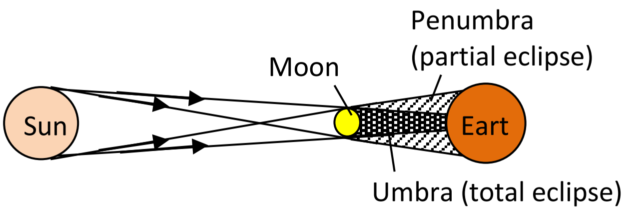
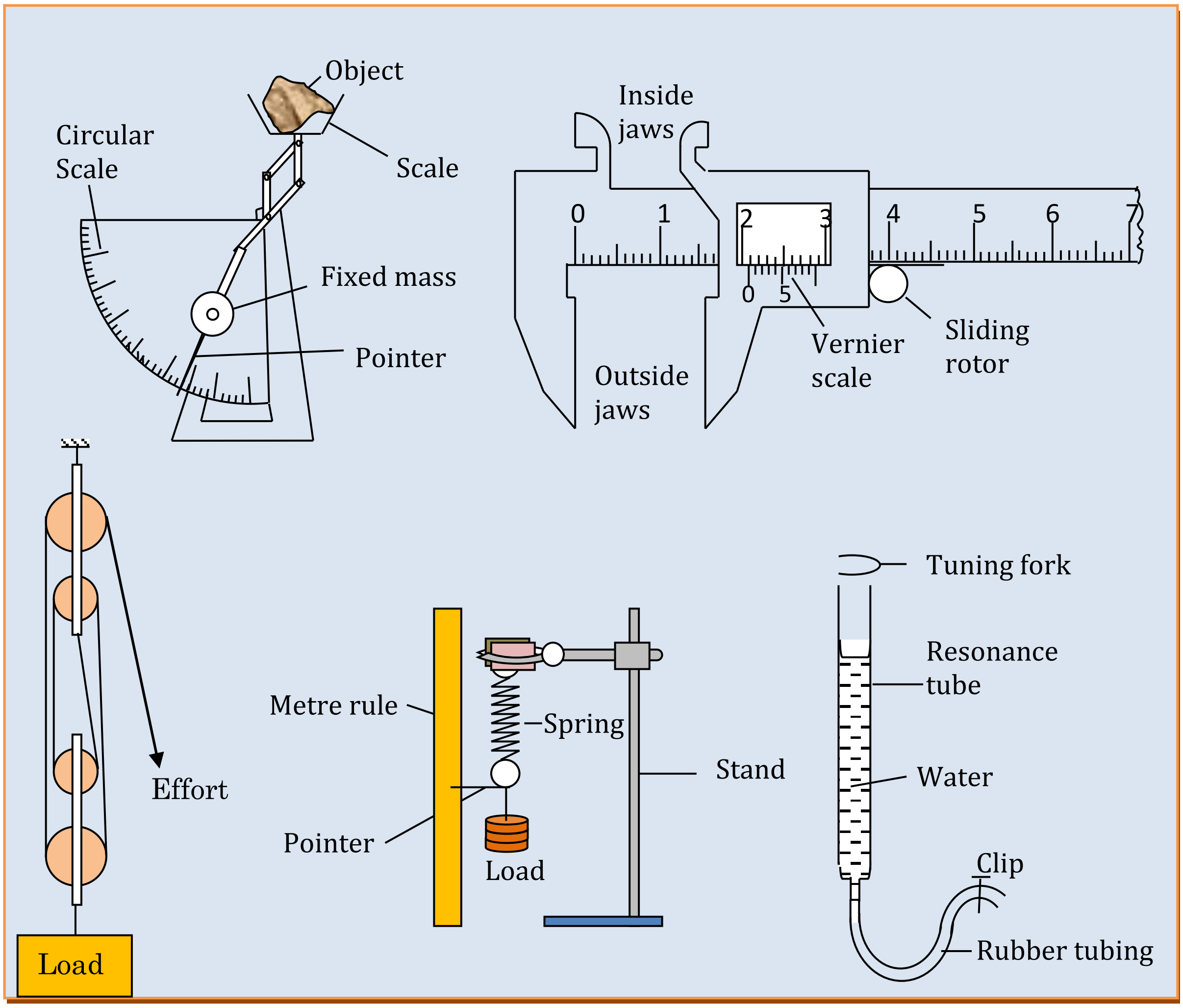


PHYSICS FOR LIFE
O -LEVEL

Senior One and Two

by
MUSISI SAMUEL



Contents

1. MEASUREMENT

1. 1: INTRODUCTION

Scientific methods require careful measurement and analysis. Measurements are used to determine how much, how long, how big the physical quantity of matter is. The importance of measurement is to ascertain quantity and quality. After careful measurement and analysis, conclusion can be made

1.1.1: Instruments

Measurements are often made using instruments like meter rules, balances, thermometers, clocks, etc.
All measurements involve comparison of the quantity to be measured to a chosen standard unit. Throughout history different people have been measuring different quantities using different familiar objects and standards e.g. the distances were measured in strides or feet, time was measured in seasons or the duration of certain familiar events.

1.1.2: The International System of Units (SI)

It is a standard international language of measurement. It was established by agreement (convention).
All SI units satisfy the following conditions

- they are well defined
- they can easily and accurately be reproduced whenever needed
- they don’t change with time
- they don’t change with environment
- they are easily comparable with other similar units
- they have a fixed value

1.1.3: The Basic Quantities

These are quantities which cannot be expressed in terms of other quantities. They are also called ***fundamental quantities***. All the basic quantities have clearly defined SI units.

Basic quantity	SI unit	Symbol for unit
Length	Meter	m
Mass	kilogram	kg
Time	Second	s
Temperature	Kelvin	K
Amount of a substance	Mole	mol
Luminous intensity	Candela	cd

1.1.4: Derived Quantities

These are quantities that are obtained from basic quantities by mathematical relationship. They can be got by multiplication and/or division of two or more basic quantities.

Quantity	SI unit	Symbol
Area	Square meter	m^2
Volume	Cubic meter	m^3
Density	kilograms per cubic meter	kgm^{-3}
Power	Watts	W
Speed	meter per second	ms^{-1}

Force	Newton	N
Pressure	Newton per meter squared	Nm^{-2}
Energy	Joule	J

1.1.5: Conversion of Units

The SI system is based on the number 10. SI units can be multiplied or divided by 10 to make them larger or smaller. This is done by adding prefixes to the units.

Prefix	Symbol	Number / fraction	Power of 10
Tera	T	1,000,000,000,000	10^{12}
Giga	G	1,000,000,000	10^{9}
Mega	M	1,000,000	10^{6}
Kilo	k	1,000	10^{3}
Hecto	H	100	10^{2}
Deka	D	10	10^{1}
Deci	d	1/10	10^{-1}
Centi	c	1/100	10^{-2}
Milli	m	1/1000	10^{-3}
Micro	µ	1/1,000,000	10^{-6}
Nano	n	1/1,000,000,000	10^{-9}
Pico	p	1/1,000,000,000,000	10^{-12}

1.1.6: Scientific notation

Scientists usually deal with very large or small figures .e.g. the speed of light is 300,000,000ms^{-1}, the mass of earth is 6,000,000,000,000,000,000,000,000 kg, the mass of an electron is 9.11 x 10^{-31} kg.
Scientific notation greatly simplifies the handling of very large or very small numbers. To write numbers using scientific notation move the decimal point until only one non-zero digit appears to the left of the decimal point.
Count the number of places moved by the decimal point and use that number as a power of 10.
A positive power shows that the number of places the decimal point has been moved to the left.
A negative power shows the number of places the decimal point has been moved to the right.
The speed of light is 3.0 x 10^{8} ms^{-1}
The mass of the earth is 6.0 x 10^{24} kg
The mass of the electron is 9.11 x 10^{-31}kg

Exercise

Write the following in scientific notation.
i) 5.880 ii) 430000 iii) 60000 iv) 86000000
v) 5000000000000 vi) 0.00058
vii) 0.0000047

1.2: MEASUREMENT OF LENGTH

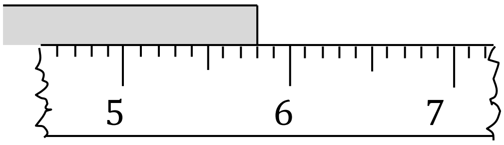
1.2.1: General Techniques

Various instruments are used to measure length. The choice of the instrument to be used depends on

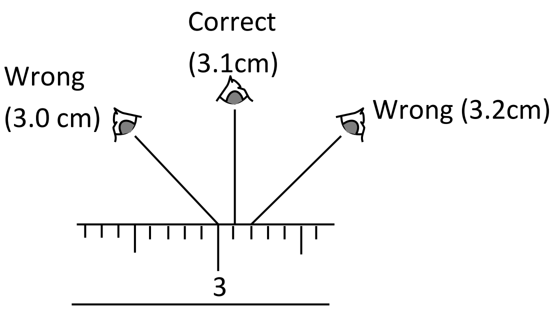
(i) What is to be measured
(ii) The precision required.

Examples of measuring instruments for length include;
Meter rule, tape measure, micrometer screw gauge, vernier calipers.

A meter rule is used to measure length from 0 to 100cm. It is calibrated in centimeters and millimeters.
The meter rule can be used to measure length in centimeters to one decimal place.



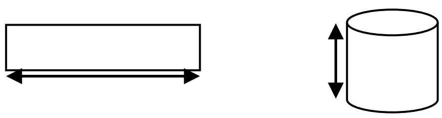
When taking readings on a meter rule the eye should be positioned as in the diagram below, where is indicated as correct.



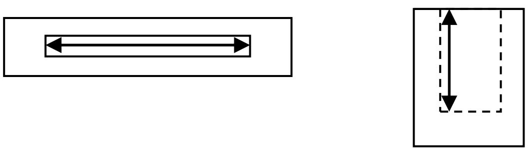
Which of the following measurements were taken using a metre rule?
(i) 32.0cm (ii) 2.72cm (iii)50cm (iv) 0.56cm (v) 0.8cm
(vi) 66mm (vii) 0.785cm

Use the meter rule provided to measure the width of your book.

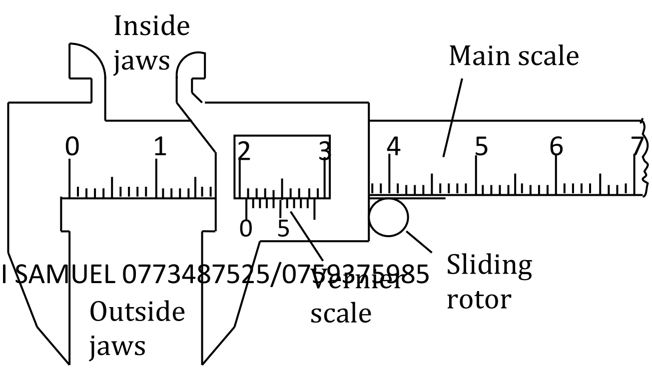
1.2.2: Vernier Caliper
Calipers are tools used in home, small shop, industrial settings and laboratories. They are used to make precise (accurate) length measurement e.g. the thickness of an exercise book, the diameter of a ball bearing, the thickness of a meter rule.
Some reasons for their popularity include:
- Can as well measure inside diameters, widths and depths with accuracy.
- wide measuring range
- English and metric scales are usually found on the same instrument.



- Calipers can also make inside measurements and also depth measurements.



The diagram below shows the main features of a vernier caliper.



Reading a vernier caliper

1. The zero mark of the vernier scale is between 2.0cm and 2.1cm but nearer to 2.1cm than 2.0cm. We take the mark just before the vernier scale in this case 2.0 cm. Then we use the vernier scale to determine where the zero mark of the vernier scale actually is. (diagram)
2. To determine where it is, find on the vernier scale a mark coinciding with any mark on the main scale. Here it is the 4^{th} mark.
3. But for the 4^{th}mark to coincide with a mark on the main scale, the zero mark of the vernier scale must have moved 0.04 cm to the right of the 2.0 cm mark.
4. Therefore the reading is 2.0 + 0.04 = 2.04 cm.

Note that all vernier readings are given to two decimal places or to the smallest unit of 0.01cm.

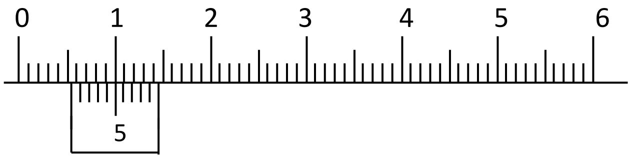
Some Precautions for Diameters and Thicknesses

When finding the diameter of a lengthy object, like a rod, a wire, etc, the diameter should be measured at several places (at least three) along the specimen and then the average diameter found. This is because the diameter may not be perfectly uniform along the specimen. The same precaution should be taken for the thickness of objects like a meter rule, a sheet, etc, for the same reason.

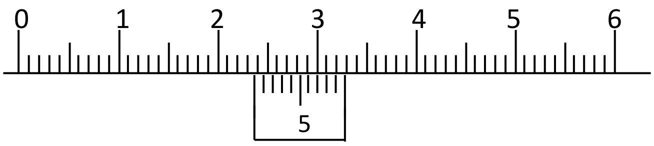
Exercise 1a

1. Give the reading of each of the vernier caliper setting shown below:

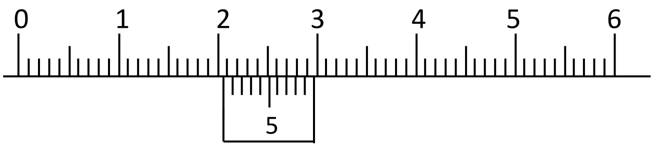
(a)



(b)



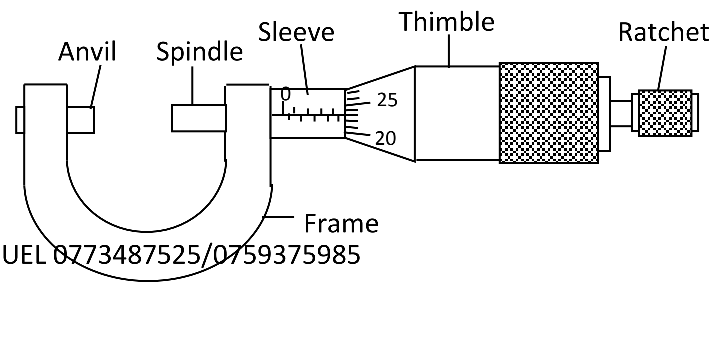
(c)



2. Draw a diagram of a vernier caliper reading

(a) 3.42 cm (b) 9.07 cm

1.2.3: Micrometer Screw Gauge



The main millimeter scale is engraved on the sleeve along with markings halfway each millimeter. Each revolution is equivalent to 0.5 mm on the main scale. The reading indicated by the diagram is obtained as follows:

Sleeve reads 4.5 mm

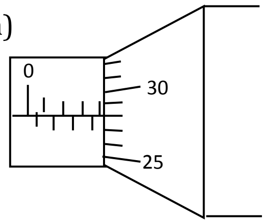
Thimble reads 0.23 mm

So the total reading is 4.50 + 0.23 = 4.73 mm

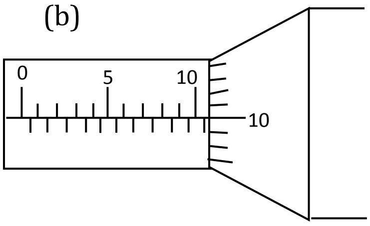
Exercise 1b

1. Give the reading indicated by each of the micrometer screw gauge setting shown below.

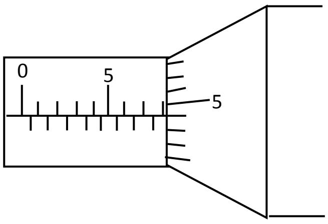
(a)



(b)



(c)



2. Draw a diagram of a micrometer screw gauge reading

(a) 6.69 mm (b) 2.26 mm (c) 0.58 mm (d) 0.47 mm

1.2.4: Summary of Measuring Instruments

Instrument	Smallest unit	Accuracy	Examples
Micrometer screw gauge	0.01mm	2 dp in mm	Diameter of wire, thickness of a cardboard
Vernier calipers	0.1mm or 0.01cm	1 dp in mm or 2 dp in cm	Thickness of a book, Diameter of a tennis ball, Internal diameter of a test tube
Meter rule	1mm or 0.1cm	1 dp in cm or 3 dp in m	Length of a classroom bench
Tape measure	1cm		Length of football field

Test Yourself

1. State the main advantages of scientific notation.
2. What are basic quantities? Give three examples of them.
3. List all the instruments used in measuring length.
4. Which instrument is most suitable for measuring each of the following?
Width of a book, diameter of a wire, height of a table, depth of a groove, internal diameter of a test tube, length of a football pitch.
5. Why is it NOT advisable to measure the thickness of a razor blade using just a single razor if the experimenter had access to many of them?
6. You are provided with 30 razor blades and a micrometer screw gauge. How would you use the apparatus to find the thickness of one razor blade most accurately?
7. You are to measure the thickness of a table top. Why is it advisable to take measurements at several places of the table top?

8. What is the use of a ratchet on a micrometer screw gauge?

1.3: MEASUREMENT OF VOLUME

Volume is the amount of space occupied by a substance. It is a derived quantity. The SI unit of volume is the cubic meter (m^3). Other commonly used units include cubic centimeter (cm^3) and the litre.
The litre measures liquid volumes
1 litre = 1000 cm^3
For small volumes a milliliter is used.
1000 ml = 1 litre
$\therefore$ 1 ml = 1 cm^3

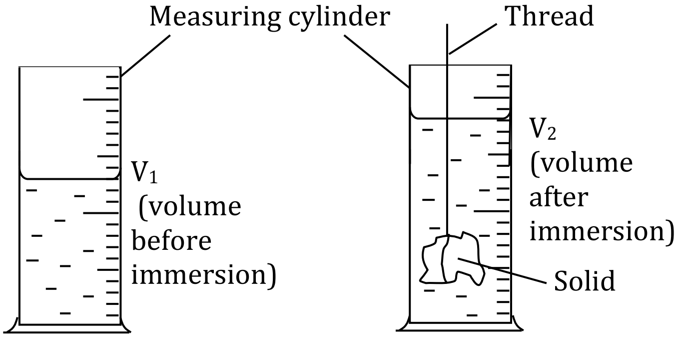
1.3.1: Regular Solids

The volume of a regular solid is calculated by measuring the appropriate sides and using the appropriate formulae, for example:

- volume of rectangular box = length x width x height
- volume of cube = (length of sides)^3
- volume of cylinder = $\pi r^2 l$ (where r = radius of cross section and *l* is length)
- volume of sphere = $\frac{4}{3}\pi r^3$ (where r = radius)
- volume of cone = $\frac{1}{3}$ x area of base x height

1.3.2: Irregular solids

The volume of irregular solids can be obtained by completely immersing it in a liquid in which it does not dissolve and measuring the volume of the displaced liquid. This equals to the volume of the solid. The measuring cylinder or the Eureka (or overflow can) can be used for the above experiment.
(a) Measuring Cylinder:



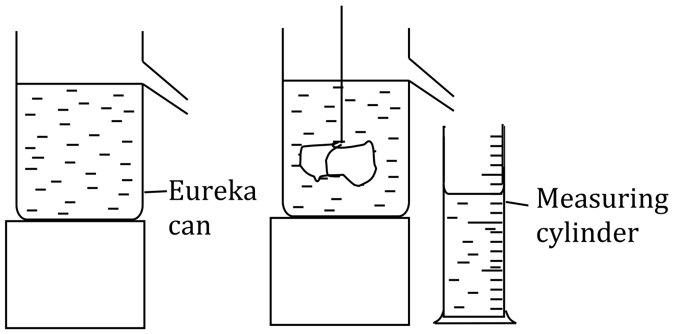
- A good amount of water is poured into a measuring cylinder and the volume reading is noted as V_1 cm^3.
- Then the solid is hung on a piece of thread and fully immersed in the water in the measuring cylinder, and the new volume reading, V_2, is noted

The volume of the solid is calculated and is $V_2 - V_1$.

(b) Eureka Can with Measuring Cylinder

- Water is poured into a Eureka can until it begins dripping through the spout.
- When the water has stopped dripping, a dry measuring cylinder is placed under the spout
- The solid is then carefully lowered and immersed in the water by means of a string
- When the water stops dripping from the spout, the volume reading of the displaced water in the measuring cylinder is noted.

It is equal to the volume of the immersed solid.



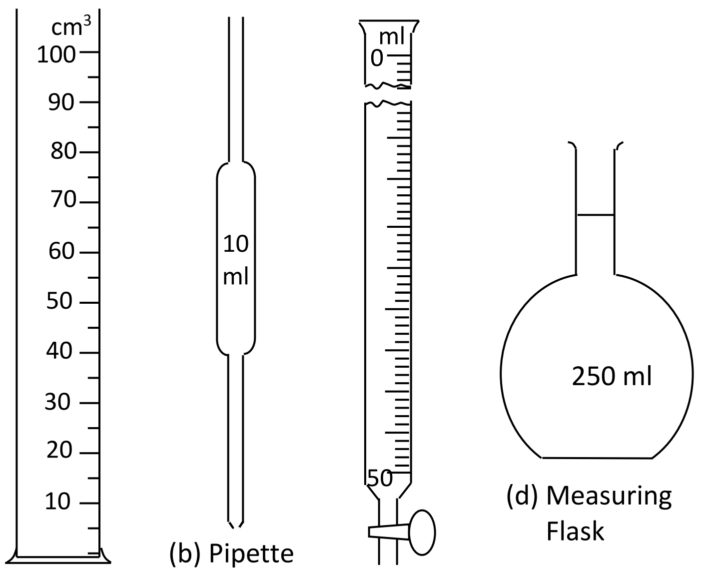
Exercise:

You are provided with a test tube containing small ball bearings, a measuring cylinder and water. Describe how you would measure the volume of one ball bearing.

1.3.3: Liquids

Different types of graduated vessels are used in measuring the volumes of liquids. These include:

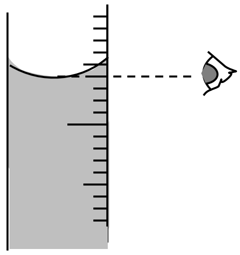
- The measuring cylinder – these are graduated in 1, 5 or 10 ml intervals depending on their sizes
- The measuring flask – used to measure a fixed volume of liquid.
- The pipette – also used for measuring a fixed volume of liquid.
- The burette – used for delivering any required volume of liquid, up to its total capacity, which is usually 50 cm^3 although there are smaller ones as well. It is long and thin so as to make it easy to read off fractions of 1 cm^3. It has divisions up to 0.1 cm^3.



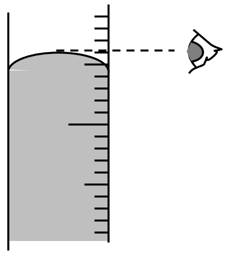
(a) Measuring Cylinder (b) Pipette (c) Burette (d) Measuring Flask

Reading of Liquid Levels

Whenever taking reading of the levels of liquids on all the instruments mentioned above, the readings must be taken at the bottom of the meniscus, for liquids such as water, which curve downwards (concave meniscus). But for liquids whose surfaces curve upwards (convex meniscus), e.g mercury, the reading should be taken at the top of the meniscus. See illustrations below



(i) Concave meniscus



(ii) Convex meniscus

In reading the liquid level in the instruments to find volumes, the eye must be at the same level as the liquid surface, in order to avoid an error due to parallax.

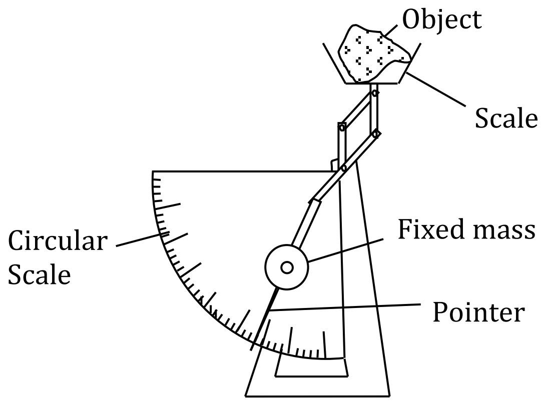
1.4: MEASUREMENT OF MASS

The mass of a substance is the quantity of matter in it. It is a scalar quantity and it is constant. It is a basic quantity. The SI unit of mass is the kilogram (kg). The following are some of the instrument that may be used to find mass of a substance.

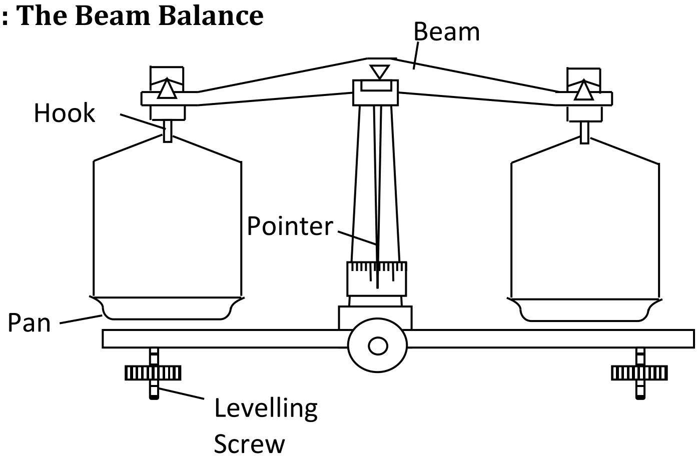
(i) lever balance
(ii) beam balance
(iii) top pan balance
(iv) triple beam balance
(v) electronic balance

1.4.1: The Lever Balance

This balance has a scale pan, a pointer and a circular scale graduated in grams. It measures masses by raising a fixed mass. The distance the fixed mass is raised depends on the mass of the object placed on the scale pan (See the figure following)



1.4.2: The Beam Balance



The hooks which support the scale pans are hung at equidistant points from the pivot of the beam.
One or both of the levelling screws is/are adjusted until the pointer is at the central mark.
The object whose mass is to be determined is placed in the left-hand scale pan and standard masses are placed in the right-hand scale pan. When the two masses are equal, the pointer settles at the central mark.

1.5: DENSITY

Density is defined as the mass per unit volume of a substance. It is a derived quantity.

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

Therefore the SI unit of density is the kilogram per cubic metre (kg m^{-3}). Other commonly used units are g cm^{-3}.

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

1.5.1: Measurement of Density

To find the density of an object:
- Measure the mass of the object
- Measure the volume of the object (by performing the respective steps as outlined before for measuring volume).

Then apply the formula

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

Density of a Rectangular Object:
- Measure the mass of the object using a balance
- Determine its volume by measuring its length, breadth and height using a suitable instrument.

Then apply the formula

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

Density of an Irregular Object:

- Measure the mass of the object using a balance
- Determine the volume by using either an overflow can or the displacement method using a cylinder

Then apply the formula for density.

Example:

1. Calculate the mass of air in a room of floor dimensions 10m x 12m and height 4m. [Density of air = 1.26 kg m^{-3}]

Solution:

Volume of air = 10 x 12 x 4 = 480 m^3

Mass = volume x density = 480 x 1.26 = <u>604.8 kg</u>

2. A tin containing 5000 cm^3 of paint has a mass of 8.0 kg. If the tin, including the lid is 0.5 kg, calculate the density of the paint in kg m^{-3}.

Solution:

Volume = 5000 x 10^{-6} = 5.0 x 10^{-3} m^3

Mass of paint = total mass - mass of tin with lid

= 8.0 – 0.5 = 7.5 kg

$$\therefore \text{Density of paint} = \frac{7.5}{5.0 \times 10^{-3}} = \underline{1500\ \text{kg m}^{-3}}$$

1.5.2: Relative Density

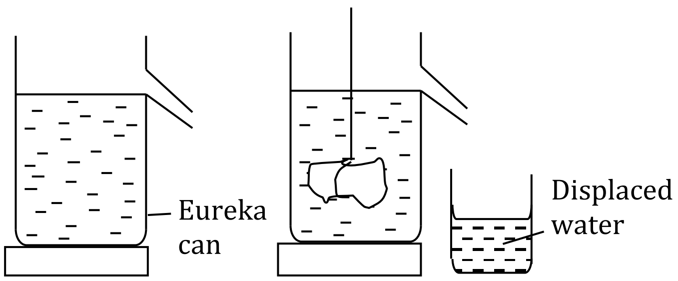
The relative density of a substance is ***the ratio of the mass of the substance to the mass of an equal volume of water***.

Or it is **the ratio of the density of a substance to the density of water.**

Or it is **the ratio of the weight of a substance to the weight of an equal volume of water**.

Therefore relative density has NO UNITS because it is a ratio of masses.

Measurement of Relative Density of a Solid



- Water is poured into a Eureka can until it begins dripping through the spout.
- When the water has stopped dripping, a dry beaker is weighed and placed under the spout
- The solid is weighed and then carefully lowered into the Eureka can until it is fully immersed in the water.

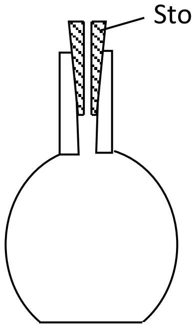
- When the water stops dripping from the spout, the beaker with its contents is weighed again.

Now, the displaced water has the same volume as the solid.
Let M = mass of the solid
m_1 = mass of empty beaker
m_2 = mass of beaker + displaced water

Then, relative densiy of solid $= \frac{M}{m_2 - m_1}$

Measurement of Relative Density of a Liquid

To measure the relative density of a liquid a ***density bottle*** is used.



Suppose the relative density of a certain liquid is required. Then
- The empty bottle is first weighed
- It is filled with the liquid under investigation and the stopper inserted.
- The outside of the bottle is wiped dry and it is weighed again
- The bottle is emptied, rinsed and filled with water
- After inserting the stopper and wiping the outside, the bottle with its contents is weighed once again

Calculation of Results:
Mass of empty bottle = a
Mass of bottle full of liquid = b
Mass of bottle full of water = c
Mass of liquid = b – a
Mass of water = c – a

Relative density of liquid $= \frac{\text{Mass of liquid}}{\text{Mass of water}} = \frac{b - a}{c - a}$

Precautions when Using a Density Bottle:

The bottle should not be held in the warm palm of the hand. Instead it should be held by the neck in order to avoid expansion of the liquid and subsequent spillage of some of it.

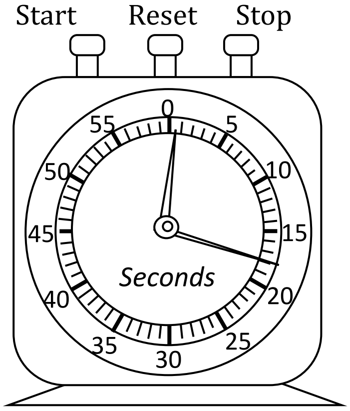
Advantages of the density bottle:
- No volume measurement is required
- High accuracy can be achieved in measuring the masses as a top pan or beam-balance may be used

1.6 MEASUREMENT OF TIME

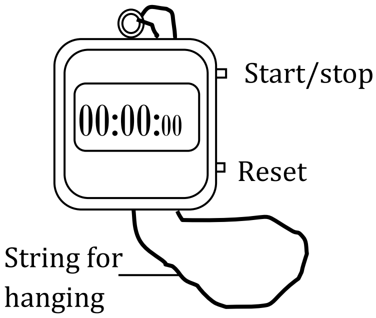
Time is measured using a stopwatch or stop clock and the SI unit of time is the second (s)

The stopwatch/stop clock must be reset to zero before using it to take any measurement, and this is done by depressing the knob provided for this purpose. A stop clock is reset when all the hands are in zero position while a stopwatch appears as the diagram above shows when reset. On a stopwatch, a reading like **00:17**$_{68}$ is recorded as 17.68 seconds.

In order to get acquainted with the use of these instruments, it is advisable that the reader tries to time different events e.g. time to walk round the laboratory block, etc.



Stop clock



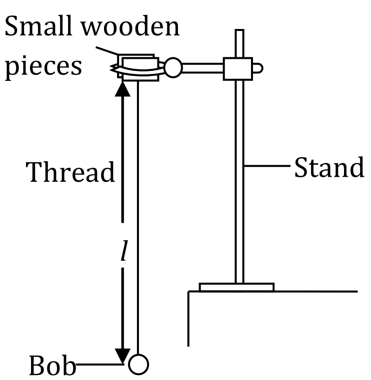
Stopwatch

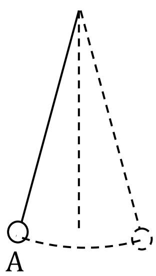
Accuracy in Timing

Hold an object, say a pen, at some height above the floor. Find the time the object takes to hit the floor when released. You may repeat the measurement several times. What is your experience as far as the accuracy of the time is concerned?
It is very challenging to time brief events accurately. In fact, if the event to be timed is a repetitive periodic occurence, it is better to find the time for a good number of them. Then, the time for a single event is found by dividing the total time by the number of events.

Experiment: *To Measure Time for One Oscillation of a Simple Pendulum*

- Fix a bob to one end of thread of about 120 cm length.
- Clamp the free end of your thread so that the length *l* is 100 cm.
- Pull the bob a short distance sideways to a point A (See diagram on the right below) and then release it. It will move to and fro (oscillate) between points A and B. A complete oscillation is the movement from A and back to A once. You may practice the counting of complete oscillations.





- As the bob oscillates, start the clock when it is at the extreme point like A and find the time for 40 complete oscillations. Hence find the time, T, for one oscillation.
- Repeat the experiment when the length *l* of the thread is 50 cm. compare and comment on the results for the two experiments.

From the above experiment, you will see that it would have been difficult to measure the time for one oscillation accurately but it has been made easy by first timing several oscillations.

2. FORCES

A force is that which changes a body's state of rest or uniform motion in a straight line.
We can therefore say that a force is a push or pull on an object.

Thus a force may:
- cause a stationary body to move
- change the shape of a body
- change the direction of motion of a body
- increase or decrease speed of a moving body
- stop motion

A force is specified by both magnitude and direction. Therefore it is a vector quantity.
A vector quantity is a physical quantity with both magnitude (size) and direction.

2.1: TYPES OF FORCES
- Friction
- Gravitational force
- Magnetic force
- Electric force
- Centripetal/centrifugal force
- Tension/elastic force
- Up thrust
- Cohesion
- Adhesion
- Weight e.t.c

Friction

This is a force that opposes relative motion between two surfaces in contact. When a force is applied to pull (or push) an object that is in contact with a surface, a friction force comes into existence and acts in the opposite direction. The object cannot move until the friction force is overcome.
The frictional force in fluids is called ***viscosity*** or ***viscous force***.

Types of friction

1. **Static friction.** This is the frictional force between tow bodies or surfaces at rest.
2. **Dynamic or sliding or kinetic friction.** This is the frictional force between two surfaces or bodies sliding relative to each other
3. **Limiting friction.** This is the maximum frictional force between two bodies or surfaces at the point or verge of sliding relative to each other.

Disadvantages of Friction

Friction:
- wears out surfaces
- causes unnecessary noise

- produces unnecessary heat
- slows motion
- reduces efficiency of machines

Friction can be reduced by

(i) Lubrication of the surfaces in contact.
(ii) Using smooth surfaces
(iii) Using rollers
(iv) Using ball bearings

Advantages of Friction
Friction makes it possible for:

- one to write
- one to walk
- a moving vehicle to brake
- knife to be sharpened
- a match stick to produce fire

Experimental measurement of coefficient of friction

Centripetal Force

This is a force that keeps a body moving in a circular path. Its direction is towards the centre of the circle made by the path. It keeps the planets in their respective orbits round the sun.
On the other hand, a centrifugal force acts in the opposite direction to the centripetal force and is the force that tries to cause the body moving in a circle to maintain a straight path.
Both the centripetal and the centrifugal forces increase with increase in speed of the body. You may prove this if you whirl an object fixed on a string in a circle.

Magnetic Force

This is the force of attraction between a magnet and a ferromagnetic material.

Electric Force

This is a force between bodies due to a surplus or a deficiency of electrons on the bodies.

Nuclear Force

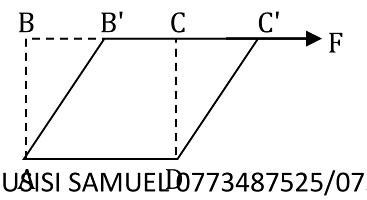
These forces exist in the nucleus of an atom. They bind together the particles of the nucleus and are very strong.

Elastic Force

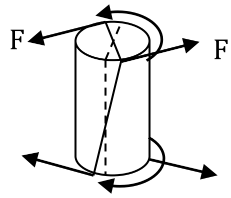
This is a force that exists in a body that is stretched, compressed or twisted due to the body's tendency to regain its original size and shape.

Shear Force

A shear force is one which changes the shape of a body without changing its volume. It is applied tangentially (i.e. in a brushing manner). For example, to twist a wire or a rod, a shear force must be applied. It is like a couple (a pair of opposite coplanar forces) which, instead of turning the whole body, makes the particles (molecules) of the body slide slightly over their neighbors. See the figures below.



The shear force, F, applied along the upper face BC when the lower face AD is fixed, makes the upper face shift to B'C'. the originally rectangular body ABCD becomes a parallelogram AB'C'D



The forces, F, twist the cylinder with the top face rotating anticlockwise as the lower face rotates clockwise.

Gravitational Force

This is a force of attraction between any two masses. It is not always noticed because it is a very weak force. It can only be noticed when at least one of the masses is very big. For example an object on the Earth's surface experiences a force of attraction towards the centre of the Earth. Any object thrown vertically upwards always returns to the Earth because of this attraction. It is this force that enables objects to stay on the Earth's surface.

WEIGHT

What is Weight?

This is the force ………

The force of gravity on an object is called the ***weight*** of the object and it depends on its mass. Every 1 kg of it is attracted by a force of about 9.8 Newton's. For simplicity we shall approximate it to 10 Newton's. So the weight of a 1 kg mass is about 10 N.
The force of attraction on 1 kg mass towards the centre of the Earth is known as the Earth's ***gravitational acceleration***. It is commonly denoted by a symbol g. The SI unit of g is m s^{-2}

In general

Weight = mass x gravitational acceleration

i.e. the weight of mass m is mg
For example a mass 3 kg has a weight of 30 N
Gravitational acceleration changes from place to place. So the weight of a body varies likewise. For example the weight of a body on the moon is less than on the Earth's surface because the gravitational acceleration at the moon is less than it is on the Earth.

Different Causes of Variation of Gravitational Acceleration

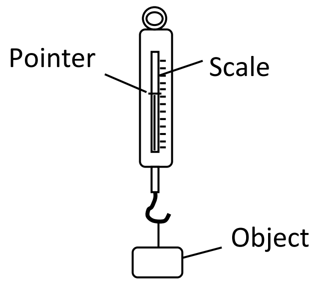
1. Over the Earth's surface g varies from to place because the Earth is not a perfect sphere. Its polar radius is shorter than its equatorial radius. So the value of g increases as one moves from the equator towards the poles.
2. Altitude affects the value of g. The higher one goes the lower the value of g becomes

Differences between Mass and Weight

Mass	Weight
Is the quantity of matter in a substance	Is the pull of gravity on a body

Is constant in all places	Varies from place to place
Is a scalar quantity	Is a vector quantity
Its S.I unit is kilogram (kg)	Its S.I unit is newton (N)
It's measured using a beam balance	It's measured using a spring balance

Measurement of Weight



Weight of an object is measured using a spring balance. The object is freely hung from the hook of the spring balance and the weight is read from the scale as indicated by the pointer.

Test Yourself

1. What is a force?
2. List five effects of a force.
3. How does the stiffness of the combination compare with that of one spring when springs are combined in
   (i) series (ii) parallel?

3. PRESSURE

Pressure is defined as the force acting normally (perpendicular) per unit area. i.e

$$\boldsymbol{Pressure = \frac{Force}{Area}}$$

The S.I unit for pressure is ***Newton per square meter*** **(N m^{-2})**, referred to as the Pascal (Pa)

3.1: Solid Pressure

The pressure exerted by a solid is due to its weight and depends on what area of it is resting on the supporting surface and also the angle of application of the force. It should be obvious that the smaller the area the greater is the pressure. This is why a shoe with a narrow sole sinks more easily in mud than a flat one, or a cow sinks more easily in mud than a hippopotamus which is heavier.

Example:

A rectangular block of dimensions 10cm x 6cm x 4cm weighs 90 N. Find the maximum and the minimum pressure it can exert on a horizontal floor in N m^{-2}.

Solution:
The maximum pressure is exerted when resting on the smallest area.
Now, the smallest area = 0.06 x 0.04 = 0.0024 m^2

$$\therefore \text{ Maximum pressure } = \frac{90}{0.0024} = 37{,}500 \text{ N m}^{-2}$$

$$\text{and the minimum pressure } = \frac{\text{weight}}{\text{largest area}} = \frac{90}{0.01 \times 0.06} = 15{,}000 \text{ N m}^{-2}$$

Question. Explain the following observations;

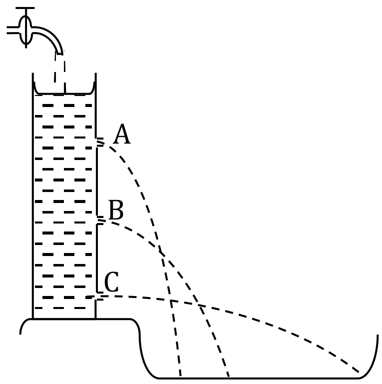
a) A hippopotamus is able to walk on the mud but a goat gets stuck.
b) A woman putting on high heeled shoes spoils the cemented floor compared to one putting on flat shoes.
c) Water containers (reservoirs) are usually made wider at the base.

3.2: Liquid Pressure

Pressure at a point in a liquid at rest depends on ;

- The depth of the point.
- Density of the liquid.
- Acceleration due to gravity.

Experiment: To Show that Liquid Pressure Increases with Depth of the Liquid.

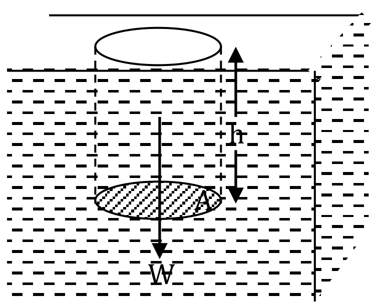


- Three or more identical holes A, B and C are made in a can at different heights and the can is filled with water.

Observation: Water from the lowest hole, C, spurts out with the greatest force and hits furthest while that from the top hole, A, hits nearest.

Conclusion: Liquid pressure increases with depth of the liquid.

Formula for Liquid Pressure



Imagine a horizontal plate of area A at a depth h in a liquid of density ρ.
Then, the volume liquid directly above the plate
= area (A) x height (h)
And the weight of the liquid directly above the plate = mass x g
= $Ah\rho g$

Therefore the pressure exerted on the plate by the liquid

$$= \frac{\text{Force}}{\text{Area}} = \frac{\text{Weight of liquid}}{\text{Area}} = \frac{Ah\rho g}{A} = h\rho g$$

Thus, pressure, $\mathbf{P = h\rho g}$

Example

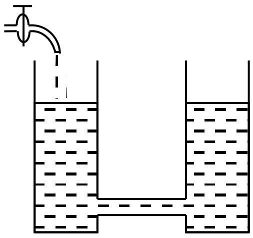
The density of sea water is 1030 kg m^{-3}. Find the pressure due to the sea water on a diver at a depth of 20 m.

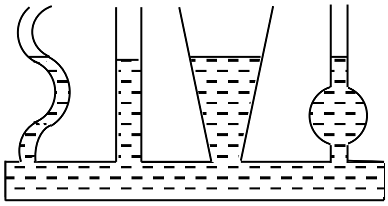
Solution

Pressure due to sea water = depth x density x g
P = 20 x 1030 x10 = $\underline{\underline{206{,}000 \text{ N m}^{-2}}}$

A Liquid finds its Own Level (Experiment to show that pressure in liquids is independent of the shape and cross-sectional area of a container)

If a liquid is introduced in any part of a communicating vessel, it will rise to the same level everywhere. This is so because at the same depth in a liquid, pressure must be the same. This therefore shows that liquids find their own level and the pressure in liquids does not depend on the shape and area of cross section of the container.





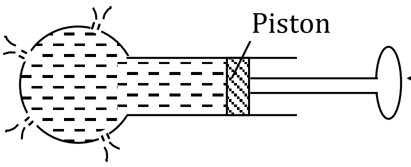
Communicating tubes

Note: A water supply system applies the same principle.

The principle of transmission of pressure (Pascal's principle)
It states that for an incompressible fluid held in a container, pressure at any part (point) is equally transmitted throughout the fluid.
This principle works on the assumption that the fluid is incompressible i.e. the fluid cannot be compressed.

Other Characteristics of Liquid Pressure

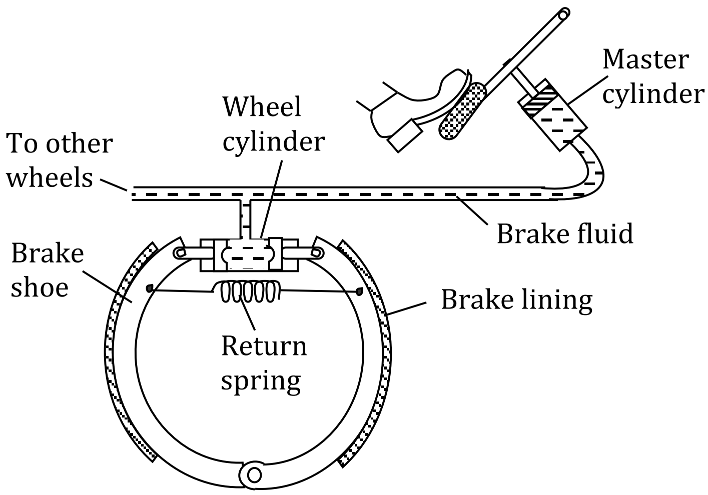
- Pressure at any point in a liquid is the same in all directions.
- Pressure at any part of a wholly enclosed liquid filling the whole container is transmitted equally throughout the liquid. This is Pascal's principle and can be demonstrated as follows:



A liquid is enclosed in a container with holes drilled evenly on it. A force is applied, by means of a piston, to a liquid.
The liquid jets out with equal force from all the holes in the different directions.
Applications of Pascal's principle include:

- Hydraulic brake system
- Hydraulic press
- Hydraulic jack
- Hydraulic lift/loader
- Etc.

Hydraulic Brake System

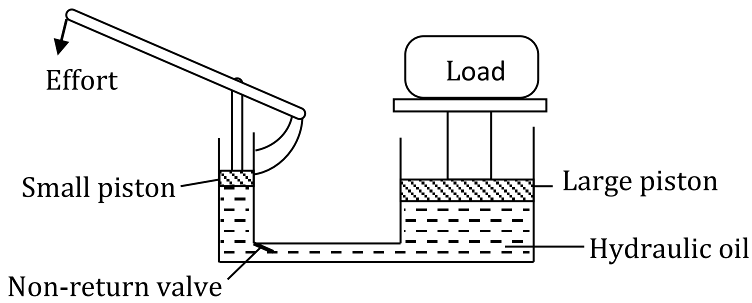


By stepping on the brake pedal, pressure is applied to the brake fluid in the master cylinder and this pressure is transmitted equally and simultaneously to all the wheel cylinders. Now, the wheel cylinders are of larger diameter and therefore larger cross sectional area. So, the force experienced by the pistons in the wheel cylinders is greater than what the foot applies on the pedal. Therefore the brake shoes are pushed outwards with a great force for the car to brake. When the brake pedal is released, the return spring pulls back the brake shoes to release the wheels.

This system has the advantage that:

- All the wheels brake simultaneously using one master cylinder.
- Only a small force is required to be applied at the pedal.

Hydraulic Press



Pressure applied to the oil by the small piston is transmitted equally up to the large piston. Now, the force experienced by the large piston is the product of pressure and the area. Since the area is large, this force is correspondingly larger than that applied by the small piston. This way a small force applied on the small piston results in a much bigger force.

3.3: Gas Pressure

A gas occupies the whole container in which it is placed and exerts pressure equally on all the walls of the container. Unlike solid or liquid pressure, gas pressure is due to bombardment of its molecules with the walls of the container.

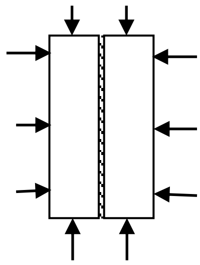
Low gas pressure can be measured using a manometer containing a suitable liquid. For high gas pressure, a pressure gauge may be used.

3.4: Atmospheric Pressure

The atmosphere consists of gases, collectively referred to as air. This air exerts pressure on all surfaces of objects in the atmosphere, including the Earth's surface. Apart from the Magdeburg hemisphere experience, a few demonstrations can prove this.

Definition: Atmospheric pressure is the pressure exerted by the weight of air to the earth's surface or all objects on the earth's surface.

1. *Wetted Glass Blocks*

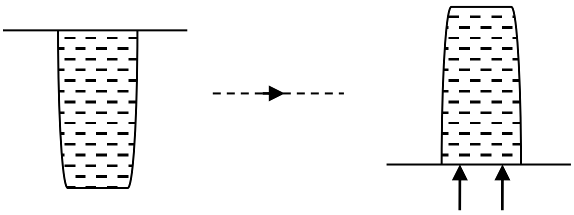


- One face of a glass block is wetted with a liquid and a second one is intimately placed on it.
- Attempt to move them apart proves difficult.

This is because the atmosphere is pressing them together.

NB: The liquid in between helps to expel any air that might be trapped in there.

2. *Liquid Trapped in an Inverted Container*

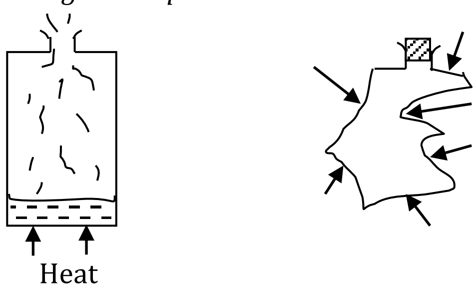


- A glass or gas jar is filled with water and then covered with a smooth card or sheet of paper.
- The card is held and the glass is then inverted.

Observation: On releasing the card, it remains firmly fixed to the glass preventing the water from pouring out.

Explanation: The atmospheric pressure acts on the card so strongly that it supports the weight of the water, which therefore remains in the glass.

3. *The Crushing-Can experiment*



- A little water is poured in a tin can.
- While the can is open, the water is boiled to expel the air from it.
- Heating is stopped; the can is sealed with a cork and then cooled.

Observation: The can crushes inwards.

Explanation: When the can is cooled, the steam inside condenses, leaving a partial vacuum there. So, the atmospheric pressure outside crushes in the walls of the can.

For mercury, the atmospheric pressure is $1.03 \times 10^5\ Nm^{-2}$

Measurement of Atmospheric Pressure

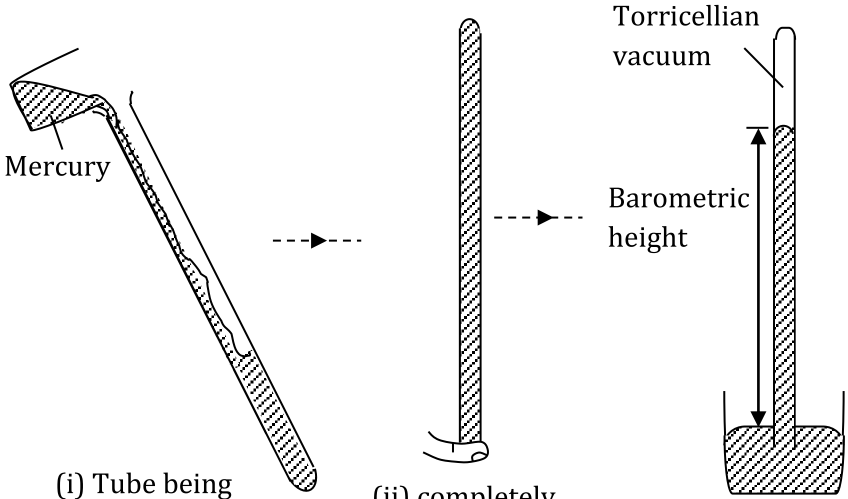
A ***barometer*** is used to measure atmospheric pressure. There are different types of barometers.

1. *Simple Barometer*

A simple barometer is made as follows:

- Mercury is carefully poured into a glass tube, which is closed at one end, making sure no air is trapped, until it is completely full.
- While fully covering the mouth, the tube is inverted into some mercury in a dish and its mouth then released.

Some mercury comes out, leaving a tall column of it in the tube and a space above. The space is known as the Torricellian vacuum. It is not a perfect vacuum because it contains some mercury vapour.
Even when the tube is tilted, the vertical height of the column remains the same. It is the atmosphere that is supporting this column of mercury.



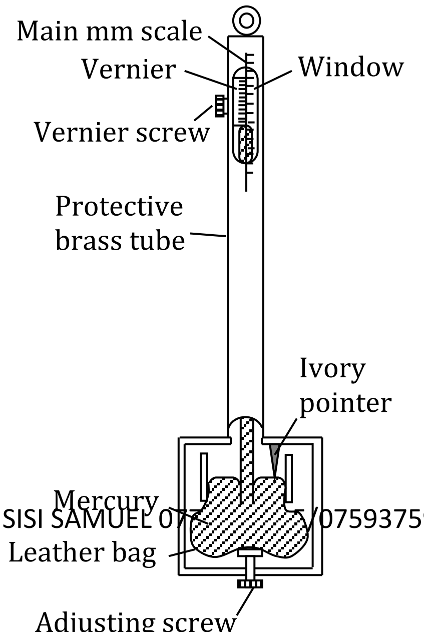
(i) Tube being filled with mercury

(ii) completely full of mercury

(iii) Tube full of mercury inverted into mercury and then released

So the atmospheric pressure must be equal to the pressure exerted by the mercury above the surface that in the dish.
If the mercury column is H metres and the density of mercury is ρ, then the atmospheric pressure is
$P_a = H\rho g$
Standard atmospheric pressure supports a column of mercury of height 0.760 m. calculate the standard atmospheric pressure in N m^{-2}.
If the barometer contained water instead of mercury, what would be the water barometric height?

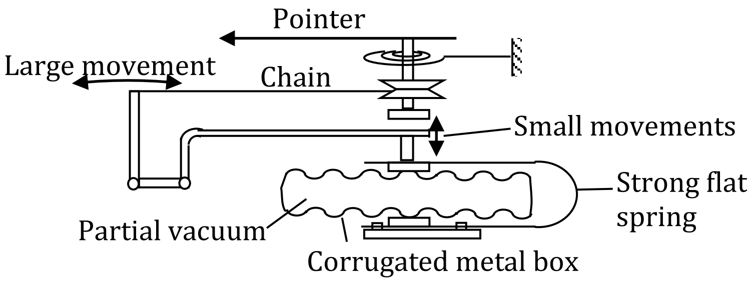
2. *Fortin Barometer*



Before any reading is taken, the zero adjusting screw must be turned until the ivory pointer just touches the mercury level in the reservoir. This marks the zero level of the mercury column.
Then the vernier is adjusted until its lower end coincides with the mercury level, visible through the window. Finally the reading of the barometric height is taken.

3. *Aneroid Barometer*

This barometer uses no liquid and is therefore much more portable than the first two. Secondly, it is easier to use since it gives the pressure values directly in cm (or mm) of mercury.



It consists of a corrugated flexible metal box which is partially evacuated. A strong flat spring prevents the box from being crushed in by the atmospheric pressure. The upper part of the box is connected to a system of levers.

- When the atmospheric pressure rises, there is a small inward movement of the walls of the corrugated box.
- A system of levers magnifies this movement into a large movement at the end of the final lever. It is this end that pulls a chain wound round a pulley that is caused to rotate accordingly.

A pointer is fixed to the pulley and it moves over a circular scale. The hair spring provides a counter torque.
When the pressure falls, there is a small outward movement of the walls of the corrugated box and finally the pulling force on the chain becomes smaller. So the pointer moves in the opposite direction due to the action of the hair spring. The aneroid barometer is calibrated by referring to a Fortin barometer.

Variation of Atmospheric pressure with Altitude

Atmospheric pressure decreases as altitude increases. However, the decrease is not uniform all through since the density of the air is not uniform. It is higher towards the Earth's surface.

Uses of Barometers

1. *Measurement of Altitude*: Since atmospheric pressure varies with altitude, barometer can be used to measure altitude (as an altimeter).
2. *Weather forecast*: dry air is denser than humid air and hence exerts higher atmospheric pressure. So, by measuring the atmospheric pressure, weather forecast is possible. High pressure would indicate dry weather while lower pressure would be associated with impending rain.

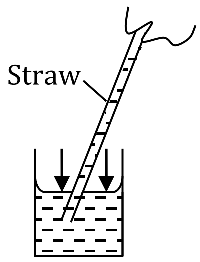
High Altitude Flying and Deep Diving

When flying at high altitude, one may not breathe properly or may have bleeding in the nose due to reduced atmospheric pressure. In fact, the inside of a high flying plane must be pressurized, i.e kept at 1 atmosphere pressure artificially.
On the other hand, a diver under water experiences a higher pressure than normal and at a great depth nitrogen may be forced into the circulatory system and cause bubbles in the blood on returning to the surface and finally cause death. So, deep divers should have protective suit with cylinders of compressed air for breathing.

Applications of Atmospheric Pressure

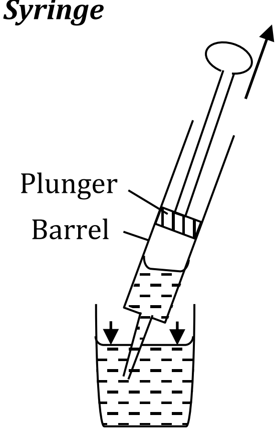
1. Drinking straws
2. Hare's apparatus
3. Force pumps
4. Lift pumps
5. Bicycle pumps
6. Preserving jars
7. Syringes
8. Vacuum pumps

The Drinking Straw



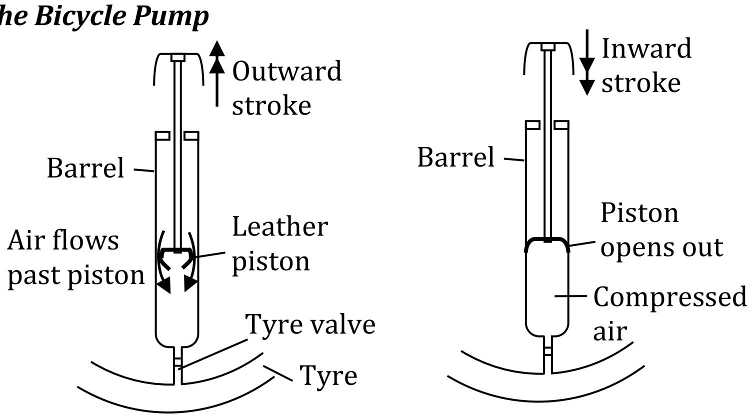
When the air is sucked out of the straw, the atmospheric pressure pushes the liquid into the straw up to the mouth.

The Syringe



When the plunger is pulled outwards, a partial vacuum is created inside the barrel. So, the atmospheric pressure forces up the liquid into the barrel.

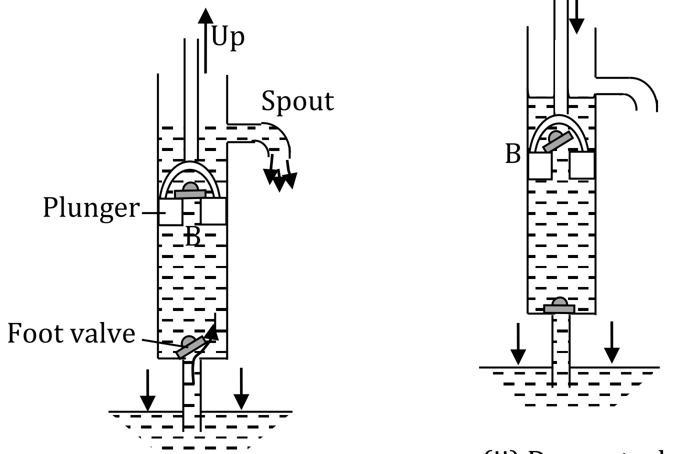
The Bicycle Pump



During the outward stroke a partial vacuum is formed between the tyre valve and the piston. So, the atmospheric pressure forces the flexible leather piston to curve in and air is pushed past it into the enclosed part of the barrel, meanwhile the air already in the tyre is prevented from flowing out by a tyre valve.
During the inward stroke the compressed air in the barrel opens out the piston and this air is pushed through the tyre valve to the tyre.

Lift Pump (common pump).

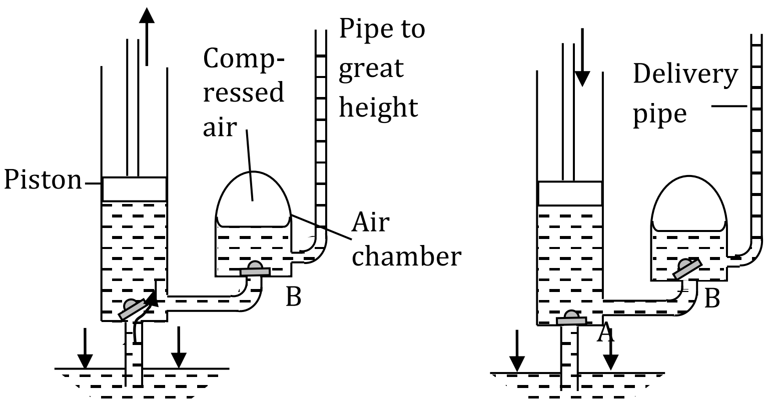
It is used to raise water in wells to a height less than 10m



(i) Up stroke (ii) Down stroke

During the up stroke the plunger moves upwards and atmospheric pressure pushes water through the inlet pipe and forces open the foot valve. So, water flows into the barrel. Meanwhile valve B in the plunger, is kept closed by its own weight plus the weight of the water above it. The plunger now lifts the water up to the spout where it flows out.
In the down stroke, the foot valve is closed by the weight of the water above it. Since water is incompressible, the water below the plunger forces valve B open and it flows to the upper side of the plunger.
So, the outflow from this pump pulsates according to the strokes performed.

Force Pump



(i) Up stroke (ii) Down stroke

During the up stroke the atmospheric pressure pushes water through the inlet pipe and forces open the foot valve, A. So, water flows into the barrel. Meanwhile valve B is kept closed by the pressure of the compressed air in the air chamber and the great water head in the delivery pipe.
During the down stroke, the foot valve is closed by the force of the piston. The same force pushes the valve in the chamber to open letting water into the chamber. Because air is compressible it acts as a cushion that maintains a continuous flow of water in the delivery pipe.

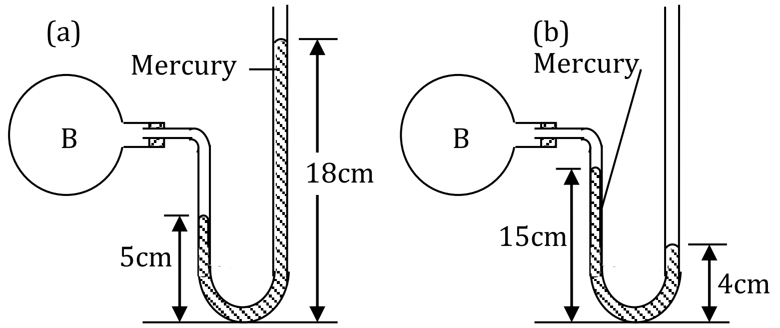
The height to which this pump can deliver water depends on the force applied on the piston and consequently on the mechanical strength of the pump's parts.

***Limitations of the above pumps*:**

The atmospheric pressure cannot support a column of water higher than about 10 metres. So, if the water level in the well is 10 or more metres below the inlet valve, the pump cannot suck in the water.

Example

Given that the density of mercury is 13600 kg m^{-3} and the atmospheric pressure is 1.01×10^5 N m^{-2}, calculate the pressure of the gas in bulb B in each case.



Solution

(a) Gas pressure = Atmospheric pressure + pressure due to extra mercury column

The extra mercury column has height = $(18 - 5) \times 10^{-2}$ m

= 0.13 m

$\therefore$ pressure due to mercury column = $0.13 \times 13600 \times 10$

= 1.768×10^4 N m^{-2}

$\therefore$ gas pressure = $1.01 \times 10^5 + 0.1768 \times 10^5$

= $\underline{\underline{1.19 \times 10^5 \text{ N m}^{-2}}}$

(b) The mercury level in the open limb is $(15 - 4) \times 10^{-2}$ m below

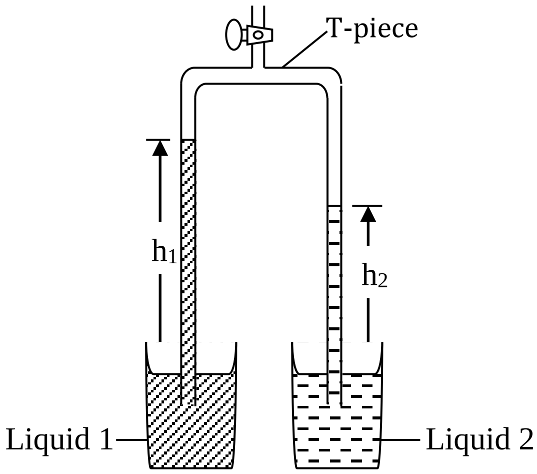
Gas pressure = atmospheric pressure $- 0.11 \times 13600 \times 10$

= $1.01 \times 10^5 - 1.496 \times 10^4$

= $\underline{\underline{8.6 \times 10^4 \text{Nm}^{-2}}}$

Hare's Apparatus

This set up can be used to compare densities of liquids or indeed find relative densities of lquids.



It consists of two transparent tubes connected to a T-piece.

- The open ends of the limbs are each dipped into a liquid.

- Some air is sucked out of the limbs through the centre tube of the T-piece and this reduces the pressure in them.
  So the atmospheric pressure pushes the liquids up the respective limbs until the pressure at the bottom of each column is equal to that of the atmosphere.

Let ρ_1 = density of liquid 1
ρ_2 = density of liquid 2
Then $h_1\rho_1 g = h_2\rho_2 g$

$$\therefore \quad \frac{\rho_1}{\rho_2} = \frac{h_2}{h_1}$$

Exercise 15
1. The atmospheric pressure is 1.01×10^5 N m^{-2}. A diver dives to a depth of 20 m below the surface of water of density 1000 kg m^{-3}. Find the pressure experienced by the diver.

4. INTRODUCTION TO LIGHT

Light is a form of energy that propagates as electromagnetic waves and brings about the sensation of sight.
It is the form of energy produced by very hot objects.
Natural sources of light include:
- the sun and other stars
- certain living things like glow warms and fire flies

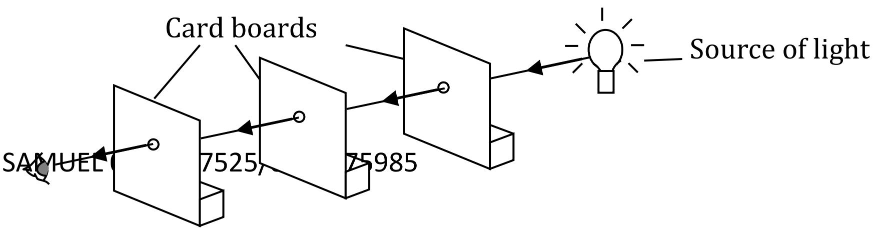
Objects that produce their own light are called ***luminous*** objects. The sun and other stars are natural luminous objects. Some sources of light are artificial luminous sources and examples of these include fire, electric bulbs, etc.
Most objects do not produce their own light but instead reflect light from luminous objects. Such are known as ***non-luminous*** objects. Examples of these are the moon, planets, mirror and ordinary visible objects.
An object that receives energy incident to it and reflects it immediately is called **a fluorescent object** and an object that receives the energy incident to it, stores and reflects it when the energy is cut off is called **a phosphorescent object.**

Media of transmission of light
Light is electromagnetic waves in nature and therefore it travels in a vacuum with the speed of $3.0 \times 10^8 ms^{-1}$
Some objects do not allow light to go through them and are referred to as ***opaque*** objects. Objects that allow light to pass through them without allowing an observer to see through them are called ***translucent*** objects. **Transparent objects** allow all light incident to pass through them and allow the observer to see through them.

4.1: Rectilinear Propagation of Light

This is the fact that light travels in straight lines. Formation of shadows with sharp edges is the evidence for this.

Experiment: To Demonstrate that Light Travels in straight Lines



- Small holes are made in the centre of three cardboard screens, which are then set up so that the holes are in a straight line (Stretching a string through the holes can help to put them in a straight line easily)
- A source of light is placed behind the arrangement. Light can be received by the eye from the opposite side of the arrangement.
- When one of the screens is displaced. This time light is cut off and this confirms that light can only travel through a straight line.

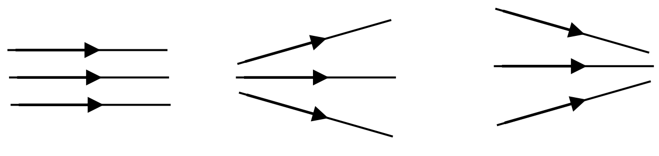
4.2: Rays and Beams

A ray is the direction of the path taken by light. It is represented by a line segment with an arrow.
A beam is a stream of light energy **OR** is the collection of light rays and may be represented by a number of rays.

Types of beams:

a) **Parallel beam:** Is a collection of light rays which do not meet.
b) **Divergent beam:** Is a collection of light rays which originate from a source (point) and move outwardly in various directions.
c) **Convergent beam:** Is a collection of light rays which originate from different directions and meet at one point.

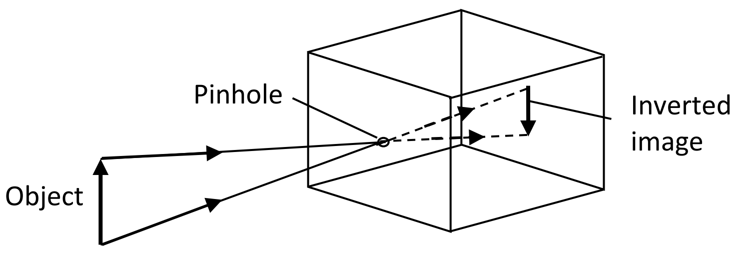
In a parallel beam the intensity of light remains constant with distance from the source.
In a divergent beam the intensity of light decreases with distance from the source while in a convergent beam the intensity increases with distance from the source. See the illustrations below:



(i) Parallel beam (ii) Divergent beam (ii) Convergent beam

4.3: The Pinhole Camera

This device applies the principle of rectilinear propagation of light to form an image of an object. It consists of a rectangular box of opaque material with a small hole (the pinhole) in the centre of the front face and a screen in the rear face. For observation of the image, the screen may be a translucent material. To take a photograph, the screen is replaced by a film.



The rays of light from the object intersect at the pinhole as they enter the camera. The image formed is inverted and its size depends on:

- the distance of the screen from the pinhole and
- the distance of the object from the pinhole

$$\frac{\text{Height of image}}{\text{Height of object}} = \frac{\text{distance of screen from pinhole}}{\text{distance of object from pinhole}}$$

This fraction is the ***magnification*** of the camera.
If the pinhole is made wider, the image becomes blurred (although brighter). This is because a wider hole is equivalent to many pinholes, each forming its own image in a slightly different position. So a collection of all these images is one blurred image.
Magnification is the ratio of the image size (height or distance) to the object size (height or distance). It shows the number of times the image is bigger or smaller than the object and it has no units since it is a ratio of similar quantities (heights).

Effects of object size and distance to image formation

- **Object size.**
- **Object position.**

An advantage of a pinhole camera is that images in this camera are free of distortions that would be brought about by dispersion as may happen in lens cameras.

Example
A pinhole camera forms an image of height 2 cm on the screen, which is 5 cm away from the pinhole. If the object is 6 cm tall, how far is it from the pinhole?
Solution

$$\frac{\text{Distance of object from pinhole}}{\text{Distance of image from pinhole}} = \frac{\text{height of object}}{\text{height of image}}$$

Let x be the distance of the object from the pinhole

Then $= \frac{x}{5} = \frac{6}{2}$

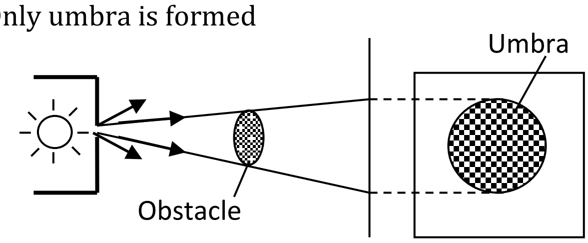
$\therefore \quad x = \frac{6 \times 5}{2} = 15 \text{ cm}$

4.4: Shadows

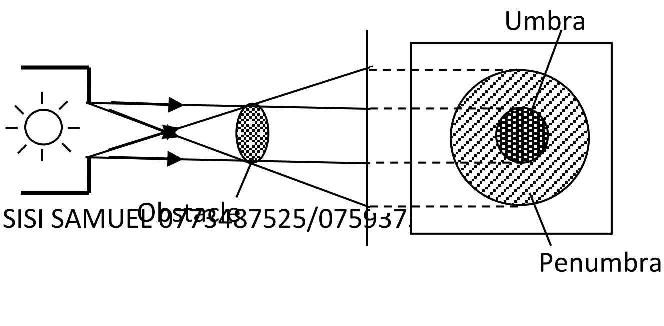
A shadow is the region of darkness formed due to obstruction of light by an opaque object. Shadows are formed because light travels in a straight line.

There are two types of shadows depending on whether the light source is a point or an extended one, namely ***umbra*** and ***penumbra***.

1. *Light from a Point Source*
   Only umbra is formed



2. *Light from an Extended Source*
   Two types of shadows are formed – umbra and penumbra



Points inside the umbra receive no light at all from the source. However, some light from the source reaches the penumbra.

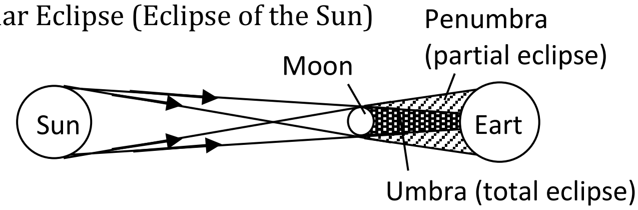
Note:

- A point source is a very small source of light whereas an extended source is a large source of light.
- For an extended source, the umbra is smaller than the penumbra and therefore the shadow is spread out. The umbra (shadow) formed by a point source is evenly distributed.
- Umbra is the region of total darkness (which does not receive light at all).
- Penumbra is the region of partial darkness (which receives some light).

Eclipses

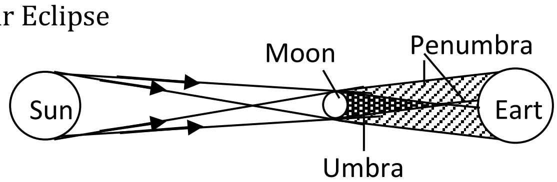
An eclipse is the study of formation of shadows when the sun, moon and earth are in a straight line. There are three types of eclipse

1. Solar Eclipse (Eclipse of the Sun)



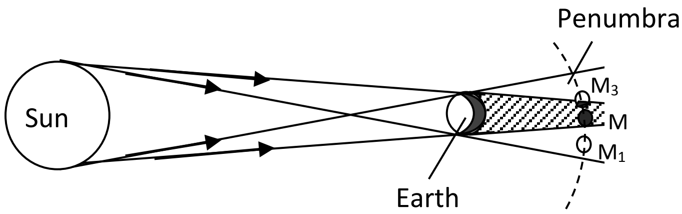
This occurs when the moon is between the sun and the earth such that the shadow of the moon is cast on the earth. The sun rays are obstructed from reaching the earth by the moon. Both the umbra and penumbra reach the earth and therefore, the earth experiences both total and partial eclipse.

2.Annular Eclipse



Since the moon describes an ellipse round the earth, the distance between the earth and the moon is not always the same. So sometimes the eclipse may occur when the moon is so far from the earth that the tip of the umbra fails to reach the earth's surface. This is then termed ***annular eclipse***- see the figure above.

3. Lunar Eclipse (Eclipse of the moon)



This occurs when the earth is between the sun and the moon such that the shadow of the earth is cast on the moon.

The diagram shows the moon in three positions: M_1, M_2 and M_3

- In position M_1 there is no eclipse of the moon. The whole moon is seen
- In position M_2 there is total eclipse of the moon. The whole of the moon is in the umbra part of the shadow.

- In position M_3 there is partial eclipse of the moon since only part of the moon can be seen. The other part lies in the umbra.

Principle of Reversibility of Light

This is the fact that if any point on the path of light became a source, then light from it traces the same path back to the original source. This means that the path of light can be reversed.

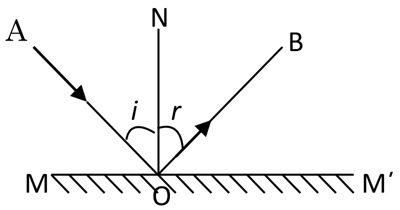
Test Yourself

1. Distinguish between a ray of light and a beam of light.
2. What evidence supports the fact that light travels in straight lines?
3. What property of light does a pinhole camera work on?
4. How is the image in a pinhole camera affected when the pinhole is enlarged?
5. State the factors on which magnification by a pinhole camera depends and state how you would increase the magnification.
6. When light encounters an obstacle, explain what causes the formation of two types of shadows. Name the shadows.

5. REFLECTION OF LIGHT BY PLANE SURFACES

5.1: Introduction

Reflection is the change of direction of light when it bounces off shinny surfaces.



O is the point of incidence
AO is the incident ray
OB is the reflected ray
Line NO is the normal to the mirror MM′.
$\angle i$ is the angle of incidence and
$\angle r$ the angle of reflection

Reflection can simply be defined as the bouncing off of light rays (light) when they fall (it falls) on a shinny surface.

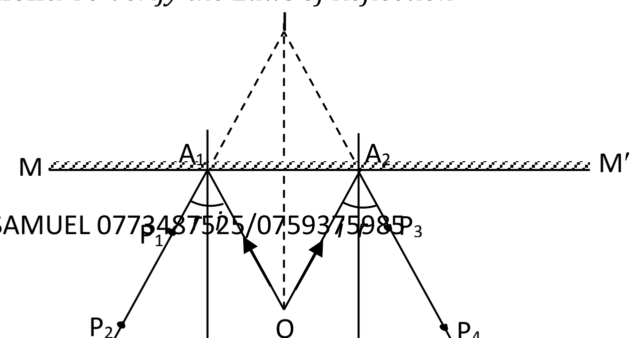
Terms used:

1. Incident ray
2. Reflected ray
3. Angle of incidence
4. Angle of reflection
5. Normal
6. Glancing angle

Laws of light

1. The reflected ray, the incident ray, and the normal at the point of incidence all lie in the same plane.
2. The angle of incidence is equal to the angle of reflection

Experiment: *To Verify the Laws of Reflection*

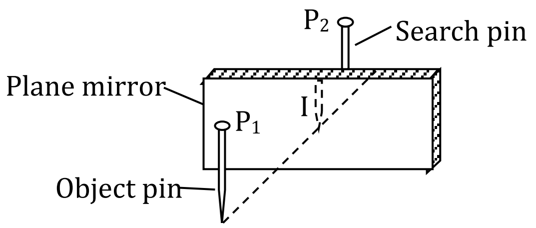


- A straight line is drawn on a white sheet of paper to divide the paper into about two equal parts.
- Using four drawing pins, the paper is fixed onto a soft board on a horizontal bench.
- A strip of plane mirror is placed vertically so that its silvered surface lies on the straight line.
- An object pin O is stuck about 5 cm from the straight line.
- While observing from position E_1, sighting pins P_1 and P_2 are stuck so that they appear to be in a straight line with the image I of the object O as seen through the mirror.
- The sighting pins are removed and their positions marked with small crosses.
- The mirror and the pins are removed and the points P_1, P_2 are joined to intersect the mirror line MM′ at A_1.
- The same procedure is repeated while observing from position E_2 and using sighting pins P_3 and P_4.
- Normals A_1N_1 and A_2N_2 are drawn and the angles *i* and *r* are measured
- The above steps are repeated for different positions of the eye, at least two on each side of the object.

It is observed that in each case $\angle i = \angle r$

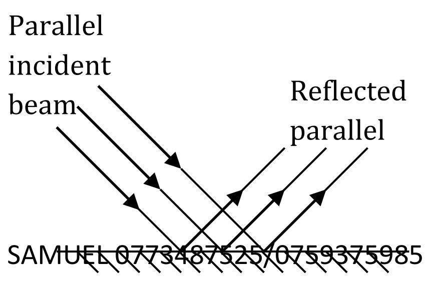
Now, when the above experiment is attempted with the mirror not perpendicular to the sheet of paper, the above results cannot be obtained. This shows that reflected ray, the incident ray, and the normal to the mirror at the point of incidence all must lie in the same plane.

How to Locate the Position of an Image in a Plane Mirror

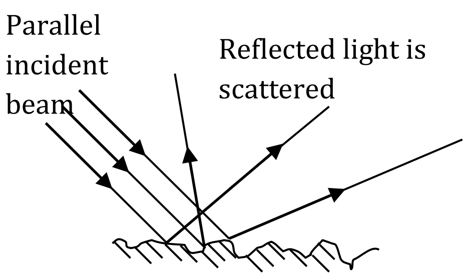


- A strip of plane mirror is set up vertically on a soft board.
- An object pin, P_1, is set up vertically in front of the plane mirror.
- While viewing through the mirror, a second pin, P_2, is held behind the mirror and shifted along the soft board until a point is found where both P_2 and the image of P_1 coincide in the same straight line and do not separate when the eye is swerved across field of view (i.e when there is no parallax between the two). The search pin P_2 is then fixed and its position gives the position of the image of P_1.

5.2: Regular and Diffuse Reflections



(i) Regular

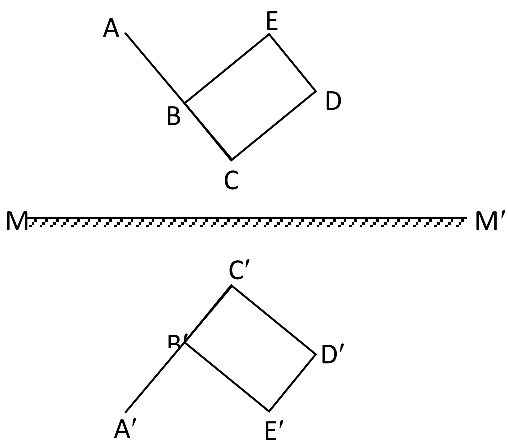


(ii) Diffuse

In regular reflection a parallel beam of light is reflected parallel. This occurs on a smooth polished surface.
In diffuse (irregular) reflection a parallel incident beam of light is dispersed in haphazard directions i.e. light is scattered. This occurs on a rough surface.

In both, the laws of reflection are obeyed. The only difference is that for diffuse reflection the rays in the parallel incident beam strike the various parts of the surface at varying angles of incidence. Thus they are accordingly reflected in various directions.
Because of diffuse reflection, our surroundings remain lit during day even if the sun may be shielded by clouds.

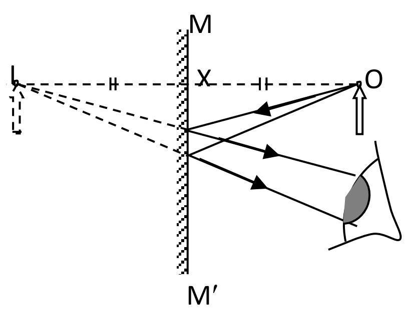
5.4: Characteristics of images Formed by Plane Mirrors



The image in a plane mirror is
- the same size as the object
- the same distance behind the mirror as the object is in front
- laterally inverted
- virtual (it cannot be formed on a screen)
- erect (upright)

Note:
- A real image is an image formed by actual intersection of light rays. It is always formed on the screen.
- A virtual image is an image formed by apparent intersection of light rays when their directions have been produced backwards. It can not be formed on the screen.

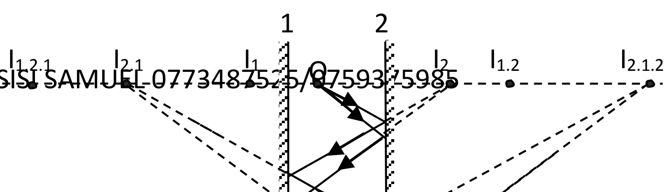
5.5: How the Eye Sees the Image



The rays from a point O are reflected and on entering the eye, appear to come from I. so I is the image of O. Likewise all other points on the object form their images accordingly.
The position of the image I can be got by construction as follows:
- A line from O perpendicular to MM′ at X is drawn.
- A point I behind the mirror is marked such that OX = XI

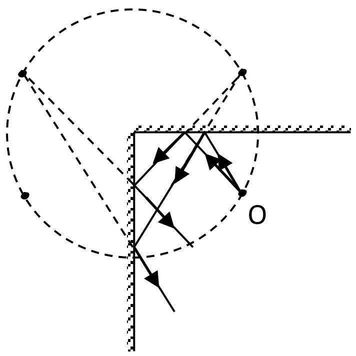
5.6: Images Formed by Two Mirrors

Two Parallel Mirrors



An object, like O, gives rise to an infinite number of images one behind the other. Some of the light energy is absorbed at each successive reflection. So the images become fainter the further away from the mirrors.

Two Perpendicular Mirrors



Three images are formed at corners of a rectangle

The number of images formed by inclined mirrors.

When the mirrors are inclined at an angle θ to each other, the number of images formed is given by the formula $n = \frac{360}{\theta} - 1$

E.g. Find the number of images formed by two plane mirrors inclined at

a) 60^0 c) 120^0 e) 30^0

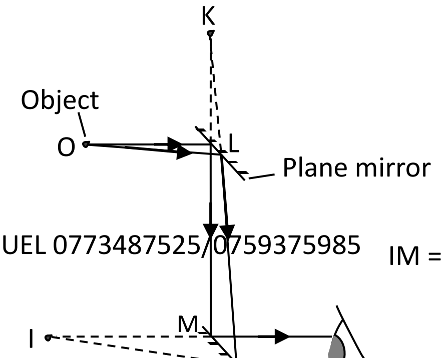
b) 90^0 d) 45^0

5.7: Applications of Plane Mirrors

- Dressing mirrors
- As monitoring devices e.g. in supper markets
- Periscope
- As shaving mirrors in saloons.

The Mirror Periscope

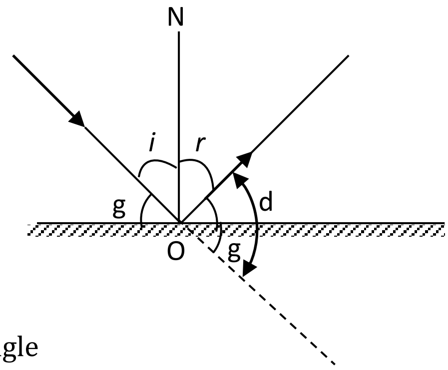
A periscope is used to see over obstacles, e.g in submarines.



IM = OL + LM

The mirrors L and M are inclined at an angle of 45^{o} to the line joining them. So they are parallel to each other.

5.8: Deviation of a Ray of Light by a Plane Surface



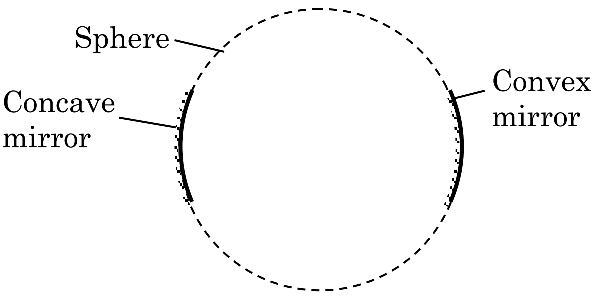
g = glancing angle
d = angle of deviation
d = 2g
Thus, the angle of deviation is twice the glancing angle
Test Yourself

1. Distinguish between angle of incidence and glancing angle for a ray that is incident on a surface
2. What is meant by a "virtual image"?
3. State the characteristics of images formed by plane mirrors.
4. Mention three applications of plane mirrors

6. SPHERICAL MIRRORS

6.1: Introduction

These mirrors are said to be spherical because each is part of a sphere



If the reflecting surface is on the inner surface of the sphere the mirror is said to be ***concave*** while if the reflecting surface is on the outer surface it is termed ***convex***.
Imagine a parallel beam of light incident on each of such mirrors

Term:

P = pole
AB = aperture of the mirror
F = principal focus
CFP = principal axis
C = centre of curvature,
FP = focal length, f
CP = radius of furniture, r

Definitions:

Pole- This is the central point of the curved reflecting surface.
Centre of curvature- this is the centre of the sphere of which the mirror is part.
Principal axis- the line passing through the pole and centre of curvature.
Radius of curvature- the distance between the pole and centre of curvature.
Principal focus

For a concave mirror it is the point to which all rays originally parallel and close to the principal axis converge after reflection.
For a convex mirror it is the point from which all rays originally parallel and close to the principal axis appear to diverge from after reflection.
Generally, principal focus is the point on the principal axis to which all rays originally parallel and close to the principal axis converge or appear to diverge from after reflection.

Focal length- This is the distance between the pole and the principal focus.
Aperture- this is the width of the mirror OR is the reflecting surface of the mirror

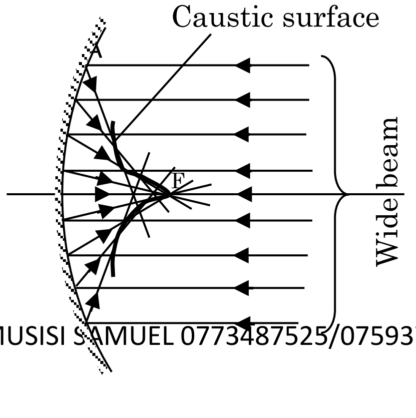
Relation between focal length and radius of curvature

$$focallength = \frac{radiusofcurvature}{2}$$

i.e. If f is the focal length and r the radius of curvature, then

$$\boldsymbol{f = \frac{r}{2}}$$

Caustic surface



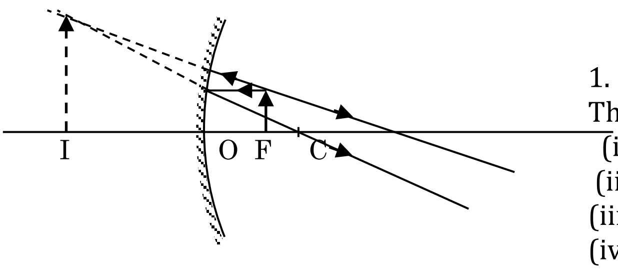
When a wide beam of light parallel to the principal axis is incident on a concave mirror with a wide aperture, the reflected rays do not pass through a single point as a narrow beam does. The subsequent reflected rays meet at other point before the principal axis. The locus of such points forms a bright surface known as the ***caustic surface***.

6.2: Construction of ray diagrams.

The following rules should be applied when constructing ray diagrams:

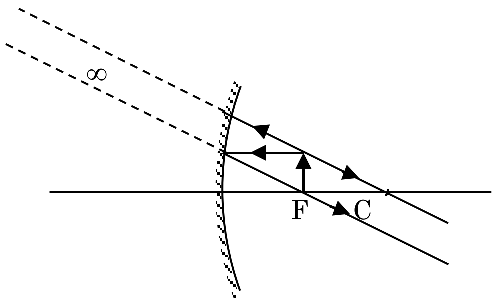
1. Rays passing through the centre of curvature are reflected back along their own paths.
2. Rays parallel to the principal axis are reflected through the principal focus.
3. Rays through the principal focus are reflected parallel to the principal axis.
4. A ray incident at the pole is reflected at the same angle with the principal axis

6.3: Images formed by concave mirror

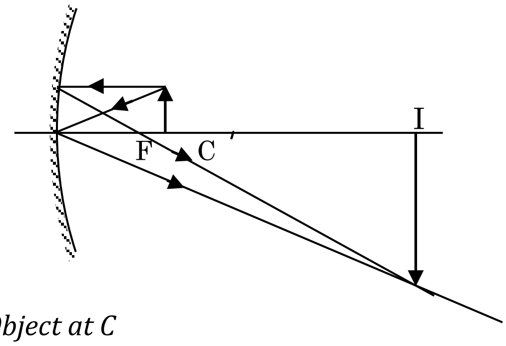


1. *Object between F and P*
The image is:
(i) behind the mirror
(ii) virtual
(iii) erect
(iv) magnified

2. *Object at F*
Image is at infinity

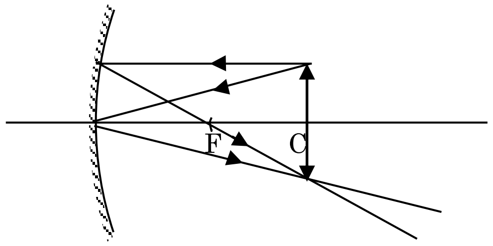


3. *Object Between F and C*



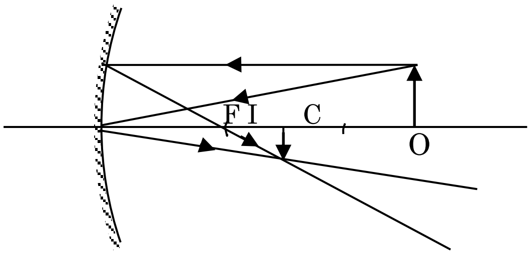
The image is:
(i) beyond C
(ii) real
(iii) inverted
(iv) magnified

4. *Object at C*



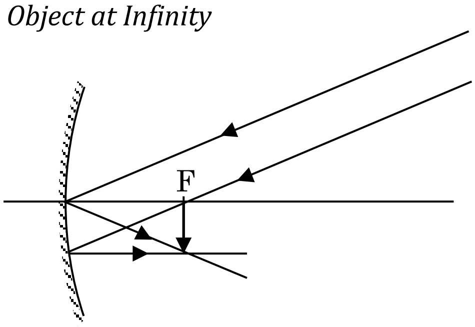
The image is:
(i) at C
(ii) real
(iii) inverted
(iv) same size as object

5. *Object Beyond C*



The image is
(i) between C and F
(ii) real
(iii) inverted
(iv) diminished

6. *Object at Infinity*

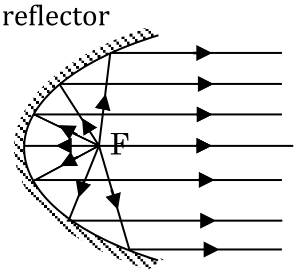


The image is
(i) at F
(ii) real
(iii) inverted
(iv) diminished

6.3: Parabolic reflector

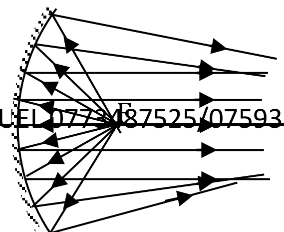
This is a symmetrical concave reflector whose surface is parabolic. It provides a wide parallel beam of light when the source is placed at its principal focus.

(i) Parabolic reflector



Wide parallel reflected beam

(ii) Spherical reflector



Only a narrow beam is reflected parallel

It is preferred to spherical reflector because if the source of light is placed at the principal focus of the spherical mirror of wide aperture, only a narrow beam is reflected parallel. The rest of the rays are not parallelto the principal axis. (Compare the figures (i) and (ii) above)

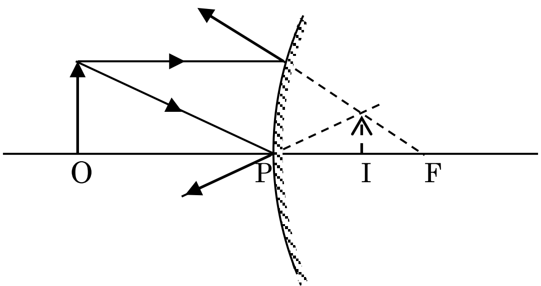
Parabolic reflectors are used in

- Headlamps of vehicles
- Searchlights
- Reflector telescopes

In headlamps and searchlights the purpose is to produce a wide parallel beam. In reflector telescopes the purpose is to bring a wide beam of light (e.g. from a point on a stars) to a single focus.

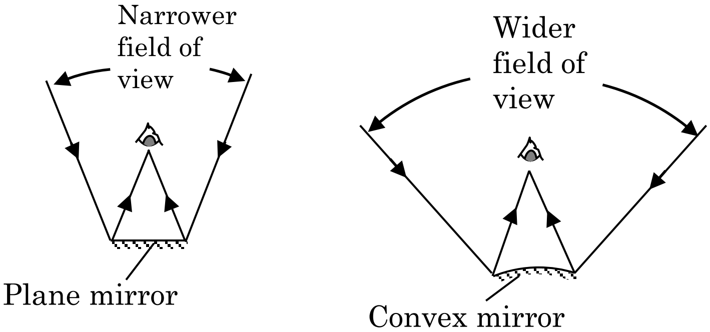
On the other hand a spherical mirror may be used as a shaving mirror because it can produce an erect magnified image.

6.4: Images Formed by a Convex Mirror



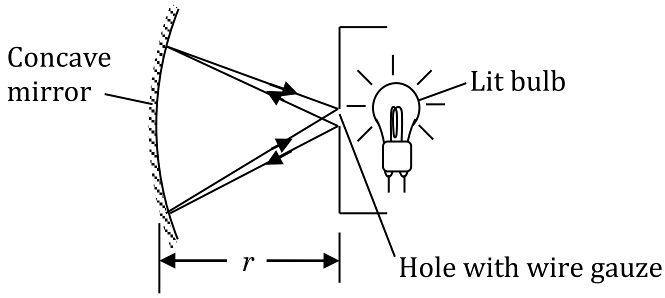
Whatever the position of the object, the image is:
(i) between P and F
(ii) virtual
(iii) erect
(iv) diminished

Compared to a plane mirror, a convex mirror of the same aperture has a wider field of view. See illustrations below. Because of this advantage and the characteristics of the images formed by a convex mirror, it is widely used as a driving aid on vehicles.



6.5: Determination of Radius of Curvature (and Focal Length) of a Concave Mirror

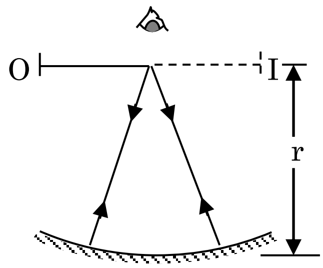
(a) ***Using an illuminated object:***



- The concave mirror is placed facing the wire gauze fixed in a hole in a white screen .
- The gauze is illuminated from behind and the mirror shifted along its axis until a sharp image of the gauze is formed on the screen.
- The distance between the pole and the screen is measured. It is equal to the radius of curvature, **r**.

The focal length, **f** can be calculated from $f = r/2$.

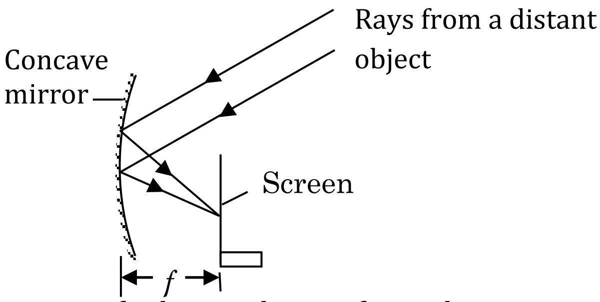
(b) ***By method of no parallax***



- The mirror is placed on a bench, facing up.
- A horizontal pin, **O** is held above the mirror with its tip on the axis of the mirror.
- The pin, **O** is moved up or down until it coincides in position with its image, **I**.
- The distance between the pin and the pole is measured and it is equal to the radius of curvature, **r**.

$$f = \frac{1}{2}r$$

(c)Simple method for focal length of a concave mirror



A sharp image of a distant object is focused on to a screen. The distance between the pole and the screen is measured and it is equal to the focal length.

(d)Measurement of object and image distances

The

Exercise 6

1. An object 3 cm high is placed 15 cm in front of a concave mirror of focal length 10 cm. By graphical construction find the
   (i) image distance
   (ii) magnification

2. An object 2 cm high is placed 10 cm in front of a converging mirror of focal length 15 cm. By graphical construction find the magnification produced.

3. When an object is placed 20 cm in front of a converging mirror, a real image of the object is formed 60 cm from the mirror. Determine the magnification, and by graphical construction find the focal length of the mirror.

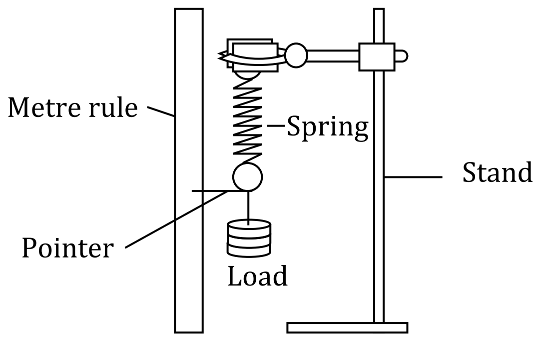
4. An object 4 cm high is placed 20 cm in front of a convex mirror of focal length 15 cm. By graphical construction find the
   (i) image distance
   (ii) magnification

7. MATERIALS AND STRUCTURES

ELASTICITY

A solid is said to be ***elastic*** if when it is deformed and then released, it regains its original dimensions. For deformation to occur, a force must be applied to the solid.
The normal force per unit area is called the ***tensile stress***.
The extension per unit original length of the solid is called the ***tensile strain***.
There is a relationship between the applied force and the extension produced as long as the force is not so great that the solid is permanently deformed. Experiments with springs can be used to investigate the relationship.

Experiment: *to Investigate the Relation between the Tension (force) and Extension of a spring*
Obtain a spring that has a pointer fixed to one of its ends.
(a) Fix the end of the spring that has no pointer in a clamp so that the spring hangs vertically.



(b) Support a metre rule vertically beside the pointer. Record the position of the pointer as read from the metre rule – call it P_o.
(c) Hang a mass m = 10 g on the lower end of the spring.

(d) Record the new position, P, of the pointer. Hence calculate the extension, e, of the spring, where $\boldsymbol{e = P - P_o}$.
(e) Repeat procedures (c) to (d) for values of m = 20g, 30g, 40g and 50g and fill the table shown below. Convert mass to force, F in newtons.

Mass, m(g)	Force, F(N)	P(cm)	e (cm)	$\frac{e}{F}$/ cm N^{-1}
10	0.1			
20				
30				

40				
50				

By studying the values of e/F or e/F, what conclusion can you draw about the extension and the force? Plot a graph of e against F or F against e. Notice that it is a straight line.
This leads us to **Hooke's law**, which states that ***the extension produced in an elastic material is directly proportional to the load (applied force) provided the elastic limit is not exceeded***.
Mathematically, $F \propto e$
Thus, $F = ke$
A spring balance uses this principle. The force per unit extension is known as the ***spring constant, k*** for the spring used and its S.I units is Nm^{-1}
The above experiment was, for simplicity, performed on a spring but the observations and conclusion do apply to a majority of elastic materials, especially metallic ones.

Note on springs:

For a spring of the same material, its stiffness depends on:
(i) the thickness of the wire from which it is made.
(ii) the diameter of the spring
(iii) the number of turns (length) of the spring
All these factors can be investigated by using various springs of the same material.

Here we shall be looking at behaviour of materials under the action of forces.

Question. Describe an experiment to verify Hooke's law.
Answer. The apparatus is as shown in the above experiment.
- A spring with a pointer is suspended from the retort stand. The initial position of the pointer, P_o is recorded against the metre rule.
- A mass (load), M is suspended from the lower end of the spring. The new position of the pointer, P is obtained.
- The extension, e is obtained from the expression $e = P - P_o$
- The experiment is repeated for various values of M and the corresponding extensions are obtained. Each time the load is removed to check whether the spring has not lost its elastic limit.
- A graph of M against e is plotted. A straight line passing through the origin is obtained which shows that load is directly proportional to extension hence verifying Hooke's law.
  N.B. The graph of weight, W against e can also be plotted and it is a straight line through the origin and W=mg.

Terms:

Strength:-
This is a measure of how much force a material can withstand without breaking. It depends on the length and diameter (area) i.e. long materials require a large force to break and larger objects require much force to break them.
***Hardness*:-**
This is the resistance to plastic (permanent) deformation.
Toughness:-
This is the resistance of a material to formation of cracks.
Stiffness:-
This is the ability of a material to resist being bent.
Malleability:-
This is the ability of a material to be made into laminars or small sheets.
***Breaking Stress*:-**

This is the force per unit area required to break the material.

Plastic Deformation:-

If the applied stress exceeds a certain value, the material becomes permanently deformed. This behaviour is exhibited by a wire when it is subjected to a tensile force. If the material remains permanently extended even when the force is removed, it is said to have undergone ***plastic deformation***. If more force is applied, the material eventually snaps.

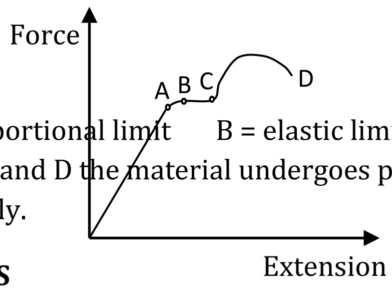
These factors should be considered when choosing a material for use:-

Strength, availability, safety, chemical behavior, cost.

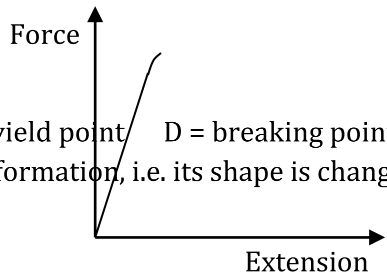
7.1: Ductile and Brittle Materials

A ductile material is one that can undergo both elastic and plastic deformation before it breaks.

OR is a material that can be hammered, rolled and moulded into other shapes without breaking. Examples of these include copper, mild steel, aluminium, etc. Ductile materials can be bent or forged into various shapes.
Brittleness is therefore the ability of a material to be hammered, rolled or moulded into other shapes without breaking. OR is ability of a material to undergo both elastic and plastic deformation before breaking.
On the other hand, a brittle material cannot undergo plastic deformation. It breaks suddenly as soon as its elastic limit is exceeded and it doesn't warn before breaking. Examples of these include glass, cast iron, concrete, etc. As a comparison, the graphs below show force against extension for:
(i) ductile material and (ii) brittle material



(i) Ductile material



(ii) Brittle material

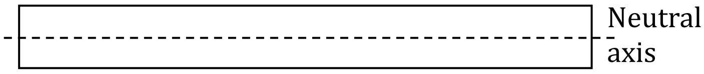
A = proportional limit B = elastic limit C = yield point D = breaking point

Between B and D the material undergoes plastic deformation, i.e. its shape is changed permanently.

7.2: BEAMS

A beam is a horizontal structure (usually of uniform cross-section) laid to bear loads along its length. OR it is the major structural material in a structure.
When a beam is loaded, the upper side is in compression while the lower side is in tension.There is a plane in which there is neither tension nor compression. This is where the neutral axis is found.

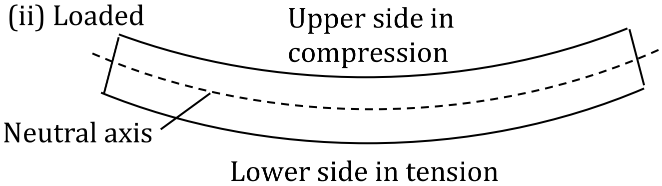
(i) Free

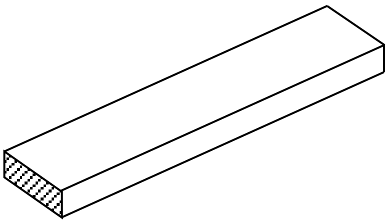


A crack is likely to start from the lower side.

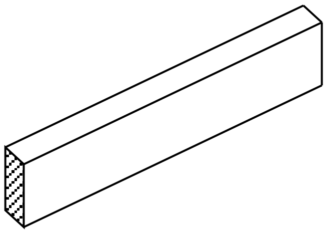
A beam is stiffer in an arrangement in which its material extends further below and above the neutral axis. For example,imagine a beam of rectangular cross- section in the arrangements shown below.

(ii) Loaded



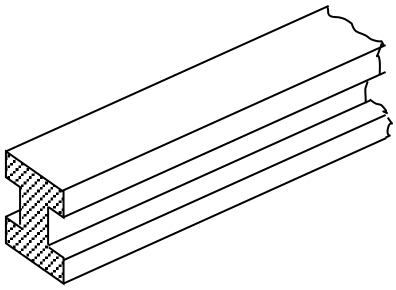


(i)Vertical side is shorter



(ii)Vertical side is longer

The beam will be stiffer in arrangement (ii) where the vertical side is longer.
When a beam is loaded, the force of compression or tension in its material increases with the distance from the neutral axis. So the extreme parts away from the neutral axis experiencea greater force than those near the neutral axis. Thus, to make a beam stiffer, the furthest parts from the neutral axis are made thicker. E.g. in I-beams – see figure below.



Reinforced Concrete Beams

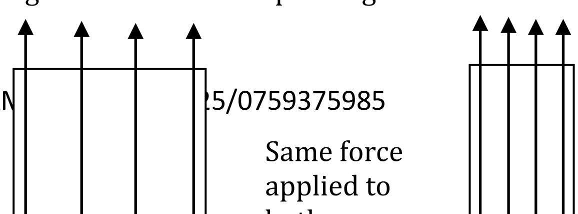
Concrete is a mixture of cement, sand and gravel mixed with water and allowed to set. Concrete is strong under compression, but weak in tension. So concrete beams are reinforced by imbedding steel bars in them (especially in the lower side which is always in tension)

7.2: STRUCTURES

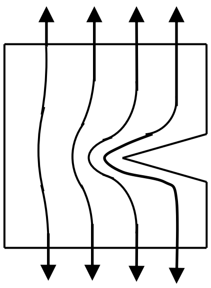
Structures for supporting loads are constructed by assembling members of different lengths fixed at different angles to each other. In such a structure some parts are in tension while the others are in compression. A ***tie*** is a girder in tension while a ***strut*** is a girder in compression. While a tie can be replaced by a rope or chain, a strut cannot.
A **girder** is a small piece of material used to strengthen the structure.
Identification of ties and struts.
A piece of string or rope is tie at the position of the girder to be studied. If the girder can be replaced by the string, then it is a tie i.e. if the ends of the girder move apart, then it is a tie but if the ends come closer (are not replaced by string), then the girder is a strut.
Note: A girder cannot be replaced by the string if the string placed in its position becomes slack or loose.

7.3: Notches and their Effects

A notch is a wedge-like dent in a solid material. **OR** is a weakest point (crack or cut) on a material.
A notch can be created by hard pressing a sharp object such as a knife on the hard material.
When a material is loaded, the force from the load travels through the material to the support and a stress is set up. The thinner the material is, the more bunched together are the lines representing the forces. This implies a greater stress. The material is more likely then to break.



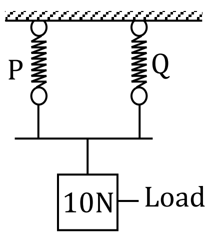
If a material has a notch in its side, the forces cannot be transmitted through the crack. The lines of force go around it.



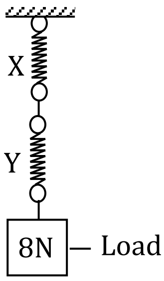
Near the tip of the crack the lines of force are very trenched together, indicating a much greater stress there.
A notch is a ***stress concentrator*** and initiates breaking of a material by breaking interethnic loads. If the tip is rounded, or made blunt, this reduces the stress concentration.

Exercise 7

1. A spring is found to extend by 2.0 cm when a load of 0.10 N is hung on it. Find the value of the force that will produce an extension of 5.0 cm.

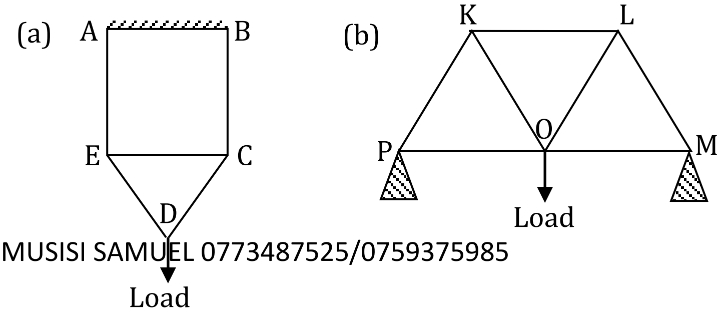
2. 

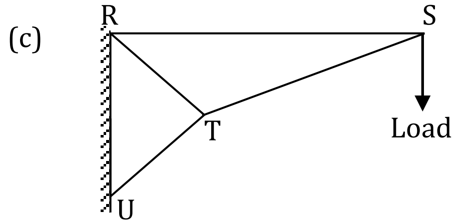
The figure shows two identical springs, P and Q, each of which extends by 3 cm when pulled by a force of 6N. In the arrangement shown find the extension of each spring.

3. 

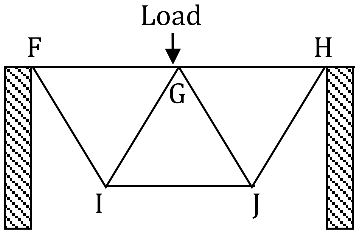
Two identical springs, X and Y, are connected in series as shown in the diagram. When a load of 8N is hung from the lower end of Y, the total extension of the combination is found to be 4 cm. Find the extension that a force of 12N would produce in each of the springs.

4. In the structures shown below, identify the ties and struts:





(d)



8. TEMPERATURE

This is a number expressing the degree of hotness of a substance on some scale. **OR** is the measure of the degree of hotness or coldness of an object or place on a given scale. (In other words it is the intensity of heat).
It is measured by a thermometer and its S.I unit is Kelvin (K) or degrees Celsius (^0C)

8.1: Temperature Scales

To measure temperature, a temperature scale must be established. This is done in the following steps:

1. Selection of some thermometric property whose value varies continuously with temperature. Some examples of thermometric properties are:
   - Volume or length of a liquid column
   - Pressure of a fixed mass of gas at constant volume.
   - Volume of a fixed mass of gas at constant pressure.
   - Thermoelectric emf
   - Electrical resistance of a wire

2. Choice of a suitable instrument in which to observe the property.
3. Choice and determination of two fixed points – the upper and lower fixed points

On the Celsius scale the lower fixed point is the temperature of pure melting ice and the upper fixed point is the temperature of steam at standard atmospheric pressure.

4. Subdivision of the fundamental interval into 100 divisions (for a Celsius scale)

The difference between the two fixed points is known as the ***fundamental interval.***

8.2: Thermometers

Liquids-in-Glass Thermometers

These use the fact that a liquid expands when heated. So, the property employed is volume. Examples of such thermometer include:

- mercury-in-glass thermometers
- alcohol-in-glass thermometers

NB: Water cannot be used as a thermometric liquid because

(i) it exhibits anomalous expansion

(ii) it freezes at 0^oC and boils at 100^oC , i.e it has a rather narrow temperature range in which it exists as a liquid.

(iii) it has high specific heat capacity

(iv) it is transparent and sticks to glass

Choice of a liquid for Thermometers

This depends on the range over which temperature is to be measured. For example where the temperatures go for below ice point alcohol is preferred since it freezes at -115°C and boils at 78°C.

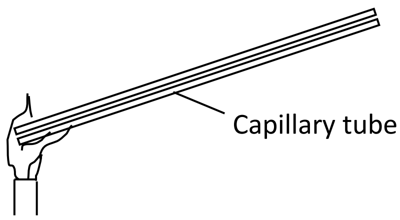
Advantages of Mercury over Alcohol

Mercury	Alcohol
(i) Opaque and easily seen (ii) Does not vaporize (iii) Does not wet glass (iv) Better conductor of heat, therefore responds more rapidly	- transparent and has to be coloured. - vaporizes easily - sticks to glass - inferior conductor of heat.

However, alcohol has an advantage over mercury when it comes to expansivity, since its expansivity is about six times that of mercury.

Construction of a Mercury-in-Glass Thermometer

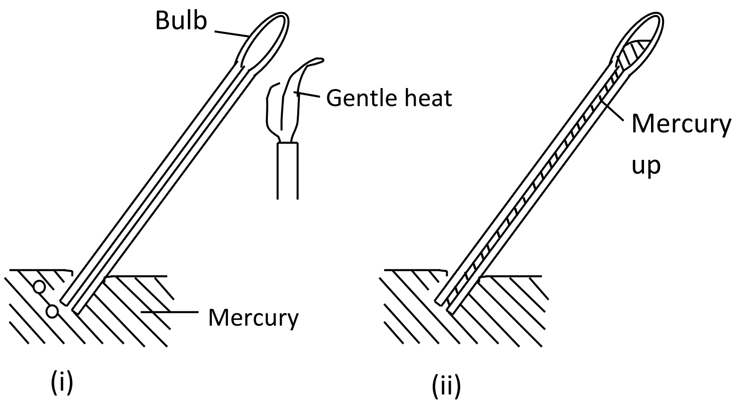
1. *Formation of Bulb*
- One end of a clean capillary tube is heated in a bunsen flame until it softens and seals that end.



- The tube is withdrawn from the flame and by repeated blowing from the cool end, a bulb of desired size is formed.

2. *Filling with Mercury*

- The open end is now placed beneath the surface of some mercury and the bulb is gently heated. (fig (i))



On cooling, the air contracts and some mercury runs up into the bulb. (fig (ii))
- The thermometer is taken out and the bulb heated to boil the mercury so as to expel all the air.

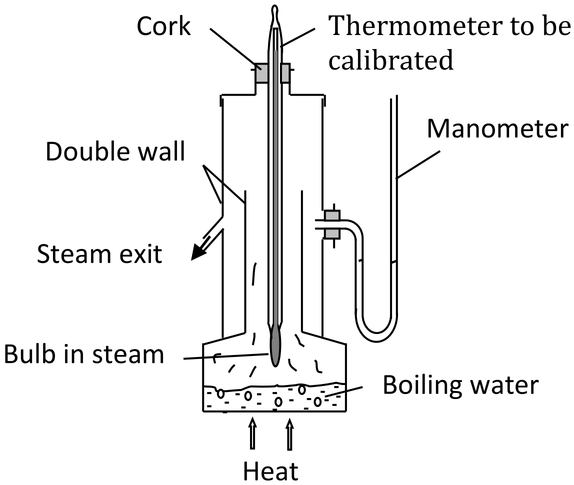
- Then the open end is quickly inverted again in mercury. On cooling, mercury rises and completely fills the bulb and stem.

3. *Sealing the thermometer*
- The thermometer is now heated to a temperature above the maximum for which it is to be used and while at that temperature its open end is softened by a blow pipe flame and sealed.

Establishment of a Temperature Scale

This involves the following steps:

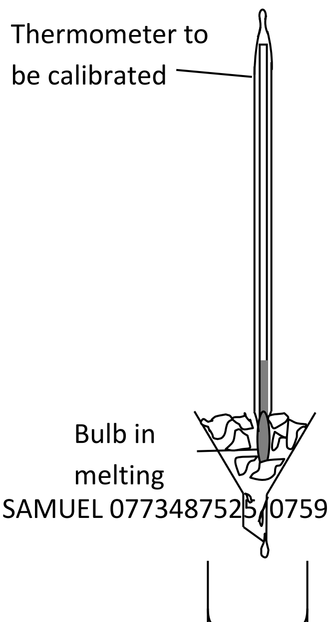
(a) *Determination of the upper Fixed point*
A hypsometer is used.



The bulb of the thermometer should NOT be allowed to dip into the boiling water. This is because if the water is not pure it will be boiling at a different temperature from that of the steam
- Water is steadily boiled to generate steam that surrounds the bulb.
- When the thread, seen above the cork, remains steady for some time its level is marked on the stem. This mark gives the upper fixed point.

The double walls reduce loss of heat and the resulting cooling of the steam and the manometer tests the equality of the pressure inside to the atmospheric pressure.

(b) *Determination of the Lower Fixed Point*



- The thermometer is placed in a glass funnel full of melting ice.
- When the mercury thread, seen just above the ice, remains steady for some time, its position is marked on the stem. This mark gives the lower fixed point

c) *Calibration*

For a Celsius scale the space between the two marks on the stem is divided into 100 equal spaces each representing 1°C with the lower mark given a value 0°C.

Numerical Example:

The length on the stem of a mercury-in-glass thermometer between the lower and upper fixed points is 18 cm.

(i)When the bulb of this thermometer is dipped in a liquid the mercury level in the stem is found to be 10 cm above the lower fixed point. What is the temperature of the liquid?

(ii) How far above the ice point will the mercury level be when the bulb is in a region at a temperature of 45°C?

Solution:

$$\text{(i)Temperature} = \frac{\text{Length of thread above ice point}}{\text{Length of the fundamental interval}} \text{ x } 100^{o}\text{C}$$

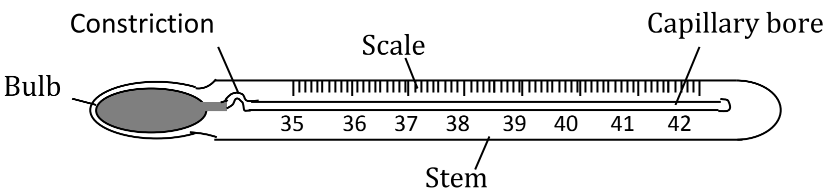
$$\therefore \theta = \frac{10}{18} \text{x } 100 = 55.6^{o}\text{C}$$

$$\text{(ii)} \frac{\text{Length of thread above ice point}}{\text{Length of the fundamental interval}} = \frac{\text{Temperature}}{100}$$

$$\therefore \quad \text{Length of thread above ice point} = \frac{45}{100} \text{x } 18 = 8.1 \text{ cm}$$

Special Thermometers

1. *The Clinical Thermometer*

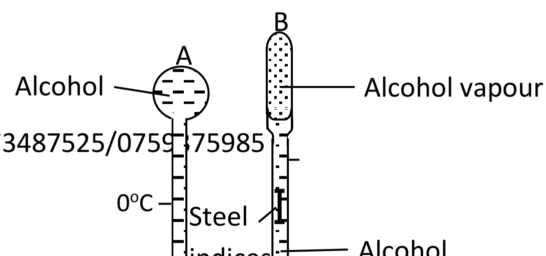


The range of this thermometer is 35°-42° because the human body temperature cannot lie outside this range. Such a short range makes the scale very sensitive since a single degree on it is large enough to be subdivided. The high sensitivity on this thermometer is achieved by manufacturing it with a large bulb and a narrow bore.

The constriction near the bulb prevents mercury from flowing back before the temperature is read.

It is not advisable to sterilize this thermometer in boiling water, since this would require the mercury to expand far beyond the space provided in the bore; this would just burst the bulb.

2. *Six's Maximum-Minimum Thermometer*



It is used to record the maximum and minimum temperatures during a day.
Here the thermometric liquid is alcohol contained in bulb A. When the temperature rises, the alcohol in bulb A expands forcing the mercury round and pushing the steel index in right hand limb up. This index records the maximum temperature reached. Bulb B contains saturated alcohol vapour, some of which condenses as it is compressed.
When the temperature falls, the alcohol in bulb A contracts. This causes the mercury in bulb A to contract making the mercury in the left hand side to rise thereby pushing up the steel index there. This index records the minimum temperature reached.
The indices can be reset to the mercury menisci once again by using a magnet.

8.3: The Thermodynamic Temperature Scale

This scale has only one fixed point – the ***triple point of water***. It is independent of the properties of the substance used in the thermometer.
The other scales are dependent on the properties of the substance used and therefore different thermometers using different properties may give different readings for the same temperature except at the fixed points.
Triple point of water is the temperature at which pure ice, pure water and pure water vapour exist in equilibrium.

On the thermodynamic scale the temperature is measured in kelvin (K). The ice point is about 273K. The temperature on this scale is known as the ***absolute temperature.*** In general, if T is the absolute temperature and θ the corresponding Celsius temperature, then

$$T = 273 + \theta$$

e.g $50^0C = 273 + 50 = 323\ K$

The zero of this scale is the ***absolute zero***, which is theoretically the lowest possible temperature. It is assumed that at the absolute zero a substance has lost all heat.

Test Yourself

1. Define each of these: temperature, thermometer.
2. List the steps involved in establishing a temperature scale.
3. What is the absolute zero of temperature?
4. For a liquid-in-glass thermometer, what are the governing factors for choosing the liquid to be used?
5. Why is water NOT suitable as a thermometric liquid?
6. In what circumstances could an alcohol thermometer be preferred to a mercury one?

7. On the hypsometer, what is the use of the manometer? Why should the bulb of the thermometer not dip in the boiling water?
8. When determining the lower fixed point of a mercury-in-glass thermometer, why should the ice be contained in a funnel and not in a beaker?
9. What is meant by sensitivity of a thermometer?
10. How would you increase the sensitivity of a liquid-in-glass thermometer?
11. Explain the fact that a thermometer may be quick-acting and yet not very sensitive.
12. Why is the range of a clinical thermometer usually
$35^oC - 42^oC$?
13. What is the use of the constriction on a clinical thermometer?
14. Why are the indices of a Six's thermometer made of steel and not any other metal like copper?

9. HEAT TRANFER

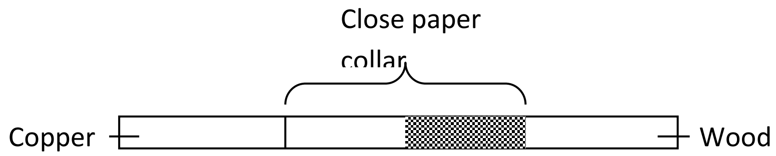
Heat is energy that flows from one body to another due to a temperature difference between them. (It is the energy possessed by a body due to the vibration and spacing of its particles)

9.1: CONDUCTION

Introduction

This is heat transfer by means of a stationary material medium.
Most metals are good conductors of heat, silver being the best followed by copper.
A metallic chair feels colder than a wooden one in same room. This is because the metal of the chair is a better conductor of heat than wood so it conducts away heat from the user's body much faster.

Experiment: To Demonstrate the Difference in Conductivities of
Copper and Wood.



- A piece of paper is tightly wrapped round the joint so that if covers the copper and wood equally.
- The rod is passed several times through a bunsen flame.

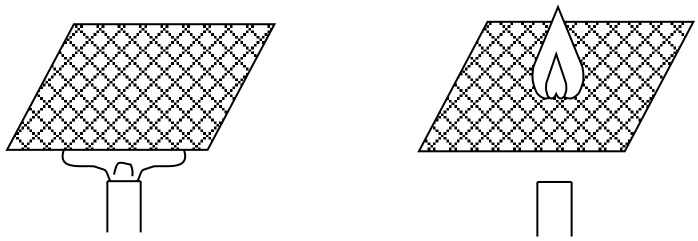
Observation: The part of the paper on the wood gets charred while that over copper remains unharmed.

Explanation: Copper conducts away heat from the paper much faster than the wood does. So the temperature of the paper over copper remains low while that of the paper over wood rises.

Effects of a Good Conductor near a Flame

Wire gauze is placed about 5cm above the burner and the gas is turned on

If it is lit underneath the gauze, the flame does not pass through the gauze. If instead the gas is lit above the gauze after the gauze has cooled, the flame remains on top.

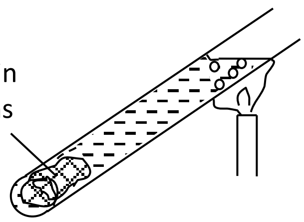


(i) The flame fails to pass through the gauze

(ii) The flame stays on top of the gauze

Explanation:
In case (i) the gauze conducts away heat from the region of the gauze so fast that the gas above it is cooled below ignition point.
In case (ii) the rapid conduction by the gauze keeps the gas in contact with the underneath below ignition point. This behaviour was applied in the Davy Safety lamp

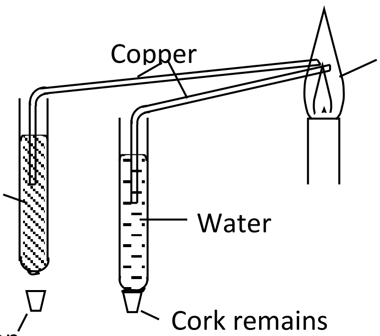
Experiment: To show that Water is a poor Conductor of Heat.



Ice is wrapped in wire gauze and placed in a test tube which is then filled with water. The gauze helps the ice to sink to the bottom. When the water is heated near the top, it boils locally while ice at the bottom remains unmelted. This shows that heat could not sufficiently be conducted from the top to the bottom by the water. Ice is kept at the bottom to eliminate convection from participating.

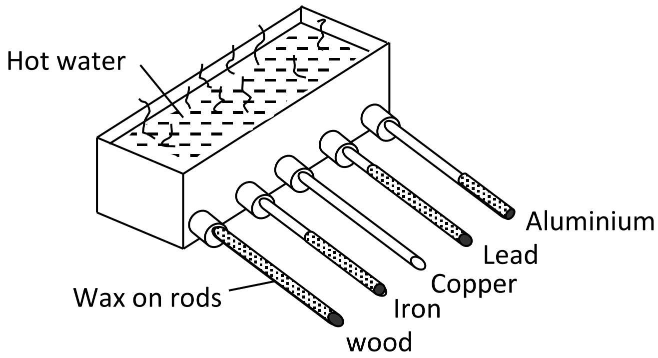
***Experiment**: To Show that Mercury is a better Conductor of Heat than Water*

- Two test tubes are filled with equal volumes of mercury in one tube and water in the other and a cork is attached to the bottom of each using wax.
- The test tubes are held vertical in stands.
- Thick identical copper rods are bent and one end of each dipped into one of the liquids while the free ends are brought together in a flame



In a very short time the wax on the mercury-filled tube melts and the cork falls off while that on the water-filled one remains for a very long time.
Since heat is equally conducted to each liquid by the copper rods, mercury is a much better conductor of heat.

Comparison of Thermal conductivities of Solids



- Rods of different materials but of the same dimensions are passed through corks inserted in holes in the side of a metallic vessel. The rods are coated with wax.
- Boiling water is poured into the vessel to heat the ends of the rods equally.

After some time it is observed that wax melts to different distances along the rods.

Which metal does the above set-up show to be the best conductor?

Uses of Different Materials

Both good and bad conductors of heat have useful applications. In situations where heat loss or gain is to be prevented, a poor conductor is used to cover the container- e.g in fridges, ovens, water heaters, etc.
A material of low conductivity used for preventing heat transfer is called **lagging.**
Handles of heating appliances are made of poor conductors.

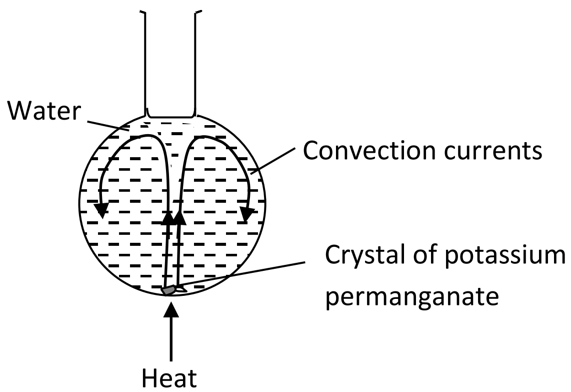
Questions: Why are woolen materials bad conductors of heat?

9.2: CONVECTION

This is heat transfer facilitated by movement of the particles of the medium. It occurs in fluids.

Convection Currents in Water

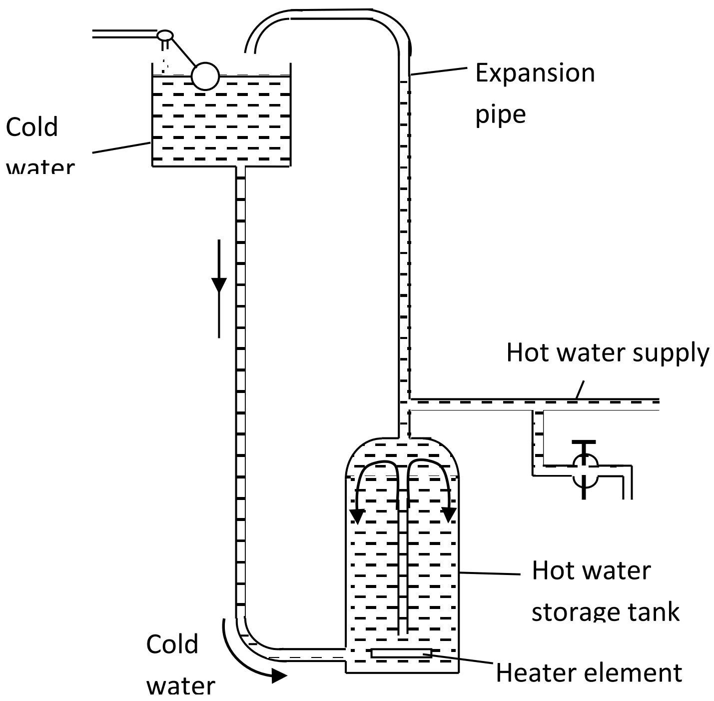
A glass flask is filled with clear water up to the neck. Using a glass tube, a few crystals of potassium permanganate are placed at the bottom of the flask. The water is gently heated at the bottom.



*Observation:*Coloured streams are seen to rise to the top and descend at the sides.

Explanation:
When the portion of the liquid at the bottom is heated, it expands, becomes less dense and rises to the top. The cooler and denser liquid flows to replace the risen liquid.
So the liquid circulates in the container and forms currents. This continues until all the liquid boiled.

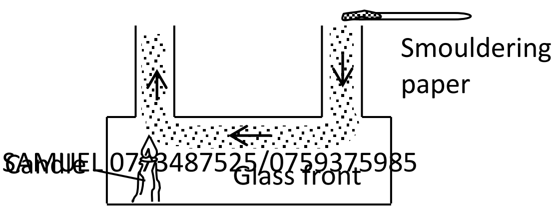
The Domestic Hot-water Supply System.



Hot water rises to the top of the hot water storage tank. Therefore hot water to the taps is drawn from the top of this tank and cold water to replenish it enters at the bottom. Whatever water is heater keeps rising to the top.
The expansion pipe provides room for the heated water to expand into and also permits dissolved air to escape.

Ventilation by Convection

This may be demonstrated using the following set-up consisting of two wide glass tubes projecting from the top of a rectangular box having a transparent front.



- A lit candle is placed at the base of one of the tubes.
- A smoldering piece of paper is placed above the edge of the other tube.
It is observed that smoke is drawn down the tube and expelled via the one above the candle.
Explanation: The air above the candle is heated, so it becomes less dense and rises. It is replaced by the smoke, which is also heated in turn and rises

Ventilation is an application of convection. It is a process of providing cool fresh air to an enclosure e.g a room or building. When a room is heated up by the occupants, the warm air rises, escaping through the ventilators, and is replaced by fresh air flowing through the windows.
Question: Why are ventilators constructed above windows and doors?
How does a chimney make life more comfortable in the kitchen?

Effects of Convection

- Wind
- Land and sea breezes

Land and Sea Breezes:

(i) Sea breeze (During day) (ii) Land breeze (At night)

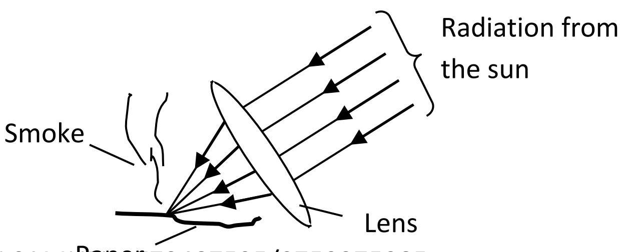
Generally the specific heat capacity of the land is lower than that of the sea and sea water keeps on mixing its warmed layers with cooler ones. So, during the day the land is heated by the sun to a higher temperature than the sea. Air over the land is therefore heated, expands and rises while cooler air blows in from the sea to replace it – Hence Sea Breeze.
Wind in the upper atmosphere blows in the opposite direction to complete the circulation.
At night the land cools rapidly while the temperature of the sea remains unchanged. So the land becomes cool while the sea remains warm. Therefore warm air over the sea rises while cool air blows from the land to replace it. – hence land breeze.

9. 3: RADIATION

This is heat transfer by electromagnetic waves. No material medium is required.

Similarity to Light

Heat from the sun reaches the earth by radiation. It travels in the same way as light does and behaves in many ways like light. For example, a lens converges heat in the way it does light.

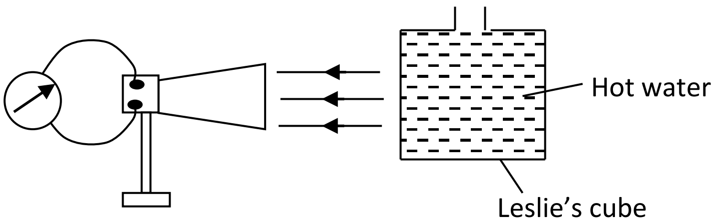


On a sunny day, when a converging lens is held in sunshine above a piece of paper at a height such that a bright spot appears on the paper, the paper begins to smoke after a short time. This shows that the lens converges heat to the same spot as it does light.

Radiation by Different Surfaces

Experiment: To Compare Radiation from Different Surfaces

A hollow copper cube, each side of which has a different surface is filled with hot water.
- A thermopile is placed at the same distance from each face in turn while observing the deflection of the galvanometer.



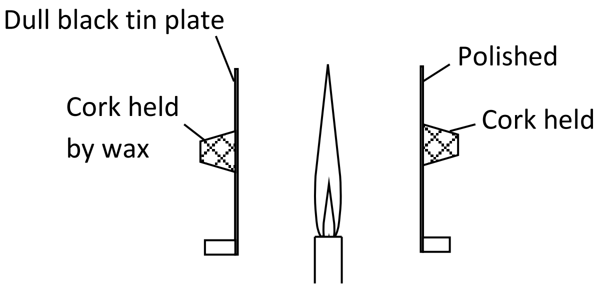
Observation: The deflection is greatest when the thermopile is facing the dull black side, and least when facing the polished shiny side.

Conclusion: Rough, dull black surfaces are good radiators while smooth shiny ones are poor radiators.

More about Radiation:
It is important to note that in general, that the rate at which a body radiates energy depends on:
(i) its temperature
(ii) nature of its surface
(iii) surface area

Absorption by Different Surfaces

Experiment: *To Compare Absorption of Radiation by Different Surfaces*
- Two sheets of tin plate, one polished and the other dull black, are set up vertically a short distance apart.
- On the back side of each is fixed a cork by means of wax.
- A burner is placed midway between the plates.

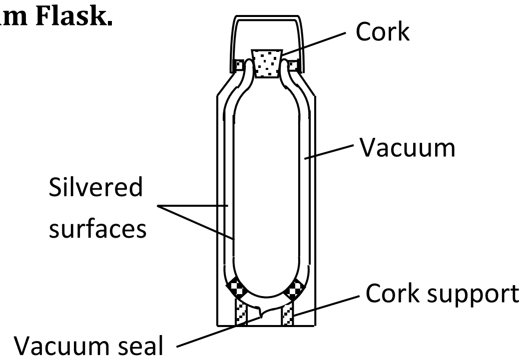


- As the burner continues burning, eventually the wax on the back of the dull black plate melts and the cork falls while that on the polished plate remains.

Conclusion: The dull black plate must have absorbed heat faster than the polished one. So, dull black surfaces are better absorbers than polished ones.

In general, good radiators are good absorbers of radiation and vice versa.

The Vacuum Flask.



The main features may be summarised in a table as follows:

PART	FUNCTION
Vacuum	To eliminate heat transfer by convection and conduction
Silvered surfaces	To minimise heat transfer by radiation
Top cork	To stop convection and minimise conduction

Green House

The sun and other hot bodies emit radiation of short wavelength. This radiation is able to enter the green house through the glass walls. The objects inside the house absorb the radiation and have their temperature raised so that they also radiate heat. But the radiation from the objects inside the house is of longer wavelength and therefore is unable to pass through the glass of the walls. So the temperature inside the green house rises and the house feels warm.

Global Warming (Green House Effect)

The Earth's atmosphere behaves like a green house. Radiation from the sun easily passes through the atmosphere and is absorbed by the earth. The Earth warms up and re-radiates energy but of longer wavelength. So the atmosphere, consisting of water vapour, carbon dioxide and other gases, absorbs this energy and re-radiates it back to the Earth. Thus the Earth gets warmer than it would be. Today global warming has become an important issue.

Test Yourself

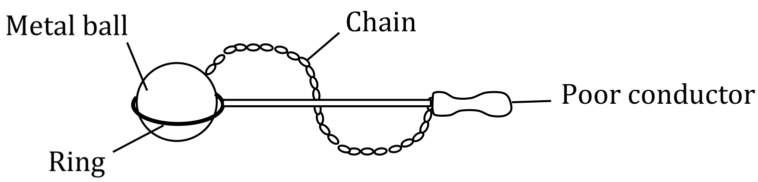
1. Distinguish between heat and temperature
2. What is meant by each of the following modes of heat transfer?
   - conduction, convection and radiation

3. Explain why a metallic chair feels colder than a wooden one in the same room.
4. In the copper-wood experiment to demonstrate difference in conductivities, explain why the paper wrapped round the wood gets charred first.
5. Explain why when gas from a burner is lit underneath a metallic wire gauze, the flame does not cross to the top of the gauze. Name one application of this behaviour.
6. In the experiment to demonstrate the poor conductivity of water, why is the ice wrapped in a wire gauze?
7. In order to warm a liquid, heat is applied at the bottom. Explain why.
8. Explain how a sea or land breeze comes about.
9. How would you show that heat radiation travels in the same way as light.
10. Explain why bodies of appliances that heat up as they work are perforated with holes.
11. What colour would you choose for a car radiator? Why?
12. Name the main parts of a vacuum flask stating the purpose each serves.
13. Why is global warming referred to as 'green house effect"?

10. THERMAL EXPANSION

10.1: Expansion of solids

The Ball and Ring Experiment to Demonstrate Expansion of Solids

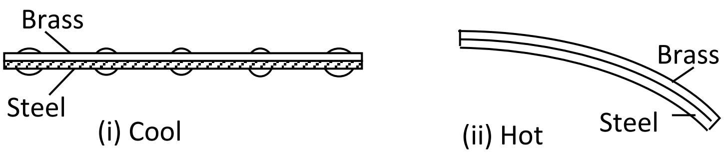


- At room temperature the metal ball can slip through the ring.
- When the ball is heated alone and then tried in the ring it fails to go through.
- On cooling, the ball can slip through the ring as before.

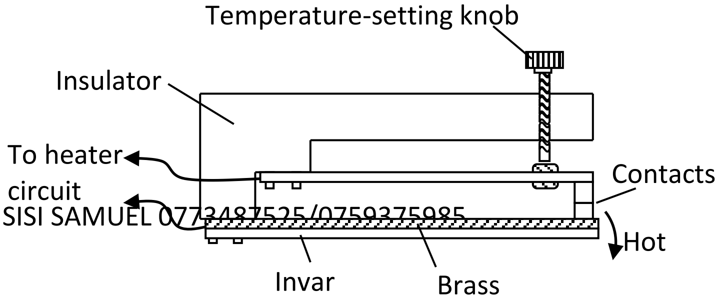
These observations indicate that the ball expands when heated, and it contracts on cooling. This can be generalised for all solids.

The Bimetallic Strip

It is a strip consisting of two strips of metals of different expansivities laid side by side in tight contact e.g brass and steel

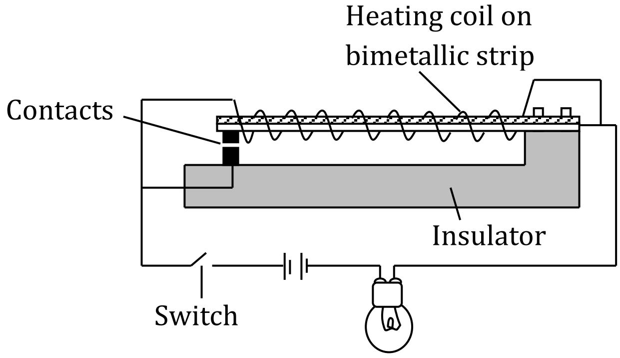


In this case, brass having a higher expansivity than steel, elongates more causing the strip to bend towards the steel.
Bimetallic strips are widely used in the thermostats for temperature control e.g in cookers, flat irons, e.t.c
The diagram below shows a thermostat for controlling an electric heater.



The circuit is complete when the contacts are closed. As the temperature rises, the differential expansion of invar and brass the bimetallic strip makes the strip bend away from the contacts thus opening them and current stops flowing in the heater.
On cooling, the bimetallic strip straightens out and remakes the contacts switching on the heater current again and the cycle is repeated.
The temperature at which the contacts open is set by the temperature-setting knob.

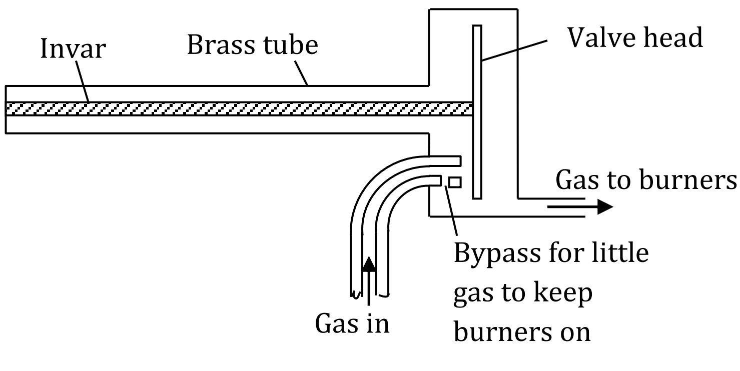
Flasher Unit



At the beginning the contacts are open. On switching on, the current flows through the heating coil. However, owing to the high resistance of the coil, the current is too small to light the bulb but enough to heat the bimetallic strip which bends downwards and closes the contacts.
This connects the lamp to the full voltage and shorts out the heating coil. So the bulb lights up but the strip begins cooling and after a short time the strip straightens out and separates the contacts and the bulb goes off. The cycle repeats.

Gas thermostat

We may look at a thermostat for controlling the oven temperature. It consists of a brass tube enclosing a coaxial invar rod housed in the oven chamber.

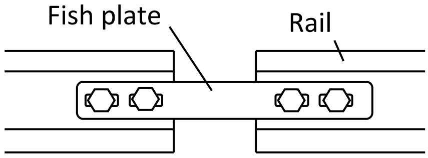


Action
As the temperature of the oven rises, both the brass tube and the invar rod expand; but the brass tube elongates more than the invar. So, the invar rod is dragged to the left carrying along with it the valve head and narrowing the gas passage. At a certain temperature the valve head

closes the gas passage completely leaving only a little gas going through the bypass just to keep the burners on. The oven then begins cooling but the higher rate of contraction of the brass tube causes the valve head to be pushed to the right, thus opening the main gas passage. This way the thermostat prevents the temperature of the oven from rising indefinitely but maintains it at a more or less constant value.

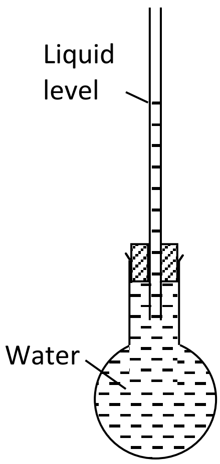
Disadvantages of Solid Expansion

Expansion of solids is responsible for cracking of continuous concrete road surfaces or buckling and tearing of long continuous metal sheets or rails.
Under hot weather expansion occurs and these structures, if fixed, buckle. In cold weather contraction occurs and the structures, if restrained, crack or tear.
To avoid these damages short pieces with gaps in between are used. E.g railway lines are constructed with gaps, perimeter walls are segmented.



10.2: Expansion of Liquids

Demonstration:

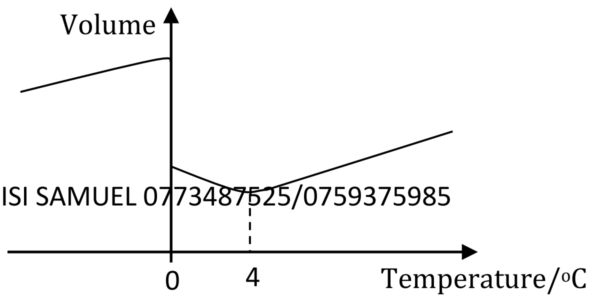


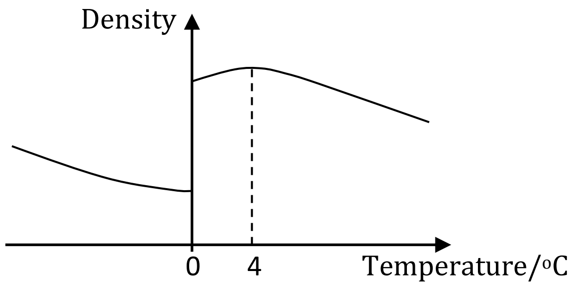
A flask is completely filled with water and sealed with a cork which has a narrow tube projecting through it.
The flask is then immersed in a hot bath. The water level at first falls andthen begins to rise.The flask gets heated up and expands before the water does. So the water level falls at first.Soon the water gets the heat and since the expansivity of the wateris greater than that of glass, itslevel in the tube rises.

10.3: Anomalous Expansion of Water

Most substances would expand continuously when heated and contract continuously on cooling. However, water has a minimum volume (and a maximum density) at 4°C. Therefore if it is cooled from 4°C, it expands instead of contracting. And at 0°C, when it freezes, the ice formed occupies a greater volume than its water at 0°C. This is an abnormal expansion exhibited by water. Thus the ice is less dense and floats on water.
Below are graphs of
(i) volume vs temperature and
(ii) density vs temperature

(i)





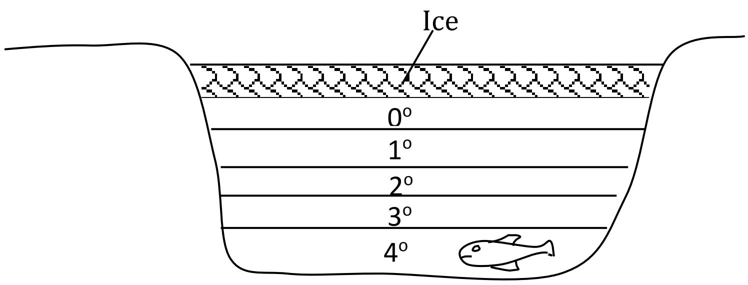
Effects of Anomalous Expansion of Water

1. A glass bottle, filled completely with water and sealed, breaks apart when the water freezes to ice. This is because the ice formed requires a greater volume; so it bursts the bottle.

2. Frost Heave: This is the bulging of a floor and walls of a building caused by expansion of the water in the subsoil as it freezes to ice. The ice occupies a greater volume.

3. Floating of Ice on water: Because ice occupies a greater volume, its density is lower than that of water. So it floats on water.

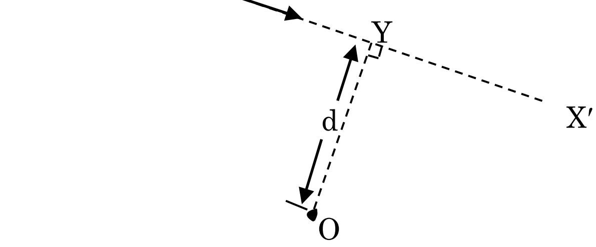
Biological Importance of Anomalous Expansion of Water



In winter, as water cools, that which reaches 4°C sinks to the bottom. Cooler water settles on top. As ice forms, it floats on top since it is less dense than water.
Ice itself is a poor conductor of heat and therefore considerably insulates the water below it from cooling further even if the temperature above it may be much lower than 0°C. So, aquatic life continues beneath.

11. MOMENTS

The moment of a force about a point is the product of the force and the perpendicular distance of its line of action from the point.
For example, imagine a force F acting along a line XX′

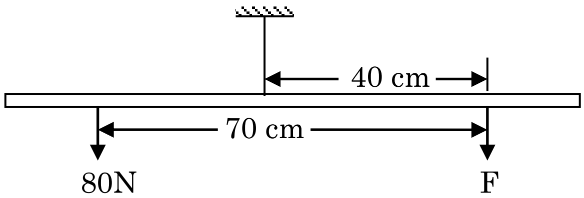


The moment of F about a point O is M = F x d, where d = distance OY and OY is a line perpendicular to XX'
Applications of moments include beam balances, steel yard weighing scale, spanners, sea saw, etc

11.1: The Principle of Moments

If a rigid body is in equilibrium, then the sum of the clockwise moments about any point is equal to the sum of the anticlockwise moments about the same point.

Example:
The bar shown below is in equilibrium.



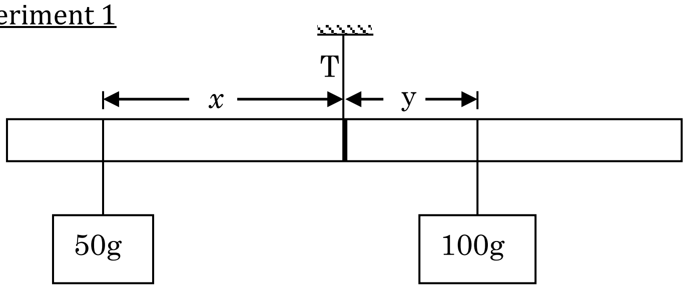
Find the force F.
Solution:
We shall take moments about the point of support. F tends to turn the bar clockwise about the point of support. So it is said to have a clockwise moment about that point. On the other hand, the 80 N force tends to turn the bar anticlockwise about the same point. So it has an anticlockwise moment about the same point.
The 80 N force is (70 – 40) cm from the point of support. Thus, applying the principle of moments:

$$F \times 40 = 80 \times 30$$

$$\therefore \quad F = \frac{80 \times 30}{40} = \underline{\underline{60\ N}}$$

Investigation of the Principle of Moments

<u>Experiment 1</u>



a) By means of thread T, hang a metre rule so that it balances horizontally with its scale facing you.
b) Hang a 50g mass from the 10cm mark. Determine x, the distance of the 50g mass from T.
c) Find the distance y where 100g must be hung in order to restore equilibrium.
d) Repeat procedure (b) to (c) when the 50g mass is hung at 15cm, 20cm, 25cm, and 30cm marks and fill the table below.

Position of 50 g				

mass from zero mark/cm	x/cm	y/cm	50x	100y
10				
15				
20				
25				
30				

e) Comment on the values in the last two columns for each position of the 50g mass.
f) What conclusion can you draw?

Experiment 2

a) By means of a thread T, hang the metre rule so that it balances horizontally with its scale facing you.
b) Hang a 20g mass from the 5cm mark. Determine distance x of the 20g mass from T.
c) Hang a 50g mass from the 10cm mark and determine its distance y from T.
d) Find the distance z from T where a 100g mass must be hung to restore equilibrium.
e) Repeat procedures (c) to (d) when the 50g mass is hung at the 15cm, 20cm and 25cm marks and fill the table below.

Position of 50 g mass from zero mark/cm	y/cm	z/cm	50y	20x + 50y	100z
10					
15					
20					
25					

f) What conclusion can you draw from the experiment?

11.2: Centre of Gravity

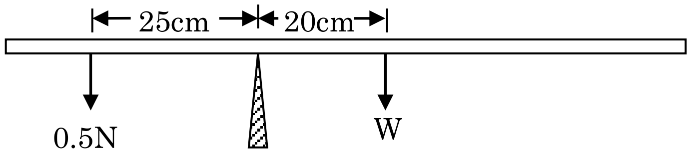
This is the point through which the weight of the whole body appears to act. The table below gives examples of bodies and location of their centres of gravity.

Uniform Body	Position of Centre of Gravity
Square	Intersection of its diagonal
Rectangle	Intersection of its diagonal
Circular	Centre of disc
Cylinder	Mid-point of its axis

Example:
The figure shows a uniform metre rule in horizontal equilibrium supported at the 30cm mark while weight of 0.5N hangs from its 5cm mark. Find the weight of the metre rule.

Solution

The first task is to indicate all the forces acting on the metre rule and the distances at which they act.
Let the weight of the metre rule be W. It acts through the mid-point of the rule



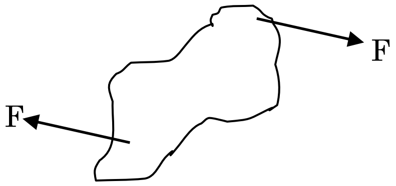
Taking moments about the point of support:

$W \times 20 = 0.5 \times 25$

$\therefore \quad W = \frac{0.5 \times 25}{20} = \underline{\underline{0.625 \text{ N}}}$

11.3: Couples

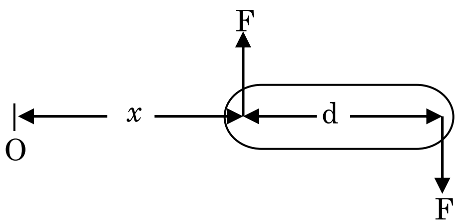
A couple is a pair of equal but opposite parallel forces having different lines of action.



A couple rotates a body on which it acts. For example, when turning a tap, a couple is applied.

Moments of a couple

Imagine two parallel forces, each of magnitude F, separated by a distance d and acting on a body as shown.



Then, taking moments about any point O we have,
Sum of moments about point O = moment of the couple
$\therefore\ F(d+x) - Fx = Fd$
The moment of a couple is called the ***torque***

Example:
A couple of forces each 80N and separated by a distance of 0.6m acts on a body. Find the moment.
Solution:
Moment of couple = 80×0.6 = $\underline{\underline{4.8 \text{ N m}}}$

11.4: Parallel Forces:

This is a group of forces having parallel lines of action.

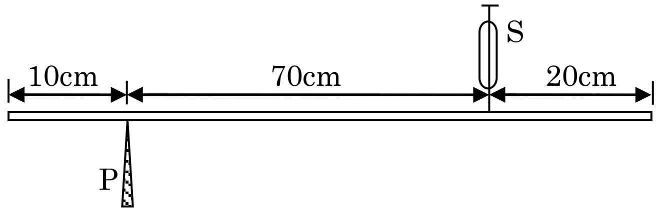
Conditions of equilibrium:

1) The sum of the clockwise moments about any point is equal to the sum of the anticlockwise moments about the same point.

2) The sum of the components of the forces in one direction is equal to the sum of the components of the forces in the opposite direction.

Examples

1. The figure shows a uniform horizontal bar supported by a peg P and spring balance S.

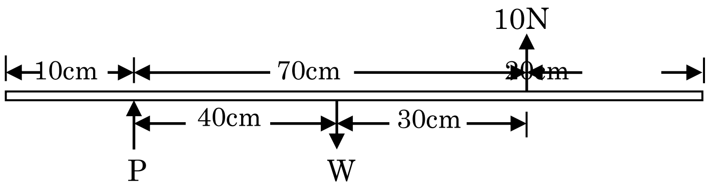


The spring balance reads 10N. Find

(i) The weight of the bar
(ii) The reaction of the peg

Solution:

The first task is to show all the forces acting on the bar remembering that, since the bar is uniform, its weight acts through the mid-point, which is 50 cm from either end.



(i) Let W be the weight of the bar and P the reaction of the peg.
Then, taking moments about the peg, we have:

$$W \times 40 = 10 \times 70$$

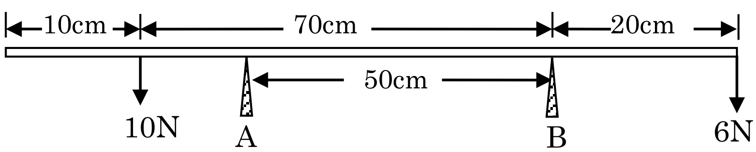
$$\therefore \quad W = \frac{10 \times 70}{40} = \underline{\underline{17.5\ N}}.$$

(ii) The sum of the upward forces = sum of the downward forces

$\therefore P + 10 = W$

$\therefore \quad P = W - 10 = 17.5 - 10 = \underline{\underline{7.5\ N}}.$

2. The diagram shows a uniform bar of weight 0.8 N resting on pegs A and B.

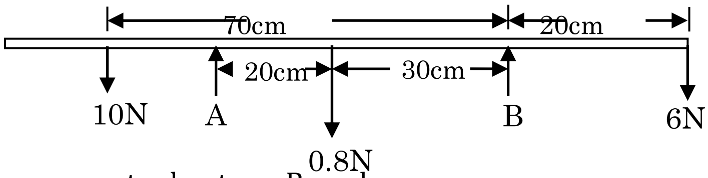


Find the reaction at each peg.

Solution:

The length of the bar is 10 + 70 + 20 = 100 cm.
Since the bar is uniform, its weight acts through its mid-point. We can therefore redraw the bar to show all the forces acting on it as follows:

Let A and B be the reactions at pegs A and B respectively.



Taking moments about peg B, we have:

Sum of clockwise moments = sum of anticlockwise moments

A x 50 + 6 x 20 = 10 x 70 + 0.8 x 30

$\therefore$ 50A + 120 = 700 + 24

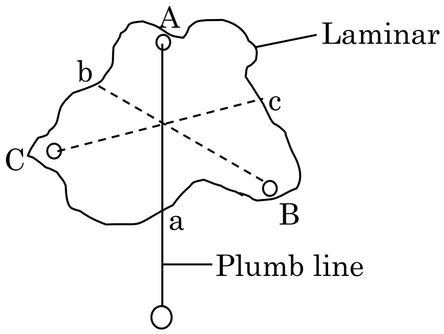
$\therefore$ A = $\frac{604}{50}$ = 12.08 N

Now, sum of upward forces = sum of downward forces

A + B = 10 + 0.8 + 6

$\therefore$ B = 16.8 – 12.08 = 1.72 N

Determination of Centre of Gravity of uniform irregularly shaped laminar.



- Three small well-spaced holes A, B and C are made at the edge of the laminar.
- The laminar is freely supported on a horizontal pin through one of the holes, say A. A plumb line is also supported from the same pin.

When both the plumb line and the laminar have settled, a mark **a** is made at the point where the plumb line crosses the edge. A line **Aa** is drawn on the laminar.

- The procedure is repeated with the laminar supported from hole**B** and a mark **b** is made where the plumb line crosses the edges. A line **Bb** is drawn.

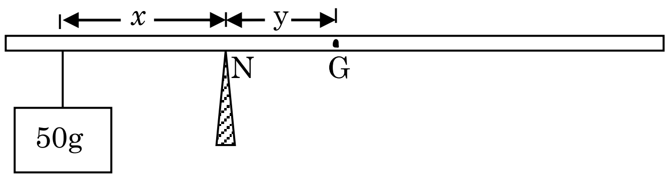
The point of intersection of the lines **Aa** and **Bb** is the centre of gravity of the laminar.

For confirmation, if the laminar is supported from hole C, the plumb line should pass through the point of intersection.

Determination of Mass Using Moments

Experiment 1: *To Determine the Mass of a MetreRule*

- The metre rule is first placed on a knife edge and the position, G, of the knife edge at which it balances horizontally is noted.
- A known mass, e.g 50 g, is hung from the 5-cm mark and the metre rule is adjusted until equilibrium is restored. The new position, N, of the knife edge is noted.
- The distance between the point of support of the 50 g mass and point N is measured and noted. Let it be x. Also the distance NG is noted. Let it be y.

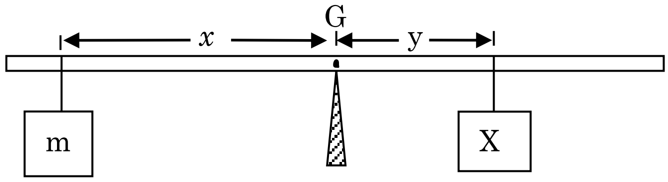


Let the mass of the metre rule be M.
Then yM = 50x

$$M = \frac{50x}{y}$$

The procedure can be repeated using different positions of the hanging mass and the average value of M obtained.
NB: The repetition is for the purpose of obtaining a more reliable value out of the so many trials.

Experiment 2: To Determine the Mass of an Object using Moments.



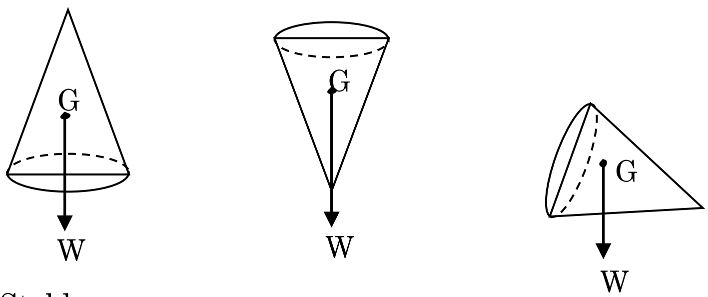
- The metre rule is first placed on a knife edge and the position, G, of the knife edge at which it balances horizontally is noted.
- A known mass, m, is hung from, say the 5-cm mark.
- The object, X, whose mass is required, is hung on the opposite side of the knife edge.
- While maintaining the point of support, the position of X is adjusted until equilibrium is restored.
- The distances x and y (see diagram) are noted.

Let M be the mass of X.
Then yM = xm

$$M = \frac{xm}{y}$$

11.5: Stable, Unstable and Neutral Equilibria

Stable Equilibrium
This is a configuration, in which if a body is slightly displaced and then released, it goes back to its original position.
It does not topple because the line of action of its weight remains within the base e.g a cone resting on its base.

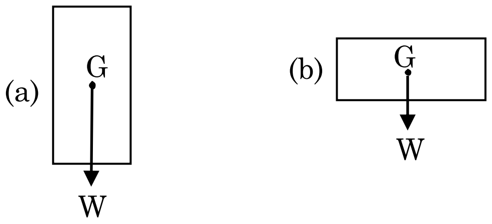


(i) Stable (ii) Unstable (iii) Neutral

Unstable Equilibrium
A body is said to be in unstable equilibrium if when slightly displaced, the line of action of its weight falls outside the base. It cannot stay in this configuration without support.
In this case the body continues to fall e.g. a cone resting on its apex.

Neutral Equilibrium
In this configuration the body simply remains in its new position when displaced. The line of action of its weight always passes through the line of support whatever the displacement, e.g. a cone or cylinder resting on its side.

Relation between Stability and Location of its Centre of Gravity



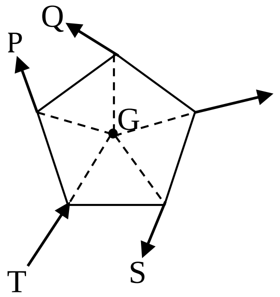
Always the body topples when the line of action of its weight falls outside the base of the body.
Thus a body is more stable if:
(i) itscentre of gravity is lower
(ii) its base is wider
For example see the figures above
(b) is more stable than (a)
For the same reason racing cars are given a wider base and are made low

Test Yourself

1. It is easier to open a door by applying a force at the extreme side from the hinge than when the force is applied near the hinge. Explain.
2. State three applications of moments.
3. Describe how you would find the mass of a bar without using a balance if an abject of known mass is available.
4. What is meant by centre of gravity?
5. What are the conditions for equilibrium of a rigid body?
6. What is meant by stability of a body?

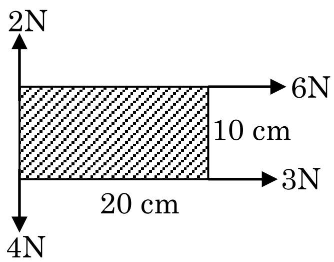
Exercise 11

1. Forces P, Q, R, S and T act in a single plane on the plate shown.



Name which forces have clockwise and which one have anticlockwise moments about. Point G

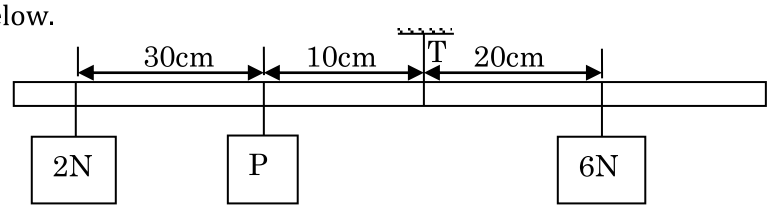
2. For the forces shown below acting on the rectangular uniform plate, find the resultant moment about its centre of gravity.



3. A uniform metre rule AB of weight 2N supports 5N at a point 20cm from end A and 3N at a point 10cm from end B. Find
   (i) how far from the mid-point of the rule must a spring balance be fixed for the rule to balance horizontally.
   (ii) the reading of the balance

4. Two spring balances P and Q support a uniform metre rule of weight 0.8N at the 10cm mark and 80cm mark respectively. A weight of 0.2N is hung at the 90cm mark.
 Find
 a) the readings of the spring balances
 b) where the 0.2N must be shifted to for the balances to read the same.

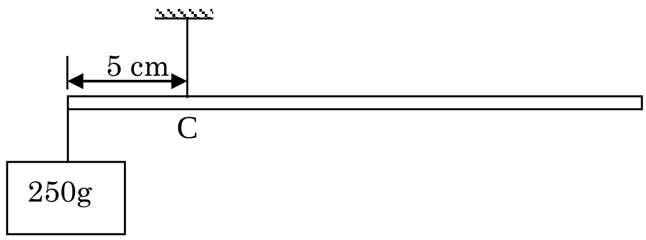
5. A light beam AB is in equilibrium when forces of 2N, P and 6N act on it as shown in the diagram below.



Find the magnitude of P and the tension in the supporting thread T

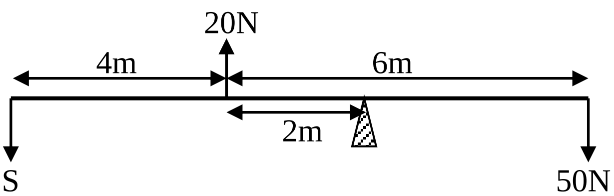
6. A uniform roller of radius 30cm and weight 200N is resting on a horizontal floor and in contact with a 10cm high step. If the step is rough, find the magnitude of a horizontal tangential force, H, that will reduce the reaction at the floor to zero.

3. The diagram below shows a uniform half-metre rule suspended at point C

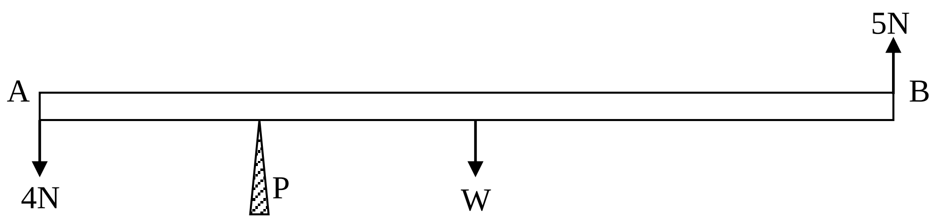


Find the mass of the half-metre rule and the tension in the supporting string

8. If the system shown in the diagram below is in equilibrium, find the value of S.



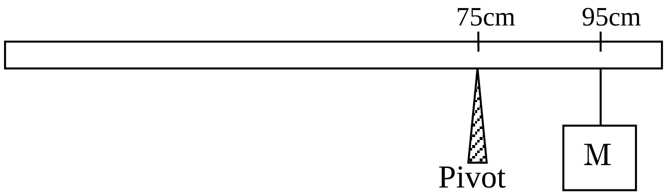
9. A uniform metal bar of weight W is pivoted at a distance which is ¼ of its length from end A and kept in equilibrium by applying forces of 4N and 5N as shown in the diagram below



Find (i) the weight W

(ii) the force exerted by the pivot, P, on the bar.

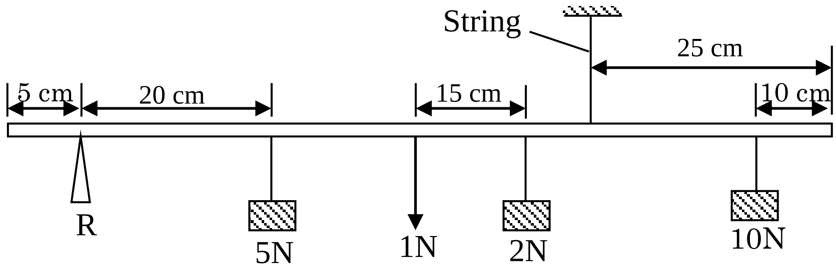
10. The figure below shows a uniform metre rule of mass 1.2 kg pivoted at the 75-cm mark. It balances horizontally when a mass M is hung at the 95-cm mark.



Find: (i) the value of M and

(ii) the reaction in N of the pivot

11. A uniform metre rule of weight 1N is pivoted on a wedge 5 cm away from one end and suspended by a string 25 cm from the other end.



If the metre rule is in equilibrium when weights of 5N, 2N and 10N are attached to it as shown in the diagram, calculate thetension in the string and the normal reaction, R, at the wedge.

12. MACHINES

A machine is a device by means of which a force is applied at one point to overcome a force at some other point more easily. - it makes work easier.

Terms:

Effort :- This is the force applied to overcome a load

Load :- force to be overcome

Mechanical advantage (.M.A) :- This is the ratio of the load to effort. i.e

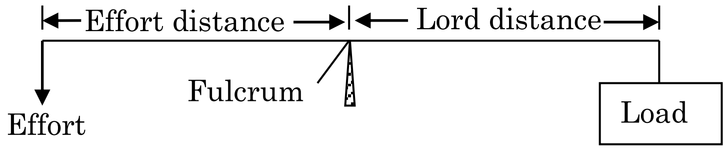
$$\text{M.A} = \frac{\text{Load}}{\text{Effort}}$$

Mechanical advantage has no units.

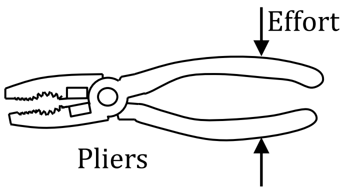
12.1: Levers

A lever is a rigid bar arranged to turn about a fixed point (***fulcrum***) when an effort is applied to overcome a load.

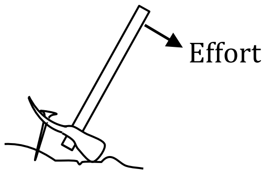
Fisrt Class Lever:



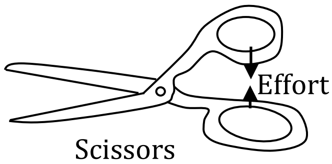
<u>Examples: </u> see saw, pliers, claw hammer, scissors, crowbar.



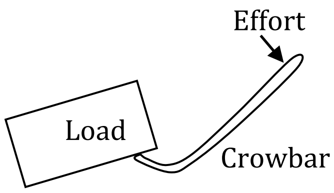
Pliers



Claw hammer



Scissors

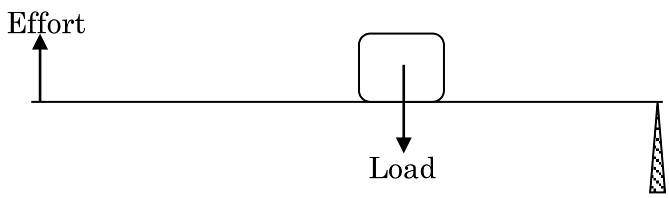


Crowbar

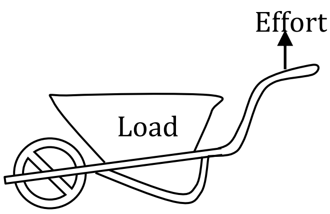
By application of moments, the effort will overcome the load if the moment of the effort about the fulcrum just begins to exceed that of the load about the fulcrum. Thus, before the load is overcome, the condition that
Effort x *effort distance = load* x *load distance*
must be fulfilled.
Thus a smaller effort than the load can be used if the effort distance is greater than the load distance

Second Class Lever

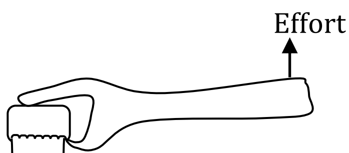
In this arrangement the load is between the fulcrum and the effort



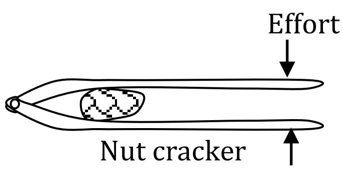
Examples of second class lever include: wheel barrow, bottle opener, nut cracker.



Wheel barrow



Bottle opener

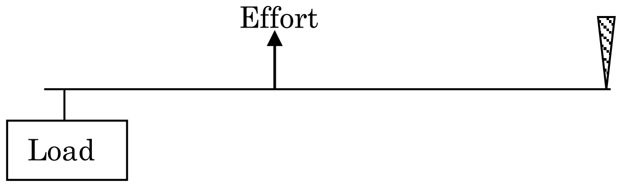


Nut cracker

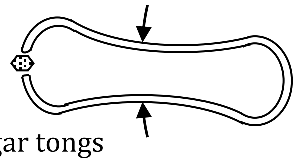
In second class levers, because effort distance is always greater than the load distance, it follows that the effort is always smaller than the load. See the diagrams of the examples given above.

Third Class Lever:

Here the effort is between the load and the fulcrum.



It is clear that in this arrangement the effort is always greater than the load. Examples of third class levers include: sugar tongs, the arm, table knife



Relationship between Distances moved by the Load and Effort

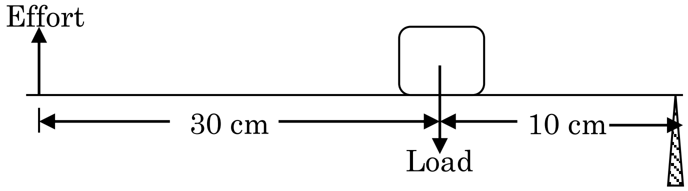
In order for an effort to move a load through a given distance, the effort must move a certain distance.

$$\text{Velocity ratio} = \frac{\text{Distance moved by effort}}{\text{Distance moved by load in the same time}}$$

Velocity ratio has no units.

Example:

What is the velocity ratio in the lever system below?



Solution

$$\text{Velocity ratio} = \frac{\text{Effort distance from fulcrum}}{\text{Load distance from fulcrum}} = \frac{40}{10} = 4$$

Efficiency: (η)

This is the ratio of the useful work got out of a machine to the work put in a machine.

$$\text{i.e Efficiency} = \frac{\text{Useful work got out of a machine}}{\text{Work put in the machine}}$$

$$= \frac{\text{Load x distance moved by load}}{\text{Effort x distance moved by effort}}$$

$$= \frac{\text{Load}}{\text{Effort}} \text{ x} \frac{\text{load distance}}{\text{effort distance}}$$

$$= M.A \text{ x } \frac{1}{\text{V.R}} = \frac{\text{M.A}}{\text{V.R}}$$

Example:

An effort of 100N moves through 12cm while moving a load of 400N through 2cm. Find

(i) the mechanical advantage

(ii) the velocity ratio

(iii) the efficiency of the machine

Solution

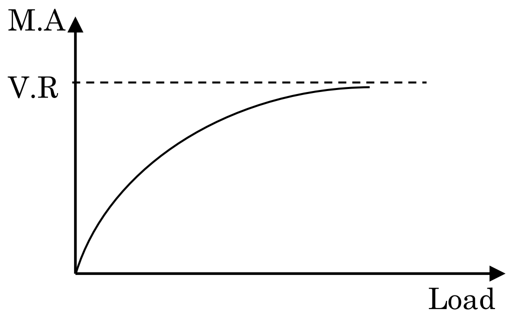
$$\text{(i)Mechanical advantage} = \frac{\text{load}}{\text{effort}} = \frac{400}{100} = 4$$

$$\text{(ii)Velocity ratio} = \frac{\text{effort distance}}{\text{load distance}} = \frac{12}{2} = 6$$

$$\text{(iii)Efficiency} = \frac{\text{mechanical advantage}}{\text{velocity ratio}} \text{ x } 100\% = \frac{4}{6} \text{ x } 100 = 66.7\%$$

Graph of Mechanical Advantage (M.A) against Load

The mechanical advantage of a machine does not remain the same as the load is varied. For any machine the maximum possible mechanical advantage is equal to its velocity ratio. The following graph shows the variation of mechanical advantage with load.

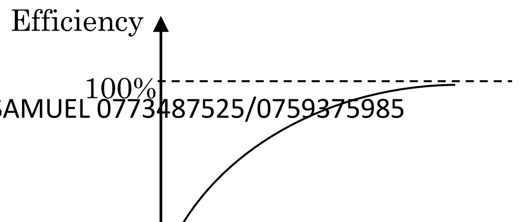


Graph of Efficiency against Load

Like the mechanical advantage, the efficiency varies as the load varies but can never reach 100%. This is so because

(i) The machine has to overcome the frictional force in the moving parts.

(ii) Some work is spent in lifting parts of the machine.



steeeper

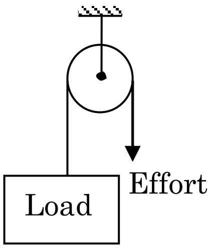
Why M.A or Efficiency increases with the Load

Since the weight of the moving parts remains the same, and the frictional force may NOT increase proportionally, the work wasted on these become a smaller portion compared to that done against the actual load as the load increases. Thus mechanical advantage and efficiency become greater.

12.2: Pulleys

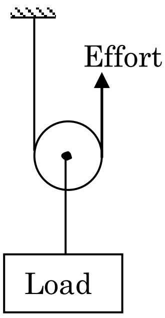
A pulley is a wheel, usually with a groove over which a string or rope can be passed.

SINGLE FIXED PULLEY

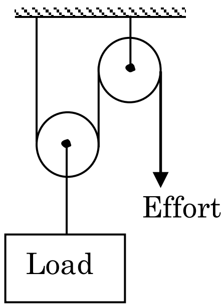


V.R = 1

SINGLE MOVABLE PULLEY



V.R = 2

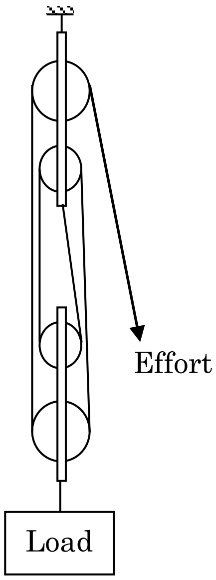


(i) (ii)

The system in figure (ii) is the same as the single movable pulley in figure (i) except that the effort is applied downwards. This makes it more convenient since part of the operator's weight can form the effort E

V.R = 2

BLOCK AND TACKLE SYSTEM



V.R = number of strings supporting the movable block (or number of pulleys if the effort is applied downwards).
In this case the V.R = 4
The system consists of two blocks, with the upper fixed and the lower movable. Each block may contain any number of pulleys with a single string rope going round the pulleys.

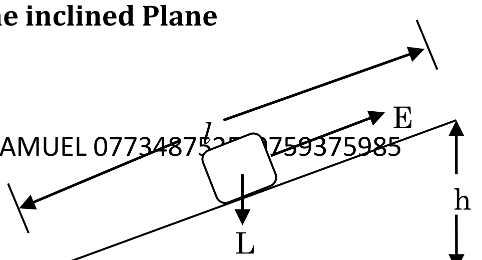
Experiment: To investigate the V.R of a Block and Tackle System.

a) Record the total number of pulleys provided
b) Arrange a block-and-tackle system with a mass hanging at the lower block
c) Make a mark x on the free part of the string
d) Note the position of the hanging mass and that of the mark x.
e) Pull gently the free end of the string through a distance e = 10cm and note the corresponding distance l moved by the hanging mass.
f) Repeat the procedure (e) when e = 15, 20, 25, 30,and 35cm and fill the table below:

e/cm	l/cm	e/l
10		
15		
20		
25		
30		
35		

What is the velocity ratio?

12.3: The inclined Plane



When the effort E, acting along the plane, moves the load L through a distance *l* along the plane, the load is effectively raised vertically a height h.
This arrangement enables an effort E to lift a bigger load L

$$\text{Velocity ratio} = \frac{\text{distance moved by effort}}{\text{height risen by the load}} = \frac{l}{h}$$

Example:

An effort of 50N is used to haul a 300N box along an incline which rises vertically 1 m for every 8 m distance along the plane. Find

(i) the velocity ratio
(ii) the mechanical advantage
(iii) the efficiency

State the factors in this arrangement that make the efficiency become less than 100%

Solution

(i) The velocity ratio = 8/1 = 8

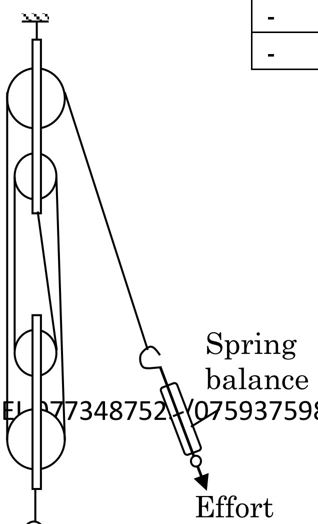
(ii) $\text{Mechanicaladvantage} = \frac{\text{Load}}{\text{Effort}} = \frac{300}{50} = 6$

(iii) $\text{Efficiency} = \frac{\text{Mechanicaladvantage}}{\text{velocityratio}} \text{ x } 100 = \frac{6}{8} \text{ x } 100 = 75\%$

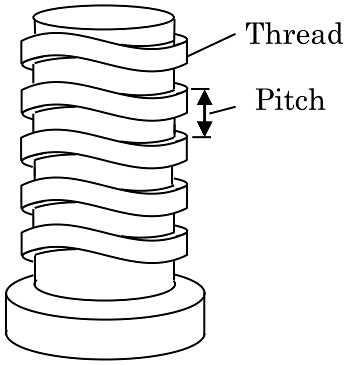
Experiment: To investigate the variation of M.A of a Pulley System with the load.

- The pulley system is arranged with the string appropriately assembled.
- A load is fixed to the lower block.
- A spring balance is fixed at the free end of the string.
- By pulling on the spring balance, the minimum effort E, required to lift the load, is found and noted.
- The procedure is repeated for several other values of the load and a table as shown below is filled.

Load/N	Effort, E/N	Load/Effort
-	-	-
-	-	-
-	-	-



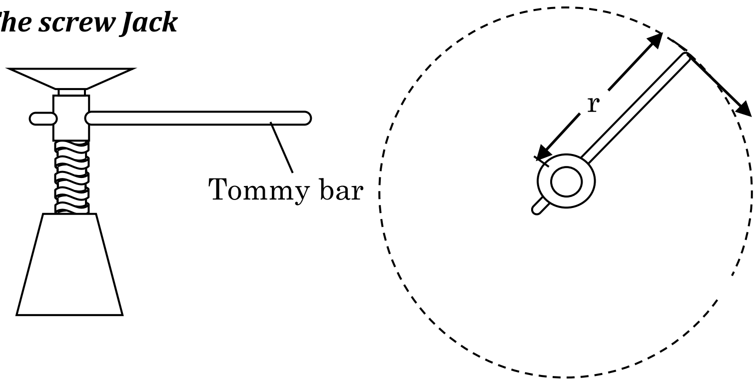
12.5: The Screw



This is an application of an inclined plane. It is an inclined plane which, instead of stretching it in a straight line, has been taken round a cylinder. It can be likened to stairs climbing up to, say the fifth floor. The stair cases are arranged to turn several times in a narrow vertical space instead of following a single straight line.

Pitch:- This is the distance between adjacent threads

The screw Jack



When the screw is turned through one complete revolution, it advances a distances equal to one pitch

$$\therefore \qquad \text{V.R} = \frac{\text{Circumference of circle made by E}}{\text{Pitch}}$$

Usually, the effort is applied on a tommy bar some distance r from the axis of the screw. So

$$\text{V.R} = \frac{2\pi r}{\text{pitch}}$$

Example:

A screw jack is found to be 70% efficient. If an effort of 20N is used to lift a vehicle of 5000N and the pitch of the screw is 2 mm, what is the length of the tommy bar?

Solution:

Let r = length of the tommy bar

Then velocity ratio, $V.R = \frac{2\pi r}{pitch} = \frac{2\pi r}{2} = \pi r$

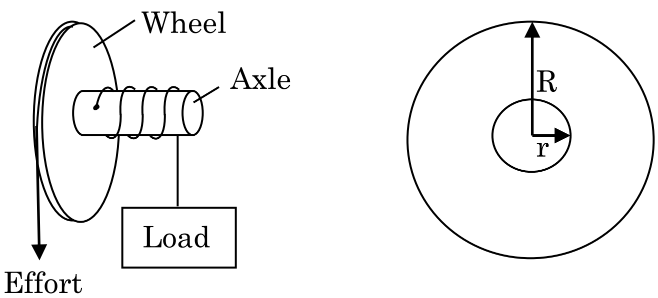
Mechanical advantage, M.A = 5000/20 = 250

Now, efficiency = M.A/V.R

$\therefore \quad 70/100 = 250/\pi r$

$\therefore \quad r = \frac{250 \times 100}{\pi \times 70} = 113.6 \text{ mm}$

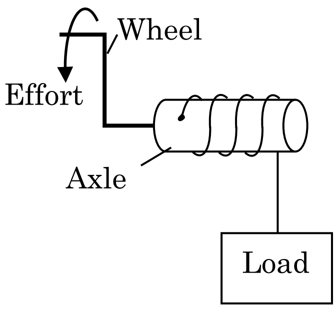
12.6: Wheel and axle



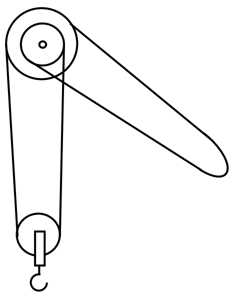
The effort is normally applied on the rope that goes round the wheel, while the load is lifted by the rope fixed on the axle. When the wheel makes one revolution, the axle also turns one revolution.

So, $V.R = \frac{\text{Circumference of wheel}}{\text{Circumference of axle}} = \frac{R}{r}$

Windlass

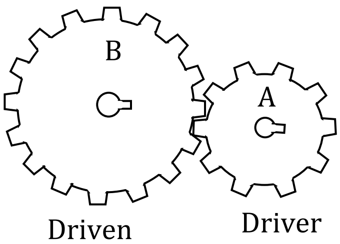


Weston differential pulley



$V.R = \frac{2R}{R - r}$

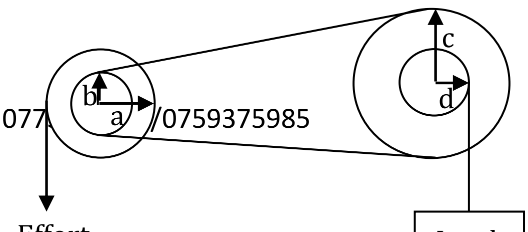
12.7: Gear systems



If two gears engage such that gear A drives gear B, A is referred to as the driver and B as the driven.

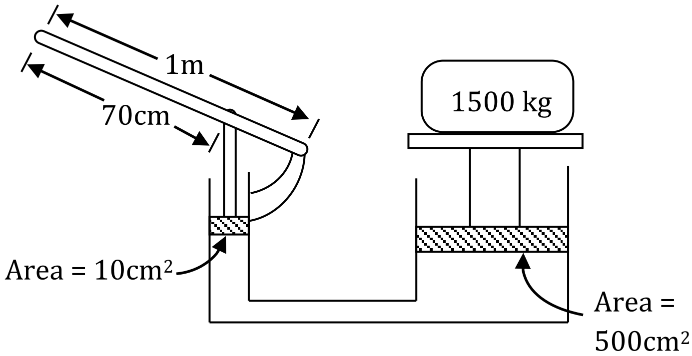
$V.R = \frac{\text{No. of teeth on the driven}}{\text{No. of teeth on the driver}}$

Combination of simple machines



V.R = Product of the individual velocity ratios
= a/b x c/d

Example:



For the hydraulic press shown , find the
(i) Velocity ratio
(ii) Efficiency

Solution

(i) V.R = V.R of lever x V.R of hydraulic pressure

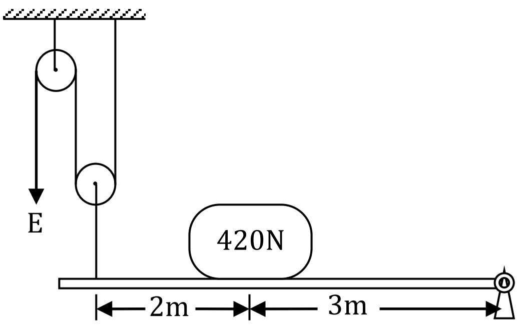
$$= \frac{\text{effort distance}}{\text{Load distances}} \times \frac{\text{load piston area}}{\text{effort piston area}}$$
= 100/30 x 500/10 = 500/3
= 166.7

(ii) Efficiency $= \frac{M.A}{V.R} \times 100\%$

$$= \frac{1500 \times 10}{100 \times 500/3} = 90\%$$

Example:

An effort E is used to just lift a load of weight 420 N using the arrangement shown below



If the efficiency of the arrangement is 70%, find
(i) the velocity ratio of the system

(ii) the effort E.

Solution:
Overall velocity ratio = velocity ratio of the pulley system x velocity ratio of the lever

$$= 2 \text{ x } \frac{5}{3} = \frac{10}{3} = 3.33$$

$$\text{Efficiency} = \frac{\text{M.A}}{\text{V.R}} \text{x } 100 = \frac{420 \text{ x } 3}{\text{E x } 10} \text{ x } 100\%$$

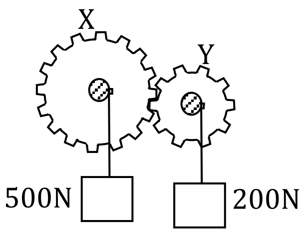
$$\therefore 70 = \frac{420 \text{ x } 3}{\text{E x } 10} \text{ x } 100$$

$$\therefore \text{E} = \frac{420 \text{ x } 3}{70 \text{ x } 10} \text{ x } 100 = 180 \text{ N}$$

Exercise 12

1. A load of 600 N is placed at 1.5 m from the pivot of a sea saw. Find the distance from the pivot at which a weight of 300 N should be placed to balance the sea saw.

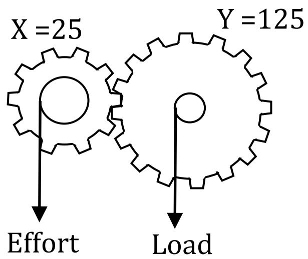
2. Two gear wheels X and Y having 100 and 25 teeth respectively, mesh with each other.



They are fastened on axles of equal diameters such that a weight of 200 N attached to a string wound round one axle raises a load of 500 N attached to a string wound round the other axle as shown. Find
(i) the velocity ratio
(ii) the efficiency of the system

3. A screw jack with a tommy bar of length 50 cm and a pitch of 2.5 mm is used to raise a load of 1200 N. If the efficiency is 40%, find
(i) the velocity ratio
(ii) the mechanical advantage

4. In the gear system shown below the wheels X and Y have the number of teeth shown. If the



shaft diameters are 20 cm and 10 cm respectively, and the efficiency is 30%, find
(i) the velocity ratio
(ii) the effort required to lift a load of 900 N.

13. WORK, ENERGY AND POWER.

13.1: WORK

Work is said to be done if the point of application of a force moves in the direction of the force.It is measured as the product of the force and the distance moved in the direction of the force.

i.e.***Work = force x distance***

The SI unit of work is the joule (J)
A joule is the work done by a force of 1N in moving a distance of 1m
$\therefore$ 1J = 1Nm

Examples:

1. A force of 10N moves a body along a straight path and stops after 200J of work has been done. What distance was moved?
Solution:

$$\text{Distance} = \frac{\text{work}}{\text{force}} = \frac{200}{10} = 20 \text{ m}$$

2. A tangential force of 15N is applied to turn a wheel of radius of 70cm about the centre. How much work is done in 2 revolutions?
Solution:
In the 2 revolutions the force moves a distance equal to two circumferences of the circle described, i.e $2 \times 2\pi r = 4\pi \times 0.70$
$\therefore$ Work done = Force x distance = $15 \times 4\pi \times 0.70$ = $\underline{\underline{131.9 \text{ J}}}$

3. A body of mass 5kg is raised vertically a height of 8m. How much work is done?
Solution:
Work done = weight of body x height raised = $5 \times 10 \times 8$ = $\underline{\underline{400 \text{ J}}}$

13.2: POWER:

Power is the rate of doing work.

The SI unit of power is the watt (W)
$1W = 1Js^{-1}$
A watt is the rate of doing work at 1 joule per second.

Examples
A pump delivers water at a rate of 1 litre per hour to a tank 20m above a well. Find the power of the pump.
Solution:

1 litre of water has a mass of 1 kg, and 1 hour = 3600 seconds
Work done every hour = weight raised per hour x height

$$\text{Power} = \frac{\text{Workdone}}{\text{Time}} = \frac{1 \times 10 \times 20}{3600} = 0.556 \text{ W}$$

13.3: ENERGY:

This is the capacity to do work. It is also measured in joules.
Examples of forms of energy

(i) Mechanical energy
(ii) Electrical energy
(iii) Chemical energy
(iv) Heat energy
(v) Light energy
(vi) Nuclear energy

Renewable and Non-renewable Sources of energy

Renewable sources always avail energy, e.g. solar, wind, geothermal, hydro
Non-renewable sources run out of energy, e.g. oils, gas, coal, charcoal, etc.

Mechanical Energy

This is energy possessed by a body due to movement and location. It is made up of two parts.

1. ***Potential Energy:***

This is energy possessed by a body because of its position. It is equal to the work done in raising a body to that position above the reference level.
The body is capable of doing work equal to the potential energy if it returns to the reference level.
Therefore a body of mass m at a height *h* above the reference level has potential energy equal to *mgh*.

2. ***Kinetic energy***

This is the energy possessed by a body by virtue of its motion.
A body of mass *m* is moving at a speed *v* has kinetic energy equal to $\frac{1}{2}mv^2$.
If a body is moved from rest to acquire a speed *v*, then the kinetic energy it has is equal to the work done by the external agent that makes it acquire this velocity.

Examples:

1. An object of mass 3kg is moving at a speed of $5ms^{-1}$. If it is to be stopped in 5s using a uniform force, find the power to do so.

Solution:

Work done to stop the object = Original kinetic energy
$= \frac{1}{2}mv^2 = \frac{1}{2} \times 3 \times 5^2 = 37.5$ J

$$\therefore \quad \text{Power} = \frac{37.5}{5} = \underline{\underline{7.5\text{ W}}}$$

2. In the previous example suppose the stopping force acted over a distance of 4m, what was the force?

Solution:

$$\text{Force} = \frac{\text{Workdone}}{\text{Distance}} = \frac{37.5}{4} = 9.375\text{ N}$$

3. A man of mass 75kg walks up 12 steps each 20cm high in 5s. Find the power he develops.

Solution:

Work done = weight of man x total height risen = 750 x 12 x 0.20 = 180 J

$\therefore$ Power = 180/5 = <u>36 W</u>

13.4: Principle of conservation of energy

This principle states that:

Energy is neither created nor destroyed but can change form.

In other words, ***in a closed system the total energy is always constant***

Interchange of Energy in the Gravitational Field

A body moving under the influence of gravity possesses constant mechanical energy made up of two parts i.e.

Mechanical energy = kinetic energy + potential energy = constant

Thus a particle projected upwards keeps on losing kinetic energy and gaining potential energy such that

Kinetic energy lost = potential energy gained.

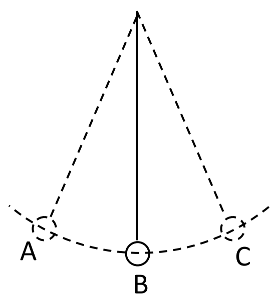
At the highest point, the particle has no kinetic energy but has maximum potential energy. On falling it keeps on gaining kinetic energy but losing potential energy

The Simple pendulum

A mass freely suspended on a string forms a simple pendulum.

When the mass is pulled to one side and then released, it swings between extreme points A and C.

It has maximum potential energy at A and C but zero kinetic energy there. At point B, the kinetic energy is maximum while the potential energy is minimum there.



Since mechanical energy is conserved, it implies that a simple pendulum would swing for ever with a constant amplitude. However, in practice, the amplitude keeps on decreasing until it is completely zero i.e. it stops. This is because of

(i) Air resistance

(ii) Friction at the point of support.

Example:

1. A particle of mass 2 kg is at rest, freely suspended on a string. It is then struck horizontally and starts off with a velocity of $10ms^{-1}$.

Find how high above the initial position is rises.

What kinetic energy does it have on retuning to the initial position?

Solution:

Let h = height risen

Potential energy gained = kinetic energy lost

$\therefore mgh = \frac{1}{2}mv^2$

$\therefore \quad h = \underline{v^2} = \underline{10^2} = \underline{\underline{5\ m}}$

2g 2 x 10

When the particle returns to the point of projection it will have the same kinetic energy as it had when it was leaving equal to $\frac{1}{2}mv^2$

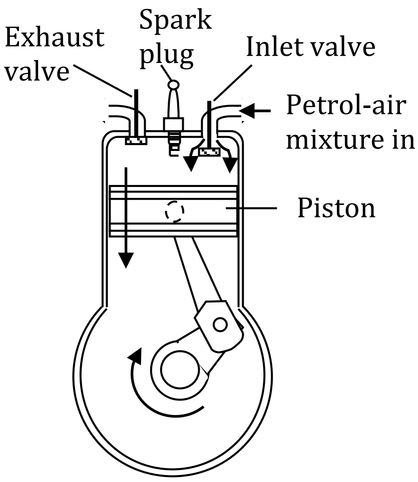
$= \frac{1}{2} \times 2 \times 10^2 \quad = \underline{100\ J}$

Engines

The main aim of making an engine is to transform chemical energy into mechanical energy. In an engine, fuel (a chemical) is burnt to produce mechanical power. However, not all the chemical energy is transformed into mechanical for running the engine. Some is wasted as heat and sound. Although sound is itself a form of mechanical energy, it is not used to run the engine. We shall briefly look at a four-stroke petrol engine and a four-stroke diesel engine.

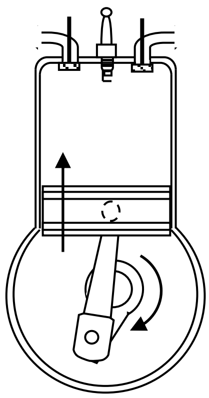
(a) *Four-Stroke Petrol Engine*

1. ***Inlet (Induction)Stroke***



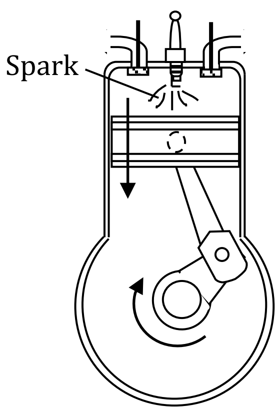
- Inlet valve is open
- Exhaust valve is closed
- Piston is moving down
- Petrol-air mixture is sucked into the cvlinder

2. ***Compression Stroke***



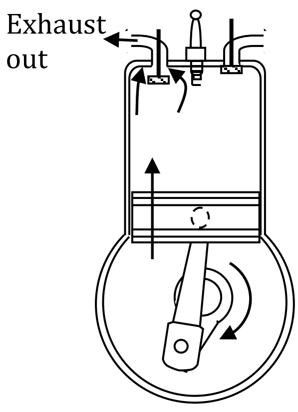
- Both valves are closed
- Piston is moving up

3. ***Power Stroke***



- Both valves are still closed
- When the piston is at the top the spark plug ignites the petrol-air mixture and the explosion pushes the piston down

4. ***Exhaust Stroke***



- Inlet valve is still closed
- Exhaust valve is open
- Piston is moving up
- Burnt gases are driven out

(b) Four Stroke Diesel Engine

A four-stroke diesel engine also performs the four stages of a cycle except:

1. During the inlet stroke ONLY AIR enters the cylinder.
2. During the compression stroke only air is compressed.
3. Instead of a spark plug a FUEL INJECTOR is used. At the end of the compression stroke diesel is injected into the cylinder and it burns automatically because the temperature of the compressed air is very high then.

Exercise 13

1. The work done to move a body through a distance of 6 m is 30 J. Find the force that acts on the body.

2. A bullet of mass 12g strikes a solid surface at a speed of 200 ms^{-1}. If the bullet penetrates to a depth of 3cm, calculate the average net force acting on the bullet while it is being brought to rest.

3. A machine lifts 4 boxes per minute through height 8 m. If each box weighs 100 N, find the power that is expended.

4. A pump rated at 500 W is used to raise water to a height of 60 m. What mass of water can it deliver in one hour?

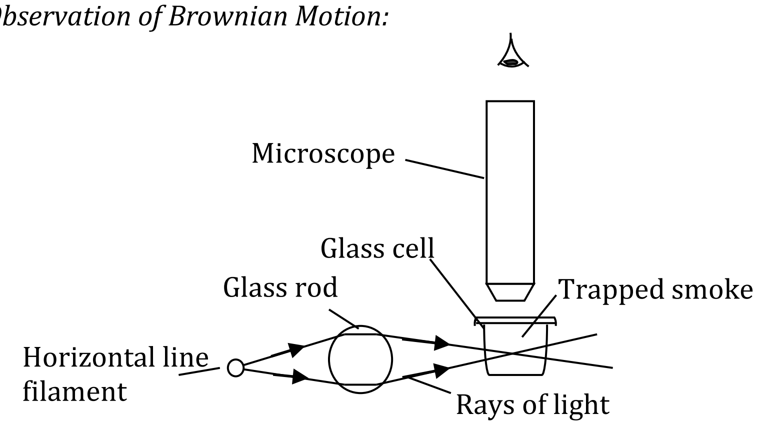
5. A ball is dropped from rest at a height of 20 m above the ground. If the ball bounces on hitting the ground and lost 20% of its original energy, calculate the maximum height it reaches again.

14. MOLECULAR NATURE OF MATTER

Matter is made up of particles (molecules or atoms) which are in continuous random motion. Such motion is referred to as ***Brownian motion*** since the first person to observe it was Brown.

14.1: Brownian Motion

Observation of Brownian Motion:



The line filament provides light for illuminating the smoke trapped in the glass cell while the glass rod acts as a cylindrical lens to focus the light onto the trapped smoke.

The smoke particles are observed through a microscope and are seen to be in continuous random motion. This is because they collide with air molecules.

At higher temperature the random motion of the particles is more violent.

14.2: States of Matter

Solid:

A solid has a definite shape and volume. The molecules of a solid maintain a constant pattern and vibrate about their fixed positions with strong intermolecular forces.

Liquid:

A liquid has a definite volume but an indefinite shape. It takes the shape of the container. The molecules of a liquid wander about and they aren't fixed. However, the intermolecular forces can still maintain a definite volume.

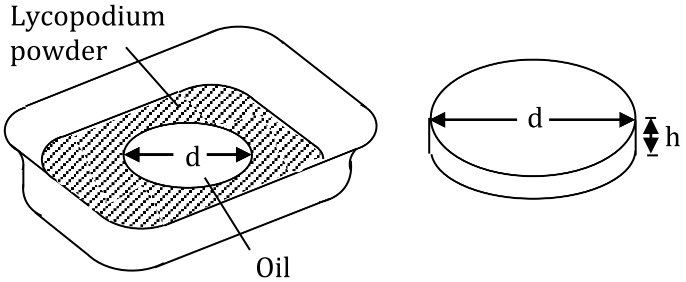
Gases:

A gas has no definite volume or shape. The molecules are much further apart, with weak intermolecular forces. A gas occupies the volume of the container and exerts pressure equally on all the walls of the container. The gas molecules continuously strike the walls of the container thus creating a force and therefore pressure on them.

When the temperature of the gas is increased at constant volume, the speed of the molecules exerts a greater force on the walls. Therefore pressure increases.

14.3: Estimation of the Length of a Molecule

- A 5 in 1000 solution of oleic acid in methanol is prepared, by running 1cm^3 of oleic acid into a 200 cm^3 measuring flask containing some methanol. More methanol is added to fill the flask to the 200 cm^3 mark.
- Still water in a large plastic dish is lightly dusted with lycopodium powder.
- 0.01 cm^3 of the oleic acid solution prepared is run into the centre of the water surface. It forms a patch which is approximately circular. The lycopodium powder helps to clarify the boundaries of the patch.



- The diameter of the patch is measured
- The experiment is repeated a number of times and the mean diameter, d, is determined

Calculation of results:

0.01 cm^3 contains $0.01 \text{ x } \frac{1}{200}$ = 0.00005 cm^3 of oil

If the film is a flat cylinder of height h, then $\frac{1}{4}\pi d^2 h = 0.00005$ cm^3

$\therefore$ Height $h = 0.00005 \text{ x } \frac{4}{\pi d^2}$ cm = ………….. m

This is the length of the molecule

ALTERNATIVELY:

- A known volume, x, is mixed with a suitable solvent, e.g. methanol to make a total volume, V, of solution.
- Still water in a large plastic dish is lightly dusted with lycopodium powder.
- A volume, y, of the solution is run into the centre of the water surface. It forms a patch which is approximately circular. The lycopodium powder helps to clarify the boundaries of the patch.
- The diameter of the patch is measured
- The experiment is repeated a number of times and the mean diameter, d, is determined

Calculation of results:

A volume y cm^3 of solution contains $\frac{xy}{V}$ cm^3 of oil

If the film is a flat cylinder of height h, then $\frac{\pi d^2}{4}h = \frac{xy}{V}$

$\therefore$ height, h $= \frac{4xy}{\pi d^2 V}$

Assumptions:

1. The film is one molecule thick.
2. Intermolecular distance (space) is negligible
3. The molecules are standing perpendicularly on the water surface.

14.4: Crystals

A crystal is a solid that forms by a regular repeated pattern of molecules connecting together. In crystals a collection of atoms, called the Unit Cell, is repeated in exactly the same arrangement over and over throughout the entire material.

Because of this repetitive nature, crystals can take on strange and interesting looking forms, naturally.

Why different crystals have different shapes and sizes

This depends on 2 factors:

- The internal symmetry of the crystal, and
- The relative growth rates along the various directions in the crystal.

Growing Crystals

Apparatus and Materials:

Baking soda (sodium bicarbonate)- 3 tsp, possibly more.
Water - 1/2 cup
Electric hot plate
String - 10 cm (5-6 in)
Small weight for string

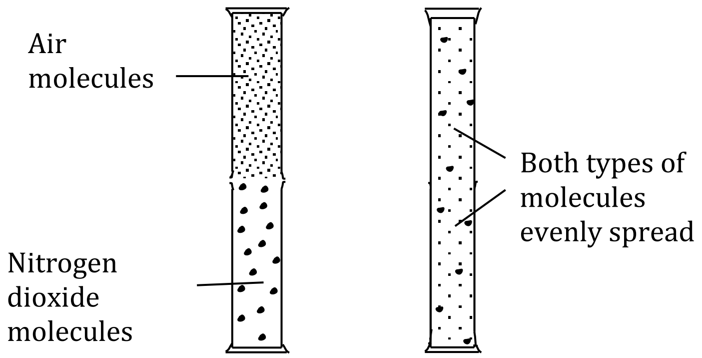
A clear glass or vial.

Procedure:
- Pour about half a cup of water into a pan.
- While stirring, dissolve as much baking soda as possible in the water, 1 teaspoon at a time.
- Heat the solution (do not boil).
- Remove from heat source, stir, and add more baking soda until no more will dissolve and solution is saturated.
- Cool the solution.
- Pour the solution into a clear glass.
- Tie a weight onto the end of the string and hang it into the solution.
- Leave everything to stand undisturbed

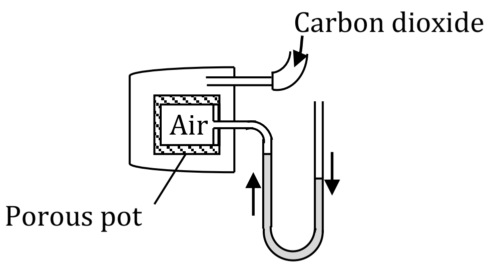
After several days crystals will begin growing on the string as the water evaporates.

14.5: Diffusion

This is the spreading of fluid molecules from a region of high concentration to regions of lower concentration of it.

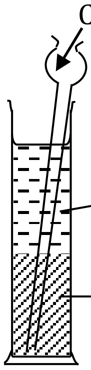


The speeds of random motion of the molecules of gas at the same temperature depend on the masses of the molecules. The heavier the molecules, the lower their speed. So a denser gas will be slower in diffusion than a less dense one. i.e. gases diffuse at rates that are inversely proportional to their densities.
In the set-up below a porous pot containing air is connected to a U-tube with a liquid.



When carbon dioxide surrounds the porous pot the liquid levels in the U- tube move in the directions indicated by the arrows. This is because the lighter molecules of air diffuse out of the pot faster than the heavier carbon dioxide molecules diffuse into the pot. So there is lower pressure inside the pot than outside it.

Diffusion in liquids can be demonstrated using the set-up below.



Using a thistle funnel, copper(II)sulphate solution is introduced to the bottom of clear water contained in a gas jar. The set-up is left for a time.
After about 24 hrs the blue copper sulphate solution has diffused upwards in the water.

14.6: Surface Tension

This is the behavior of a surface of a liquid as an elastic sheet in tension. It is due to intermolecular forces.
The existence of surface tension is exhibited by
(i) walking on water of an insect.
(ii) Floating of small, yet dense, objects e.g. a steel pin, on water
(iii) Formation of spherical liquid drops.
(iv) sack-like shape of a liquid drop as it begins falling from the source, e.g tap.

Experiment:To Demonstrate Surface Tension

- Some grease is applied on a pin
- The pin is placed on a piece of filter paper, which is finally placed on top of water.

Observation:
After some time, when the filter paper has absorbed enough water, it sinks leaving the pin floating.
When some soap solution is applied to one side of the pin, the pin moves away from that side until it eventually sinks.
Conclusion:
The water surface acts as an elastic skin enabling the pin to float.
When the soap solution is added, it reduces the surface tension on the side where it is applied, so the pin is dragged away from this area. As more soap solution is added, the surface tension of the whole liquid is reduced so that it can no longer support the pin.

Factors Affecting Surface Tension:
1. Temperature – surface tension decreases as temperature of the liquid rises.
2. Freshness of the liquid – impurities in the liquid reduce its surface tension.

14.7: Adhesion and Cohesion

Adhesion is the attraction between molecules of different substances.

Cohesion is the attraction between molecules of the same substance.
A liquid that wets a surface on which it is placed has greater adhesion forces than cohesion forces, e.g water in a glass. Such a liquid rises in a capillary tube placed in it and its meniscus is concave.
Dampness of walls of buildings from the foundation is caused by capillary rise. It is prevented by interposing a damp course paper on top of the foundation.
A liquid with greater cohesive forces than adhesive will not wet the surface on which it is placed, e.g mercury on glass.Such a liquid falls in a capillary tube placed in it and forms a convex meniscus. The rise or fall is greater for a narrower tube.

Applications of capillarity

- Use of a blotting paper.
- Use of a wick in paraffin stoves and lamps.
- Use of a towel.
- Intake of water and nutrients by plants

e.t.c

14.8: Viscosity

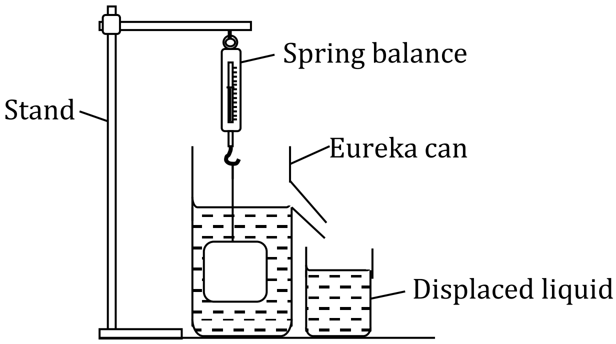
This is resistance of a fluid to flow or to movement of an object through it. The thicker the liquid the greater the viscous force.
If a body is moving through a fluid, the higher the speed the greater the viscous force on it.
This is why a body falling through a fluid reaches a constant speed called the **terminal velocity**.
At this speed the viscous force is so great that the body cannot accelerate anymore.

15. FLOATING AND SINKING

15.1: ARCHIMEDES' PRINCIPLE

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

Experiment: To Verify Archimedes' Principle



-A eureka can is placed on the bench and filled with water until it spills out of the spout.
When water has stopped dripping from the spout an empty beaker is weighed and placed under the spout.
-A suitable object is weighed on a spring balance.
-The object, still hanging from the spring balance, is carefully lowered into the eureka can (without allowing to touch the walls) until it is partially or wholly immersed.

- The reading of the spring balance is taken again (This gives the apparent weight of the object when immersed)
- When water has stopped dripping from the spout, the beaker is removed and weighed again with its contents.

Results:

Weight of object in air = m_1
Weight of object when immersed = m_2
Therefore Upthrust = (m_1-m_2) gf
Mass of empty beaker = m_3
Mass of beaker + displaced water = m_4
Mass of displaced water = m_4-m_3
Weight of displaced water = (m_4-m_3) gf

Observation

Within limits of experimental errors it is found that $m_1-m_2 = m_4-m_3$
i.e up thrust = weight of fluiddisplaced

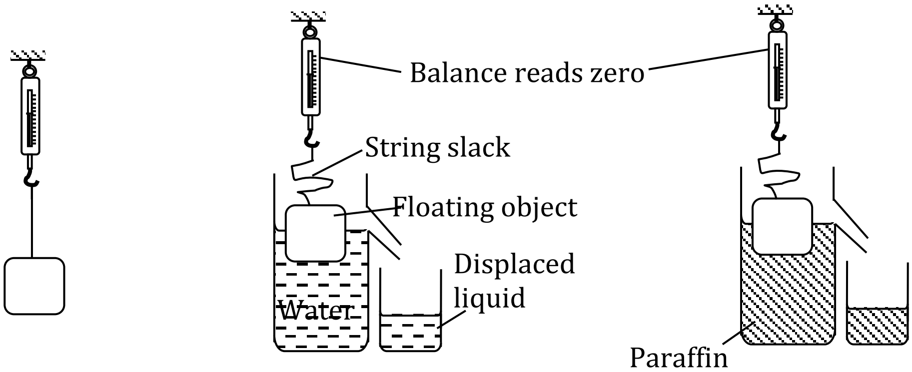
15.2: FLOTATION

Law:

A floating body displaces its own weight of the fluid in which it floats.
Interpretation: The up thrust is equal to the weight of the floating body.

This law means that the apparent weight of a floating body is zero.

Verification of the Law of Flotation

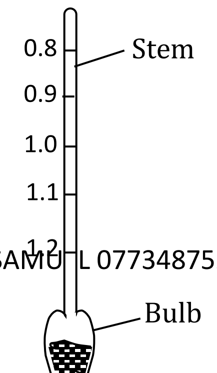


(i) In air (ii) On water (iii) On paraffin

A suitable object is first weighed in air.
Then it is floated on a liquid and the weight of the displaced liquid is found.
Observation:
In each case the weight of the displaced liquid is equal to the weight of the solid in air.

Applications of Floatation

Hydrometer:



A hydrometer is used to find relative densities of liquids.Since a body displaces its own weight of the fluid in which it floats, it always displaces a volume of the fluid that will make up the weight of the object.
Consequently if it floats in a denser liquid, it displaces a smaller volume of that liquid than if it floated in a less dense liquid.Thus a hydrometer sinks more in a less dense liquid. i.e a

greater fraction of the body gets submerged in a less dense liquid.
Hence, calibrations on the stem of a hydrometer increase downwards. (see the diagram below)

The bulb of a hydrometer is made heavy so that the hydrometer always floats upright (i.e vertically)

Relation between the Fraction submerged and the Relative Density

Imagine an object of density ρ_1 having uniform cross-sectional area A and height h, floating in a liquid of density ρ_2 with height d of it submerged.
Then mass of liquid displaced = Mass of floating object
∴ Volume of displaced liquid x ρ_2 = volume of object x ρ_1
∴ $Ad\rho_2 = Ah\rho_1$
∴ $\frac{d}{h} = \frac{\rho_1}{\rho_2}$

But $\frac{d}{h}$ is the fraction of the object submerged

$$\therefore \textbf{Fraction submerged} = \frac{\textbf{Density of object}}{\textbf{Density of liquid}}$$

Examples

1. An object of R.D 0.8 floats in water. Find:
   (i) the fraction of it exposed.
   (ii) the fraction submerged if it floats in a liquid of density $1200 kgm^{-3}$.

Solution

$$\text{(i)Fraction submerged} = \frac{\text{Density of object}}{\text{Density of liquid}} = \frac{0.8}{1} = \frac{4}{5}$$

∴ Fraction exposed = 1/5

$$\text{(ii)Fraction submerged} = \frac{\text{Density of object}}{\text{Density of liquid}} = \frac{800}{1200} = \frac{2}{3}$$

2. A cube made of oak and of side 15cm floats in water with 10.5cm of its depth below the surface and with its side vertical.
What is the density of oak?

Solution

$$\frac{\text{Density of oak}}{\text{Density of water}} = \frac{10.5}{15}$$

$$\therefore \text{Density of oak} = \frac{10.5 \text{ x } 1000}{15} = 700 \text{ kg m}^{-3}$$

15.3: Balloons, Ships and submarines

A balloon, filled with a light gas like hydrogen, rises in air
The hydrogen inside the balloons plus the fibre, etc, displace air of such bigger weight than that of the inflated balloon. So the up thrust is greater than the weight of the balloon; therefore it is forced up.

Steel has a relative density of 7.8; but a ship made of steel floats on water

This is because the ship is hollow and therefore the average density of the air space and steel is less than that of water. It is capable of displacing a large amount of water whose weight balances the total weight of the ship.

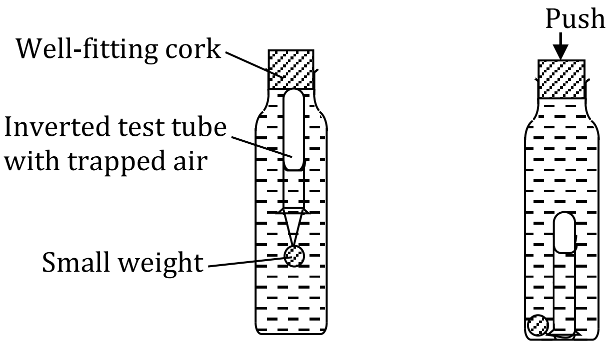
A boat sinks more as more weight is added to it

When weights are added to a boat its total weight increases. So, it has to displace more water to equalise its weight with that of the displaced water. It does so by sinking further.

A submarine can move under water or float. It has tanks that may be filled with water or air. Depending on how much water or air is left in the tanks the submarine may sink or float.

Cartesian Diver

A small inverted test tube with trapped air in a water container can be used to demonstrate the Cartesian diver.



(i) Before applying pressure on the cork: Test tube floats

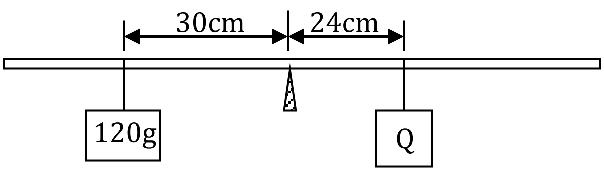
(ii) Cork pushed in: Test tube sinks

Explanation:
Before the cork is pushed in there is a big volume of air in the test tube. So the average density of the tube and the air is less than that of water. So the test tube floats.
When the cork is pushed in, the pressure transmitted equally throughout the liquid, forces more water into the test tube reducing the air space. So the average density of the tube and air increases until it sinks.

Exercise 15

1. A solid weighs 80 g in air and 30 g submerged in water. When it is submerged in oil it weighs 40 g. Find the density of oil.

2. The diagram shows a bar in equilibrium supported at its centre of gravity with the masses shown.

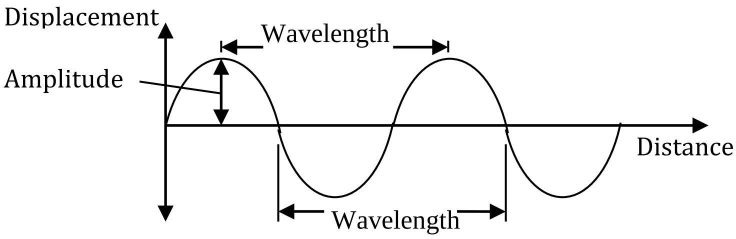


When Q is fully immersed in water the point of its support has to be shifted by 16 cm from where it is. Find the density and volume of Q.

16. WAVES

16.1: Introduction

A wave is a travelling disturbance.
Mechanical waves require a material medium while electromagnetic waves do not require one.
A mechanical wave travels by causing the particles of the medium to vibrate in a particular manner. Taking the example of a mechanical wave, we shall define the following:
Amplitude :– This is the maximum displacement of a particle, of the medium in which the wave is moving, from its rest position.
Wavelength: – This is the distance between two successive particles which are in phase (i.e which are exactly at the same displacement and moving in the same direction).
A wave may be represented as shown in the following diagram.



Frequency: – This is the number of cycles per second.
S.I unit of frequency is the hertz (Hz). Hz = 1 cycle per second.

Velocity (speed) :- It is the distance moved by wave per second.
Now, the distance between adjacent wavefronts is one wavelength (λ).
Let t = time taken for a wavefront to advance to the position of the one next to it ahead
f = the frequency of the source

Then $t = \frac{1}{f}$

$$\therefore \; velocity\ of\ the\ wave, V = \frac{Distance}{Time} = \frac{\lambda}{1/f} = f\lambda$$

$\therefore$ **$V = f\lambda$**

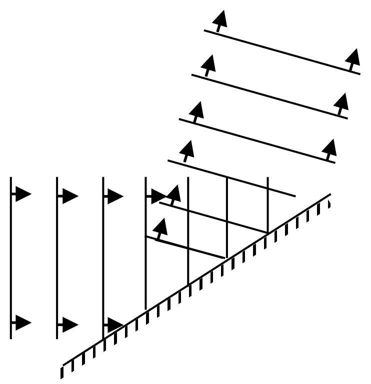
i.e. Velocity = frequency x wavelength

Example:
A wave of wavelength 2m travels at a speed of $3 \times 10^8 ms^{-1}$. What is the frequency?
<u>Terms:</u>
Wave front: – This is a line or surface, perpendicular to the direction of the wave, on which the disturbance has the same phase at all points.
Phase:- This a state of displacement and movement in relation to a given reference.
Thus, particles are said to be in phase if their displacement is the same and they are moving in the same direction.
Particles are in antiphase when they are at the same displacement but moving in opposite directions.

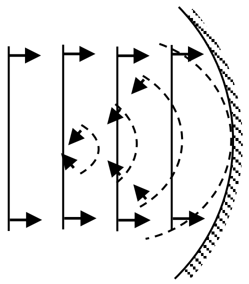
16.2: Properties of Waves

1. ***Reflection***

a) Straight waves on plane surface.

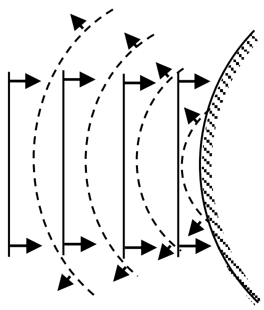


b) Straight waves incident on a concave circular reflector.



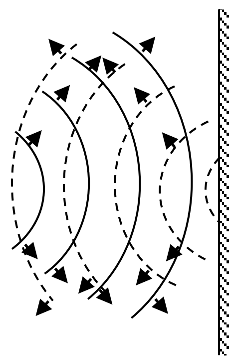
The reflected wavefronts are more curved than the reflecting surface

c) Straight waves incident a convex reflector.

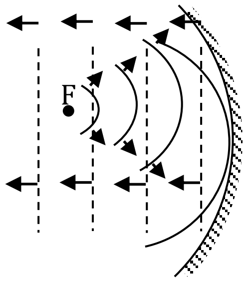


The reflected wavefronts are more curved than the reflecting surface

d) Curved waves incident on a straight reflector.



e) Curved waves incident on curved reflector

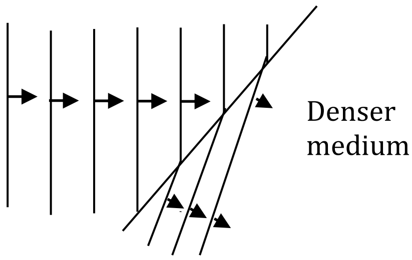


The shape of the reflected wavefronts depends on the relative position of the centre of the incident wavefronts. If the centre of the wave front coincides with the principal focus, F, of the reflector, the reflected wave fronts are straight and parallel. Otherwise they are curved either as concave or convex wave fronts.

2. *Refraction*

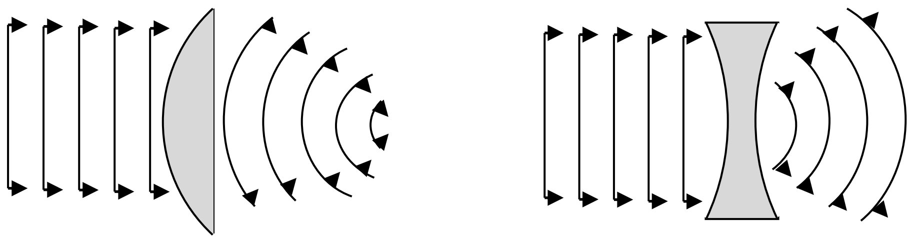
This is the change in direction of travel of a wave when it crosses from one medium to another due to change in speed.

a) Straight wave fronts meeting a plane boundary at an angle.



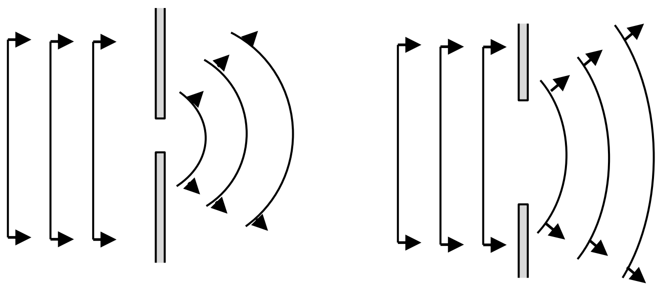
On crossing to a denser medium:
- The speed of the wave decreases
- The wavelength decreases but
- The frequency remains the same

b) Refraction of straight waves at a curved boundary.



3. ***Diffraction***

This is the spreading of waves when they pass through an opening or round an obstacle.

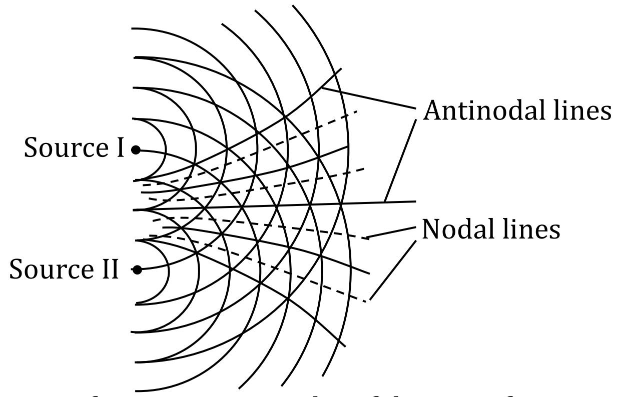


(i) Narrow aperture (ii) Wider aperture

Diffraction is greater when the aperture is narrower

4. ***Interference***

This is an overlap of two or more waves resulting in a pattern of alternate regions of high and low intensity.



Circular waves from sources I and II of the same frequency overlap in space.
At points where the two waves are exactly in phase the amplitude of the wave is increased and ***constructive interference*** is said to occur.A line joining such points in the direction of the wave is known as an ***antinodal line.***
At points where the waves are exactly antiphase, the amplitude of the resultant wave is zero (or minimum) and ***destructive inteference*** is said to occur. A ***nodal line*** joins points of destructive interference.
The distance between the nodal (or antinodal) lines increases:-

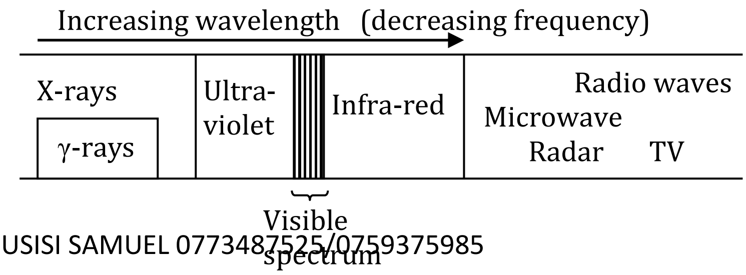
(i) As the distance from the sources S_1 and S_2 increases
(ii) When the separation of S_1 and S_2 is made smaller
(iii) If the wavelength increases (i.e as frequency decreases)

16.3: Types of Waves

1) *Transverse wave*
   In a transverse wave the particles of the medium vibrate in a direction perpendicular to the direction of the wave travel e.g waves formed by a rope, water waves, (electromagnetic waves – these do not involve particles)
2) *Longitudinal waves*
   In these the particles of the medium vibrate in a direction parallel to the direction of wave travel e.g sound.

Electromagnetic Waves

These are produced by oscillations of electrical charge in a circuit. there are no particles involved. So, an electromagnetic wave does not require a material medium and therefore can travel through vacuum.
All electromagnetic waves are transverse and travel at the same speed. Examples include: X-rays, light, heat radiation, radio waves. Below is the electromagnetic spectrum.

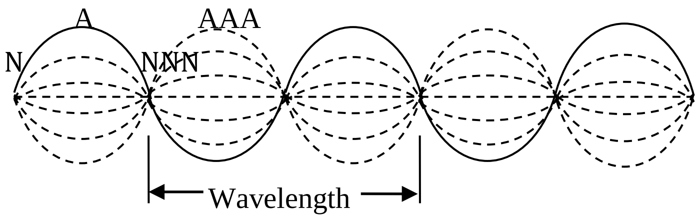


The visible spectrum (i.e light) lies between ultra-violet and infra-red.

Progressive and Stationary Waves

In a progressive wave the wave profile moves in the medium.
However, in a stationary wave the wave profile is stationary e.g. in a vibrating string of a stringed instrument.

Stationary waves

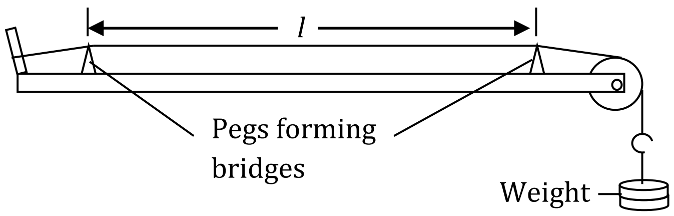


A node is appoint of zero amplitude. The particles at the node are not vibrating.
An antinode is a region of maximum amplitude. i.e moving from a node, the amplitude of vibration progressively becomes greater up to the antinode.
∴ Wavelength = 2NN = 4NA
i.e two loops make one wavelength.

Conditions for stationary wave
Two identical waves travelling in opposite directions must meet.

The Sonometer

This is an instrument used for studying behaviour of vibrating strings. It consists of a string or wire kept in tension by either a weight or other means.



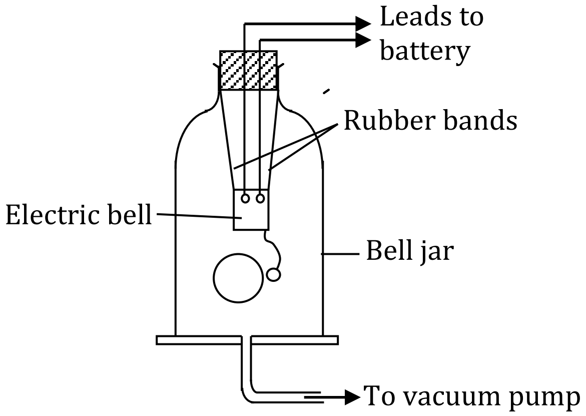
When the string is gently plucked in the centre, waves travel out to the bridges and are then reflected back, thus setting up a stationary wave of the string (not of air).The simplest wave produced will be that due to vibrations of the string as a single segment and the note given out is termed as the ***fundamental***.
If l is the distance between the pegs, then the fundamental has a wavelength equal to $2l$.

Factors affecting the frequency of vibrating string
(i) ***Tension***: The higher the tension the higher the frequency.
(ii) ***Length***: The longer the string the lower the frequency.
(iii) ***Mass per unit length***: The thicker the lower the frequency.

16.4: SOUND

Sound is a disturbance in a medium, carrying energy from one region to another with a frequency in the audio range. It is produced by vibration of its source. The vibrations cause the air in the neigbourhood to vibrate also at the frequency of the source. This disturbance travels out in the form of a longitudinal wave.
Sound, therefore, is a mechanical wave and cannot travel through a vacuum.
It can travel through matter in any state, i.e solid, liquid and gas. It obeys the same laws of reflection as light.

Experiment: To show that sound cannot travel through vacuum



- A small electric bell is hung from rubber bands inside a bell jar and switched on.
- A vacuum pump connected to the bell jar is operated to evacuate it.

Observation:
As the air is sucked out, the sound of the bell becomes fainter and fainter until it dies out completely, although the hammer can still be seen striking the gong. When now air is gradually allowed in, the bell is heard again and its loudness keeps on increasing with more let in.
This shows that actually sound requires a material medium for its propagation.

Factors affecting speed of sound in air

1) ***Temperature***:- speed of sound increases as temperature rises. This is because air particles move faster at higher temperature.
2) ***Humidity***:- speed of sound increases with humidity,
3) Speed of the air in which sound is moving

NB: Pressure does not affect speed of sound in air.

Sonic and Ultrasonic Sound

The audio frequency range for human beings is between 20Hz and 20,000Hz. If sound has a frequency higher than 20,000Hz, then it is ***ultrasonic*** and cannot be detected by the human ear.Sound of lower frequency than 20Hz is ***subsonic***.
If the speed of sound in air is 330 ms^{-1}, calculate the range of wavelength of audible sound to a human being.

Echoes

An echo is reflected sound. Echoes can be an advantage or a disadvantage
The characteristics of a building in relation to sound (i.e the absorption or reflecting behaviour for sound), is termed the *acoustics of a building*.
Reverberations are the multiple reflection of sound especially in a building.
In large halls multiple sound reflections can occur from roofs and floor. In some cases, this is undesirable e.g. in a concert hall. It may take about 5s for the organ to die away after the organist has stopped playing, whereas when the cathedral is full of people, this may take about 1s.This is because in an empty cathedral, the only surfaces to absorb sound are the roof, walls,

floor and may be some additional furniture implying longer time for sound to die out but when it is full of people, people's soft bodies and clothes occupy much of the space and on the whole reflection of sound is reduced.

A building is said to be ***acoustically dead***if no multiple reflections of sound occur in it. Such rooms are used in investigation of the properties of sound equipment.

Applications of Echoes

- In fathometers for measuring the depthof the sea.
- In ultrasound equipment used in hospitals for producing pictures of internal parts of the body.
- In industries for checking the quality of certain products.
- In radar equipment for finding distances of various objects from the transmitter using high frequency radiowaves.

Measurement of speed of sound in air by echo method

Two experimenters standing at least 100m from a wall are required

- One claps together two pieces of wood and listens to echoes
- He keeps clapping and gradually changing the frequency of the clapping until apparently no echo is heard.
- Then his colleague starts the stop clock and finds the time for a good number of claps e.g 30 or more.

The time taken between claps is calculated

$$\text{Then, speed of sound } = \frac{2 \text{ x distance from the wall}}{\text{Time between claps}}$$

The value of velocity obtained may an error due to the following factors:

- Human reaction time in timing the sound when it is made and heard
- Interference due to sound and echo when the distance between is small
- Wind

Comparison of Sound Waves and Light Waves

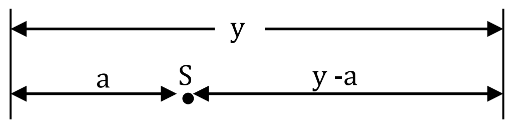
SOUND WAVES	LIGHT WAVES
- Mechanical in nature - Longitudinal in propagation - Need a material medium - Travel at much lower speeds - Havelonger wavelength	- Electromagnetic in nature - Transverse in nature - Can travel in vacuum - Travel at much higher speed - Have shorter wavelength

Exercise: Compare sound waves with water waves.

Example:

A boy standing between two parallel cliffs, but nearer to one of them, makes a loud noise. He hears one echo after 1s and another after 2s. If the speed of sound is 330 ms^{-1}, calculate the distance between the two cliffs.

Solution



Suppose that one cliff is a metres from the source S and that the cliffs are y metres apart. Then, if the distance 2a took 1 s, the distance 2(y – a) took 2 s.
Since the velocity of sound is the same for both distances, it follows that

$2a = 330 \times 1$

$\therefore \quad a = 165$ m

And $2(y - a) = 330 \times 2$

$\therefore \quad y - a = 330$

$\therefore \quad y = 330 + a = 330 + 165 = 495$ m

MUSICAL SOUNDS

Music is a combination of sounds of regular frequencies, while noise is a combination of sound of irregular frequencies.

Pitch: This is the position of a note on the musical scale. It depends on the frequency of the note i.e the higher the frequency the higher the pitch.
The ratio of frequencies of two notes is called the musical interval between them.

Intensity and Loudness of Sound

The intensity of sound is the rate of flow of energy per unit area perpendicular to the direction of the wave.It depends on:

1) Density of air
2) Frequency of sound
3) Amplitude

Quality (or Timbre) of a musical note

The same note played on two instruments does not sound the same. The notes are said to have different quality. This is because sounds (except those produced by tuning forks) are never of one frequency. They consist of a main, or ***fundamental note***, which usually dominates, plus others with smaller intensities and higher frequencies called ***overtones***.
The fundamental is the component of lowest frequency. The overtones have frequencies which are multiples of the fundamental frequency.
The quality of sound is determined by the number and intensity of overtones.

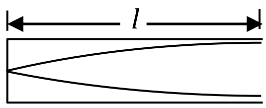
Harmonics and overtone in pipes

A harmonic is a note whose frequency is a simple multiple of the fundamental frequency.The fundamental is the first harmonic.
If f_o is the fundamental frequency, then a note of frequency $2f_o$is the 2nd harmonic, that of $3f_o$the 3rd harmonic, and so on.

Stationary Sound Waves in Pipes

There are two types of pipes, namely closed and open-ended. In a closed pipe one end is closed while in an open one both ends are open. A stationary wave will be formed in a pipe if the closed end corresponds to a node and the open end to an antinode. We shall compare the stationary waves in the two types.

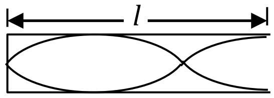
Closed-end pipe



The simplest harmonic, the fundamental, is one for which the length of the pipe is one quarter of the wavelength.
Let λ_o be the wavelength of the fundamental note and V the velocity of sound.

Then $l = \frac{1}{4}\lambda_o \therefore \lambda_o = 4l$ and the fundamental frequency,

$f_o = \frac{V}{\lambda_o} = \frac{V}{4l}$



The next harmonic to be obtained is such that the length l of the pipe is equal to ¾ of the wavelength, say λ_1, as shown.

Thus, $l = \frac{3}{4}\lambda_1$

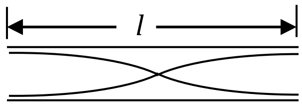
$\therefore \lambda_1 = \frac{4l}{3}$, and the frequency, $f_1 = \frac{V}{\lambda_1} = \frac{3V}{4l} = 3f_o$

i.e, the frequency is three times the fundamental frequency. So, this is the third harmonic. But realise that it is the first overtone.

You may prove that the next harmonic will have a frequency equal to $5f_o$, hence it will be the 5^{th} harmonic. Can you guess the next one?

It can be realised that only odd-numbered harmonics are possible in a closed pipe.

Open Ended Pipe

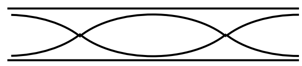


The simplest harmonic, the fundamental, is one for which the length of the pipe is half of the wavelength.

Let λ_o be the wavelength of the fundamental note and V the velocity of sound.

Then $l = \frac{1}{2}\lambda_o$, $\therefore \lambda_o = 2l$ and the fundamental frequency,

$$f_0 = \frac{V}{\lambda_0} = \frac{V}{2l}$$



The next harmonic to be obtained is such that the length l of the pipe is equal to the wavelength, say λ_1, as shown.

Thus, $l = \lambda_1$ and the frequency,

$$f_1 = \frac{V}{\lambda_1} = \frac{V}{l} = 2f_0$$

i.e, the frequency is twice the fundamental frequency. So, this is the second harmonic. In fact you may prove that in open-ended pipes all harmonics are possible.

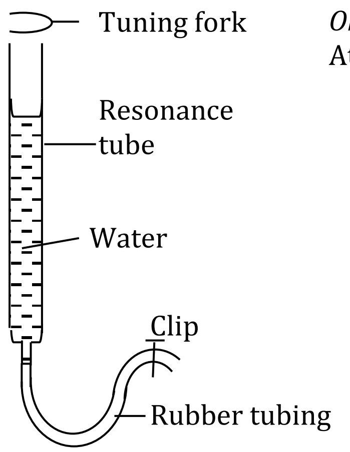
So closed-end pipes produce purer but less loud sound since some harmonics are suppressed. On the other hand, open ended pipes produce louder sound but of more inferior quality.

Resonance

Resonance is an increase in the amplitude of a vibrating system as a result of impulses received from some other system also vibrating at the natural frequency of the system.

Experiment: To Demonstrate Resonance in a closed Tube

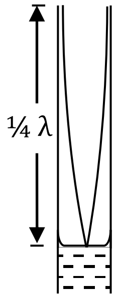
- A resonance tube is almost filled with water
- A tuning fork is sounded near and above the mouth of the tube while the water level is allowed to fall gradually.



Observation:

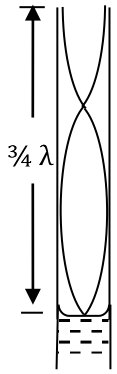
At some level the sound suddenly becomes louder. Resonance is said to have occurred.

Explanation



Sound from the tuning fork travels down and is reflected by the water surface and a stationary wave is formed of a node corresponds to the water level.

The air column in the tube = ¼ λ



If the water level is lowered further, another point is reached lower down for which resonance again occurs. The air column = ¾ λ

Experiment to measure speed of sound in air by the resonance tube

- The resonance tube is first filled with water
- A tuning fork of known frequency is sounded near and above the mouth of the tube, and the water level is lowered slowly until the sound increases in intensity. Then the length of the air column is measured and noted. It is equal to a quarter of the wavelength (λ).

Let l = length of the air column

f = frequency of the fork

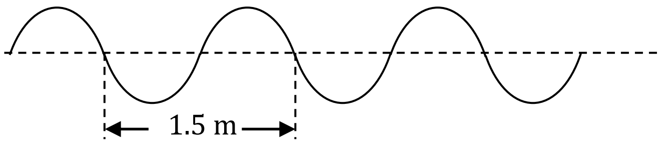
Then $\lambda = 4l$

$\therefore$ Velocity, $V = 4fl$

Exercise 16

1. A vibrator produces a sound wave that travels 660 m in 2s. Given that the wavelength is 1.32 m, find the frequency of the vibrator.

2. The figure shows a wave produced in a string at a frequency of 2 Hz.



Find the speed at which the waves travel.

3. An echo sounder on a ship sends down a pulse through the water and receives its echo 1.2 s later. What is the depth of the water, if the speed of sound in water is 1350 m s^{-1}?

4. A boy standing between two walls makes a loud sound. He hears the first echo after 1 s and the second after 2 s. find the distance between the two walls if the speed of sound is 330 ms^{1}

ANSWERS TO NUMERICAL EXERCISES

Ex. 3

1. 3.01 x 10^5 N m^{-2}

Ex. 6

1. (i) 30 cm (ii) 2 **2.** 3 **3.** 15 cm **4.** (ii) 14.3 cm (ii) 0.7

Ex. 7

1. 0.25 N **2.** 2.5 cm **3.** 3 cm

4 **(a)** Ties: AE, BC, CD, ED. Struts: CE
(b) Ties: KO, LO, PO, MO. Struts: PK, KL, LM
(c) Ties: RS Struts: RT, UT, TS
(d) Ties: IF, IJ, JH. Struts: FG, GH, IG, GJ

Ex. 11

1. (i) 10 cm (ii) 10 N **2.** 5 Nm CCW
3. (a) 0.275 N, 0.725 N (b) 10-cm mark **4.** 89.4 N

Ex. 12

1. 3 m **2.** (i) 4 (ii) 62.5% **3.** (i) 1257 (ii) 502.8 **4.** (i) 10 (ii) 300 N

Ex. 13

1. 5 N **2.** 8000 N **3.** 53.3 N **4.** 3000 kg **5.** 16 m

Ex. 15

1. 800 kg m^{-3}**2.** 2500 kg m^{-3}, 60 cm^3

Ex. 16

1. 250 Hz **2.** 3 m s^{-1}**3.** 810 m **4.** 480 m