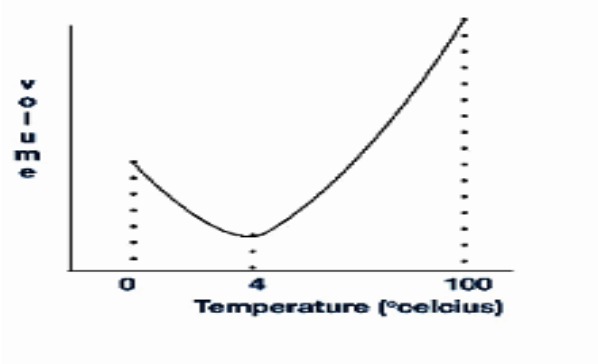


figure: 2.11 graph of expansion of unusual expansion of water

Above **4^{0}C,** the water expands with increase in temperature. Since volume of a given mass of water has minimum volume and maximum density at **4^{0}C.**

-

Some effects of anomalous expansion of water

Ice bergs

In cold weather, when the temperature of the atmosphere falls to 0^0C, water in a lake or pond freezes and ice is formed. How do fish then survive in frozen water?

Ice is less density than water (because water has greatest density at 0^0C) and flouts on the surface of water, this allows fish and other animals for survival inside water.

Bursting of water pipes

When water in pipes expand due to freezing, it can burst water pipes. This effect is disadvantageous one.

Weathering of rocks

When water inside the crack of a rock freezes, it expands. This expansion breaks the rock in to small pieces.

Expansion of gases

in gases, the molecules are much further apart than in solids and liquids. This is because the attractive forces between gas molecules are very weak. When heated gas molecules gain more energy and move further apart, occupying more space, that results the expansion of gases.

Experiment

To show expansion of gases

Apparatus

A round-bottomed flask with glass tube in tight-fitting rubber cork, and a basin of wa

Procedure

- Invert the flask with the glass tube dipped in to the water as shown in the figure
- Warm the flask with your hands for some time and note what happens.
- Remove your hands and let the flask cool while the tube is still inserted in water. Observe what happens.

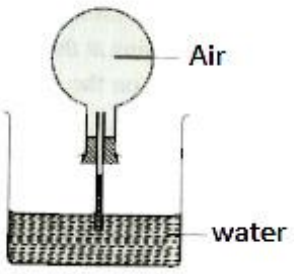


figure: 2.12 shows a round bottomed flask

Observations

When the flask is warmed, the level of the water column inside the glass tube drops. When the flask is warmed further, some bubbles are seen at the end of the tube in water. On cooling, the air inside the flask contracts and water rises up the glass tube.

Explanation

The column drops, indicating that air expands. Bubbles are seen at the end of the tube as air escapes from the flask.

-

Effects of expansion of gases

- One of the reasons why bread and cakes rise when baked is because the gases inside the dough expand when heated.
- Hot air balloons rise because the hot air inside the balloon is heated by the flame and expands. The air is less dense than the surrounding air and the balloon rises.

Exercise

1- State and explain the advantages of unusual expansion of water.
2- If a gas is heated, what happens its volume?

2.3 Heat transfer

Heat can travel through a medium and also through a vacuum. There are three modes of heat transfer, and they are; *Convection*, *Conduction* and *Radiation.* Both conduction and convection require a material medium, but radiation can take place in a vacuum. Conduction of heat takes place in solids while convection takes place in fluids (liquids and gases).

Conduction

Thermal conduction is the transfer of thermal (heat) energy through a substance without the substance itself moving.

If you stir hot tea using a metal spoon, you will observe that the handle of the spoon becomes warm. The mechanism which heat is conducted through the spoon can be explained in two ways:

i- Heat energy entering the spoon from the hot end increases the vibrations of the atoms in the spoon at this end. These atoms in turn collide with neighboring atoms, increasing their vibrations and hence passing the heat energy along, till heat reaches the cool end. If this continuous for same time the whole spoon will be same temperature.

ii- Metals have free electrons which travel throughout the body of the metal. Heat energy injected at the hot end of the metal spoon increases the vibrations of the particles at that end. The free electrons in that region gain more kinetic energy and because they are free to move, spread heat energy to the other parts of the spoon.

-

Comparing conductivity of metals

Experiment

Comparing thermal conductivity of various conductors

Apparatus

Rods of aluminium, iron, copper, rubber, glass, wood (all must be of same length and cross-sectional area) are waxed on the surface, thermal conductivity tank, source of heat.

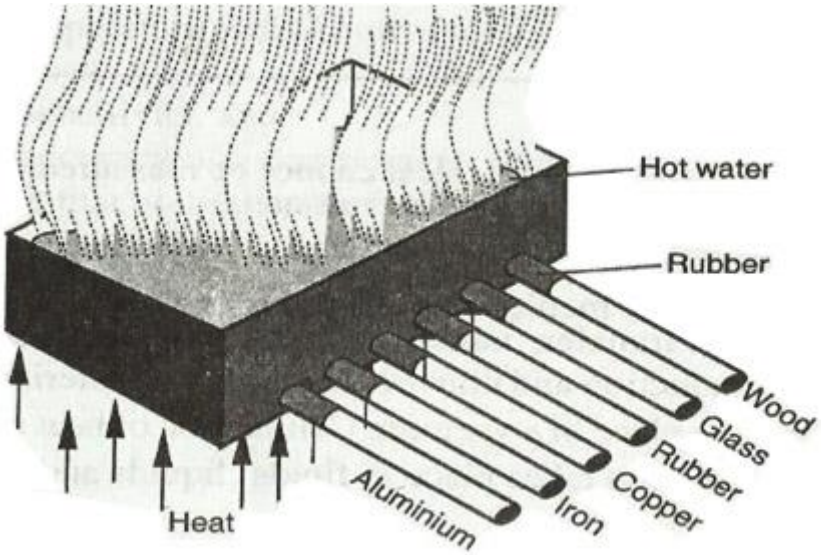


figure: 2.13 shows expansion of solids

Procedure

- Set the apparatus as shown. Ensure that the rods are held firmly. Pure boiling water in to the container.
- The hot water bath is used for the uniform heating of the rods.
- Observe the order in which the wax (or vaseline) melts off the rods. The best conductor is one whose wax melts off first.
- List the rods in order of decreasing conductivity.

Observations

Different materials have different thermal conductivities. Metals are generally good conductors of heat. Non-metals are poor conductors of heat (insulator)

From the foregoing, solids that are good conductors of heat (metals) use both *atom vibration*and *free electrons* to conduct heat. Solids that poor conductors of heat like glass, wood and rubber make use of atoms vibration as a mechanism to conduct heat because they have no free or mobile electrons.

-

The *table below* shows some of good and poor conductors in decreasing order of thermal conductivity.

Good conductors	**Poor conductors**
Silver	Concrete
Copper	Glass
Aluminium	Brick
Brass	Asbestos paper
Zinc	Rubber
Iron	Wood
lead	Water
Mercury	Air

Factors affecting thermal conductivity

a-	The temperature difference between the ends of a conductor	The rate of heat flow is directly proportional to the temperature difference.
b-	The length of the conductor	The rate of heat flow is inversely proportional to the length of the conductor.
c-	The cross-sectional area of the conductor	The rate of heat flow is directly proportional to the cross-sectional area of the material.
d-	The nature of the material	The rate of heat flow is dependent on the type of material by nature.

Rate of heat flow can be calculated using this formula

$$R = \frac{KA(T_2 - 1)}{d}$$

R = rate of heat flow, **T1** and **T2** indoor and outdoor temperature

A = surface area, **K**= thermal conductivity

-

Example-1

Calculate the rate at which heat flows through a window of area $2m^2$with a thickness of 6mm, if the indoor temperature is maintained at $20C^0$and the outdoor temperature is 30^0C. (k = 0.7w/m/^{0}C)

Given

$\Delta T = 30C^0 - 20C^0 = 10C^0$

$A = 2m^2$

K = 0.7w/m/^{0}C

R = ?

Solution

$$R = \frac{KA\Delta T}{d}$$

$$R = \frac{(0.7w/m/C^0)\,(2m^2)(10C^0)}{0.006m} = 2.333w$$

Using insulating materials in a house

1- Plastic foam lagged round the hot water storage tank
2- Wool or plastic foam insulation in the loft
3- Wall cavity filled with plastic foam, beads or wool
4- Double glazed windows: two sheets of glass with air between them

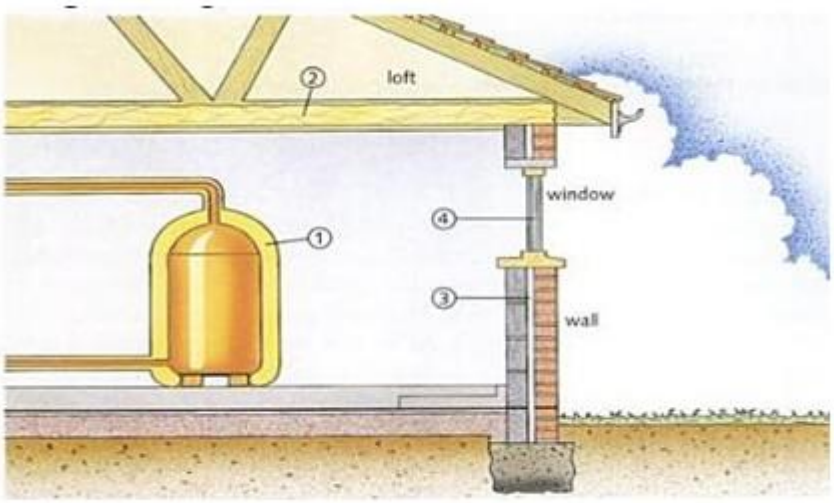


figure: 2.14 shows insulating materials used in housees

Convection

Convection is the transfer of heat through fluids (liquids and gases) by the upward movement of warmer, less dense regions of fluid.

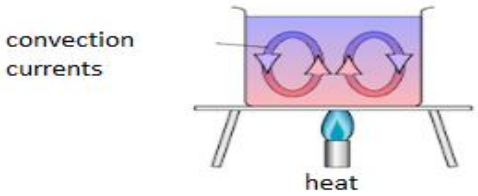
The heat transfer is made by the actual movement of the fluid, called convection currents, which arise out of the following;

i- Natural convection: involves change in density of the fluid with temperature.

ii- Forced convection: mixing hot and cold parts of the fluid through some external stirring. Like a fun or pump.

-

For example, water inside a saucepan is heated throughout by convection. Water near the bottom of the pan warms up first, expands, becomes less dense and rises. Cold water near the top of the pan sinks to the bottom of the pan where it is too heated. Convection currents are set up and continue until all the water is warmed up.



Molecular explanation of convection in fluids

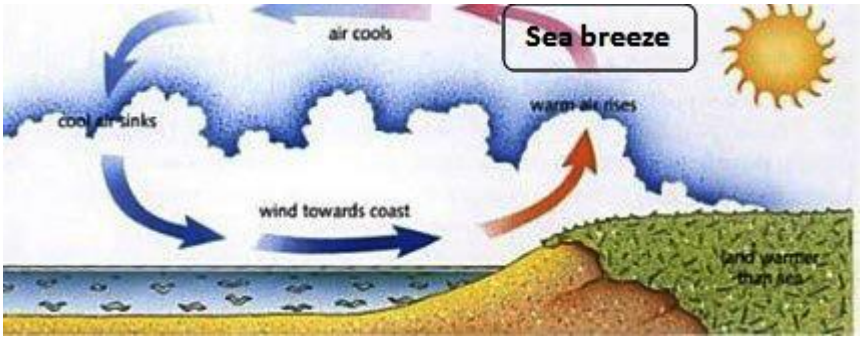
Molecules in fluids are further apart and have negligible cohesive force. Heating a fluid increases the kinetic energy of the vibrating molecules and their random movement. As the fluid rises, these molecules pass energy to the molecules in the colder regions which have less energy. Because the molecules are further away from the heating source. Their temperature is reduced. Meanwhile, the pressure near the heating source decreases because of depletion of molecules as they rise. Colder molecules move in to the low pressure zone to fill up the void being created.

This movement of molecules constitutes convection current. Convection currents are set up much faster in gases than in liquids because of the extremely low cohesive forces existing between the molecules of the gases.

Effects of convection in fluid

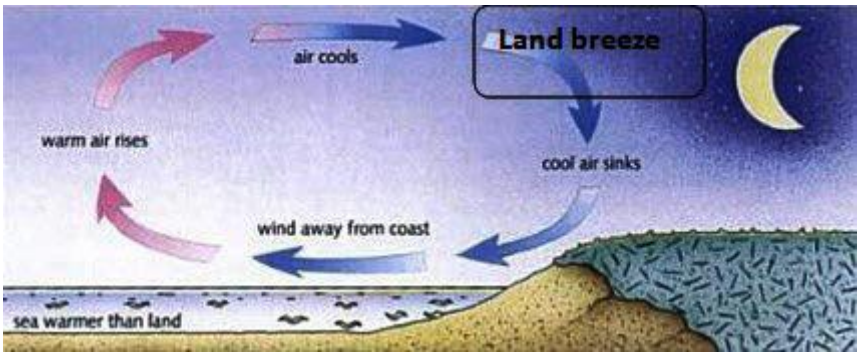
Coastal breezes

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 than that of water. The hot air above the land rises and is replaced by colder and denser air from the sea. Breeze from the sea, known as **sea breeze** is resulted.



-

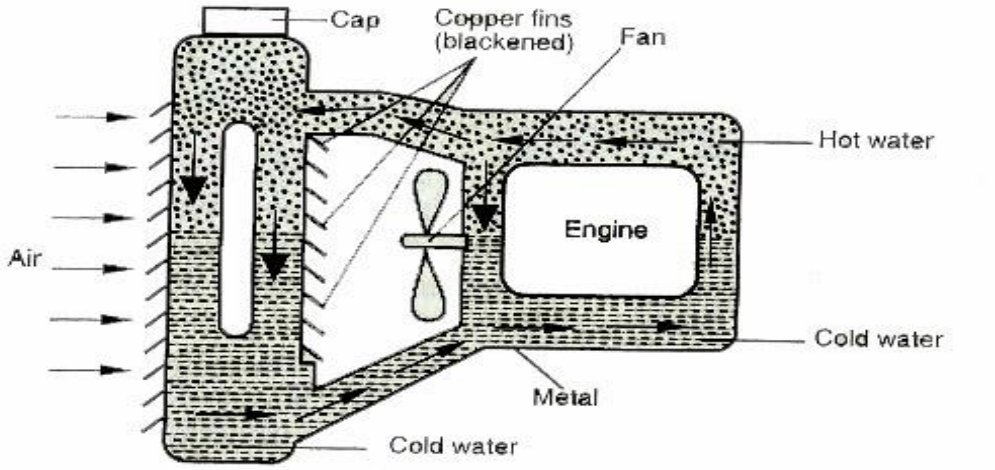
At night when the temperature falls, the opposite happens. The sea cools more slowly than land, which is the air above the sea is warmer than that over the land then it rises and is replaced by colder, denser air from the land. Breeze from the land, known as **land breeze** is resulted.



C**ar engine cooling system**

Conduction and convection of heat play a very crucial role of taking away heat from a car engine that would otherwise reduce its efficiency. The engine is surrounded by a metal water jacket that is connected to the radiator.

The metal surface conducts away heat from engine. This heats up the water, setting up convection currents. The hot water is pumped into the radiator which has thin copper fins that conducts away heat from the water. Fast flowing air past the fins speeds up the cooling process.



Radiation

Radiation is a third way in which heat can travel but whereas both conduction and convection need matter to be present, radiation can occur in a vacuum; particles of matter are not involved. It is the way heat reaches us from the sun.

Radiation is the flow of heat from one place to another by means of electromagnetic

When radiation falls on an object, it is partly reflected, partly transmitted and partly absorbed; the absorbed part rises the temperature of the object.

Radiation is emitted by all bodies above absolute temperature (0k, -273^0C or -460^0F), and consists of mostly infrared radiation, but light and ultraviolet is present if the body is very hot.

-

Good and bad absorbers and emitters of thermal radiation

Some surfaces are better emitters of thermal radiation than others. For example, a black saucepan cools down more quickly than a similar white one because it emits energy at a faster rate.

Good emitters of thermal radiation are also good absorbers. White or silvery surfaces are poor absorbers because they reflect most of the thermal radiation away. That is why in hot sunny countries are often painted white to keep them cool inside.

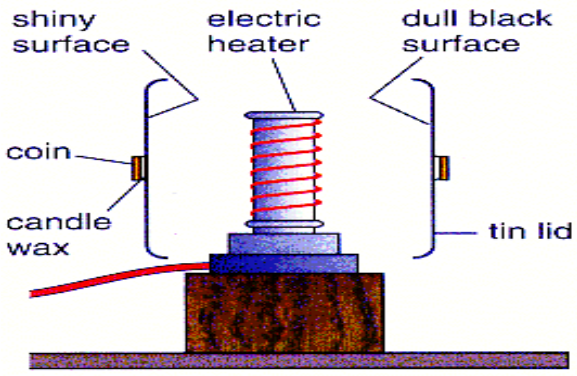
Surface	Absorption	Emission
Dull, matt or rough	Good	Good
Shiny	Poor	Poor

Experiment

To compare radiation from different surfaces

Apparatus

Two similar sheets of aluminum plates, one polished and the other painted black (dull), source of heat.



Procedure

- Using wax, fix a cork on the reverse side of each plate, as shown in the figure below.
- Set the plates vertically at a reasonable distance apart.
- Place the Bunsen burner midway between the plates and away from draught. Observe the corks fixed on the plates.

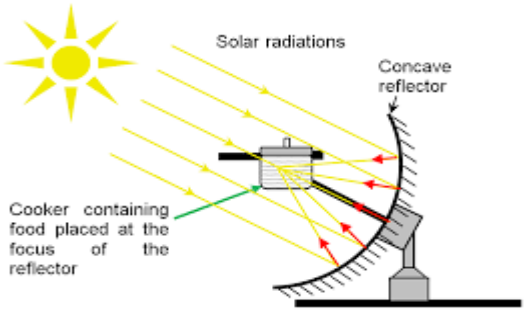
Observation

The cork fixed on the dull plate falls off after the wax melts, while the cork on the polished plate remains fixed for a longer time.

Application of thermal radiation

In **solar concentrators**, electromagnetic waves in form of radiant heat are reflected to a common point (Focus) by a concave reflector. The temperature at this point can be sufficiently high to boil water.

-



Spherical reflector type solar cooker

Kettles and cooking pans have polished surfaces to reduce heat loss through thermal radiation.

pan

Kettle

Houses in hot areas are painted white

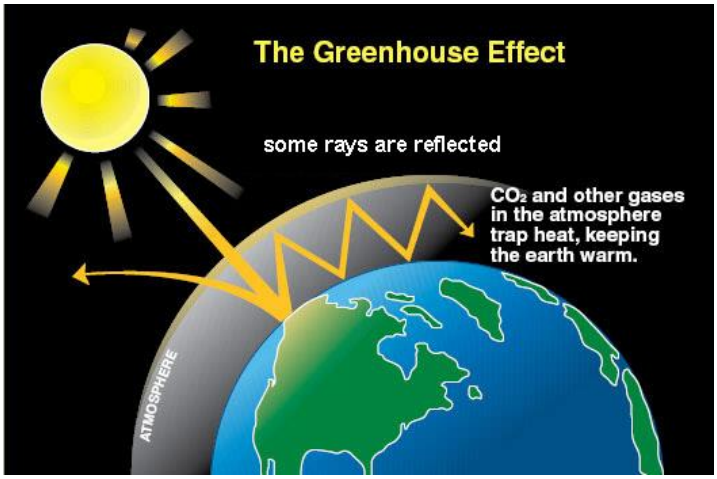
Houses in hot areas have their walls and roofs painted with bright colours to reflect away heat, while those in cold regions have walls and roofs painted the dull colours.

White painted houses in hot areas

Greenhouses (glasshouses) are used to grow plants. Shorter wavelengths infrared rays and light rays from the sun can pass through the glass or plastic panes of a greenhouse and are absorbed by the soil and plants, raising their temperature. The soil and plants in turn emit longer wavelengths infrared rays which cannot penetrate glass. The inside of the greenhouse stays hot. (Very hot objects like sun emit short wavelength infrared rays; less hot objects like the soil emit longer wavelength infrared rays which cannot penetrate glass.)

-

Carbon dioxide and other gases such as *methane* in the atmosphere help the atmosphere to act in a similar way to a greenhouse. The atmosphere lets infrared and light rays pass through to the surface of the earth. There they are absorbed and converted to internal energy of the plants and land mass. The warmer land now radiates long wavelength infrared radiation. This is absorbed by carbon dioxide and water vapour in the atmosphere. These gases are warmed up as a result, and they in turn radiate energy in all directions as infrared rays. Some of this energy is radiated back to the earth. Without the carbon dioxide and water vapour this energy would have been lost, so the earth is warmer as a result.

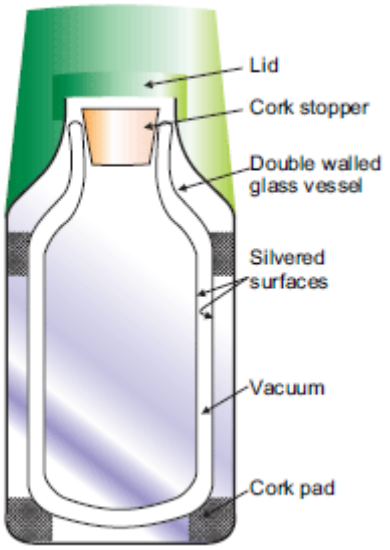


Vacuum flask (thermo flask)

Vacuum flask is designed to deep its contents at a fairly constant temperature by minimizing transfer of heat between the contents of the flask and the surrounding. The figure below shows main parts of vacuum flask.

The flask is made of a high quality glass, blown in such a way that is double-walled. The air between the walls is pumped out to create a vacuum. This vacuum is an excellent insulator, minimizing heat transfer by conduction and convection.

Heat transfer by radiation which might be relatively large, is reduced by a layer of silver coating on the inside surfaces, so that each wall is a poor emitter and a poor absorber of heat. Heat loss by evaporation from the liquid surface is prevented by well-fitting cork. The metal or plastic case is necessary as a protection for the glass envelope. The soft padding holds the glass flask firmly in the case.



Exercise

1- Distinguish between natural and forced convection currents.
2- Explain why the feet feel colder when a person stands on a cemented floor than when on a wooden floor.
3- Explain why some houses in hot areas like *Mombasa* should be painted white while those in colder places like *Timboroa* should be painted with dull colours.
4- Explain the greenhouse effect and how it affects the earth.

-

5- How would you, on a sunny day, use a concave reflector to heat some water in a black container? What difference is expected when the container is made shiny?
6- Explain each of the following:

a- A saucepan might have a copper bottom but a plastic handle.

b- An aluminium window frame feels colder than a wooden window frame when you touch it.

7- Give three ways in which insulating materials are used to reduce thermal energy loses from a house.
8- A hot water tank loses thermal energy even when lagged. How could the energy loss be reduced?
9- Why are metals much better thermal conductors than most other materials?
10- In hot summer's day, coastal winds often blow in from the see.

a- What caused the winds?

b- Why do the winds change direction at night?

11- What feature does a vacuum flask has to reduce the transfer of heat by thermal radiation?
12- Suppose you have three surfaces; white, silvery and matt black. Which of the surfaces is best at

a) absorbing thermal radiation
b) emitting thermal radiation
c) reflecting thermal radiation

2.4 Temperature

Temperature is the degree of hotness and coldness of an object. There is a more precise definition of temperature. In any object, the particles (atoms or molecules) are in constant random motion. They move at varying speeds, but the higher the temperature, the more kinetic energy they have, and the faster they move.

If a hot object is placed in contact with a cold one, there is a transfer of thermal energy from one another. As the hot object cools down, its particles lose kinetic energy. As the cold object heats up its particles gain kinetic energy. So,

> Temperature is the average kinetic energy per particle of an object.

The SI unit of temperature is Kelvin (K), but there are other units like *degree Celsius* and *Fahrenheit.*

Heat and temperature

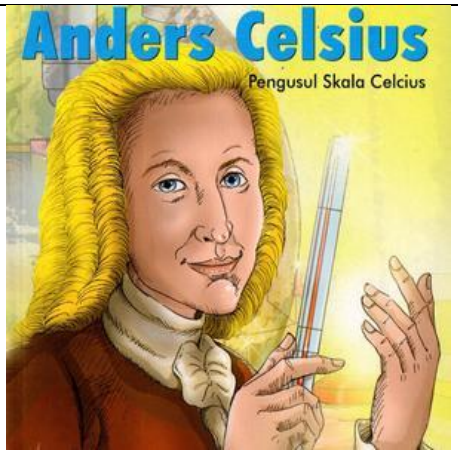
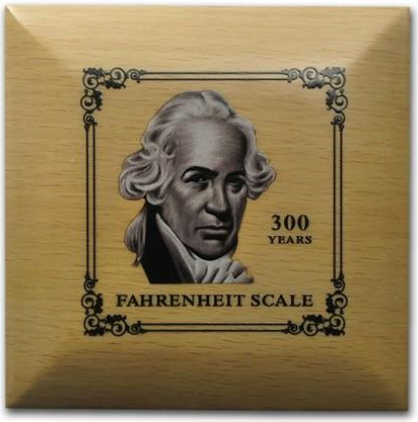
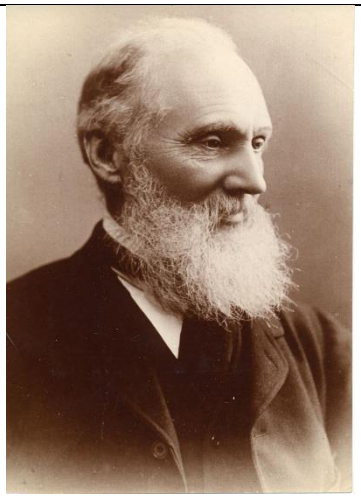
It is important not to confuse the temperature of the body with the heat energy that can be obtained from it. Temperature and heat are different. For example, a spoonful of boiling water has exactly same temperature (100^0C) as a saucepan full of boiling water, but you could get less thermal energy from the spoonful of boiling water than the saucepan full of boiling water, because they have different amount of thermal energy.

Temperature scales

A scale and unit of temperature are obtained by choosing two temperatures called fixed points and dividing the range between them in to a number of equal divisions or degrees.

There are different types of temperature scales. Some of them are discussed below.

-

Celsius scale Celsius scale is one common temperature scale. This scale was developed by the Swedish scientist, *Andres Celsius* in 1784. This scale uses two fixed points: the lower fixed point, **0 C^0**, is the temperature which pure ice melts (ice point), while the upper fixed point, **100 C^0**, is the temperature which pure water boils (steam point). It was called for *centigrade scale* for many years, but this name should no longer be used.	
Fahrenheit scale This scale was developed by German physics, *Gabriel Fahrenheit* (1686-1736), it is based two fixed points: the lower fixed point, **0 F^0**, for the melting point of pure ice, while the upper fixed point, **98F^0**, for the boiling point for pure water.	
Kelvin scale This scale was developed *Lord Kelvin* (1824-1927), it is based on two fixed points: the lower fixed point, 0K for lowest possible temperature which means the temperature that particles of the substance have their lowest possible kinetic energy. This temperature is known as *absolute temperature*. And the upper fixed point is 373K for the boiling point of pure water.	

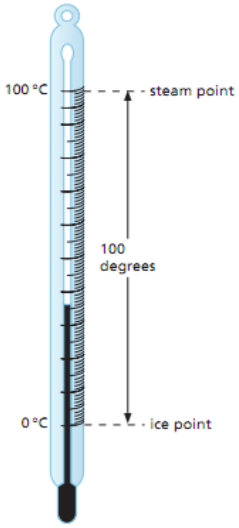
-

Types of thermometers

Thermometer is an instrument used for measuring temperature. There are different types of thermometers, each type being more suitable than other for certain task.

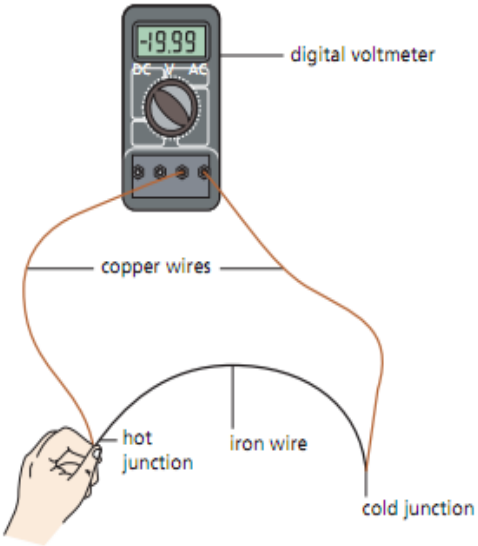
Liquid in glass thermometers

In this type the liquid in a glass bulb expands up a capillary tube when the bulb is heated. The liquid must be easily seen and expand and contract linearly with change in temperature, it must not stick to the inside of the tube. Mercury and coloured alcohol are in common use. Mercury freezes at **-39^{0}C** and boils at **357^{0}C.** Alcohol freezes at **-115^{0}C**and boils at **78 ^{0}C.**



Thermocouple thermometer

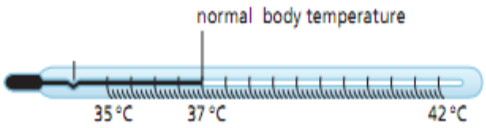
A thermocouple thermometer consists of wires of two different materials, such as copper and iron joined together. When one junction is at a higher temperature than the other, then an electric current flows and produces a reading on sensitive meter which depends on the temperature difference.



Clinical thermometer

A clinical thermometer is a special type of mercury in glass thermometer used by doctors and nurses. Its scale only extends over a view degrees on either side of the normal body temperature of 37 ^{0}C.

Digital thermometers are now replacing mercury thermometers for clinical use.



-

Digital thermometers

Digital thermometers contain an electrical circuit which changes electric temperature signals into numbers. The numbers appear in a display window; these have the advantage that the sensor which reads the thermometer can be some distance from the indicator itself.

Exercise

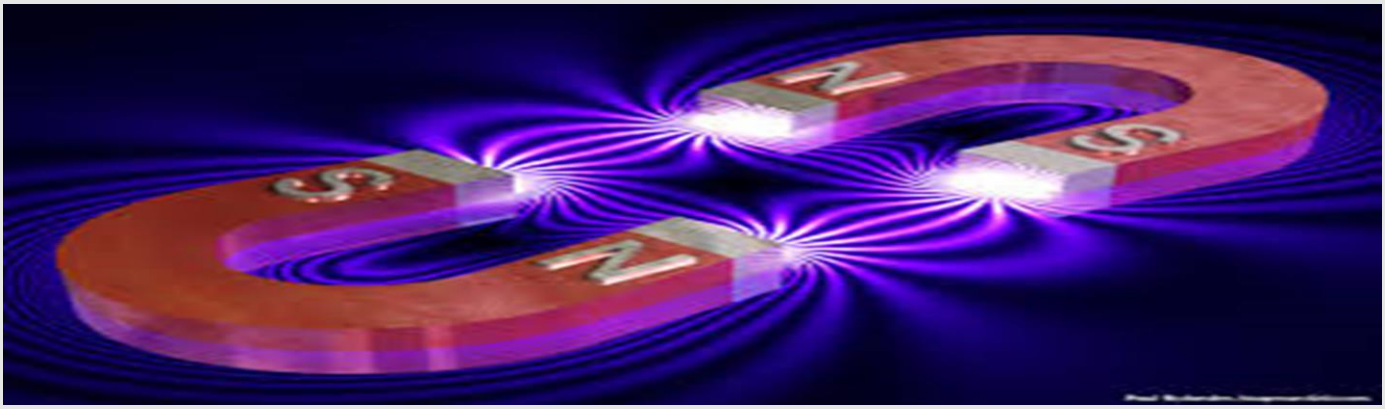
1- Distinguish heat and temperature.

2- What is meant by absolute temperature?

3- Why mercury and alcohol are used in liquid-in-glass thermometers rather than water?

-

CHAPTER THRE: Magnetism



CHAPTER OBJECTIVES

By the end of this chapter the learners will be able to:

- describe early history magnetism (lodestone)
- identify magnetic and non-magnetic materials
- describe the properties of magnets.
- state and observe that like poles repel and unlike poles attract(basic law of magnetism)
- construct a simple compass.
- show the difference between a temporary (eg soft iron) and a permanent magnet (eg steel) and an electromagnet
- understand that a magnetic field is regions of space where magnetic material experience magnetic forces
- describe magnetic field patterns
- show the field pattern produced by a bar magnet and proper use of the terms 'magnetic flux or lines of force ', 'neutral points', magnetic induction, and 'magnetic shields'
- show that the earth possess a magnetic field.
- describe methods of magnetisation
- show how to make magnets
- describe the methods of demagnetization.
- describe how to care for magnets
- have a basic idea of the 'domain theory' of magnetism
- describe the uses of magnets
- describe the magnetic field surrounding a current-carrying conductor or wire using the corkscrew rule
- perform and describe an experiment to determine the direction of a magnetic field round a current carrying conductor.
- determine the magnetic field patterns on solenoid
- construct a simple electromagnet.
- experimentally determine the factors affecting the strength of an electromagnet
- describe an electromagnet and some application (electric bell, telephone, moving-coil loudspeaker)
- describe some simple uses of electromagnets
- state that the interaction of magnetic fields produce motion and is called the motor effect
- state and use Fleming's Left Hand rule
- explain and show how a simple D.C. motor works
- explain factors effect speed of simple D.C. motor

3.0.Introduction

Origin of magnet, the name magnet is came from a Greek town called magnesia which was the first place found something attract other things such as iron and it was *2500years* ago .The people of Magnesia in Asia Minor observed that certain kinds of naturally occurring ores possessed an iron-attracting property. The ore was discovered near the city of Magnesia and hence it was named Magnetite. Huge lumps of magnetite were often called ***lodestone*** meaning ***"leading stone"*** stone or natural magnet. Chemically lodestone consists of iron oxide. Pieces of magnetite are known as ***natural magnets.*** A suspended piece of magnetite aligns itself with the magnetic field of the earth. About the twelfth century men began to use these natural magnets, as the first magnetic compasses

Dr. William Gilbert **(1540-1603)** did a lot of work with the natural magnets. He published a book called **De magnete** in 1600 in which he gave an account of his research into the magnets and their properties.William Gilbert's report on his experiments with natural magnets, published in **1600,** probably represents the first scientific study of magnetism. In the years that followed, discoveries by Coulomb, Oersted, and Ampere added to our knowledge of the behavior of magnets and the nature of magnetic forces. However, physicists believe that it is only within this century that they have begun to understand the true nature of magnetism. The present view is that the magnetic properties of matter are electric in origin, probably resulting from the movements of electrons within the atoms of substances.***Magnet*** is a piece of metal which attract or repel other pieces of metal.

3.1 Properties of magnet

Magnetic and non-magnetic materials

Materials are commonly classified as magnetic or nonmagnetic.***Magnetic materials*** are materials which magnets attract and can be made magnet, magnetic materials include the elements **iron, nickel, cobalt,** alloys containing some of these such as **steel** and the pure metals which magnet attract strongly are called ***ferromagnetic materials.***

Ferrimagnetic materialsare metaloxides which magnet attract and also called **Ferrites**. e.g. copper oxide, , manganese oxide, zinc oxide and aluminium oxide.

Materials that magnets do not attract are called ***non-magnetic materials***, for example; *plastic, wood, rubber and paper, are* those which do not demonstrate the strong ferromagnetism of the Iron Family of metals are said to be "nonmagnetic." However, if these materials are placed in the field of a very strong magnet, some are observed to be slightly repelled by the magnet, while others are very slightly attracted.

-

Zinc, bismuth, sodium chloride, gold, and mercury are a few of the substances that are feebly repelled, and are said to be *diamagnetic.* The property of *diamagnetism* is an important concept in the modern theory of magnetism,

Wood, aluminum, platinum, oxygen, and copper (II) sulfate are examples of substances which are very slightly attracted by a strong magnet. Such materials are said to be ***paramagnetic,*** and this type of magnetic behavior is called ***paramagnetism.***

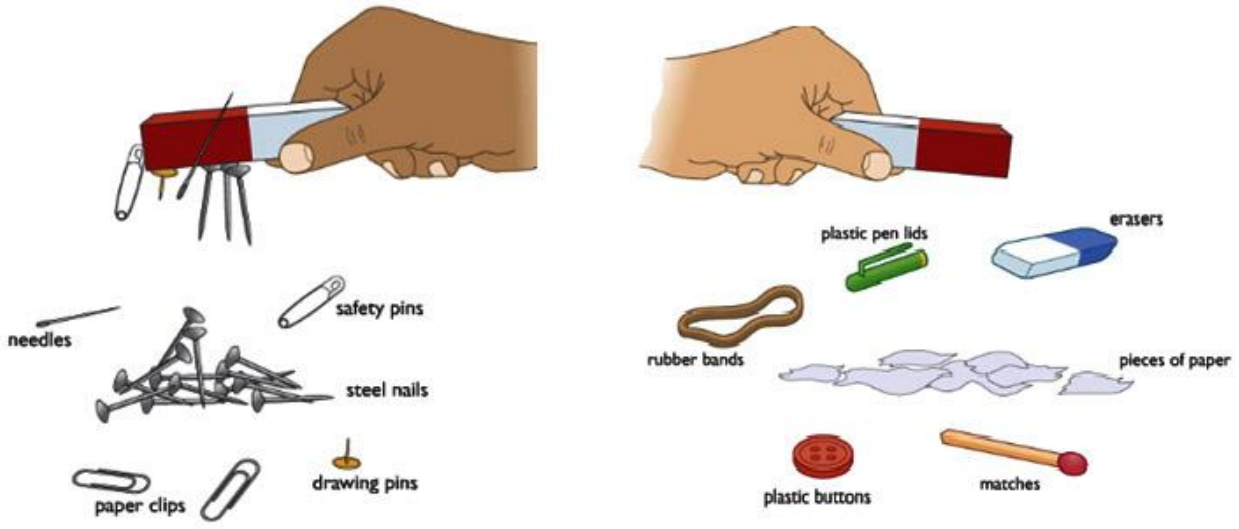


Figure shows magnetic and non-magnetic

Experiment: To determine magnetic and non-magnetic materials

Place some iron nails on the bench. Bring a bar magnet close to the iron nails and record what happens. Repeat the experiment with other material e.g. copper, cobalt, steel, sulphur, brass, wood, cork, nickel, plastics, wax, glass, carbon, aluminium, paper, chalk etc. Record your observations in a tabular form shown in Table 1.1.

Table **1.1**

Substances attracted by a bar magnet	Substances not attracted by a bar magnet
1.	
2.	
3.	
4.	

Some materials are attracted while others are not attracted by bar magnets. Those which are attracted are called *magnetic materials* while those not attracted are called *non-magnetic materials.* Examples of nonmagnetic materials include copper, brass, alluminium, wood, cork, plastics etc. The magnetic materials that are strongly attracted by a magnet are called *ferro-magnetic materials.* These include nickel, iron, cobalt and steel.

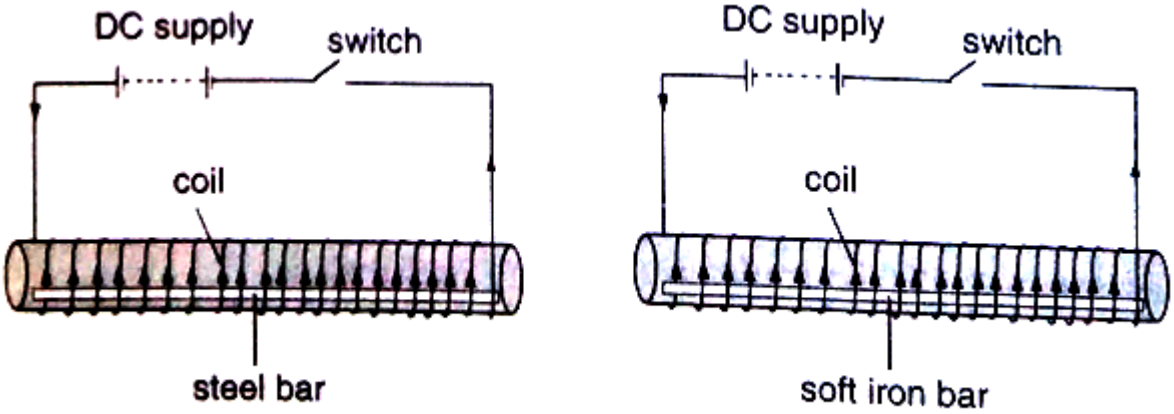
-

Hard and soft magnetic material

Hard Magnetic Materials	Soft Magnetic Materials
Materials which retain their magnetism and are difficult to demagnetize are called hard magnetic materials. **These materials retain their magnetism even after the removal of the applied magnetic field. Hence these materials are used for making permanent magnets. In permanent magnets the movement of the domain wall is prevented. They are prepared by heating the magnetic materials to the required temperature and then quenching them. Impurities increase the strength of hard magnetic materials.**	Soft magnetic materials are easy to magnetize and demagnetize. These materials are used for making temporary magnets. The domain wall movement is easy. Hence they are easy to magnetize. By annealing the cold worked material, the dislocation density is reduced and the domain wall movement is made easier. Soft magnetic materials should not possess any void and its structure should be homogeneous so that the materials are not affected by impurities.
They have large hysteresis loss due to large hysteresis loop area.	They have low hysteresis loss due to small hysteresis area.
They are used for permanent magnets	Soft magnetic material are used as the core of the electromagnet because their magnetism can be easily switched ON or OFF

Experiment: To distinguish between hard and soft magnetic material.

Introduce a steel bar into a coil as shown in Figure (a). Close the switch to pass the current for a short time and then open the switch. Remove the material and test for magnetism. Repeat the experiment but using other magnetic materials such as a soft iron bar (Figure (b))



(a) steel bar *(b) soft iron bar*

Magnetic materials such as soft iron are magnetised easily but do not retain their magnetism for long. Such materials are called *soft magnetic* materials. They are usually used in making *temporary magnets.* Other materials such as steel are difficult to magnetise but once magnetised, they retain the

-

magnetism for long. Such materials are referred to as *hard magnetic* materials. They are usually used in making permanent magnets.

Some chemical combination such as zinc oxide with ferric oxide produce strong magnetic materials called *ferrites*. They have the advantages that they can be strongly magnetised and yet not demagnetized easily.

3.2 Types of magnet

Magnets can be classified into two; **Permanent magnets** and **Temporary magnets** according to the time they keep their magnetism.

Permanent magnets: are magnets that retain (keep) their magnetism once magnetized. Ferromagnetic material which include nickel, cobalt, some alloys of rare earth metals, and some naturally occurring minerals such as lodestone, Permanent magnets are made from hard magnetic material such as *alloy or steel*

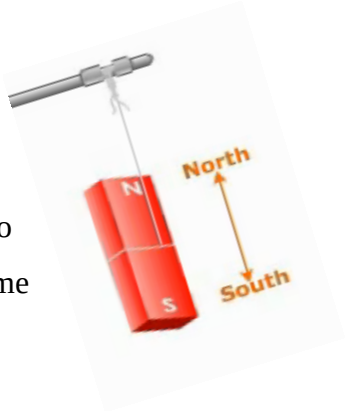
Temporary magnets: are materials magnets that perform like permanent magnets when in the presence of a magnetic field, but lose magnetism when not in a magnetic field and temporary magnets are the made from *pure iron*. Example: Electromagnets.

Magnetic poles

Experiment: to investigate the directional property of a magnet

Apparatus

Bar magnet, cotton thread, and wooden stand



Procedure

- Suspend a bar magnet with a cotton thread from a wooden stand, so that the magnet freely swing around in horizontal plane. Give it time and observe the direction in which it comes to rest.

Observation

- it comes to rest with one end pointing south pole of the earth (this pole is called south seeking pole or simply **South pole**) and the other end pointing the north pole of the earth (this pole is called north seeking pole or simply **North pole**).

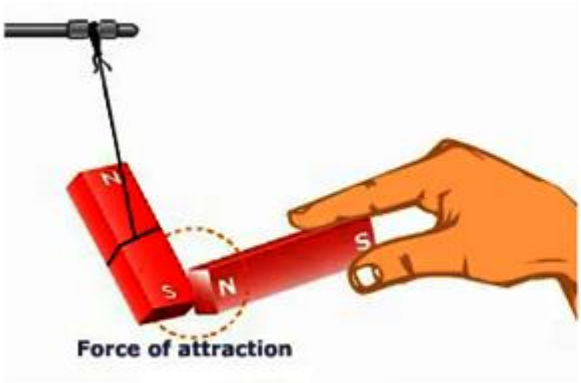
Conclusion

Magnets have two poles. The pole which is pointing roughly the north is called N-pole and the other end is pointing south is called S-pole. A magnet can be used as a compass.

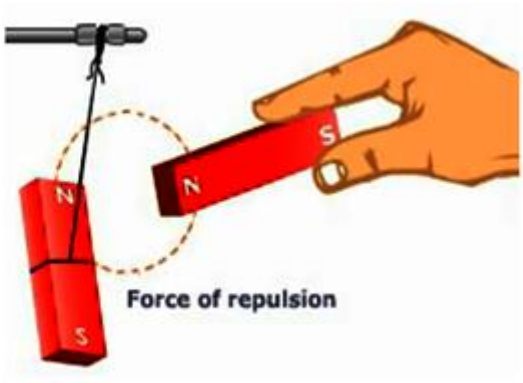
-

Experiment: To investigate the basic law of magnetism
Apparatus
Long Bar magnet, long cotton thread and stand Procedure

Suspend a bar magnet using a cotton thread with its north and south-pole clearly marked. Bring a *N-pole* of a second bar magnet slowly towards the *S-pole* of the suspended magnet. Observe what happens, (Figure (a)). Repeat the experiment using the *N-pole* of the suspended magnet and the *N-pole* of the second magnet. (Figure (b))



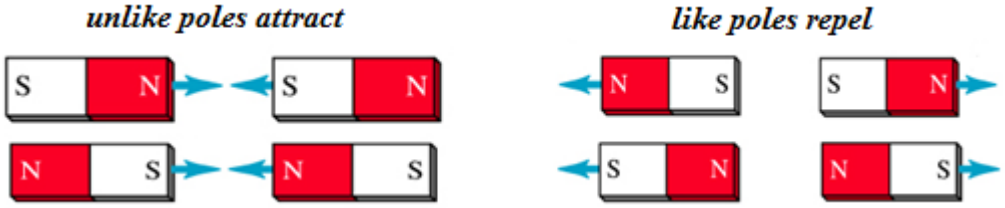
(Figure (a))



(Figure(b))

Law of magnetic poles

Like poles repel and unlike poles attract, this is also called the law of magnetism.



South	*South*	
South	*North*	
North	*South*	
North	*North*	

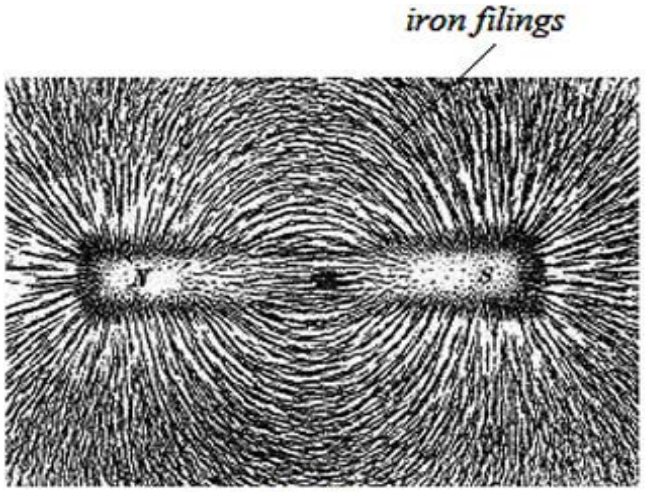
Repeat using the other poles and record your observation in a table (see Table1.2)

Poles exist in pairs; if a magnet is broken from middle, then each part is found to be magnet

-

3.3 Magnetic field

A magnet creates a magnetic field around it. The space surrounding a magnet in which magnetic force is exerted, is called a ***magnetic field.*** A compass needle placed near a magnet gets deflected due to the magnetic force exerted by the magnet, and the iron filings also cling to the magnet due to magnetic force. The magnetic field pattern due to a bar magnet is shown in Figure. The magnetic field has both, *magnitude* as well as *direction*. *The* direction of magnetic field at a point is the direction of the resultant force acting on a hypothetical north pole placed at that point. The north end of the needle of a compass indicates the direction of magnetic field at a point where it is placed. The magnetic field lines are the lines drawn in a magnetic field along which a north of compass needle would point. The *magnetic field lines* are also known as *magnetic lines of force*. The direction of a magnetic field line at any point gives the direction of the magnetic force on a north pole placed at that point. Since the direction of magnetic field line is the direction of force on a north pole, so the magnetic field lines always begin from the N-pole of a magnet and end on the S-pole of the magnet. Inside the magnet, however, the direction of magnetic field lines is from the S-pole of the magnet to the N-pole of the magnet. Thus, the magnetic field lines are closed curves.



magnetic field of Bar magnet

magnetic field of U-shaped magnet

-

Magnetic field pattern due to bar magnets

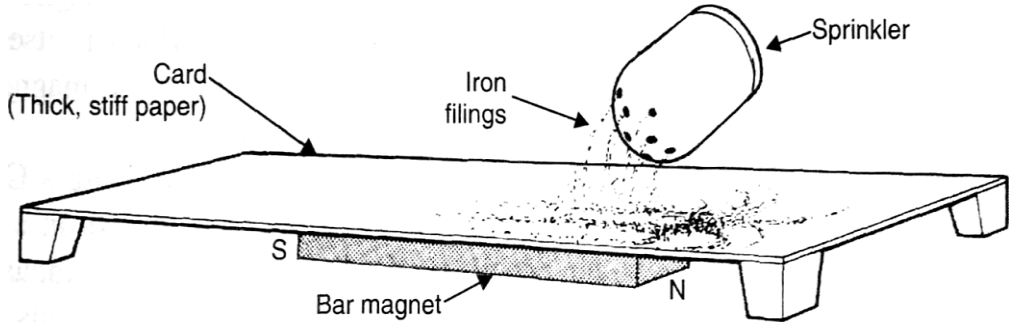
Experiments: To show the magnetic field pattern due to a bar magnet.

Apparatus

Bar magnet, iron filings and smooth stiff cardboard

Procedure

Place a smooth stiff paper on top of a bar magnet. Sprinkle iron fillings onto the stiff paper. Tap the paper gently and draw the pattern displayed by the iron fillings as shown in figure (a). Iron fillings are attracted by the magnet. Note the observation. Hence there is a magnetic effect in the space around a bar magnet. The pattern displayed by the iron fillings represents the magnetic lines of force. Figure shows the photograph of the arrangement of iron fillings around the magnet. Figure (b) shows the magnetic field lines. Note that the lines do not cross each other



Figure(a). Experiment to trace the magnetic field pattern of a bar magnet by using iron filings

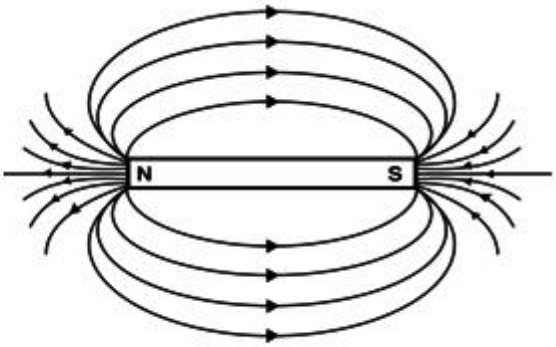
Observation

The iron filings experience the force of magnetic field of the bar magnet. The force of magnetic field

-

of the bar magnet makes the iron filings to arrange themselves in a particular pattern. Actually, under the influence of the magnetic field of the bar magnet, the iron filings behave like tiny magnets and align themselves along the directions of magnetic field lines. Thus, iron filings show the shape of magnetic field produced by a bar magnet by aligning themselves with the magnetic field lines.

magnetic field pattern around a bar magnet



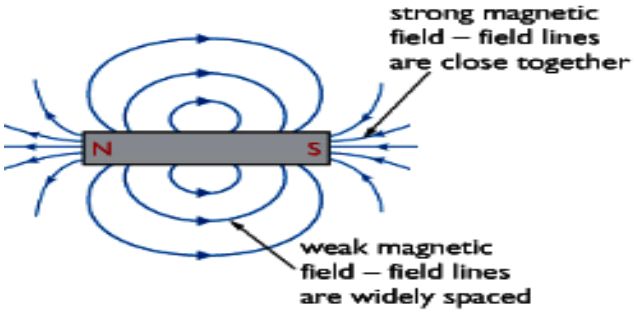
magnetic field lines around Bar magnet

Properties (or Characteristics) of the Magnetic Field Lines

1. The magnetic field lines originate from the north pole of a magnet and end at its south pole.
2. The magnetic field lines come closer to one another near the poles of a magnet but they are widely separated at other places. A north magnetic pole experiences a stronger force when it approaches one of the poles of the magnet. This means that the magnetic field is stronger near the poles. From this we conclude that where magnetic field lines are closer together, it indicates a stronger magnetic field. On the other hand, when magnetic field lines are widely separated, then if {indicates a weak magnetic field.
3. The magnetic field lines do not intersect (or cross) one another. This is due to the fact that the resultant force on a north pole at any point can be only in one direction. But if the two magnetic field lines intersect one another, then the resultant force on a north pole placed at the point of intersection will be along two directions, which is not possible.

The magnetic field is strongest where the magnetic lines are closes together. Two magnetic field lines never intersect each other

Magnetic field lines are sometimes called lines of ***magnetic flux***. Magnetic flux is a vector quantity which has both magnitude and direction. The strength of the field is defined in terms of flux density. A high flux density means that the lines of force are close together.



Magnetic flux density (magnetic field strength) is measures by an instrument called ***Hall probe***

-

Direction of magnetic field

Experiment: To investigate the direction of the magnetic field.

Apparatus

Bar magnet, magnetic needle fixed to a cork, glass trough.

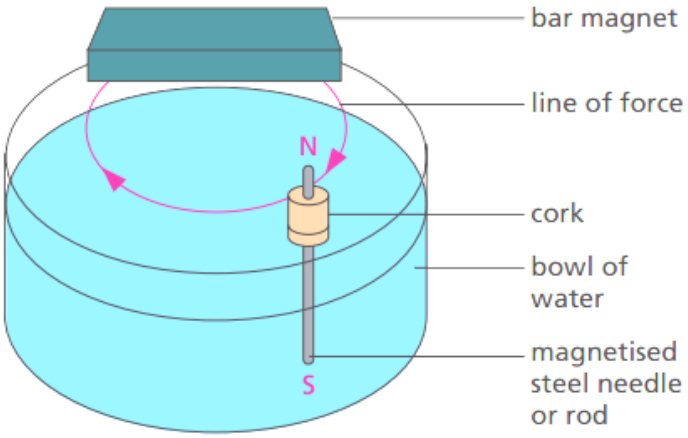


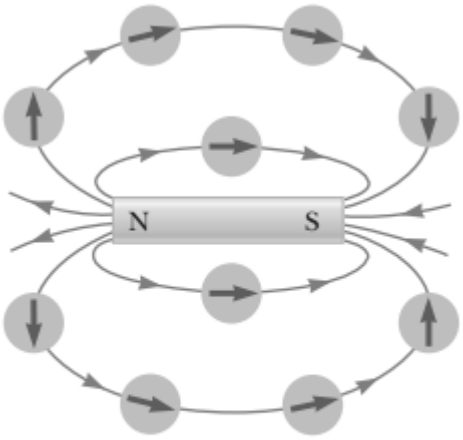
Figure 34.2 Detecting magnetic force

Procedure

- Fasten a small bar magnet on a wooden lath. Place the lath on top of a deep basin containing water.
- Using a cork, float a long magnetized knitting needle on the water so that it floats with its north pole as far away from the south of the bar magnet as possible.
- Bring the north pole of the needle close to the north pole of the bar magnet.
- Release the needle and note the path followed by the north pole of the needle.
- Repeat the experiment with the needle on the other side of the bar magnet (Figure)

DID YOU KNOW?

Birds can detect the Earth's magnetic field, and use the field to find their way when they migrate from cold to warm climates or from warm to cold climates. Cows stand or lie so that their bodies are in a north–south direction but the magnetic fields surrounding high voltage power lines can confuse their sense of direction!

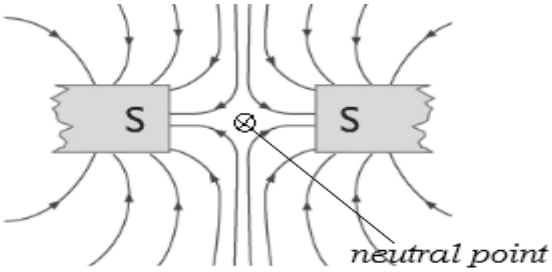


Compass needles can be used to trace the magnetic field lines in the region outside a bar magnet.

-

Observation

When the needle is held with its north pole near the north of the magnet and released, the needle is repelled. It moves towards the South Pole along a curve. The direction of the magnetic field at a point is direction which a free north pole would move if placed at that point in the field. Thus, a magnetic line of force can be defined as the path along which a north pole would move if free to do so.There is also another method of obtaining the magnetic field pattern around a bar magnet. This is done by using a compass. A compass is a device used to show magnetic field direction. When a small compass is moved along a magnetic field line, the compass needle always sets itself along the line tangential to it. So, a line drawn from the south pole of the compass needle to its north pole indicates the direction of the magnetic field at that point.



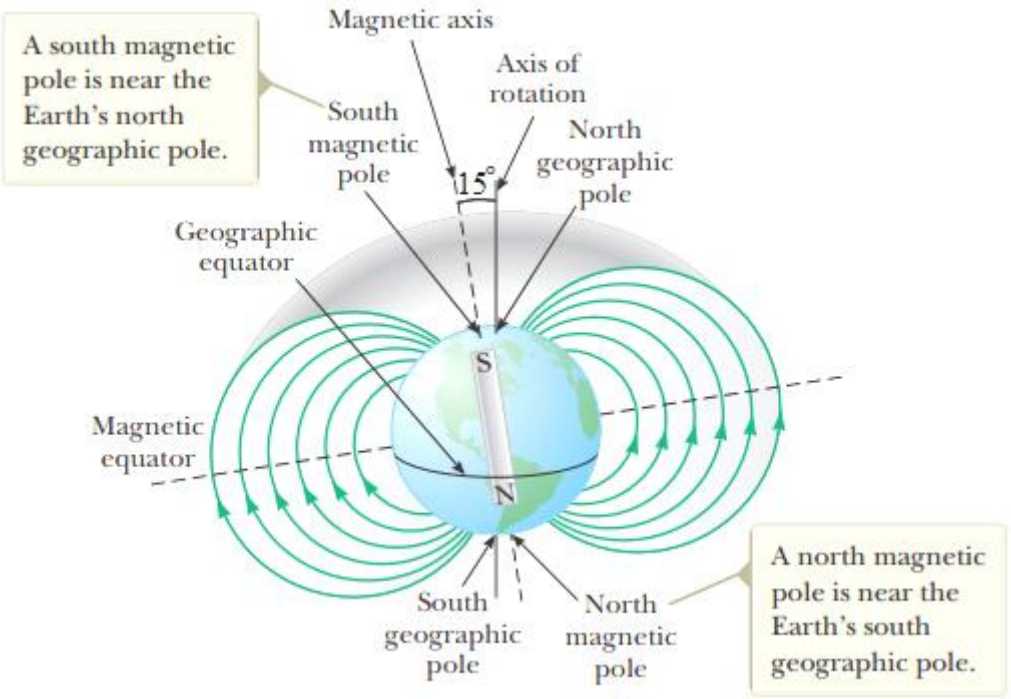
At the ***Neutral point,*** the magnetic field from one magnet exactly cancels the field from other magnet, so this point has zero magnetic field and force, if compass is placed at neutral point, compass does not deflect.

Earth's Magnetic Field

A freely suspended magnet always points in the north-south direction even in the absenceof any other magnet. This suggests that the earth itself behaves as a magnet which causes a freely suspended magnet (or magnetic needle) to point always in a particular direction: north and south. The shape of the earth's magnetic field resembles that of an imaginary bar magnet of length one-fifth of earth's diameter buried at its centre.

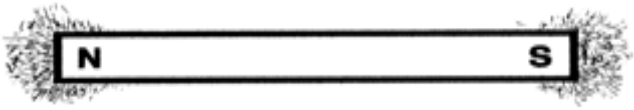
The south pole of earth's magnet is in the geographical north because it attracts the north pole of the suspended magnet. Similarly, the north pole of earth's magnet is in the geographical south because it attracts the south pole of the suspended magnet. Thus, there is a magnetic S-pole near the geographical north, and a magnetic N-pole near the geographical south. The positions of the earth's magnetic poles are not well defined on the globe, they are spread over an area. The axis of earth's magnet and the geographical axis do not coincide with each other. The axis of earth's magnetic field is inclined at an angle of about***15°***with the geographical axis. Due to this a freely suspended magnet (or magnetic needle) makes an angle of about 15° with the geographical axis and points only approximately in the north-south directions at a place. In other words, a freely suspended magnet does not show exact geographical north and south because the magnetic axis and geographical axis of the earth do not coincide. It is now believed that *the earth's magnetism is due to the magnetic effect of current* which is flowing in the liquid core at die centre of the earth.

-



Magnetic force

If an iron filings spread over bar magnet, it gathers in large clusters around the ends of the magnet. More iron filings are attracted at the ends. So magnetic force is more concentrated at the poles



Domain Theory of magnetism

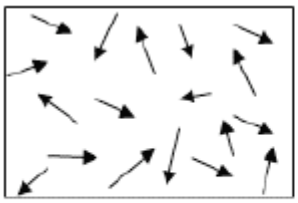
Since the electron is an electrically charged particle, this theory suggests that *magnetism is a property of a charge in motion.* If so, we can account for the energy associated with magnetic forces by using known laws of physics.

Two kinds of electron motions are important in this modern concept of magnetism. *First, an electron revolving about the nucleus of an atom imparts a magnetic property to the atom structure*.When the atoms of a substance are subjected to the magnetic force of a strong magnet, the force affects this magnetic property, opposing the motion of the electrons. The atoms are thus repelled by the magnet; this is diamagnetism. If the movement of the electron about the nucleus were its only motion, all substances would be diamagnetic. Diamagnetic repulsion is quite feeble in its action on the total mass of a substance.

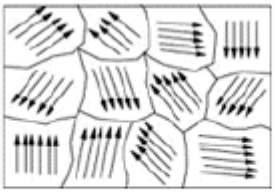
The second kind of electron motion is the spinning of the electrons its own axis. The magnetic property of matter stems basically *from* the spin of electrons as well as their orbital motions; *each spinning electron acts as a tiny permanent magnet* Opposite spins are designated as + and — spins; electrons spinning in opposite directions tend to form *pairs* and so neutralize their magnetic character.

-

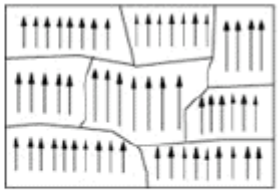
Magnetic materials consist of smaller particles called ***magnetic domains***. Each domain consists of two poles called North Pole and South Pole. The domains vary in size and shape. In an *un-magnetized material*, the domains cancel out each other and in a magnetized material the domains are lined up in one direction as shown below.



Non-magnetic Material (no domains)



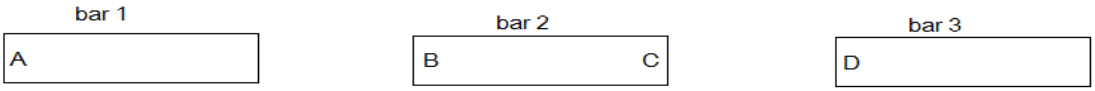
Magnetic Material (domains, but not lined up)



Magnet (domains, and all are lined up)

Exercise

1. Magnetic materials are sometimes described as ***hard*** and ***soft***.
   a) What is the difference between the two types?
   b) Give one example of each?
2. The diagram below shows three bar magnets.



When different ends are brought together, it is found that **A** and B attract, **A** and **C** attract, But **A** and**D** repel. Decide whether each of the bars is a permanent magnet or not?

3. If you are given three iron nails and told that one is magnetized, how would you find out which one is the magnet?
4. If you are given three iron nails and told that two are magnetized, how will you find out which one is not a magnet?

3.4 Making magnets (Magnetization)

Magnetization is a process of making magnets from magnetic materials. During magnetization, the magnetic domains of the magnetic materials are lined up in one direction.

Permanent magnet

In the second century A.D, Chinese found a method of making magnets by rubbing pieces of common iron against lodestone. Nowadays magnets are made using various methods. Some of these methods include stroking or touching method, electric method, hammering, and induction method.

-

Stroking or touching method

Single stroking

In this method, a magnet is stroked against the object (steel bar) to be magnetized, there are two ways of stroking and they are:

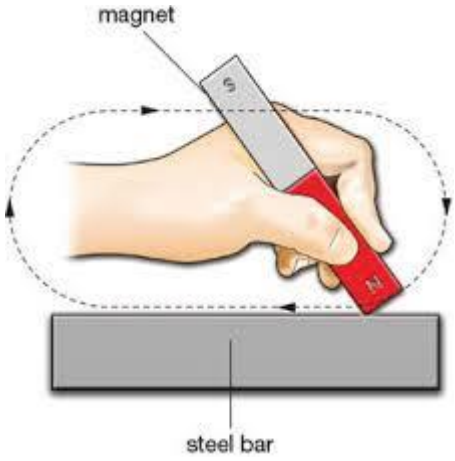
a) Single stroke

b) Double stroke

A piece of steel e.g. steel needle placed near a magnet becomes magnetized. However the magnetism acquired usually disappears quickly when the magnet is removed. This magnetism may be enhanced by stroking.

Experiment: To make a magnet by single stroking.

Place a steel needle on the bench. Stroke the steel needle with the south pole of a bar magnet along the whole length of the steel bar. Once at the end, lifts the magnet well away from the steel needle i.e. make a wide sweep as shown in Figure. Repeat the process several times. Test the polarity of the steel bar by the repulsion method. — The steel bar becomes magnetized with one end becoming a S-pole and other end becoming a N-pole. *Note that, the end of the magnetic material last touched by the magnet acquires a polarity opposite to the one touching it.*



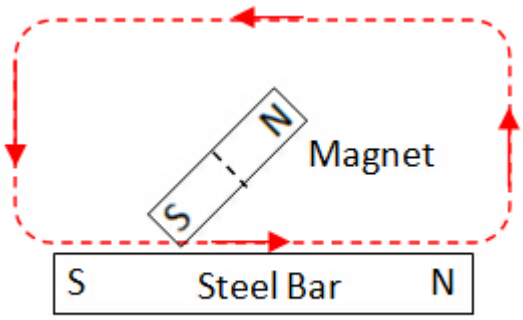


Figure: Single stroking

Double stroking

Experiment: To make a magnet by double stroking.

Apparatus

Steel nail, two bar magnet, a cotton thread, plotting compass

-

Stroke a steel nail using two magnets as shown in Figure. The stroking should begin at the middle of the steel nail each time making sure that the two bar magnets are lifted far away from the steel nail once you reach the ends.

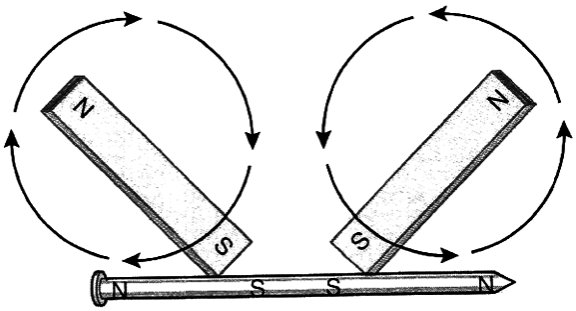


Figure: Making magnets by double or divided stroke method.

A bar magnet with north pole at each end and south poles at its centre can be made by double stroking as shown the diagram below

Consequent poles

It is possible to have a magnet with like poles on both ends. These are called *consequent poles*.

Electrical method

Experiment: Making magnet by electrical method.

Wind a number of turns of coil around a steel bar and pass a direct current (DC) through the turns as shown in Figure. Switch off the current and remove the needle.

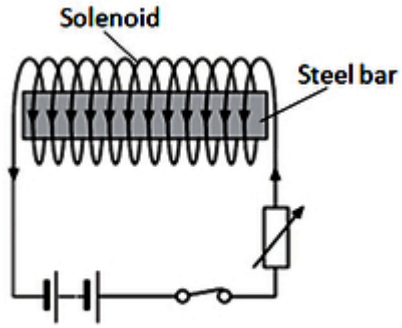


Figure: Magnetisation by Electric method

Test for polarity of the needle. Repeat the experiment but with the electric current direction reversed. Test for polarity of the needle. The polarity of the magnet produced in electrical method depends on the direction of the electric current. The poles can be confirmed by the use of a magnet with known poles.

-

Hammering

Experiment: To make a magnet by hammering.

Hammer one end of a steel bar fixed in north-south direction several times.(Figure).

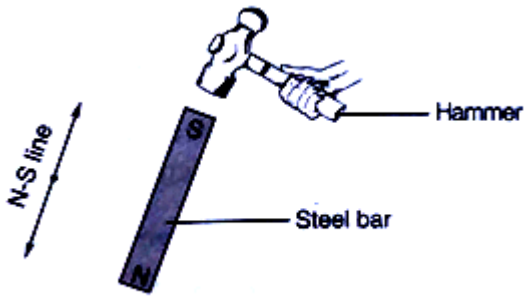


Figure: Magnetisation by hammering

Test the polarities

You will find that the steel bar becomes a weak magnet. The end pointing northward becoming a north pole and the other end a south pole, in this method the influence of earth magnetic field is used to magnetize the steel bar being hammered.

Magnetisation by induction

Experiment: To make a magnet by induction.

Place a magnet near an un-magnetized steel pin and note what happens. The pin is attracted by the bar magnet. Bring another pin next to the first pin and note what happens.The second pin is attracted to the first pin (Figure (a)).

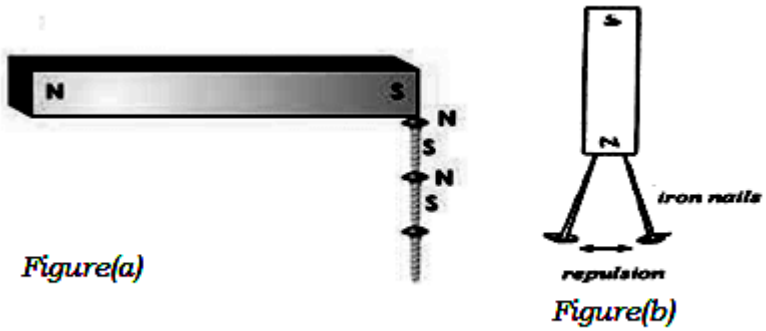


Figure: magnetisation by induction

The first pin becomes magnetised by the magnet through a process called ***induction*** and then gets attracted to the magnet. The second pin gets magnetised by the first pin through the same process.

-

Separate the first pin from the magnet and note what happens to the second pin—The second pin falls off. This shows that it is the presence of the bar magnet that sustains the magnetism between the first and second pin.

Repeat the experiment using two pins placed side by side. Introduce a north pole between the two pins and observe what happens. The two pins separate further when a north pole is placed in between them. (Figure (b). This shows that the induced pole nearest to the magnet is of opposite sign to that of the inducing magnet.

Demagnetization

Demagnetization is the process through which magnets lose their magnetism. The process can be achieved through a number a methods

a) Heating:

When a magnet is heated until red hot, then placed pointing in east-west direction until it cools, it loses its magnetism.

b) Hammering:

Hammering a magnet which it is placed in east-west direction demagnetizes the magnet. Or dropping the magnet on hard floor several times can also demagnetize it.

c) Electrical method:

A magnet can be demagnetizes by placing it inside a solenoid while pointing east-west direction and passing alternating current *(AC)* through the solenoid.

Uses of magnets

Magnets have many uses, they are used in;

- Hospital for removing iron piece from eyes of the patients
- Industries as stirrers, lifting iron scraps etc.
- Weather stations for resetting six's maximum and minimum thermometer
- Navigation for showing the direction as in compass needles
- Magnetic tapes used in audio and video recording

-

Storing magnets

A bar magnet loses its magnetism with time due to *self-demagnetisation*. The process of *self-demagnetisation* starts at the ends of a magnet in which the free like poles repel each other and slowly upset the alignment of the molecular magnet inside it. To *minimise* this, soft iron bars called *keepers* are placed across their like ends. The dipoles find themselves in a closed chain or loops round the magnet and the keepers, with no free poles, available to upset the domains as shown on Figure 1.19. The soft iron keepers are used since they are easily *magnetised* by induction.

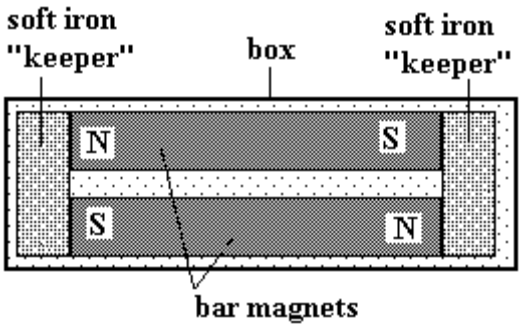


Figure: Storing magnet

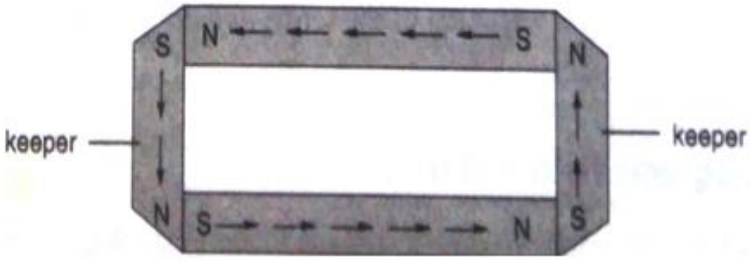


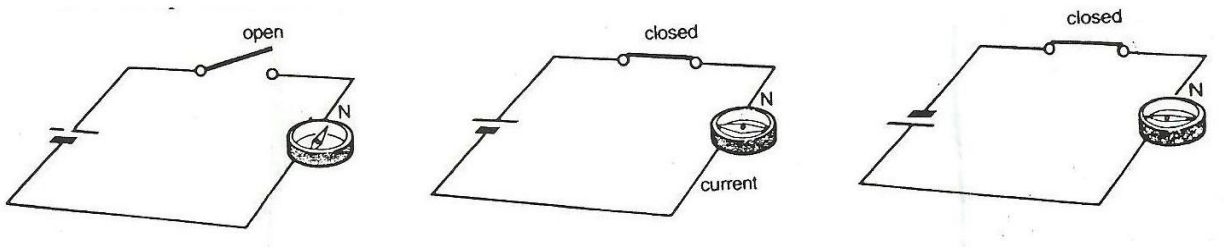
Figure: Soft iron keeper are used to store magnets

-

3.5 Magnetic Effect of Electric Current (Or Electromagnetism)

The magnetic effect of current was accidentally discovered by Christain Hans Oersted in 1820. Oersted found that a wire carrying a current was able to deflect a compass needle. Now, the compass needle is a tiny magnet which can be deflected only by a magnetic field. Since a current carrying wire was able to deflect a compass needle, it was concluded that a current flowing in a wire always gives rise to a magnetic field around it. From Oersted's experiment it was realized that there exists a relationship between an electric current and magnetism. The importance of magnetic effect of current lies in the fact that it gives rise to mechanical forces. The electric motor, electric generator, telephone and radio, all utilize the magnetic effect of current.we will to study the magnetic effect of an electric current and some of its applications in technological development. The magnetic effect of current is also called electromagnetism which means electricity produces magnetism.

Experiment to Demonstrate the Magnetic Effect of Current



Observations

- When the switch is closed, it is observed that the north pole of the compass needles deflect, as shown in figures to with respect to the direction of current flow
- The extent to which the needles deflect increases with the strength of the current flowing.
- Reversing the direction of current reverses the direction of deflection.
- The compass needles settle back into their original positions when the switch is open, as shown in figure.

Explanation

A flow of current is basically a flow of charges. When charges flow, they have an associated magnetic field which interacts with the field due to the magnetic compass, causing deflection of the compass needle. The strength of the magnetic field increases with the strength of the current.

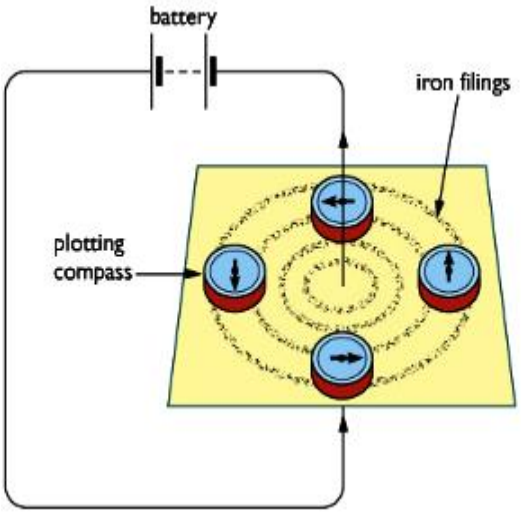
Ampere devised a rule, Ampere's swimming rule, to predict the direction of the compass needle deflection;

If one imagines to be swimming along a wire in the direction of the current and facing the compass needle, then the north pole of the needle will be deflected towards the swimmer's left hand

-

Magnetic Field Pattern due to Straight Current-Carrying Conductor (Straight Current-Carrying Wire)

The magnetic field lines around a straight conductor (straight wire) carrying current are concentric circles whose centres lie on the wire. In Figure, we have a straight vertical wire (or conductor) which passes through a horizontal cardboard sheet. The ends of the wire are connected to a battery through a switch. When current is passed through wire, it produces a magnetic field around it. This magnetic field has magnetic field lines around the wire which can be shown by sprinkling iron filings on the cardboard. The iron filings get magnetized. And on tapping the cardboard sheet, the iron filings arrange themselves in circles around the wire showing that the magnetic field lines are circular in nature therefore iron filings indicate the shape of the magnetic field around the conductor and compass needle indicate the direction of the magnetic field.



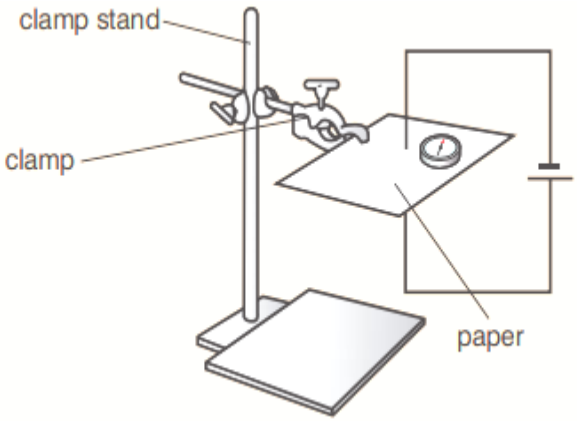
EXPERIMENT: To investigate the magnetic field pattern due to a straight conductor carrying current Using Iron Filings

Apparatus

Iron filings, a straight wire, current power source, four magnetic compass, variable resistor and cardboard sheet

Procedure

- Set up the apparatus as shown in Figure.
- Close the switch and sprinkle iron filings on the card.
- Tap the card gently.
- You may use the variable resistor to vary the current (*I*).
- When the card is tapped the iron fillings settle in *concentric circles* round the wire.



- It was found that iron filings settle in a particular pattern depending on the magnetic field present.

-

Observation

In this experiment, we can conclude that the current in the conductor has produced a magnetic field around it. *Thus a magnetic field around a straight current-carrying conductor is a pattern of concentric circles round the conductor.* The magnetic field is strongest near the wire and gets much weaker as it moves away. When current in the wire flows in the *upward* direction (as shown in Figure), then the lines of magnetic field are in the *anticlockwise* direction. If the direction of current in the wire is reversed, the direction of magnetic field lines also gets reversed.

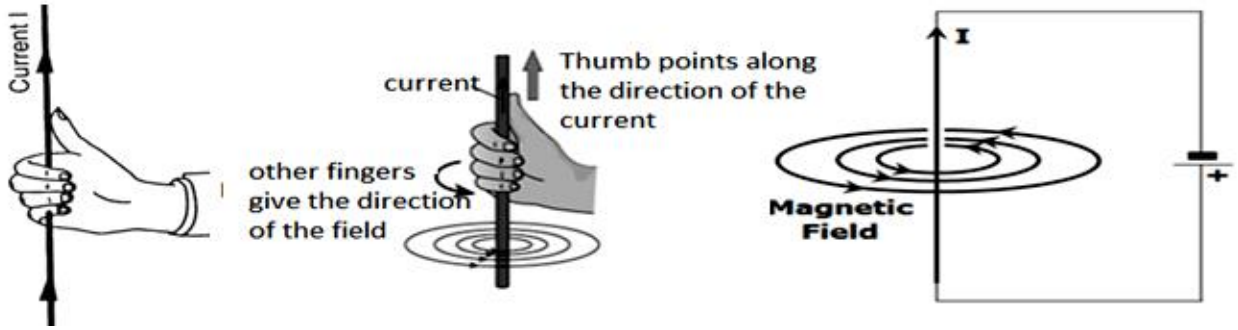
It has been shown by experiments that the magnitude of magnetic field produced by a straight current-carrying wire at a given point is.

(i) directly proportional to the current passing in the wire, and

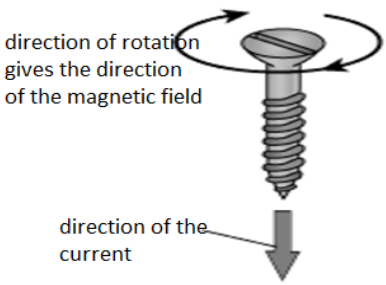
(ii) Inversely proportional to the distance of that point from the wire. So, greater the current in the wire, stronger will be the magnetic.

Direction of Magnetic Field Produced by Current-Carrying Conductor (Current-Carrying Wire)

a) If the direction of current is known, then the direction of magnetic field produced by a straight wire carrying current can be obtained by using *Maxwell's right-hand thumb rule*. According to Maxwell's right-hand thumb rule ; Imagine that you are grapping (or holding) the current carrying wire in your right hand so that *your thumb points in the direction of current*, then the *direction in which your fingers encircle the wire will give the direction of magnetic field lines around the wire.* Figure shows a current carrying wire in which the current is flowing vertically upwards.

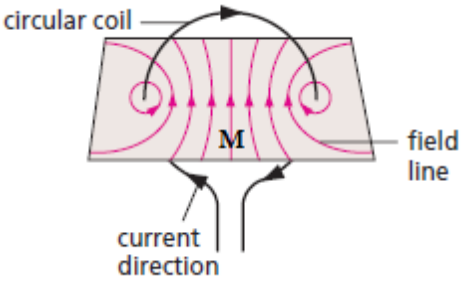


b) ***Right-hand screw rule.*** this rule states "if a right-hand screw moves forward in the direction of the current, the direction of rotation of the screw gives the direction of the field around the conductor"



-

Magnetic Field Pattern due to a Circular Loop (or Circular Wire) Carrying Current



We know that when current is passed through a straight wire, a magnetic field is produced around it. It has been found that the magnetic effect of current increases if instead of using a straight wire, the wire is converted into a circular loop (as shown in Figure 12).

In Figure 12, a circular loop (or circular wire) is fixed to a thin cardboard sheet. When a current is passed through the circular loop of wire, a magnetic field is produced around it. The pattern of magnetic field due to a current carrying circular loop (or circular wire) is shown in Figure 12. The magnetic field lines are *circular* near the current-carrying loop. As we move away, the concentric circles representing magnetic field lines become bigger and bigger. At the centre of the circular loop, the magnetic field lines are *straight* (see point *M* in Figure 12). By applying right-hand thumb rule, it can be seen that each segment of circular loop carrying current produces magnetic field lines in the same direction within the loop. At the centre of the circular loop, all the magnetic field lines are in the same direction and aid each other, due to which the strength of magnetic field increases.

The magnitude of magnetic field produced by a current-carrying circular loop (or circular wire) at its centreis :

(i) *directly proportional to the current passing through the circular loop (or circular wire), and*

(ii) *Inversely proportional to the radius of circular loop (or circular wire).*

In this discussion we have considered the magnetic field produced by a circular loop (or circular wire) which consists of only 'one turn' of the wire. The strength of magnetic field can be increased by taking a circular coil consisting of a number of turns of insulated copper wire closely wound together. Thus there is a circular coil having *n* turns, the magnetic field produced by this current? Carrying circular coil will be *n* times as large as that produced by a circular loop of a single turn of wire. This is because the current in each circular turn of coil flows in the same direction and magnetic field produced by each turn of circular coil then just adds up. We can now say that: The strength of magnetic field produced by a circular coil carrying current is directly proportional to both, number of turns *(n)*and current (I); but inversely proportional to its radius (r). Thus, the strength of magnetic field produced by a current carrying circular coil can be increased by:

(i) increasing the number of turns of, wire in the coil
(ii) increasing the current flowing through the coil and
(iii) Decreasing the radius of the coil. A current-carrying wire (or coil) behaves as *a*thin disc magnet, whose one face is *a*north pole and the other face is a south pole.

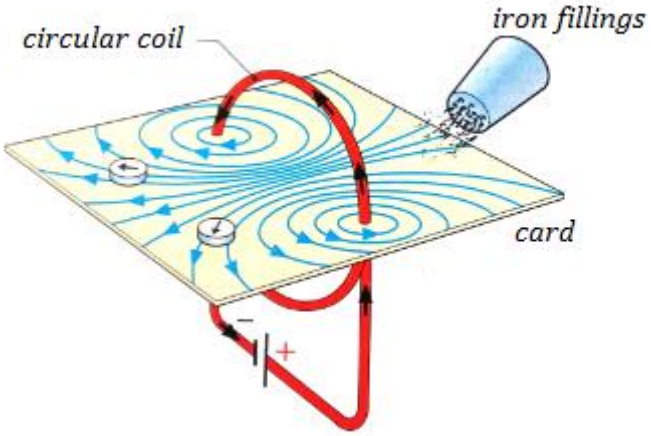
-

Magnetic Field Pattern of a Circular Current-carrying Loop

EXPERIMENT: To investigate magnetic field pattern due to a circular current-carrying loop

Apparatus

A card, thick wire, iron filings, magnetic compass, power source, clamp.



Procedure

- Drill two holes in the card and pass the wire through the boles make a loop.
- Set the apparatus as shown in figure
- *Gently sprinkle* the iron fillings on the card.
- Switch on (he current and tap the card gently. Note the effect on the iron filings
- Switch off the current and remove the iron filings.
- Switch on the current and, using the magnetic compass needle, trace the magnetic field lines.

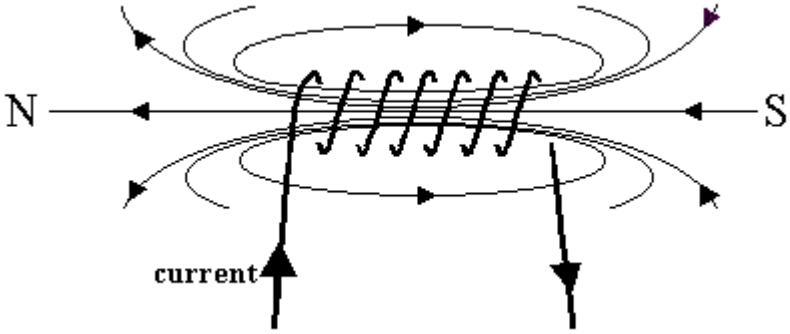
Observation

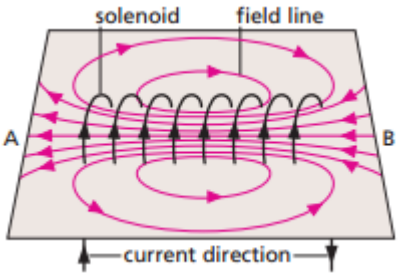
The pattern formed by the iron filings is similar to that of a small magnet. The magnetic compass traces the field pattern shown in figure

Magnetic Field due to a Solenoid

The solenoid is a long cylindrical coil containing a large number of close turns of insulated copper wire. Figure 13(a) shows a solenoid whose two ends are connected to two battery *terminals* through a switch. When an electric current is passed through the solenoid, it produces a magnetic field around it. The magnetic field produced by a current carrying solenoid is shown in Figure 13(A). This magnetic field produced by a current carrying solenoid is *similar* to the magnetic field produced by a bar magnet. Please note that the lines of magnetic field pass through the solenoid and return to the other end as shown in Figure 13(A). The magnetic field lines inside the solenoid are in the form of *parallel straight lines.* This indicates that the strength of magnetic field is the *same* at all the points inside the solenoid. If the strength of magnetic field is just the same in a region, it is said to be *uniform* magnetic field. Thus, the magnetic field is *uniform* inside a current-carrying solenoid. The uniform magnetic field inside the current-carrying solenoid has been represented by drawing parallel straight field lines (see Figure **13).** Even the earth's magnetic field at a given place is *uniform* which consists of parallel straight field lines (which run roughly from south geographical pole to north geographical pole).

-





One end of the current-carrying solenoid acts like a north-pole (N-pole) and the other end a south pole (S-pole) So, if a current-carrying solenoid is suspended freely, it will come to rest pointing in the north and south directions (just like a freely suspended bar magnet). We can determine the north and south poles of a current-carrying solenoid by using a bar magnet. This can be done as follows: We bring the north pole of a bar magnet near both the ends of a current-carrying solenoid. The end of solenoid which will be repelled by the north pole of bar magnet will be its north pole, and the end of solenoid which will be attracted by the north pole of bar magnet will be its south pole.

The current in each turn of a current-carrying solenoid flows in the same direction due to which the magnetic field produced by each turn of the solenoid adds up, giving a strong magnetic field inside the solenoid.

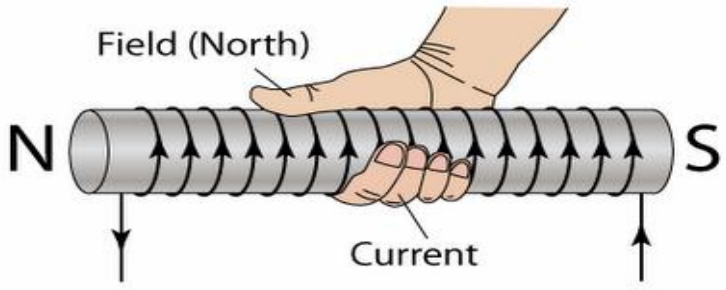
When magnetic field inside and outside solenoid is explored, the following properties emerge:

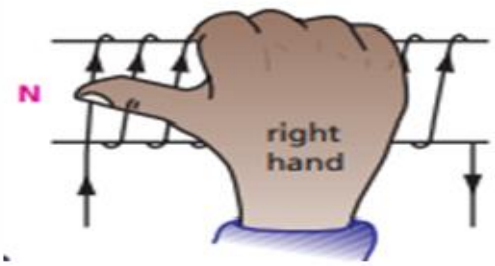
1. The field near the ends is non-uniform compared to the field inside the solenoid.
2. The field near the end of the solenoid is weaker than that inside the solenoid.
3. The field outside the solenoid is oppositely directed to that inside the solenoid.
4. The field outside the solenoid is less than that inside the solenoid

Poles of solenoid can be found

1. *Right hand grip rule*
2. *Alphabet rule*

1. The ***right hand grip rule*** can be used to determine the magnetic poles of the solenoid as shown in the figure below.

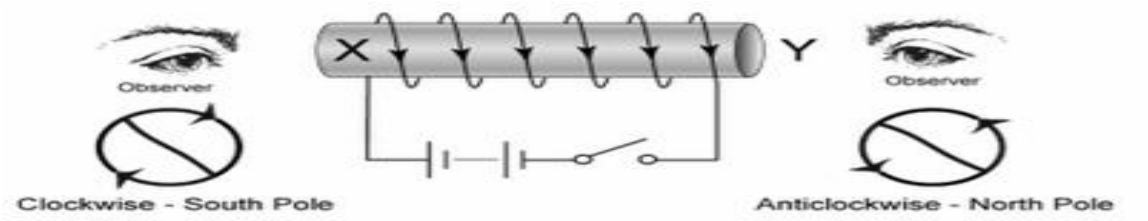




The fingers of your right hand to show the direction of the current in the loops of wire and your right thumb then shows the north pole of the solenoid.

-

2. The ***Alphabet rule***; this rule for polarity can be used:



This rule states: "when the solenoid viewed from one end, if the current seems to flow in the ***clockwise*** direction that end is the ***south pole***. If it seems to flow in the ***anticlockwise*** direction, then that end is a ***north pole***."

- If the *direction of the current* flowing through the solenoid is *reversed*, so *poles of the solenoid reverses*

The strength of magnetic field produced by a current carrying solenoid depends on:

(i) The number of turns in the solenoid. Larger the number of turns in the solenoid, greater will be the magnetism produced.

(ii) The strength of current in the solenoid. Larger the current passed through solenoid, stronger will be the magnetic field produced.

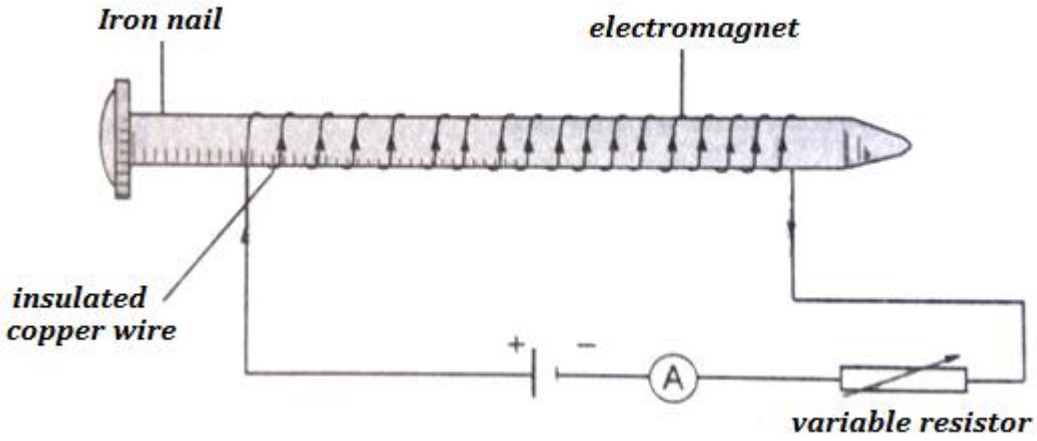
(iii)Using a soft-iron core within the solenoid.

The strong magnetic field produced inside a current-carrying solenoid can be used to magnetize a piece of magnetic material like soft iron, when placed inside the solenoid. The magnet thus formed is called an electromagnet. So, a solenoid is used for making electromagnets.

Electromagnet

An electric current can be used for making temporary magnets known as electromagnets. An electromagnet works on the magnetic effect of current. Let us discuss it in detail. We have just studied that when current is passed through a long coil called solenoid, a magnetic field is produced. It has been found that if a soft iron rod called core is placed inside a solenoid, then the strength of magnetic field becomes very large because the iron core. Coil of insulated wire gets magnetized by induction. *This combination of copper wire solenoid and a soft iron core is called an electromagnet.* Thus, an electromagnet consists of a long coil of insulated copper wire wound on a soft iron core. A simple electromagnet is shown in Figure 14. To make an electromagnet all that we have to do is to take a rod N-S of soft iron and wind a coil *C* of insulated copper wire round it.

-



It should be noted that the solenoid containing soft iron core in it acts as a magnet only as long as the current is flowing in the solenoid. If we switch off the current in the solenoid, it no more behaves as a magnet. All the magnetism of the soft iron core disappears as soon as the current in the coil is switched off. A very important point to be noted is that it is the iron piece inside the coil which becomes a strong electromagnet on passing the current. The core of an electromagnet must be of soft iron because soft iron loses all of its magnetism when current in the coil is switched off. On the other hand, if steel is used for making the core of an electromagnet, the steel does not lose all its magnetism when the current is stopped and it becomes a permanent magnet. This is why steel is not used for making electromagnets. Electromagnets can be made in different shapes and sizes depending on the purpose for which they are to be used.

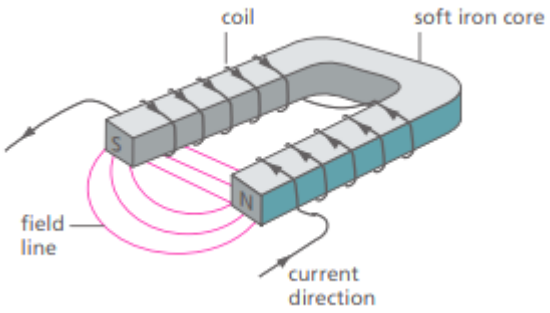
Factors affecting the Strength of an Electromagnet

The strength of an electromagnet depends on:

(i) The number of turns in the coil. If we increase the number of turns in the coal, the strength of electromagnet increases.

(ii) The current flowing in the coil. If the current in the coil is increased, the strength of electromagnet increases.

(iii) The length of air gap between its poles. If we reduce the length of air gap between the poles of an electromagnet, then its strength increases. For example, the air gap between the poles of a straight, bar type electromagnet is quite large, so a bar type electromagnet is not very strong. On the other hand, the air gap between the poles of a U-shaped electromagnet is small, so it is a very strong electromagnet.



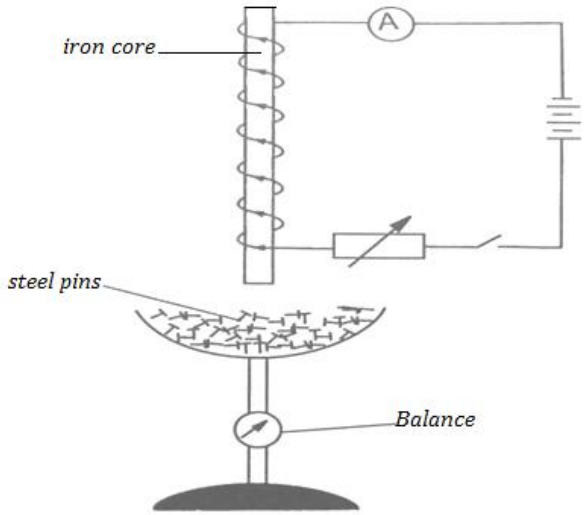
It should be noted that in many respects an electromagnet is better than a permanent magnet

-

because it can produce very strong magnetic fields and its strength can be controlled by changing the number of turns in its coil or by changing the current flowing through the coil.

The experiments outlined below explore how the size of the current, the number of turns and the shape of the core affect the strength of electromagnets

***EXPERIMENT*:** to investigate how the size of the current and length of the solenoid affect the strength of an electromagnet



Apparatus

Long insulated copper wire, rheostat, ammeter, power source, preferably a 6.0 V lead-acid accumulator, switch, connecting wires, and a dish containing paper pins, balance, and iron rod.

Procedure

- Wind 20 turns of insulated copper wire tightly round the iron rod.
- Connect it to the battery as shown in figure
- Switch on the current and adjust the rheostat to give a current of 0.5 A. Find what mass of the paper pins the electromagnet can support.
- Repeat the experiment with the current of 1.5 A and 2.0A.

Observation

As the current and the length of solenoid are increased, the mass of the pins supposed (representing the strength of the magnet) increases. Beyond a particular value, however, the strength of the electromagnet remains constant.

Differences between a Bar Magnet (or Permanent Magnet) and an Electromagnet

PERMANENT MAGNET	ELECTROMAGNET
1. A permanent magnet produces a comparatively weak force of attraction	**1.** An electromagnet is a temporary magnet. Its magnetism is only for the duration of current passing through it. So, the magnetism of an electromagnet can be switched on or switched off as desired.
2. The strength of a permanent magnet cannot be changed.	**2.** An electromagnet can produce very strong magnetic force.
3. The (north-south) polarity of a permanent magnet is fixed and cannot be changed.	**3.** The strength of an electromagnet can be changed by changing the number of turns in its coil or by changing the current passing through it.
	4. The polarity of an electromagnet can be changed by changing the direction of current in its coil.

-

Permanent magnets are usually made of alloys such as; Carbon steel, Chromium steel, Cobalt steel, Tungsten steel, and Alnico (Alnico is an alloy of aluminium, nickel, cobalt and iron). Permanent magnets of these alloys are much stronger than those made of ordinary steel. Such strong permanent magnets are used in microphones, loudspeakers, electric clocks, ammeters, voltmeters, speedometers, and many other devices. Let us solve one problem now.

Factors affecting the strength of an electromagnet are:

i. The **size of the current** in the solenoid
ii. The **number** of **turns** of the wire in the solenoid
iii. The **shape** of the core
iv. The **length** of the solenoid

The magnetism of an electromagnet is temporary and it can be switched on and off, unlike that of a permanent magnets. It has a core of soft iron which is magnetized only when current flows in the surrounding coil.

-

Applications such of electromagnets

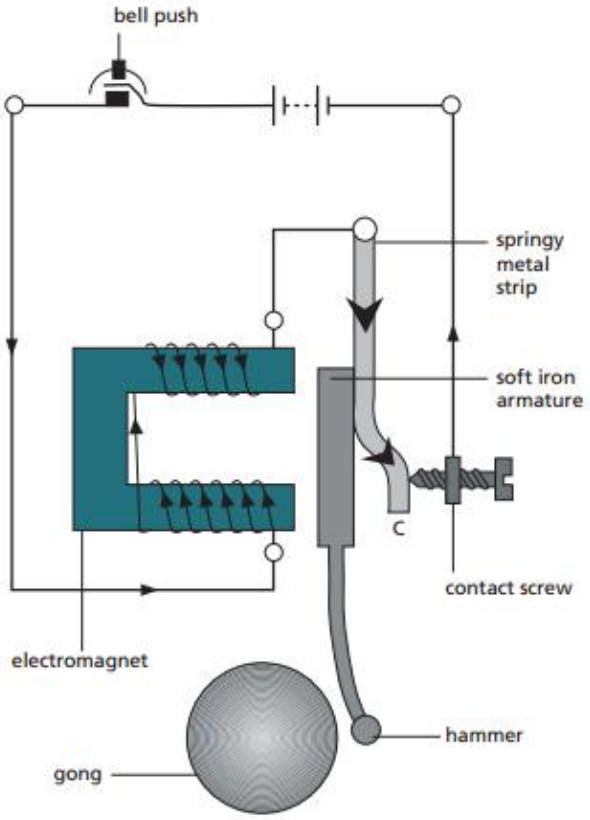
Electromagnets are used in various industrial and domestic instruments or devices. Some of the common applications are illustrated below.

- ***a)*** Electric bell
- ***b)*** Relay.
- ***c)*** Scrap yard cranes
- ***d)*** Circuit breaker
- ***e)*** Telephone earpiece
- ***f)*** An electric door lock

ELECTRIC BELL

When the switch is on, the circuit is completed and current flows. The electromagnet becomes magnetized and hence attracts the soft-iron armature and at the same time the hammer strike the gong

As soon as the hammer moves towards the gong, the **circuit is broken**. The current stops flowing and the electromagnet lose its magnetism. This causes the spring to pull back the armature and **reconnect the circuit** again and the whole process begins again.

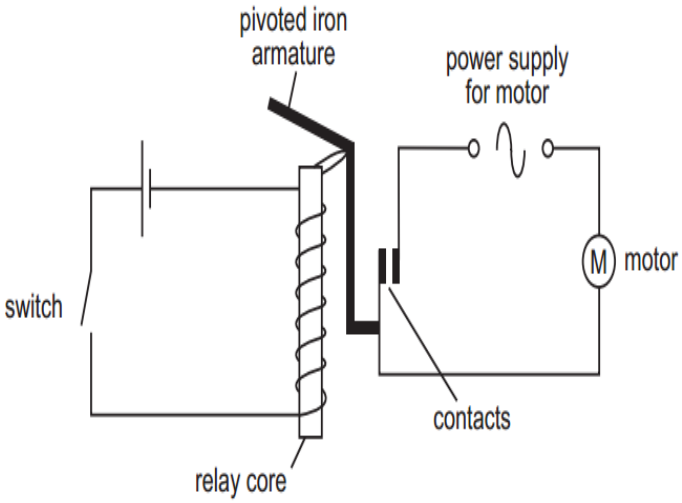


RELAY

A relay is an electrical switch that opens and closes under the control of another electrical circuit.

A relay has at least two circuits. One circuit can be used to control another circuit. The 1st circuit (input circuit) supplies current to the electromagnet. The electromagnet is magnetized and attracts one end of the iron armature.

The armature is then closes the contacts (2nd switch) and allows current flows in the second circuit. When the 1st switch is open again, the current to the electromagnet is cut, the electromagnet loses its magnetism and the 2nd switch is opened. Thus, current in the 2nd circuit stop to flow.

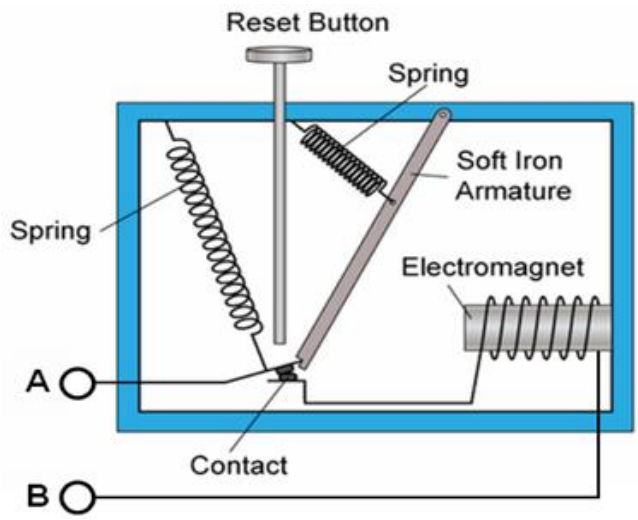


SCRAP YARD CRANES:

Steel scrap can be lifted in a scrap yard by a powerful electromagnet. The crane is moved towards the scrap and when it is above the scrap the current is switched on and the electromagnet attracts all the iron and steel in the scrap. Then the crane moves the scrap to its new place and when the current is turned off, the scrap falls from the electromagnets.

CIRCUIT BREAKER:

A circuit breaker is an automatic switch that cut off current in a circuit when the current become too large. When the current in a circuit increases, the strength of the electromagnet will increase in accordance; this will pull the soft iron armature towards the electromagnet. As a result, the spring pulls apart the contact and disconnects the circuit immediately, and the current stop to flow. We can reconnect the circuit by using the reset button



Domestic circuit breakers

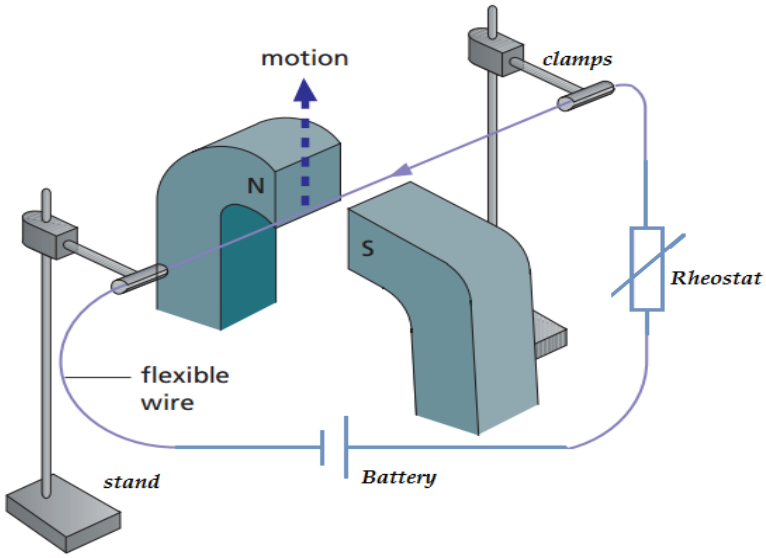
3.6 Magnetic Force on Current Carrying Conductor Placed in a Magnetic Field

We have already described Oersted's experiment which shows that a current carrying wire exerts a force on a compass needle and deflects it from its usual north-south position. Since a compass needle is actually a small freely pivoted magnet, we can also say that a current carrying wire exerts a mechanical force on a magnet, and if the magnet is free to move, this force can produce a motion in the magnet. The reverse of this is also true, that is, a magnet exerts a mechanical force on a current carrying wire, and if the wire is free to move, this force can produce a motion in the wire. In fact, this result can be obtained by applying Newton's third law of motion according to which if a current carrying wire exerts a force on a magnet, then the magnet will exert an equal and opposite force on the current carrying wire. In 1821, Faraday discovered that: When a current carrying conductor is placed in a magnetic field, a mechanical force is exerted on the conductor which can make the conductor move. The interaction between two magnetic fields (magnetic field of magnet and that of conductor carrying current) causes the force on the conductor , because in certain places the fields are in same direction and reinforce while other place they are opposite and cancel out as shown the figure(). This is known as the motor principle (motor effect) and forms the basis of a large number of electrical devices like electric motor and moving coil galvanometer.

Experiment: to demonstrate the force acting on a current carrying conductor placed in a magnetic field

Apparatus

U-shaped magnet, two stand and clamps, insulating support, rheostat, switch, battery



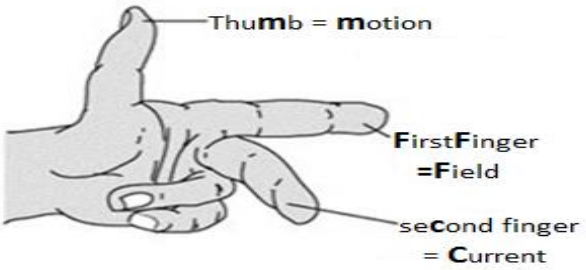
Procedure

- Arrange the apparatus as shown the diagram
- The flexible wire is loosely supported in the strong magnetic field of a C-shaped magnet (permanent or electromagnet).
- Close the switch, and observe

Observation

When the current flows in the wire, it jumps upwards as shown in the diagram. Because there is force which acts on a current-carrying conductor placed in a magnetic field, the magnitude of this force increases with increase in current and therefore magnetic field strength. It is maximum when the angle between the conductor and the field is 90°. The force decreases and becomes zero when the conductor is parallel to the magnetic field. It can also be shown that the force on the conductor increases with increase in length of the conductor in the magnetic field. If either the direction of the current or the direction of the magnetic field is reversed, direction of the force changes and the wire moves downwards**.**

The direction of the force (or motion) can be determined by ***Fleming's left hand rule*** (motor rule):



1. The first finger indicate magnetic **f**ield direction,
2. se**c**ond finger indicate direction of the **c**urrent in the wire
3. the thu**m**b indicate the direction of the **m**otion of the wire in the magnetic field

The size of the force on the conductor can be increased by

i) using stronger magnet
ii) Increasing the size of the current flowing through the wire.
iii) Increasing the number of turns of wire in the magnetic field (using longer wire)

The magnitude of magnetic force on the wire can be calculated by this formula

$$F = BIL$$

$$F = BIL\sin\theta$$

Where:

B *= magnetic field strength (its unit is tesla "T", T = N/Am)*

F *= force on the conductor.*

I *= current through the conductor.*

Example 1:

A straight wire that carries a current of 5A is in a uniform magnetic field oriented at right angle to the wire. if the length of the wire is in the magnetic field is10cm and the force on the wire is 0.20N. Calculate the strength of the magnetic field?

Solution

$$B = \frac{F}{IL} = \frac{0.20N}{(5Ax0.1m)} = 0.4T$$

Example 2:

A wire of 0.8m long carrying a current of 4A is placed in a magnetic of 3T at 45^0. Calculate the magnitude of the force?

Solution

$$F = BILsin\theta = (3T)\ (4A)\ (0.8m)\ (sin45^0) = 6.8N$$

Test your self

A wire, 5m long, carrying electric current of 6A is placed in a field of flux density 0.5T. What is the force on the wire if it is placed?

a) At right angle to the field?

b) At 30^0 to the field?

c) Along the direction of the field?

Electric motor

A motor is a device which converts electrical energy into mechanical energy. Every motor has a shaft or spindle which rotates continuously when current is passed into it the rotation of its shaft is used to drive the various types of machines in homes and industry. Electric motor is used in electric fans, washing machines, refrigerators, mixer and grinder, and many, many other appliances. A common electric motor works on direct current so, it is also called D.C. motor, which means a "Direct Current motor".

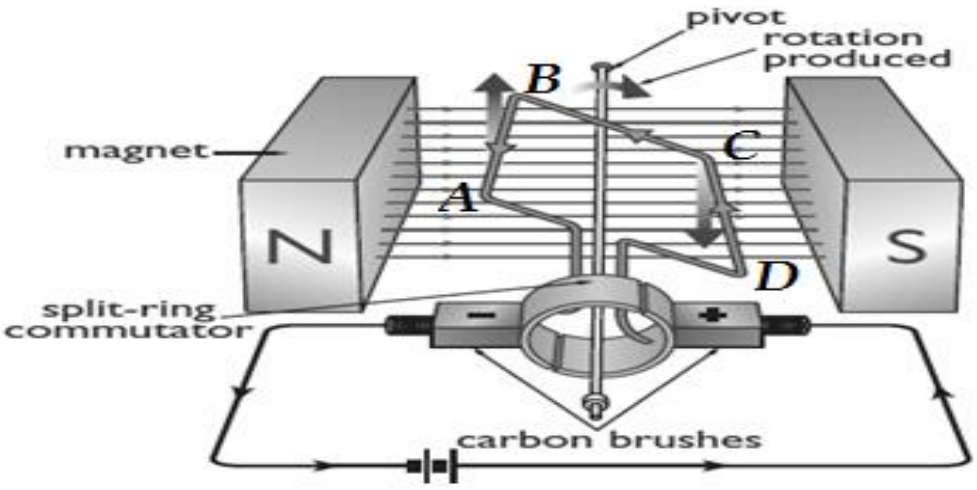
Principle of a Motor

An electric motor utilises the magnetic effect of current. A motor works on the principle that when a rectangular coil is placed in a magnetic field and current is passed through it, a magnetic force acts on the coil which rotates it continuously. When the coil rotates, the shaft attached to it also rotates. In this way the electrical energy supplied to the motor is converted into the mechanical energy of rotation.

Construction of a Motor

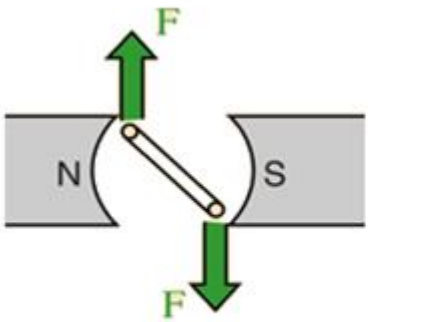
An electric motor consists of a rectangular coil ABCD of insulated copper wire, which is mounted between the curved poles of a permanent magnet in such a way that it can rotate freely between the poles N and S on a shaft (The shaft is a long cylindrical rotating rod at the centre of the coil). The two sides of the coil are kept perpendicular to the direction of magnetic field between the poles of the magnet. This is done so that the maximum magnetic force is exerted on the two current-carrying sides of the coil. A device which reverses the direction of current through a circuit is called a commutator (or split ring). The two ends of the coil are soldered (or welded) permanently to the two half rings of a commutator and rotate with the coil. A commutator is a copper ring split into two parts; these two parts are insulated from one another and mounted on the shaft on the motor. The function of commutators is to reverse the direction of current flowing through the coil every time the coil just passes the vertical position during a revolution.

The battery to supply current to the coil is connected to the two carbon brushes through a switch. The function of carbon brushes is to make contact with the rotating rings of the commutator and through them to supply current to the coil. It should be noted that any one brush touches only one ring at a time, so that when the coil rotates, the two brushes will touch both the rings one by one

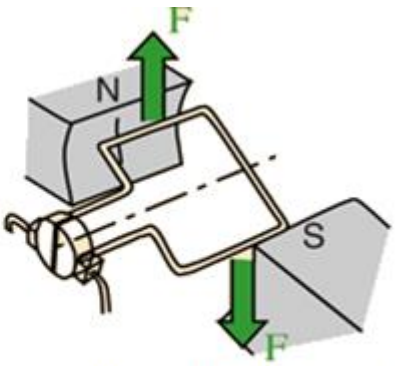


Working of a Motor

When an electric current is passed into the rectangular coil, this current produces a magnet field around the coil. The magnetic field of the permanent magnet then interacts with the magnetic field of the current-carrying coil as figure(a)shows and produce two parallel, equal and opposite forces on the two sides of the rectangular coil which causes the coil to rotate (or spin) continuously as shown figure (b)



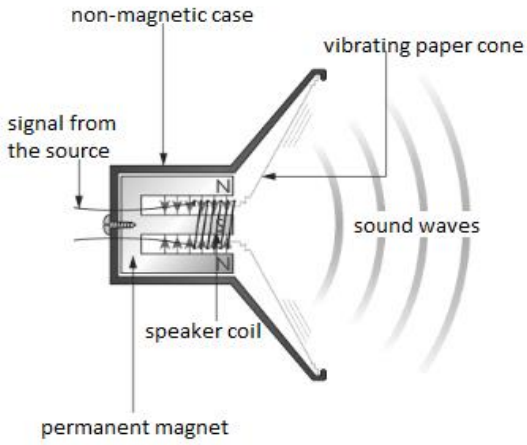
Figure(a) two opposite force on the coil



Figure(b) two force rotate the coil

Moving coil Load speaker

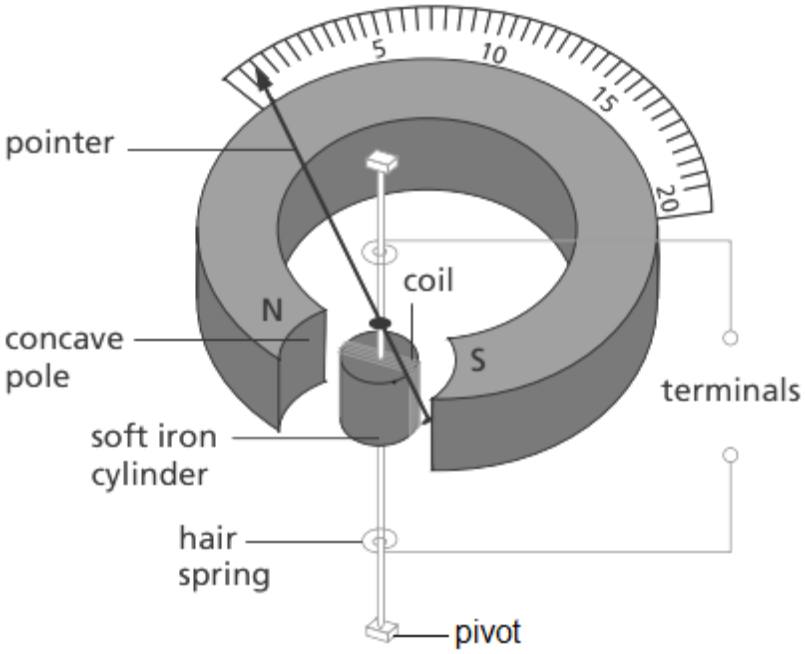
The moving coil loudspeaker uses motor effect to change electrical energy into sound energy. Signal from the source, such as amplifier, are fed into the coil of the speaker as currents that are continually changing in size and direction. The overlapping fields of the coil and the magnet therefore create varying force on the wires on the coil, which causes the speaker cone to vibrate. These vibrations cause the sound waves we hear.



Moving- Coil Meter

Figure shows a moving coil meter. The instrument is adapted to measure the strength of current flow or voltage. It has the following components:

i. A coil of insulated copper wire wound on soft iron core.
ii. Two hair-springs.
iii. Two pivots.
iv. Curved magnetic poles.
v. Pointer and scale



When an electric current flows

through the coil via the hair-springs, the magnetic field set up by the coil interacts with the field due to the permanent magnet, producing a force. This force is experienced by the sides of the coil, causing it to turn about the low-friction pivots. The poles of the magnet are curved and together with the soft iron core produce an intense radial field that cuts the coil at right angles whatever the position of the coil. This ensures that a maximum force that is directly proportional to the current acts on the coil.

As the coil turns, the springs are wound up, producing a mechanical force that opposes the turning of the coil. The turning stops when the restoring force by the springs is equal to the force due to the current. The springs unwind when the current stops flowing in the coil, returning the coil to its original position.

Exercise

Part one: Multiple choice Questions

1. When a magnet is brought close to a piece of iron
   A. Nothing happens.
   B. The magnet and the piece of iron repel each other.
   C. The iron gets hotter.
   D. There is attraction between the magnet and the piece of iron.
2. Of the following substances the one which is magnetic is
   A. Copper.
   B. Iron.
   C. Aluminium.
   D. Brass.
3. A freely suspended magnet always comes to rest
   A. With its N-pole pointing north and its S-pole pointing south.
   B. In an east-west direction.
   C. With its S-pole pointing north and its N-pole pointing south.
   D. With either the N-pole or the S-pole pointing north.
4. When like poles of two bar magnets are brought together
   A. The magnets attract each other.
   B. There is no effect.
   C. Magnetization occurs.
   D. The magnets repel each other.
5. The poles of a magnet which attract each other are
   A. Alike.
   B. Metallic.
   C. Unlike.
   D. Non-magnetic.
6. one way of making a magnet is by
   A. Strongly heating a piece of iron.
   B. Stroking a piece of steel with another magnet.
   C. Hammering a nail.
   D. Keeping a piece of non-magnetic material near another magnet.
7. A naturally occuring magnet is
   A. Magnesia.
   B. Touchstone.
   C. Lodestone.
   D. Magnesium.

8. An important consequence of the earth's magnetism is

A. it causes freely suspended magnets to set in a north south direction.

B. it makes men mad.

C. it causes tides.

D. itinteferes with navigation.

9. A piece of "soft" iron is placed inside a coil in which an electric current is passing. When the current is switched off

A. the soft iron loses its magnetism.

B. B- the soft iron remains magnetised.

C. the magnetism of the soft iron piece increases.

D. an electromagnet is formed.

10. The magnetic compass is used for

A. Drawing cricles.

B. Making a magnetic circle.

C. Playing with.

D. Finding direction.

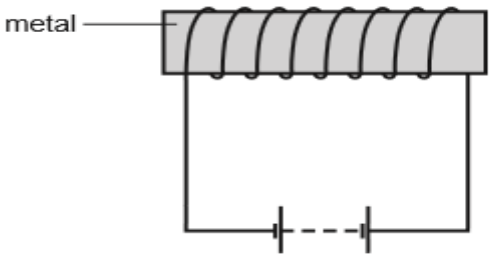
11. A student wishes to use a magnetizing coil to make a permanent magnet from a piece of metal.. Which metal should she use?

a) aluminium

b) copper

c) iron

d) Steel



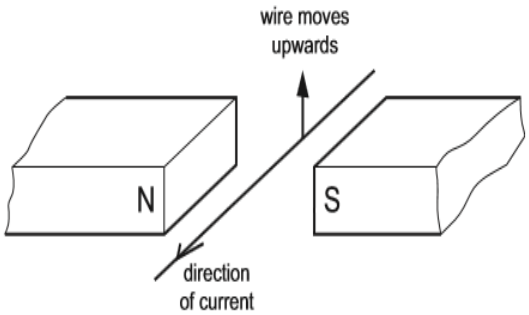
12. A student carries out an experiment to see the effect of a magnetic field on a wire carrying a current. The wire moves upwards as shown. What should the student do to make the wire move downwards?

a) Change the direction of the current.

b) Move the poles of the magnet closer together.

c) Send a smaller current through the wire.

d) Use a stronger magnet.



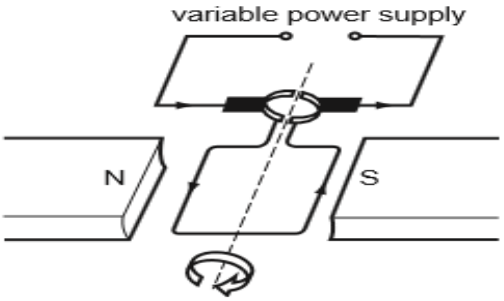
13. A current-carrying coil in a magnetic field experiences a turning effect. How can the turning effect be increased?

a) Increase the number of turns on the coil.

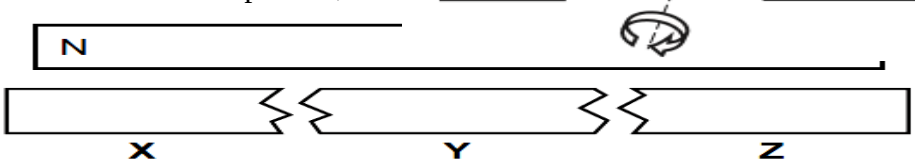
b) Reduce the size of the current.

c) Reverse the direction of the magnetic field.

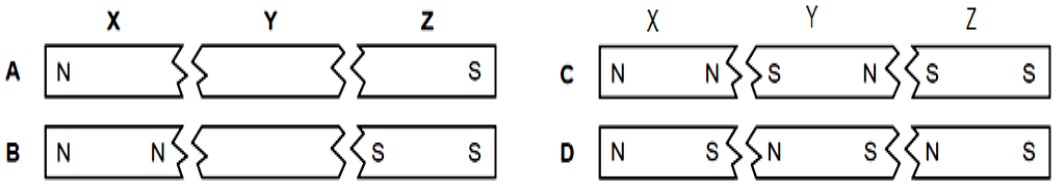
d) Use thinner wire for the coil.



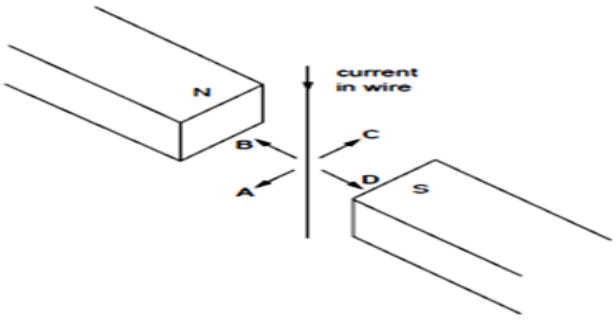
14. A bar magnet is broken into three parts X, Y and Z.



Which diagram shows the poles in X, Y and Z?



15. A wire hangs between the poles of a magnet. When there is a current in the wire, in which direction does the wire move?



PART TWO: STRUCTURE QUESTION

1. a) The lines of . . . .round a straight current-carrying conductor are in the shape of

b) The Right-hand Grip Rule: if you grip the…….with your right…. . . . pointing With the……., your fingers curl with the . . . . . field lines. For a solenoid, the magnetic field is like that of a ……

If a coil is viewed from one end and the current flows in an anticlockwise direction, then this end is a . . . .pole.

The magnetic effect of a coil can be increased by increasing the number of increasing the . . . . , or inserting an.... Core

2. Draw a magnetic field pattern around a circular coil.

3. Draw magnetic field patterns around a straight current-carrying conductor.

4. State and explain the effect on an electromagnet of:

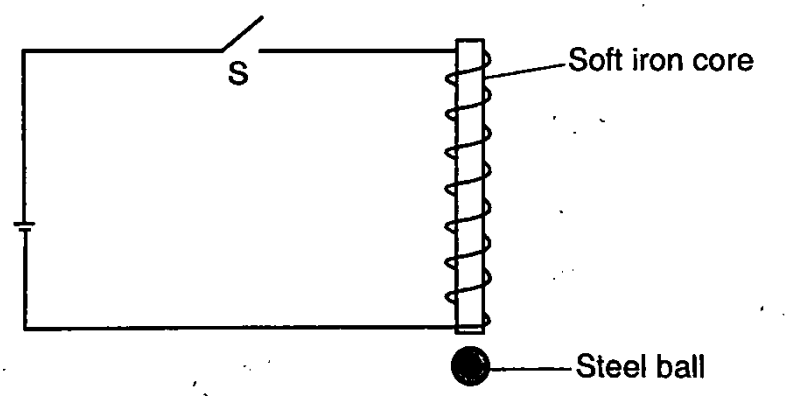
(a) Removing the core.

(b) Replacing the iron core with a steel core.

5. (a) Draw a labelled diagram of a simple D.C. electric motor.

(b) State and explain three ways in which the forces on the coil, and hence the speed of the motor, can be increased.

6. A small electromagnet, used for lifting and then releasing a small steel ball, is made in the laboratory as shown in the figure below.



(a) Explain why soft iron is a better material than steel to use for the core.

(b) In order to lift a slightly larger ball, it is necessary to make a stronger electromagnet.

(c) State two ways in which the electromagnet could be made more powerful.

7. Use the idea of magnetic domains to explain

a) If a magnet is broken in half, each half is a magnet.

b) Heating and hammering magnetizes magnetic material.

c) Magnetism is felt strongly at the poles but not at the centre of a magnet.

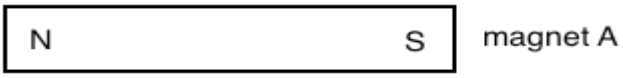
d) Magnetism is induced into an iron bar placed near a magnet.

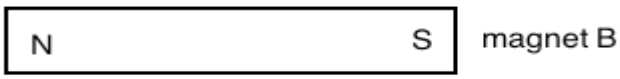
8. Draw the magnetic field lines between the following magnets.

a)

b)

9. Two magnets A and B are placed with their poles as shown below.





a) draw arrows to show the directions of the forces exerted on the north pole of magnet A by each of the poles of magnet B

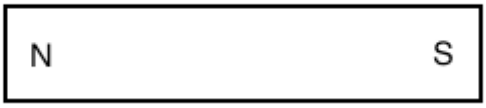
b) draw arrows to show the directions of the corresponding forces exerted on the south pole of B by each of the poles of A

c) draw an arrow to show the direction of the resultant force exerted by magnet B on magnet A. Label the arrow with letter R

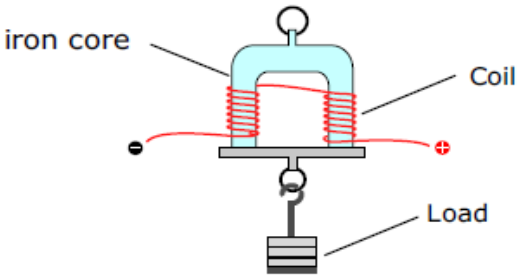
d) Explain why the resultant force acts in the direction you have shown in c.

10. a) Explain what is meant by magnetic field

b) Complete the diagram to show the pattern and direction of the magnetic field in the space around a bar magnet



11. The diagram below shows an electromagnet which is used to lift a load.

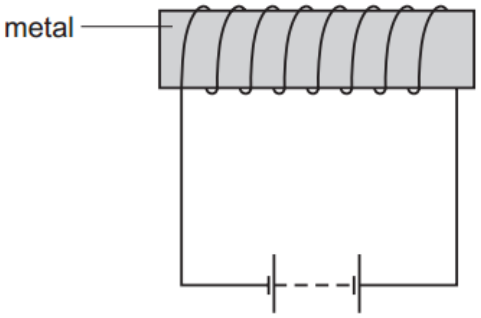


12.

a) Write down two ways you can increase the strength of the electromagnet

b) Explain why, the soft iron is used as the core of electromagnet?

c) Write down two uses of electromagnet?



13. The figure left shows a simple electromagnet.

a) What happens to the paper clips when the switch is open? Explain your answer.

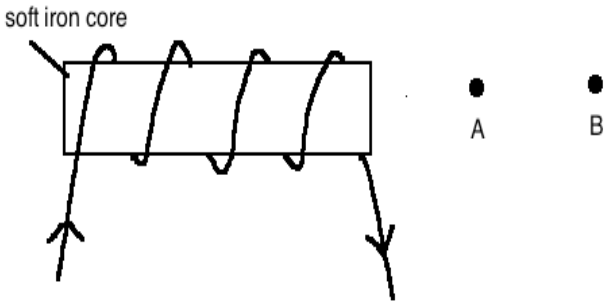
b) Explain why the core is made of soft iron?

c) Suggest two ways in which the strength of this electromagnet could be increased?

14. The diagram below shows a coil of wire wound on a soft iron core. A current is passed through the coil in the direction indicated by the arrows.

a) Mark the N and S poles produced in the iron core.

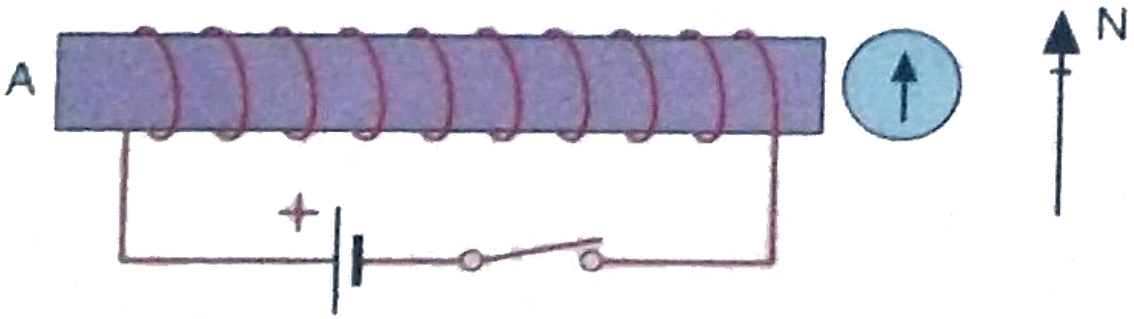
b) Show by an arrow the direction in which the N end of a compass needle would point when placed at A.



15. For the coil in the diagram, when the switch is pressed:

a) What is the polarity of end A?

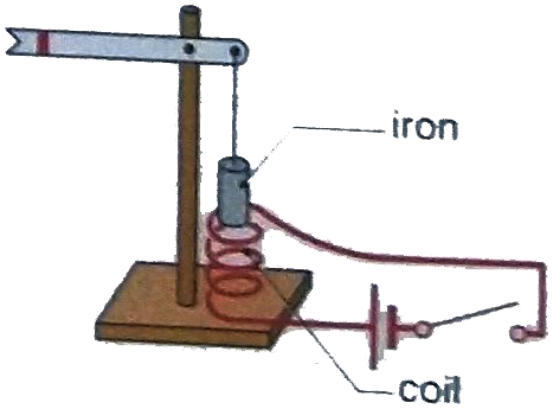
b) Which way will the compass point then?



16. The diagram shows a design for an electrically operated model railway signed.

a) Explain, step by step, how it works.

b) Explain how, by adding a scale and a spring, you could use it as an ammeter.



17. The figure below shows a wire in a magnetic field.

a) Use an arrow on the figure to indicate the direction of the current?

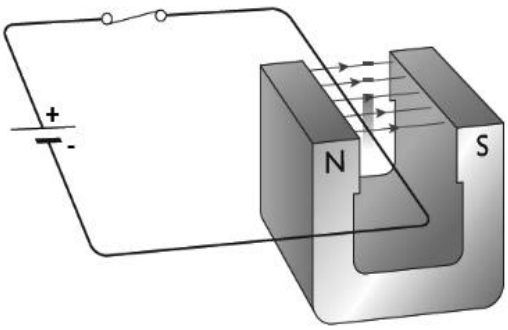
b) The wire moves when the current passes through it

i. Use an arrow to indicate the direction of the motion of the wire?

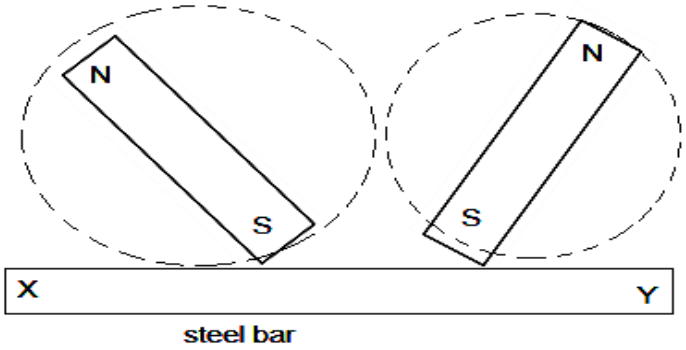
ii. What causes the wire to move when the current passes through it?

c) State two changes that could be made to increase the force acting on the wire?

d) State two ways that can be used to change the direction of the motion of the wire?



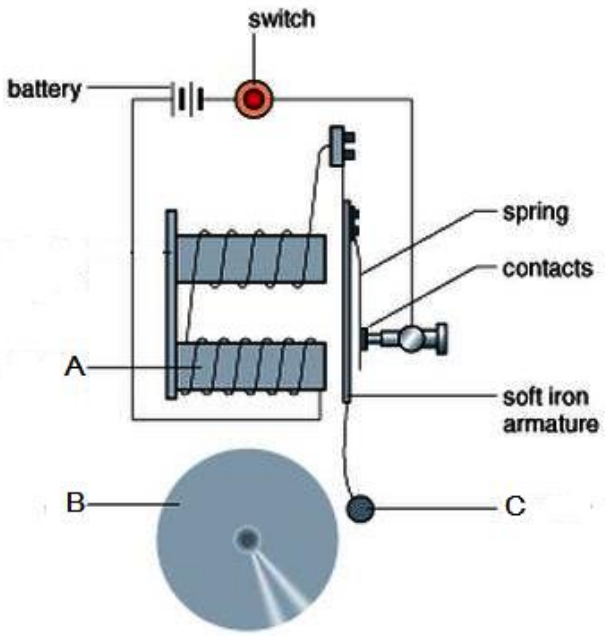
18. A steel bar is magnetized using two magnets as shown below.



a) Use an arrow to show on the diagram the direction in which the magnets should be moved?
b) State the polarity of X and Y?
c) By using domain theory, explain how the steel bar is magnetized in this way?

19. The figure below shows an electric bell.

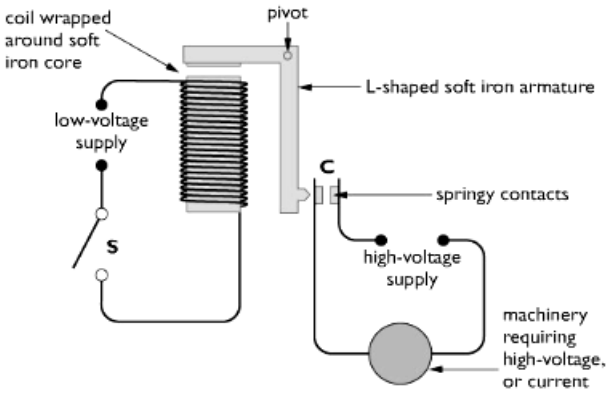
a) Name the parts labeled A, B and C?
b) Which material is used for making A and why?
c) Explain how the bell works?



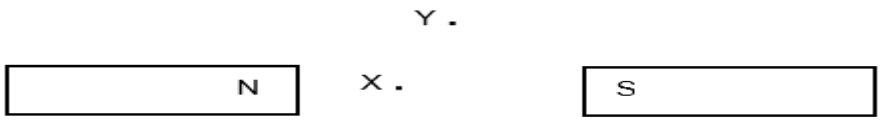
20. The diagram below shows a relay circuit. This circuit can be used to turn other circuit carrying high currents on and off safely.

a) What happens to the soft iron core when switch "**S**" is closed?

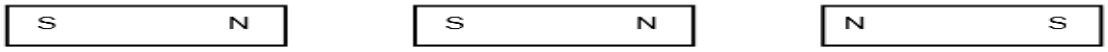
b) Explain in your own words how contact "**C**" becomes closed and the other circuit works?
c) Explain in detail what happens when switch S is then opened?
d) Why would the relay circuit not work if the soft iron core is replaced with steel



21. The figure below shows tow bar magnets near each other.

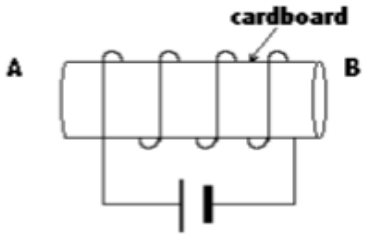


a) Sketch the magnetic field pattern of the two bar magnets?
b) Use n arrow in the diagram to indicate the direction of the magnetic field?
c) At which point "**X**" and "**Y**" does the magnetic is stronger?
d) Three bar magnets are placed on a table as shown. Draw magnetic lines of force in the spaces between the poles of the magnets?

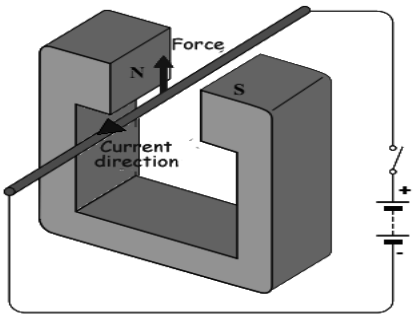


22. The figure below shows a device used for making electromagnet.

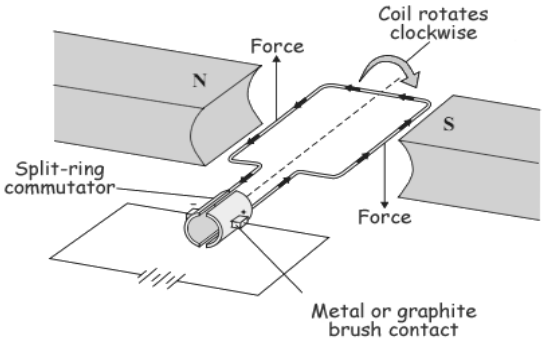
a) Use an arrow to mark the direction of the current in the wire?
b) Mark the polarity of the ends A and B?
c) State three ways to increase the strength of the electromagnet?



23. When a conductor carrying an electric current is placed in a magnetic field a force may act on it as shown below.
a) State two ways in which this force can be made to act in opposite direction?
b) In what circumstance will no force act on a conductor carrying an electric current in a magnetic field?



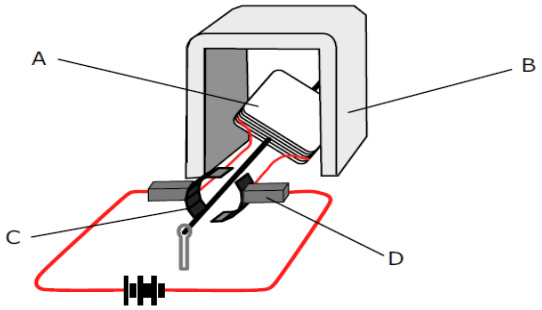
24. The diagram below shows a coil which spins between the ends of a magnet.



i. What is the name of the device shown above?

ii. State two ways that can be increased by the force that acts on the wire?

25. The diagram shows a simple electric motor.



a) Name the parts labeled

A: ……

B: ……

C: ……..

D: ……..…….

b) What is the function of the part labeled C?

……

c) When the current flows through the coil, it rotates write down three ways you can increase the rotation (or speed) of this simple electric motor

1) ……

2) ……

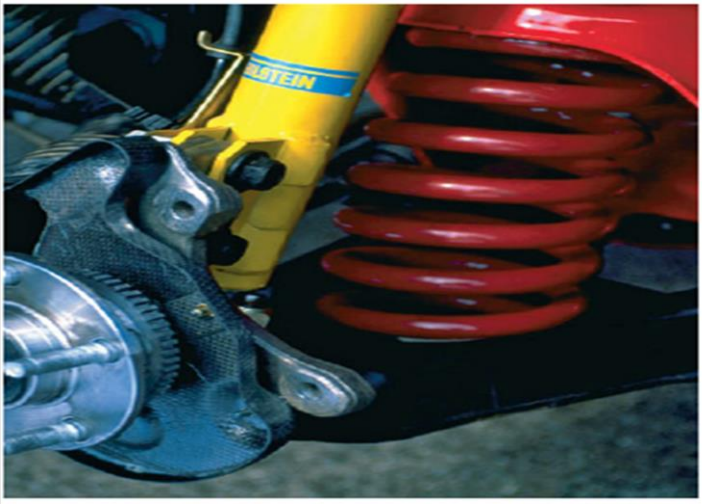
3) …….

d) Write down two ways you can change the rotation of the motor?

1) ……

2) ……...

Chapter four: Oscillation and introduction of waves



Chapter objectives

By the end of this chapter the learners will be able to:

- state that an 'oscillation' (or vibration) is a forward and backwards movement
- use pendulums (clock in mosque) to illustrate amplitude, frequency and period.
- demonstrate experiment about the factors that influence the period
- demonstrate basic experiments of spring oscillation
- identify the factors that effects period of simple spring oscillator
- perform basic calculations of frequency and period of spring oscillation
- state the two types of waves (longitudinal (a rope) and transverse)
- define the characteristics of waves and solve some basic calculations.
- give a simple explanation of a wave and some examples, e.g. ripples on water, using a slinky spring

4.1 Oscillation

Things which move with a regular **to** and **fro** motion are said to **Oscillate** or **vibrate**. In another word Oscillation is defined as **to** and **fro** motion of a body that repeated itself. Many mechanical systems oscillate if they are disturbed. For examples, a child swing backwards and forwards if it is pushed once. Similarly the motion of a mass attached to a spring, the motion of pendulum bob, tuning fork and musical instruments are examples of oscillations (figure 4.1).

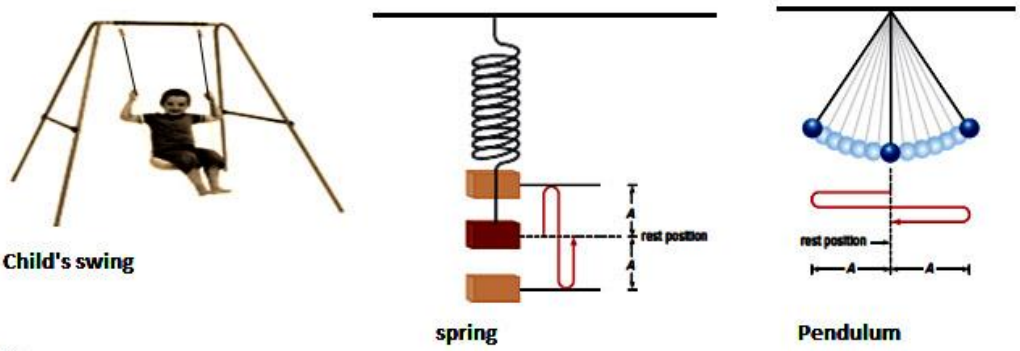


figure 4.1

There are different types of oscillations in nature. All these type of oscillations have the same common characteristics.

Common characteristics of oscillation

Period (T)

As the mass moves from **A** to **B** and back to **A,** it makes one complete oscillation (figure 4.2).

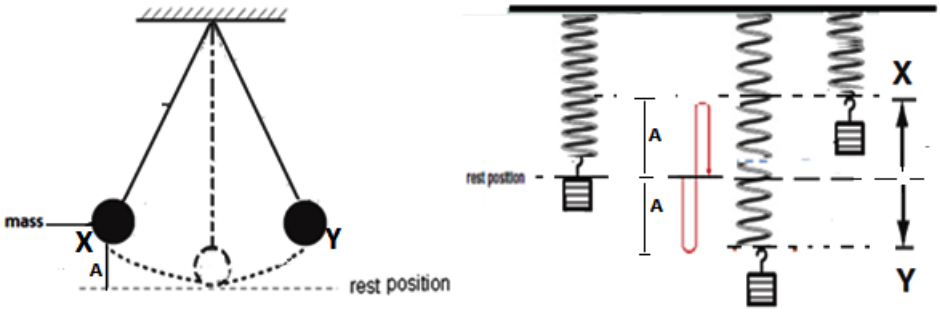


Figure 4.2

The time taken for one complete oscillation is called **period (T).**the period, like all time intervals, is measured in seconds.

$$\textbf{Period} = \frac{\textbf{TotalTime}}{\textbf{NumberofSwings}}$$

Frequency (f)

The number of complete oscillations (or cycles) made in one second is called a frequency (f). Frequency is measured in cycles per second called Hertz, symbolized by Hz.

$$\textbf{Frequency}(\textbf{f}) = \frac{\textbf{Numberofswings}}{\textbf{Totaltime}}$$

$$\textbf{Frequency}(\textbf{f}) = \frac{\textbf{1}}{\textbf{Period}}$$

The Amplitude

The amplitude of an oscillation is the maximum displacement from rest position**.**

Example: 1

A child on swings goes backwards and forwards 100 times in 5 seconds. Calculate

(a) The period of oscillation
(b) The frequency of oscillation

Answer:

(a) $\text{Period} = \frac{\textbf{TotalTime}}{\textbf{NumberofSwings}}$

$$\text{Period} = \frac{\textbf{5 sec}}{\textbf{100}}$$

$$= \textbf{0.05 sec}$$

(b) $\text{Frequency(f)} = \frac{\textbf{1}}{\textbf{Period}}$

$$\text{Frequency(f)} = \frac{\textbf{1}}{\textbf{0.05 sec}}$$

= 20 Hz

Example 2

A vibrating fork makes 2 complete oscillations in 1 second.

(a) What is its frequency?
(b) What is its period?

Answer:

(a) $\text{Frequency} = \frac{\textbf{NumberofSwings}}{\textbf{Total time}}$

$$\text{Frequency} = \frac{\textbf{2}}{\textbf{1sec}}$$

$$\textbf{=2 Hz}$$

(b) $\text{Period(T)} = \frac{\textbf{1}}{\textbf{Frequency}}$

$$\text{Period (T)} = \frac{\textbf{1}}{\textbf{2 Hz}}$$

= 0.5 sec

Simple pendulum

A simple pendulum can be made by hanging a small bob of mass **m,** suspended by a light in extensible thread of length **L** from a fixed point as shown in the figure 4.3.
When the bob is pulled to one side and then released it moves forwards and backwards. If the bob moves from **A** to **B** and back to **A** it makes one complete oscillation or cycle.

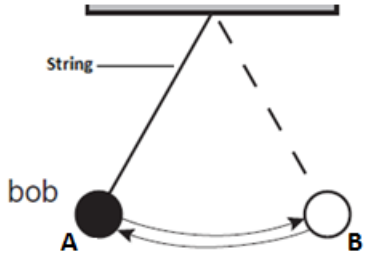


Figure 4.3

Experiment: The period of simple pendulum

Aim: To investigate factors which affect the period of simple pendulum, in this the length of string?

Apparatus:

- Stand and clamp
- different masses
- long string
- stop watch
- graph paper
- Meter ruler.

Procedure:

- Arrange the apparatus as shown in the figure 4.4.

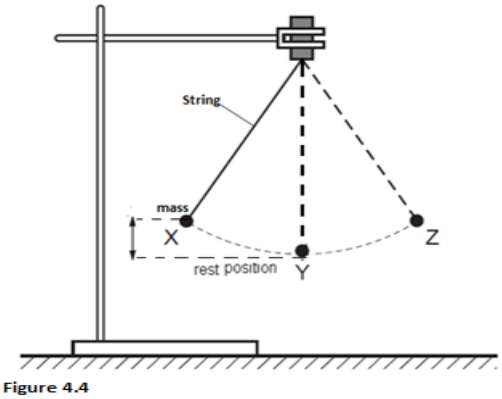


Figure 4.4

- Use **100g** mass for the bob and a string **10cm** long and amplitude of **6cm** in each case. Pull the mass aside and then release it so that it oscillates forward and backwards.
- Measure the time for **20** swings. One swing is being from **X** to **Z** through **Y** twice and back to **X**.
- Find the period of the oscillation using the formula

$$\text{Period} = \frac{\text{TotalTime}}{\text{NumberofSwings}}$$

- Redo the experiment by changing the lengths 20cm, 30cm, 40cm and 50cm, in same way, keeping the amplitude and the mass of the bob unchanged.

Discussion

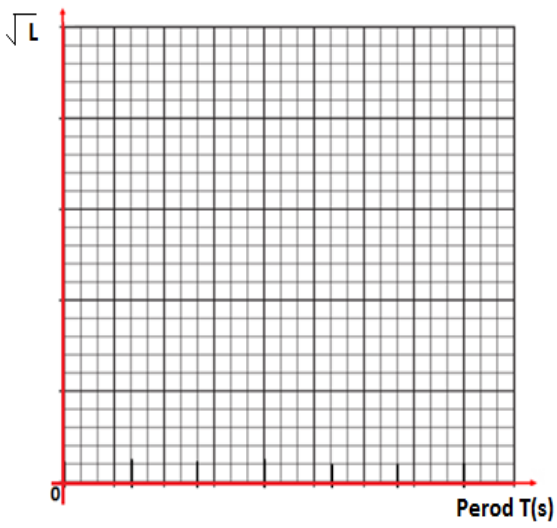
(a) Which factor (length of the string or amplitude of swing) effected the period of the simple pendulum.

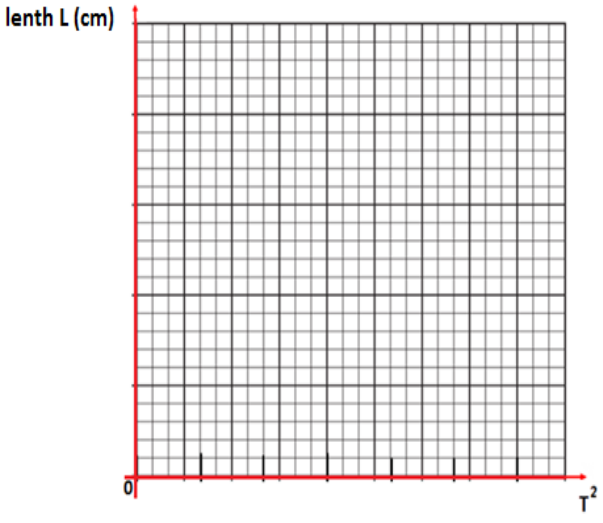
Answer:

- Fill the tables below and plot a graph of **T** against $\sqrt{L}$ **or** $\mathbf{T^2}$against **L**

Length, L (cm)	**0**	**10**	**20**	**30**	**40**	**50**
$\sqrt{L}$						
Period, T (s)						

Length, L (cm)	**0**	**10**	**20**	**30**	**40**	**50**
Period, T (s)						
$\mathbf{T^2}$						





Results and conclusions

✓ The period of simple pendulum is depends on:

(i) The l**ength** of pendulum, the period increases with the increasing the length of pendulum

(ii) The strength of the gravity.

Period (T) = $2\pi\sqrt{\frac{L}{g}}$ where L = length of the string

g = gravity

- ✓ The period of simple pendulum does **not** depend on:
  - (a) The Amplitude
  - (b) The mass of the bob.

Example: 3

A simple pendulum with a mass of 5kg is 40m long and has amplitude of 10cm (Take g = 10N/kg). Calculate:

(a) The period of the oscillation

(b) The frequency of the oscillation?

Answer:

(a) **Period (T) =** $2\pi\sqrt{\frac{L}{g}}$

Period (T) = $2(3.14)\sqrt{\frac{40\ m}{10\ N/kg}}$

Period (T) = 6.28 x $\sqrt{4}$

= 6.28 x 2 sec= 12.56sec

(b) Frequency (F) = $\frac{1}{period}$

Frequency (F) = $\frac{1}{12.56\ sec}$

= 0.08 Hz

4.2 Spring oscillation

The figure 4.2 shows a mass on spring rest at equilibrium position. When **a mass** on the lower end of spiral-spring is pulled down, energy is stored in the stretched spring. When released the mass stars to move upwards accelerated by the force of the spring. It shoots past the rest position and starts to compress the spring. The compressed spring gives a force downward. This force slows the mass down until it just stops. Then the mass accelerates downwards past the rest position, and stretches the spring again. The motion keeps repeating itself

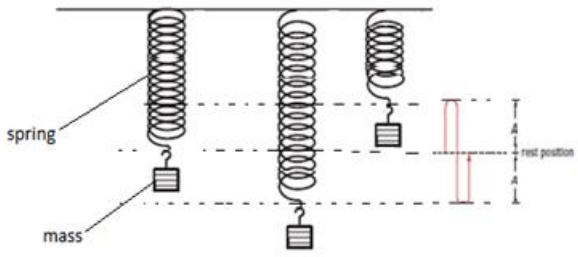


Figure 4.5 a spring oscillation

During each oscillation the mass loses some of its energy to the air due to air resistance. The spring also heats up a bit as it is continually stretched and compressed.

Experiment: 4.2. The period of spring oscillator

Aim = to investigate factors affecting the period and frequency of spring oscillator

Apparatus needed

- Stand and clamp
- Light spiral spring
- Stop watch
- Metre
- Graph paper
- Different

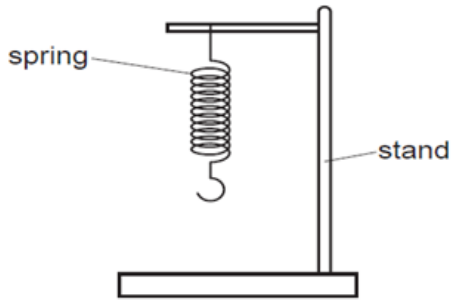


Figure 4.6

Procedure

- Support the spiral spring as shown in the figure 4.6.
- Hang a mass **(e.g. 100g)** from its end so that it stretches several centimeters.
- Pull the mass vertically downwards few centimeters so that it oscillates up and down above and below its rest position.
- Measure the time for **20** oscillations.
- Redo the experiment by changing the amplitude while the mass is kept constant.

$$\text{Period} = \frac{\text{TotalTime}}{\text{NumberofSwings}}$$

Discussion

(a) What happened when the amplitude is changed?

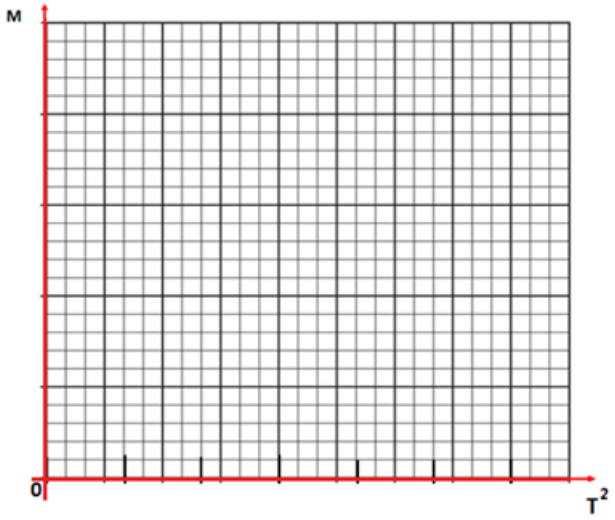
(b) What did you observe on the period when the mass is changed?

Answer

(a) The amplitude of oscillation has **no** effect on the period of the spring oscillator

(b) Plot a graph of mass against time

Mass (g)	100 g	200 g	300 g	400 g	500 g
Time(s)					
T^2					



Increasing the mass increases the period, so the mass has effect on the period of the spring oscillator.

Period (T) = $2\pi\sqrt{\frac{M}{k}}$ where k = spring constant

M = mass of the object

Example: 4

What is the period and frequency of oscillation spring which oscillates **20** times in **10**seconds?

Answer:

$$\textbf{Period} = \frac{\textbf{TotalTime}}{\textbf{NumberofSwings}}$$

$$\text{Period} = \frac{10\ \text{sec}}{20}$$

= 0. 5 sec

Frequency (F) = $\frac{\mathbf{1}}{\boldsymbol{period}}$

Frequency (F) = $\frac{1}{0.5\ sec}$

= 2Hz

Example: 5

Calculate the period and frequency of simple harmonic motion for spring loaded with **4 kg** where k = **10N/m**?

Answer:

Period (T) = $\boldsymbol{2\pi\sqrt{\frac{M}{k}}}$

Period (T) = $2(3.14)\sqrt{\frac{5kg}{10\ N/m}}$

Period (T) = $6.28\ \sqrt{0.5}$

=6.28 x 0.7071 sec

= 4.44 sec

Frequency (F) = $\frac{\mathbf{1}}{\boldsymbol{period}}$

Frequency (F) = $\frac{1}{4.44\ sec}$

= 0.225 Hz

4.3 introduction of waves

Waves:

It is a common experience that if a stone is dropped in to a pool of water, disturbance is created where the stone strikes the water. The disturbance moves in a circle and reaches the other parts of the pool, figure 4.7.This phenomenon in which a disturbance at one parts of the medium and the progress of the disturbance to the other parts of the medium is known as a **wave**.

Medium is the name given to the material through which a wave is propagated

Figure 4.7 water waves

According to the nature of vibrating medium waves are classified into two:

Mechanical waves: waves that need a material medium for their propagation are called mechanical waves. These waves are produced by the vibration of physical bodies. E.g. sound waves, water waves, waves of string, etc.

Electromagnetic waves: waves that are propagated through a material medium as well as through a vacuum are called electromagnetic waves. These waves are characterized by the oscillation of electric and magnetic field. E.g. light waves, radio waves, x-ray, microwaves, etc.

Types of waves

Waves can be classified by the way in which they travel relative to the motion of the particles of the vibrating medium. There are two general type **Transverse waves** and **longitudinal waves.**

A transverse wave is a wave in which the particles of the medium vibrate perpendicular to the direction of travel of the wave motion, figure 4.8.

The wave moves along the rope, however, the particles of the rope move at right angle to the motion of the wave. For example, water waves, vibrating string and all electromagnetic waves are transverse waves.

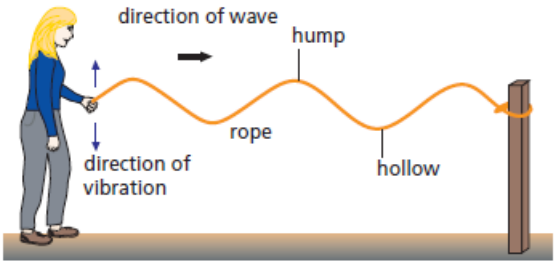


Figure 4.8 Transverse waves

A longitudinal wave is a wave in which the particles of the medium vibrate in line or parallel to the direction of travel of the wave motion, figure 4.9.

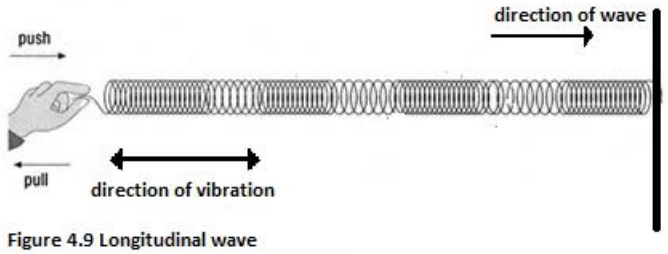
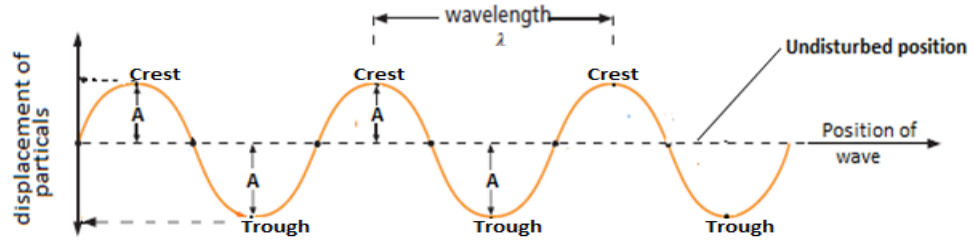


Figure 4.9 Longitudinal wave

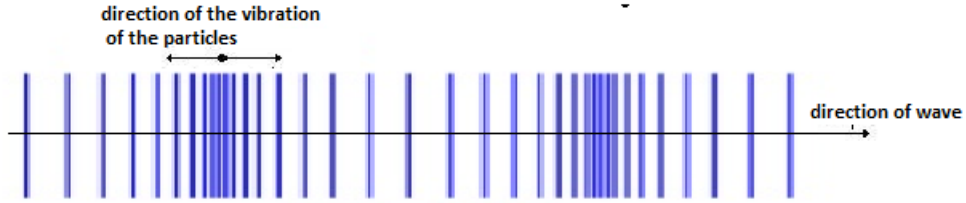
A quick movement of the hand (push or pull of the spring) produces a wave along the spring and the particles of the spring move in a line with the direction of travel of the wave. A sound wave is an example of a longitudinal wave.

Both transverse wave on a rope and longitudinal wave on the spring can be represented by the graphs. Figure 4.10, (a) transverse wave, (b) longitudinal wave.



(a) Transverse Wave

- Crest : high point of the wave form
-Trough: low point of the wave form



(b) Longitudinal Wave

C = compression
R = rarefaction

Figure 4.10

- Compression: more dense region of a longitudinal wave
- Rarefaction : less dense region of a longitudinal wave

Characteristics of wave

Waves are characterized by the quantites such as ***Wavelenght***, ***Amplitude***, ***Frequency***, ***Period***, etc.

Wavelenth (λ) :

The distance between successive crest or trough is known as the wavelength, represented by the Greek letter lambda (λ).

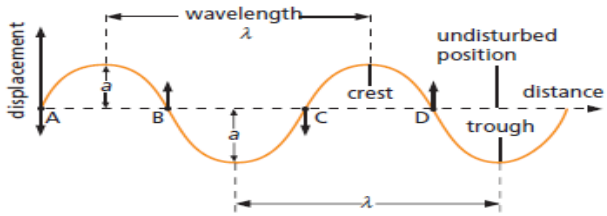


Figure 4.11 disolacement-distance graph of a wave

- ✓ ***Wavelenth*** (λ) $= \frac{Total\ distace}{number\ of\ waves}$
- ✓ Si unit of wave lenth is metre (m)

Period (T) :

The maximum time taken by the wave to travel from one crest to the adjacent crest is known as the period (T).

- ✓ Si unit of period is second (s)
- ✓ Period(T) = $\frac{total\ time\ taken}{Number\ of\ waves}$
- ✓ Period(T)= $\frac{1}{frequency}$

Frequency (f):

The number of waves generated by a source in one second is known as frequency (f).

- ✓ Si unit of frequency is hertz (Hz)
- ✓ Frequency(f)= $\frac{number\ of\ waves}{total\ time\ taken}$
- ✓ Frequency(f)= $\frac{1}{period}$

Amplitude (A):

The displacement of the particles of the medium above or below the undisturbed position is known as the Amplitude (A).

Velocity of a wave(v):

The velocity of a wave can be determined in terms of the distance moved in a given unit time as

$$speed\ (v) = \frac{wavelength}{period}$$

$\mathbf{V} = \frac{\lambda}{\mathbf{T}}$, but $f = \frac{1}{T}$ and we obtain

$$V = \lambda F$$

Example: 1

Figure 4.12 represents a water wave.

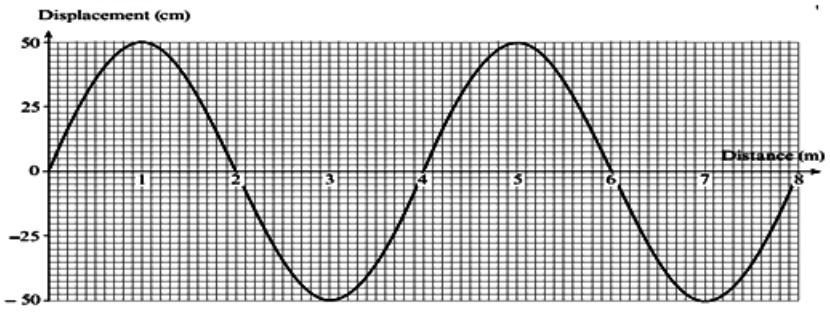


figure 4.12

Calculate:

(a) Wavelength of the wave?

(b) Amplitude of the wave?

(c) If the frequency of the wave is 4Hz what is the

(i) Period of the wave?

(ii) Speed of the wave?

Answer:

Wavelength (λ) = $\frac{\textbf{Total distace}}{\textbf{number of waves}}$

= $\frac{\mathbf{8\ m}}{\mathbf{2}}$ = 4m

Amplitude (A) = 50 cm or 0.5m

Period(T) = $\frac{\mathbf{1}}{\textbf{frequency}}$

= $\frac{\mathbf{1}}{\mathbf{4\ Hz}}$

= 0.25 sec

V = f λ

= 4Hz x 4m

= 16 m/s

Example 2

Transverse waves travelling along a rope have a frequency of 10Hz. If the distance between successive crest (wavelength) is 2m, what is

(a) The period of a wave

(b) The velocity of a wave

Answer:

(a) The Period T is determined by

$$\text{Period} = \frac{\mathbf{1}}{\mathbf{T}}$$

Period = $\frac{1}{10\text{Hz}}$ = 0. 1 sec

(b) Velocity V is determined by

V = $f\lambda$

V = 10Hz x 2m

= 20m/s

Example: 3

A radio wave has a frequency of 3 x10^7Hz. What is its wavelength? A radio wave is an electromagnetic wave and its speed in air is 3 x10^8 m/s.

Answer:

From $\mathbf{V = F\lambda}$, we obtain

$\lambda = \frac{\mathbf{V}}{\boldsymbol{F}} = \frac{3 \times 10^8}{3 \times 10^{\mathbf{8}}}$ = 10m " the wavelength of radio wave is called meter band."

Chapter five:Reflection of light

CHAPTER OBJECTIVE

By the end of this chapter the learners will be able to:

- state that light rays enters our eyes from luminous sources
- show that in a uniform medium, light travels in straight lines
- state that light travels at a finite speed (this you cannot show)
- state sources of light and recognize luminous and opaque objects (lamps, fire etc.)
- show how shadows are formed
- show how light travels in different matter (transparent, translucent and opaque)
- explain that non-luminous objects are seen because the light scattered from them enters the eye.
- define reflection of light
- state and use the law of reflection
- observe and describe the images formed in plane mirrors.
- show the positions of virtual images of plane mirrors using ray diagrams
- describe how periscope works and state its applications
- describe types of curved mirrors
- determine the radius of curvature (curved mirrors), centre of curvature, centre of the mirror, principal axis, and focal length of curved mirrors
- locate the position of images of curved mirrors with ray diagrams
- use and solve problems with the mirror formula
- describe some application of curved mirrors

5.0 Introduction

Light is a form of energy which produced by the matter around us. Light is the major source of energy that can be detected by the eyes or causes photosynthesis in plants. It is therefore, one of the things responsible for our life. It is almost impossible to imagine the world without light. Because of light and our eyes, we are able to see things around us.

Objects that emit (sent out) their own lights are called **luminous objects**. E.g. the **sun**, **lamps, candles**, **stars** etc. Objects that do not produce their own light are called non-**luminous objects** (E.g. the moon, table, wood, etc.). However, they are seen when they **reflect** light from luminous objects, figure 5.1.

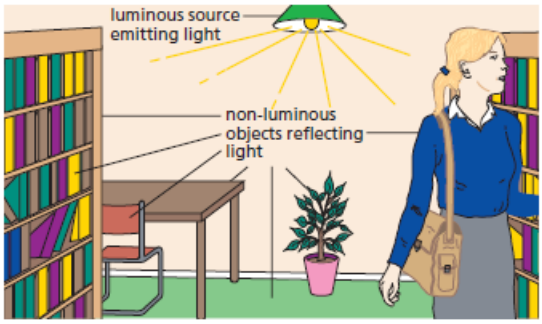


Figure 5.1 Luminous and non-luminous objects

The word **luminous** refers only to bodies that emit light. All warm objects emit radiation, but not all emit visible light.

5.1Propagation of Light

Light travels in a straight line in a uniform medium. This is known as rectilinear propagation of light. We use a line with an arrow on its head out from source to represent the direction in which light wave is traveling. This line is called a **ray**. A number of rays or stream of light is known as a **beam** of light. A beam of light could be **parallel**, come towards a point (**converge**) or it may be spread out (**diverge**), Figure 5.2.

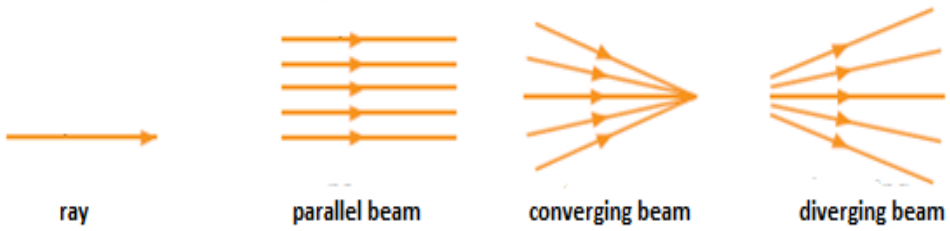


Figure 5.2

For example, laser is a source of parallel beam. Car headlights and torches produce divergent beams.

There are many facts in our daily lives which prove that light travels in straight lines:

(i) We cannot see round corners because light travels in a straight line

(ii) Shadows occur because light travels in a straight line. If light could bend around corners, there would be no shadows.

(iii) The light from the setting sun is often seen to travel in straight lines especially when the sky is cloudy.

(iv) By shaking some chalk dust near a sunny window, beams of sunlight can be made visible. They are straight. The chalk dust makes the beams visible by scattering light towards our eyes.

Speed of Light

The speed of light in air or vacuum is approximately **300 000 km/s**, **(3 x10^8 m/s).** The speed of light is different in different materials, like glass and water; light does not travel as fast as it does in air or vacuum. Light travels very much faster than sound.

There are many examples to show this:

(i) We hear the sound of thunder after we have seen the lightning flash.
(ii) At race tracks, the flash of the starter's gun is seen before the bang is heard.
(iii) You may have stood some distance from a man cutting a tree. The sound of the axe is heard after we have seen it strike the tree.

Transparent, Translucent and Opaque objects

Materials that allow light to pass through them clearly are called **transparent materials**. E.g. clear glass, air, Figure 5.4. Materials that allow light partially to pass through them are called **translucent materials**. Some light pass through but objects cannot be seen through them clearly and distinctly .E.g. oiled paper, frosted glass.
Materials that do **not** allow light to pass through them are called **Opaque materials**. E.g. books, wood, etc.

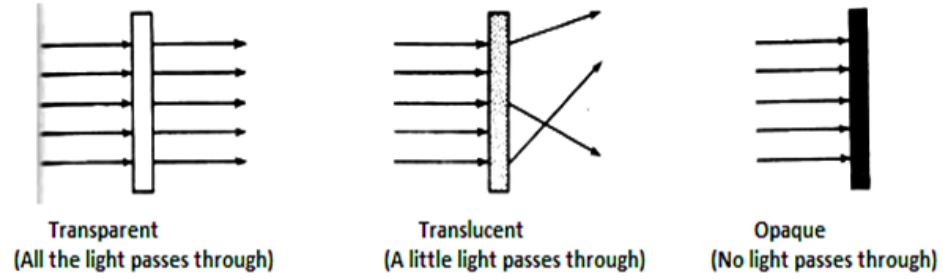


Figure 5.4

Experiment: 5.1. To investigate how light travels

Aims: To demonstrate that light travels in straight lines

Apparatus needed:

- A candle,
- Matches and
- Three sheets of paper (card).

Procedure:

- Make a small hole in the middle of each of the three sheets of paper.
- Light the candle.
- Look at the burning candle through the hole in the first sheet of paper.
- Place the second sheet of paper between you and the candle so that you can still see the candle through the holes.

- Now do the same with the third sheet so that you can still see the candle. The sheets of paper must not touch each other, figure 5.5.

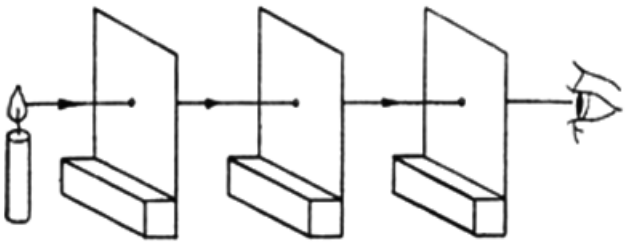


Figure 5.5 Light travels in a straight line

Discussion:

What do you notice about the holes in the paper?

Conclusions

In the investigation you will notice that the holes in the paper need to be in a straight line. This shows that light travels in a straight line. We cannot see around corners. This also proves that light does not bend around a corner, but travels straight.

A shadow

One direct effect of light traveling in a straight line is the casting of a shadow behind an opaque object. A shadow is a region behind an opaque material where light can't reach.

When the source of light is small as in fig 5.6 (a), a shadow with sharp edge is formed, when the source is larger, shadow with shaded edges is formed, fig 5.7 (b). The part of a shadow which is in total darkness is called **umbra** and the part which is partially illuminated is called **penumbra**.

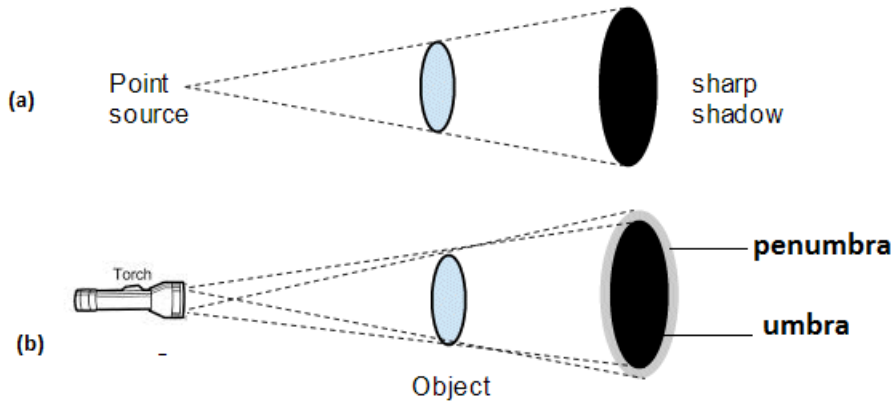


Figure 5.6 forming a shadow

5.2 Reflection of light

When a ray of light falls on a polished and shining surface of an object, then it is sent back in the same medium. The process of sending back the light rays after falling on the shining surface of an object is called **reflection of light**. In another word, the bouncing back of light from a shining surface is known as **reflection** of light.

Reflection of Light from a Plane Mirror

when a ray of light **(AO)** falls on a plane mirror at the point **O** then it gets reflected by the mirror in the direction **OB**.

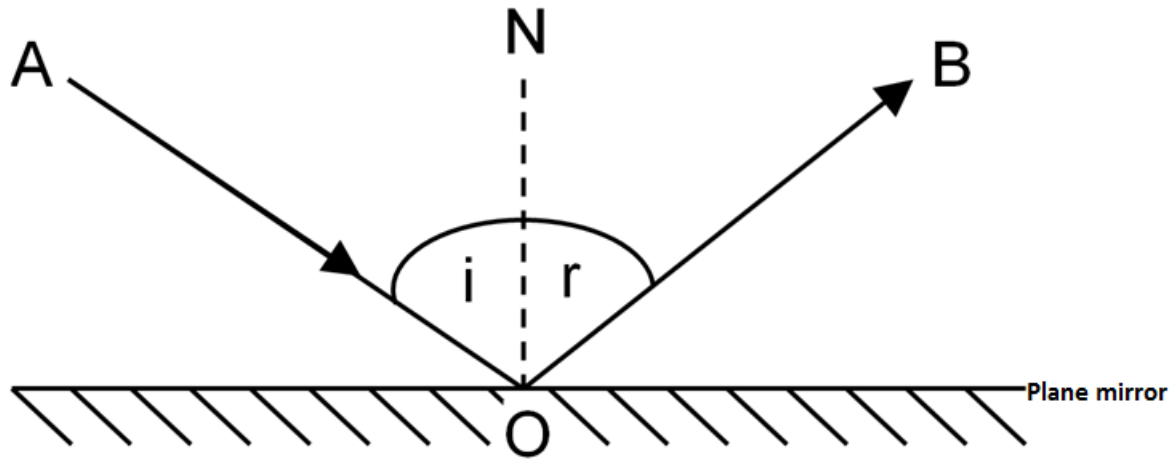


Figure 5.7 Reflection of plane mirror

Now we shall discuss some important terms related with the reflection of light by a mirror.

- ✓ **Incident Ray**

  The ray of light which falls on the surface of mirror is called **incident ray**. In figure5.7, AO is the incident ray of light.

  Point of Incidence

  The point at the surface of mirror at which the incident ray falls is called the **point of incidence**. In figure the point **O** on the surface of mirror is the point of incident.
- ✓ **Reflected Ray**

  When the incident ray falls on the surface of a mirror, the mirror sends it back in another direction (in same medium). The ray of light which is sent back by the mirror is called **reflected ray**.
- ✓ **Normal**

  Normal may be defined as a line which is perpendicular to the mirror at the point of incidence. In figure line **ON** is normal to the mirror at point **O**. the normal is always represented by a dotted line.
- ✓ **Angle of Incidence**

  The angle of incidence may be defined as the angle which is made by the incident ray with normal at the point of incident. It is denoted by the letter **i**. In figure5.7, the angle **AON** between the incident ray **AO** and the normal **ON** is the angle of incidence.
- ✓ **Angle of Reflection**

  The angle of reflection may be defined as the angle which is made by the reflected ray with normal at the point of reflection. It is denoted by the letter **r**. In figure5.7, the angle **NOB** between the reflected ray **OB** and the normal **ON** is the angle of reflection.

Types of reflection of light

1. **Regular reflection**: Regular reflection takes place from the surfaces of polished and very smooth surface like mirror. Here parallel rays that fall on the surface are reflected in the same direction, Fig 5.7.

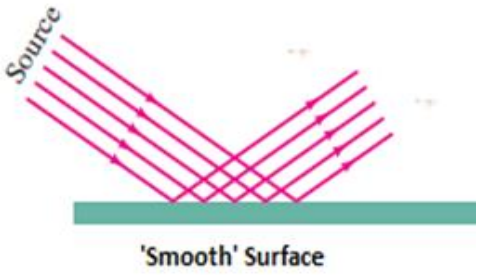


Figure 5.8 Regular reflection

2. **Diffuse reflection:** Diffuse reflection takes place from rough surfaces. Here parallel rays that fall on the surface are scattered in different directions after reflection, Fig 5.7(b).

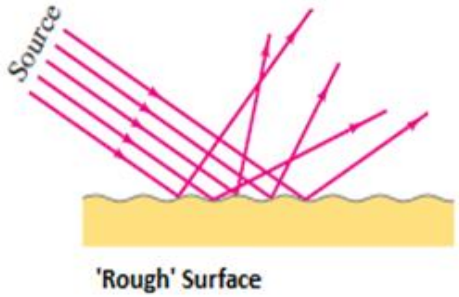


Figure 5.9 diffuse reflection

Laws of Reflection

There are two law of reflection of light which are applicable both in the reflection of light from the plant mirrors or from spherical mirrors. These are:

1. The angle of incidence is always equal to the angle of reflection. I.e. **i = r**. It means that during the reflection of light if the angle of incidence is 25^0 then the angle of reflection will also be 25^0. And if the angle of incidence is 60 then the angle of reflection will also be 60^0.
2. The incident ray, the normal at the point of incidence of mirror and the reflected ray, all lie in the same plane.

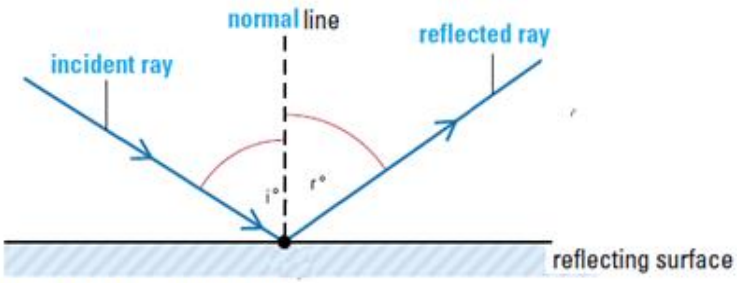


Figure 5.10 Laws of reflection

Special Case: - As we have already discussed that during the reflection of light the angle of incidence is always equal to the angle of reflection i.e. **i = r**. But now a question arise in our mind that what would happen if a ray of light falls perpendicularly on the surface of mirror? The answer to this question is that the incident light which falls perpendicularly on the surface of mirror will be reflected back along the same path, because the angle of incident for such a ray of light is zero. And because **i = r** so the angle of reflection will also be zero.

Example:

1. Calculate the angle of incident and angle of reflection in each figure 5.11below.

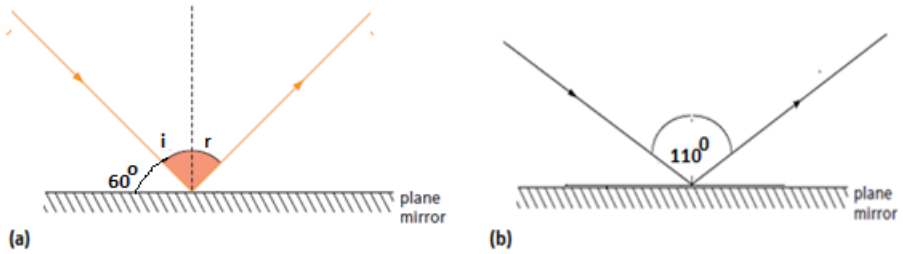


Figure 5.11

Answer:

a) $i + 30^0 = 90^0$ ……..*angle at normal*

$i = 90^0 - 30^0 = 60^0$

$i = 60^0$

r $=60^0$ ……According to the law of reflection, the angle of reflection is also 60^0.

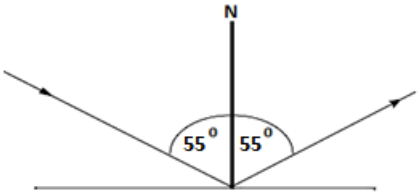
b) $i + r = 110^0$

i = r……According to the law of reflection, the angle of incident is equal to the angle of reflection.

$i + i = 110^0$

$2i = 110^0$

$i = 55^0$ *and* $r = 55^0$



The angle of incidence = $\mathbf{55^0}$, and angle of reflection = $\mathbf{55^0}$

2. A light ray makes an angle of 30^0 with the reflecting surface.
   (a) Whatis the angle of incidence?
   (b) What is the angle between the incident ray and the reflected ray? See figure 5.12

Answer:

a) $i + 60^0 = 90^0$

$i = 90^0 - 60^0 = 60^0$

$i = 30^0$

b) The angle between the incident and the reflected ray is equal to I + r. but i= r = 30^0. Therefore, they make an angle of 60^0.

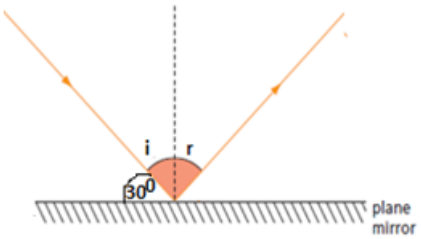


Figure 5.12

Images

When we see ourselves in a mirror, what we see is commonly called reflection. In physics the appearance if anything we see in mirror or through a lens is known as an **image**. In another word an image may be defined as that point, where the light rays coming from an object meet or appears to meet after reflection.

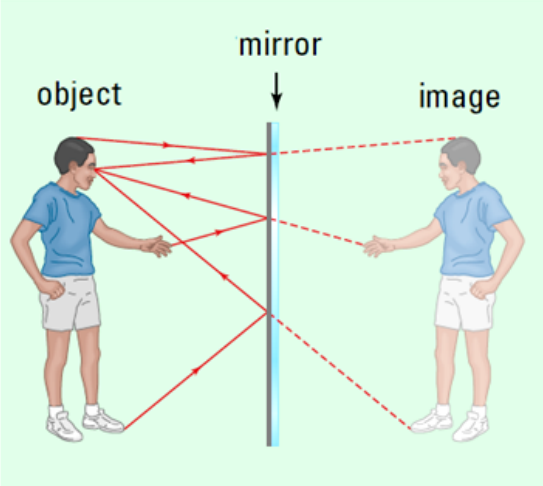
Types of Images

The images are of two types:

1. Real images
2. Virtual images

Real and virtual images

If you stand in front of a mirror to see your image, you observe that light rays form appoint on your body that fall on the mirror bounce off the mirror. These rays are known as **real rays**. Looking at your image light rays appears to come from the image. But in fact, there is nothing behind the mirror and light can't pass through the mirror. These imaginary rays are known as **virtual rays.** To distinguish theserays from real ray we draw them as broken lines, figure 5.13 (**a)**.



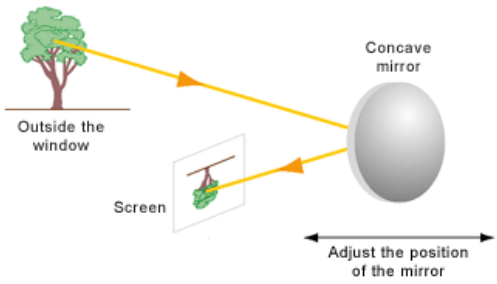


Figure 5.13 (a) virtual image

(b) real image formed on the screen

A virtual image is the image which is formed when the light rays coming from an object do not actually meet, but appear to meet when produced backwards. These images cannot be obtained on the screen. The virtual image is always erect. The common example of virtual image is the image formed in the mirror when we stand in front of that mirror.

A real image is the image which is formed when the light rays coming from an object actually meet each other after reflection, figure 5.13 b. A real image can be obtained on the screen. The real image is always inverted. The common example of real image is the image formed on the cinema screen or on a photographic film.

Table 5.1 Differences between Real Images and Virtual Images

No.	Real image	Virtual image
1.	A real image is that image which is formed when the light rays coming from an object actually meet each other after reflection or refraction.	A virtual image is that image which is formed when the light rays coming from an object do not actually meet, but appear to meet when produced backwards.
2.	A real image can be obtained on the screen.	These images cannot be obtained on the screen.
3.	The real image is always inverted.	The virtual image is always erect.
4.	The common example of real image is the image formed on the cinema screen.	The common example of virtual image is the image formed in the mirror when we stand in front of that mirror.

Image Formed by a plane Mirrors

If an object is placed in front of a plane mirror, its image will have the following features.

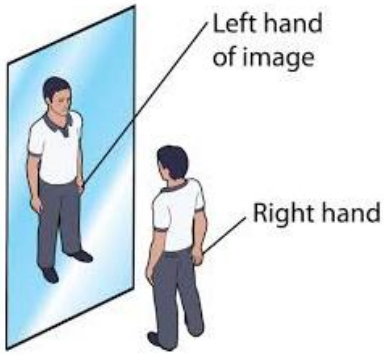


Figure 5.14

Characteristics of an Image Formed by a Plane Mirror:

a) It is virtual
b) It is as far behind the mirror as the object is in front
c) It is the same size as the object
d) It is upright (erect).
e) It is laterally inverted (it has the left side and right side inversion), Figure 5.14.

Reflected Light can be reflected again

Recall the last time you visited a hair dresser. She/he makes you sit in front of a mirror. After your hair cut is complete, she/he places a mirror at your back to show you how the hair has been cut (Figure 5.15). Can you think how you could see the hair at the back of your head?

Figure 5.15 mirror at the hairdresser shop

Image formed by More than one mirror

When **two** plane mirrors are placed at an **angle**, multiple images are formed due to reflections from the two mirrors. The number of images depends on the angle between the mirrors. At an angle **θ**, the number, **n**, of images formed is given by:

$$No\ of images = \frac{360}{\theta} - 1, \quad \text{or} \quad n = \frac{360}{\theta} - 1$$

For Example, A student places two plane mirrors at an angle of **90^0** each other figure 5.16.calculate the number of images produced?

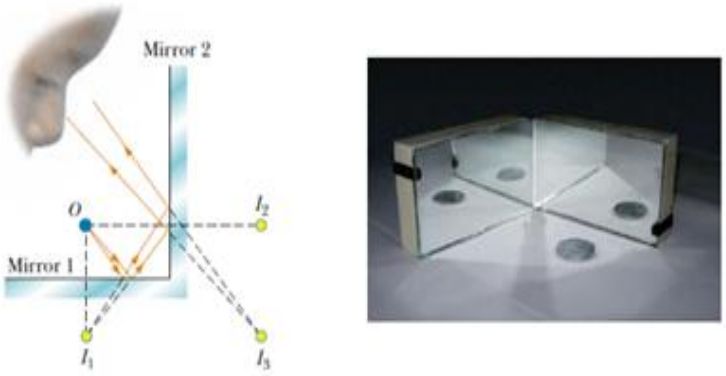


Figure 5.16 Images in plane mirror at right angle to each other

Answer

$$n = \frac{360}{\theta} - 1$$

$$n = \frac{360}{90} - 1$$

n=4 - 1

n= 3 images.

Exercise

1. For each of the following calculate the angle of incidence and the angle of reflection.

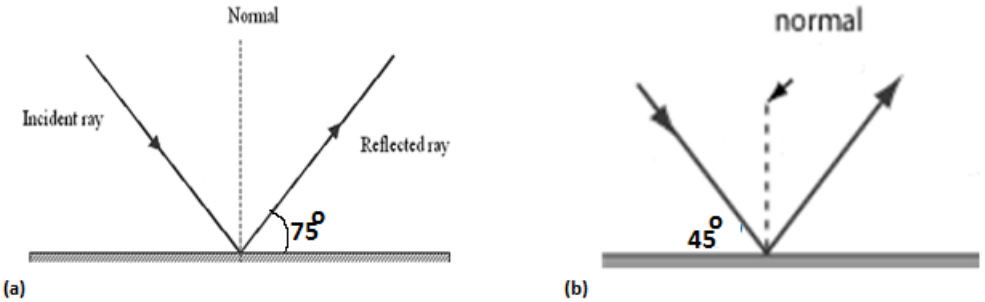


Figure 5.17

2. A ray of light strikes a plane mirror at an angle of incidence of 30°, is reflected from the mirror and then strikes a second plane mirror placed so that the angle between the mirrors is 90°. What is the angle marked at **θ,** figure 5.18.

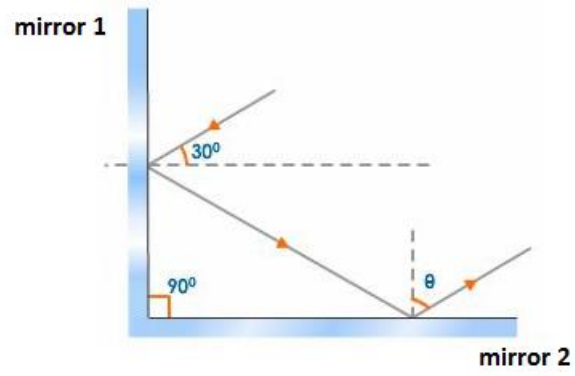


Figure 5.18

3. A ray of light strikes a mirror surface with an angle of incidence of 60^0.
   a) Draw a diagram to show the reflected ray plus the normal to the surface?
   b) What is the angle between the incident ray and the reflected ray?
   c) If the angle of incidence is 0^0, what is the angle of reflection?

4. Which phrase best finishes this statement:
   A sheet of white paper will not act as a mirror because the paper ……..
   a) Absorbs light
   b) Is transparent
   c) reflects light
   d) is diffuse
5. A girl standing 3m in front of a plane mirror, holding a camera. If the girl wants to make a picture of herself in the mirror.
   a) What is the distance between the mirror and her image?
   b) What is the distance between the girl and her image?
6. When two plane mirrors are placed at 120^0, how many images are formed?

Applications of plane mirrors

1. Plane mirrors are used as **looking glass**.
2. Plane mirrors also have many **scientific uses**. In most of the measuring instruments, a plane mirror is placed under the scale and pointer.
3. Plane mirrors are also used in constructing **periscope**.

A periscope is equipment used to view an object over top of an obstacle. It consists of two parallel plane mirrors in a tube, facing each other and positioned at an angle of $\mathbf{45^0}$.
The image in the periscope which the observer sees is not laterally inverted and it is upright and virtual.

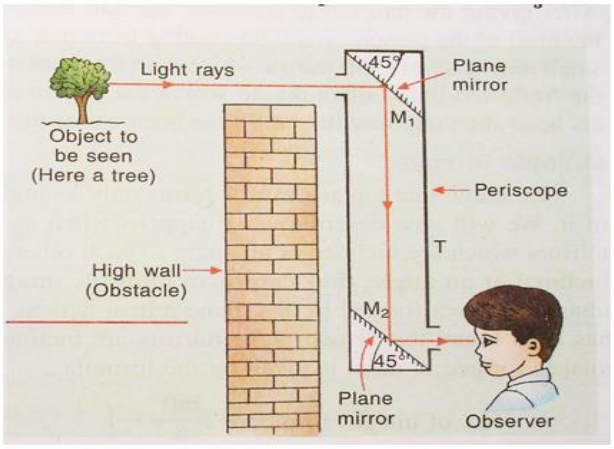


Figure 5.19 A periscope

Periscopes have several important applications such as:

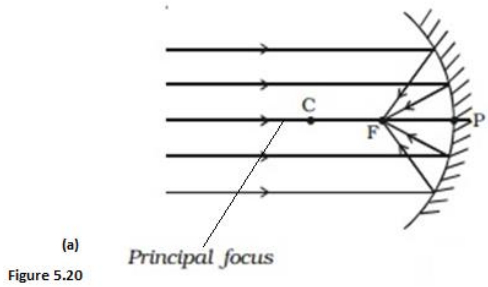
- ✓ They are used to see objects over the top of an obstacle.
- ✓ They are used for submarines under water to view objects on the surface of the water.
- ✓ In double Decker buses to let the driver to see people in the upper deck.
- ✓ At sporting events for spectators to see over crowd.

Spherical Mirror

Mirrors having curved reflecting surface are called spherical mirrors. A spherical mirror is a part of a sphere.

Concave Mirror: Spherical mirror with reflecting surface curved inwards is called concave mirror or converging mirror, figure 5.20 a.

Convex Mirror: Spherical mirror with reflecting surface curved outwards is called convex mirror or diverging mirror, figure 5.20 b.



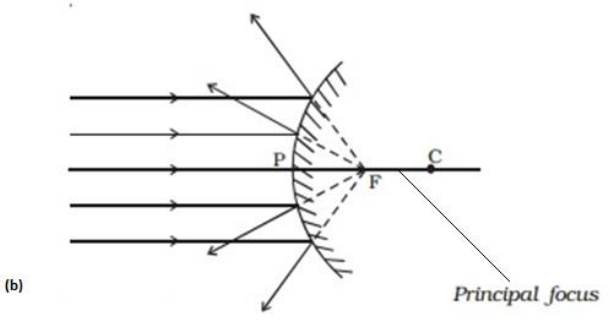
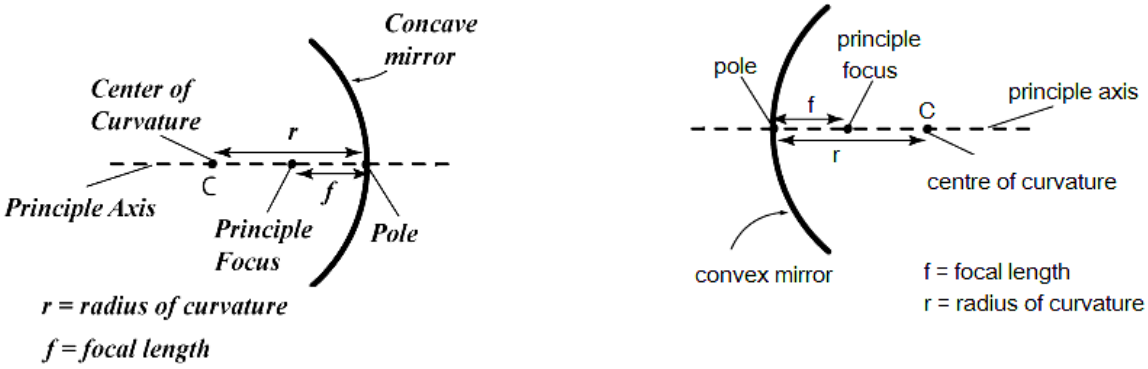


Figure 5.20

The figure below shows some of the technical terms used for both concave and convex mirrors.



- ✓ ***The pole P of a mirror*** is the center of the reflecting surface of the mirror.
- ✓ ***The center of curvature C of a spherical mirror*** *is* the center of the sphere of which the mirror is part.
- ✓ ***The principal axis of a mirror*** is the line passing through its pole and the center of curvature.
- ✓ ***The principal focus F of a concave mirror*** is the point which all rays close to and parallel to the principal axis pass after reflection by the mirror. This is a real focus.
- ✓ ***The principal focus F of a convex mirror*** is the point from which all rays close to and parallel to the principal axis appear to come after reflection by the mirror. This is a virtual focus.
- ✓ ***The focal length f of a mirror*** is the distance between the pole of the mirror to its principal focus.
- ✓ The radius of curvature **r** of a spherical mirror is the radius of the sphere of which the mirror is part.

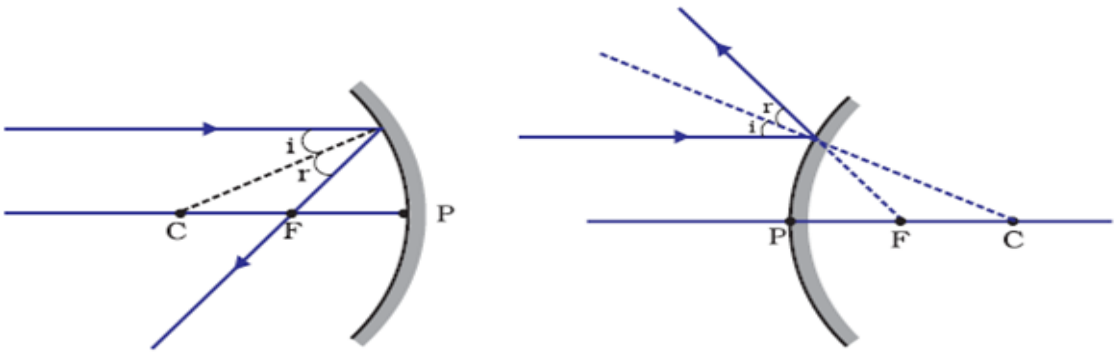
$$r = 2f \qquad or \qquad f = r/2$$

Where r = radius of curvature and f = focal length.

Rules for obtaining images formed by spherical mirrors

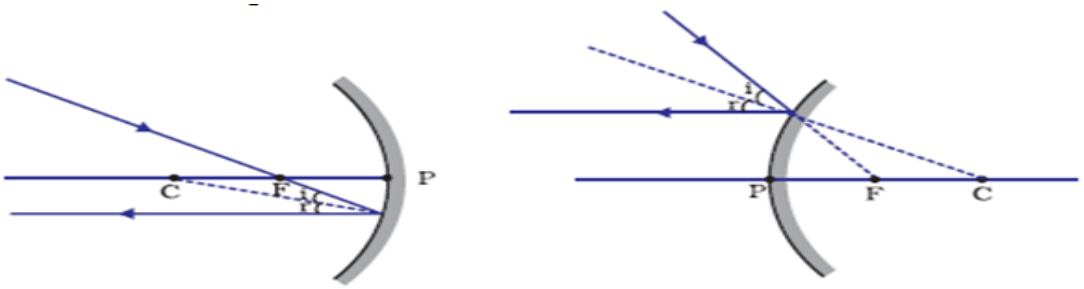
The position of the image formed by spherical mirrors can be found by taking two rays of light coming from a point on the object which intersect each other to form an image. Following are the rules which are used for obtaining images formed by spherical mirrors.

1. A ray of light which parallel to the principal axis, after reflection, passes through the principal focus **F** of a concave mirror, or appears to pass through the principal focus of a convex mirror.



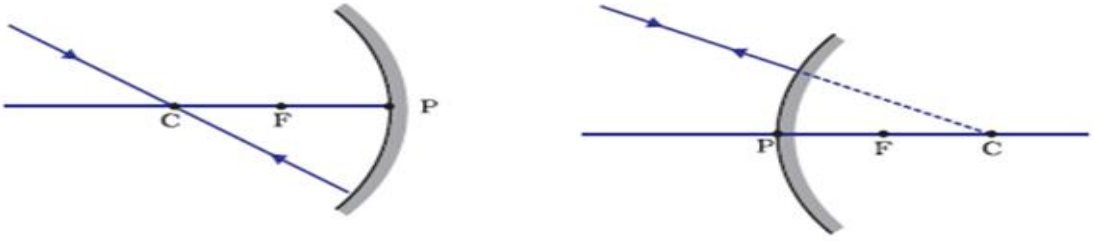
(a) concave mirror (b) convex mirror

2. A ray of light passing through the principal focus of a concave mirror or appearing to pass through the principal focus of a convex mirror becomes parallel to the principal axis after reflection.



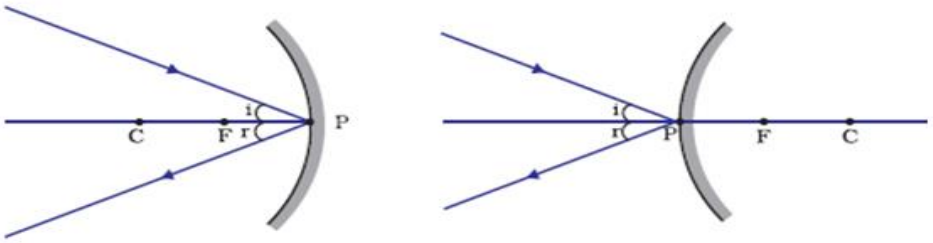
(a) concave mirror (b) convex mirror

3. A ray of light passing through the centre of curvature C in a concave mirror or a ray of light going towards the centre of curvature of a convex mirror is reflected back along the same path.



(a) concave mirror (b) convex mirror

4. A ray incident obliquely to the principal axis, towards a point P (pole of the mirror), on the concave mirror or a convex mirror, is reflected obliquely. The incident and reflected rays follow the laws of reflection at the point of incidence (point P), making equal angles with the principal axis and is shown below in the figure.



(a) concave mirror (b) convex mirror

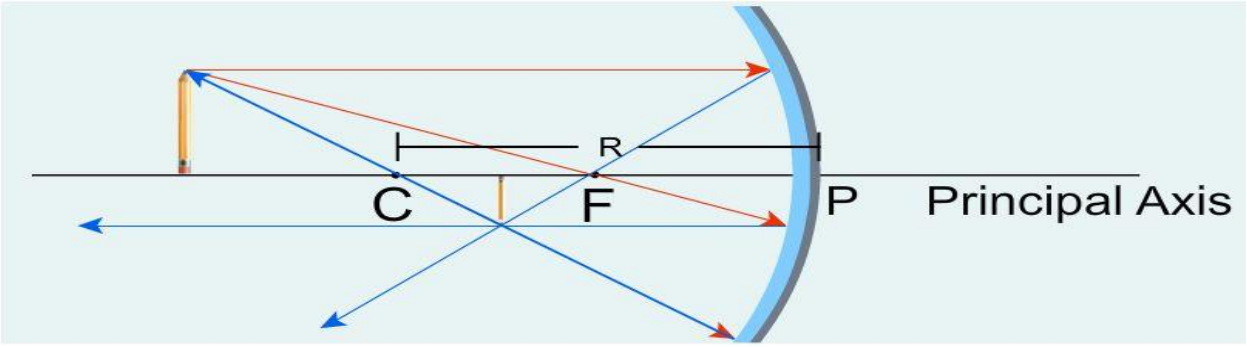
Any two of the four rays can be used to describe an image formed by curved mirrors.
The types of image formed by curved mirrors depend on the position of the object to the mirror and type of mirrors.

Formation of Different Types of Images by A concave Mirror

Depending on the position of the object in front of the concave mirror, the position, size and the nature of the image varies.

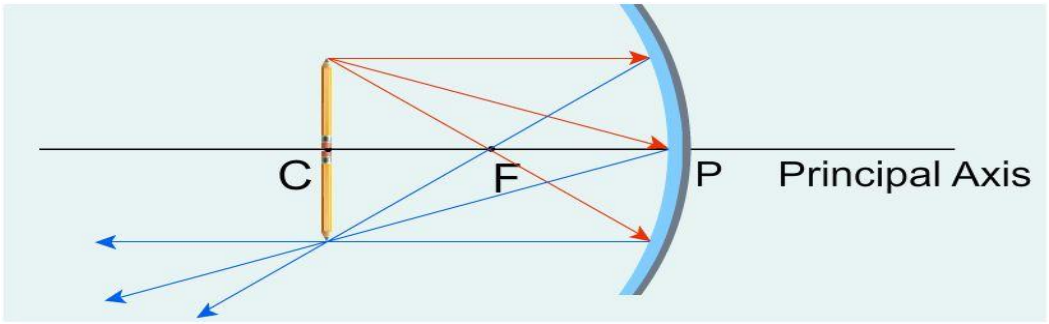
Different types of images can be formed by a concave mirror depending on the position of the object in front of the concave mirror, the position, size and the nature of the image also Depending on the position of the object from the concave mirror. Therefore different types of images are formed when the object is placed:-

1. **beyond the centre of curvature**



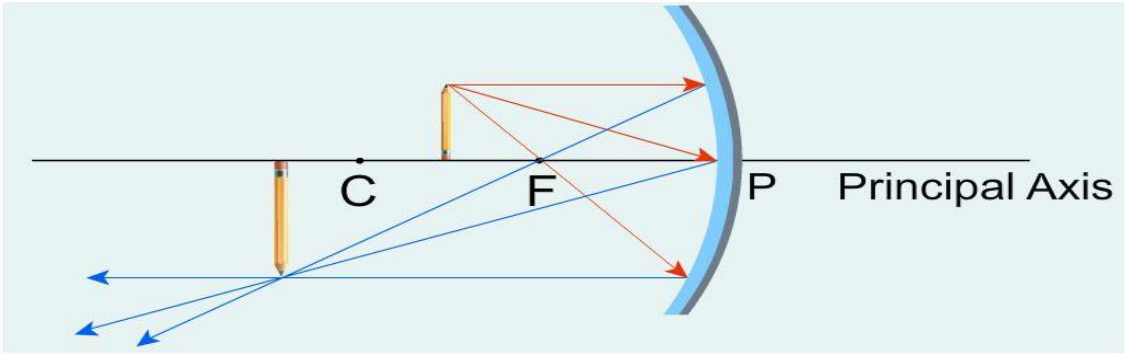
A real, inverted, diminished image is formed between C and F, in front of the concave mirror.

2. **at the center of curvature**



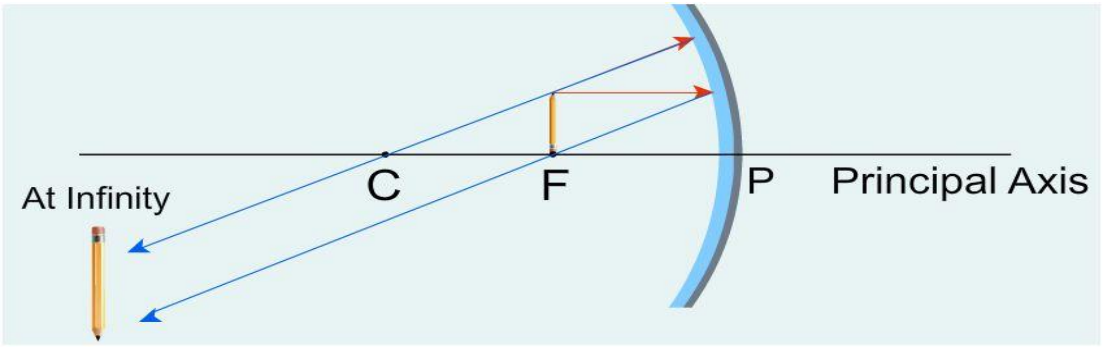
A real, inverted, same sized image is formed at C, in front of the concave mirror.

3. **between the center of curvature and principal focus**



A real, inverted, magnified image is formed beyond C, in front of the concave mirror.

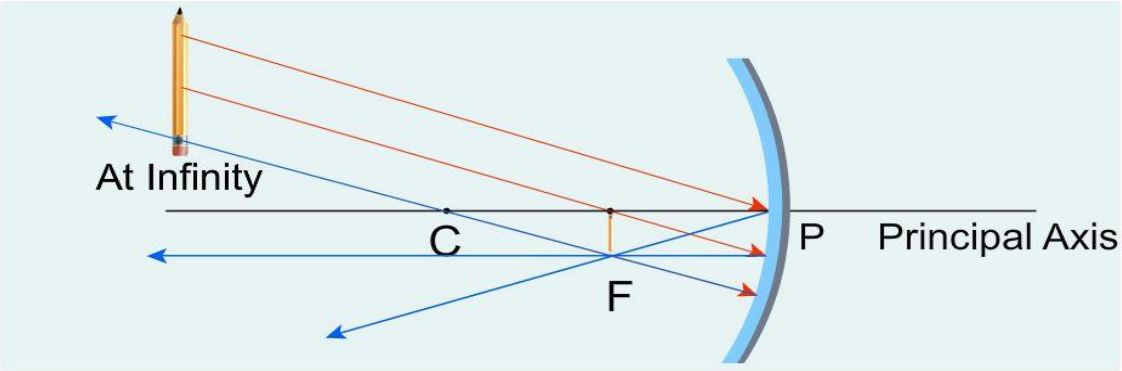
4. **at principal focus**



A real, inverted, highly enlarged image is formed at **infinity**, in front of the concave mirror.

5. When the object at infinity

A real, inverted, diminished image is formed at the focal point F, in front of the concave mirror.



6. between the principal focus and the pole

A virtual, erect and magnified image is formed behind the concave mirror.

This is the **only** case, that concave mirrors form a virtual image.

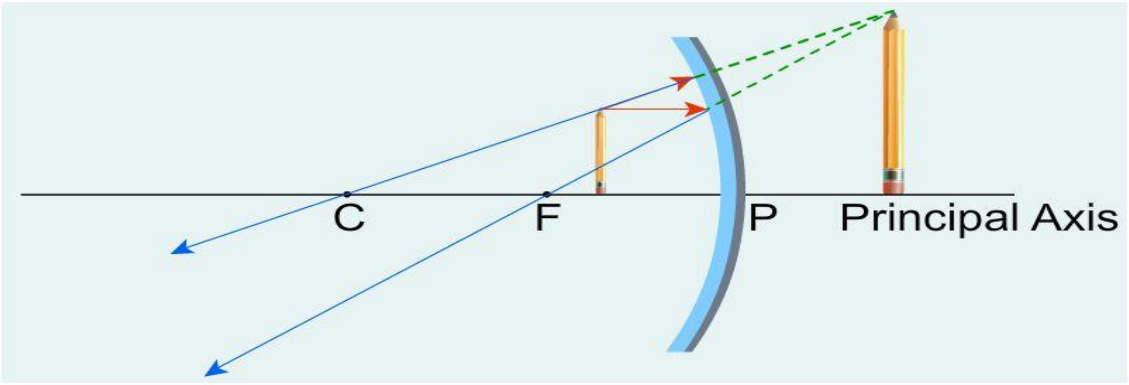


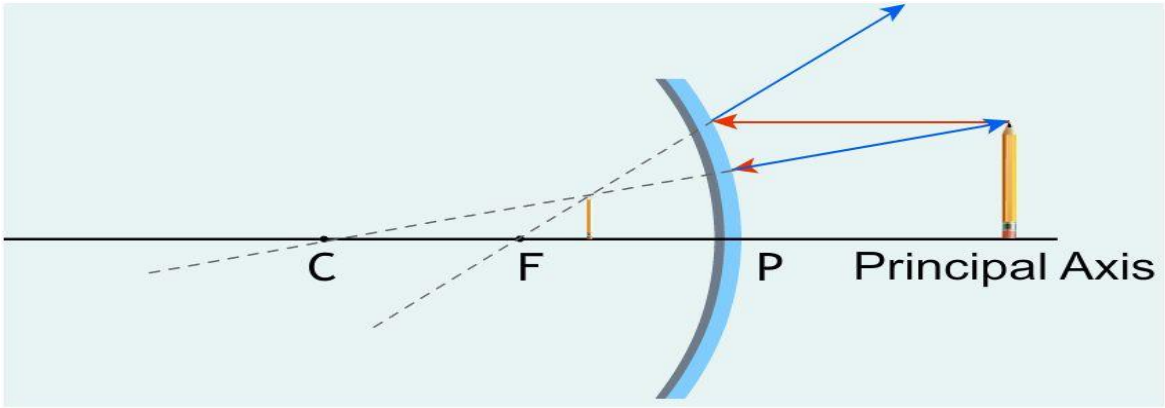
Table5.2:

Summary of images formed by a concave mirror

No.	Position of Object	Position of Image	Size of Image	Nature of Image
1.	Beyond the centre of curvature C	Between F and C	Diminished	Real and inverted
2.	At the centre of curvature C	At C	Same size	Real and inverted
3.	Between C and F	Beyond C	Magnified	Real and inverted
4.	At focus F	At infinity	Magnified	Real and inverted
5.	At infinity	At the focus F	Diminished	Real and inverted
6.	Between F and P	Behind the mirror	Magnified	Virtual and erect

Formation of Image By A convex Mirror

The image formed in a convex mirror is always virtual and erect, whatever be the position of the object.



Irrespective of the position of the object, a virtual, erect and diminished image is formed between F and P, behind the convex mirror.

Table5.3: Summary of images formed by a convex mirror

No.	Position of Object	Position of Image	Size of Image	Nature of Image
1.	Between infinity and the pole P	Between P and F, behind the mirror	Diminished	Virtual and erect

5.4 Uses of Spherical Mirrors

Uses of Concave Mirrors:

1. Concave mirrors are used as **shaving mirrors** to see a larger image of the face.

2. Dentists use concave mirrors to view the back of the tooth.
3. **ENT** doctors use them for examining the internal parts of the ear, nose and throat.
4. They are used as reflectors in the headlights of vehicles, search lights and in torch lights to produce a strong parallel beam of light.
5. Huge concave mirrors are used to focus sunlight to produce heat in solar furnaces.

Uses of Convex Mirrors:

1. Used as rear view mirrors in automobiles as it covers wide area behind the driver.

2. Used as reflectors for street light bulbs as it diverges light rays over a wide area.

mirror formula

A mirror formula may be defined as the formula which gives the relationship between the distance of image v, distance of object u, and the focal length of a mirror f. It may be written as,

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

Where,
f *= Focal length of the mirror*
u *= Distance of object from pole of mirror*
v *= Distance of image from pole of mirror*

Mirror Equation

The position, nature and size of an image formed by curved mirrors can also be determined using mathematical relation called mirror equation.

All distances in curved mirrors are measured from the pole of the mirror and if

a) The focal length (f) is the distance from the pole of the mirror to its principal axis.
b) The object distance (u) is the distance from the pole to the object,
c) The image distance (v) is the distance from the pole to the image then for all carved mirrors, the mirror equation is

Sign Conventions

For real images and real focus distances are positive.

For virtual images and virtual focus distance are negative.

According to this sign convention, the focal length of concave mirror is positive and that of a convex mirror is negative.

Magnification of Images

The numerical comparison of the size of the image (h_i) with the size of the object (h_0) is called magnification (m). It is given by the formula.

Magnification $= \frac{\boldsymbol{height\ of\ the\ image}}{\boldsymbol{height\ of\ the\ object}}$ *In Symbols,* $m = \frac{h_i}{h_0}$

Magnification can also be expressed in terms of the object distance v and the image distance u as

Magnification $= \frac{\boldsymbol{image\ distance}}{\boldsymbol{object\ distance}}$ *In Symbols,* $m = \frac{v}{u}$

Table5.4: Summary of sign convections for mirrors

No.	Quantity	Positive when ……	Negative when…….
1.	Object location (u)	Object is in front of mirror (real object)	Object is in back of mirror (virtual object)
2.	Image location (v)	Image is in front of mirror (real image)	Image is in back of mirror (virtual image)
3.	Image height (h_i)	Image is upright	Image is inverted
4.	Focal length (f)	Mirror is concave	Mirror is convex
5.	Magnification (m)	Image is upright	Image is inverted

Magnification	**M > 1**	**M = 1**	**M < 1**
Meaning	Magnified	Same size	Diminished

Examples:

1. Find the distance of the image from a concave mirror of focal length 15cm if the object is 20 cm from the mirror? Find the magnification and describe the nature of the image?

   f = 15 cm *u = 20cm* *v =?*

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

   $$v = \frac{fu}{u-f} = \frac{(20cm)(15cm)}{20cm - 15cm} = \frac{300cm^2}{6cm} = 60cm$$

   m = v/u = (60cm)/20cm = 3

   So the image is 60cm in front of the mirror and it is real and magnified.

2. Find the distance of the image from a convex mirror of focal length 10 cm if the object is 15 cm from the mirror? Calculate the magnification and describe the nature of the image?

   f = - 10 cm *u = 15cm* *v =?*

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

   $$v = \frac{fu}{u-f} = \frac{(-10\ cm)(15cm)}{15cm - (-10cm)} = \frac{150cm^2}{25cm} = -6cm$$

   m = v/u = -6cm/15cm = - 0.4

   v = - 6cm (the minus sign indicates that the image is virtual)

   The image is 6cm behind the mirror and it is virtual and diminished.

3. Find the distance of the image from a concave mirror of focal length 10 cm if the object is 5 cm from the mirror? Calculate the magnification and describe the nature of the image?

   f = 10 cm u = 5cm v =?

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

$$v = \frac{fu}{u - f} = \frac{(10cm)(5cm)}{5cm - 10cm} = \frac{50cm^2}{-5cm} = -10cm$$

The image is 5 cm behind the mirror. It is virtual because v is negative and magnified.

4.When an object is placed 20cm from a concave mirror, a real image magnified three times is formed.

i) Find the focal length of the mirror?
ii) Where the object must be placed to give a virtual image magnified three times?

m = v/u therefore v = mu = (3) (20cm) = 60cm.

f = uv/ (v +u) = (20cm x 60cm)/ (20cm + 60cm)

= 1200cm^2/80cm = 15cm

m = - 3 therefore v = - 3u

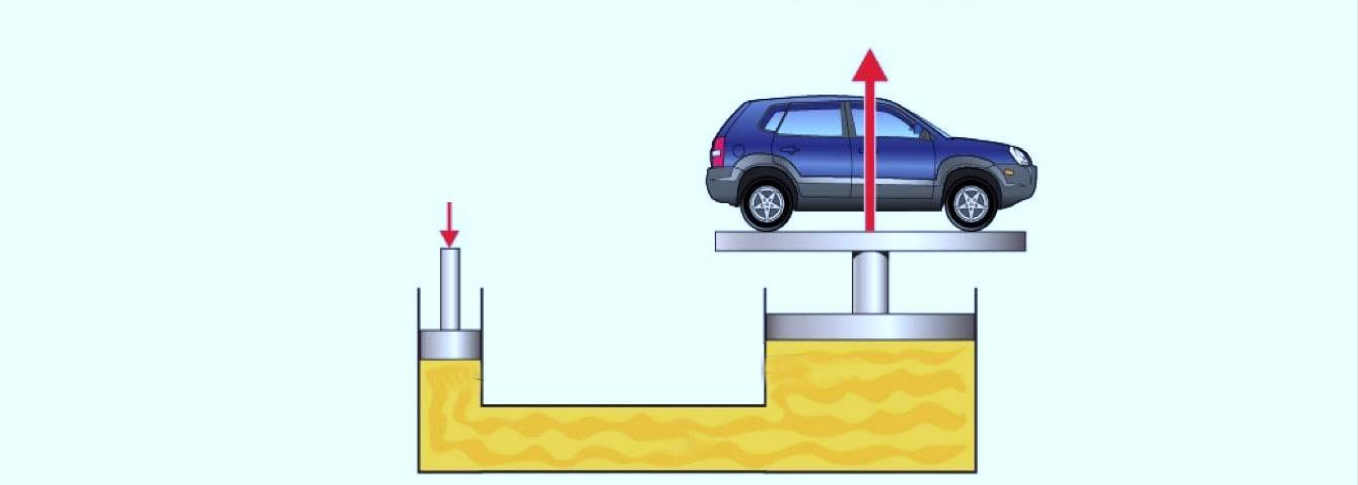
$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

1/15cm = (1/u) + (1/- 3u) then 3u = 30cm and u 10cm.

Exercise:

1. A concave mirror of focal length 15cm has an object placed 25cm from it. Find the position (image distance) and the nature of the image?
2. A concave mirror of focal length 15 has an object placed 10cm from it. calculate
   a) The distance between the image and the mirror?
   b) The magnification of the image?
   c) The height of the image if the object is 4cm high?
   d) Describe the nature of the image?
3. An object 5cm high is placed 30cm in front of a concave mirror. The image is 60cm in front of the mirror. Find
   a) The focal length of the mirror?
   b) The magnification?
   c) The size of the image?
4. When an object is 42cm from a concave mirror, the object and image are of same height. What is the focal length of the mirror?
5. An object is 32cm in front of a convex mirror of focal length 16cm. describe the image and give its position?
6. Motorist use a convex mirror, rather than a plane mirror, as a rear view mirror. State one advantage and one disadvantage of a convex mirror?
7. An object is placed 20cm in front of a concave mirror. A real image magnified two times is formed. Calculate
   a) The image distance?
   b) The focal length of the mirror?
   c)

Chapter six: More about forces



Chapter objectives

By the end of this chapter the learners will be able to:

- describe Newton's Laws of Motion in simple language
- give simple examples of 'inertia' and as 'reluctance to change its state of motion' see also form 4
- state that zero acceleration =constant velocity= no resultant force.
- explain further (see form 1) what is meant by friction, air resistance and surface tension
- state that acceleration is caused by a resultant force acting on the accelerating object
- define the moment of a force about a point and state its SI unit
- state that the moment of a force is a measure of its turning effect
- use the principle of moments and solve problems
- explain the action of common tools and as levers.
- a simple machines as a force multiplier or distance multiplier
- define the terms mechanical advantage (MA) and Velocity ratio (VR) a machine and solve problems using them.
- define center of gravity.
- determine center of gravity of lamina objects.
- explain the conditions for an object to be in equilibrium
- identify and explain the states of equilibrium.
- state and explain the factors affecting stability of an object
- describe some application of stability.
- define pressure and state the units of pressure
- determine pressure exerted by solids of different surface areas
- calculate pressure problems
- show how to measure pressure of a gas and air (e.g. manometer, barometer)
- investigate experimentally the factors that affect pressure in liquids(fluids)
- state Pascal's Principle
- explain that pressure in liquids increases with depth (divers; mine; mountain)
- show how hydraulic machines are able to use a small effort to lift a heavy load
- state the conditions required for an object to float or sink (include density and specific gravity)
- state Archimede's principle and use it in real life examples
- describe streamline and turbulent flow.
- derive the equation of continuity.
- describe experiments to illustrate Bernoulli's effect.
- describe where Bernoulli's effect is applied such as in the Bunsen burner, spray gun, carburetor, aerofoil and spinning ball.

6.0 Introduction

A force is what causes a body to change its state of motion or its shape. Unit of force is newton.
Unit of force is newton (N). 1N = 1kgm/s^2
Force is measured by using spring balance or newton meter.

6.1 Newton's law of motion

Newton's first law of motion

Newton's first law of motion also called law of inertia states that:

An object at rest will remain at rest unless acted on by an external force. An object in motion continuous in motion with the same speed and in the same direction unless acted upon by an unbalanced force

This means that objects have natural tendency keep their state of motion or rest. When there is no unbalanced force acting on the object

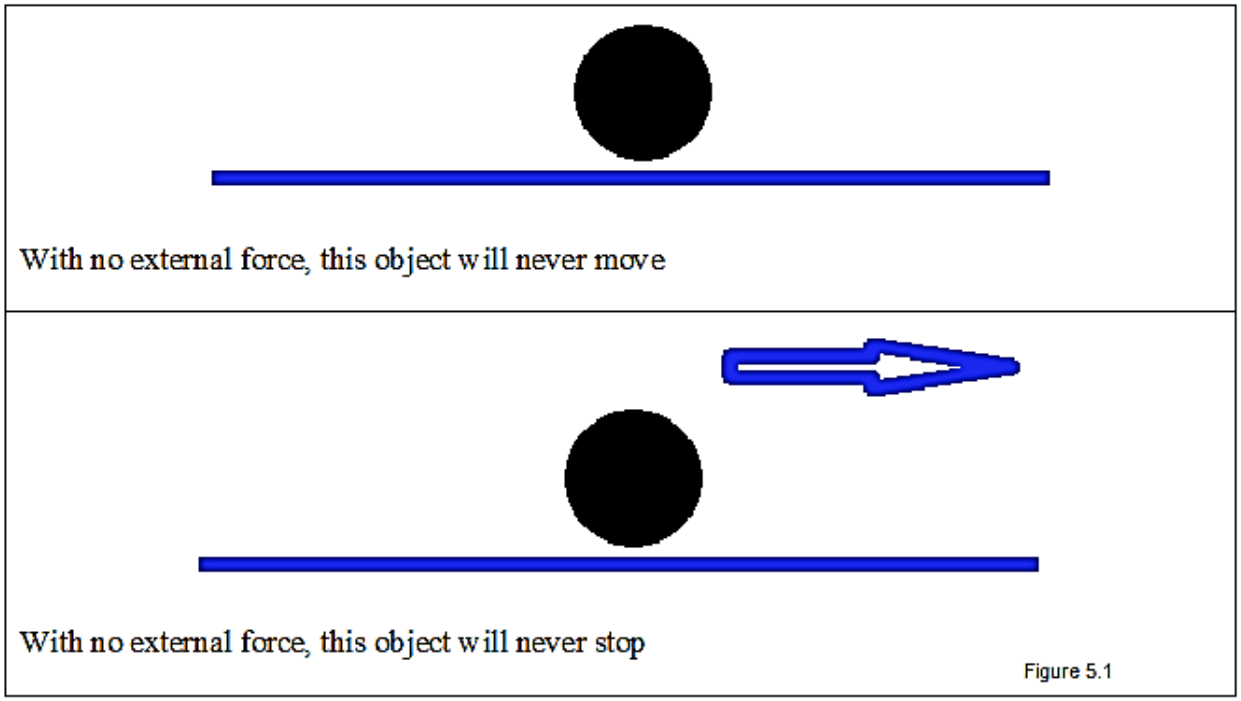


Figure 5.1

Inertia

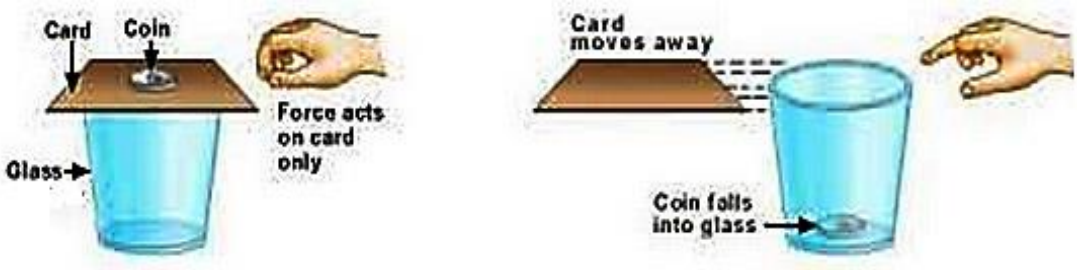
Inertia is the tendency of a body to preserve its state of rest or uniform motion unless acted on by an external force
The external force can be: an applied force to the object or resistance between the object and the surface by which the object is moving

The **applied** force used by this man causes the object to move but the **frictional** force opposes its motion.

Demonstration of inertia

- A car is moving at a fast speed and stops abruptly because of hitting a wall, you lurch forward;

- A coin is sitting on a piece of paper over a cup. The paper is quickly pulled out from under the coin. Then the coin falls in the cup because gravity is free to act on it



Inertia and mass

Inertia depends on the mass of an object; objects with greater mass have greater inertia also objects with greater inertia need more force to overcome. Mass is the measure of inertia

Passengers of a car must wear seatbelts to prevent from inertia

You can push object with small mass

It is difficult to push an object with greater mass

Resultant force

All forces acting on a body can be combined to form a net force or resultant force. Consider a book on a table.

Figure 5.2

If the book is at rest, only two forces act on it; upward force used by the table on the book and the downward force which is the weight of the book.

Upward force = down ward force

Resultant force is the result obtained after combining forces acting on the object. It is also called net force

In case of the book on the table: resultant force = up ward force – down ward force

If the forces are equal the resultant force is zero so the forces are said to be balanced but if one is greater than the other we get a net force greater than zero which are said to be unbalanced

Example

1. In each of the figures below, calculate the resultant force if each object is at rest

a)

F_{net}= 5N – 3N = 2N

b)

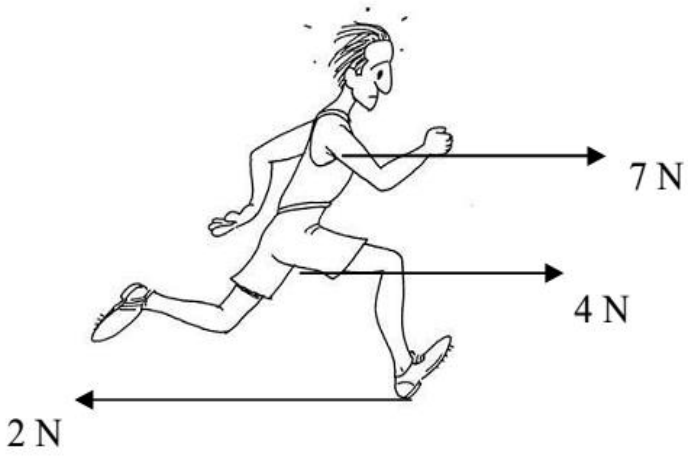
F_{net}= 9N – (6N + 2N) = 9 – 8 = 1N

2. Find the resultant force on the block and explain its motion

Resultant force = 0 it moves with constant velocity in straight line

Exercise

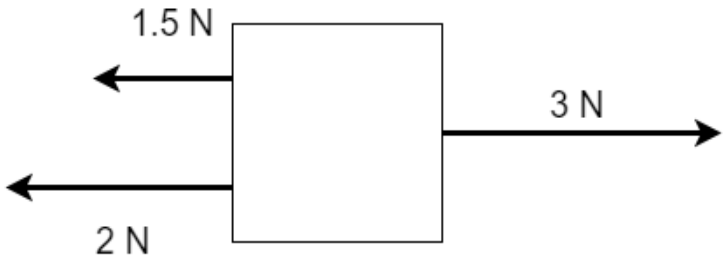
1. Find the resultant force acting on the following objects. State both the size as well as the direction of the resultant force.



i) Resultant Force = _____
_____

ii) Resultant Force = _____
_____

2. Three forces of 3 N, 1.5 N and 2 N are acting on an object, as shown in the picture below.



What is the resultant due to the three forces?

Newton's second law of motion

Newton's second law of motion can be stated as follows: The acceleration of an object as produced by a net force is directly proportional to the magnitude of the net force, in the same direction as the net force, and inversely proportional to the mass of the object.

Consider the following diagrams. In diagram 5.3 a, if you kick a soccer ball of mass 1kg with a force of 1N, the force causes the ball to accelerate with $1m/s^2$ and doubling the mass of the ball halves its acceleration as shown in figure 5.3 b

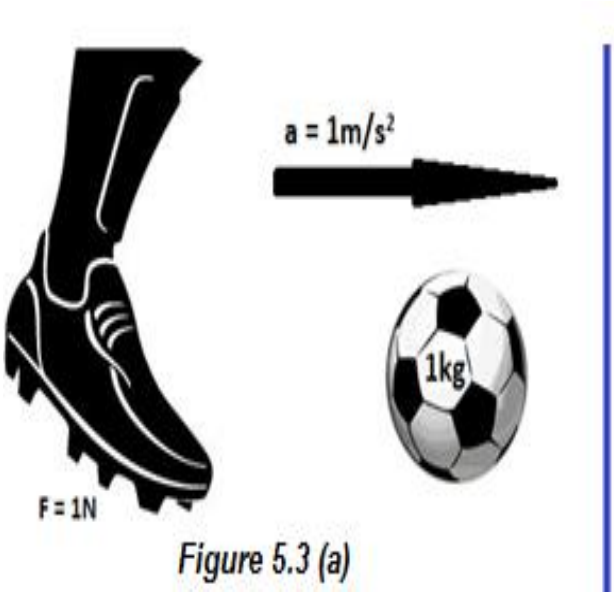


Figure 5.3 (a)

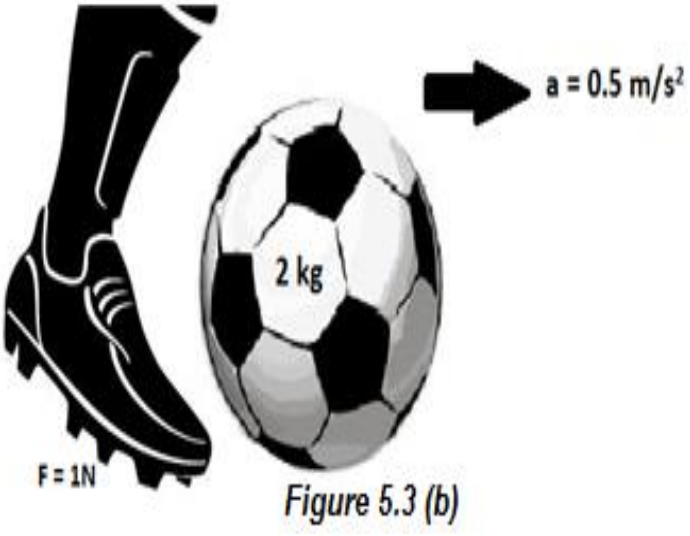


Figure 5.3 (b)

We can see that

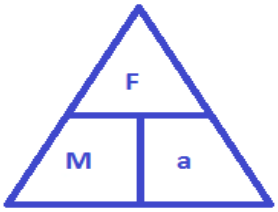
$\mathbf{a} \propto \mathbf{f}$ and $\mathbf{a} \propto \frac{\mathbf{1}}{\mathbf{m}} \rightarrow \quad \boldsymbol{a} \propto \frac{\boldsymbol{F}}{\boldsymbol{m}} \quad \rightarrow \quad \boldsymbol{F = kma}$

$where\ f = force$

$m = mass(kg)$

$a = acceleration$ m/s^2

Since the unit of the force is Newton.

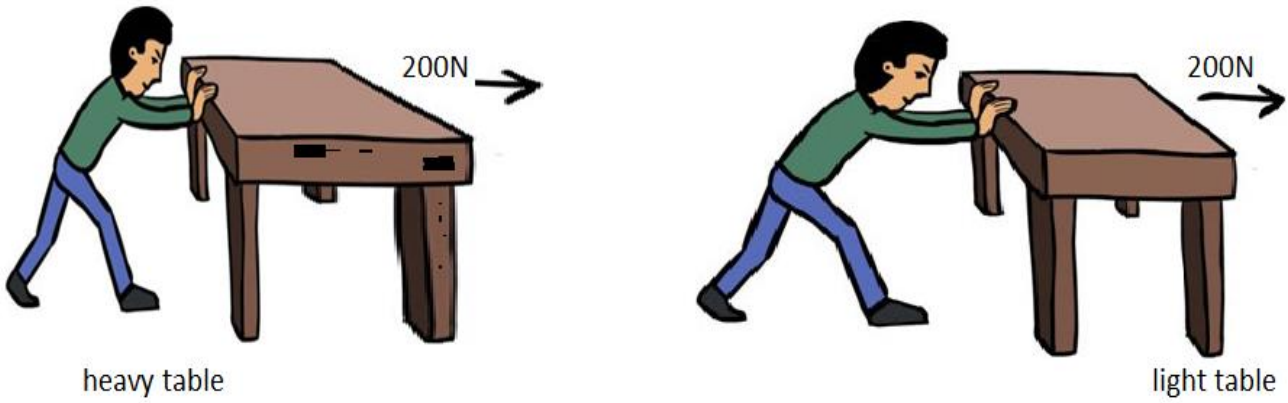


$$\boldsymbol{F = ma}$$

Practical work

Place a heavy table on a horizontal floor; push it as fast as you can

Now replace it with lighter one and push it as fast as you can



By using with a same force which one is difficult to push? Why?

Examples

1. A wheelbarrow of mass 2kg is pushed with a force of 40N, the wheelbarrow moves with constant velocity. If the force is increased to 45N fine

Resultant force

Acceleration

Resultant force = 45N – 40N = 5N

$$\text{Acceleration} = \frac{resultant\ force}{mass} = \frac{5}{2} = 2.5\ \text{m/s}^2$$

2. If a force of 4N acts on a body of mass 6kg, what amount of acceleration does it produce?

$$\boldsymbol{a = \frac{f}{m} = \frac{4}{6}}\ \text{m/s}^2$$

A force of 10N produces an acceleration of 5m/s^2, what is the mass of the body?

$$mass = \frac{force}{acceleration} = \frac{10}{5} = 2\text{kg}$$

Friction and air resistance

Friction

The friction force is the force exerted by a surface as an object moves across it or makes an effort to move across it. There are at least two types of friction force - sliding and static friction.

On the other hand friction is a force against motion of an object.

For example, if a book slides across the surface of a desk, then the desk exerts a friction force in the opposite direction of its motion. Friction results from the two surfaces being pressed together closely, causing intermolecular attractive forces between molecules of different surfaces. As such, friction depends upon the nature of the two surfaces and upon the degree to which they are pressed together.

Kinds of friction

There are two kinds of friction: static friction and sliding friction

a. **Static friction**
   Static friction is the friction that exists between a stationary object and the surface on which it's resting. A frictional force occurs when you try to push an object alongside a surface.

The car in the diagram is at rest, there is a static friction between the surface of the road and its tires.

b. **Dynamic friction**

Dynamic friction also called kinetic friction is the friction force between two sliding surfaces

Sliding friction is usually less than static friction so less force is required to continue motion than to start motion

Coefficient of friction

A coefficient of friction is a value that shows the relationship between the force of friction between two objects and the normal force between the objects.

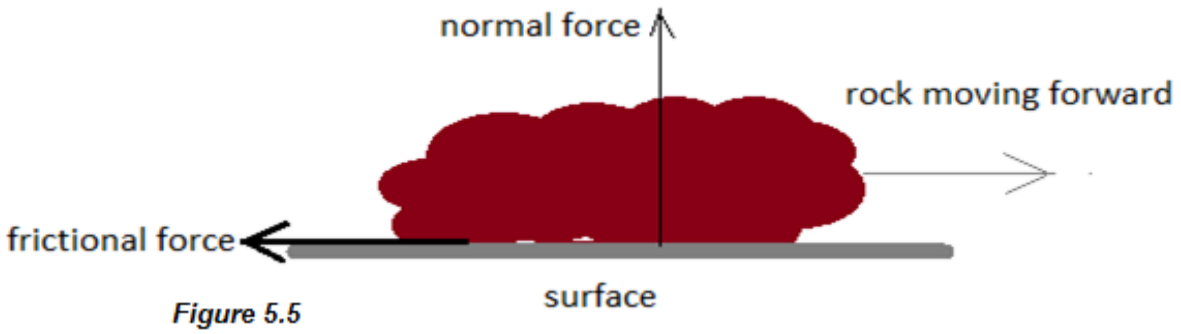


Figure 5.5

The above diagram in figure 5.5 shows a moving rock. Frictional force acts horizontally while the normal force is at right angle with the surface.

Normal force is equal to the weight of the object.

Wight = mass x gravity or W = mg, on the Earth gravity is about $10m/s^2$

The ratio of the frictional force to the normal contact force is called the coefficient of friction μ

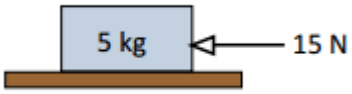
$$coefficient\ of\ friction = \frac{frictional\ force}{normal\ contact\ force}$$

$$\mu = \frac{F_r}{F_n}$$

Coefficient of friction is usually less than 1

Examples

1. A 5 kg box on a horizontal table is pushed by a horizontal force of 15 N as shown on the right. If the coefficient of friction is 0.4, what is the frictional force on the object?



Use $g = 10m/s^2$

Solution

Mass = 5kg

Weight = mg = 5x10 = 50N

Normal force = weight = 50N

$$\mu = 0.4$$

Fn = $\boldsymbol{\mu F_n}$= 0.4 x 50 = 20N

The frictional force is 20N

2. A horizontal force pulls a 50kg bag of fertilizer across the floor. What is the minimum frictional force exerted between the bag and the floor if the coefficient of friction is 0.30?

Weight = mg = 50 x 10 = 500N

Normal force = weight = 500N

Therefore: $F_r = \mu F_n$ = 0.30x500 = 150N

3. A metal brick weighing 90N is sliding on a wooden table; the force of friction between their contact surfaces is 45N. What is the coefficient of friction between the brick and the table?

$$\mu = \frac{f_r}{f_n} = \frac{45}{90} = 0.5$$

Experimental Determination of the Coefficient of friction, μ

A weight is placed onto the inclined ramp. The weight will want to slide but is prevented from doing so by the frictional force between the two touching surfaces.

If the ramp is inclined further, the frictional force will grow until the point that it is unable to prevent the mass from sliding. Just before the weight slides, we are at the *limiting friction*.

$F_R=\mu F_N$ where F is the frictional force, μ is the *coefficient of friction* and N is the normal force acting particularly to the surface of contact. Since the weight is not moving this force is equal and opposite to the vertical component of the weight force on the ramp, it is defined by:

$$F_N=mg\cos\theta \quad (1)$$

At the point of limiting friction, the friction force is equal to the component of the weight force parallel to the slope of the ramp.

$$\mu F_N=mg\sin\theta \quad (2)$$

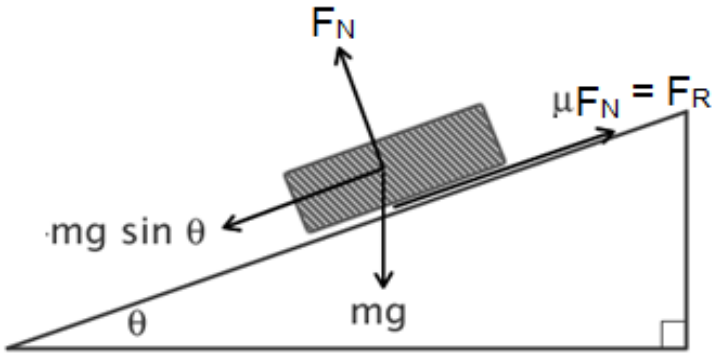
Substituting for F_N gives: $F=\mu F_N$

Equating terms:

$$mg\sin\theta = \mu mg\cos\theta \quad (3)$$

Rearranging for μ

$$\mu = \tan\theta \quad (4)$$



Air resistance and terminal velocity

Air resistance, also called drag, is the forces that are in opposition to the relative motion of an object through the air. Drag forces act opposite to the oncoming flow velocity. Drag, unlike other resistive forces, depends directly on velocity

Moving objects are designed to allow air slip past more easily. They are streamlined to reduce the air resistance.

Figure 5.6: air resistance opposses the motion of a car travelling on a flat road

Terminal velocity and falling objects

When an object falls in air, the air resistance opposing its motion increases as its speed rises, so reducing its acceleration. Eventually air resistance acting up wards equals the weight of the object acting downwards. The resultant force on the object is then zero since the gravitational force balances the frictional force. The object falls at a constant velocity, called its terminal velocity whose value depends on the size, shape and weight of the object.

Small dense object e.g. a steel ball bearing has a high terminal velocity and falls a considerable distance with a constant acceleration of 9.8m/s^2 before air resistance equals its weight.

Light objects or objects with large surface area e.g. a parachute, have low terminal velocity and only accelerate over short distance before air resistance equals their weight.

Figure 5.7: a parachutist falling in air

A parachutist falls with increasing speed before opening the parachute because his with is greater than air resistance and pulls him downwards. One of the main factors that affect air resistance is the surface area, so as a person falls he must stretch his arms and legs as shown in the figure 5.7

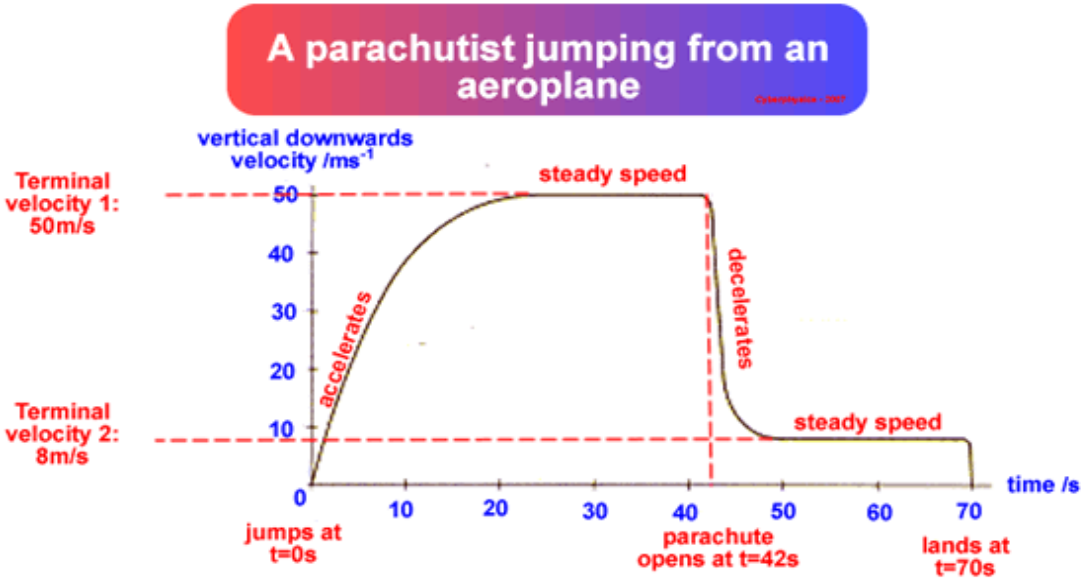
The resultant force of gravity minus air resistance acting on the skydiver as he fall makes him accelerate according to the equation F = ma.

So,

$$F_w - F_{AR} = ma$$

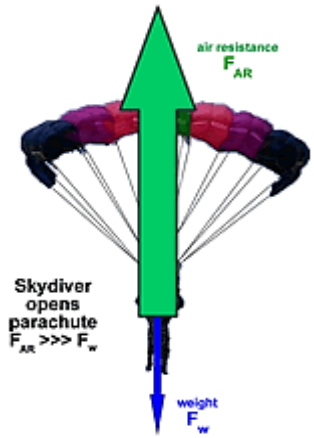
As long as F_w is greater than the F_{AR} the skydiver will accelerate - get faster.

If Fw is smaller than F_{AR} he will decelerate - undergo negative acceleration - get slower.



When s/he steps out of the plane his/her vertical velocity component is 0 m/s so air resistance is zero. That means only the force of gravity acting on his mass - his weight - is acting. That means his vertical velocity rapidly increases.

As the speed of the skydiver increases every second as he or she plummets towards the ground there is an increase in air resistance (as this gets bigger as his/her speed increases). This results in a smaller net force acting on the skydiver. S/he is still getting faster, but not at the same rate as s/he did initially. Look at the graph representing how the vertical velocity changes during the fall. You can see that the gradient decreases as the speed increases.

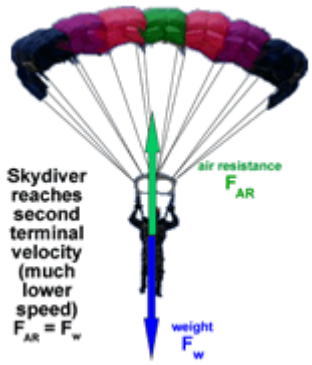


When the parachute is opened the force of air resistance becomes much, much greater than the force of gravity.

The net force on the descending skydiver now has an acceleration that points upward - negative acceleration or deceleration.

This causes a rapid decrease in the skydiver's velocity.

Look at the graph representing how the vertical velocity changes during the fall. You can see that the gradient becomes strongly negative when the parachute is opened.

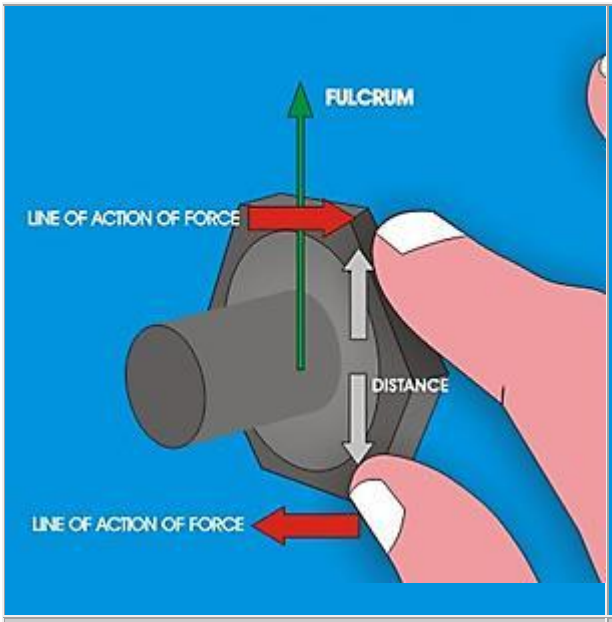
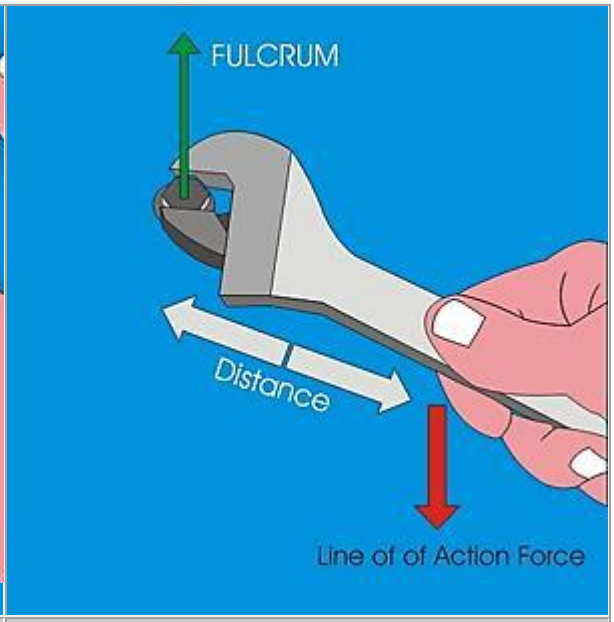


As the speed of descent decreases, the amount of air resistance also falls, until once again a terminal velocity is reached because Fw = F_{AR}. This second terminal velocity is now slow enough to allow the skydiver can land safely on terra firma without his legs snapping in two - assuming s/he lands correctly.

6.2 Moment and levers

Moment of a force

The handle on a door is at the outside edge so that it opens and closes easily. A much larger force would be needed if the handle were near the hinge. Similarly when undoing a nut fastened to a screw by hand one realizes that the amount of force required is a lot greater than when undoing the same nut using a spanner. The spanner increases the distance between the fulcrum and the line of action of the force, thus for the same force a greater moment is obtained.

	
SMALL MOMENT The distance from the fulcrum to the line of action of force is very small	**LARGE MOMENT** The distance from the fulcrum to the line of action of force is large

The turning effect or moment of a force depends on both the **size of the force** and **how far it is applied from the pivot or fulcrum** it is measured by multiplying the force by the perpendicular distance of the line of action of the force from the fulcrum. The unit is the newton meter (Nm)

Moment of a force (Newton meters)	=	Force (Newtons)	X	Perpendicular distance from the force to the pivot (meters)

In figure 21.1a a force F acts on a gate at its edge, and in b at the centre

In a:

Moment of F about O = 5 N × 3 m = 15 Nm

In b:

Moment of F about O= 5N ×1.5 m =1.7Nm

The turning effect of F is greater in the first case; this agrees with the fact that a gate opens most easily when pushed or pulled at the edge furthest from the hinge

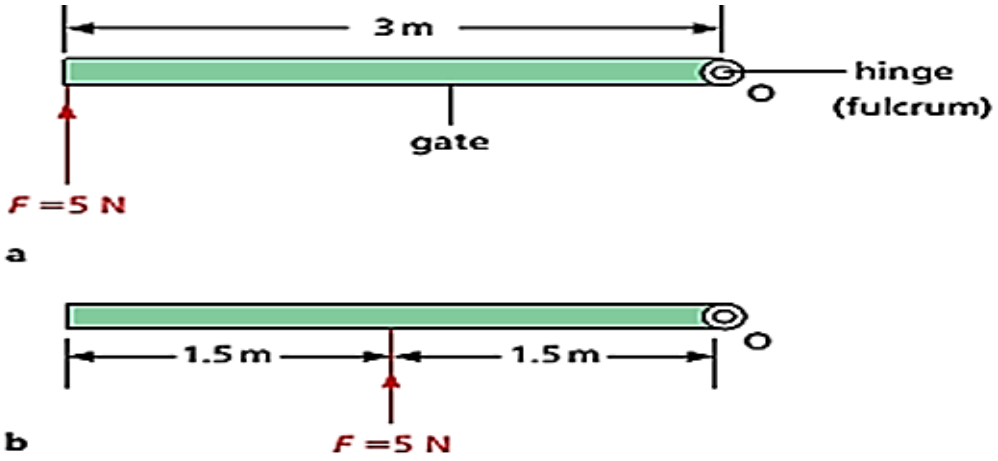


Figure 5.10

Practical work

Law of moments

Balance a half-meter ruler at its centre, adding plasticine to one side or the other until it is horizontal.

Hang unequal loads $\boldsymbol{m_1}$and $\boldsymbol{m_2}$ from either side of the ruler and alter their distances d_1 and d_2 from the centre until the ruler is again balanced, Figure 5.11 Forces $\boldsymbol{F_1}$ and $\boldsymbol{F_2}$are exerted by gravity on $\boldsymbol{m_1}$ and $\boldsymbol{m_2}$and so on the ruler; on 100g the force is 1N. Record the results in a table and repeat for other loads and distances

m_1 /g	F_1 /N	d_1 /cm	$F_1 \times d_1$ /Ncm	m_2 /g	F_2 /N	d_2 /cm	$F_2 \times d_2$ /Ncm

$\boldsymbol{F_1}$is trying to turn the ruler anticlockwise and $\boldsymbol{F_1 \times d_1}$ is its moment. $\boldsymbol{F_2}$ is trying to cause clockwise turning and its moment is $\boldsymbol{F_2 \times d_2}$. When the ruler is balanced or, as we say in equilibrium the results should show clockwise moment $\boldsymbol{F_1 \times d_1}$ equals the clockwise moment $\boldsymbol{F_2 \times d_2}$

The law of moments (also called the law of the lever) is stated as follows

When a body is in equilibrium the sum of the clockwise moments about any point equals the sum of the anticlockwise moments about the same point.

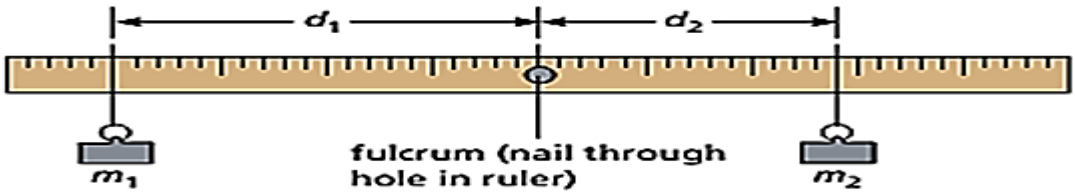
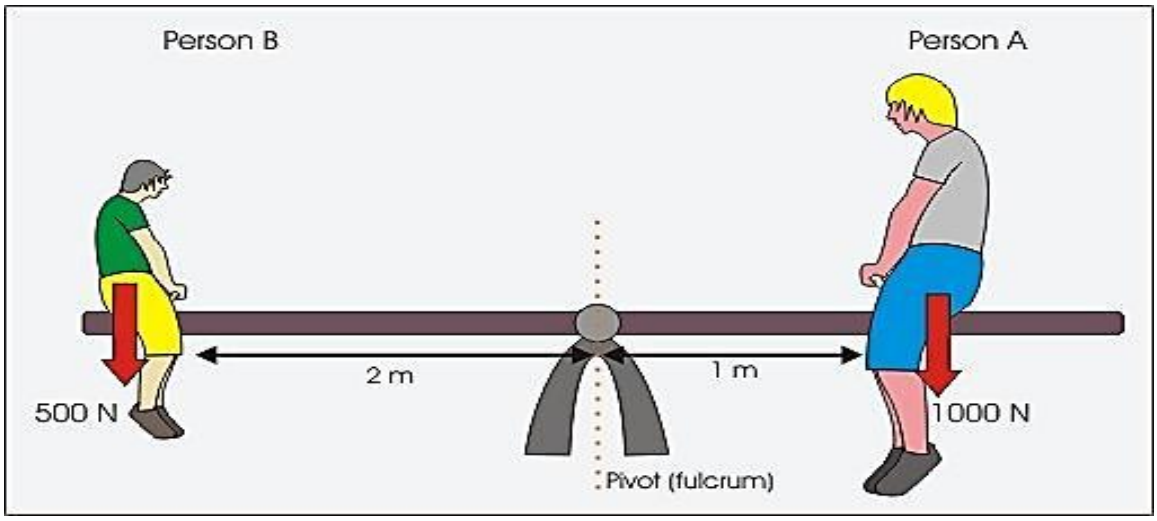


Figure 5.11

Therefore In equilibrium

Total Anticlockwise Moment = Total Clockwise Moment

This principle can be explained by considering two people on a seesaw.



Moments Acting On A Seesaw

Both people exert a downward force on the seesaw due to their weights.
Person A's weight is trying to turn the seesaw anticlockwise whilst person B's weight is trying to turn the seesaw clockwise.

Person A's Moment = Force x perpendicular distance from fulcrum

1000 x 1 = 1000 Nm

Person B's Moment = Force x perpendicular distance from fulcrum

500 x 2 = 1000 Nm

Persons A's moment = Persons B's Moment

Anticlockwise moment = Clockwise moment

Therefore seesaw is in equilibrium.

Example 1

Is the see-saw shown in figure 5.12 below Balanced or will start to rotate

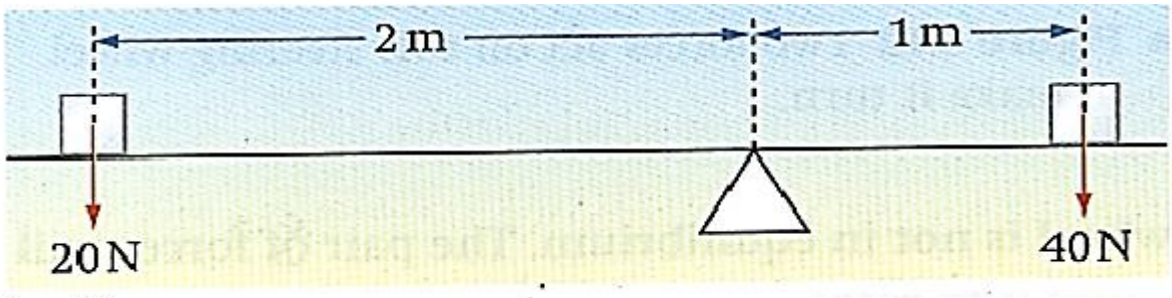


Figure 5.12

Answer

Step1. Moment of anti-clockwise force = 20 N x 2 m = 40 Nm

Step2. Moment of clockwise force = 40 N x 1 m = 40 Nm

Step3. We can see that

Clockwise moment = anti-clockwise moment

So the see-saw is balanced

Worked example

1. The see -saw in figure 5.13 balances when khadra of weight 320 N is at A, Wardaof weight 540N is at B and Zainab of weight W is at C

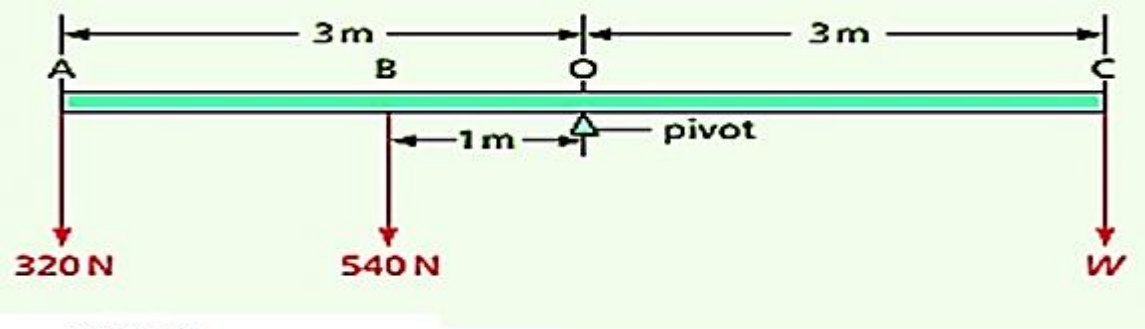


Figure 5.13

Taking moments about the fulcrum O:

Anticlockwise moment=320N ×3m +540N×1m=1500N

Clockwise moment =W×3m

By the law of moments,

Clockwise moments=anticlockwise moments

$W \times 3m = 1500Nm W = \frac{1500\ Nm}{3} = 500N$

Exercise

1. What force X is needed to balance the beam shown in figure 5.14

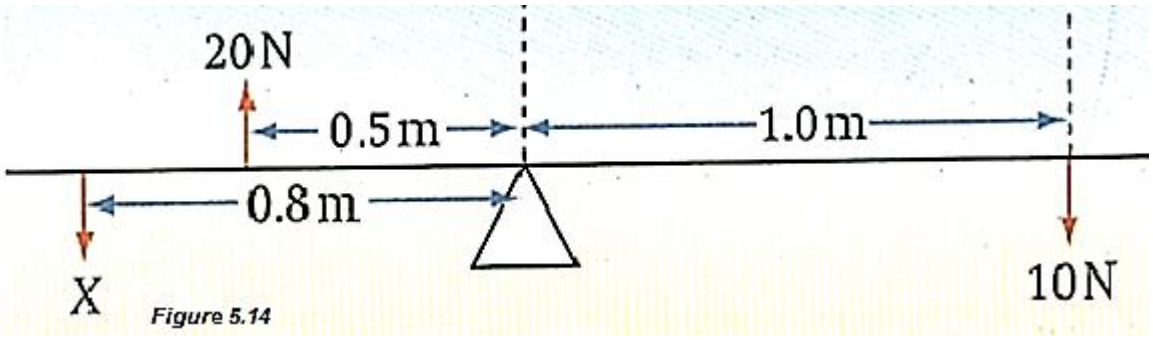


Figure 5.14

2. A wheelbarrow is loaded as shown in figure 5.15 below

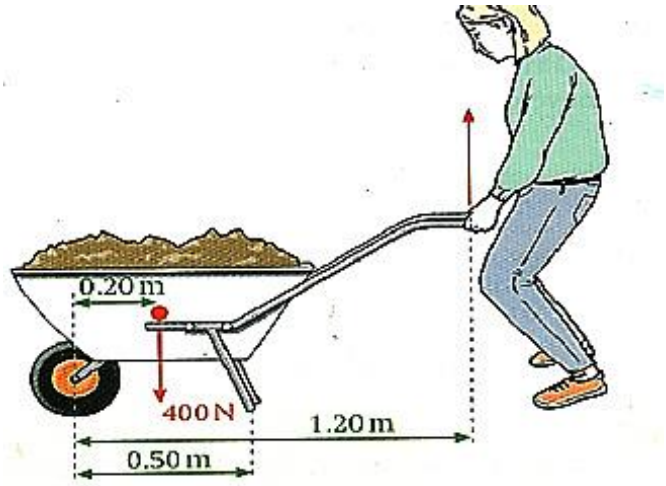
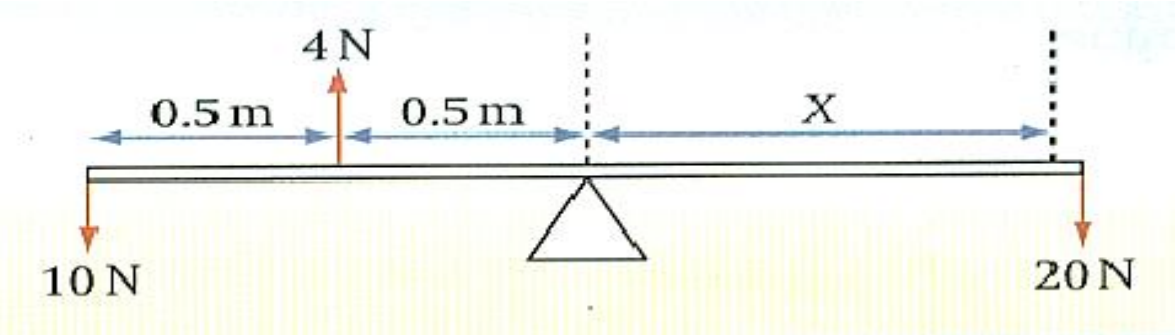


Figure 5.15

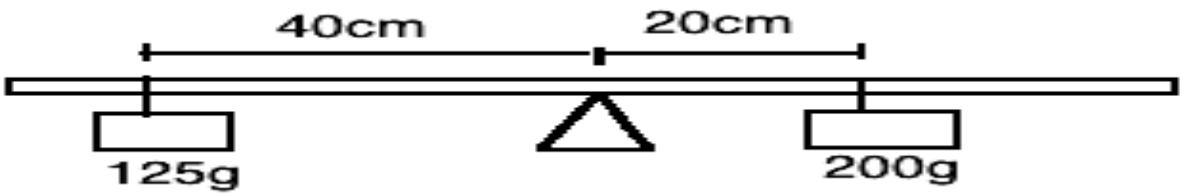
a) Calculate the force that gardener needs to exert to hold the legs of the ground.

b) What force is exerted by the ground on the legs of the wheelbarrow (taken both together) when the gardener is not holding the handles?

3. A force of 20 N acts as shown to balance the beam in the figure below. At what distance X from the pivot point must it acts



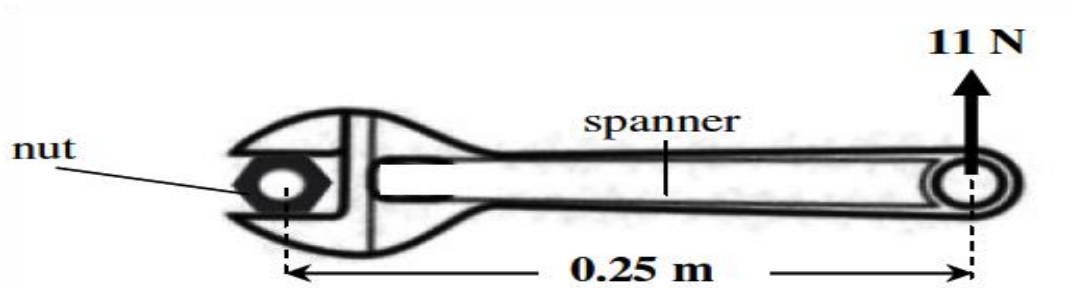
4. The figure shows a uniform meter rule pivoted at the 50 cm mark. 125 g and 200g weights hang from the rule as shown.



a. Calculate where you would hang a 25 g mass in order to balance the rule horizontally

b. State, without calculation, how the rule with the two masses hanging as shown in the figure could be balanced without using any extra mass.

c. Farah needs to loosen a nut by using a spanner



(i) Calculate the resulting moment in Nm.

(ii) State the direction of the moment.

(iii) The nut did not become loose with the moment applied.

(iv) Give **two** ways how Farah could increase the moment.

Levers

- A lever is any device which can turn about a pivot. In a working lever a force called the effort is used to overcome a resisting force called the load. The pivotal point is called the fulcrum
- When we use a crowbar to move a heavy boulder, Figure 5.18, our hands apply the effort at one end of the bar and the load is the force exerted by the boulder on the other end. If distanced from the fulcrum O are as shown and the load is 1000N (i.e. the part of the weight of the boulder supported by the crowbar) the effort can be calculated from the law of moments. As the boulder just begins to move we can say, taking moments about O, that

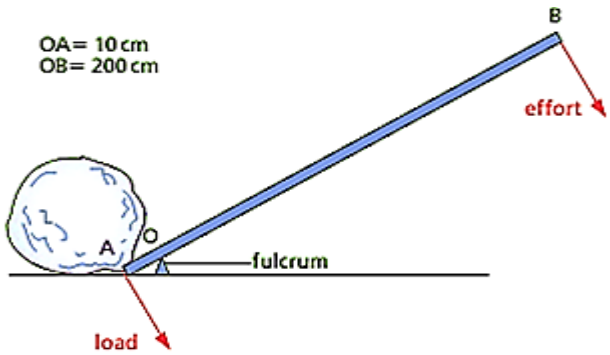
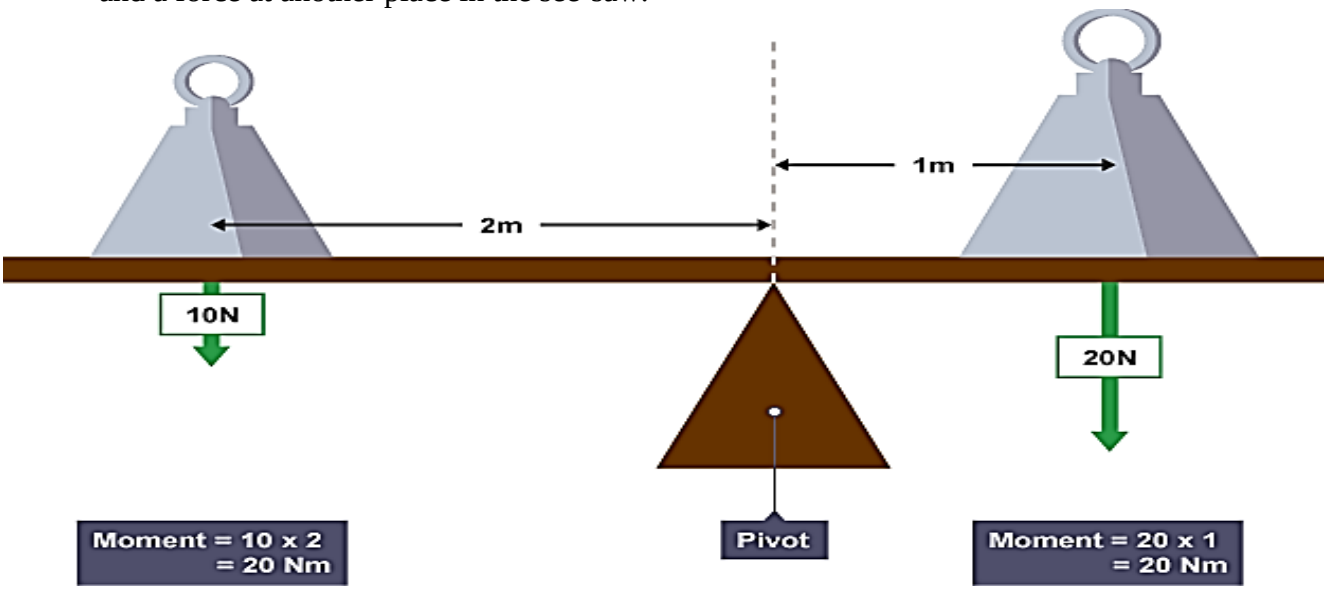


Figure 5.18 Crowbar

Clockwise moment=anticlockwise moment

Effort×200cm=1000N×10cm Effort=$\frac{10000\ Ncm}{200}$ =50N

- A see-saw is another example of a lever. A force is exerted in one place, causing movement and a force at another place in the see-saw.



A balanced beam where the pivot is not in the middle

An **effort** of 10 N on the left is able to balance a **load** of 20 N on the right. This would be useful if you were trying to lift a heavy load on the right and you pushed down on the left.

Notice that the distance from the pivot is greater on the left than it is on the right.

Simple machines give a bigger force but with a smaller movement

If you multiply the force by the distance travelled, you get the same value for the effort and for the load.

Force and distance multipliers

Figure 5. … above shows that the crowbar has enabled an effort (E) to raise a Load(L) 20 times as large, i.e. it is a force multiplier, but E has had to move 20 times as far as L. The lever has a mechanical advantage (MA) of 20 and a velocity ratio (VR) of 20 where

DEFINITIONS

MA = $\frac{Load}{Effort}$ **and VR =** $\frac{distanced\ moved\ by\ Effort}{distance\ moved\ by\ Load}$

Other examples of levers are shown in figures 5.19a to d overleaf. In diagram a load is between the effort and the fulcrum; in this case as in figure 5.19 the effort is less than the load. In b the effort (applied by the biceps muscle) is between the load and the fulcrum and is greater than the load the forearm is a type of lever called distance multiplier because the load moves farther than the effort ,i.e., its VR (and MA) is less than 1

How does the effort compare with the load for scissors and spanner and forceps in figures 5.19c d and e?

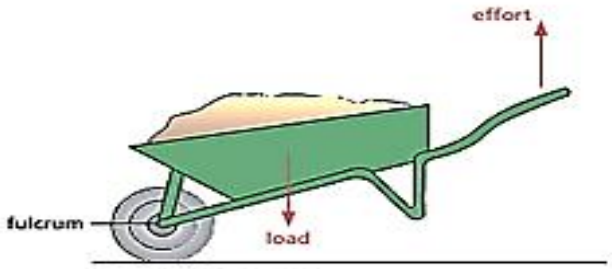


Figure 5.19a Wheelbarrow

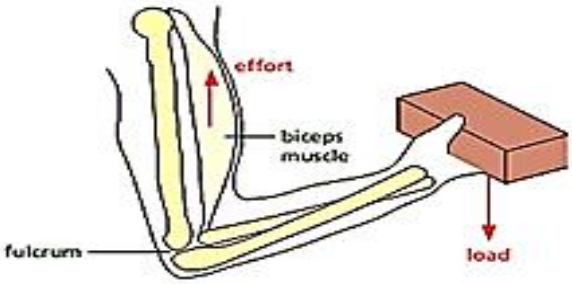


Figure 5.19b Forearm

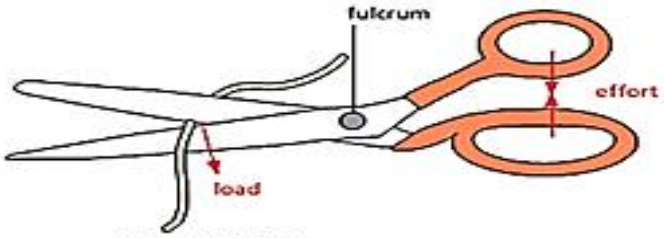


Figure 5.19c Scissors

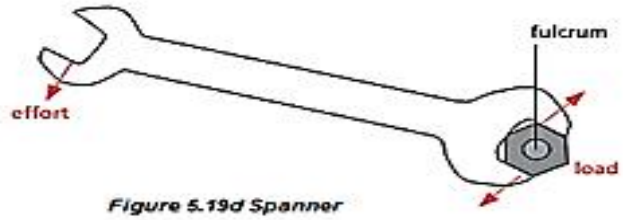


Figure 5.19d Spanner

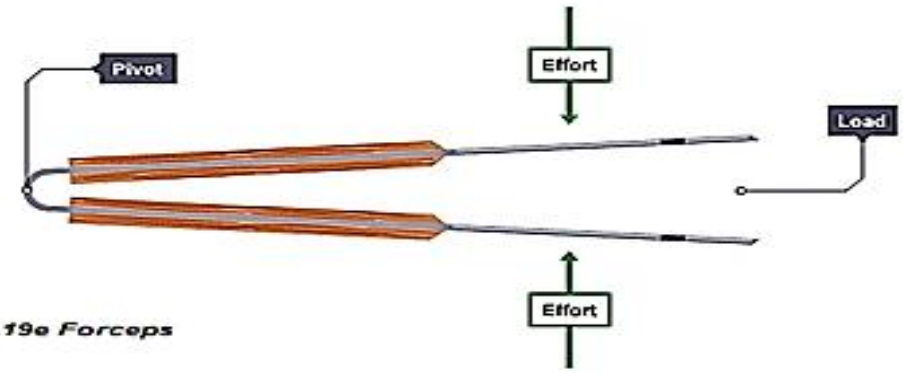


Figure 5.19e Forceps

Example 1

In operating a water pump, a resistance of 480 N is overcome by an effort of 72 N. If the distance of fulcrum from the point where resistance acts is 0.2 m. find the distance of fulcrum from where the effort acts

Answer

Load = 480 N

Effort = 72 N

Distance of load from fulcrum = 0.2 m

Effort x Distance of effort from fulcrum = load x Distance of load from fulcrum

72 x D = 480 N x 0.25 m

D = $\frac{480 \times 0.25}{72}$ = 1.67 m

Example 2

A crow bar of length 120 cm has its fulcrum situated at a distance of 20 cm from the load. Calculate mechanical advantage of a crow bar.

Answer

Distance of load from fulcrum (d) = 20 cm

Distance of effort from fulcrum (D) = (120 – 20) = 100 cm

Mechanical advantage of crow bar = $\frac{\square}{\square} = \frac{100\ \square\square}{20\ \square\square} = 5$

Example 2

A crow bar of length 120 cm has its fulcrum situated at a distance of 20 cm from the load. Calculate mechanical advantage of a crow bar.

Answer

Distance of load from fulcrum (d) = 20 cm

Distance of effort from fulcrum (D) = (120 – 20) = 100 cm

Mechanical advantage of crow bar = $\frac{D}{d} = \frac{100\ cm}{20\ cm} = 5$

Example 3

A machine displaces a load of 125 N through a distance of 0.30 m, when an effort of 12.5 N acts through a distance of 4 m. calculate

8. Velocity ratio
9. Mechanical advantage

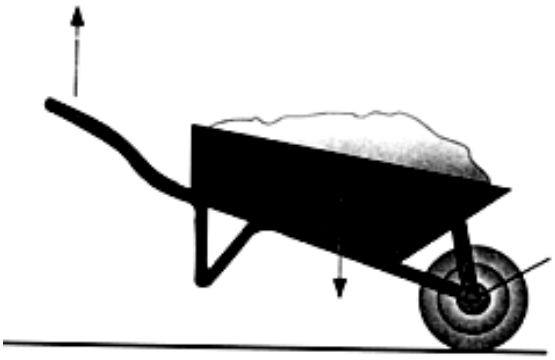
Answer

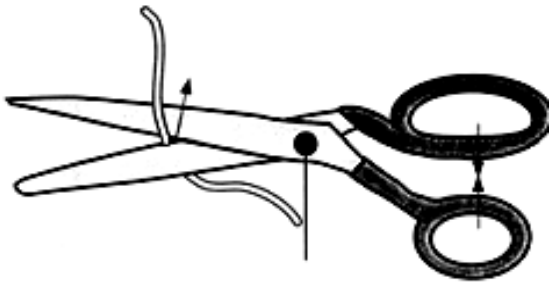
Given L = 125 N E = 12.5 N d = 0.3 m D = 4 m

10. VR = $\frac{D}{d} = \frac{4}{0.3} = 13.33$
11. MA = $\frac{L}{E} = \frac{125\ N}{12.5\ N} = 10.$

Exercise

1. **(a) (i)** On each of the diagrams of a wheelbarrow and a pair of scissors, mark the Pivot **(P),** the load **(L)** and the effort **(E).**

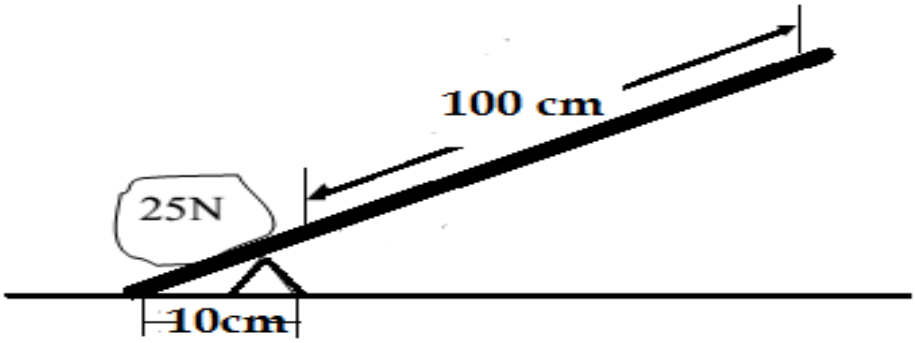




(ii) How does the position of the pivot on a wheelbarrow differ from its position in a pair of scissors?

b) Why is it best to use a long handled screwdriver to undo a tight screw?

2. The diagram shows a rock being lifted with a wood.



(i) Calculate the effort needed at point A to lift the rock.

(i) Name this type of simple machine

Centers of gravity

A body behaves as if its whole weight were concentrated at one point called centre of gravity (c.g) or of centre of mass, even though the earth attracts every part of it the centre of gravity of a uniform ruler is at its centre and when supported there it can be balanced, figure 5.20a if it is supported at any other point it topples because the moment of its weight W about the point of support is not zero, figure 22.1b

Figure 5.20

Your center of mass is near the centre of your body and the vertical line from it to the floor must be with in the area enclosed by your feet or you will fall over.You can test this by standing with one arm and the side of one foot pressed against a wall, figure 5.21now try to raise the other leg sideways

A tight-rope walker has to keep his center of gravity exactly above rope. Some carry along pole to help them to balance, figure 5.22 he combined weight of the walker and pole is then spread out more and if the walker begins to topple to one side he moves the pole to the other side

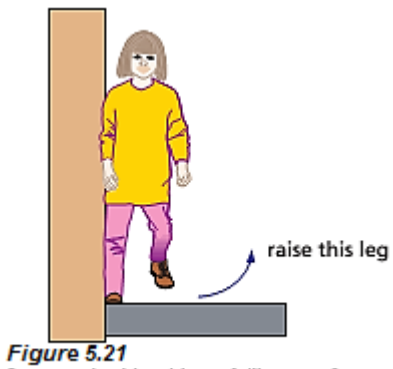


Figure 5.21
Can you do this without falling over?

The center of gravity of a regularly shaped body of the same density throughout is at its centre. In other cases it can found by experiment

Figure 5.22 A tightrope walker using a long pole

Experiment: Centre of gravity using a plumb line

Suppose we have to find the center of gravity of an irregularly shaped lamina (a thin sheet)of cardboard.

- Make a hole A in the lamina and hang it so that it can swing freely on a nail clamped in a stand. It will come to rest with its center of mass vertically below A. To locate the vertical line through A tie a plumb line (a thread and a weight) to the nail figure22.4 and mark its position AB on the lamina. the center of gravity lies somewhere on AB
- Hang the lamina form another position C and mark the plumb line position CD the center of gravity lies on CD and must be at the point of intersection of AB and CD.

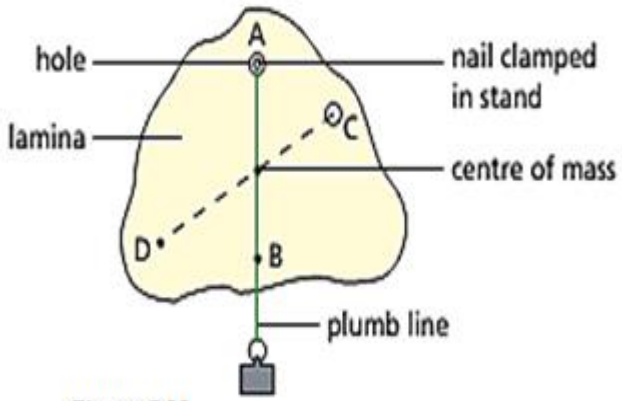


Figure 5.23

- Check this by hanging the lamina from a third whole. Also try balancing it at its center of gravity on the tip of your forefinger.
  Devise a method using a plumb line for finding the center of gravity of a tripod

Toppling

The position of the center of gravity of a body affects whether or not it topples over easily. This is important in the design of such things as tall vehicles (which tend to overturn when rounding a corner), racing cars, reading lamps and even drinking glasses.

A body topples when the vertical line through its center of gravity falls outside its base, figure 5.24a.Otherwise it remains stable figure 5.24b

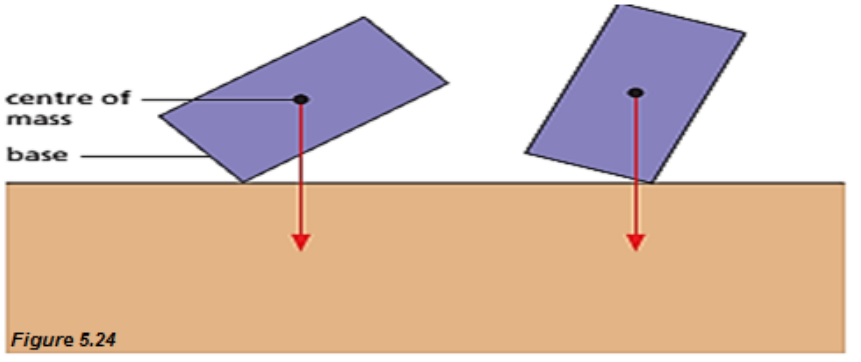


Figure 5.24

a Topples

b Will not topple (stable)

Toppling can be investigated by placing an empty can on a plank (with a rough surface to prevent slipping) which is slowly tilted. The angle of tilt is noted when the can falls over. This is repeated with a mass of 1kg in the can. How does this affect the position of the center of gravity?

The same procedure is followed with a second can of the same height as the first but of greater width. It will be found that the second can with the weight in it can be tilted through the greater angle.

The stability of a body therefore increased by

(i) Lowering its center of gravity.
(ii) **Increasing the area of its base**.

Figure 5.25a A tractor under test to find its center of gravity

Figure 5.25b A double-decker bus being tilted to test its stabilty

- In figure 5.25a the center of gravity. of a tractor is being found.it is necessary to do this when testing a new design since tractors are often driven over sloping surfaces and any tendency to overturn must be discovered
- The stability of double-decker buses is being tested in figure 5.25b. When the top deck only is fully laden with passengers (represented by sand bags in the test), it must not topple if tilted through an angle of 28^0.
- Racing cars have low center of gravity, and a wide wheel base for maximum stability.

Equilibrium and stability

Conditions for equilibrium

Sometimes a number of parallel forces act on a body so that it is in equilibrium .We can then say:

(i) The sum of the forces in one direction equals the sum of the forces in the opposite direction
(ii) The law of moments must apply

As an example consider tow decorators of weights 500N and 700N standing at A and B on aplank resting on two trestles, Figure 5.26 In the next chapter we will see that the whole weight of the plank (400N) may be taken to act vertically downwards at its centre, O. if P and Q are upward forces exerted by the trestles on the plank (called reactions) the we have from (i)

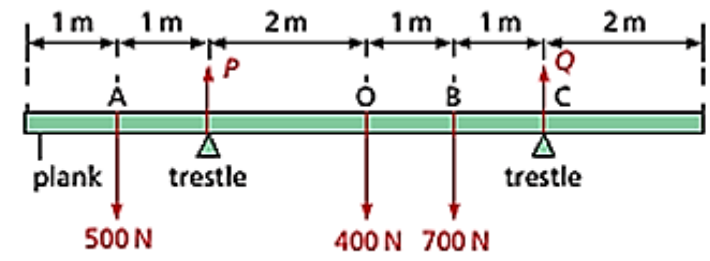


Figure 5.26

P+Q=500N +400N+700N= 1600N

Moments can be taken about any point but if we take them about C the moment due to Q is zero

Clockwise moment=P×4m

Anticlockwise moments = 700N × 1m + 400N×2m +500N×5m

=700Nm+800Nm+2500Nm=4000Nm

Since the plank is in equilibrium we have from (ii)

P×4m= 4000 Nm P= $\frac{4000}{4}$ = 1000N

From (1), Q= 600N

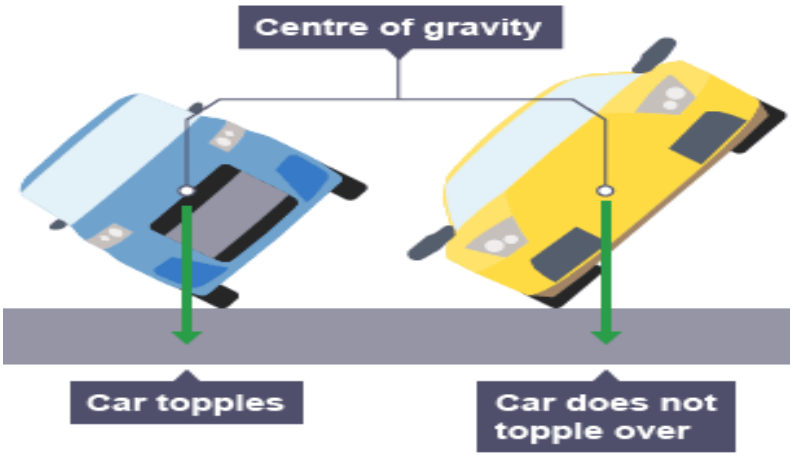
Stability

Stability is a measure of how likely it is for an object to topple over when pushed or moved. Stable objects are very difficult to topple over, while unstable objects topple over very easily.

The stability of an object is affected by two factors:

- the width of the base of the object
- the height of its *centre of mass*

Objects with a wide base, and a low centre of mass, are more stable than those with a narrow based and a high centre of mass.



The wider car will not topple over because it has a lower centre of gravity, but the narrow car will

If you are standing in a bus that is accelerating or braking, you usually spread your feet apart to increase the width of your base to make you more stable.

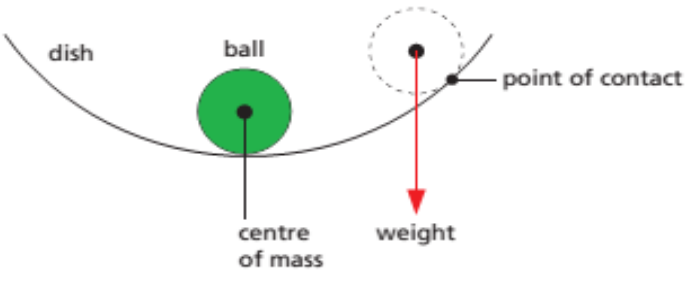
Everyday objects are also designed with this in mind. For example, a traffic cone has a wide base and is weighted at the bottom to give it a low centre of mass.

Motorway traffic cones

There are three types of equilibrium

Stable equilibrium

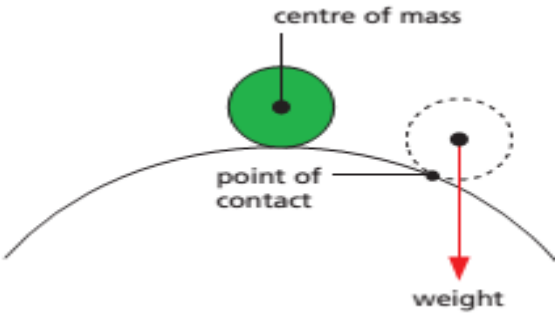
A body is in 'stable equilibrium' if when slightly displaced and then released it returns to its previous position. The ball at the bottom of the dish in figure 5.27a is an example. Its center of gravity rises when it is displaced. It rolls back because its weight has a moment about the point of contact that acts to reduce the displacement.



a Stable

Unstable equilibrium

A body is in 'unstable equilibrium' if it moves farther away from its previous position when slightly displaced and released. The ball in figure 5.27b behaves in this way. Its center of gravity falls when it is displaced slightly because there is a moment which increases the displacement. Similarly in figure the balanced ruler is in unstable equilibrium



b Unstable

Neutral equilibrium

A body is in 'neutral equilibrium' if it stays in its new position when displaced (figure5.27c). Its center of gravity does not rise or fall because there is no moment to increase or decrease the displacement.

c Neutral

Figure 11.7 States of equilibrium

Examples of applications of stability

Stability is important in the following examples:

a. Car and bus design
b. Car wheels – small lead weights are fitted to the rim so that the wheel balances in any position
c. New born animals
d. furniture design
e. Plank roots in rainforest trees

All these cases the aim is to give a broad base and/or a low centre of gravity and therefore stability.

The position of the centre of gravity is also important in balancing in the following examples:

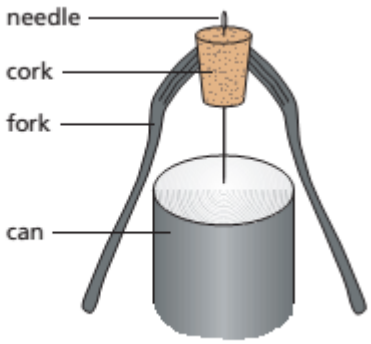
a) Counterbalance weights to balance the load on a crane

b) Tightrope walking

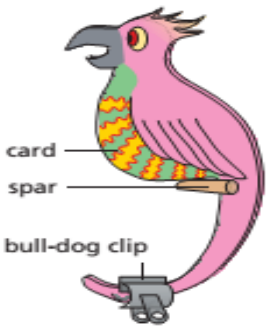
c) Gymnastics and other sports, etc.

Balancing tricks and toys

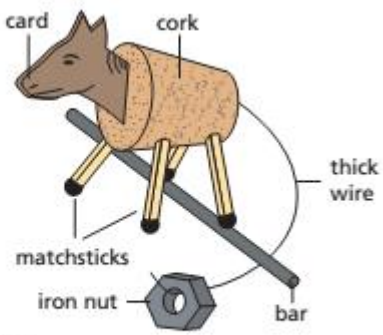
Some tricks that you can try or toys you can make are shown in figure 22.8 in each case the center of gravity. Is vertically below the point of support and equilibrium is stable.



a Balancing a needle on its point



b The perched parrot



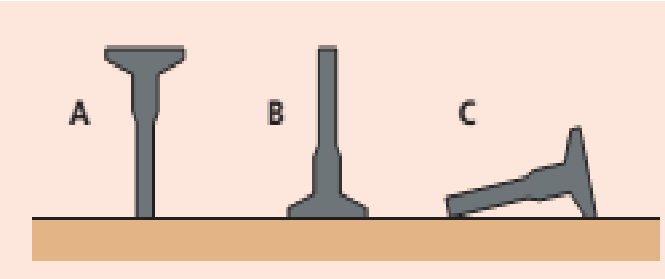
c A rocking horse

Figure 11.8 Balancing tricks

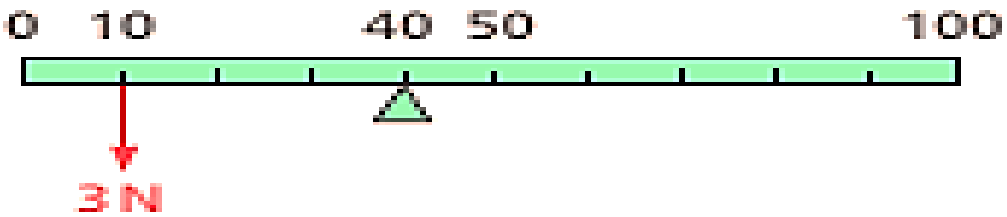
A self-righting toy, figure 22.9 has a heavy base and when tilted the weight acting through the center of gravity has a moment about the point of contact. This restores it to the upright position

Exercise

1. Figure below shows a Bunsen burner in three different positions. State in which position it is in
   a) Stable equilibrium
   b) equilibrium
   c) Neutral equilibrium



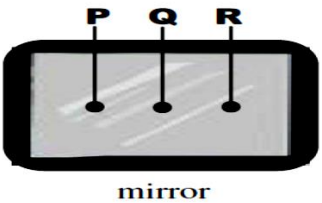
2. The weight of the uniform bar in figure 22.13 is 10N. Does it balance, tip to the right or tip the left?



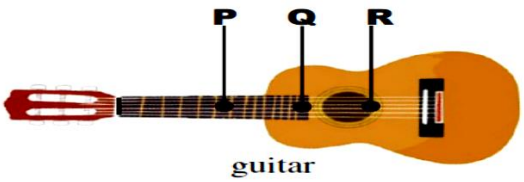
3. **a)** define center of gravity
   b) State two factors that affect the stability of an object and explain how they affect?

c) Circle **ONE** of the letters P, Q or R showing the correct position of the center of gravity of each object:

(i)

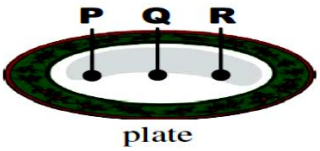


(ii)



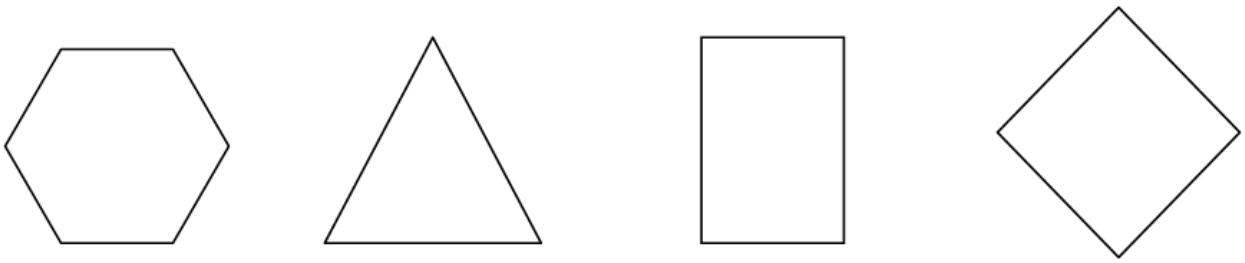
(iii)

(iv)



4. a. The Centre of gravity of an object is the point where the object _____.

b. Find and mark the Centre of gravity of the following shapes.



6.3 Pressure

The term pressure is used in day-day life. To understand its meaning consider the following example of experiences with force on solids

(i) A person makes deeper marks while walking on soft ground in a very narrow and sharp-heeled shoes than when in ordinary shoes with flat heels.

(ii) It is easier to push a sharp pin through cardboard than it is to push a blunt one through the same material using the same force, see figure 5.33 (a) and (b).

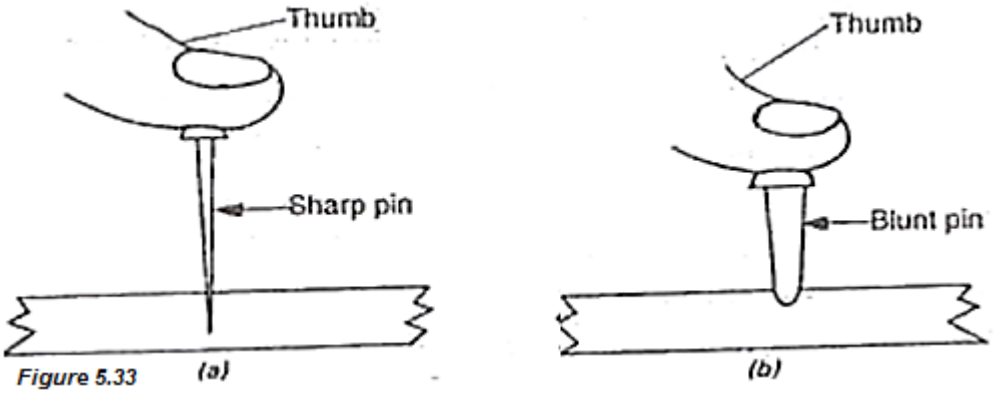


Figure 5.33

In (i) above, sharp pointed heels dig deeper on soft ground because the weight of the body acts on a small area.

In (ii) the sharp pin penetrates on cardboard because the force applied acts on small area than when the blunt pin is used.

In all these cases, force acting on surface produces a penetration effect. This penetration effect is larger when the force acts on small area than when the same force acts on larger area.

The pressure is defined as **the force acting normally (perpendicularly) per unit area.**

Unit of pressure

From the definition, pressure $P=\frac{force(f)}{area(A)}$

Therefore, the SI unit of pressure $=\frac{SI\ unit\ of\ force}{SI\ of\ area}=N/m^2$ or Nm^{-2}

The SI unit of pressure is thus newton per square (NM^{-2}),which is also called the pascal (pa).Other unit include mmHg. cmHg and atmosphere (atm).

$P = \frac{force(f)}{area(A)}$ $P \alpha \frac{1}{area(A)}$

From the formula pressure is inversely proportional to the area when force is kept constant. So that the smaller the area of contact the greater the pressure and vice versa.

Increasing the pressure by reducing the area ***Reducing pressure increasing the area***

The studs on a football boot have only a small area of contact with the ground. The pressure under the studs is high enough for them to sink into the ground, which gives extra grip

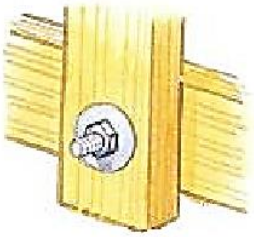
Skis have large area to reduce the pressure on the snow so that they do not sink in too far. Camels also have large feet to reduce pressure on the sand so they do not sink in.

The area under the blade is small. This increases pressure to enable the blade push through the material easily.

Wall foundations have larger area to reduce pressure on the ground so that the wall does not sink further into ground. The dam walls are thicker at the bottom to withstand the high pressure there.

Under the tiny area of the point of a drawing pin, the pressure is far too high for the wood to withstand.

A load-spreading washer ensures that the nut is not pulled into the wood when tightened up.



Example 1

A man of mass 84 kg stands upright on a floor. If the area of contact of his shoes and floor is 420cm^2, determine the average pressure he exerts on the floor.(take g=10Nkg^{-1}**)**

Solution

Pressure= $\frac{force}{Area}$Force = weight of the man = 84x10 = 840N

Area = 420cm^2 = $\frac{420}{10000}$=0.042m^2

Thus, pressure = $\frac{840}{0.042}$ =$\frac{840x1000}{0.042x1000}$= 20000Nm^2.

Example 2

A metallic block of mass 40 kg exerts a pressure of 20Nm^2 on flat surface. Determine the area of contact between the block and the surface (take g=10kg$^{-1)}$

Solution

Force =weight of the block

= 40x10 N = 400N

Since P=$\frac{f}{A}$: $A = \frac{F}{P}$= (400/20) m^2 = 20 m^2

From the formula P =$\frac{f}{a}$ it follows the pressure increases with increase in force, if the area is kept constant. Similarly, pressure increase with decreasing area and decreases with increasing area, if the force is kept constant.

Example 3

A brick 20 cm long, 10 cm wide and 5 cm thick has a mass of 500 g.

Determine the:

12. Greatest pressure that can be exerted by the brick on flat surface.
13. Least pressure than can exerted by the brick on flat surface.(take g =10Nkg^{-1})

Solution

14. Dimensions of the brick are 0.20m, 0.010m and 0.05 m .

Weight of the brick = $\frac{500}{1000}x10$ =5N

From the formula =$\frac{F}{A}$;

P is greatest when area A is smallest.

Area of the smallest face of the brick = 0.10 x 0.05 = 0.005 m^2

Therefore, P =$\frac{F}{A\ smallest}$= $\frac{5}{0.005}$= 1000Nm^{-2}

15. Pressure is least when A is greatest

Therefore p = $\frac{5}{0.20x0.10}$ = 250Nm^{-2}

Exercise

1. a force of 100 N is applied to an area of 100 mm$^{2.}$ What is the pressure exerted on area in Nm^{-2}?
2. a girl standing upright exerts a pressure of 13600 Nm^{-2} on the floor. Given that total area of contact of shoes and floor is 0.0368 m^2.
   (a) Determine the mass of the girl.
   (b) Determine the pressure she would exert on the floor if she stood on the foot.
3. truck which carry heavy loads have many wheels, explain.
4. a block of copper of density 8.9/cm^3 measures 5 cm x 3 cm x 2cm.

   Give that the force of gravity is 10Nkg^{-1}, determine

   (a) The maximum pressure.
   (b) The minimum pressure that it can exerts on a horizontal surface.
5. how much force must be applied on blade of length 4cm and thickness 0.1mm to exert a pressure of 5000000 pa?

Pressure in liquid

Figure 5.34 (a) and (b) show an aerial view of dam and its cross sectional.

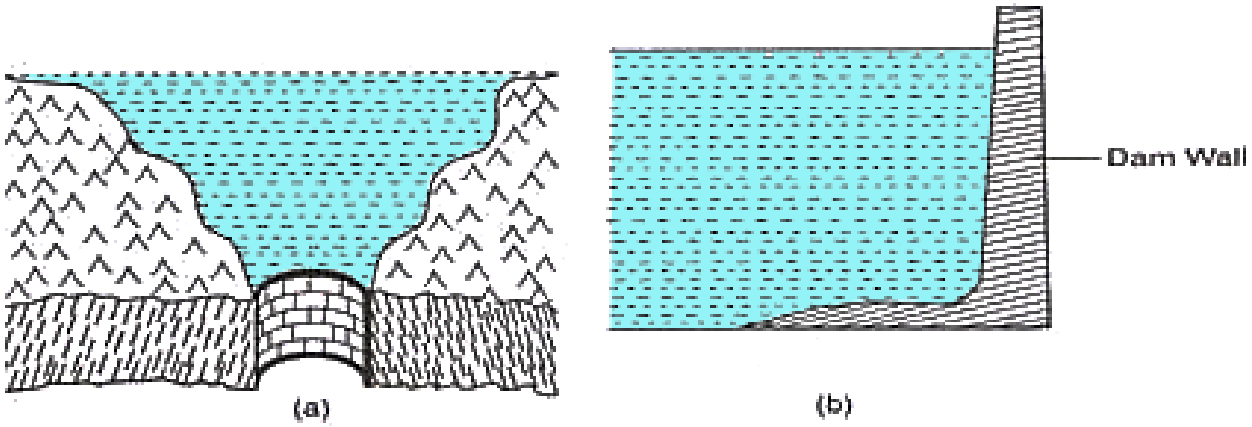


Fig. 5.34: curved wall and section of dam

Why the wall is curved in fig 5.34 (a) why is it wider at the bottom then the top in (b)?

The demonstration below will assist in addressing the above question

EXPERMIMANT : to show variation of pressure in liquid

Apparatus

Tall, small nail water

Procedure

- Using the nail, make three holes, A,B and C of the same diameter along a vertical line on one side of the tin.
- Fill the tin with water as shown in figure 5.35
- With the hole of water observe the jest of water from the holes A,B and C.

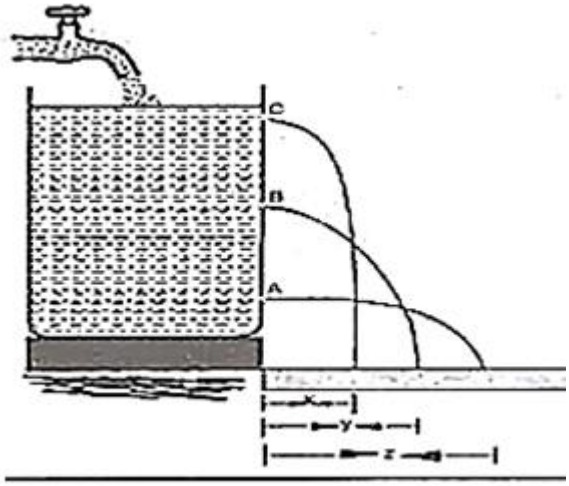


Figure 5. 35 Pressure and depth

Observation

The lower holeA, throws water farthest, followed by B and lastly C.

Conclusion

Pressure of water at A is greater than pressure at B and pressure at B is greater than at C. Hence, pressure increase with depth.

For this reason , diver at the bottom of the dam experiences pressure due to the weight of water the bottom of the above him. The deeper the diver goes, the greater the pressure.

Liquid levels

When a liquid is poured into a set of connection tubes with different shapes, it flows until the levels are the same in all the tubes, as shown in Figure 5.36.

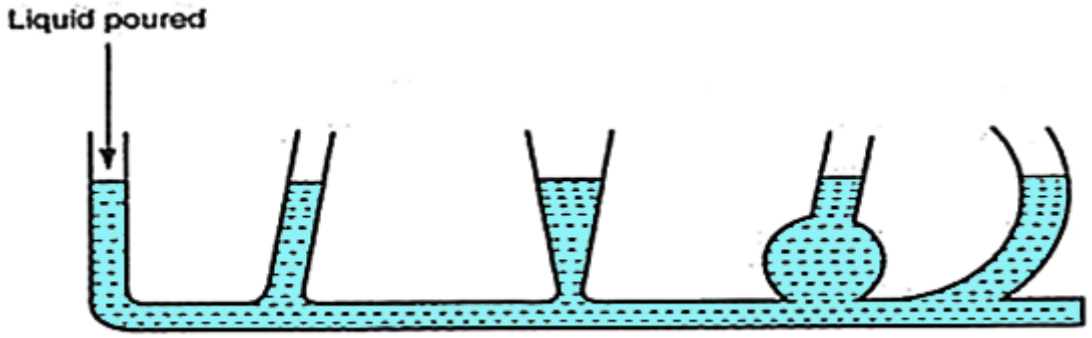


Figure 5.36: A liquid finds its own level

This shows that the liquid flows to find its own level.

Liquid levels in a U-tube

When water poured into a U-tube, it will flow into the other arm. The water will settle in the tube with the levels on both arms being same, see figure 5.37(a).

When one arm of the U-tube is blown into with the mouth, the level moves downwards, while on the other arm it raises, see figure 5.37(b). This is caused by pressure difference between the two arms. The pressure increases on the arm that is blown into and causes water to rise on the other arm.

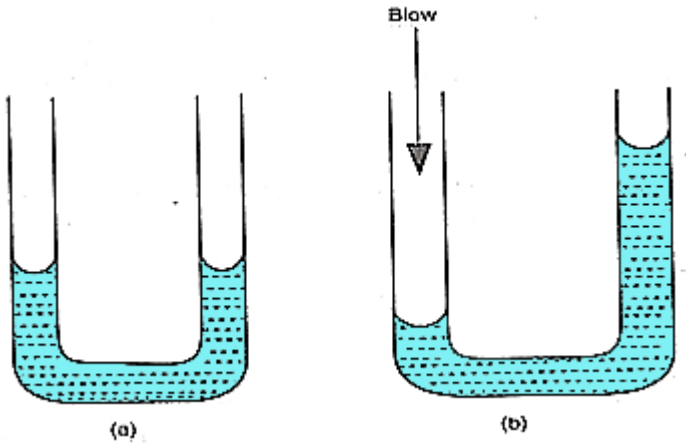


Fig. 5.37: effect of pressure on liquid levels

Experiment (a) to investigate the variation of liquid pressure with depth and density

Apparatus

A tall, jar liquid of different densities, thistle funnel, U-tube, rubber tubing.

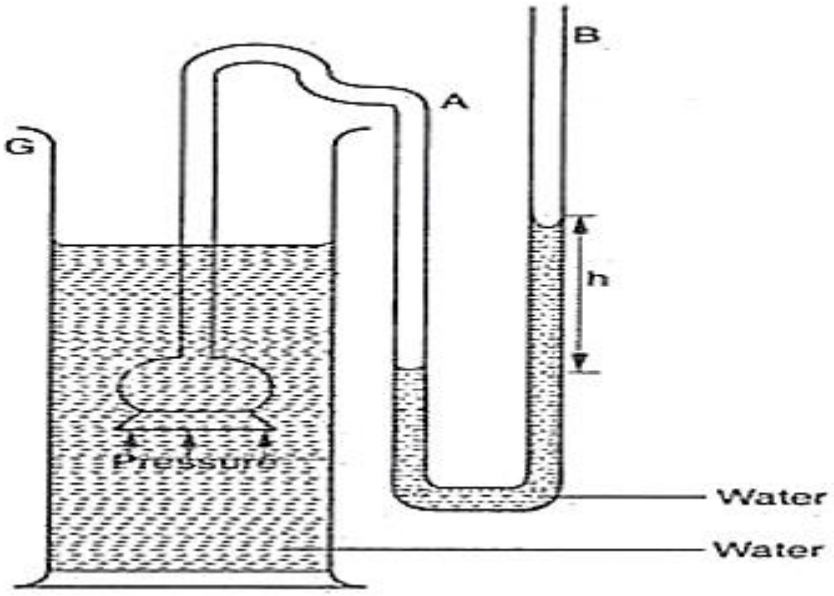


Fig. 5.38: pressure variation in liquid

Procedure

- Fill the glass vessel G with water.
- Connect the thistle funnel to a U-tube filled to some level with water.
- Lower the funnel to different depth surface and notice the difference in levels, h,of water in tube, see figure 5.38.
- Replace water in G with a denser liquid, such as sodium chloride solution (brine).
- Lower the funnels to the same depth as above and compare the heights obtained.

Observations

(i) The deeper the funnel goes below the surface, greater the difference in level, h.

(ii) The different levels, h, obtained with brine at a particular depth are greater than obtained with water at the depth.

Experiment (b): To show the distribution of pressure at a point in a liquid

Apparatus

A tall jar water, this funnels, U-tube, rubber tubing

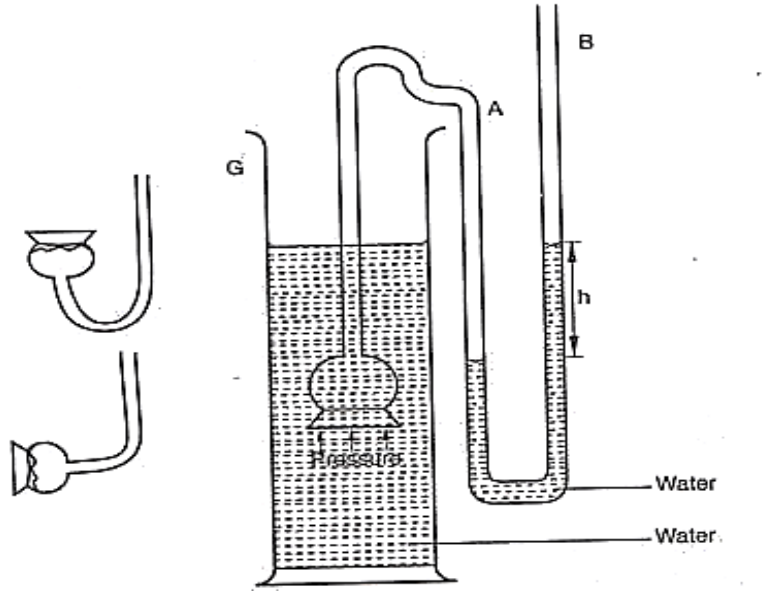


Figure5.39: Pressure distribution

Procedure

- Fill the glass vessel G with water
- Connect one of the thistle funnels to a U-tube filled to some level with water.
- Lower the funnel to a depth from the surface of water and notice the difference in levels, h of the water in U-tube
- Replace the funnel with others ,in turn, whose mouths are pointing in different directions
- Lower the funnel into the water so that the mouth of the funnel is at the same point as the straight one. Observe the difference in levels of the water in the U-tube

Observation

At the same depth in a given liquid, difference in levels obtained is the same regardless of the direction which the funnel faces

Conclusion

Pressure in liquids increases with density and depth

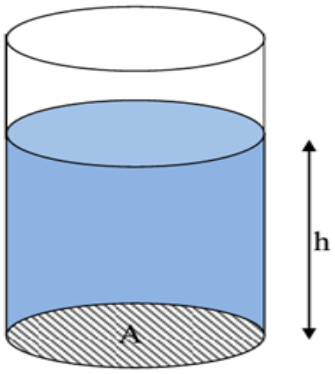
In summary

(i) Pressure in a liquid increases with depth below its surface

(ii) Pressure in a liquid at a particular depth is the same in all directions

(iii) Pressure in a liquid increases with the density of the liquid

Fluid pressure formula



The volume of liquid, V = A X h = Ah

The mass of the liquid, m = density X volume

So, m = ρ X V = ρ X Ah = Ahρ

The weight of the liquid, W = m X g

Weight, W = Ahρ X g = Ahρg

The pressure due to liquid, $P = \frac{F}{A} = \frac{Ah\rho g}{A}$

$P = h\rho g$

From the formula P =hρg it can be seen that the pressure due to a liquid column is directly proportional to

(i) height of the column
(ii) the density ρ of the liquidand does not depend on the cross-sectional area o th container which holds the liquid
(iii) The formula is also used to determine pressure due to gas column

Example4

A diver is 10m below the surface of water in a dam. If the density of the water is 1000kgm^3 determine the pressure due to the water on the diver (take g=10N/Kg)

Solution

Pressure on the diver is given by

P=hρg = 10 × 1000 × 10 = 100000Nm^{-2}

Example 5

The density of mercury is 13600kgm^{-3} determine the liquid pressure at a point 76cm below the surface of mercury (take g=10N/kg

Solution

Pressure is given P = hρg=0.76×13600×10 =103360Nm^2

Transmission of pressure in liquids

Figure 5.40 shows a liquid under pressure due to the force F acting on the plunger

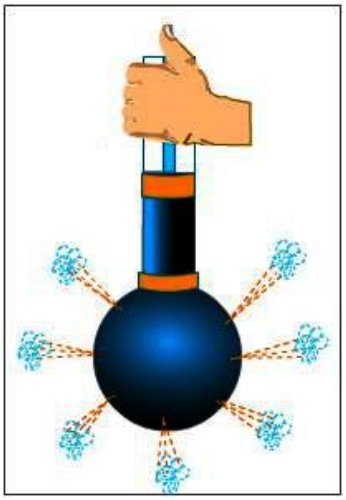


Fig 5.40 pressure transmission in liquids

When the plunger is pushed in the liquid squirts out of the holes with equal force. If the plunger exerts a force F and the piston area is A then the pressure P developed is $\frac{F}{A}$ this pressure is transmitted equally to all parts of the liquid

Note

The holes must have the same diameter

Experiment: To investigate how pressure is transmitted in liquids using identical syringes

Apparatus

Two identical syringes, Rubber, Tubing, Water, Pairs of different masses

Procedure

- set up the apparatus as shown in figure 5.41
- place a mass m on one of the plungers and observe what happens
- place an identical mass on the other plunger and observe what happens
- repeat with the other pairs of identical pairs of masses

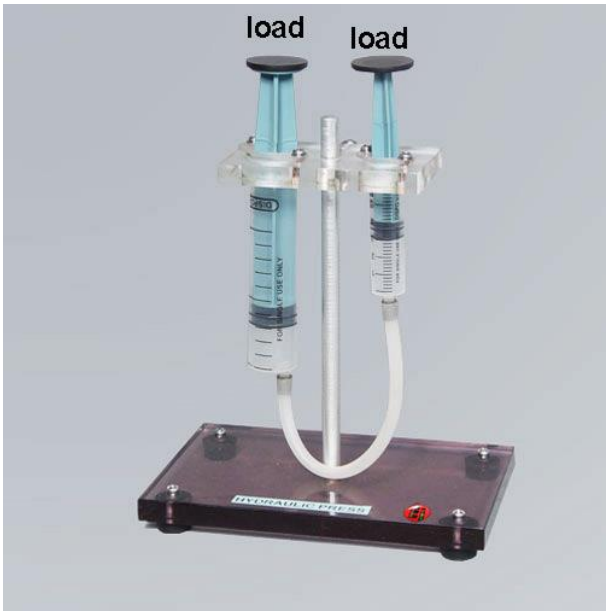


Fig: 5.41: Transmission of pressure in liquids

Observation

(i) the first mass is placed on the plunger, the plunger moves downwards and the second plunger when moves upward

(ii) when an identical mass is placed on the second plunger ,the first plunger with the mass on it moves upwards and stops when their levels are the same

The pressure in the two syringes is the same; this is because the masses and the diameters of the syringes are the same

Using different syringes

Apparatus

Syringes of different sizes,

Two stands and clamps,

Different masses,

Water,

Rubber tubing

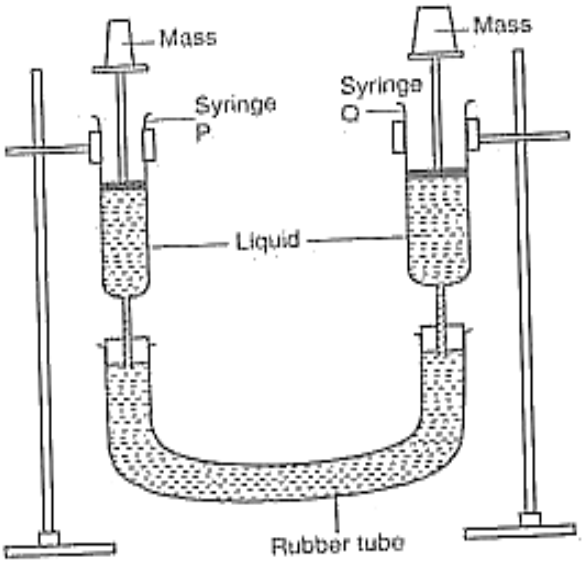


Figure 5.42 effects of transmitted pressure

Procedure

- Replace one of the syringes in experiment (a) with syringe of different diameter, and set up the apparatus as shown in figure 5.42
- starting with a large mass on syringe Q, put masses on syringe P until Q just starts to move upwards. Note the mass on P and Q as in table 5.2

	Syringe P	Syringe Q
Area of piston(m^2)		
Weight F on piston (N)		
Ratio $\frac{F}{A}$		

From the table, compare the ratio $\frac{F}{A}$ in P and Q

Conclusion

At balance, the pressure due to the mass in P is equal to the pressure due to the other mass in Q

Pressure applied at one part in liquid is transmitted equally to all other parts of the enclosed liquid. This is called the principle of transmission of pressure in liquids (Pascal's principle) gases may transmit pressure in a similar way when they are confined and incompressible.

Hydraulic machines

The principle of transmission of pressure in liquids is made use of in hydraulic machines where a small force applied at one point of a liquid produces a much larger force at some other point of the liquid

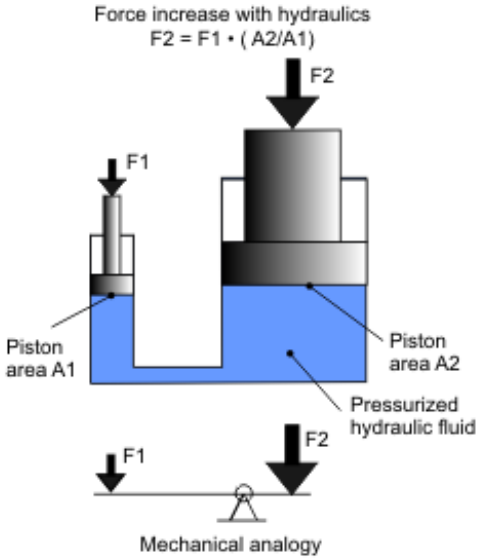


Figure 5.43: hydraulic lift

Hydraulic lift

The hydraulic lift consists of a small piston S of cross-sectional area A_1 and a large piston L of cross-sectional area A_2 when a force is applied on piston S, the pressure exerted by the force is transmitted throughout the liquid to piston L, see figure 4.12

Consider a force F_1 applied on the small piston of cross-section area A_1 suppose the force produced on the large piston of cross-section area of A_2 is F_2.Then, pressure P_1 exerted on the liquid by the piston S due to F_1 is given by

$P_1=F_1/A_1$

This pressure will be transmitted by the liquid to the large piston L therefore, pressure of liquid acting on the area A_2 of the large piston is equal to P_1.Thus, the force F_2 produced on the large piston is given by

F_2= *pressure*×*area*

$P_1 \times A_2$

But $P_1=F_1/A_1$

So $F_2 =F_1/A_1 \times A_2$

Therefore $F_2/F_1=A_2/A_1$

Note:

This equation only applies if the pitons are at the same level. For example A_1,is $0.25m^2$, A_2 is $10m^2$and force applied on the small piston F_1 is 100N,then;

$F_2=\frac{100\times10}{0.25}=4000N$

Note that a small force applied on the small piston produces a much bigger force on the large piston Hydraulic lifts are used for hoisting cars in garages. Hydraulic presses on the other hand are used to compress certain materials such as cotton bales into the required shapes and sizes.

Example

Figure 5.44 shows two masses placed on the light pistons. The pistons are held stationary by the liquid, whose density is $0.8g/cm^3$

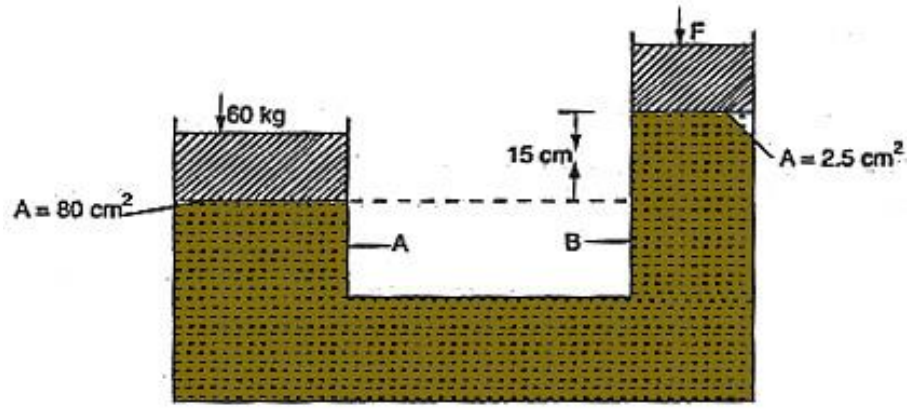


Figure 5.44 determine the value of the force F

Solution

Pressure in A = pressure in B

$\frac{60\times10}{0.0080}=\frac{F}{0.00025}+0.15\times800\times10$

$\frac{F}{0.00025}+1200$ F= (75000-1200)× 0.00025 =18.45N

Hydraulic brake system

The hydraulic brake system is shown in figure 5.45

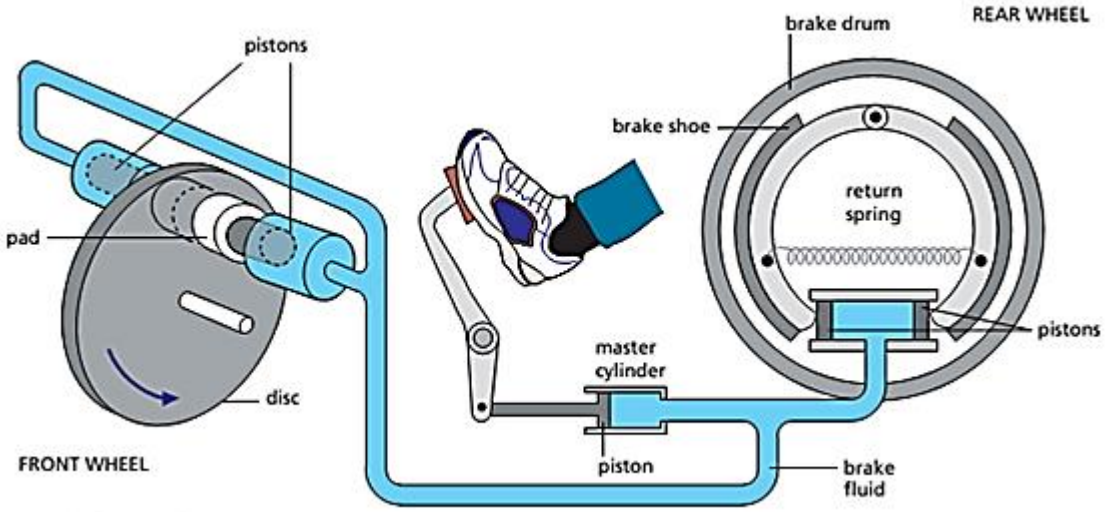


Figure 16.8 Hydraulic car brakes

Figure 5.45 hydraulic brake system

The force applied on the foot pedal exerts pressure on the master cylinder. The pressure is transmitted by the brake fluid to the slave cylinder. This causes the pistons of the slave cylinder to open the brake shoe and hence the brake lining presses the drum. The rotation of the wheel is thus resisted

When the force on the foot pedal is withdrawn, the return spring bulls back the brake shoe which then pushes the slave cylinder piston back

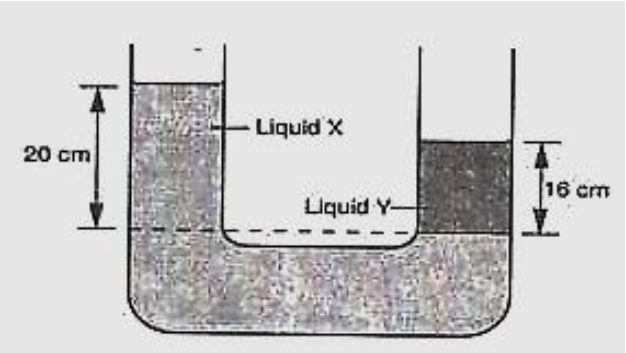
The advantage of this system is that the pressure exerted in master cylinder is transmitted equally to the entire four wheel cylinder. Hence the braking force obtained is uniform.

The liquid to be used as a brake fluid should have the following properties:

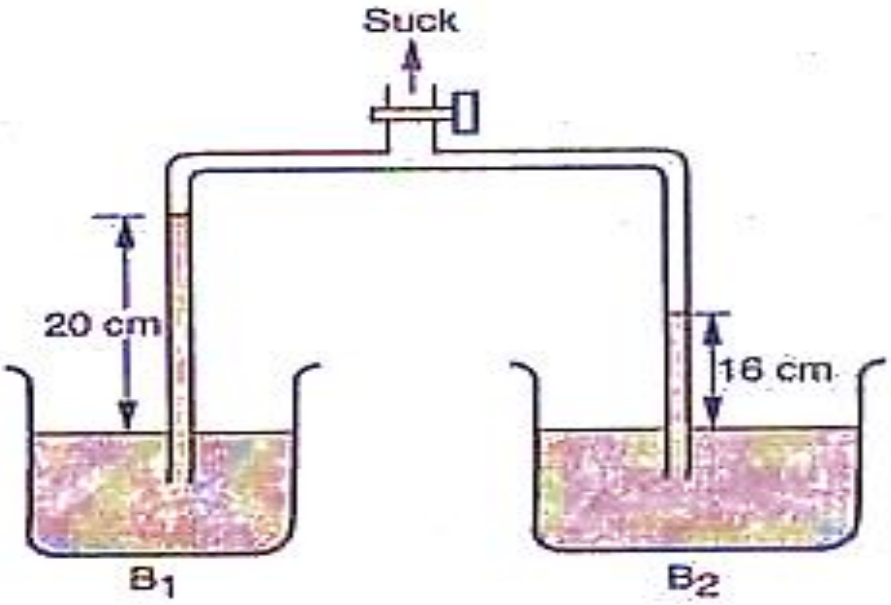
(i) Be incompressible, to ensure pressure exerted at one point is transmitted equally to all other parts in the liquid
(ii) Have low freezing point and high boiling point
(iii) should not corrode the parts of the brake system

Exercise 5.4.2

1. The diagram below shows a U-tube filled with two liquids X and Y if the density of Y is 1.26g/cm^3 determine the density of liquid X what would be the effect of increasing the diameter of one arm of the U-tube on the height of the liquid column?



2. Two liquids were sucked up into two identical tubes as shown in figure below.Given that liquid in beaker B_2 is water(density 1g/cm^3) determine the density of liquid in beaker B_1

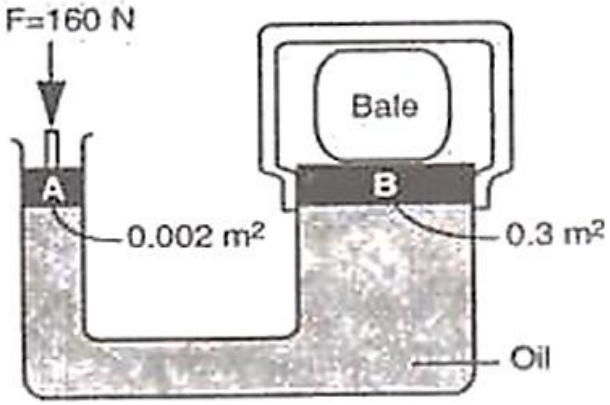


3. Calculate the pressure the due to water experienced by a diver working 15m below the surface of the sea(take g=N/kg) and density of sea water(1.03g/cm^3)
4. An outlet of diameter 1m is made 20m below the surface of water in a dam. What would be the force with which the water spews out when it is fully opened?(Take g = 10N/Kg and density of water 1g/cm^3
5. Why are water storage tanks in houses erected as high as possible
6. Describe a simple experiment to demonstrate that the pressure in a liquid increases with dept

7. The figure below shows a simple hydraulic press used to compress a bale. The cross-section areas of A and B are 0.002m^2 and 0.30m^2 respectively

Determine the:

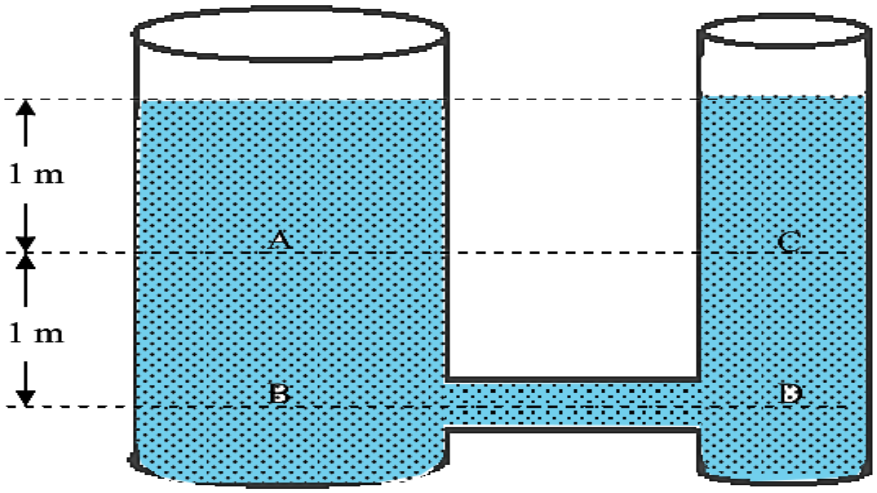
a. pressure exerted on the oil by the force applied at A
b. Pressure exerted on B by the oil
c. force produced on B compressing the bale



8. Explain how a syringe draws

(a)Injectable drug from a bottle (b) Blood from a patient's body

9. in the diagram shown:



a) How does the pressure at A compare with the pressure at B?
b) How does the pressure at B compare with the pressure at D?
c) How does the pressure at Acompare with the pressure at C?
d) Calculate the pressure at B due to the water.
e) If the water in the system were replaced with paraffin, how would this affect the pressure at B?

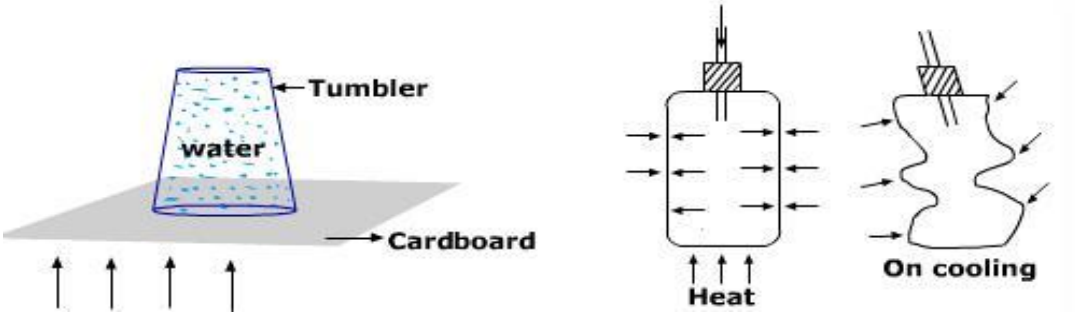
Atmospheric pressure

The gaseous envelope surrounding the Earth is called earth's atmosphere, extending to a few kilometers above the surface. The pressure exerted by the atmosphere is called atmospheric pressure. The magnitude of this pressure is nearly $1.01 \times 10^5 N/m^2$ (Refer Torricelli's experiment) at sea level.

An experiment was conducted by Otto Van Guericke at Magdeburg, where ten horses, unsuccessfully, tried to pull two copper hemispheres (with no air inside) apart.

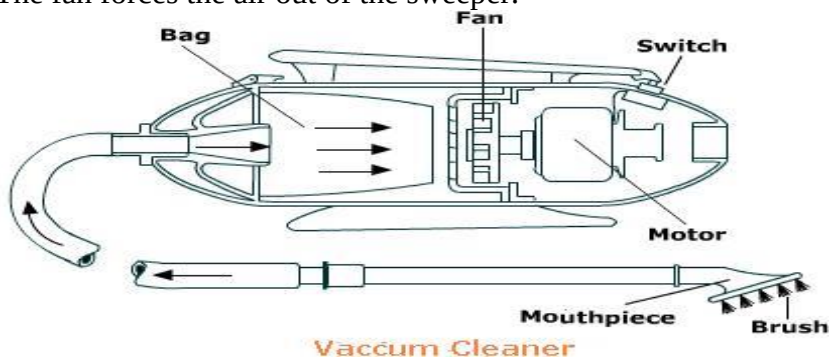
The presence of atmospheric pressure can be studied through following illustrations

Activity I
Remove air from a can by putting a little water into the can and boiling the water in it. The steam forces the air out. Close the opening and keep it below a tap, we find the can crumbling as the pressure inside the can is very small when compared to the pressure outside.

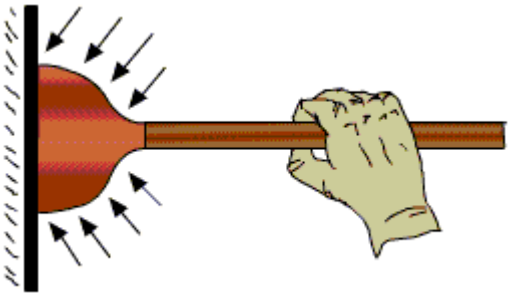


Activity II
In the above arrangement where the cardboard is intact, water does not come out of the tumbler as the cardboard is balanced due to pressure of liquid in the tumbler and the atmospheric pressure from below.

Activity III
The fan driven by an electric motor reduces the pressure near the mouthpiece. The pressure due to atmosphere being large, forces air along with dust particles into the long tube and then, into the bag. The fan forces the air out of the sweeper.



Activity IV
Wet the rim of the plumber's force cup with water and press it against the wall to squeeze out most of the air. We find it difficult to pull the cup. (This simple principle is used to remove any blocks in holes of washbasin)

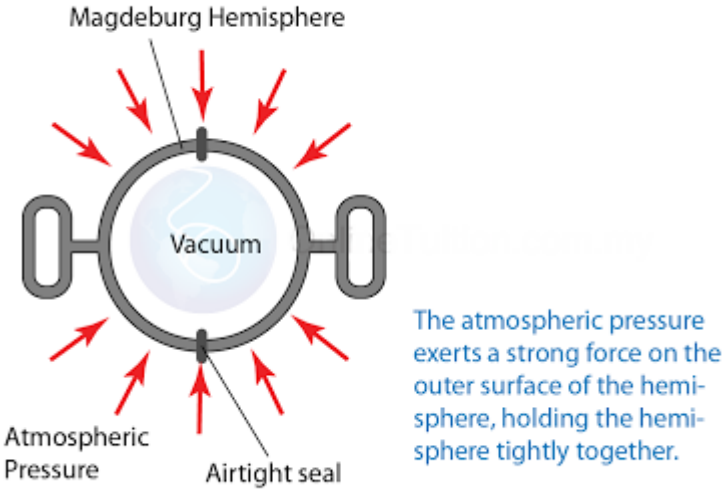


A Plumber's force cup pushed against a blackboard

A Plumber's force Cup is pushed against the blackboard. What prevents it from being pulled away?

While drinking through a straw, we suck. This expands the lungs and air passes into them. Since atmospheric pressure inside the bottle is greater, the liquid is pushed up through the straw.

Magdeburg Hemisphere

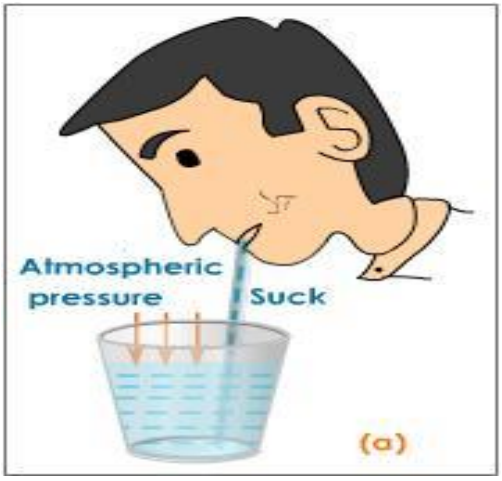


When the air inside the hemisphere is pumped out so that it becomes a vacuum, the hemisphere cannot be separated even by a very great force.

This is because when the air is pumped out, the pressure inside the hemisphere becomes very low. The atmospheric pressure exerts a strong force on the outer surface of the hemisphere, holding the hemisphere tightly together.

Maximum column of liquid that can be supported by atmospheric pressure

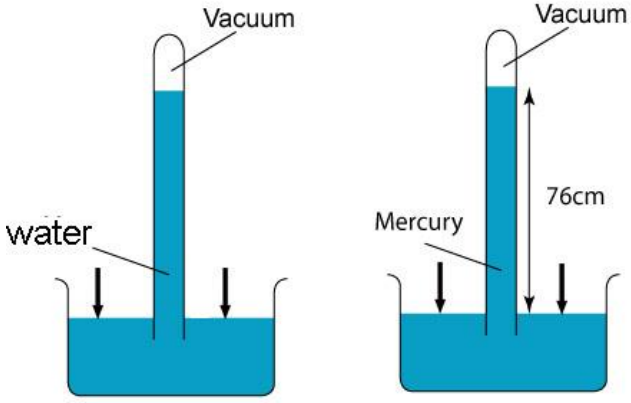
When water is sucked up a straw as in figure 5.46,the air pressure inside the straw reduces



The atmospheric pressure acting on the surface is now greater than the pressure inside the straw. Water is thus pushed up the straw by the atmospheric pressure
If the straw was long enough and sealed at the top, it would be possible to estimate the height of water in the straw that would be supported by the atmospheric pressure.

Figure 5.46

A more convenient method is to use a glass tube sealed at one end, as in figure 5.47 (a)



Fill glass tubes of different lengths completely with water and invert them in a water reservoir. You will realize that the water column can be very large, infect too large for your available apparatus to accommodate

However, if the mercury ,which is much denser than water is used ,the column supported is found to be much shorter ,see figure 5.47(b) in this figure ,the mercury column in the tube exerts pressure at point B for the height of this column to remain constant ,there must be a counter pressure to hold it up ,this counter pressure is provided by the atmosphere .at sea level the atmospheric pressure supports approximately 76 cm of mercury column or approximately 10m of water column

Example 7

A girls in a BVTC school situated in the coast region (sea level) plants to make a barometer using sea-water of density 1030kgm^{-3} if the atmospheric pressure is 103000Nm^{-2},what is the minimum length of the tube that she will require ?

Solution

Pressure in liquids is given by P=hpg

But p is atmospheric pressure

Therefore hpg =atmospheric pressure

h x10330 x 10 =103000 so h =$\frac{103000}{10300}$=10m

Example 8

A sea diver is 35 m below the surface of sea water,if the density of the sea water I 1.03g/cm^3 an g=Nkg^{-1}determinethe total pressure on him

Solution

But the total pressure is =atmospheric pressure +liquid pressure

$=P_{A+}\ hpg$

10300+(35x1030x10)Nm^{-2} =463500Nm^{-2}

Example 9

The air pressure at the base of mountain is 75.cm of mercury while at the top it is 60 cmof mercury given that the average density of air is 1.25kgm^{-3}nd the density of mercury is 136000kg/m^{3}calculate the height of the mountain

Solution

Pressure difference due to column of air = pressure difference due to

(Height of mountain = mercury column

$H_a p_a g = h_m p_m g H_a = \frac{75.0-60.0}{125x10} = 1632m$

The height of the mountain is 1632

Exercise 5.4.3

Explain why is a the big difference between height of water and the mercury column that can be supported by atmospheric pressure

The barometric height at sea level is 76cm of mercury while that at point on a high land is 74cm of mercury ,what is the altitude of point?(take g =10N/kg,the density of the mercury is 136000kgm^{-3}and density of air is 1.25kgm^{-3}

What is mean by barometer liquid? give an example of one such liquid starting its properties?

A student were in a place where the mercury barometer reads 75cm wanted to make an alcohol barometer ,if alcohol has a density of 800kgm^{-3}what is the minimum length of the tube that could be used ?

Measurement of pressure

U-tube manometer

A manometer is an instrument that is used to measure fluid pressure it consist of u-tube filled with water or any suitable liquid see figure 4.19

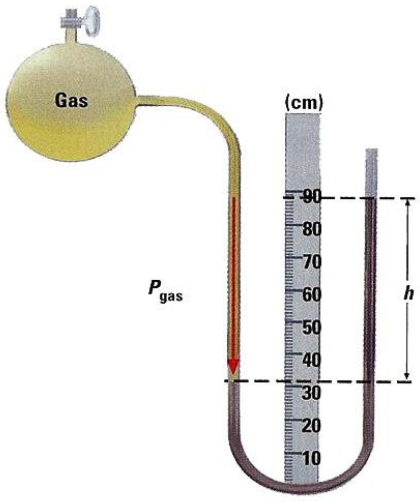


Fig 5.48.measurement of gas pressure

Suppose one limp of the manometer is connected to a gas supply, due to pressure of the gas P_g the water level in the other limp rises to Y, the difference in water levels is the difference between gas pressure P_g and the atmospheric pressure P_a
Since X and Z are the same horizontal level pressure at X equals pressure at Z pressure at X is a pressure of gas P_g
Pressure at Z= atmospheric pressure +pressure due to the column of water
Therefore, $P_g=P_a+hpg$
Since density of water, p and are know, we can determine pressure of gas if the atmospheric pressure is known
Suppose h =20.0cm and $p_a=103000Nm^{-2}$ then taking the density of water as $1000kgm^{-2}$
$P = 103000 + 0.20 \times 1000 \times 10 = 105000\ Nm^{-2}$
Mercury barometer
It has been shown that atmospheric pressure a liquid column in a tube, when this arrangement is used to measure pressure, it is called a barometer
At sea-level a column of mercury and water supported by atmospheric pressure is approximately 76cm and 10 m respectively atmospheric pressure measurement since it gives a much shorter and measurable column

Construction
A thick –walled glass tube of about one meter long and sealed at one end is used
It is carefully filled with mercury to the top and any bubbles of air in the tube removed by closing the open end and investing it severally .it is necessary to remove the bubbles because they make the barometer defective the tube is refilled and the open end closed tightly .it is then inverted into a dish filled with mercury and supported upright with a stand and clamp see fig 5.49 the tightly closed end is then opened while under the surface of mercury .the column of mercury in the tube drops to create a vacuum in the space above the column

The height h of the column is a measure of the atmosphere pressure at sea level, h=76 cmHg

Since density p of mercury is $13600\ kgm^{-3}$
$P_a=hpg = 0.76 \times 13600 \times 10 = 103360Nm^{-2}$
This is the standard atmospheric pressure and it sometimes referred to as one atmosphere

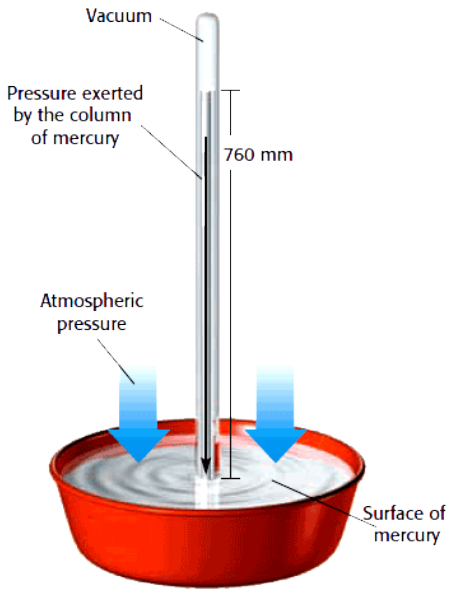


Fig 5.49 barometer

Testing the vacuum in a barometer
If the barometer has air at the top, then its faulty the value of pressure indicates by such a barometer is less than the actual value since the trapped air also exerts pressure on the mercury column

To test for the vacuum the table is tilled as shown in figure 5.50

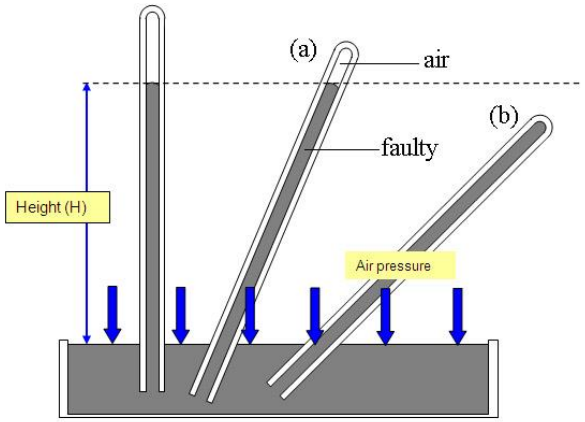
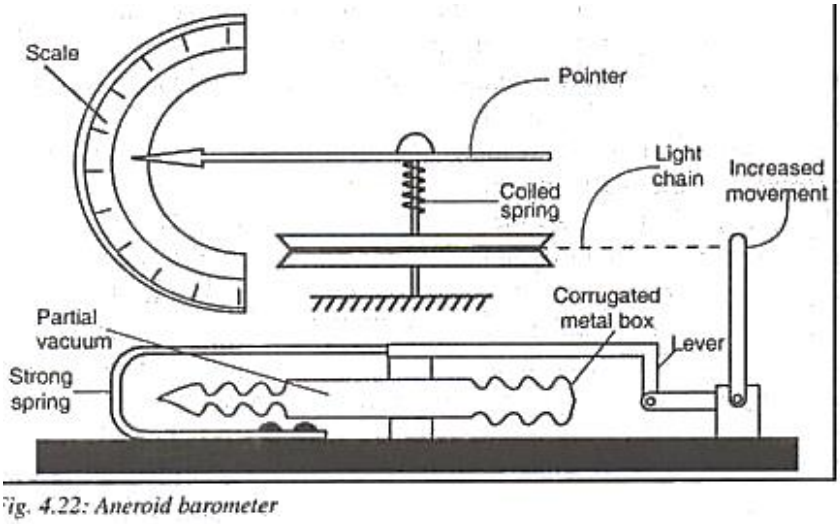


Figure 5.50

If there is air in the tube, the mercury will not fill the tube completely. However, if the space is a vacuum, the mercury fills the tube completely. The space above the mercury in the tube when upright is called Toricelian vacuum and contain a little mercury vapor

Aneroid Barometer

The mercury barometer is the most reliable type of barometer, but is not readily portable.
The aneroid barometer is a portable type of barometer consisting of a sealed, corrugated metal box, as shown in figure 4.22 this metal box expands a little if pressure outside is reduced, and reduces in volume a little if subjected to higher pressure from outside. The motion due to the changes in the shape of the metal box is magnified by the corresponding movements of the spring strips, lever arm, chain and finally the pointer on the scale



ig. 4.22: Aneroid barometer

fig:5.51 Aneroid barometer

Normally, the pointer would indicate a particular value of the atmospheric pressure of the surrounding so that any changes in pressure would be noticeable by the movement of the pointer to either side of this atmospheric value on the scale

The aneroid barometers movements make it adaptable to measure heights. Altimeters are basically aneroid barometers, and are used in aircrafts to measure heights
The aneroid barometer is normally calibrated in millibars.1bar is a pressure of100000Nm^{-2} (standard atmospheric pressure)
1millibar (mbar)$\frac{100000}{1000}$ =100Nm^{-2}

Pressure Gauges
Pressure gauges are portable and are used mostly for measuring gas pressure, tyres pressure, pressure of compressed air in compressors and steam pressure
They are basically made of coiled flexible metal tubes which uncoil when the pressure inside increases. The movement of the tube is made to drive a pointer across a scale ,through a combined system of levers and gears see figure 5.52

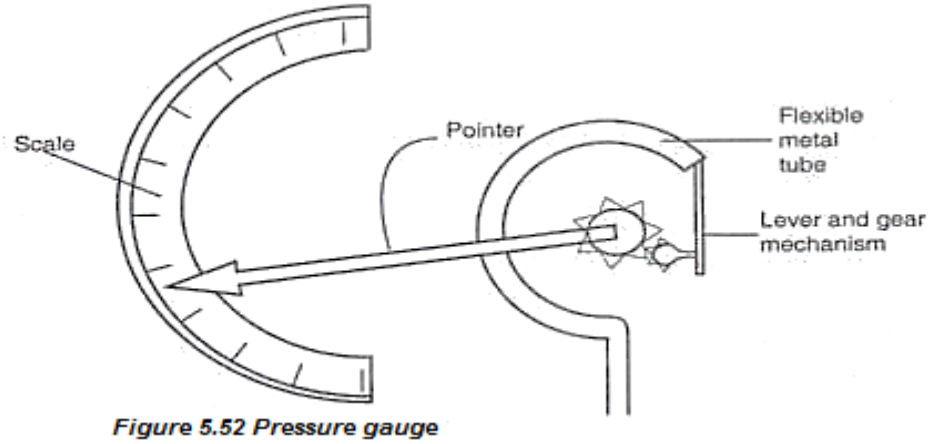


Figure 5.52 Pressure gauge

Example 10
The pressure of car tyres, measured with a pressure gauge, is 40N/cm^2
What is the total pressure of the tyres in Nm^{-2}
Solution
Total pressure=Atmospheric *pressure+gauge* pressure
=103360+(40×10000)
=103360+400000
=503360N/m^2
Applications of pressure in gases and liquids
The bicycle pump
Bicycle pump is a simple form of a compression pump figure 5.53 shows the main parts of the pump

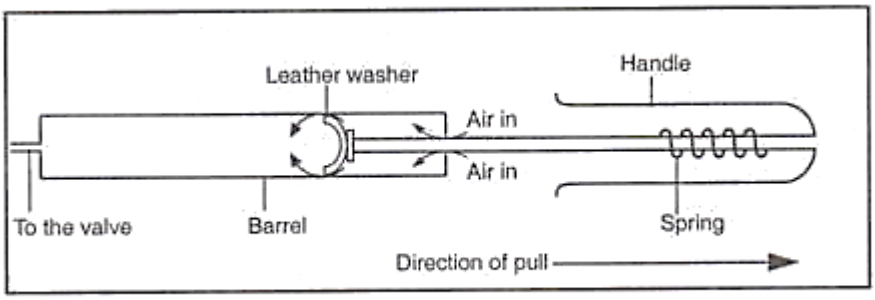


Figure 5.53 Bicycle pump

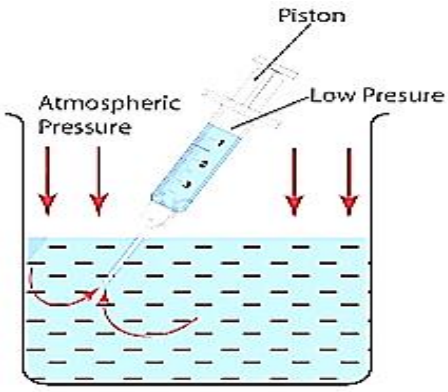
It has a flexible leather washer which works both as a valve and a piston inside the pump barrel. Before the pump is used, it is connected to a tyre which has a rubber valve in it.

When the pump handle is drawn out as shown, air below the washer expands and its pressure is reduced is reduced below the atmospheric pressure. Air from outside the pump then flows past the leather washer into the barrel. At the same time, the higher air pressure in the tyre closes the tyre valve. When the pump handle is pushed in, the air in the pump barrel is compressed. The high pressure in the barrel presses the leather washer against the sides of the barrel. When the pressure of the compressed air becomes greater than that of air in the tyre, air is forced into the tyre through the tyre valve which now opens.

Now that there is an increase in temperature of the pump barrel during pumping. This is because of the work done in compressing air

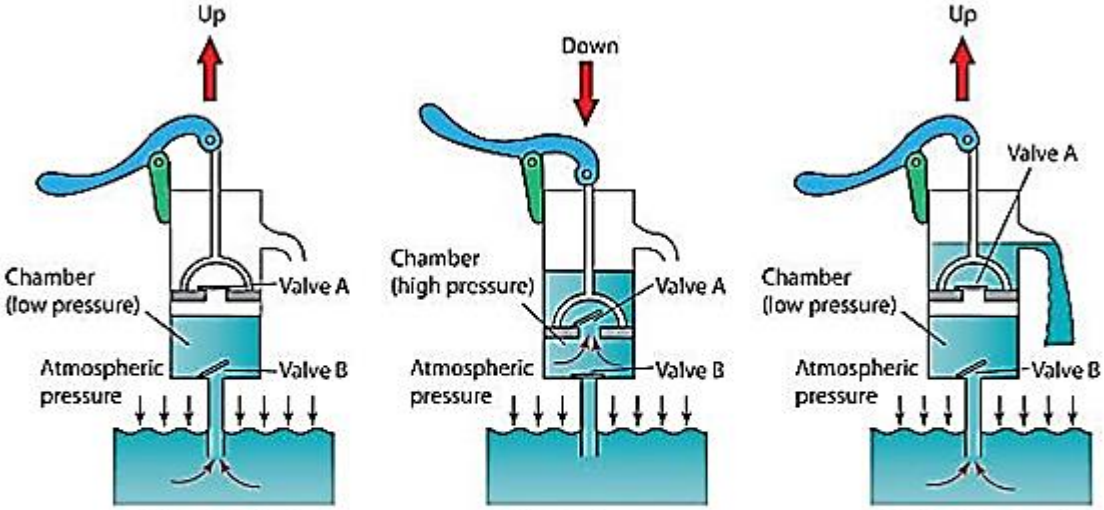
Applications of Atmospheric Pressure

Syringe



When the piston is pulled up, the atmospheric pressure inside the cylinder will decrease. The atmospheric pressure outside pushes the liquid up into the syringe.

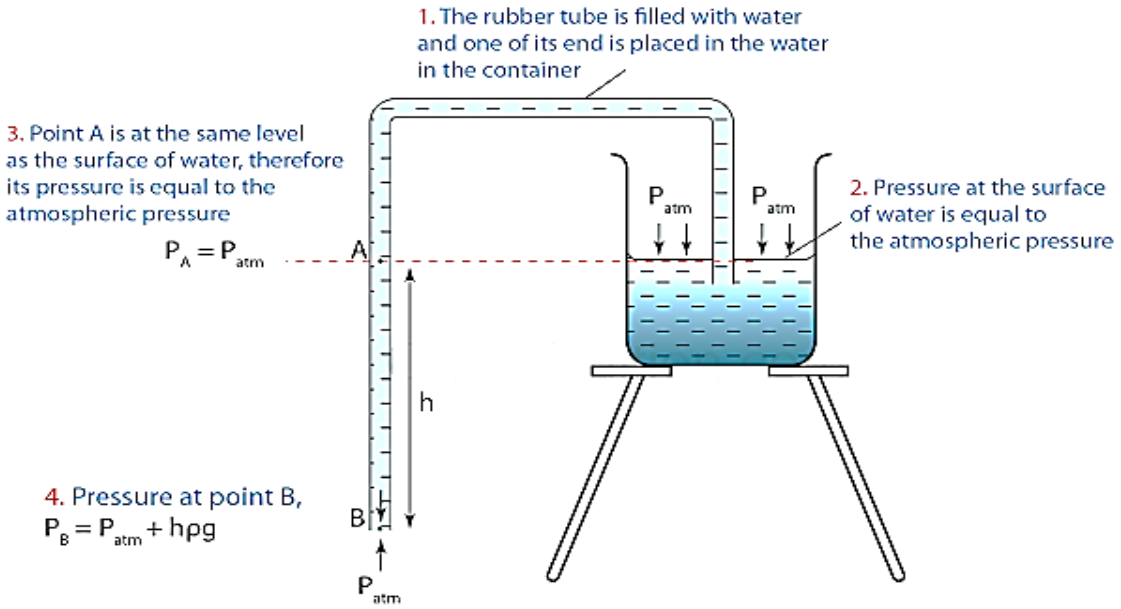
Lift Pump



1. Valve A is closed, valve B is open, water is sucked into the lower part of the chamber.

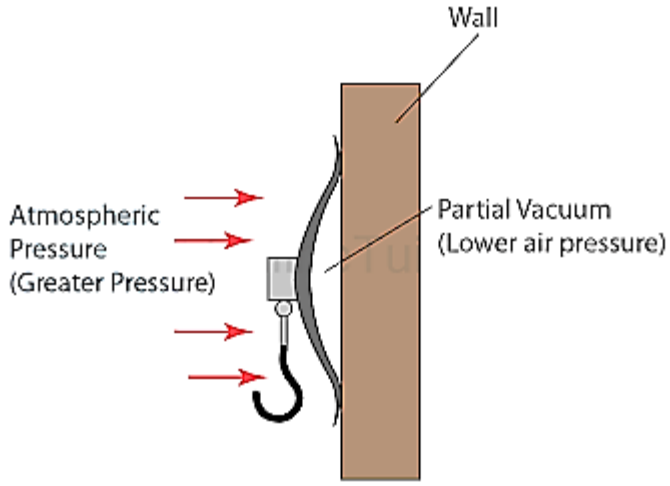
2. Valve A is open, valve B is clode, water is tranfered into the uppper part of the chamber.

3. Valve A is closed, valve B is open, water is sucked into the lower part of the chamber again. At the same time, water flow out of the nozzle



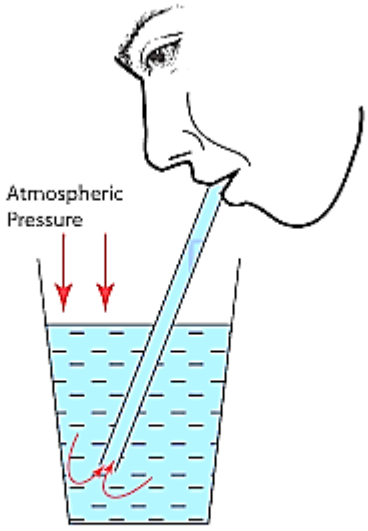
Siphon

Sucker Hook



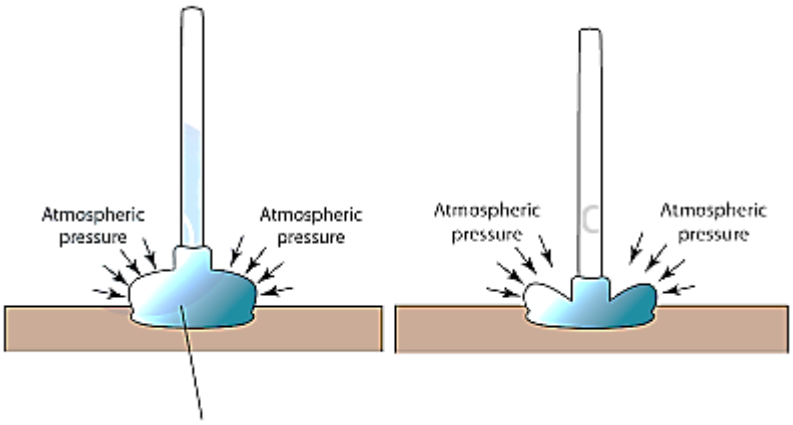
When the sucker is pressed into place, the air inside is forced out. As a result, the pressure inside the sucker become very low. The sucker is then held in position by the high atmospheric pressure on the outside surface.

1. Straw



When a person suck through the straw, the pressure in the straw become low. The atmospheric pressure outside which is higher will force the water into the straw and consequently into the mouth.

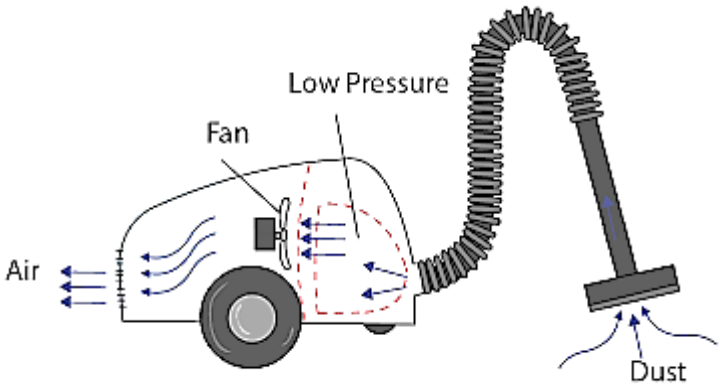
2. Rubber Sucker



Before the plunger is pressed, pressure inside the rubber cup is equal to the atmospheric pressure

After the plunger is pressed down, the pressure inside the rubber cup is lower than the atmospheric pressure. The high atmospheric pressure will hold the plunger in its position.

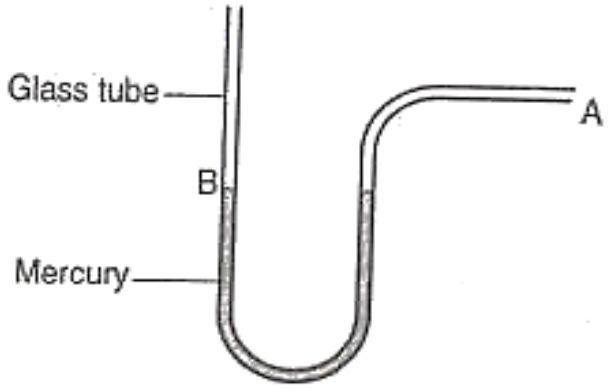
3. Vacuum Cleaner



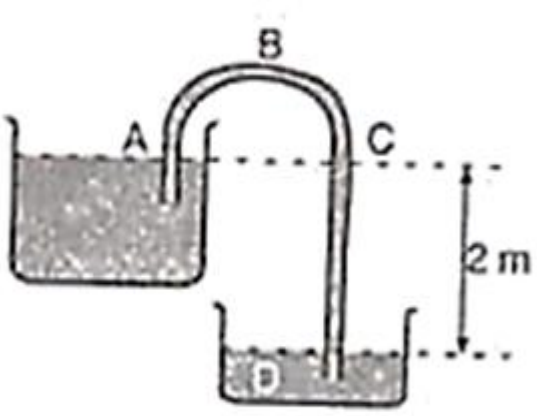
When a vacuum cleaner is switched on it sucks out air inside the cleaner, causes the pressure inside the cleaner very low. The atmospheric pressure which is higher in magnitude, forces the air and dust particles get into the cleaner.

Revision exercise 5.4.4

1. Define pressure and state its nit.
2. Explain how a fountain pen is filled up with ink.
3. The atmospheric pressure on particular day was measured as 750mmHg. Express this in Nm^{-2}. (assume density of mercury is $13600kgm^{-3}$ and $g=10\ nkg^{-1}$)
4. In a hydraulic press, a force of 200 N is applied to master piston of area $25cm^2$. If the press is designed to produce a force of 5000N, determine:
   a. The area of the slave piston.
   b. The radius of slave piston.
5. The barometric height in town is 70cmHg. Give the standard manometer pressure is 76cmHg and density of mercury is 13 600 kg^{-3}, determine the altitude of tow.(density of air $125kg^{-3}$)
6. Height of water thermometer is 20cm when used to measure the pressure of gas. What would be height of manometer whose liquid is glycerin of density $1.26g/cm^3$? (Take $g=10Nkg^{-1}$).
7. explain how the pressure of gas can be examined using the apparatus show in figure below:

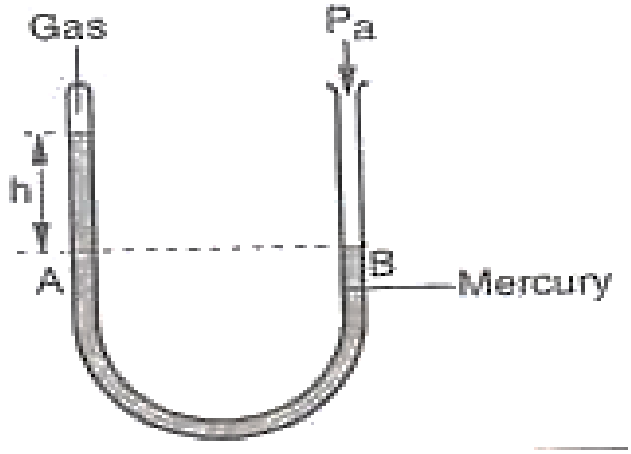


8. the figure below shows how to empty water from a large tank into a low-lying container tubing:

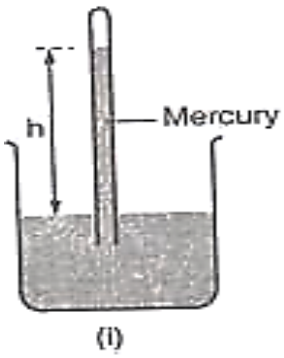


(a) Explain why the tube must be filled with water before the emptying process starts.
(b) Soon after the tank begins to empty, the lower end is momentarily blocked by placing a figure at end. Determine the pressure difference between point A and D. (take density of water to be 1000kgm^{-3})

9. The diagram below shows a mercury monometer. Some dry gas is present in the closed space in limb A, while limb B is is open. If atmospheric pressure P_a =100000Nm^2, h=20mm density of mercury is 13600kgm^{-3}, determine pressure P_g of the gas in mmHg.
(take g=10nkg^{-1})



10. (a) Explain briefly the principle of a simple mercury barometer.
(b) What test would be made to find out whether such a barometer has any gas in space above the mercury ?
(c) Figure (i) below shows a simple mercury barometer, while figure (ii) shows a same barometer, while from the vertical.



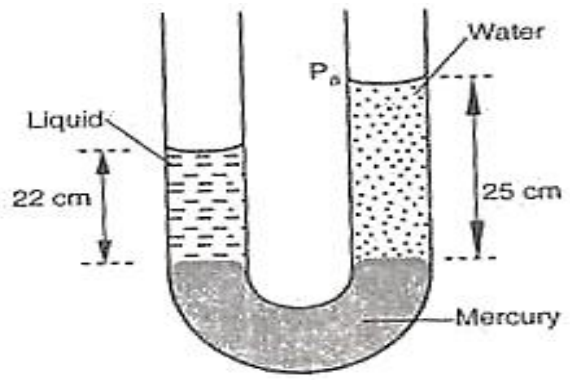
(i)

(ii)

Mark the level of mercury in tube (ii).

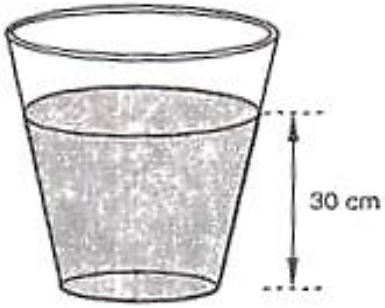
11. the figure below shows a U-tube filled with water, mercury another liquid:

a) Determine the density of liquid .
b) A possible reason why mercury is used.

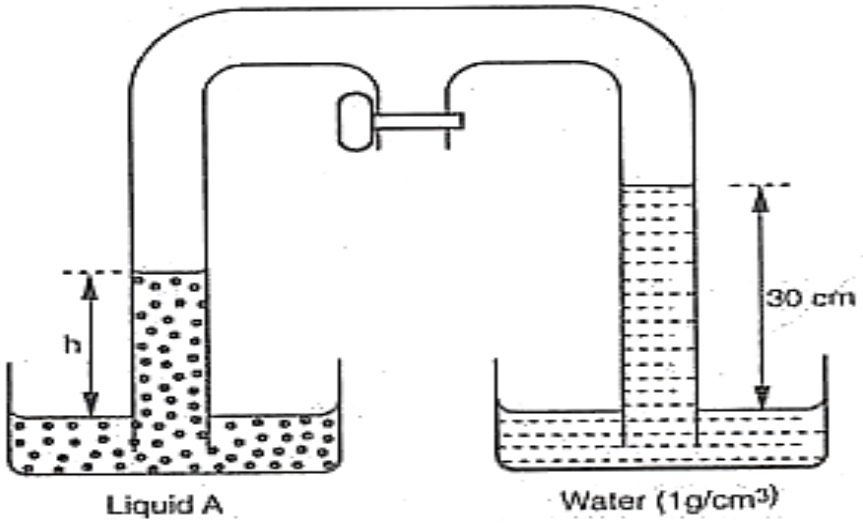


12. The figure right shows a liquid in a pail.

a) If liquid has a density of the 1.20gcm^{-3}, determine the pressure exerted at the bottom of container by liquid.
b) Suggest a reason why pail manufacturers prefer the shape shown to other shapes.



13. The figure below shows two columns of liquids in tube. Determine the height of liquid A if its density is 1.20g/cm^3



14. A roof has surface area of 20000 cm^2 .If the atmospheric pressure exerted on the roof is 100000 Pa, determine the force on it . Take g=10Nkg^{-1}

Floating, Sinking and flying

A ship gets support from the water and floats because its average density is less than that of the water(see chapter 18) Any object in a liquid, whether floating or submerged, is acted on by an upward force or up thrust this makes it seem to weigh less than normal

Archimedes' principle

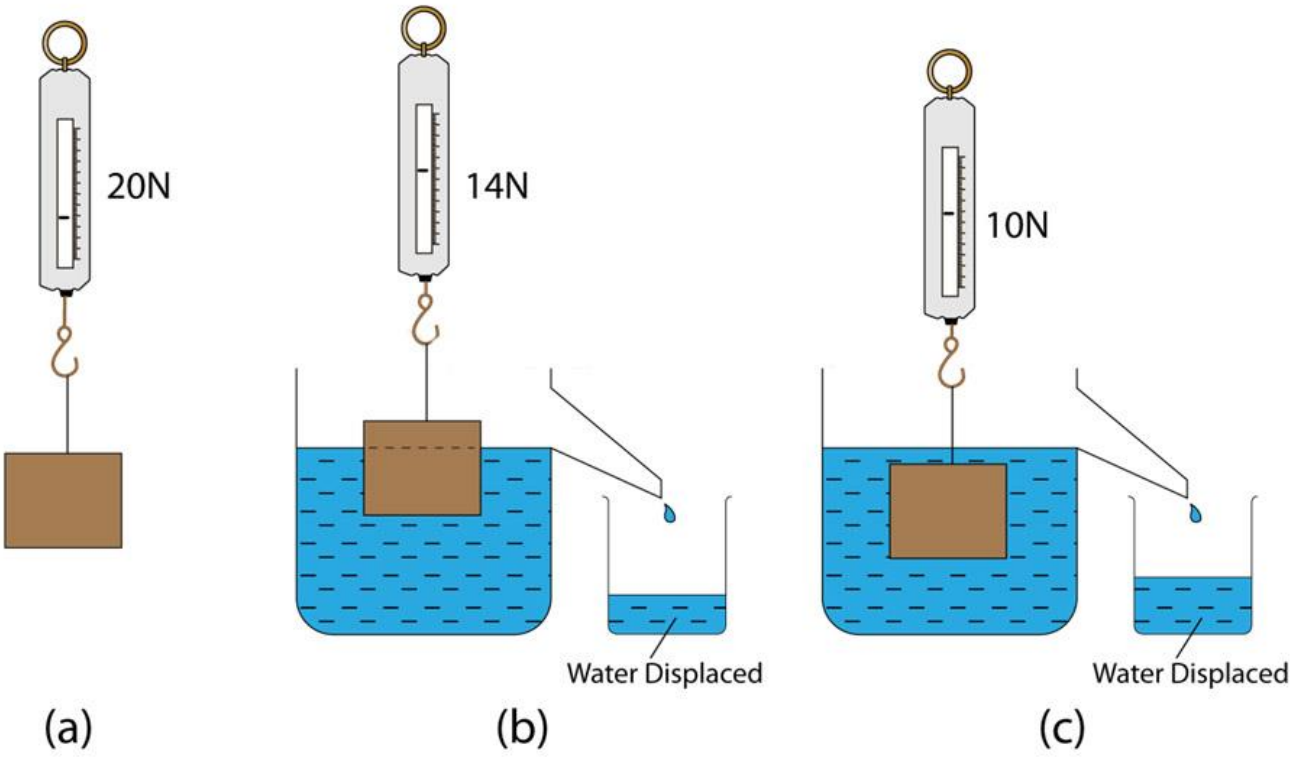
In figure 26.1a the block hanging from the spring balance weighs 10N in air. When it is completely immersed in water the reading becomes 6N, figure 26.1b the loss in weight of the block is 10-6=4N

The upthrust of the water on it is therefore 4N

If a can like that in figure 26.1c is used, full of water to the level of the spout, the water displaced (the overflow) can be collected and weighed .Its weight here is 4N, The same as the upthrust.(Its volume is exactly equal to the volume of the block) Experiments with other liquids and also with gases lead to the general conclusion called **Archimedes' Principle**

When a body is wholly or partly submerged in a fluid the up thrust equals the weight of fluid displaced (i.e. pushed aside)

A fluid means either a liquid or agas. The case of gases will be dealt with later.

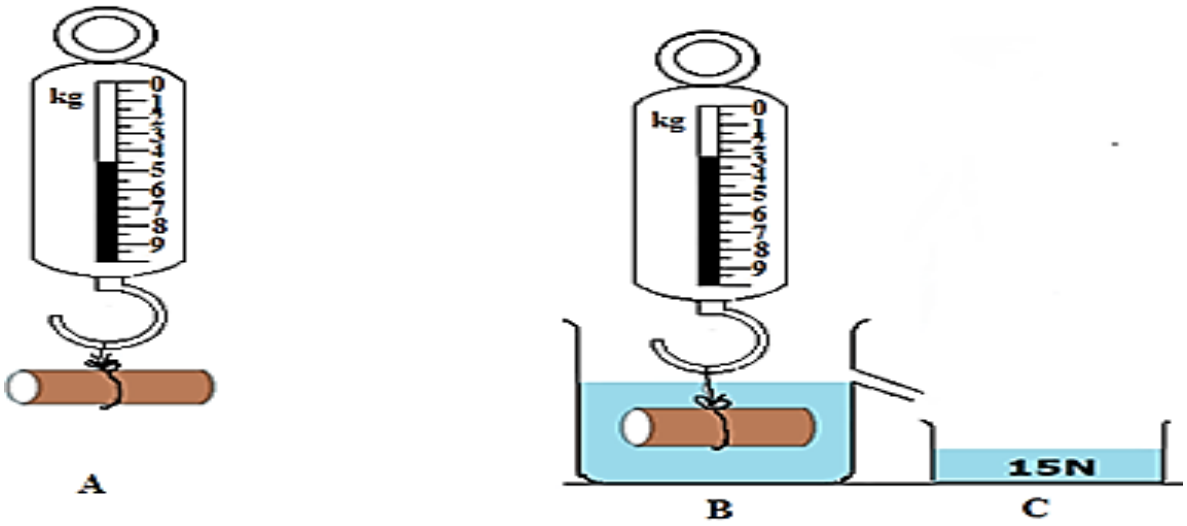


*What is a **buoyant force**?*

*Upthrust force is also known as **buoyant force***

Buoyant force *is an upward force exerted by a fluid to a body which is partially or totally immersed in it and it is equal in magnitude to the weight of fluid displaced by a body.*

Practical activity: to show up thrust is equal to the weight of the fluid displaced



A. is a **real weight** (weight of an object in air) 4.5 N
B. is **apparent weight** (weight of an object in fluid) 3.0 N
C. is **apparent loss of weight** (weight of fluid displaced) 1.5 N

Measuring the weight of displaced fluid is equal to apparent loss of weight; this apparent loss is the buoyancy force on an object which is upthrust.

Conclusion

Apparent loss of weight is equal to the weight of displaced fluid.

Real weight = apparent weight + apparent loss

Since apparent loss is equal to upthrust

Real weight = apparent weight + upthrust

Up thrust =real weight – apparent weight.

Example1.

A body weighs 5.5 N when measured in air and 3 N when completely immersed in kerosene, what is upthrust experienced by a body.

Solution

Weight of body in air (Real weight) =5.5 N

Apparent weight of a body when immersed in kerosene = 3 N.

But upthrust = real weight – apparent weight loss

Upthrust = 5.5 N – 3 N = 2.5 N.

Example2.

A body weighs 3 N when totally immersed in water contained in an overflow can, if weight of displaced water was 2.6 N, what is the real weight of an object.

Solution

Apparent weight = 3 N

Upthrust = 2.6 N (according to Archimedes' principle)

But

Upthrust = real weight – apparent weight

2.6 N = Real weight – 3 N.

Real weight = 2.6 N + 3 N= 5.6 N.

Example 3

A metal block of density 2500kgm^{-3}occupies a volume of 0.1m^{3}. Find

a) The weight of the metal

b) The apparent of the block when immersed in water of density of 1000kgm^{-3}

Answer

a) Mass = density x volume weight = mg

= 2500 x 0.1 = 250 x10

= 250kg = 2500N

b) Apparent weight loss = upthrust on metal block

= weight of water displaced

= volume x density x g

= 0.1 x 1000x10

= 1000N

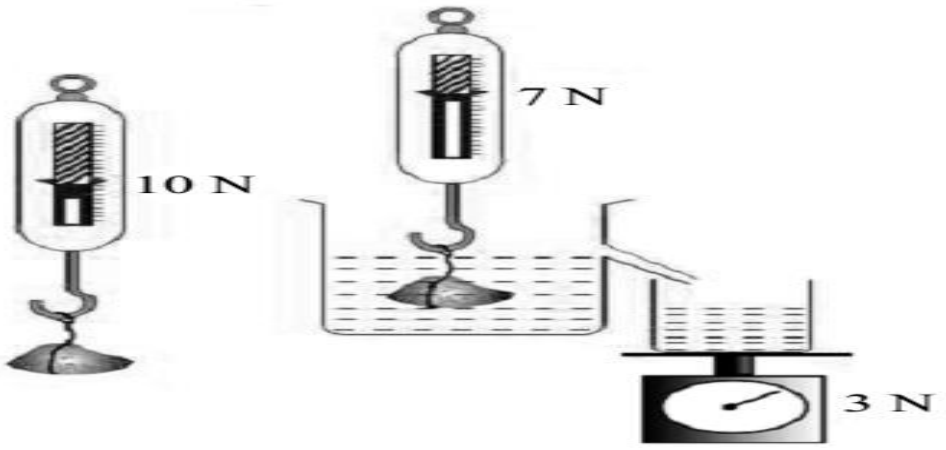
Weight of the metal in water = 2500 – 1000

= 1500N

Exercise

(a) State Archimedes' principle.

(b) The diagram shows the reading on a Newton balance for an object suspended in air and in a liquid.



The weight of the liquid displaced is also shown on a balance.

What is the up thrust force on the object caused by the liquid?

Will the object float in the liquid if released? Explain your answer.

Out in the open sea the ship comes to rest.

Draw a labeled diagram showing the vertical forces acting on the ship as it floats at rest in the water.

(i) Explain why the ship floats.

A block of granite has a volume of 0.2 m^3. It is resting on a hard, flat surface at the bottom of a lake. Using density of granite = 2700 kg/m^3, density of water =1000 kg/m^3 and g = 10 ms^{-2}.

What is the weight of the block

What is the weight of water is displaced by the block

What is the up thrust force on the block

What is the minimum upward force needed to lift the block clear of the bottom

Floating

a stone held below the surface of water sinks when released, a cork rises, The weight of the stone is greater than the upthrust on it(i.e. the weight of water displaced) and there is a net or resultant downward force on it, figure 26.2a if the cork has the same volume as the stone, it will displace the same weight (and volume) of water. The upthrust on it is therefore the same as for the stone but it is greater than the weight of the cork. The resultant upward force on the cork makes it rise

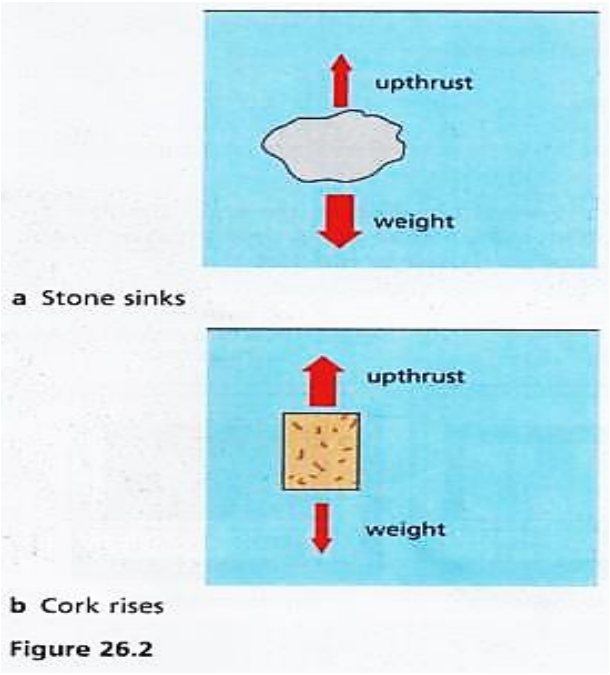


Figure 26.2

When a body floats in water the upthrust equals weight of the body. The net force on the body is zero. this is a case of the principle of floatation

A floating body displaces its own weight of fluid

For example a floating block of wood of weight 10N displaces an amount of water (or any other liquid in which it floats)having weight 10N

Ships, submarine, balloons

Ships

A floating ship displaces a weight of water equal to its own weight including that of the cargo. The load lines <called the plimsoll mark > on the side of a ship show how low in the water it can lie and be safely and legally loaded under different conditions, figure 26.3

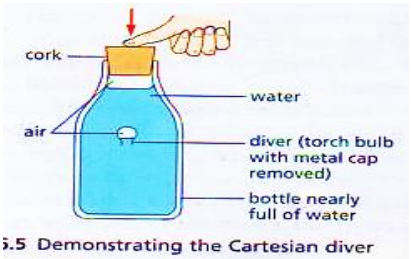
3 Simplified Plimsoll mark

Why is it allowed to take a greater load in summer than in winter

submarine

A submarine figure 26.4 sinks by taking water into its buoyancy tanks once submerged the upthrust is unchanged but the weight of the submarine increases with the inflow of water and it sink faster .to surface ,compressed air is used to blow the water out of the tanks

5.4 A submarine



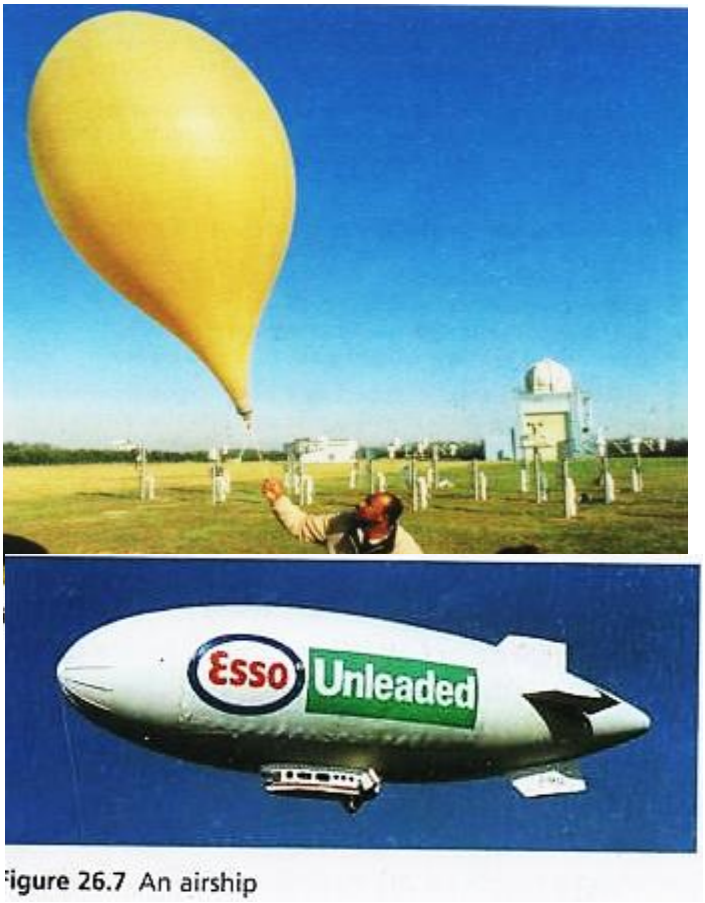
5.5 Demonstrating the Cartesian diver

In the Cartesian diver, figure 26.5 pressure on the cork forces more water into the bulb, the diver's weight increases and it sinks ,decreasing the pressure causes it to rise

c) Balloons

A balloon filled with hydrogen or hot air weighs less than the weight of air it displaces. The upthrust is therefore greater than its weight and the resultant upward force on the balloon causes it to rise.

Meteorological balloons, figure 26.6 carrying scientific instruments called radiosondes are sent into the upper atmosphere. A small radio transmitter sends signals back to earth which contain information about the temperature pressure and humidity. They are tracked by radar to give data on wind direction and speed



igure 26.7 An airship

d) Airship

An airship such as that in figure 26.7 has a plastic gas bag filled with non-flammable helium (a gas less dense than air) it is powered by two car engines which drive swiveling propellers to provide vertical thrust for takeoff and landing and horizontal thrust for forward motion. It can climb at about 700 meters a minute, cruise sedately at 80km per hour(50kmp) and travel 1600km(1000miles) on just 550 liters(120 gallons) of fuel

Airships are used for aerial surveys, photography and advertising

Fluids in motion

Introduction

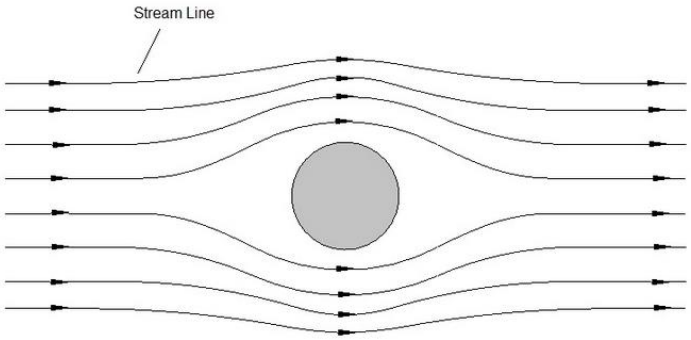
Fluid is a state of matter, such as liquid or gas, in which the particles can move past one another. Fluids flow easily and conform to the shape of their containers.

There are many occasions in everyday life when fluids have to flow through pipes or when objects such as air craft have to move through the air. A knowledge of understanding of fluid flow is necessary to ensure that these processes occur naturally and it is an important aspect of engineering.

There are two main types of fluid flow: streamline flow and turbulent flow

a. Streamline flow

Streamline flow also called ***laminar*** is a flow of a fluid in which its velocity at any point is constant or varies in a regular manner.

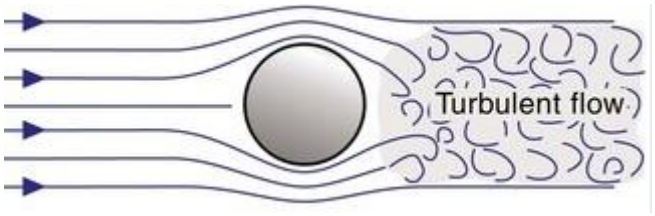


Streamline flow is possible only when the speed of the fluid is low. In streamline flow, each path that the particles follow is called a streamline. No two streamlines can cross each other in standard flow. Another property of streamlines is that the streamline will always be in the same direction as the ***velocity*** of the fluid.

This effect can be seen in wind tunnels

b. Turbulent flow:

If the flow of a fluid is very fast and exceeds a certain critical speed, the flow becomes turbulent and the fluid is churned up. The motions of a fluid in turbulent flow can become irregular and will not always be in the same direction as the velocity. Such motions are called eddy currents.



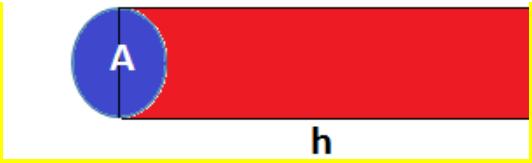
Viscosity

Viscosity is a measure of the degree of internal friction in a fluid. This internal friction is the result of the resistance between adjacent layers of the fluid as they move relative to each other. Viscosity is commonly viewed by the thickness of the fluid, for example maple syrup has a much higher viscosity than water. The SI unit for viscosity is Pascals multiplied by seconds (Pa· s), however it is commonly measured in centipoise (cp)

Equation of continuity

Before describing the equation of continuity we consider the rate of fluid flow which is volume of a fluid flowing through a tunnel per second

Suppose that the fluid is flowing through a pipe or cylinder of cross-sectional area **A** and height **h** as shown in the diagram below.



Rate of fluid flow is the volume of fluid in the cylinder per unit that is:

Rate of fluid flow = $\frac{volume\ of\ fluid}{time}$

Volume of the fluid in the cylinder = volume of the cylinder it self

Volume = cross-sectional area x height

In this case; height of the cylinder is the distance covered by the moving fluid in a certain time

Height = distance = velocity x time

Rate of fluid flow = $\frac{Avt}{t}$ = Av(unit is m^3/s)

Where A = cross-sectional area

V = velocity

$t = ime$

Now consider a fluid in a tube of varying cross-section as shown in diagram c, the mass flow rate is the same in everywhere in the tube.

Let the area of the cross-sections be A_1 and A_2 respectively, and the corresponding speeds of the fluids be V_1 and V_2

Provided there is no leakage in the pipe

The volume of the fluid entering the first cross-section = the volume of the liquid entering the second cross-section

If the

Volume of fluid flowing in each section is given by: volume = area (A) x velocity (V)

Since the density of incompressible fluid is constant, there is conservation of mass in the fluid system.

Therefore: $(mass)_1 = (mass)_2$

Mass = density x volume = $\rho x(Av)$

$\therefore \rho\ (Av)_1 = \rho(Av)_2$

Dividing both sides byρ, we get

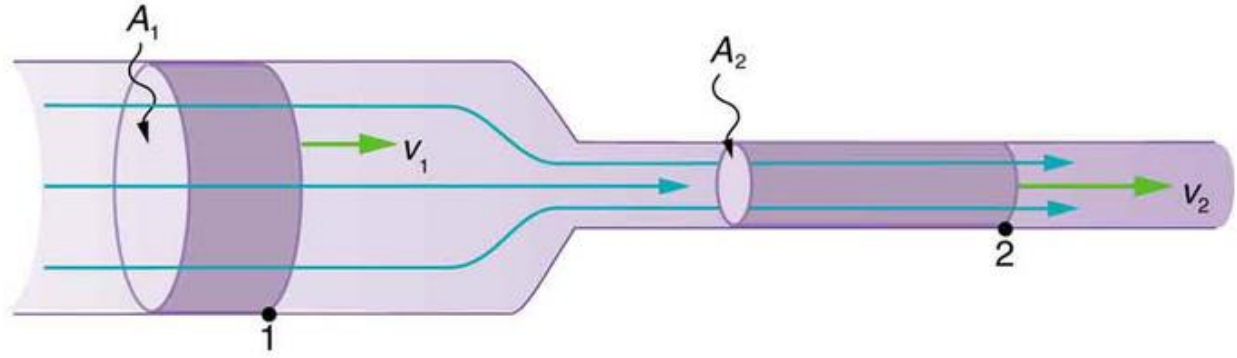
$A_1v_1 = A_2v_2$

A = cross-sectional area

V = velocity

This equation is called equation of continuity

Diagram c: tube with different cross-section



It also proved that cross-sectional area of a tube is proportional to the square of the diameter of the tube: $A = d^2$

So if we replace d in the place of A we get

$$A_1 d_1^2 = A_2 d_2^2$$

Examples

1. Water flows through a rubber hose of 2cm in diameter at a velocity of 4m/s. what must be the diameter of the nozzle in order that the water emerge at 16m/s?

The area is proportional to the square of diameter, so:

$$A_1 d_1^2 = A_2 d_2^2$$

$$d_2^2 = \frac{v_1 d_1^2}{v_2} = \frac{(4\ \text{m/s})(2\ \text{cm})^2}{(20\ \text{cm})^2} \qquad d_2 = 0.894\ \text{cm}$$

2. A sprinkler designed to spray a garden has 300 small holes, each with a cross-sectional area $4x10^{-2}cm^2$. If water is supplied at the rate of $6x10^{-3}m^3/s$, what is the average velocity of the water from each hole of the sprinkler

$A = 4x10^{-2}cm^2$

Volume rate = $6x10^{-3}m^3/s$

Number of holes = 300

Volume rate = Av

$$v = \frac{volume\ rate}{A} = \frac{= 6x10^{-3}}{4x10^{-2}x300} = 5ms^{-1}$$

3. A pipe of uniform cross-sectional area of $1.0 \times 10^{-4}m^2$ and length 5.0×10^{-1} m lets in water from one end to the other in 5 seconds. Calculate the rate of flow of water?

Solution

Volume of water in the pipe = A x l

= 1.0x10-4 m2 x5.0x10-1 m

= 5.0 x 10 -5 m3

Rate of flow of water

$= \frac{volume}{time} = \frac{5.0\ x\ 10-5}{5} =$ 1.0 x 10 $^{-5}$m^3 s^{-1}

4. A pipe of cross-sectional area of 50cm^2 carries water at the rate of 0.2 liters per second. Determine:

i. The speed of water in the pipe

ii. The speed of water when the tube narrows to 20cm^2 at another point.

Solution

Volume rate = 0.2L = 200cm^3/s = 2x10^{-4}m^3

Volume rate = Av

$$v = \frac{volume\ rate}{A} = \frac{2x10^{-4}}{5x10^{-3}} = 0.04 \text{ m/s}$$

From the expression $A_1v_1 = A_2v_2$

$$V_2 = \frac{A_1v_1}{A_2} = \frac{5x10^{-3}x0.04}{2x10^{-3}} = 0.1\text{m/s}$$

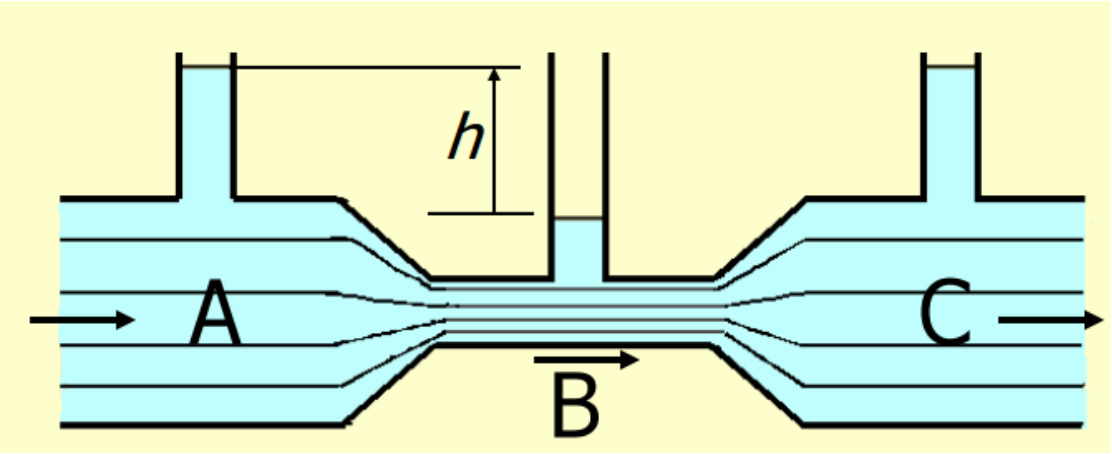
Bernoulli's principle

When the fluid is at rest, pressure is the same at all points in the same level. This is not so when the fluid is moving

Bernoulli's principle states that:

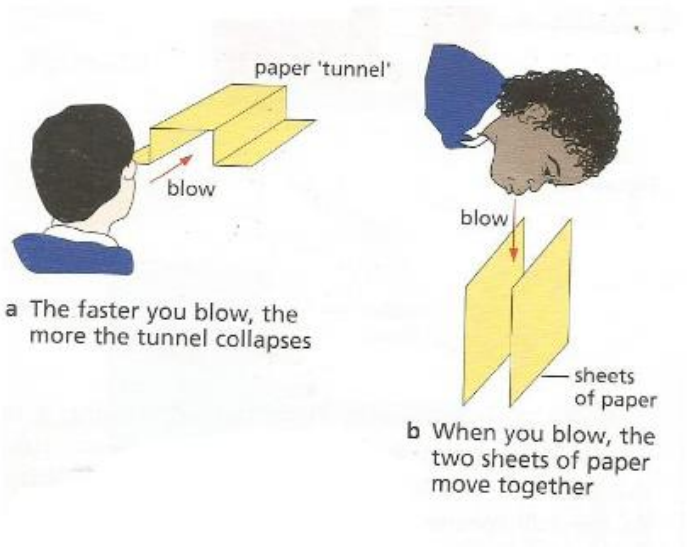
When the speed of a fluid in smooth flow increases, the pressure in the fluid decreases and vice versa

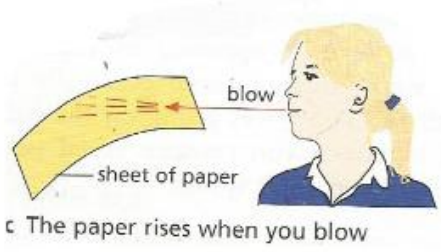
The diagram below shows a liquid flowing through a tube with different diameter. The pressure falls in the narrow part B but rises again in the wider part C. since the same volume of liquid passes through B in a certain time as enters A, the liquid must be moving faster in B than in A. therefore a decrease in pressure occurs when the speed of the liquid increases.



Simple demonstration of Bernoulli's effect

Consider the figure below. In all cases the pressure is lower in the fast moving air stream

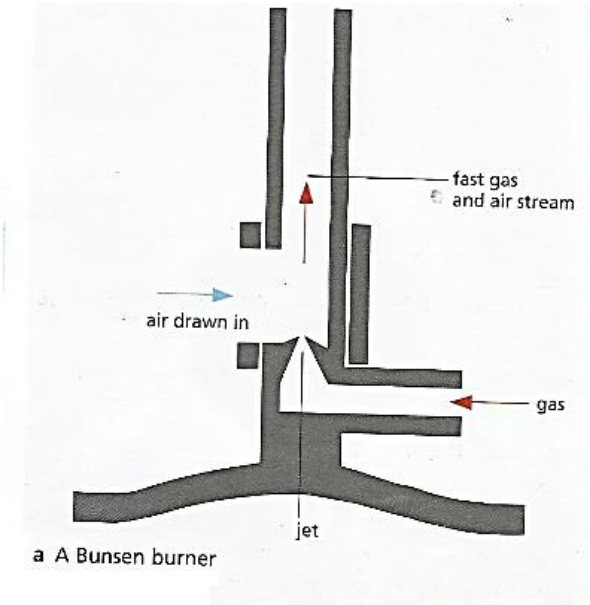


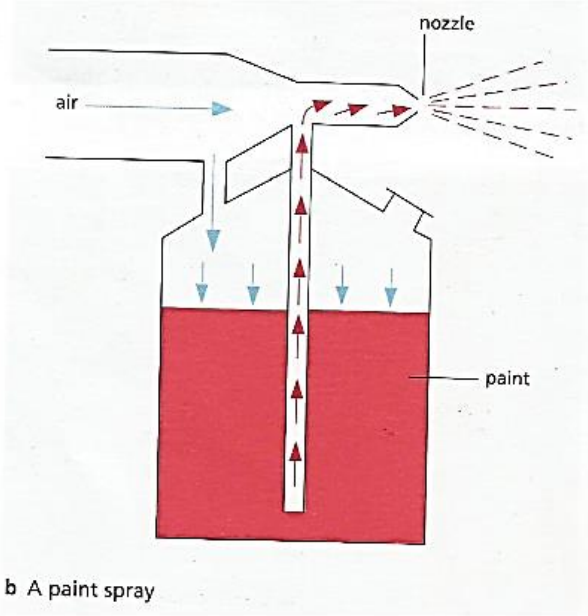


Applications of Bernoulli's effect

a. Jets and nozzles

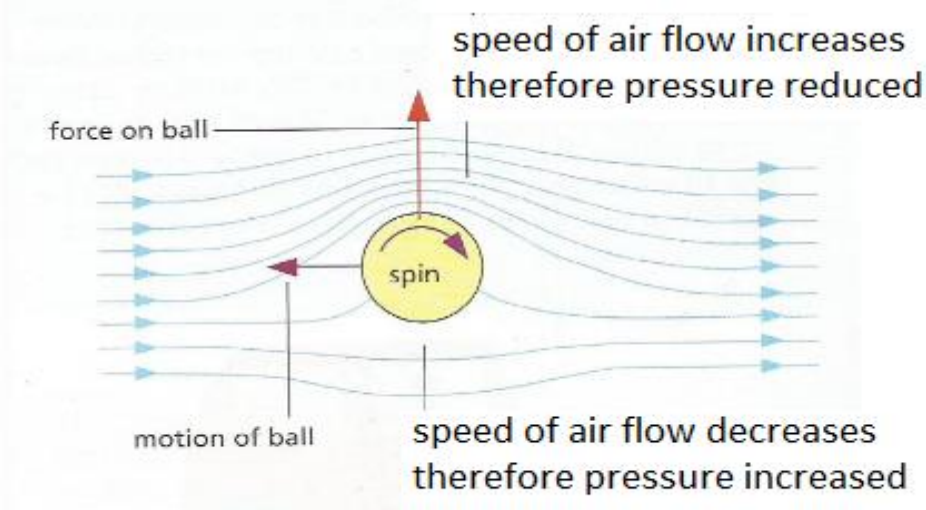
A slow stream of water from a tap can be changed into a fast jet by narrowing the outlet with a finger. The more it is narrowed, the greater is the increase of speed and so the greater of the pressure drop. Several devices with jets and nozzles use this effect. Figure below show the action of bunzen burner and a paint spray.





b. Spinning ball

If a tennis ball is cut or a golf ball sliced it spins as it travels through the air and experiences a sideways force which causes it to curve in flight. This is due to air being dragged round by the spinning ball, thereby increasing it on the other. A pressure difference is created

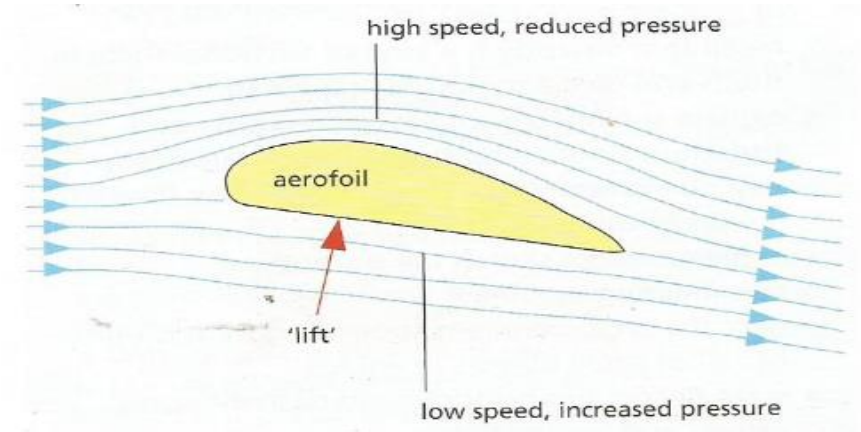


A spinning ball follows a curved path

c. Aero foil

This is a device which is shaped so that when a fluid flows over it, a force is produced at right angles to the direction of flow. Examples of Aero foil are aircraft wings, propellers and turbine blades.

An aircraft wing has a curved upper surface and a flat under surface so that air passing over the top of the wing has to travel further and so faster than over the bottom. This is represented by the streamlines being closer together above than below the Aerofoil, as in figure below. As a result the pressure underneath is increased and that above reduced and the resultant upward force on the wing provides the lift for the aircraft.



When fluid flows over an aerofoil a force is produced at right angles to the flow

The lift increases when the angle between the wing and the air flow called ‘angle of attack’ increases by raising the nose of the aircraft.

Glossary

Absolute humidity (or Saturation value): The maximum amount of water vapor, which could be present in 1 m^3 of the air at any given temperature, is called absolute humidity.

Absolute magnitude: A classification scheme, which compensates for the distance, differences to stars. It calculates the brightness that stars would appear to have if they were all at a defined, standard distance of 10 parsec

Absolute scale: Temperature scale set so that zero is at the theoretical lowest temperature possible. This would occur when all random motion of molecules has ceased

Absolute zero: The theoretical lowest temperature possible, which occurs when all random motion of molecules has ceased

Amplitude (of waves): The maximum displacement of particles of the medium from their mean positions during the propagation of a wave is called the amplitude of the wave.

Amplitude (of an oscillation): The maximum displacement of a body from its mean position during an oscillatory motion is called the amplitude of oscillation.

Angle of incidence: Angle of an incident (arriving) ray or particle to a surface; measured from a line perpendicular to the surface (the normal)

Angle of reflection: Angle of a reflected ray or particle from a surface; measured from a line perpendicular to the surface (the normal)

Atom: The smallest unit of an element that can exist alone or in combination with other elements

Axis: The imaginary line about which a planet or other object rotates

Balanced Forces: When a number of forces act on a body, and the resultant force is zero, then the forces are said to be resultant forces.

Barometer: An instrument that measures atmospheric pressure, used in weather forecasting and in determining elevation above sea level

Blackbody radiation: Electromagnetic radiation emitted by an ideal material (the blackbody) that perfectly absorbs and perfectly emits radiation

Boiling point: The temperature at which a phase change of liquid to gas takes place through boiling. It is the same temperature as the condensation point

Boundary: The division between two regions of differing physical properties

Celsius scale of temperature: In the celsius scale of temperature, the ice-point is taken as taken as the lower fixed point (0 deg C) and the steam-point is taken as the upper fixed point (100 deg C). The interval between the ice point and steam point is divided into 100 equal divisions. Thus, the unit division on this scale is 1degC. This scale was earlier called the centigrade scale. 1 deg C = 9/5 deg F.

Coefficient of cubical expansion: The increase in volume of a substance per unit original volume per degree rise in temperature is called its coefficient of cubical expansion. The SI unit of coefficient of cubical expansion is K-1.

Coefficient of linear expansion: The increase in length per unit original length per degree rise in temperature is called the coefficient of linear expansion. The SI unit of the coefficient of linear expansion is K-1.

Compression: A part of a longitudinal wave in which the density of the particles of the medium is higher than the normal density is called a compression.

Compressive stress: A force that tends to compress the surface as the earth's plates move into each other

Condensation (sound): A compression of gas molecules; a pulse of increased density and pressure that moves through the air at the speed of sound

Condensation (water vapor): Where more vapor or gas molecules are returning to the liquid state than are evaporating

Condensation nuclei: Tiny particles such as tiny dust, smoke, soot, and salt crystals that are suspended in the air on which water condenses condensation point the temperature at which a gas or vapor changes back to a liquid

Condensation point: the temperature at which a gas or vapor changes back to a liquid

Conduction: The transfer of heat from a region of higher temperature to a region of lower temperature by increased kinetic energy moving from molecule to molecule

Convection: Transfer of heat from a region of higher temperature to a region of lower temperature by the displacement of high-energy molecules-for example, the displacement of warmer, less dense air (higher kinetic energy) by cooler, denser air (lower kinetic energy)

Conventional current: Opposite to electron current-that is, considers an electric current to consist of a drift of positive charges that flow from the positive terminal to the negative terminal of a battery

Crest: The point of maximum positive displacement on a transverse wave is called a crest.

Cycle: A complete vibration

Diffraction: The bending of light around the edge of an opaque object

Diffuse reflection: Light rays reflected in many random directions, as opposed to the parallel rays reflected from a perfectly smooth surface such as a mirror

Electromagnet: A magnet formed by a solenoid that can be turned on and off by turning the current on and off

Fahrenheit scale of temperature: On the Fahrenheit scale, the ice point, the ice point (lower fixed point) is taken as 32? F and the steam point (upper fixed point) is taken as 212 deg F. The interval between these two points is divided into 180 equal divisions. Thus, unit division on the Fahrenheit scale is 1deg F. The temperatures on the Celsius scale and the Fahrenheit scale are related by the relationship, C/100 = (F - 32) / 180. The temperature of a normal healthy person is 37 deg C or 98.6 deg F.

First law of motion: Every object remains at rest or in a state of uniform straight-line motion unless acted on by an unbalanced force

Fluids: Matter that has the ability to flow or be poured; the individual molecules of a fluid are able to move, rolling over or by one another

Force: Force is a push or pull which tends to change the state of rest or of uniform motion , the direction of motion, or the shape and size of a body. Force is a vector quantity. The SI unit of force is Newton, denoted by N. One N is the force which when acts on a body of mass 1 kg produces an acceleration of 1 m/s^2.

Freezing point: The temperature at which a phase change of liquid to solid takes place; the same temperature as the melting point for a given substance

Frequency (of waves): The number of waves produced per second is called its frequency.

Frequency (of oscillations): The number of oscillations made by an oscillating body per second is called the frequency.

Friction: The force that resists the motion of one surface relative to another with which it is in contact. The cause of friction is that surfaces, however smooth they may look to the eye, on the microscopic scale have many humps and crests. Thus the actual area of contact is very small indeed, and the consequent very high pressure leads to local pressure welding of the surface. In motion the welds are broken and remade continually.

Gases: A phase of matter composed of molecules that are relatively far apart moving freely in a constant, random motion and have weak cohesive forces acting between them, resulting in the characteristic indefinite shape and indefinite volume of a gas

Greenhouse effect: The process of increasing the temperature of the lower parts of the atmosphere through redirecting energy back toward the surface; the absorption and reemission of infrared radiation by carbon dioxide, water vapor, and a few other gases in the atmosphere

Heat: Heat is a form of energy, which makes a body hot or cold. Heat is measured by the temperature-effect it produces in any material body. The SI unit of heat is Joule(J).

Incident ray: Line representing the direction of motion of incoming light approaching a boundary

Inertia: The property of matter that causes it to resist any change in its state of rest or of uniform motion. There are three kinds of inertia- inertia of rest, inertia of motion and inertia of direction. The mass of a body is a measure of its inertia.

Intensity: A measure of the energy carried by a wave

Intermolecular forces: Forces of interaction between molecules

Internal energy: Sum of all the potential energy and all the kinetic energy of all the molecules of an object

Joule: Metric unit used to measure work and energy; can also be used to measure heat; equivalent to newton-meter

Kelvin scale of temperature: On this scale, the ice-point (the lower fixed point) is taken as 273.15K and the (the upper fixed point) is taken as 373.15K. The interval between these two points is divided into 100 equal parts. Each division is equal to 1K.

Law of conservation of matter: Matter is neither created nor destroyed in a chemical reaction

Liquids: A phase of matter composed of molecules that have interactions stronger than those found in a gas but not strong enough to keep the molecules near the equilibrium positions of a solid, resulting in the characteristic definite volume but indefinite shape of a liquid

Liter: A metric system unit of volume, usually used for liquids

Longitudinal waves: The wave in which the particles of the medium oscillate along the direction along the direction of propagation of wave is called the longitudinal wave. Sound waves are longitudinal waves.

Magnetic domain: Tiny physical regions in permanent magnets, approximately 0.01 to 1 mm, that have magnetically aligned atoms, giving the domain an overall polarity

Magnetic field: Model used to describe how magnetic forces on moving charges act at a distance

Magnetic poles: The ends, or sides, of a magnet about which the force of magnetic attraction seems to be concentrated

Magnetic reversal: The flipping of polarity of the earth's magnetic field as the north magnetic pole and the south magnetic pole exchange positions

Matter: Anything that occupies space and has mass

Mechanical energy: The form of energy associated with machines, objects in motion, and objects having potential energy that results from gravity

Mechanical wave: The waves, which need a material medium for their propagation, are called mechanical waves. Mechanical waves are also called elastic waves. Sound waves, water waves are examples of mechanical waves.

Melting point: The temperature at which a phase change of solid to liquid takes place; the same temperature as the freezing point for a given substance

Momentum: Momentum is considered to be a measure of the quantity of motion in a body. The momentum of a body is defined as the product of its mass and velocity. Its SI units are kg m /s.

Natural frequency: The frequency of vibration of an elastic object that depends on the size, composition, and shape of the object

Net force: The resulting force after all vector forces have been added; if a net force is zero, all the forces have canceled each other and there is not an unbalanced force

Newton's first law of motion: A body continues in a state of rest or of uniform motion in a straight line unless it is acted upon by an external (unbalanced) force.

Newton's second law of motion: The rate of change of momentum is equal to the force applied OR the force acting on a body is directly proportional to the product of its mass and acceleration produced by the force in the body.

Newton's third law of motion: To every action there is an equal and opposite reaction. The action and reaction act on two different bodies simultaneously.

Normal: A line perpendicular to the surface of a boundary

Origin: The only point on a graph where both the x and y variables have a value of zero at the same time

Oscillatory motion: The to and fro motion of a body about its mean position is called oscillatory motion. Oscillatory motion is also called vibratory motion. Oscillatory motion is periodic in nature.

Period (wave): The time required for one complete cycle of a wave

Periodic wave: A wave in which the particles of the medium oscillate continuously about their mean positions regularly at fixed intervals of time is called a periodic wave.

Physical change: A change of the state of a substance but not the identity of the substance pitch the frequency of a sound wave

Pressure: Defined as force per unit area;

Pulse: A wave of short duration confined to a small portion of the medium at any given time is called a pulse. A pulse is also called a wave pulse.

Rad: A measure of radiation received by a material (radiation absorbed dose)

Radiant energy: The form of energy that can travel through space; for example, visible light and other parts of the electromagnetic spectrum

Radiation: The transfer of heat from a region of higher temperature to a region of lower temperature by greater emission of radiant energy from the region of higher temperature

Real image: An image generated by a lens or mirror that can be projected onto a screen

Reflected ray: A line representing direction of motion of light reflected from a boundary

Reflection: The change when light, sound or other waves bounce backwards off a boundary

Second law of motion: The acceleration of an object is directly proportional to the net force acting on that object and inversely proportional to the mass of the object

Simple Pendulum: A heavy point mass (actually a small metallic ball), suspended by a light inextensible string from a frictionless rigid support is called a simple pendulum. A simple pendulum is a simple machine based on the effect of gravity.

Solenoid: A cylindrical coil of wire that becomes electromagnetic when a current runs through it

Solids: A phase of matter with molecules that remain close to fixed equilibrium positions due to strong interactions between the molecules, resulting in the characteristic definite shape and definite volume of a solid

Steam-point: It is the temperature of steam over pure boiling water under 1 atm pressure. The steam point is taken as the upper fixed point (100 deg C or 212 deg F) for temperature scales.

Temperature: It is a numerical measure of hotness or coldness of a body. According to the molecular model, it is a measure of the average kinetic energy of the molecules of the body. Heat flows from a body at higher temperature to a body at lower temperature.

Thermal Capacity: The quantity of heat required to raise the temperature of the whole body by one degree (1K or 1deg C) is called its thermal capacity.

Thermal Equilibrium: When the two bodies in contact are at the same temperature and there is no flow of heat between them, these are said to be in thermal equilibrium. The common temperature of the bodies in thermal equilibrium is called the equilibrium temperature.

Thermal Expansion: The increase in the size of an object on heating is called thermal expansion.

Thermometer: It is a device used for numerical measurement of temperature. The commonly used thermometer is mercury thermometer.

Third law of motion: Whenever two objects interact, the force exerted on one object is equal in size and opposite in direction to the force exerted on the other object; forces always occur in matched pairs that are equal and opposite

Time Period (of a wave): The time taken by a wave to travel through a distance equal to its wavelength is called its time period. It is denoted by T. Time period of a wave=1/frequency of the wave.

Time Period (of an oscillation): The time taken to complete one oscillation is called the time period of an oscillation. The time period of a pendulum does not depend upon the mass of the bob and

amplitude of oscillation. The time period of a pendulum is directly proportional to the square root of the length and inversely proportional to the square root of the acceleration due to gravity.

Transverse waves: A wave in which the particles of the medium oscillate in a direction perpendicular of the direction of propagation of wave is called the transverse wave. Water waves, light waves and radio waves are examples of transverse waves.

Trough: The point of maximum negative displacement on a transverse wave is called a trough.

Vapor: The gaseous state of a substance that is normally in the liquid state

Vibration: A back and forth motion that repeats itself

Virtual image: An image where light rays appear to originate from a mirror or lens; this image cannot be projected on a screen

Wave mechanics: Alternate name for quantum mechanics derived from the wavelike properties of subatomic particles

Wave motion: The movement of a disturbance produced in one part of a medium to another involving the transfer of energy but not the transfer of matter is called wave motion.

Wave period: The time required for two successive crests or other successive parts of the wave to pass a given point

Wave velocity: The distance traveled by a wave in one second is called the wave velocity. The wave velocity of a wave depends upon the nature of the medium through which it passes.

Wave (mechanical): A periodic disturbance produced in a material medium due to the vibratory motion of the particles of the medium is called a wave.

Wave: A disturbance or oscillation that moves through a medium

Wavelength: The distance between the two nearest points on a wave, which are in the same phase, is called the wavelength of the wave. The distance between two adjacent crests or two adjacent troughs is called its wavelength.

Index

adhesive forces., 12
air resistance, 141
amplitude, 95
amplitude, 105
angle of incidence, 113
angle of reflection, 113
archimedes' principle, 193
arrangement, 5
atmospheric pressure, 178
atoms, 5
attractive force, 16
barometer, 185
beam, 109
bernoulli's principle, 203
bimetallic strip, 26
brownian motion, 7
capillary, 13
capillary action, 13
centre of mass, 154
christain hans oersted, 64
circuit breaker, 76
coefficient of friction, 140
cohesive forces, 12
concave mirror, 120
condensation, 10
conduction, 33
convection, 33
convection currents, 36
convex mirror, 120
crowbar, 150
demagnetised, 50
demagnetization, 62
diamagnetic, 48
diffuse reflection, 113
diffusion, 10
domains, 58
drag forces, 141
drum, 175
dynamic friction, 138
earth's magnetic, 56
electric bell, 75
electric motor, 80
electromagnetic waves, 102
electromagnetism, 64
electromagnets, 71
equilibrium, 99, 146
expansion, 29
ferrites, 50
ferro-magnetic materials., 49
fluid, 36
frequency, 94
friction, 138
fulcrum, 145
gases, 7
good emitters, 39
greenhouses, 40
hard magnetic materials, 49
hydraulic machines, 173
impurities, 18
incident ray, 113
inertia, 132
infrared radiation, 41
iron filings, 65
kinetic energy, 9
land breeze, 38
law of magnetism, 52
lever, 150
light, 110
linear expansion, 22
liquids, 6
longitudinal wave, 103
loudspeaker, 82
loudspeakers, 73
luminous, 109
magnetic field, 52
magnetic field lines, 52, 68
magnetic flux, 54
magnetic force, 52, 57
magnetic materials, 47
magnetism, 47
magnetization, 59
manometer, 183
material medium, 102
matter, 5
mechanical advantage, 151
melting, 9
melting point, 9
meniscus, 13
microphones, 73
mirror formula, 127
moment, 144
motor effect, 77
'neutral equilibrium', 159
neutral point, 56
newton's first law, 131
newton's second law, 136
nonmagnetic, 47
non-magnetic materials, 49
opaque materials, 110
oscillation, 94
parachutist, 142
penumbra., 111
period, 94
periscope, 119
permanent, 73
permanent magnets, 49
permanent magnets, 50
phenomena, 9
plane mirrors, 119
poor absorbers, 39
pressure, 162
properties, 19
radiation, 33, 38
ray., 109
real images, 115
reflected ray, 113
reflection of light, 112
regular reflection, 113
relay, 75
scrap yard cranes, 76
sea breeze, 37
simple pendulum, 95
soft magnetic materials, 49
solar concentrators, 40
solenoid, 68
solids, 6
spherical mirrors, 120
spring oscillator, 99
stability, 157
'stable equilibrium', 159
static friction, 138
streamline, 199
streamlined, 141
surface tension, 16
temperature, 18
temporary magnets, 50
terminal velocity, 141
thermal, 21
thermal expansion, 21
translucent materials, 110
transverse wave, 103
umbra, 111
'unstable equilibrium', 159
unusual expansion, 31
upthrust, 197
vacuum, 38, 41
velocity ratio, 151
virtual images, 115
viscosity, 200
volume, 7
volume expansion, 25
wave, 102
wavelength, 104

References

1. *Keith Johnson (2006**), physics for you**. CHELTENHAM: Nelson thorns Ltd.*
2. *George Bethel and David coppock (1999), **physics first**. New York: Oxford.*
3. *Tom Duncan and Heather Kennett (2001**), GCSE physics**, London: NW1 3BH.*
4. *Dr Micheal Taylor. (1999). **MACMILLAN PHYSICS**. Nairobi: Longman publishing printer.*
5. *M Bunguswa and C Obara (2006), **Longman KCSE revision**, Nairobi: Longman Kenya.*
6. *David Sang and Keith Gibbs and Robert Hitchings (2006), **physics 1**. Cambridge: Cambridge university press*
7. *Stephen pople (2007), complete physics IGCSE, New York: Oxford*
8. *David sang, Keith Gibbs and Robert Hutchings (2000**), physics 1**. Cambridge: Cambridge university press.*
9. *Ken Dobson (1999). **The physical world**. London: WC1E7DP.*
10. *Jim Breithaupt and Ken Dun (1995**). A-level physics**. London: W128AW.*
11. *Mukabi Murigi, Agnes Ngure and Githiri john (2007**): Golden tips physics KCSE.** Nairobi: Macmillan Kenya publishers.*
12. *Sisay Hailu and Yonas Nibret (1998). **Physics grades 7-8.** Addis-Ababa: Aster Nega publishing interrise.*