M E C H A N I C S

Introduction:

Physics is the branch of science that deals with matter in relation to energy.

Matter is anything that occupies space and has weight. There are three states of matter and these are

i) Solids.
ii) Liquids.
iii) Gases.

Energy is the ability to do work. There are different forms of energy and these are

i) Heat energy.
ii) Sound energy.
iii) Light energy.
iv) Chemical energy.
v) Solar energy.
vi) Nuclear energy.
vii) Mechanical energy [kinetic energy and potential energy].

The above forms will be discussed later in this book.

Career opportunities in Physics:

A student who has done physics has the following career opportunities

i) Electrical engineering.
ii) Civil engineering.
iii) Architecture.
iv) Mechanical engineering.
v) Geology.
vi) Chemical engineering.
vii) Astronomy.
viii) Information technology.
ix) Telecom engineering.
x) Teaching physics.
xi) Agricultural engineering.
xii) Medicine.
xiii) Phamarcy.
xiv) Petroleum engineering

Branches of Physics:

Physics has the following branches;

i) Mechanics.
ii) Optics [light and waves]
iii) Heat.
iv) Electricity [Electrostatics and Current]
v) Magnetism.
vi) Modern physics.

SI UNITS:

This is the System International of Units. They are specifically chosen units which have been agreed upon internationally to be used for measurements.

BASIC QUANTITIES:

These are quantities that can not be expressed in terms of other physical quantities. These quantities are sometimes referred to as Fundamental quantities and examples of the basic quantities with their SI units are given in the table below;

Quantity	SI unit	Unit Symbol
Length	metre	m
Time	seconds	s
Mass	kilograms	kg
Electric current	ampere	A
Temperature	kelvin	K
Amount of substance	mole	M

DERIVED QUANTITIES:

These are quantities that can be expressed in terms of other physical quantities. These quantities can be expressed in terms of fundamental quantities of mass, length and time and examples of the derived quantities with their SI units are given in the table below;

Quantity	SI unit	Unit Symbol
Volume	meteres cubed	m^3
Density	kilograme per metre cubed	kgm^{-3}
Area	metres squared	m^2
Weight	newtons	N
Force	newtons	N
Speed	metre per second	ms^{-1}
Velocity	metre per second	ms^{-1}
Acceleration	metre per second squared	ms^{-2}
Power	watts	W
Energy	joules	J
Work	joules	J
Pressure	newton per metre squared	Nm^{-2}
Momentum	kilogramme metre per second	$kgms^{-1}$
Impulse	kilogramme metre per second	$kgms^{-1}$
Potential difference	volts	V
Capacitance	farad	F
Electric charge	coulomb	C
Frequency	hetrz	Hz
Resistance	ohm	Ω

LENGTH:

This is the distance between two points irrespective of the path taken. The SI unit of length is metre (m) but other units of millimeter (mm), centimeter (cm), kilometer (km) e.t.c can be used.

Converting units of length:

Note:

1km = 1000m   1m = 100cm   1m = 1000mm

Convert the following units to SI unit of length

i) 200mm

$1m = 1000mm$

$1mm = \frac{1}{1000} m$

$200mm = \frac{1}{1000} \times 200.$

$= 0.2m.$

ii) 3km

$1km = 1000m$

$3km = 3 \times 1000$

$= 3000m$

iii) 0.2 cm

$1m = 100cm$

$1cm = \frac{1}{100}$

$0.2cm = \frac{0.2}{100}$

$= 0.002m$

iv) 65.8mm

$1m = 1000mm$

$1mm = \frac{1}{1000} m$

$65.8mm = \frac{1}{1000} \times 65.8.$

$= 0.0658m.$

v) 34km

$1km = 1000m$

$34km = 34 \times 1000$

$= 34000m$

vi) 24 cm

$1m = 100cm$

$1cm = \frac{1}{100}$

$24cm = \frac{24}{100}$

$= 0.24m$

Measuring length:

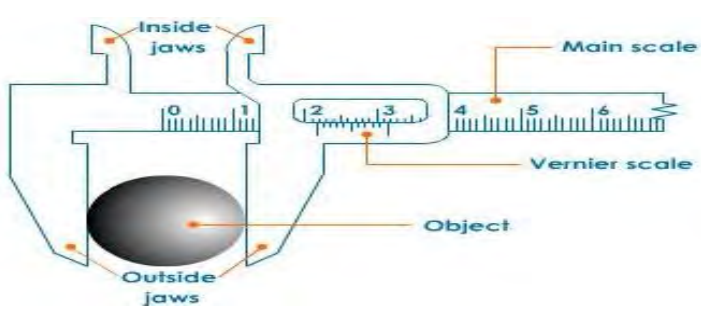
Length can be determined by estimation or accurately by using measuring instruments. There are various instruments for measuring length and the choice of the instrument is determined by the level of accuracy desired and the size of the object to be measured. These instruments include metre rule, tape measure, vernier caliper and micrometer screw gauge.

Vernier caliper:

This is used to measure short distances in centimeters that is the length between 1cm and 10cm. It can be used to measure internal and external diameter of test tube

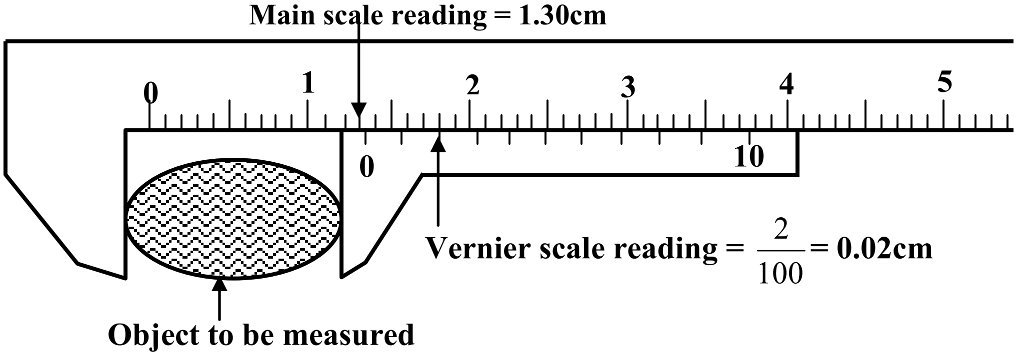
The vernier caliper has two scales, the main scale in cm and the vernier scale in mm divided into 10 equal divisions of length.

STRUCTURE OF A VERNIER CALIPER:



Using vernier calipers:

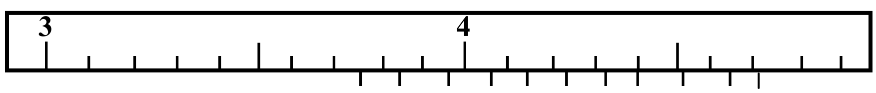
- Place the object between the jaws of the calipers and close the jaws until they just grip it.
- Read the main scale value just before the zero mark on the vernier scale.
- Read the divison on the vernier scale that coincides with the mark on the main scale. The number on this mark on the vernier scale is reading for the hundredth of centimeters. (Always divide the number read on vernier scale by 100)
- Add the reading of the main scale to that of the vernier scale to obtain the vernier caliper reading.



Therefore the reading of the above vernier caliper is 1.30 + 0.02 = 1.32cm

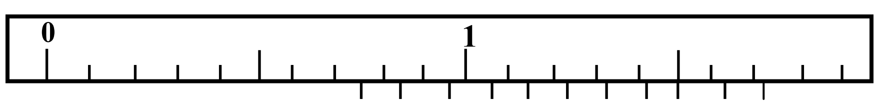
Examples

1. What is the reading of the vernier caliper below?



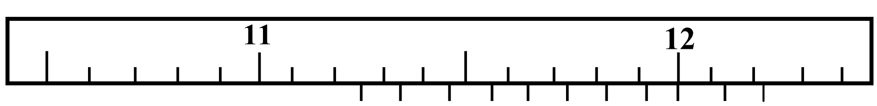
Main scale	= 3.70cm
Vernier scale	= 0.07cm
Vernier reading	= 3.77cm

2. What is the reading of the vernier caliper below?



Main scale	= 0.70cm
Vernier scale	= 0.08cm
Vernier caliper reading	= 0.78cm

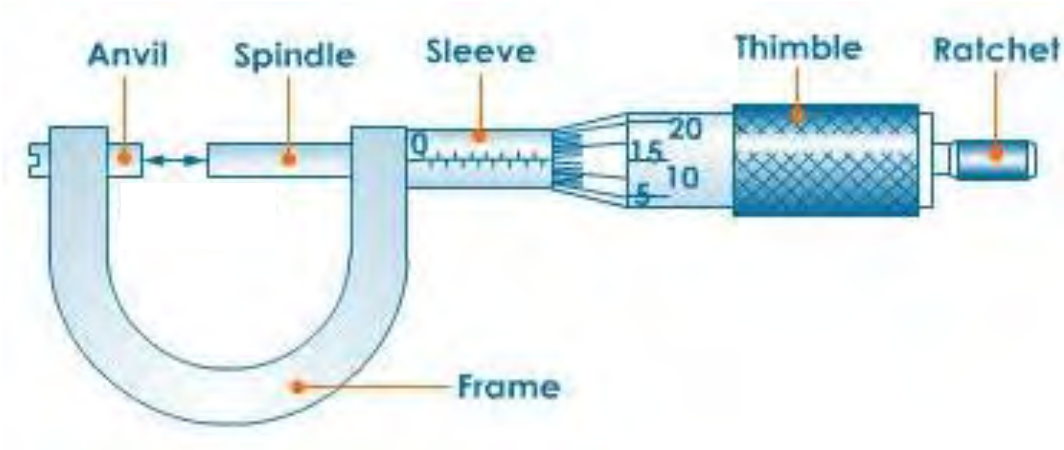
2. What is the reading of the vernier caliper below?



Main scale	= 11.20cm
Vernier scale	= 0.08cm
Vernier caliper reading	= 11.28cm

Micrometer screw gauge:

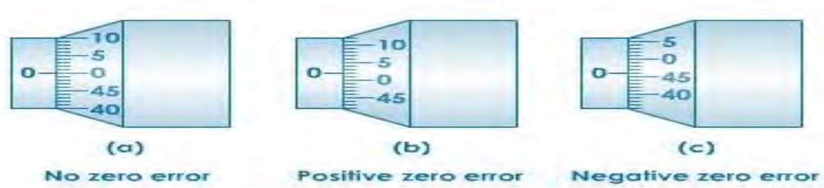
A micrometer screw gauge is used to measure very small lengths of about 0.01mm. e.g. measuring the diameter of a wire or measuring the thickness of paper. The length to measure using a micrometer screw gauge should be less than 1cm.



How to read a Micrometer screw gauge:

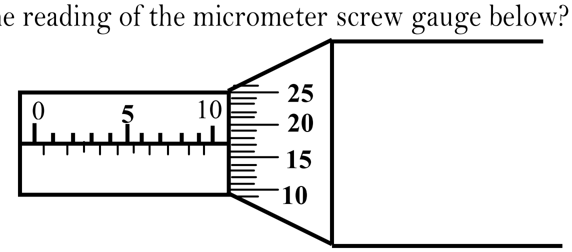
- Turn the thimble to tighten spindle very loosely on the object.
- Turn the ratchet for final adjustment until it starts to click.
- Read the last value on the sleeve scale.
- Read the value of the mark on the thimble scale which coincides with the line on the sleeve scale to two decimal places.
- Add that value to the value read on the sleeve scale which gives the final reading of the micrometer screw gauge.

NOTE: When the anvil and spindle end are brought in contact, the edge of the circular scale should be at the zero of the sleeve (linear scale) and the zero of the circular scale should be opposite to the datum line of the sleeve. If the zero is not coinciding with the datum line, there will be a positive or negative zero error as shown in figure below.



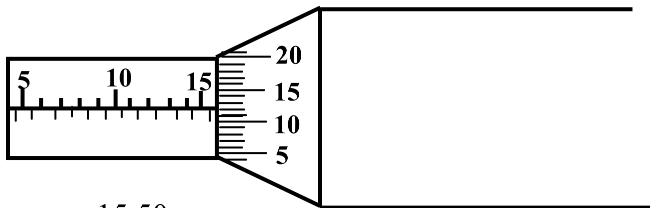
Examples:

1. What is the reading of the micrometer screw gauge below?



Sleeve scale = 10.00mm
Thimble scale = 00.17mm
Micrometer reading = 10.17mm

2. What is the reading of the micrometer screw gauge below?

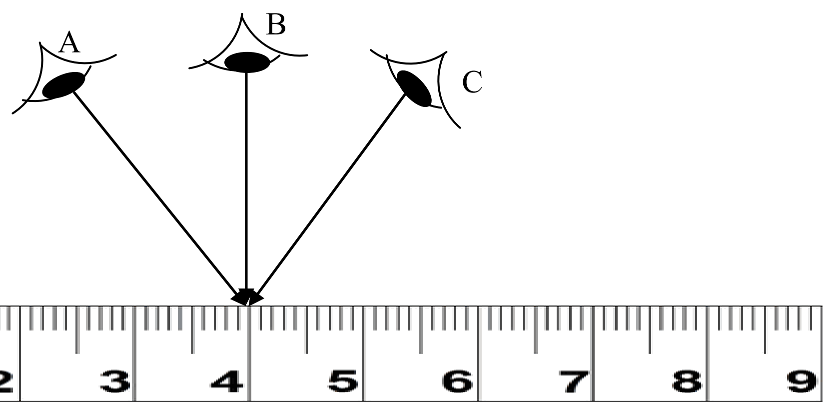


Sleeve scale = 15.50mm
Thimble scale = 00.12mm
Micrometer reading = 15.62mm

Metre rule:

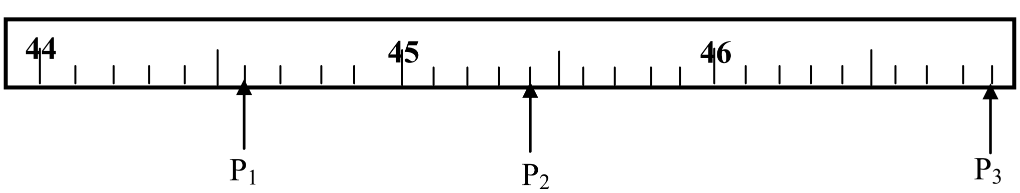
Metre rules are graduated in centimeters or millimeters. The following procedure should always be followed when using a metre rule

i) Place the metre rule in contact with the object
ii)Place the end of the object against the zero mark on the scale of the metre rule
iii) Position your eye perpendicularly above the scale but not at an angle when reading the value



A – Wrong position
B – Correct position
C – Wrong position
Examples:

What are the readings indicated by the arrows P_1, P_2 and P_3 on the metre rule below



P_1 = 44.6cm P_2 = 45.4cm P_3 = 46.9cm

Tape measure:

There are several types of tape measures and these are tailor's tape measure, carpenter's tape measure and surveyor's tape measure. The choice of the tape measure to be used depends on the length to be measured and always ensure the tape measure is taut when measuring

TIME:

This is a measure of duration of an event. The SI unit of time is second (s). Other units are minutes, hours, days, weeks, months, years etc.

Converting units of time:

Note:

1minute = 60s   1hour = 60minutes   1h = 3600s   1day = 24hours

1 week = 7 days   1 months = 30 days   1 year = 365 days

Express the following units of time to SI unit

i) 12 minutes

1 min = 60 seconds

12 min = 12 x 60

= 720 seconds

ii) 2 hours.

1min = 60 seconds.

1hour = (60 x 60) seconds.

2 hours = 2 x 60 x 60.

= 7200 seconds.

iii) 2 days

1 day = 24h

1 h = 60 min

24 h = (24 x 60)

1 min = 60 seconds

24 x 60 min = 24 x 60 x 60

2days = 2 x 24 x 60 x 60 seconds

= 172,800seconds

iv) 1 week.

1 week = 7 days.

1day = 24h.

1week = (24x7)h.

1h = 60 min.

24 x 7 hour = (24 x 7 x 60 x 60) seconds.

1 week = 24 x 7 x 60 x 60.

= 604,800 seconds.

Measurement of time:

Intervals of time are measured using either a stop watch or a stop clock depending on the accuracy required.

MASS:

Mass is quantity of matter the body contains. The SI unit of mass is kilogram (kg). Other units are grams (g), milligram (mg) and tones

The mass of an object depends on its size and the number of particles it contains therefore the mass of an object is the same everywhere because the number of particles in an object remains constant. That is an object has the same mass on the earth as on the moon.

Converting units of mass:

Note:

1kg = 1000g   1g = 1000mg

1 tonne = 1000kg   1kg = 1000mg

1. Convert the following masses to kg

i) 550g

1kg = 1000g

550g $= \frac{1}{1000}$ x 550kg

= 0.55kg

ii) 2tonnes .

1tonne = 1000kg.

2tonnes = 2 x 1000kg.

= 2000kg.

Measuring mass:

The common instruments used for measuring mass are;

i) Top pan balance.
ii) Beam balance.
iii) Lever balance.
iv) Weighing scale.
v) Spring balance.

Scientific [Standard] notation:

This is a short way of expressing very big or very small numbers using the powers of 10. The number takes the form of $a \times 10^n$ where a is a positive number i.e $(1 \leq a < 10)$ and n is an integer.

Therefore the decimal point is either moved from left to right for very small numbers less than 1 and the power of 10 is negative or from right to left for very big numbers greater than 10 and the power of 10 is positive.
However the power is zero if $1 \leq a < 10$

Examples:

1. Express the following numbers in scientific form

a) 9 b) 450000 c) 0.00056

Solution:

a) 9

The number is greater than 1 but less than 10 thus n = 0 i.e decimal point has moved no steps.

$9 = 9.0 \times 10^0$

b) 450000

The decimal point is after the last zero thus it is moved between 4 and 5 so that it is less than 10 and greater than 1 and count the number of places moved by the decimal point i.e. n = 5.

$450000 = 4.5 \times 10^5$

c) 0.00056

The decimal point is moved between 5 and 6 so that it is less than 10 and greater than 1 and count the number of places moved by the decimal point (n = -4)

$0.00056 = 5.6 \times 10^{-4}$

Note:

- When multiplying two or more numbers expressed in standard form add the powers of 10
- When dividing two or more numbers expressed in scientific form subtract the powers of 10

Example:

Work out the following;

a) $3 \times 10^6 \times 2 \times 10^3$ b) $\frac{3 \times 10^6}{2 \times 10^3}$

Solution

a) $3 \times 10^6 \times 2 \times 10^3 = 3 \times 2 \times 10^{6+3}$

$= 6 \times 10^9$

b) $\frac{3 \times 10^6}{2 \times 10^3} = \frac{3}{2} \times 10^{6-3}$

$= 1.5 \times 10^3$

AREA:

Area refers to the measure of surface. The SI unit of area is the square metre [m^2]. Other units of area are cm^2, mm^2, km^2 e.t.c

Converting units of area

$1m^2 = 10,000cm^2$ $1m^2 = 1,000,000mm^2$

1. Change the following units to SI units of area

i) $1000mm^2$

$1m = 1000mm$

$1m^2 = 1000000mm^2$

$1000mm^2 = \frac{1}{1000000} \times 1000$

$= 0.001\ m^2$

ii) $90cm^2$.

$1m = 100cm$.

$1m^2 = 10000cm^2$.

$90cm^2 = \frac{1}{10000} \times 90$.

$= 0.009m^2$.

iii) $0.0045km^2$

$1km = 1000m$

$1km^2 = 1,000,000m^2$

$0.0045km^2 = 0.0045 \times 1,000,000$

$= 4500m^2$

iv) $7600cm^2$.

$1m = 100cm$.

$1m^2 = 10000cm^2$.

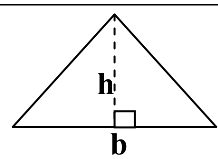
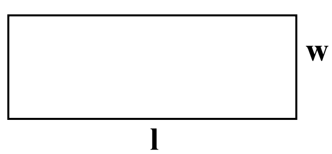
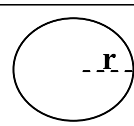
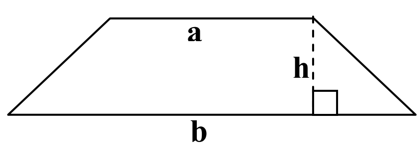
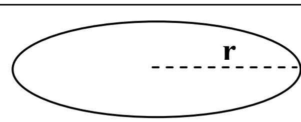
$7600cm^2 = \frac{1}{10000} \times 7600$.

$= 0.76m^2$.

Measurement of area:

Area of regular shaped objects:

The area of regularly shaped surfaces such as Rectangle, Triangle, Circle, Sphere, Square, Trapezium, and Cylinder can be obtained by applying appropriate formulae. The table shows some of the regular shapes and their corresponding formulae for area.

Name	Shape	Formular
Triangle		Area $= \frac{1}{2}$(base x height). $= \frac{1}{2}b \times h = \frac{1}{2}bh$.
Rectangle		Area = length x width = l x w = lw
Circle		Area = πr^2
Trapezium		Area $= \frac{1}{2}h(a + b)$.
Sphere		Area = $4\pi r^2$

Volume:

Volume is the amount of space occupied by matter. The SI unit of volume is the cubic metre (m^3). Other units of volume are litres, milliliters, cm^3, mm^3 e.t.c

Converting units of volume:

Note:

$1m^3 = 1000000cm^3$ $\qquad\qquad$ $1m^3 = 1,000,000,000mm^3$

1. Change the following units to SI units of volume

i) $27mm^3$

$1m = 1000mm$

$1m^3 = 1,000,000,000mm^3$

$27mm^3 = \frac{1}{1 \times 10^9} \times 27$

$= 2.7 \times 10^{-8}m^3$

ii) 34litres.

$1l = 1000cm^3$.

$1m^3 = 1,000,000cm^3$.

$34\ l = \frac{1000}{1,000,000} \times 34$.

$= 0.0034m^3$.

iii) $9000cm^3$

$1m = 100cm$

$1m^3 = 1,000,000cm^3$

$27mm^3 = \frac{1}{1000000} \times 9000$

$= 0.009m^3$

iv) 45000litres.

$1l = 1000cm^3$.

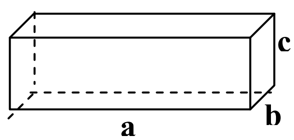
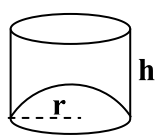
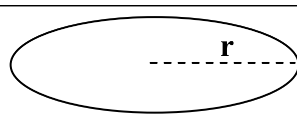
$1m^3 = 1,000,000cm^3$.

$45000l = \frac{1000}{1,000,000} \times 45000$.

$= 45m^3$.

Volume of regularly shaped objects:

The volume of regularly shaped surfaces such as cuboids, cylinder, sphere and triangular prism can be obtained by applying appropriate formulae. The table shows some of the regular shapes and their corresponding formulae for its volume.

Name	Shape	Formular
Cuboid		Volume = Base Area x height = a x b x c
Cylinder		Volume = $\pi r^2 h$
Sphere		Volume = $\frac{4}{3}\pi r^3$

Measuring volume of liquids:

Liquids have no definite shape but assume the shapes of the containers in which they are put. The following instruments are used in measuring the volume of liquids and these are measuring cylinder, pipette and burette, conical flasks, beakers, round bottom flasks e.t.c.

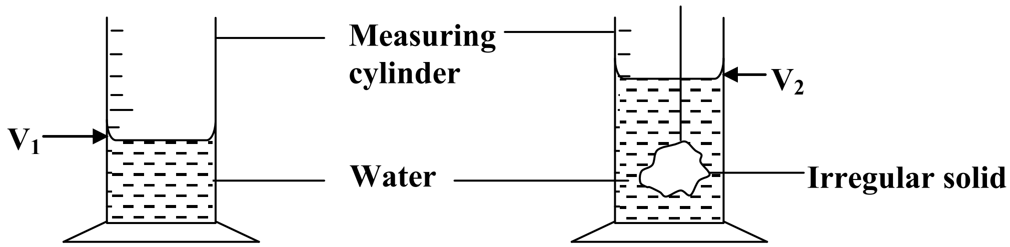
Measuring cylinders are made of glass or transparent plastic and graduated in cm^3 or ml and measuring flasks, pipettes, burettes and beakers are used to transfer known volumes of liquids.

Measuring the volume of an irregular object:

Volumes of irregular solids are measured using the displacement method.

The method works with solids that are not soluble in water i.e. do not absorb water or react with water.

1. Using a measuring cylinder



- Partly fill a measuring cylinder with water and take note of the volume, V_1 of water.
- Tie an irregular object [stone] with a thread and lower it gently into the cylinder until it is completely submerged and take note of the new volume, V_2 of water.
- The volume of irregular object is then calculated as $V_2 - V_1$.

Examples:

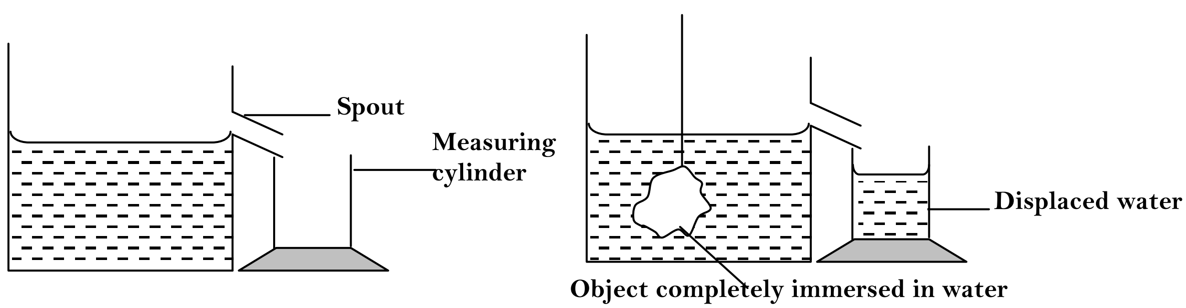
1. The volume of water in a measuring cylinder is 25cm³. If an object is immersed in water the new level is 36cm³. What is the volume of the object?

$$\text{Volume of the object} = V_2 - V_1$$
$$= 36 - 25$$
$$= 11\text{cm}^3$$

2. The volume of water in a measuring cylinder is 32cm³. If an irregualar object of volume 12cm³ is immersed in water. What is the new volume of water in a measuring cylinder?

$$\text{Volume of the object} = V_2 - V_1$$
$$12 = V_2 - 32$$
$$V_2 = 44\text{ cm}^3$$

2. Using aeureka can:



- Fill the Eureka can with water until it flows out of the spout and once the flowing stops, place a measuring cylinder under the spout of the can.
- Tie the object whose volume is required with a thread and lower it gently into the can until it is completely submerged.
- The volume of water collected in the measuring cylinder is measured and is the volume of the object.

Trial Exercise 1:

Where necessary take $\pi = \frac{22}{7}$

1. Express the following in scientific form

i) 236000 ii) 45600 iii) 0.000678 iv) 0.00000123

Ans: i) $2.36\text{x}10^5$ ii) $4.56\text{x}10^4$ iii) $6.78\text{x}10^{-4}$ iv) $1.23\text{x}10^{-6}$

2. Express the following in metres

i) 230cm ii) 6900mm iii) 0.0045km iv) 6500dm

Ans: i) 2.3m ii) 6.9m iii) 4.5m iv) 650m

3. Convert the following units to m^3

i) $25000cm^3$ ii) $56000mm^3$ iii) 20litres iv) 1200000litres

Ans: i) $2.5 \text{ x } 10^{-2}m^3$ ii) $5.6 \text{ x } 10^{-5}m^3$ iii) $2.0 \text{ x } 10^{-2}m^3$ iv) $1.2 \text{ x } 10^3m^3$

4. Calculate the area of a circle of radius 7cm in m^2

Ans: $1.54 \text{ x } 10^{-2} \text{ m}^2$

5. A sheet of paper measures 25cm by 15cm. Calculate its area in mm^2

Ans: $3.75 \text{ x } 10^4mm^2$

6. Calculate the circumference and area of the circle of radius 7.0cm

Ans: 44cm, $154cm^2$

7. If a ream of 5000 sheets has a mass of 2.5kg. Find the mass of a single sheet in

i) tones ii) kg iii) g iv) mg

Ans: i) $5 \text{ x } 10^{-7}$tonnes ii) $5 \text{ x } 10^{-4}$kg iii) $5 \text{ x } 10^{-1}$g iv) $5 \text{ x } 10^2$mg

8. The water level in a burette is $30cm^3$. If 55 drops of water fall from the burette and the volume of each drop is $0.12cm^3$. Find the final water level in the burette

Ans: $23.4cm^3$

9. A wire of radius 3mm and length 200m is made into a sphere. Calculate the radius of the sphere in m

Ans: 0.11m

10. A sphere of radius 10cm is made into a cylindrical wire of same radius. Calculate the length of the wire in mm

Ans: 133.3m

WEIGHT OF A BODY:

Weight is the force the body exerts on anything that freely supports it. OR it is the gravitational pull acting on a body towards the centre of the earth. The direction of weight is towards the centre of the earth. Weight is therefore a vector quantity and its SI unit is newton (N)

Weight = mass x acceleration due to gravity

= mg

Differences between mass and weight:

Mass	Weight
i) Quantity of matter in a body	The gravitational pull on a body
ii) Constant every where	Varies from place to place
iii) SI unit is kilogram (kg)	SI unit is newton (N)
iv) It is a scalar quantity	It is a vector quantity
v) It is a basic quantity	It is a derived quantity

Examples:

1. A body has mass of 500g. Find its weight

$$\text{Weight} = mg$$
$$= \frac{500}{1000} \times 10$$
$$= 5N$$

2. What is the weight of an object of mass 0.55kg?

$$\text{Weight} = mg$$
$$= 0.55 \times 10$$
$$= 5.5N$$

3. Find the mass of an object of weight 400N

$$\text{Weight} = mg$$
$$400 = m \times 10$$
$$m = 40kg$$

SCALAR AND VECTOR QUANTITIES:

Scalar quantity is the physical quantity that has magnitude but no direction. **Vector quantity** is the physical quantity that has both magnitude and direction. The table below shows examples of scalar and vector quantities;

Vector quantities	Scalar quantities
Force	Mass
Weight	Time
Acceleration	Length
Displament	Distance
Momentum	Power
Impulse	Work
Tension	Energy
Up-thrust	Pressure
Friction	Speed
Magnetic flux density	Temperature
Magnetic field intensity	Area
Viscous drag	Density
Magnetic field	Volume
Compression	Current
Velocity	Potential difference
Electric field	Half life
Electric field Intensity	Emf
Acceleration due to gravity	Charge

DENSITY:

The density of a substance is its mass per unit volume. The SI unit of density is kilogram per cubic metre (kgm^{-3}). Another commonly used unit is gram per cubic centimeter (gcm^{-3}). Its symbol is ρ

$$\text{Density} = \frac{\text{mass}}{\text{volume}}$$

Examples:

1. The density of water is 1gcm^{-3}. Express this density in kgm^{-3}

$$\text{Density} = \frac{\text{mass}}{\text{volume}}$$

Mass = 1g = 0.001kg Volume = 1cm^3 = 1 x 10^{-6}m^3

$$\text{Density} = \frac{0.001}{1 \times 10^{-6}}$$

$$\text{Density} = 1000\text{kgm}^{-3}$$

2. The density of mercury is 13.6gcm^{-3}. Find the volume of 2720g of mercury in m^3

$$\text{Density} = \frac{\text{mass}}{\text{volume}}$$

$$\text{Density} = 13.6\text{gcm}^{-3} = 13.6 \times 1000\text{kgm}^{-3} = 13600\text{kgm}^{-3}$$

$$\text{Mass} = 2720\text{g} = 2.72\text{kg}$$

$$13600 = \frac{2.72}{\text{V}}$$

$$\text{Volume} = 0.0002\text{m}^3$$

3. The mass of 25cm^{3}of ivory was found to be 0.045kg. Calculate the density of ivory in SI units

$$\text{Density} = \frac{\text{mass}}{\text{volume}}$$

$$\text{Mass} = 0.045\text{kg Volume} = 25 \times 10^{-6}\text{m}^3$$

$$\text{Density} = \frac{0.045}{25 \times 10^{-6}}$$

$$\text{Density} = 1800\text{kgm}^{-3}$$

FACTORS AFFECTING DENSITY:

The following are factors that affect density

Temperature: Density of a substance is inversely proportional to temperature that is the higher the temperature the lower the density and the lower the temperature the higher the density. This is because when the temperature increases the substance expands leading to increase in volume and since the mass remains constant the density reduces and when the temperature decreases the substance contracts leading to decrease in volume hence the density increases.

Pressure: Pressure only affects the density of gases, for a fixed mass of gas density is directly proportional to pressure. That is at high pressure the higher the density of a gas. This is because when the pressure of a mass of a gas is increased, its volume reduces and since the mass remains constant then the density increases and when the pressure of a mass of a gas is reduced, its volume increases and since the mass remains constant its density decreases.

Concentration of atoms: In some materials atoms are closely packed like in solids thus a material made of atoms of a lower atomic number is heavier than a material of higher atomic number. This is because atoms are larger and more spread apart hence a smaller density.

Change of state: When a substance changes its state its volume changes and since the mass is constant then the density of substance changes.

NOTE:
Size and shape of the substance do not affect the density of a substance because the arrangement of atoms inside the object remains the same even if the size or shape of the substance changes since they donot affect the packing of the molecules inside the object.

Uses of density:

The following are uses of density;
i) Indentify materials
ii) Determine the purity of a material
iii) Choose light gases for filling balloons
iv) Finding the volume of a substance

Measuring density:

Using the formula

Measure the mass and volume then calculate the density using the formula

$$\text{Density} = \frac{\text{mass}}{\text{volume}}.$$

The table gives densities of some common substances;

Substance	**Density**	
	gcm^{-3}	**kgm^{-3}**
Water	1.0	1000
Mercury	13.6	13600
Kerosene	0.8	800
Hydrogen	0.000089	0.089
Glass	2.5	2500
Lead	11.3	11300
1ron	7.86	7860
Ice	0.92	920
Silver	10.5	1050

Measuring density of a liquid

a) Using a beaker:

- Measure the mass m_1 of a clean dry beaker using a balance.
- Measure a known volume, V of the liquid using a measuring cylinder and transfer it to the beaker.
- Measure the mass m_2 of the beaker with the liquid.
- Calculate the mass of the liquid $m = m_2 - m_1$.
- Density of the liquid is then calculated as follows

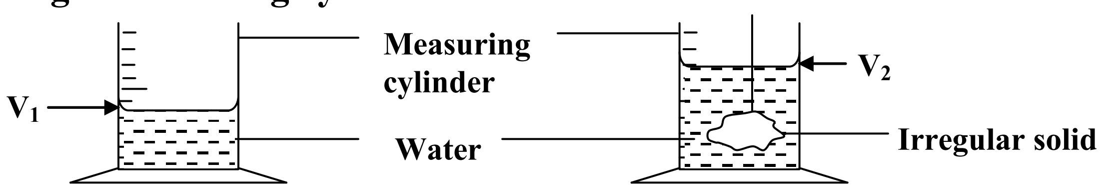
$$\rho = \frac{\text{mass}}{\text{volume}} = \frac{m_2 - m_1}{V}$$

b) Using a density bottle:

- Measure the mass, m_1 of a clean density bottle with its stopper.
- Fill the density bottle with water and replace the stopper.
- Measure the mass, m_2 of the density bottle and water.
- Calculate the mass of water = $m_2 - m_1$.
- Determine the volume of water which is the volume of density bottle = $m_2 - m_1$ since the density of water = $1gcm^{-3}$.
- Fill the density bottle with a liquid and replace the stopper.
- Measure the mass, m_3 of the density bottle and the liquid.
- Calculate the mass of a liquid = $m_3 - m_1$ and density of a liquid, $\rho = \frac{m_3 - m_1}{m_2 - m_1}$.

3. Density of irregular object:

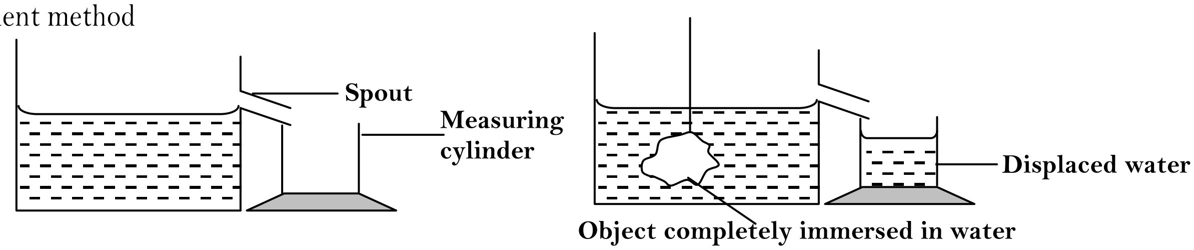
a) Using a measuring cylinder:



- Partly fill a measuring cylinder with water and note the volume V_1 of water.
- Tie a stone whose mass m is known with a thread and lower it gently into the cylinder until it is wholly submerged.
- Note and record the new volume V_2.
- Calculate the volume of the stone, $V = V_2 - V_1$.
- Density can be calculated from, $\rho = \frac{\text{mass}}{\text{volume}} = \frac{m}{V_2 - V_1}$.

b) Using Eureka can:

A Eureka can or displacement can is a container with a spout from the side and it is used to measure volumes by displacement method



- Fill the Eureka can with water until it flows out of the spout and when the flowing stops, place a measuring cylinder under the spout of the can.
- Tie the solid whose mass, m is known with a thread and lower it gently into the can until it is completely submerged
- The volume of water collected in the measuring cylinder is measured and it is the volume, V of the object.
- The density of the solid is then calculated as follows, $\rho = \frac{\text{mass}}{\text{volume}} = \frac{m}{V}$

c) Using density bottle:

- Measure the mass, m_1 of a clean dry empty density bottle.
- Fill the density bottle partly with lead shot and measure the mass, m_2.
- Fill up the density bottle with water and measure its mass, m_3.
- Empty the bottle and fill it with water and measure its mass, m_4.
- Mass of water = $(m_4 - m_1)$g.
- Mass of lead shots = $(m_2 - m_1)$g.
- Mass of water added to lead shots = $(m_3 - m_2)$g.
- Volume bottle = volume of water = $(m_4 - m_1)$ [since density of water = $1gcm^{-3}$].
- Volume of water added to lead shots = $(m_3 - m_2)$.
- Volume of lead shot = $(m_4 - m_1) - (m_3 - m_2)$

$$\text{Density of lead shots} = \frac{\text{mass of lead shots}}{\text{volume of lead shots}}$$

$$\text{Density of lead shots} = \frac{m_2 - m_1}{(m_4 - m_1) - (m_3 - m_2)}$$

Examples:

1. The mass of density bottle is 20g when empty and 45g when full of water. When full of mercury its mass is 360g. Calculate the density of mercury

$\text{mass of water} = 45 - 20$

$\text{mass of water} = 25\text{g}$

$\text{volume of water} = 25 \times 1 = 25\text{cm}^3$

$\text{volume of water} = \text{volume of mercury} = \text{volume of bottle} = 25\text{cm}^3$

$\text{mass of mercury} = 360 - 20 = 340\text{g}$

$$\text{Density} = \frac{\text{mass}}{\text{volume}}$$

$$\text{Density} = \frac{340}{25} = 13.6 \text{ gcm}^{-3}$$

2. The mass of a density bottle of volume $50cm^3$ is 10g when empty. Aluminium turnings are poured into the bottle and total mass is 60g. Water is then added into the turnings until the bottle is full and the total mass of the bottle and its contents is 90g. Calculate the density of aluminium turnings

$\text{mass of aluminium turnigs} = 60 - 10$

$\text{mass of Aluminiun turnings} = 50\text{g}$

$\text{mass of water added} = 90 - 60 = 30\text{g}$

$\text{volume of water added} = 30 \times 1 = 30\text{cm}^3$

$\text{volume of aluminium turnings} = 50 - 30 = 20\text{cm}^3$

$$\text{Density} = \frac{\text{mass}}{\text{volume}}$$

$$\text{Density} = \frac{50}{20} = 2.5 \text{ gcm}^{-3}$$

DENSITY OF MIXTURES:

A mixture is obtained by putting together two or more substances that do not react with one another. The density of mixture depends on the masses of its constituent substances and their proportions. The volume of the mixture is the sum of the volumes of individual constituents and mass of the mixture is the sum of the masses of the constituents.

$$\text{Density of the mixture} = \frac{\text{Mass of the mixture}}{\text{volume of the mixture}}$$

Examples:

1. $100cm^3$ of freshwater of density $1.0gcm^{-3}$ is mixed with $100cm^3$ of sea water of density $1.03gcm^{-3}$. Calculate the density of the mixture

$$\text{Density of the mixture} = \frac{\text{Mass of the mixture}}{\text{volume of the mixture}}$$

$$\text{Density of the mixture} = \frac{m_1 + m_2}{V_1 + V_2}$$

$\text{mass of mixture} = m_1 + m_2$

$m_1 = \rho_1 x v_1 \qquad m_2 = \rho_1 x v_2$

$m_1 = 100 \times 1 \qquad m_2 = 1.03 \times 100$

$m_1 = 100g \qquad m_2 = 103g$

$$\text{Density of the mixture} = \frac{100 + 103}{100 + 100}$$

$$\text{Density of the mixture} = \frac{203}{200}$$

$$\text{Density of the mixture} = 1.015gcm^{-3}$$

2. $0.4m^3$ of liquid Y and of density $900kgm^{-3}$ is mixed with $0.35m^3$ of liquid Z and of density $800kgm^{-3}$. Calculate the density of the mixture

$$\text{Density of the mixture} = \frac{\text{Mass of the mixture}}{\text{volume of the mixture}}$$

$\text{mass of mixture} = m_1 + m_2$

$m_1 = \rho_1 x v_1 \qquad m_2 = \rho_1 x v_2$

$m_1 = 0.4 \times 900 \qquad m_2 = 0.35 \times 800$

$m_1 = 360kg \qquad m_2 = 280kg$

$$\text{Density of the mixture} = \frac{360 + 280}{0.4 + 0.35}$$

$$\text{Density of the mixture} = \frac{640}{0.75}$$

$$= 853.3kgm^{-3}$$

RELATIVE DENSITY:

This is the ratio of density of a substance to density of water.

$$R.D = \frac{\text{density of a substance}}{\text{density of water}}$$

$$R.D = \frac{\text{mass of a substance}}{\text{mass of an equal volume of water}}$$

$$R.D = \frac{\text{weight of a substance}}{\text{weight of an equal volume of water}}$$

Relative density has no units because it is a ratio of similar quantities.

Examples:

1. Find the relative density of mercury if its density is $13.6gcm^{-3}$

$$R.D = \frac{\text{density of a substance}}{\text{density of water}}$$

$$R.D = \frac{13.6}{1}$$

$$R.D = 13.6$$

2. If a substance has relative density of 2. What is its density if density of water $1000kgm^{-3}$?

$$R.D = \frac{\text{density of a substance}}{\text{density of water}}$$

$$2 = \frac{\text{density of a substance}}{1000}$$

$$\text{Density of substance} = 2000\text{kgm}^{-3}$$

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

$\text{mass of empty density bottle} = 30\text{g}$

$\text{mass of density bottle full of a liquid} = 110\text{g}$

$\text{mass of density bottle full of water} = 130\text{g}$

Solution

$\text{mass of liquid} = 110 - 30 = 80\text{g}$

$\text{mass of water} = 130 - 30 = 100\text{g}$

$$\text{R.D of a liquid} = \frac{\text{mass of liquid}}{\text{mass of an equal volume of water}}$$

$$\text{R.D of a liquid} = \frac{80}{100}$$

$$\mathbf{R.D\ of\ a\ liquid = 0.8}$$

Trial Exercise 2:

Where necessary take acceleration due to gravity, $g = 10ms^{-2}$

1. What mass of lead of density $11{,}300kgm^{-3}$ has the same volume as 16kg of alcohol of density $800kgm^{-3}$.

   Ans: 226kg

2. An empty density bottle has a mass of 17.5g. When full of water, its mass is 37.5g. When full of liquid X, its mass is 35g. If the density of water is $1000kgm^{-3}$, find the density of liquid X

   Ans: $875kgm^{-3}$

3. An empty density bottle has a mass of 25g. Its mass is 50g when full of water and 45g when full of another liquid. Calculate

   i) Relative density of a liquid

   ii) Density of a liquid

   Ans: i) 0.8 ii) $800kgm^{-3}$

4. The mass of a density bottle of volume $160cm^3$ is 110g when empty. Aluminium turnings are poured into the bottle and the total mass is 160g. Water is then added into the turnings till the bottle is full. If the total mass of the bottle and its contents is 240g, calculate the density of aluminium turnings.

   Ans: $0.625gcm^{-3}$

5. $1800cm^3$ of fresh water of density $1000kgm^{-3}$ is mixed $2200cm^3$ of sea water of density $1025kgm^{-3}$. Calculate the density of the mixture.

   Ans: $1.01375gcm^{-3}$

6. Bronze is made by mixing molten copper and tin. If 100kg of mixture contains 80% by mass of copper and 20% by mass of tin. Calculate the density of bronze if the density of copper is $8000kgm^{-3}$ and density of tin $5000kgm^{-3}$

   Ans: $7142.9kgm^{-3}$

7. A body weighs 75N. Calculate it's mass

   Ans: 7.5kg

8. An astronaut weighs 900N on earth. On the moon, he weighs 150N. Calculate the moon's gravitational strength.

   Ans: $1.67ms^{-2}$

9. The mass of an object is 50kg. If its weight is 1000N on a certain planet, calculate

   i) The weight of the object on earth

   ii) The acceleration due to gravity on the planet

   Ans: i) 500N ii) $20ms^{-2}$

10. A man has a mass of 70kg. Calculate his weight on the moon, where the acceleration due to gravity is $1.7Nkg^{-1}$

    Ans: 119N

Multiple-choice Exercise:

1. Which of the following is not a basic unit?
   A. kilogram B. newton C. second D. metre
2. Calculate the mass of air of density $1.29kgm^{-3}$ in a room of floor 10m x 10m x 5m
   A. 3.88×10^{3}kg B. 6.45×10^{2}kg C. 1.29×10^{-2}kg D. 2.58×10^{-4}kg
3. An empty density bottle weighs 26.5g. When full of a salt solution it weighs 82.5g and 76.5g when full of water. Calculate the density of salt solution
   A. $1.078gcm^{-3}$ B. $1.120gcm^{-3}$ C. $112gcm^{-3}$ D. $1078gcm^{-3}$
4. An empty 20litre jerry can has a mass of 0.8kg. What will be its mass when full of water.
   A. 20.8kg B. 20.0kg C. 19.2kg D. 16.0kg
5. Which of the following is a scalar quantity?
   A. weight B. mass C. velocity D. force
6. The mass of a rectangular block 4cm x 6cm x 10cm is 0.18kg. What is its density in gcm^{-3}?
   A. 0.75 B. 4.32 C. 240 D. 750
7. $80cm^{3}$ of water was mixed with $100cm^{3}$ of liquid of density $0.8gcm^{-3}$. What is the density of the mixture if there is no change in total volume in mixing?
   A. $0.889gcm^{-3}$ B. $0.800gcm^{-3}$ C. $1.320gcm^{-3}$ D. $1.500gcm^{-3}$
8. Which of the following physical properties changes when a body is moved from the earth to the moon?
   A. mass B. volume C. density D. weight
9. Which of the following can be used to measure the diameter of a bicycle spoke accurately?
   A. metre rule B. vernier caliper
   C. tape measure D. micrometer screw gauge
10. 44g of salt of density $2.2gcm^{-3}$ are dissolved in 100g of water. What is the density of the salt solution if the resulting volume of solution is the same as the volumes of salt and water together?
    A. $1.20gcm^{-3}$ B. $1.44gcm^{-3}$ C. $1.80gcm^{-3}$ D. $2.00gcm^{-3}$
11. A tin containing $6 \times 10^{-3}\,m^{3}$ of paint has a mass of 8kg, if the mass of empty tin with the lid is 0.5kg. Calculate the density of paint in kgm^{-3}
    A. $\frac{8 \times 0.5}{6 \times 10^{-3}}$ B. $\frac{7.5}{6 \times 10^{-3}}$ C. $\frac{8}{6 \times 10^{-3} \times 0.5}$ D. $\frac{8.5}{6 \times 10^{-3}}$
12. Which of the following sets contains only vector quantities?
    A. weight, displacement, acceleration, magnetic field
    B. energy, electric field, momentum, distance
    C. mass, velocity, force, speed
    D. specific heat capacity, power, time, volume
13. The three fundamental physical quantities are
    A. density, mass and time B. length, time and mass
    C. length, time and weight D. volume, temperature and weight
14. A rectangular block of tin is 0.5m long and 0.01m thick. Calculate the width of the block if it has a mass of 0.365kg and density of $7300kgm^{-3}$
    A. 0.001m B. 0.01m C. 0.1m D. 1m
15. Which of the following is a vector quantity?
    A. speed B. mass C. temperature D. displacement

16. The density of a stone of volume 25cm^3 is 10kgm^{-3}. Find its mass in kg

A. 2.5×10^{-4} B. 2.5×10^4 C. 2.5×10^2 D. 2.5×10^1

17. A set of apparatus that is suitable for measurement of volume of irregular solid include

A. Overflow can, measuring cylinder and a flask

B. Overflow can, burette, string and resort stand

C. Overflow can, measuring cylinder and a string

D. Burette, overflow can, measuring cylinder, string and a retort stand.

18. The width of a metre rule is accurately measured by a

A. micrometer screw gauge B. vernier caliper

C. tape measure D. metere rule

19. The easily compressed state of matter is

A. solid B. liquid C. metal D. gas

20. Which of the following is true about a dry cell, it converts

A. mechanical energy to electrical energy B. electrical energy to kinetic energy

C. chemical energy to electrical energy D. chemical energy to mechanical

Answers:

1	B	5	B	9	D	13	B	17	C
2	B	6	A	10	A	14	B	18	B
3	B	7	A	11	B	15	D	19	D
4	A	8	D	12	A	16	A	20	C

FORCE:

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

Force is a vector quantity which has both magnitude and direction. The SI unit of force is **newton (N).**

A newton is a force which gives a mass of 1kg an acceleration of 1ms^{-2}.

Effects of a force

Force on a body has the following effects;

- ✓ It makes a stationary body move when pushed or pulled.
- ✓ It changes the direction of a moving body.
- ✓ It deforms or changes the shape of a body.
- ✓ It makes a moving body move faster or slower.
- ✓ It stops a moving body.
- ✓ It changes the speed of a moving body.

Types of forces:

The following are types of forces;

1. Frictional force.

This is a force that opposes relative motion between two surfaces.

2. Centripetal force.

This is the force that keeps a body moving in a circle and is directed towards the centre.

3. Up-thrust force.

This is an upward force acting on a body immersed in a fluid.

4. Magnetic force.

This is the force that attracts or repels magnetic substances.

5. Electrostatic force.

This is a force between two charged bodies.

6. Cohesion force.

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

7. Adhesion force.

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

8. Viscous drag force.

This is the force which opposes motion of body moving in a fluid.

9. Tensional force.

This is the pull or compression of the string at both ends.

10. Gravitational force.

This is a force that pulls a body towards the centre of the earth. Gravitational force pulls all bodies towards the centre of the earth with the same acceleration called **Acceleration due to gravity; g**. Acceleration due to gravity is therefore the acceleration with which the force of gravity pulls all objects on or near the surface of the earth towards its Centre of the earth. Hence it is the rate of change of velocity for a body moving freely under gravity. The average value of g on earth is $\mathbf{9.81 \approx 10ms^{-2}}$ but it varies slightly from place to place due to the shape of the earth and rotation of the earth.

Note:

Acceleration due to gravity depends on the distance from the centre of the earth and since the earth is not a perfect sphere then acceleration due to gravity is greater at the poles than at the equator because the polar radius is less than the equatorial radius.

RESULTANT FORCE:

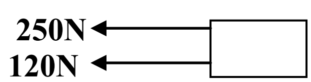
The resultant force is a single force which has the same effect as of two or more forces acting on a body. When two or more forces act on a body there is a resultant force, the resultant force may be greater or equal to zero. When the resultant force on the body is zero the body is said to be in equilibrium.

Forces acting in a straight line:

a) Forces acting in the same direction.

Examples:

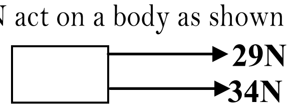
1. Two forces of 120N and 250N act on body in the same direction. Find the resultant force on the body



Resultant force, F = 120 + 250

= 370N to the left

2. Two forces of 29N and 34N act on a body as shown below. Find the resultant force on the body



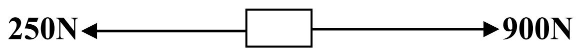
Resultant force, F = 29 + 34

= 63N to the right

b) Forces acting in the opposite direction

Examples:

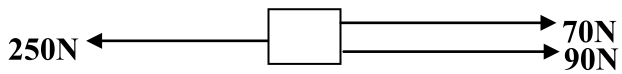
1. Two forces of 900N and 250N act on body in the opposite direction. Find the resultant force on the body



Resultant force, F $= 900 - 250$

$= 650$N to the right

2. Forces act on a body as shown below. Find the resultant force on the body

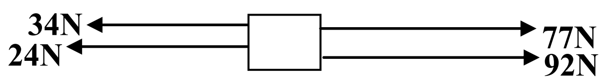


Resultant force, F $= 250 - (70 + 90)$

$= 250 - 160$

$= 90$N to the left

2. Forces act on a body as shown below. Find the resultant force on the body



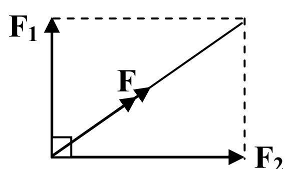
Resultant force, F $= (77 + 92) - (34 + 24)$

$= 169 - 58$

$= 111$N to the right

c) Forces acting at right angles:

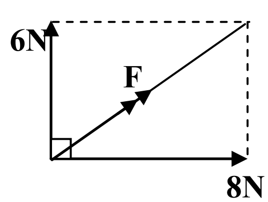
Given that the forces F_1 and F_2 act on a body at right angles as shown below



Resultant force, F $= \sqrt{(F_1^2 + F_2^2)}$

Examples

1. Two forces of 8N and 6N act on a body at right angles as shown below. Find the resultant force



The resultant force, F $= \sqrt{(6^2 + 8^2)}$.

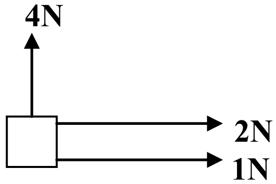
$= \sqrt{(36 + 64)}$.

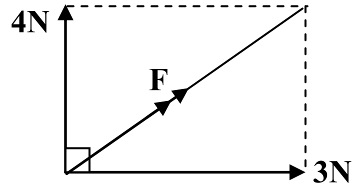
$= \sqrt{100}$.

$= 10$N.

2. Forces act on a body as shown below. Find the resultant force on the body

a)





Vertically $F_1 = 4N$

Horizontally $F_2 = 2 + 1 = 3$

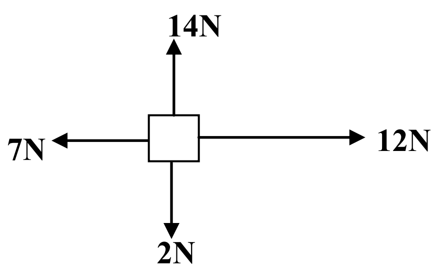
The resultant force, $F = \sqrt{(4^2 + 3^2)}$

$= \sqrt{(16 + 9)}$

$= \sqrt{25}$

$= 5N$

b)



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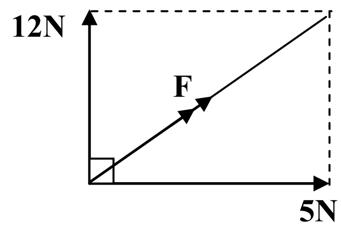


Vertically $F_1 = 14 - 2 = 12N$

Horizontally $F_2 = 12 - 7 = 5N$

The resultant force, $F = \sqrt{(12^2 + 5^2)}$

$= \sqrt{(144 + 25)}$

$= \sqrt{169}$

$= 13N$

FRICTION:

This is the force that opposes relative motion between two bodies in contact.

Types of friction:

There are two types of friction and these are

i) Static friction
ii) Dynamic [sliding or kinetic] friction

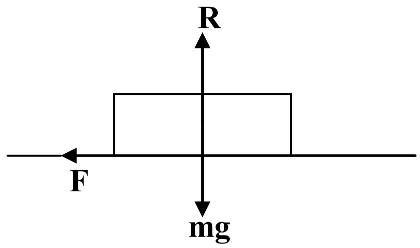
Static friction:

This is the frictional force between objects tending to slide against one another. It occurs between stationary bodies and depends on coefficient of friction and normal reaction on the body.

Coefficient of static friction, μ:

This is the ratio of limiting friction to the normal reaction.

Limiting friction is the frictional force between two surfaces when they are at the verge of sliding over each other. When a body of mass, m rests on a rough surface, the following forces act on the body.



R – Normal reaction

F – Frictional force

Mg – Weight of the body

$F = \mu R.$

$R = mg.$

$F = \mu mg.$

Where μ is a constant called coefficient of friction.

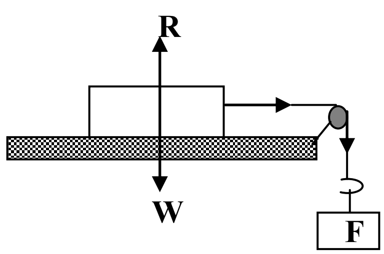
Friction force, F on the surface depends on the following factors;

i) the nature of the surface .

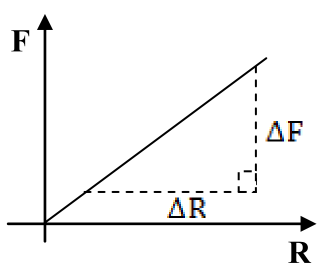
ii) the magnitude of the force moving the body.

iii) the weight/mass of the body.

Experiment to determine the coefficient of friction:



- Connect a light inextensible string to a block of wood resting on a rough horizontal surface.
- Suspend a mass hanger on its other end by a light inextensible string which passes over a smooth fixed pulley at the edge of the surface.
- Increase the force, F on the mass hanger until the block just begins to move.
- Note and record the total force, F on the mass hanger.
- Add standard weights at a time to the block of wood and repeat the above procedure to find the new total force F.
- Tabulate your results in a suitable table.
- A graph of F against R (R = W) is plotted and its slope determined which is the coefficient of friction, μ.



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

Example:

A block of wood of mass 2kg is placed on a horizontal surface. Find the limiting friction if the coefficient of friction is 0.2.

$F = \mu R, \qquad R = mg.$

$= \mu mg.$

$= 0.2 \times 2 \times 10.$

$= 4N.$

Dynamic friction:

This is the frictional force between objects moving relative to each other.

Dynamic friction depends on the following factors;

i) The weight of moving object.
ii) The nature of the surfaces in contact.
iii) The coefficient of kinetic friction.

Laws of friction:

1. Frictional force is directly proportional to the normal reaction.
2. Frictional force is independent of area of contact but depends on the nature of the surface.
3. Frictional force is independent of the relative velocity between two surfaces.
4. Frictional force always opposes relative motion.

Advantages of friction:

i) It enables movements of objects.
ii) It enables us to walk.
iii) It enables us to write.
iv) It enables us to light a match box.
v) It enables us brush our teeth, shoes, floor.
vi) It prevents the foot of ladder from slipping off.
vii) It enhances the proper functioning of braking systems.

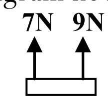
Disadvantages of friction:

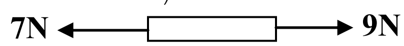
i) It causes unnecessary noise.
ii) It causes surfaces to wear off.
iii) It causes unnecessary heat.
iv) It retards movement of objects.
v) It causes energy wastage.
vi) It reduces the efficiency of machines.

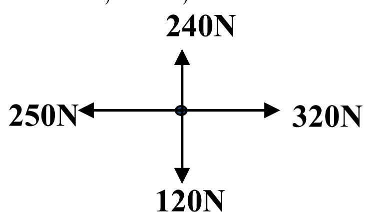
Ways of reducing friction:

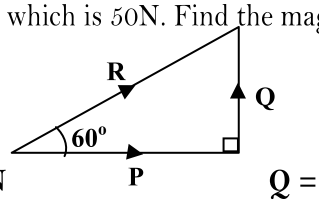
i) Lubrication by using lubricants such as oiling or greasing.
ii) Using ball bearings.
iii) Using rollers.
iv) Smoothening the surfaces that are in contact.

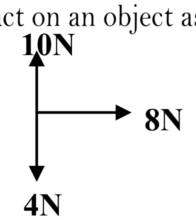
Trial Exercise 3:

1. Find the resultant force of 4N and 8N acting at the same point on an object if;
   i) The forces act in the same direction in the same straight line
   ii) The forces act in opposite directions but in the same straight line
   Ans: i) 12N ii) 4N towards 8N force
2. Show on a diagram how forces of 7N and 9N can be combined to give the resultant force of;
   i) 16N ii) 2N
   Ans: i)


   ii)


3. Four forces of 240N, 320N, 120N and 250N act on particle P as shown in the diagram below


   Determine the magnitude of the resultant force on P
   Ans: 138.9N
4. Two forces concurrently on a point P. One force is 60N due east. The second force is 80N due north. Find the resultant force acting on point P
   Ans: 100N
5. A plane flying due north at 100ms^{-1} is blown due west at 50ms^{-1} by a strong wind. Find the resultant velocity of the plane.
   Ans: 111.8ms^{-1}
6. Two forces concurrently on a point P. One force is 40N due west. The second force is 30N due south Find the resultant force acting on point P
   Ans: 50N
7. The figure below shows the resultant force R of two forces P and Q. R makes an angle of 60^o with the horizontal force P which is 50N. Find the magnitude of Q and P


   Ans: R = 100N Q = 86.6N
8. Forces of 10N, 8N and 4N act on an object as shown below. Find the resultant force on an object


   Ans: 10N
9. Two forces of 12N and 5N act on a body at right angles. Calculate the resultant force of the two forces and the angle the resultant make with the 5N force
   Ans: 13N, 67.4^o
10. Name all the forces acting on the following bodies
    i) A box placed on table. ii) A mass suspended from a spring balance.
    iii) A moving car negotiating a bend.

WORK, ENERGY AND POWER:

WORK:

This is the product of force and distance moved in the direction of force. **OR** work is done when the point of application of force moves in the direction of force. The SI unit of work is a joule (J). A **joule** is the work done when a force of 1N moves a body through a distance of 1m in the direction of force.

Work done = force x distance moved in direction of force

= F x d

If the body is projected vertically the force acting is the weight of the body

Work done = F x d

= mgd

Examples:

1. An object is pulled through a distance of 2m by a force of 55N. Calculate the work done

Work done = F x d

= 2 x 55

= 110J

2. An object is pulled through a distance of 20cm by a force of 1500N. Calculate the work done

Work done = F x d

= 0.2 x 1500

= 300J

3. An object of mass 500g moves through a vertical height of 40cm. Calculate the work done

Work done = F x d

= mg x d

= 0.5 x 10 x 0.4

= 2J

4. A body of mass 250g climbs 25 steps each of height 20cm. Calculate the work done

Work done = F x d

= 0.25 x 10 x 0.2 x 25

= 12.5J

ENERGY:

This is the ability to do work. The SI unit of energy is joule (J).

Forms of energy:

- **Heat energy.**

  This is the form of energy that is transferred from region of high temperature to region of low temperature. This form of energy is produced by burning fuels, electric heaters and radiation from the sun.

- **Sound energy.**

  This is a form of energy produced when particles in the medium are set into vibrations. This form of energy is heard by the ear.

- **Electrical energy.**

  This is a form of energy due to the flow of charges. This form of energy can be obtained by the conversion of other forms of energy using generators.

- **Light energy.**

  This is the form of energy produced by hot bodies and travels in a straight line. This form of energy can be converted into other forms of energy and helps us to see.

- **Chemical energy.**

  This is a form of energy that can be converted to heat by burning.

- **Nuclear energy.**

  This is form of energy produced when unstable nucleus splits through nuclear fission or two light nuclei fuse together through nuclear fusion.

- **Wave energy.**

  This is a form of energy which is transferred from one point to another without causing any permanent displacement of medium itself. This form of energy causes a disturbance through the medium.

Sources of energy:

- **The sun.**
  The sun produces light energy and heat energy which are used in different ways.
- **Wind.**
  Wind is moving air which can drive turbines to produce electrical energy.
- **Fuel.**
  Fuels like kerosene and petroleum when burnt produce heat energy and light energy which can be used in different ways.
- **Geothermal.**
  Geothermal is a source of electrical energy in power stations.
- **Waterfalls or Dams.**
  Waterfalls may be used to turn turbines in hydro-electric power stations.
- **Nuclear.**
  When unstable nucleus splits nuclear energy is released.
- **Oceans.**
  Ocean currents can be converted into other forms energy like electrical energy.

Renewable (Non-Exhaustible) sources of energy:

These are sources of energy which can be re-used to produce energy. Examples are wind, sun (solar), water (hydro-electric).

Non-Renewable (Exhaustible) source of energy:

These are sources of energy which cannot be re-used to produce energy. Examples are kerosene, petroleum, coal, and biogas.

MECHANICAL ENERGY:

This is divided into two forms of energy namely

i) Kinetic energy.

ii) Potential energy.

Kinetic energy:

This is the energy possessed by a body due to its motion. It depends on the speed of the body

Kinetic energy $= \frac{1}{2} \times \text{mass} \times \text{velocity}^2$

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

Examples

1. A body of mass 3kg moves with a speed of $30ms^{-1}$. Find its kinetic energy

$$
\begin{aligned}
K.E &= \tfrac{1}{2}mv^2 \\
&= \tfrac{1}{2} \times 3 \times 30^2 \\
&= \tfrac{1}{2} \times 3 \times 900 \\
&= \tfrac{1}{2} \times 2700 \\
&= 1350J
\end{aligned}
$$

2. An object of volume $100cm^3$ and density $8gcm^{-3}$ moves with a speed of $10ms^{-1}$. Find its kinetic energy

$$
\begin{aligned}
K.E &= \tfrac{1}{2}mv^2 \\
m &= \rho \times v \\
&= 8 \times 100 \\
&= 800g \\
K.E &= \tfrac{1}{2} \times 0.8 \times 10^2 \\
&= \tfrac{1}{2} \times 0.8 \times 100 \\
&= \tfrac{1}{2} \times 80 \\
&= 40J
\end{aligned}
$$

Potential energy:

This is the energy possessed by a body by virtue of its position in the gravitational field.

Potential energy $= \text{mass} \times \text{acceleration due to gravity} \times \text{height}$

$= mgh$

Examples:

1. Find the potential energy of an object of mass 350g when it is 10m above the ground

$$
\begin{aligned}
P.E &= mgh \\
&= 0.35 \times 10 \times 10 \\
&= 35J
\end{aligned}
$$

2. A 5kg mass falls from a height of 20m. Calculate the potential energy lost

$$
\begin{aligned}
P.E &= mgh \\
&= 5 \times 10 \times 20 \\
&= 1000J
\end{aligned}
$$

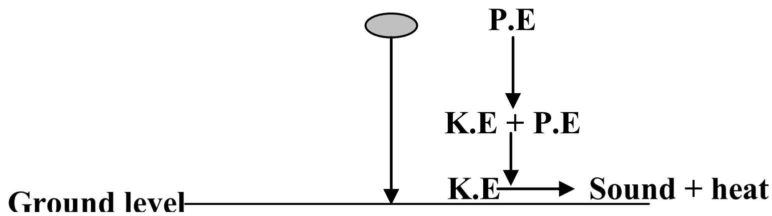
The law of conservation of energy:

It states that energy can neither be created nor destroyed but changes from one form to another.

Energy changes:

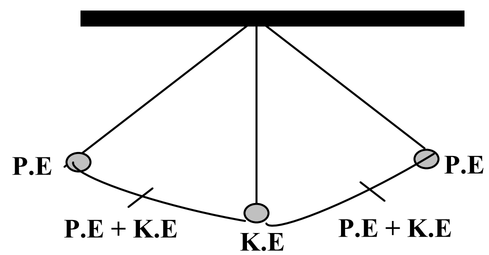
1. For a body falling freely the following energy changes take place

P.E ⟶ P.E + K.E ⟶ K.E ⟶ sound + heat



2. For a freely swinging pendulum the energy changes are

P.E ⟶ P.E + K.E ⟶ K.E ⟶ P.E + K.E ⟶ P.E



3. When lighting a match box

Chemical energy ⟶ Heat + Light

4. When a boy compresses the spring

Mechanical energy ⟶ Elastic potential energy

5. When lighting a lamp connected to a battery

Chemical energy ⟶ Electrical energy ⟶ heat + light

6. Catapult pulled by a person to propel a stone

Mechanical energy ⟶ Elastic potential energy ⟶ kinetic energy

N.B: The following devices can be used to carry out the following energy changes;

i) Electrical energy to mechanical energy ------------------------Motor

ii) Mechanical energy to electrical energy -----------------------Dynamo

iii) Electrical energy to sound energy-----------------------------Loudspeaker

iv) Sound energy to electrical energy-----------------------------Microphone

v) Heat energy to electrical energy -------------------------------Thermopile

vi) Electrical energy to heat energy-------------------------------Electrical heater

vii) Electrical energy to light energy------------------------------Electric lamps

viii) Light energy to electrical energy-----------------------------Photocells

ix) Chemical energy to electrical energy -------------------------Cell

x) Electrical energy to chemical energy --------------------------Battery charging

xi) Nuclear energy to heat energy---------------------------------Nuclear reactor

xii) Electromagnetic to electrical energy -------------------------Aerial

Note: For a body falling freely its kinetic energy before impact is equal to potential energy above the ground.

Examples:

1. A 200g body falls from a height of 0.2m. Find the kinetic energy just before it hits the ground

K.E gained = P.E lost

= mgh

= 0.2 x 10 x 0.2

= 0.4J

2. A block of mass 2kg falls freely from rest through a height of 20m above the ground. Find

i) The potential energy of the block above the ground

ii) The velocity with which the block hits the ground

i) P.E = mgh

= 2 x 10 x 20

= 400J

ii) K.E = P.E

$\frac{1}{2}mv^2 = 400$

$\frac{1}{2} \times 2 \times v^2 = 400$

$v^2 = 400$

$v = \sqrt{400}$

$v = 20ms^{-1}$

POWER:

This is the rate of doing work

$$\text{Power} = \frac{\text{Work done}}{\text{Time taken}}$$

Work done = Force x distance

$$\text{Power} = \frac{\text{Force x distance}}{\text{Time taken}}$$

= Force x velocity

The SI unit of power is a watt (W). **A watt** is the rate of working of one joule per second

Hence 1W $= 1Js^{-1}$

Other units of power include kilowatt (kW) and megawatt (MW).

1kW = 1,000W

1MW = 1,000,000W

Examples:

1. An engine raises 20kg of water through a height of 50m in 5 seconds. Calculate the power of the engine

$$\text{Power} = \frac{\text{work done}}{\text{Time taken}}$$

$$= \frac{F \times d}{t}$$

$$= \frac{mg \times h}{t}$$

$$= \frac{2 \times 10 \times 50}{5}$$

= 200W

2. What is the power of the crane which can lift a box of mass 1000kg vertically through a height of 15m in 40 seconds?

$$\text{Power} = \frac{\text{work done}}{\text{Time taken}}$$

$$= \frac{F \times d}{t}$$

$$= \frac{mg \times h}{t}$$

$$= \frac{1000 \times 10 \times 15}{40}$$

$$= 3750W$$

3. A boy whose mass is 60kg can run up a flight of 28 steps each 25 cm high in 56 seconds. Calculate the power developed by the boy

$$\text{Power} = \frac{\text{work done}}{\text{Time taken}}$$

$$= \frac{F \times d}{t}$$

$$= \frac{mg \times h}{t}$$

$$= \frac{60 \times 10 \times (28 \times 0.25)}{56}$$

$$= 75W$$

Trial Exercise 4:

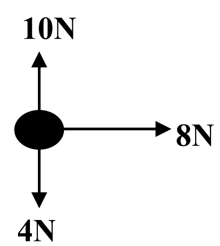
Where necessary take acceleration due to gravity, g = 10ms^{-2}

1. A boy of mass 40kg walks up a flight of 12 steps. If each step is 20cm high, calculate the work done by the boy in climbing up the stairs.
   Ans: 960J
2. An electric motor raises a 50kg load at a constant velocity. Calculate the power of the motor if it takes 40 seconds to raise the load through a height of 24m
   Ans: 300W
3. At what average velocity can a motor rated 200W raise a load of mass 40kg?
   Ans: 0.5ms^{-1}
4. An object 2.5kg is released from a height of 5m above the ground. Calculate the velocity of the object just before it strikes the ground. What assumption have you made in your calculation?
   Ans: 10ms^{-1}
5. A boy of mass 45kg develops an average power of 250W when running up a flight of stairs. How long does he take to climb up a vertical height of 4m?
   Ans: 7.2 seconds
6. Water falls through a height of 60m at a rate flow of 1.2 x 10^{4}kg per minute. Assuming there are no energy losses, calculate power generated from the base of the water fall.
   Ans: 120kW

7. A 30g bullet strikes a tree at a speed of $200ms^{-1}$ and leaves it from the opposite side at a speed of $100ms^{-1}$. Calculate
i) The kinetic energy of the bullet just before it strikes the tree
ii) The kinetic energy of the bullet just before it emerges out of the tree
Ans: i) 600J ii) 150J
8. A boy of mass 50kg runs up-flight of stairs in 2 seconds. If each step is 0.2m high and there are 60 steps in the flight. Calculate the boy's power
Ans: 3000J
9. A crane lifts 4 bricks per minute through a height of 150cm. Find the power that is expended if each brick weighs 100N
Ans: 10W
10. A boy pulls a toy car by a string which makes an angle of 30^oC with the horizontal. If the boy applies a force of 4.8N and a toy moves through a horizontal distance of 8m. Calculate the work done by the boy
Ans: 19.2J
11. An object of mass 10kg is released at a height of 25m above the ground. Calculate the kinetic energy with which it hits the ground.
Ans: 2500J
12. Describe the energy transformations that take place in each of the following;
a) A car battery is used to light a bulb
b) Coal is used to generate electricity
c) Water at the top of water fall falls and its temperature rises on reaching the bottom
13. Sometimes work is not done even if there is an applied force. Describe some situations when this is so.

Multiple-choice Exercise:

1. Two forces of 3N and 4N act at a point at right angles to each other. The magnitude of their resultant is
A. 25N B. 7N C. 5N D. 1N
2. The unit of energy is
A. the joule B. the watt C. the newton D. the newton per metre
3. Forces of 10N, 8N, 4N acts an object as shown in the figure below.



Find the magnitude of the resultant force on the object.
A.10.0N B. 16.1N C. 22.0N D. 100.0N
4. Which of the following sources of energy are exhaustible?
i) Solar energy ii) fossil fuels iii) tidal power
A. (i) only correct B. (ii) and (iii) correct
C. (ii) only correct D. (i) and (iii) correct

5 Power is defined as

A. rate of doing work, measured in watts B. ability to do work, measured in joules

C. energy x time, measured in joule time D. $\frac{energy}{time}$, measured in joules per hour

6. The forces that hold the molecules in a mercury drop together are called

A. surface tension B. adhesive forces

C. cohesive forces D. electrostatic forces

7. A pump is rated at 400W. How many kg of water can it raise in one hour through a height of 720m?

A. 0.8kg B. 5.6kg C. 33.3kg D. 200.0kg

8. A body of mass 2kg was dropped from the top of the building. It has kinetic energy of 900J when it hits the ground, the height of the building was

A. 450m B. 180m C. 90m D. 45m

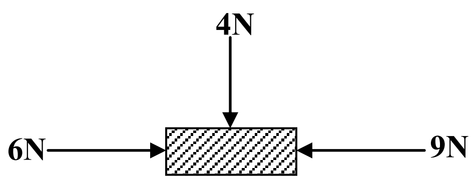
9. A mouse of mass 0.03kg climbs through a distance of 2m up a wall in 4 seconds. The power developed in watts is

A. 0.024 B. 0.15 C. 0.6 D. 2.4

10. A force of 50N moves an object through a distance of 200m in 40 seconds. Find the power developed

A. 100W B. 250W C. 160W D. 200W

11. A vertical force of 4N and horizontal forces of 6N and 9N were applied on a block as shown blow



Find the magnitude of the resultant force on the block

A. 3N B. 5N C. 15N D. 19N

12. Two forces of 12N and 5N act on a body of might angles their resultant force is

A. 7N B. 13N C. 17N D. 169N

13. A newton is defined as the

A. Unit of force

B. Force which produces an acceleration of $1ms^{-2}$

C. Force which gives a mass of 1kg an acceleration of $1ms^{-2}$

D. Force which gives any mass an acceleration of $1ms^{-2}$.

14. The rate of doing work is measure in

A. watts B. joules C. newtons D. metres

15. The energy transformation that takes place when a cell is producing electricity is

A. chemical to electrical B. mechanical to electrical

C. heat to electrical D. electrical to heat

16. The weight of body is defined as the,

A. gravitation force on it B. quantity of matter it contain

C. Maximum pressure it can exert D. the product of its density and volume.

17. Which of the following have the same units?

A. energy and power B. energy and work

C. power and work D. kinetic energy and power

18. The weight of a body varies from place to place on the earth's surface because
A. of the rotation of the earth
B. weight acts towards the earth
C. of the motion of objects in the atmosphere
D. of the total gravitational force on the body

19. An object of mass 6kg is raised from the ground to height of 4m. The work done is
A. 100J B. 240J C. 3000J D. 2400J

20. When water spreads on a glass plate, the force between its molecules and glass molecules is due to
A. surface tension B. adhesion C. cohesion D. viscosity

Answers:

1	C	5	A	9	B	13	C	17	B
2	A	6	C	10	B	14	A	18	A
3	A	7	D	11	B	15	A	19	B
4	A	8	D	12	B	16	A	20	B

PRESSURE:

This is the force acting normally per unit area of the surface.

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

The SI unit of pressure is Nm^{-2}.

$1Nm^{-2}$ = 1 pascal (Pa)

Other units are cmHg, mmHg and atmosphere (atm).

Examples:

1. A man of mass 84kg stands upright on a floor. If the area of contact of his shoes and floor is $420cm^2$ find the pressure exerted on the floor by the man

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

$$= \frac{F}{A} = \frac{mg}{A}$$

$$= \frac{84 \times 10}{0.042}$$

$$= 20{,}000Nm^{-2}$$

2 . A metallic block of mass 40kg exerts a pressure of $20Nm^{-2}$ on the surface. Find the area of contact between the block and the surface

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

$$= \frac{mg}{A}$$

$$20 = \frac{40 \times 10}{A}$$

$$A = 20m^2$$

3. A force of 100N is applied to an area of $100mm^2$. What is the pressure exerted on the area

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

$$= \frac{100}{100 \times 10^{-6}}$$

$$= 1{,}000{,}000Nm^{-2}$$

Maximum and minimum pressure:

For maximum power, the smaller is the area of contact and for minimum pressure, the larger is the area of contact. This explains why;

i) A nail has appointed end so that the driving force is applied on a very small surface area hence pressure is very high and this makes it to penetrate the material easily.

ii) An elephant has toes made of flat surface area which makes the pressure to decrease hence exerting a small force on the ground.

iii) A tractor has very broad wheels and though very heavy, it doesn't sink into the soft ground because of the large areas of the wheels which cause the tractor to exert a small pressure on the ground.

iv) Bridges are thicker at the base than at the top so that it doesn't sink on the ground.

Examples:

1. The dimensions of a cuboid are 5cm x 10cm x 20cm and weight of the cuboid is 60N. Calculate

i) Maximum pressure it exerts

ii) Minimum pressure it exerts

Solution

Max Pressure $= \frac{\text{Force}}{\text{Smallest Area}}$

$= \frac{60}{(5 \times 10) \times 10^{-4}}$

= 12,000Pa

Min Pressure $= \frac{\text{Force}}{\text{Largest Area}}$

$= \frac{60}{(10 \times 20) \times 10^{-4}}$

= 3,000Pa

2. The dimensions of a cuboid are 5cm x 10cm x 20cm and weight of the cuboid is 48kg. Calculate the maximum pressure it exerts

Solution

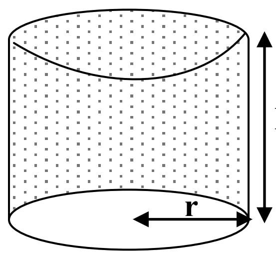
Max Pressure $= \frac{\text{Force}}{\text{Smallest Area}}$

$= \frac{480}{(5 \times 10) \times 10^{-4}}$

= 96,000Pa

Pressure in liquids:

Liquids take up the shape of the container; hence the volume of a liquid filling a cylindrical container is equal to the volume of that cylindrical container.



Volume of the liquid = Area of the base x height

= Ah

Mass = density x volume

= ρAh

Weight = Ahρg

Pressure $= \frac{\text{Force}}{\text{Area}} = \frac{Ah\rho g}{A}$

= hρg

Note that pressure at any point in a liquid is the same in all directions and depends on the following factors

i) Depth (height) below the surface of the liquid
ii) Density of the liquid
iii) Acceleration due to gravity

Examples:

1. Find the pressure in a liquid of density 1000kgm^{-3} at a height of 80cm

Pressure = hρg

= 0.8 x 1000 x 10

= 8,000Nm^{-2}

2. The pressure of in a liquid is 10,000Nm^{-2}. What is the height if its density is 1000kgm^{-3}

Pressure = hρg

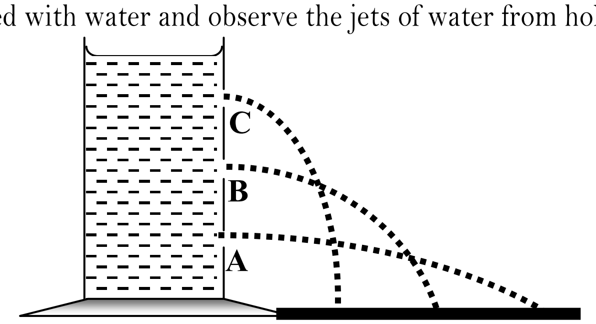
10000 = h x 1000 x 10

10000 = 10000h

h = 1m

Experiment to show variation of pressure in a liquid:

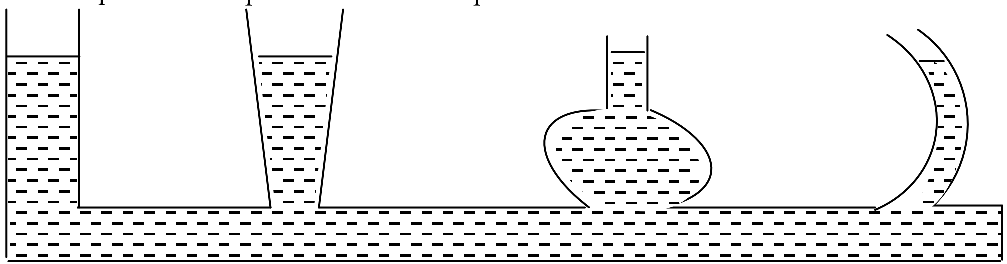
- Three holes **A**, **B** and **C** of the same diameter are made using a nail on a tall tin along a vertical line on one side.
- The tin is then filled with water and observe the jets of water from holes **A, B** and **C** as shown below.



- The lower hole, **A** throws water farthest followed by hole, **B** and lastly **C**.
- Hence pressure at **A** is greater than pressure at **B** and is greater than pressure at **C.**
- Therefore pressure increases with depth.

Liquid levels:

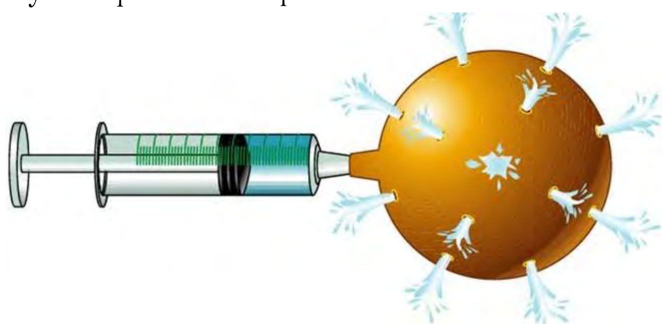
When a liquid is poured into a set of connected tubes with different shapes it flows until the levels are the same in all tubes. This shows that the liquid finds its own level and the pressure is the same in all tubes. Hence pressure in liquids is independent of the shape and area of the container.



Transmission of pressure in liquids:

The principle of transmission of pressure in liquids states that pressure applied at any point of an enclosed fluid is transmitted equally throughout the whole fluid. This is sometimes referred to as Pascal's principle.

When the plunger is pushed in the liquid comes out of the holes with equal force. This shows that pressure is transmitted equally to all parts of the liquid but the holes must have the same diameter

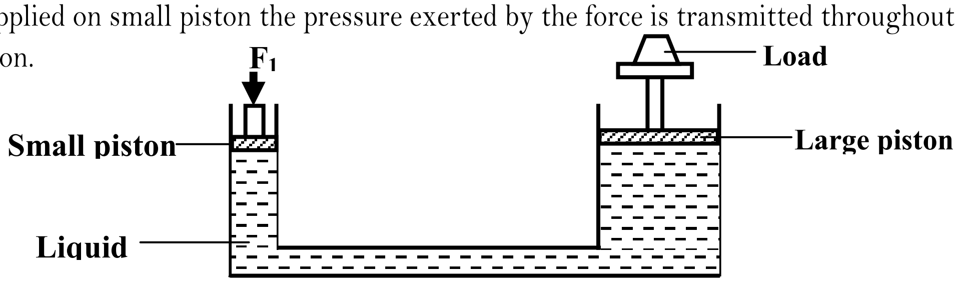


HYDRAULIC MACHINES:

The principle of transmission of pressure in liquids is applied in hydraulic machines like hydraulic press, hydraulic lift and hydraulic brake where a small force applied at one point of a liquid produces a much larger force at some other point of the liquid.

Hydraulic press/lift:

It consists of a small piston of cross sectional area A_1 and a large piston of cross sectional area A_2. When a force is applied on small piston the pressure exerted by the force is transmitted throughout the liquid to the large piston.



When a force F_1 is applied on the small piston then pressure P_1 exerted on the liquid by the small piston is given by $P_1 = \frac{F_1}{A_1}$

This pressure P_1 is transmitted by the liquid to the larger piston. Hence the pressure P_2 of the liquid acting on area of a larger piston is equal to P_1.

Where $P_2 = \frac{F_2}{A_2}$

F_2 is the force produced on a larger piston

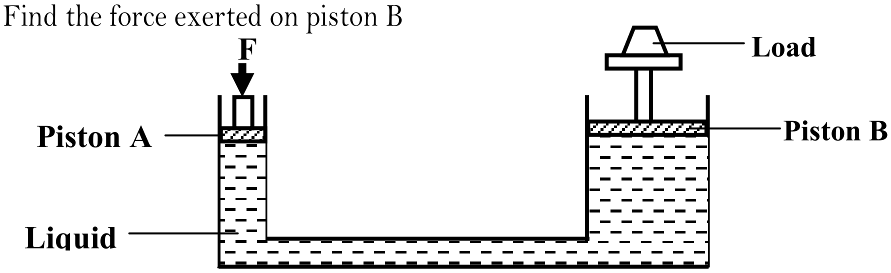
$$F_2 = P_1 \times A_2$$

$$F_2 = \frac{F_1}{A_1} \times A_2$$

$$\frac{F_2}{F_1} = \frac{A_2}{A_1}$$

Examples:

1. Given that the diameter of piston A is 14cm and diameter of piston B is 280cm. The force exerted on piston A is 77N. Find the force exerted on piston B



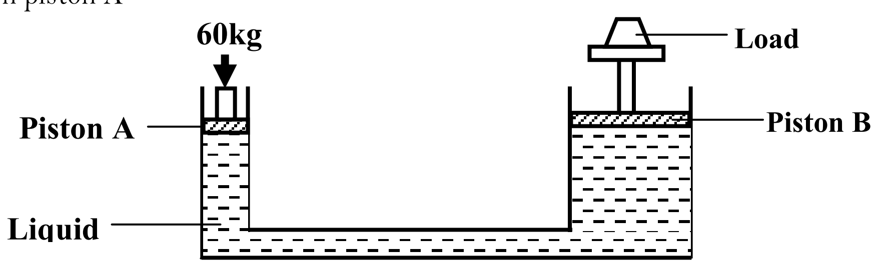
$$\frac{F_A}{F_B} = \frac{A_A}{A_B}$$

$$\frac{77}{F_B} = \frac{\pi \times 14^2}{\pi \times 280^2}$$

$$F_B = \frac{77 \times 280^2}{14^2}$$

$$F_B = 30{,}800\text{N}$$

2. The figure below shows hydraulic press. If the cross sectional area of piston B is $80cm^2$ and cross sectional area of A is $2.5cm^2$. Find the force exerted on piston B if a mass of 60kg is applied on piston A



$$\frac{F_A}{F_B} = \frac{A_A}{A_B}$$

$$\frac{60 \times 10}{F_B} = \frac{2.5}{80}$$

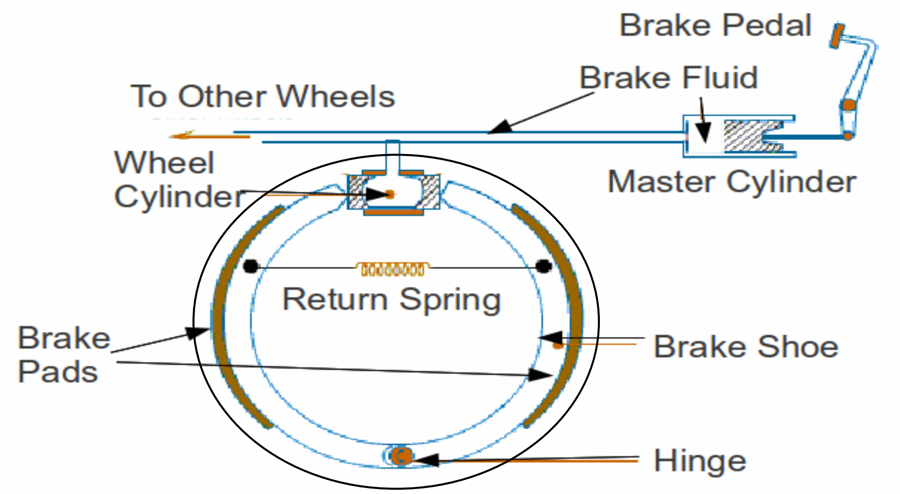
$$F_B = \frac{60 \times 10\ 80}{2.5}$$

$$F_B = 19{,}200\text{N}$$

Hydraulic brake:

It consists of brake fluid in the master cylinder connected to the slave cylinder;

- The force applied on the foot pedal exerts pressure on the master cylinder and the pressure is transmitted by the brake fluid to the slave cylinder.
- This causes the pistons of the slave cylinder to open the brake shoe hence the brake lining presses the drum and the rotation of the wheel is resisted.
- When the force on the foot pedal is removed, the return spring pulls back the brake shoe which then pushes the slave cylinder piston back.
- The brake fluid has the following properties;
  a) is incompressible to ensure pressure exerted at one point is transmitted equally to all parts in the fluid.
  b) Has low freezing point and a high boiling point.
  c) Should not corrode the parts of the brake system.



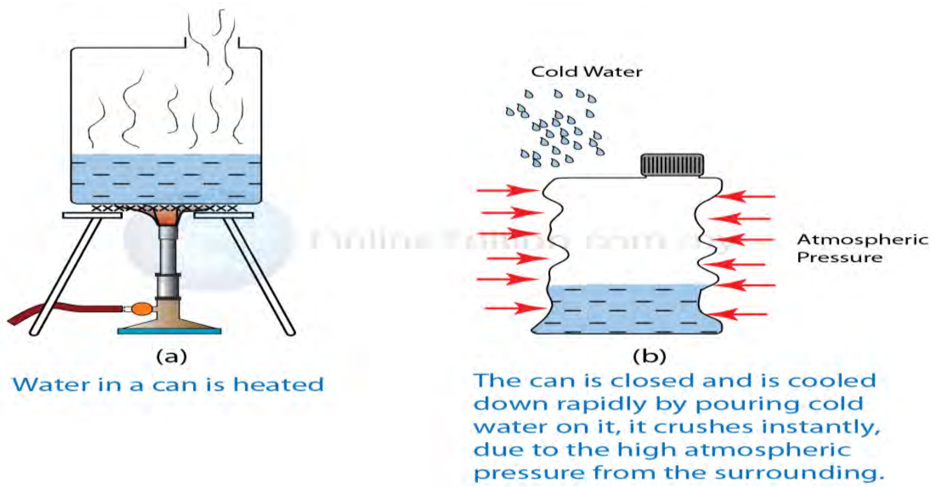
Atmospheric pressure:

Atmospheric pressure is the pressure exerted against the surface by the weight of the air above that surface. That is the pressure exerted by the weight of air in the atmosphere.
If the number of air molecules above a surface increases, there are more molecules to exert a force on that surface and consequently, the pressure increases and the reduction in the number of air molecules above a surface will result in a decrease in pressure.
Atmospheric pressure is measured with an instrument called a "Barometer", that is why atmospheric pressure is also referred to as barometric pressure. On any given planet, low-pressure areas have less atmospheric mass above their location, whereas high-pressure areas have more atmospheric mass above their location. Therefore atmospheric pressure decreases with increase in elevation.
The density of air above the earth decreases as the altitude increases leading to the decrease of atmospheric pressure at high altitude. The density of air above the earth increases as altitude decreases leading to high atmospheric pressure at high altitude.

Experiment to demonstrate atmospheric pressure:

Collapsing can:

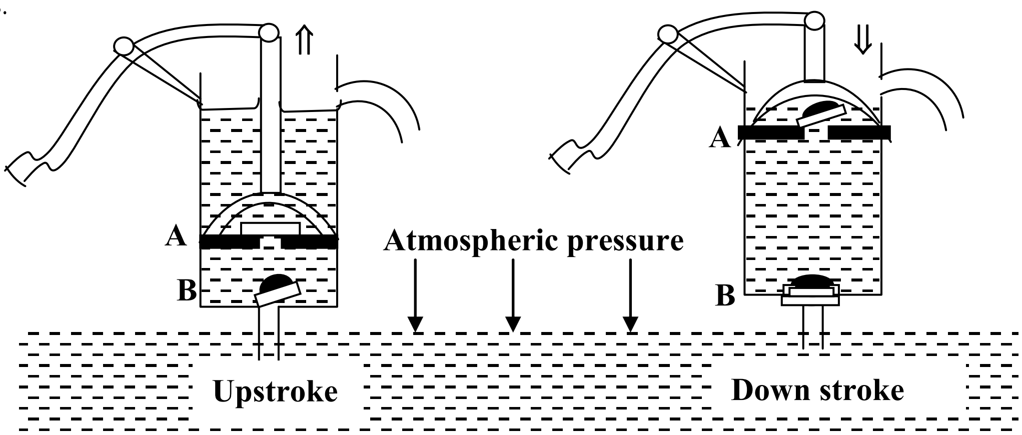
- Remove the cork from the container and pour in some water.
- Boil the water for some time
- Steam from boiling water drives out most of the air inside the container.
- Replace the cork and allow the container to cool, at first steam pressure balances with atmospheric pressure.
- Pour cold water on it to cool it faster.
- During cooling steam condenses and a partial vacuum is created inside the container and the container crushes in because the air pressure inside becomes less than atmospheric pressure.



Applications of atmospheric pressure:

1. The lift (common) pump:

A lift pump is used to raise water from wells. It consists of a cylindrical metal barrel with a side tube and two valves.

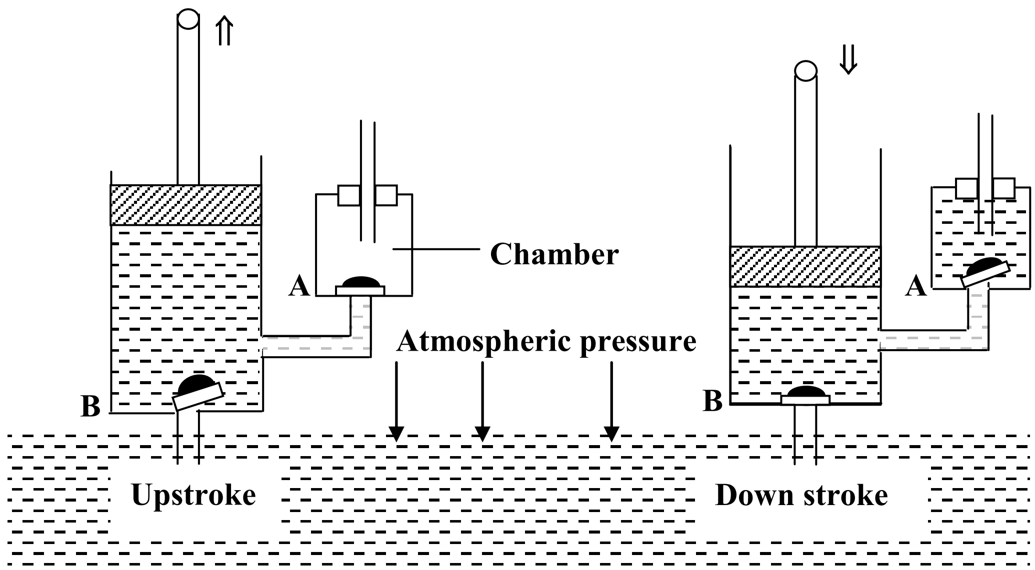


Up-stroke:

During upstroke, when the plunger moves upwards, outlet valve A closes and inlet valve B opens. Water is then pushed up the pipe through inlet valve B by atmospheric pressure acting on the surface of water in the well and moves to the space above the inlet valve.

Down-stroke:
During the down stroke inlet valve B closes and the outlet valve A opens. Water level in the barrel rises further and in the next repeated strokes water reaches the spout and pours out.
Limitations of lift pump.
- ✓ The lift pump can't raise water beyond 10m because of low atmospheric pressure in places high above sea level and leakages at the valves and pistons.
- ✓ The atmospheric pressure can only support a column of water to about 10m.

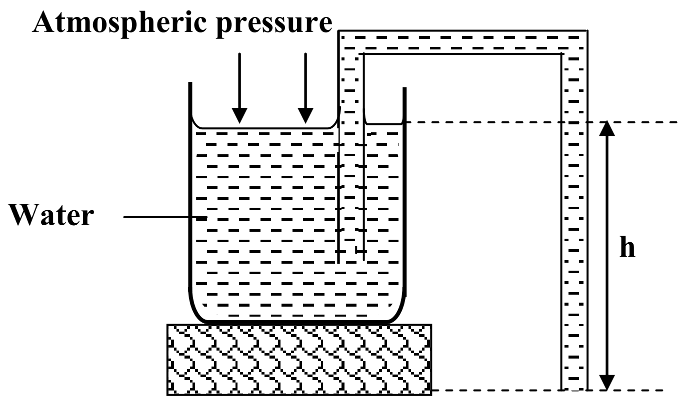
2. The force pump:
It consists of tightly fitting piston, two valves and air chamber



Up-stroke
During upstroke air above inlet valve B expands and it opens and outlet value A closes. The pressure reduces below atmospheric pressure and the atmospheric pressure on the surface of water in the well pushes water up through inlet valve B.
Down-stroke
During down stroke inlet valve B closes and increase in pressure opens the out-let valve A and forces water into the chamber so that as water fills the chamber air is trapped and compressed at the upper part. During the next upstroke valve A closes and the compressed air expands ensuring continuous flow.
NOTE:
The force pump enables continuous flow of water and the height to which water is raised does not depend on atmospheric pressure but on the following factors
- Force applied during the down stroke.
- Ability of the pump and its working parts to withstand pressure of water in the chamber

3. The siphon:

A tube can be used to empty tanks or draw petrol from petrol tanks in cars referred to as a siphon



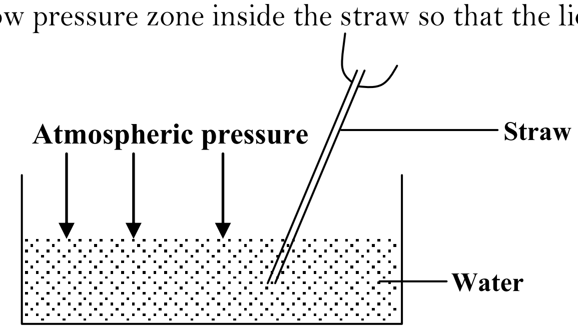
The pressure at the surface of the water is atmospheric pressure. One end of the tube is at a height, h below the surface of the water and therefore pressure at this end is greater than pressure at the surface (atmospheric pressure). The tube is then filled with water and water will continue running out so long as its end is below the water surface. Pressure at this end of the tube is equal to atmospheric pressure and pressure due to height h. $P = H + h\rho g$ where H is the atmospheric pressure. Therefore water flows out the tube at this end due to excess pressure $h\rho g$.

Conditions for a siphon to operate:

- The end of the tube must be below the surface of the liquid to be emptied.
- The tube is first filled with the liquid without any bubble in it.
- One end of the tube is inside the liquid to be emptied.
- The tube does not rise above the barometric height of the liquid from the surface of the liquid to be emptied.

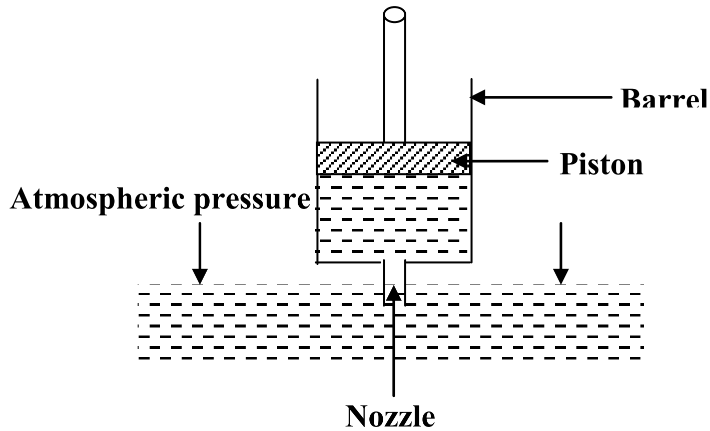
4. Drinking straw:

When one sucks from a straw dipped in a liquid, air is removed from the straw and a partial vacuum is created. The atmospheric pressure then forces the liquid to fill the vacuum which eventually ends up in the mouth. However if the straw has a hole then the air keeps entering through the hole and no vacuum is created which creates a low pressure zone inside the straw so that the liquid will not rise.



5. Syringe:

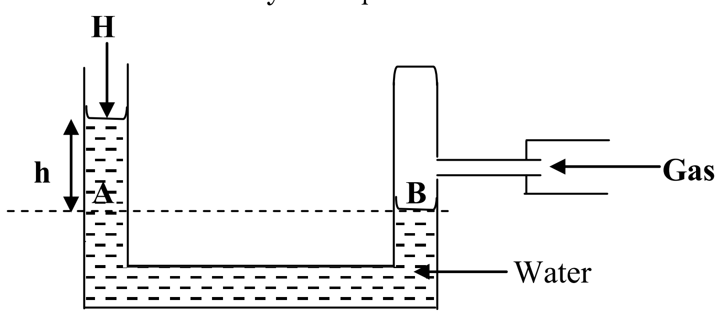
When the piston is pulled up from the lowest part of the barrel, a vacuum is created below it. Atmospheric pressure then forces the liquid into the barrel.



Measurement of pressure:

1. Manometer:

This is an instrument used to measure fluid pressure. It consists of a U-tube filled with either water if the pressure to be measured is low or mercury if the pressure to be measured is high.



- When one limb of the manometer is connected to the gas supply, the water level in the other limb rises due to the gas pressure.
- The difference in water levels is the difference between gas pressure and atmospheric pressure.
- Pressure at A is equal to pressure at b since they are at the same horizontal level and pressure at B is the pressure of the gas.
- Pressure at A = H + h. Where H is the atmospheric pressure.
- If the atmospheric pressure is known and taking the density of water to be 1000kgm^{-3}. Then pressure of the gas can be calculated as P $= H + h\rho g$

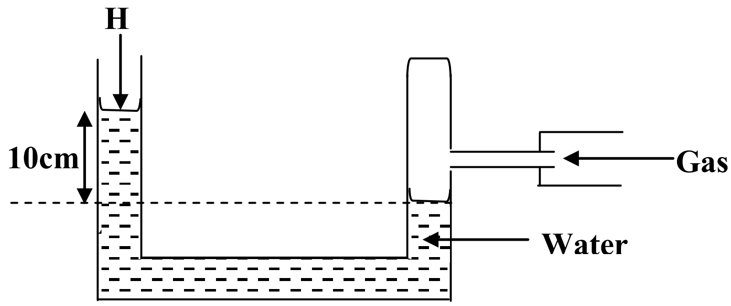
  $= 103360 + 0.2 \times 1000 \times 10$

  $= 105{,}360 Nm^{-2}$

Note: If the enclosed end is opened the gas trapped escapes and the liquid level in both arms will be the same.

Examples:

1. The diagram below shows a water manometer

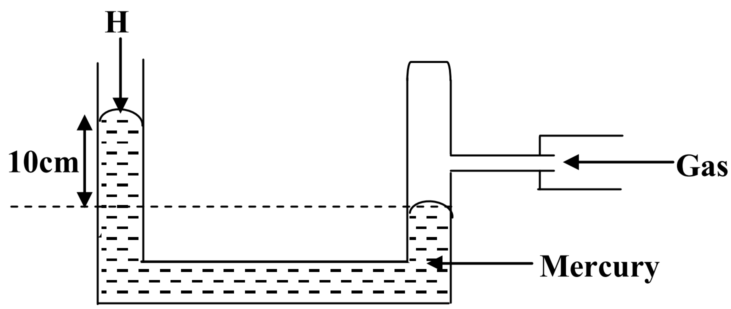


Find the pressure of the gas in Nm^{-2}

Solution:

$$P = H + h\rho g$$
$$= 0.76 \times 13600 \times 10 + 0.2 \times 1000 \times 10$$
$$= 104{,}360 Nm^{-2}$$

2. The diagram below shows a mercury manometer



Find the pressure of the gas in Nm^{-2} in cmHg and Nm^{-2}

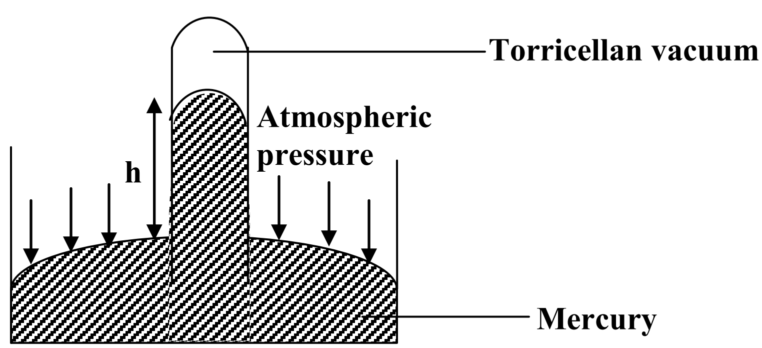
Solution:

i) $P = H + h$
$= 76 + 10$
$= 86cmHg$

ii) $P = h\rho g$
$= 0.86 \times 13600 \times 10$
$= 116{,}960Nm^{-2}$

2. A simple mercury barometer:

This is an instrument used to measure atmospheric pressure. It consists of a tube filled with mercury



A simple Barometer is made by filling a glass tube 1m long with mercury. Air trapped by mercury is removed by inverting the tube several times with the open end closed by the finger. After inverting the tube several times it is refilled with mercury with the finger on the open end, the filled tube is inverted into the beaker of mercury. When the finger is removed the mercury column falls until it is equal to the atmospheric pressure at a height of 76cm above the level of mercury in the beaker.

Density of mercury = $13600kgm^{-3}$

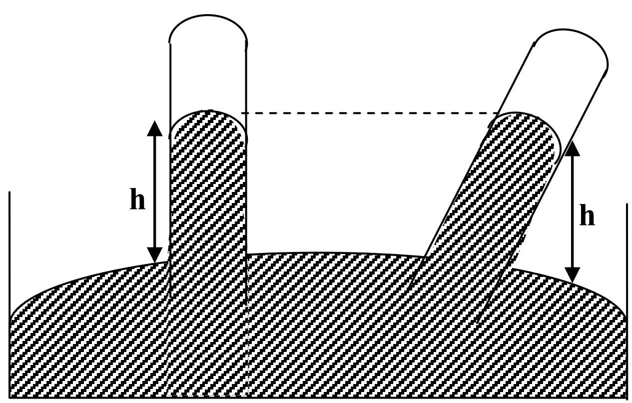
Atmospheric pressure = $h\rho g$

= 0.76 x 13600 x 10

= $103{,}360Nm^{-2}$

Note:

- Torricellian is not a real vacuum because there is some mercury vapour.
- It is more convenient to use mercury than water because the density of water is low and therefore high volume of water is required to sustain the same atmospheric pressure.
- The vertical height, h of mercury column remains the same even if the tube is tilted at an angle as shown below.



Examples:

1. A mercury barometer reads a pressure of 75cmhg at the bottom of a mountain and 73.5cmHg at the top. If the density of mercury is $13600kgm^{-3}$ and that of air is $1.25kgm^{-3}$. Calculate the height of the mountain.

Solution:

Change in pressure, P = 75.0 – 73.5

= 1.5cmHg

But P = $h\rho g$

$= \frac{13600 \times 1.5 \times 10}{100}$

= $2040Nm^{-2}$

2040 = $h_{air}\rho_{air}g$

2040 = H x 1.25 x 10

Height H = 163.2m

2. The pressure at the bottom of a mountain is 75.0cmHg. If one climbs a mountain 1 km high. What would be the pressure at the top?

Solution:

Change in pressure, $P = 75 - h$

$= (75 - h)$cmHg

But $P = h\rho g$

$= \frac{13600 \times (75-h) \times 10}{100}$

$= 1360(75 - h)\text{Nm}^{-2}$

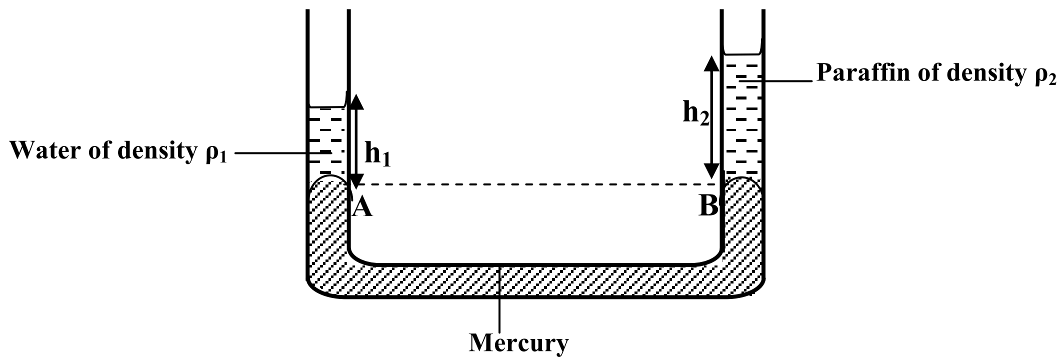
$1360(75 - h) = h_{air}\rho_{air}g$

$1360(75 - h) = 1000 \times 1.25 \times 10$

$75 - h = 9.2$cm

$h = 65.8$cmHg

Liquids which don't mix:



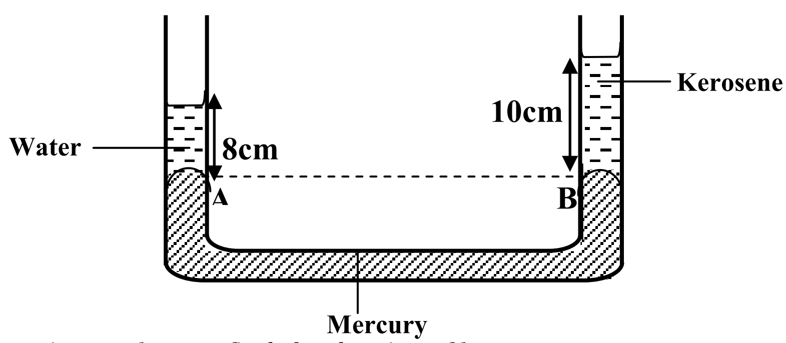
Pressure at A = pressure at B

$H + h_1\rho_1 g = H + h_2\rho_2 g$

$h_1\rho_1 = h_2\rho_2$

Examples:

1.



If the density of water is 1000kgm^{-3}, find the density of kerosene

$h_1\rho_1 = h_2\rho_2$

$8 \times 1000 = 10 \times \rho_2$

$\rho_2 = 800\text{kgm}^{-3}$

Trial Exercise 5:

Where necessary assume the following

Density of water, ρ = $1000kgm^{-3}$

Acceleration due to gravity, g = $10ms^{-2}$

Density of mercury, ρ = $13600kgm^{-3}$

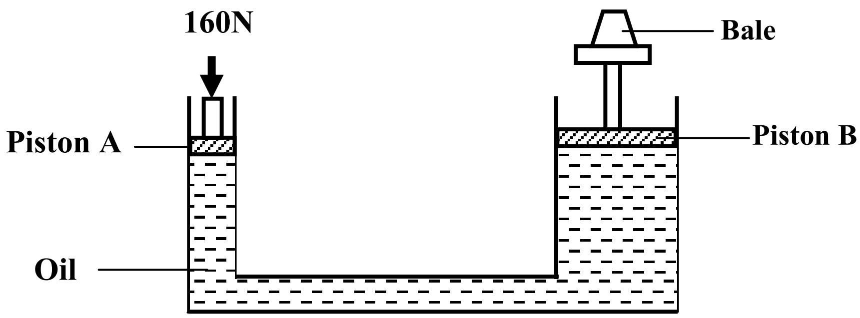
1. Calculate the pressure due to water experienced by a diver working 15m below the surface of the sea.

   Ans: 150,000Pa

2. A girl in a school situated in the coast region (sea level) plans to make a barometer using sea water. If the atmospheric pressure is $103,000Nm^{-2}$, what is the minimum length of the tube that she will require?

   Ans: 10.3m

3. The figure below shows a simple hydraulic pressure used to compress a bale. The cross section areas of pistons A and B are $0.002m^2$ and $0.3m^2$ respectively.



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Calculate

i) Pressure exerted on the oil by the force applied at A

ii) Force produced on B compressing the bale

Ans: i) 80,000Pa ii) 24,000N

4. A student in a place where the mercury barometer reads 75cm wanted to make an alcohol barometer. If alcohol has density of $800kgm^{-3}$, what is the minimum length of the tube that could be used?

   Ans: 12.75m

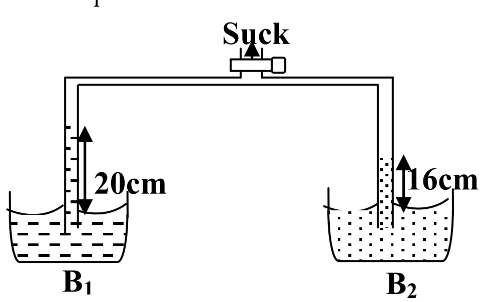
5. In a hydraulic press, a force of 200N is applied to a master piston of area $25cm^2$. If the hydraulic press is designed to produce a force of 5000N, determine

   a) The area of the slave piston

   b) The radius of the slave piston

   Ans: a) $625cm^2$ b) 14.1cm

6. Two liquids were sucked up in two identical tubes as shown below



Given that liquid in beaker B_2 is water, determine the density of the liquid in beaker B_1

Ans: $800kgm^{-3}$

7. What force is exerted on the bottom of a tank of uniform cross section area $2m^2$ by water which fills it to a depth of 0.5m?

Ans: 10,000N

8. Rectangular block of mass 48kg measures 4m x 3m x 2m. What is the least pressure and greatest pressure it can exert on a given surface?

Ans: 40Pa, 80Pa

9. A block of copper of density $8.9gcm^{-3}$ measures 5cm x 3cm x 2cm. Determine the maximum pressure and minimum pressure that it can exert on a horizontal surface

Ans: 4450Pa, 1780Pa

10. How much force must be applied on a blade of length 4cm and thickness 0.1mm to exert a pressure of 500,000Pa?

Ans: 3.93×10^{-3}N

11. A barometer reads 638.7mmHg at the top of a mountain. Calculate the pressure reading at the bottom if the mountain is 1.2km high. [Density of mercury = $13600kgm^{-3}$ and density of air =$1.25kgm^{-3}$]

Ans: 749mmHg

Multiple-choice Exercise:

1. A glass block of density $2500kgm^{-3}$ measures 20cm x 10cm x 5cm. What is the maximum pressure it exerts on a flat horizontal surface

A. 5,000 Nm^{-2} B. 1,250 Nm^{-2} C. 500 Nm^{-2} D. 5 Nm^{-2}

2. A paraffin reservoir tank contains paraffin of density $800kgm^{-3}$ to a depth of 5m. What is the pressure at the base of the reservoir?

A. 6.25×10^4 Nm^{-2} B. 4.00×10^4 Nm^{-2} C. 1.60×10^2 Nm^{-2} D. 6.25×10^{-3} Nm^{-2}

3. In a crushing can experiment, the can collapses because

A. it is weakened by the hot water

B. pressure outside is greater than pressure inside

C. it is made of very light materials

D. pressure inside is atmospheric

4. Which of the following devices depends on atmospheric pressure to operate?

A. hydraulic lift B. bicycle pump

C. automatic flushing tank D. bourdon pressure gauge

5. Which of the following is true about a lift pump?

A. it consists of only three valves

B. atmospheric pressure determines the height to which water is pumped

C. on the down-stroke all valves are open

D. on the up-stroke all valves are closed

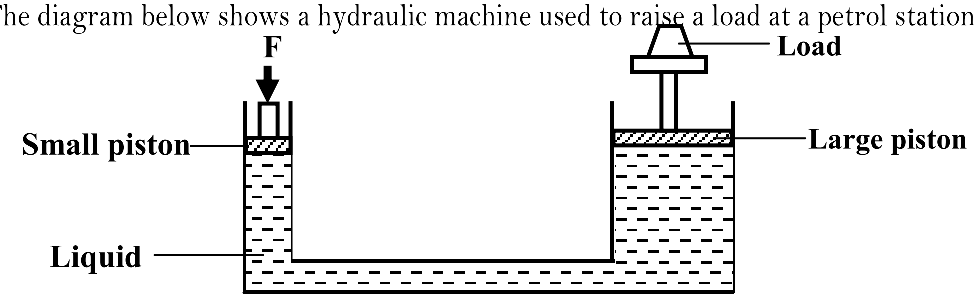
6. A water manometer connected to the gas mains reads 70mm. Calculate the gas pressure in Nm^{-2}

A. 700 B. 830 C. 103,360 D. 104,060

7. A rectangular block of metal weighs 3N and measures 2cm x 3cm x 4cm. What is the greatest pressure it can exert on a horizontal surface?

A. $5.0 \times 10^3Nm^{-2}$ B. $3.75 \times 10^3Nm^{-2}$ C. $2.50 \times 10^3Nm^{-2}$ D. $7.5 \times 10^{-3}Nm^{-2}$

8. The diagram below shows a hydraulic machine used to raise a load at a petrol station



What is the minimum force required to lift a car of mass 1500kg, if the cross section area of the small and large pistons are 0.15m^2 and 5m^2 respectively

A. 3000N B. 750N C. 450N D. 225N

9. Which of the following is true about pressure in liquids?

A. depends on the shape of the container

B. is directly proportional to the depth

C. is the same at equal depth in all liquids

D. increases with the surface area of the liquid

10. A cylindrical container of height 30cm is filled with water. Calculate the pressure exerted by the water at the bottom of the container. (Density of water = 1000kgm^{-3})

A. 300Pa B. 3,000Pa C. 30,000Pa D. 300,000Pa

11. In a liquid pressure is

A. transmitted equally in a specific direction B. transmitted equally in all directions

C. decreased with depth D. decreased with density

12. In a hydraulic press, the area of the piston on which the effort is applied is made smaller in order to

A. obtain a pressure as larger as possible

B. transmit pressure equally throughout the liquid

C. overcome a force as large as possible of the load

D. facilitate the movement of the piston downwards

13. A hydraulic brake works on the principle of

A. transmission of pressure in a liquid B. distribution of force in a liquid

C. existence of viscosity in a liquid D. high density of a liquid

14. A hipototamus can easily walk on mud without sinking while a goat will sink because

A. a hippotatomus has more weight than that of a goat

B. the centre of gravity of hipototamus is lower than that of a goat

C. a hipototamus exerts more pressure on the ground than a goat

D. a hipotatomus exerts less pressure on the ground than the goat

15. The mass of a cuboid of dimensions 4m x 2m x 3m is 48kg. The minimum pressure it can exert is

A. 20Nm^{-2} B. 40Nm^{-2} C. 60Nm^{-2} D. 80Nm^{-2}

16. A diver dives to a depth of 20m below the surface of water of density 1000kgm^{-3}. Calculate the increase in pressure he experiences in Nm^{-2}

A. 500 B. 10,000 C. 20,000 D. 200,000

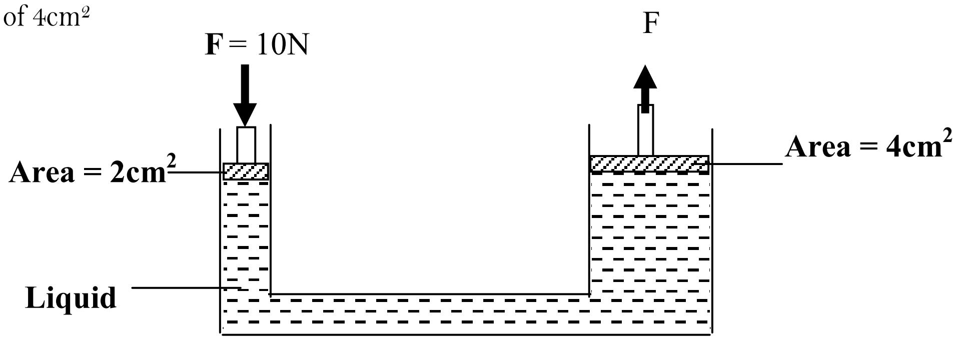
17. A rectangular block of dimensions 4cm x 2cm x 1cm exerts a maximum pressure of 2000Nm^{-2} when resting on a table. Calculate the mass of the block

A. 4g B. 16g C. 40g D. 400g

18. A rectangular block of mass 50kg measures 8cm by 10cm by 20cm. What is the minimum pressure it can exert on a given surface?

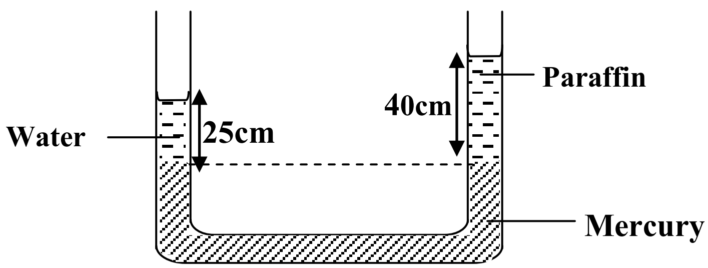
A. 6.25×10^4Pa B. 6.25×10^3Pa C. 2.5×10^4Pa D. 2.5×10^3Pa

19. The hydraulic machine below has a force of 10N acting on an area of $2cm^2$. What force will act on an area of $4cm^2$



A. 20N B. 10N C. 5N D. 2N

20. The level of mercury in the arms of the manometer are as shown below



Determine the density of paraffin

A. $1.6 \times 10^{-3}kgm^{-3}$ C. $6.25 \times 10^{-4}kgm^{-3}$ C. $1.6 \times 10^3kgm^{-3}$ D. $6.25 \times 10^2kgm^{-3}$

Answers:

1	A	5	B	9	B	13	A	17	C
2	B	6	D	10	B	14	D	18	C
3	B	7	A	11	B	15	B	19	A
4	B	8	C	12	C	16	D	20	D

Mechanical properties of materials:

These are the behaviors of materials when acted upon by a force. The following are mechanical properties of materials.

i) Strength:

This is the ability of a material to withstand an applied force before it breaks. Strong material is one which can withstand a large force examples are all metals.

ii) Stiffness:

This is the ability of a material to resist change of size and shape. Stiff materials are not flexible and resist bending examples are glass, chalk

iii) Ductility:

This is the ability of a material to be hammered, bent, rolled, moulded and stretched into different shapes without breaking. Ductile material can be hammered, pressed, bent, rolled, moulded or stretched into other shapes without breaking. Ductile materials elongate considerably under stretching forces and undergo plastic deformation until they break. Ductile materials are used in making staples, rivets and paper clips. Examples of ductile materials are lead, copper, iron and plasticine

iv) Brittleness:

This is the ability of a material to break just after the elastic limit is reached. Brittle materials are fragile and don't undergo any extension on stretching but snaps suddenly without warning. Examples of brittle materials are chalk, Bricks, cast iron, glass and dry biscuits.

v) Elasticity:

This is the ability of a material to regain its original size and shape when the stretching force has been removed. Elastic materials don't undergo plastic deformation examples are rubber, rubber bands.

vi) Plasticity:

This is the ability of a material not to recover its original shape or size when the deforming force is removed. Plastic materials don't recover their own shape and size example is plasticine.

Hooke's law:

It states that the applied force is directly proportional to the extension provided the elastic limit is not exceeded.

$\text{Force} \propto \text{extension}$

$F = ke$

$F_1 = Ke_1 \qquad F_2 = Ke_2$

$\frac{F_1}{F_2} = \frac{e_1}{e_2}$

Examples

1. A force of 50N causes an extension of 5mm on stretching material. What will the extension be when a force of 150N is applied

$\frac{F_1}{F_2} = \frac{e_1}{e_2}$

$\frac{50}{150} = \frac{5}{e_2}$

$e_2 = 15\text{mm}$

2. A mass of 10kg is applied on a spring and an extension of 2mm is obtained. What will the extension be if a force of 150N is applied?

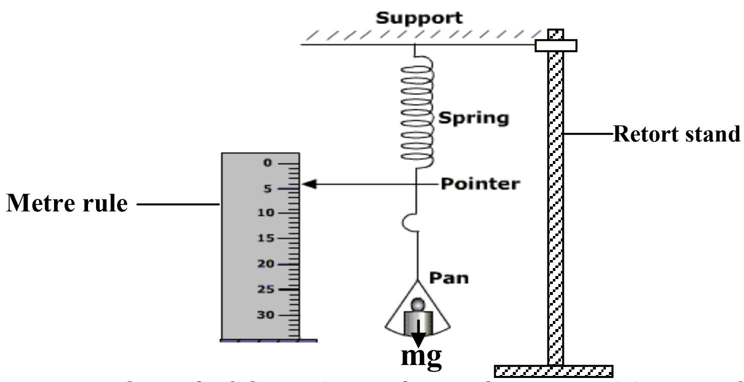
$\frac{F_1}{F_2} = \frac{e_1}{e_2}$

$\frac{100}{150} = \frac{2}{e_2}$

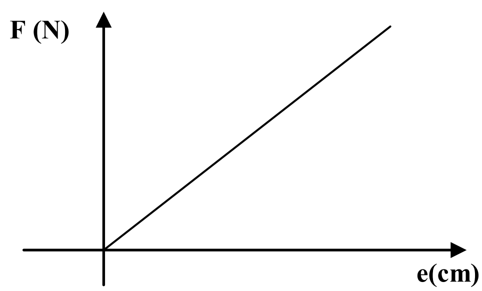
$e_2 = 3\text{mm}$

Experiment to verify Hooke's law:

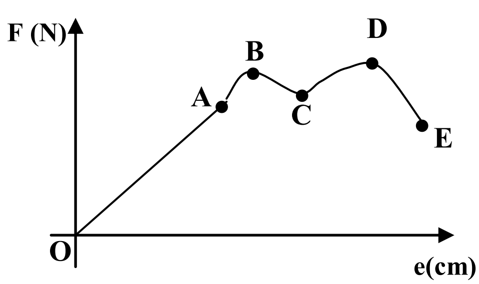
- Arrange the apparatus as shown below and note the position, P_o of the pointer when the spring is unloaded.



- Attach a mass, m at the end of the spring and note the new position, P_1 of the pointer.
- Find the extension $e = P_1 - P_0$.
- Repeat the experiment with different masses then record the new positions and calculate the extension for each mass.
- Note that the spring should not be over-stretched to exceed elastic limit.
- The results are then tabulated in the table including the stretching force, $F = mg$.
- A graph of F against e is then plotted and a straight line graph is obtained showing that force is directly proportional to extension hence Hooke's law



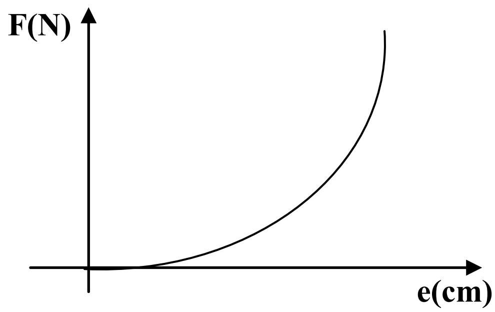
The graph of load against extension for a ductile material (copper wire) with high accuracy is as shown below;



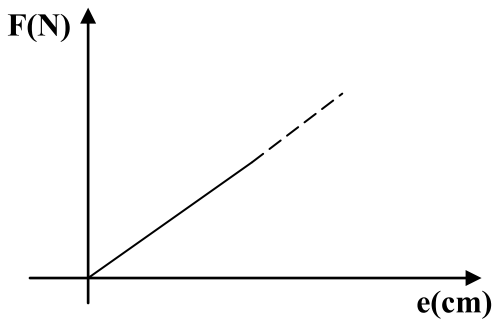
A – Proportional limit
B – Elastic limit
C – Yield point
D – Maximum stress
E – Breaking point

Between O and A the extension is directly proportional to applied force and Hooke's law is obeyed in this region until it reaches point B which is elastic limit and starts undergoing plastic deformation until point D which is the maximum stress the wire can withstand and finally breaks at point E.

The graph of load against extension for elastic material (rubber band) is as shown below;



When the force is applied to the rubber band, the coiled molecules of rubber start uncoiling hence a greater region for elatic deformation and rubber band does not under go plastic deformation until it reaches its breaking point breaks.
The graph of load against extension for brittle material (glass) is as shown below;



Glass has craks in its surface and therefore when the force is applied to a brittle material (glass), it does not undergo elastic deformation but breaks immediately because of it small elastic region.

Note: The following definitions are important;

- Elastic limit is a point beyond which a material cannot regain its original shape.
- Yield point is point corresponding to minimum stress for plastic deformation.
- Proportional limit is point beyond which force is not directly proportional to extension

STRESS, STRAIN AND YOUNG'S MODULUS:

1. Stress:

This is a ratio of force to the cross sectional area of a material

$$\text{Stress} = \frac{\text{Force}}{\text{Area}}$$

The SI unit of stress is Nm^{-2} [pascals]

2. Strain:

This a ratio of extension to original length of the material

$$\text{Strain} = \frac{\text{Extension}}{\text{Original length}}$$

Strain has no units because it is a ratio of similar quantities

3. Young's Modulus:

This is a ratio of tensile stress to tensile strain

$$\text{Young's Modulus} = \frac{\text{Tensile Stress}}{\text{Tensile Strain}}$$

The S.I unit of Young's modulus is Nm^{-2}[pascals]

Examples:

1. A mass of 2.4kg is attached to the end of a long vertical wire 2m long and produces an extension of 0.5mm. If diameter of the wire is 0.78mm, calculate

i) The cross sectional area of the wire

ii) The tensile stress

iii) The tensile strain

iv) Young's modulus

Solution:

i) $A = \pi r^2$

$A = \frac{22}{7} x 0.39^2$.

$A = 0.478 mm^2$.

ii) $\text{Stress} = \frac{F}{A}$

$= \frac{2.4 \text{ x } 10}{0.478 \text{ x } 10^{-6}}$

$= 5.02 \text{ x } 10^7 Nm^{-2}$

iii) $\text{Strain} = \frac{e}{l}$

$= \frac{0.5 \text{ x } 10^{-3}}{2}$.

$= 2.5 \text{ x } 10^{-4}$.

iv) $\text{Young's modulus} = \frac{\text{stress}}{\text{strain}}$

$= \frac{5.02 \text{ x } 10^7}{2.5 \text{ x } 10^{-4}}$

$= 2.0 \text{ x } 10^{11} Nm^{-2}$

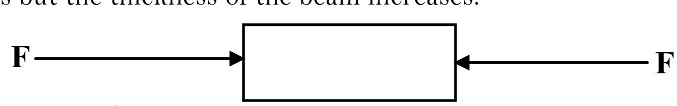
Structures and beams:

Structure is a makeup which consists of pieces of materials joined together in a particular way. The structure has organized beams to make frames and essential parts of a building.

A beam is a large and straight piece of material used as one or main supports in a structure while a piece of material that strengthens a structure is called a girder. In a structure some of the girders are in tension and others are in compression.

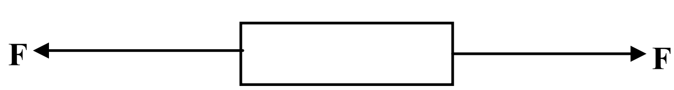
Compression and tensile forces:

Compression force results into particles of a beam to be pressed more closely and the length of the material decreases but the thickness of the beam increases.



F – Compression forces

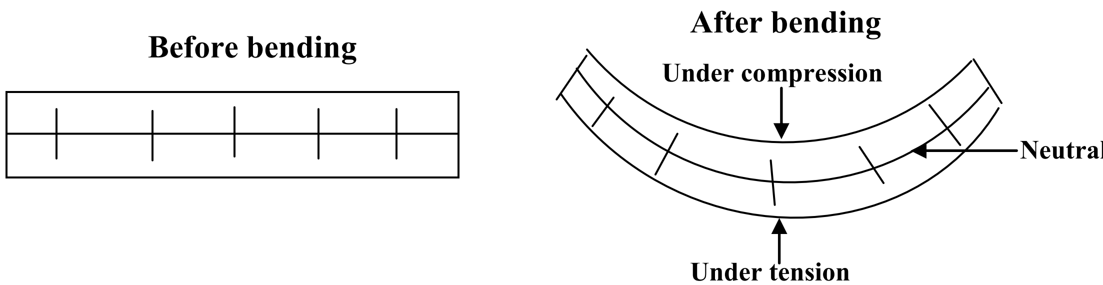
Tensile force results into the particles of the beam to be pulled further a part from one another and the length of beam increases but the thickness decreases



F – Tensile forces

Note:

When a beam bends one side is compressed and the other side is stretched but the centre is un-stretched

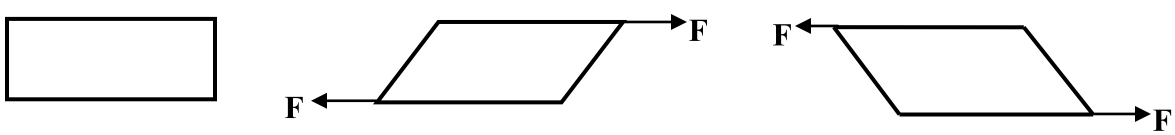


This shows that materials from a neutral plane can withstand compression and tensile forces due to loading. In general pipes for construction of structures like bicycles and bridges are made hollow because of the following reasons:

- They can withstand compression and tensile forces.
- Notches cannot spread easily so less risk of breaking.
- It is economical since less material is used for construction.
- They are lighter.
- They cause less damage in case of accidents because sharp edges can be avoided.
- Expansion and contraction can be avoided.

Shear force:

This is the force needed to fracture the material in a direction parallel to the applied force. When two equal but opposite forces are applied to an object a shear is produced that is the body is twisted and deformed.

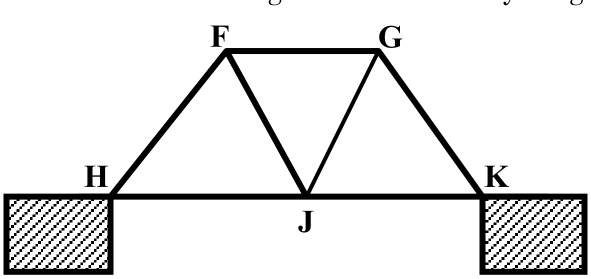


STRUTS AND TIES:

A strut is a girder which is under compression while a tie is a girder which is under tension. Ties and struts in a structure can be identified by replacing the girder with a string and if the string is tight then the girder is a tie and if the string slacks then the girder is a strut. Similarly girders in tension (ties) prevent points they separate from drifting far apart and girders in compression (struts) prevent the points they separate from moving closer together.

Example:

The figure below shows a model of a bridge structure. Identify the girders in the structure



- If girder FG is removed points F and G come closer, FG is under compression, it is a strut.
- If girder FJ is removed point J moves away from point F, FJ is under tension, it is a tie.
- If girder FH is removed point F moves closer to point H, FH is under compression, it is a strut.
- If girder HJ is removed point H moves away from point J, HJ is under tension, it is a tie.
- Girder GK is similar girder FH, therefore GK is a strut.
- Girder JK is similar to girder HJ, therefore JK is a tie.
- Girder GJ is similar to girder FJ, therefore GJ is a tie

Notch:

This is a cut or a weak point in a given material. When a notch is made in a material then the material cannot withstand compression and tensile forces and a notch on a brittle material spreads more rapidly under tension than under compression.

Methods of reducing notch effect:

- Structures are designed in a such way that all parts are under compression.
- Make surfaces of the structures as smooth as possible eg glass surfaces.
- For glasses are made by heating and cooling them is stream of air where they contract and compress the glass in the middle.
- Structures should be laminated that is layers of structures joined together with a weak layer on top.

CONCRETE:

This is a stone like material which is obtained by carefully proportioned mixture of cement, sand, gravel and water and is left to harden into desired form. Concrete is a brittle material whose tensile strength is small compared to its compression strength. This makes concrete unsuitable for use in structures under tension. In order to overcome low tensile strength concrete is reinforced. Reinforced concrete is concrete combined with steel rods, sisal fibre, bamboo stripes and wood strands

Characteristic of concrete which make it a desirable building material:

- It is strong under compression.
- It is fire resistant.
- It is weather resistant.
- It is durable.
- It is economical since it can be used for a long time.

Advantages of the reinforced concrete:

- It is strong under compression and under tension.
- It is good weather and fire resistant.
- It has a much greater ductility.
- It is relatively cheap.

Trial exercise 6:

Where necessary use acceleration due to gravity, $g = 10ms^{-2}$

1. A mass of 100g was hung from the lower end of a spring. If the spring extended by 100mm and the elastic limit of the spring is not exceeded, what was the spring constant?

   Ans: $10Nm^{-1}$

2. A metallic cube suspended freely from the end of the spring caused it to stretch by 5cm. 500g mass suspended from the same spring stretched it by 2cm. if elastic limit is not exceeded
   i) Find the weight of the metallic cube
   ii) By what length will the spring stretch if a mass of 1.5kg is attached to its end

   Ans: i) 12.5N ii) 6cm

3. The breaking stress of a material is $4x10^6Nm^{-2}$, what force is required to break a piece of material of $10m^2$ in area?

   Ans: 4×10^7N

4. A piece of wire of diameter 0.56cm and length 12m is stretched through 2.5cm by a 5kg mass
   a) What is the stress and strain in the wire?
   b) What force will stretch the wire through 4cm?

   Ans: a) $2.029 \times 10^7 Nm^{-2}$, 2.083×10^{-3} b) 80N

5. A spring stretches by 6cm when supporting a load of 15N. By how much would it stretch when supporting a load of 5kg?

   Ans: 20cm

6. A spring stretches by 4mm when supporting a load of mass 1500g. By how much would it stretch when supporting a load of weight 55N?

   Ans: 8.8mm

7. The following readings were obtained in an experiment to verify Hooke's law when a spring was extended by hanging various masses on it

Mass (g)	0	25	50	75	100	125
Reading (cm)	10.0	11.5	12.5	13.5	14.4	16.0

   Plot a graph of extension against and use it to determine
   a) The weight of the bottle of ink hung from the spring if the reading obtained is 12cm
   b) The reading for a mass of 0.02kg

   Ans: a) 0.375N b) 11.3cm

8. A 5.0cm long spring was used in an experiment. When a 200g mass was suspended using a mass hanger on the spring its new length became 6.5cm. When the mass on the hanger was changed to 410g, the length of the spring changed to 8.0cm. Calculate the mass of the mass hanger and the spring constant

   Ans: 10g, $1.4Ncm^{-1}$.

9. Use illustrations to explain the following terms
   i) Elastic deformation and elastic limit
   ii) Plastic deformation and yield point
   iii) Breaking stress and breaking point

10. Explain the function of the following girders in a structure
   i) Struts ii) ties

PARTICULATE NATURE OF MATTER:

Matter is anything that occupies space and has weight. There are three states of matter namely;

i) Solids

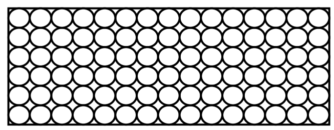
ii) Liquids

iii) Gases

Each state of matter is made up of small particles called atoms and when atoms combine they form molecules.

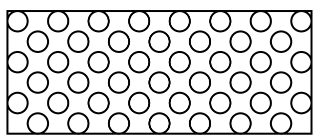
Solids:

Molecules in a solid are closely packed and therefore a solid has definite shape and definite volume. The intermolecular forces of attraction and repulsion between solid molecules are very strong.



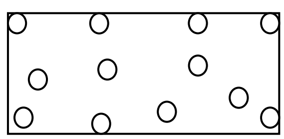
Liquids:

Molecules in liquids are fairly packed and liquids take the shape and volume of the container in which they are put. The intermolecular forces of attraction and repulsion are weaker than in solids.



Gases:

Molecules in gases are much spaced and gases have no definite shape and no definite volume. They fill the container in which they are put. Gases have weak intermolecular forces of attraction and repulsion.



Effect of heating matter:

When a solid is heated its particles acquire kinetic energy and vibrate more violently and this weakens the intermolecular forces of solid molecules and the solid changes to a liquid. On further heating the liquid molecules acquire increased kinetic energy until the intermoleculars forces are overcome hence the liquid boils and changes to a vapour.

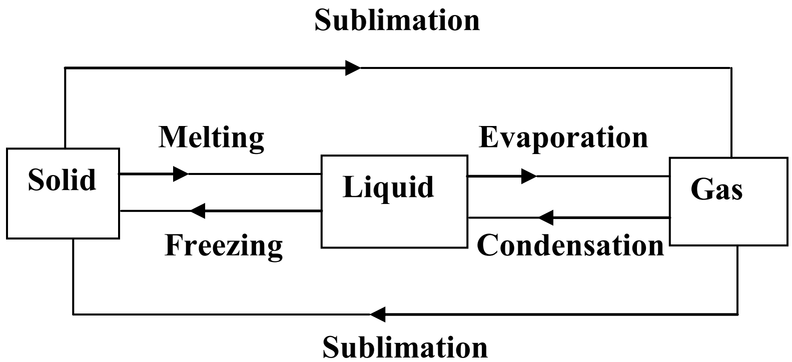
Effect of cooling matter:

When a gas/vapour is cooled the kinetic energy of the gas molecules reduces hence the speed of gas molecules reduces and the intermolecular forces start build up and the gas changes to a liquid. On cooling the liquid further kinetic energy of the molecules is lost until the partiles settle to form a solid.

NOTE:

1. The process by which a solid changes from a solid to a liquid is called melting.
2. The temperature at which a solid changes to a liquid is called melting point.
3. The process by which a liquid changes to a vapour is called evaporation.
4. The temperature at which a liquid changes to a vapour is called boiling point.
5. The process by which a liquid changes to a solid is called freezing or solidifying.

6. The temperature at which a liquid changes to a solid is called freezing point.
7. The process by which a vapour changes to a liquid is called condensation.
8. The process by which a solid changes to a vapour or a vapour changing to a solid is called sublimation.
The above processe can be summarized in the diagram below;



Kinetic theory of matter:

It states that matter is made up of small particles that are in a constant random motion and possess energy. The kinetic theory of matter can be proved using Brownian motion.

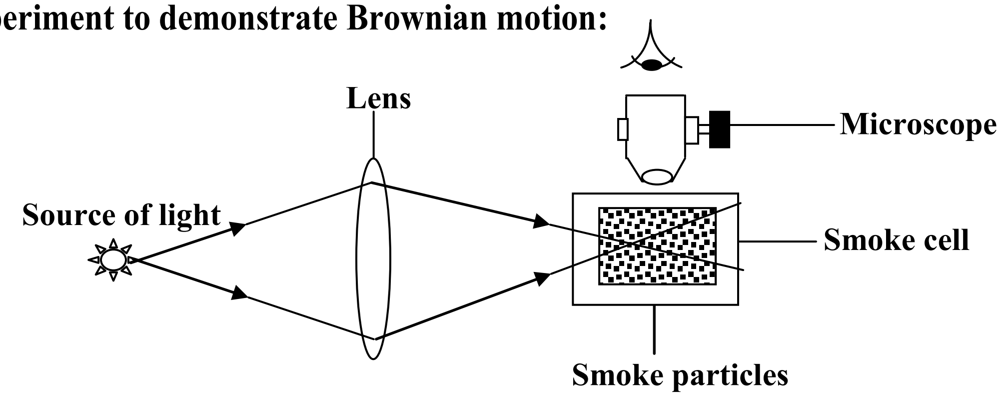
Assumptions made in kinetic theory of gases:

1. The volume of the gas molecules is negligible compared to the volume occupied by a gas.
2. The intermolecular forces between gas molecules are negligible.
3. The collisions of the molecules are perfectly elastic.
4. The time during collision is negligible compared to the time between two successive collisions.
5. Molecules of a gas move in straight lines with greater speed until they collide with each or with the walls of the container in which they are placed.

Brownian motion:

This is the random motion of molecules of fluids

Experiment to demonstrate Brownian motion:



- Place smoke particles in a smoke cell.
- Illuminate the smoke particles from one side of a smoke cell by source of light.
- View the particles using a microscope from above the smoke cell.
- Smoke particles are then seen moving randomly.
- This random motion of the smoke particles is due to collision with air molecules in smoke cell which are in constant random motion with smoke particles.

Effect of temperature on Brownian motion:

When the temperature in the smoke cell is increased the smoke particles are seen moving faster and randomly, this is because when the temperature is increased kinetic energy of molecules increases hence the speed of molecules increases and molecules move faster.

When the temperature in the smoke cell is decreased the smoke particles are seen moving slowly and randomly, this is because when the temperature is decresed kinetic energy of molecules decreases hence the speed of molecules decrease and molecules move slowly.

Properties of matter:

The properties of matter are based on the behavior of its molecules which are seen in the following processes;

- Molecular forces.
- Diffusion.
- Capillarity.
- Surface tension

MOLECULAR FORCES:

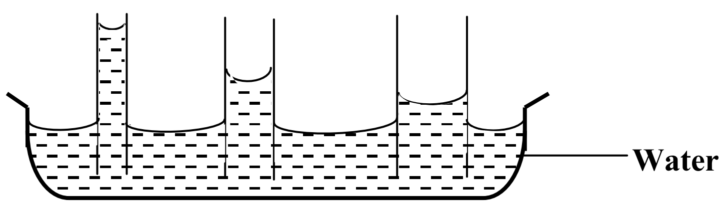
These are forces of attraction or repulsion between molecules of matter. The molecules may be of the same substance or different substances. There are two types of molecular forces;

- **Cohesion force:** This is the force of attraction or repulsion between molecules of same substance.
- **Adhesion force:** This is the force of attraction or repulsion between molecules of different substances

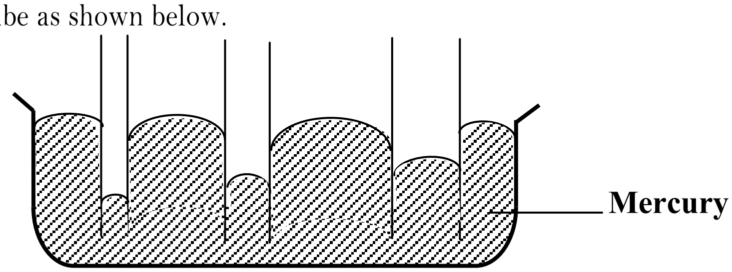
CAPILLARITY:

This is the action by which the surface of a liquid where it is in contact with a solid is elevated or depressed depending on the adhesive and cohesive properties of the liquid. That is the rise or fall of a liquid in a narrow tube, caused by the relative attraction of its molecules for each other and the tube.

When the adhesion forces are greater than cohesion forces, the liquid rises in a capillary tube and the meniscus curves downwards hence the liquid wets the surface and spreads when poured on the surface e.g water. The rise depends on the diameter of the capillary tube that is, it is higher in smaller tube than in larger tubes as shown below.



When cohesion forces are greater than adhesion forces the liquid falls in a capillary tube and the meniscus curves upwards hence the liquid does not wet the glass and forms spherical balls when poured on the surface e.g mercury. The depression depends on the diameter of the capillary tube that is depression is higher in smaller tube than in larger tube as shown below.



Note: Meniscus is the curve formed on a liquid when placed in a capillary tube.

Applications of capillarity:

- Paraffin rise in the wick of a lamp is due to capillarity.
- Top layers of soil draw water from the wet sub-soil.
- Cotton dresses are preferred in summer because cotton dresses have fine pores which act as capillaries for sweat.
- The absorption of ink by a blotting paper is due to capillary action, as the blotting paper is porous. When it is placed over the ink, the ink raises into the pores. Also rise of oil in the wick of a lamp is due to capillary action.
- If one end of a towel is dipped into a bucket of water and the other end hangs over the bucket, the entire towel soon becomes wet due to capillary action.
- The supply of water and minerals to the leaves at the top of even a tall tree is through capillary rise.

SURFACE TENSION:

This is the force acting normally per unit length on an imaginary line drawn tangentially on the surface of the liquid. It is the tendency of a liquid surface to behave like elastic skin.

Kinetic theory explanation of surface tension:

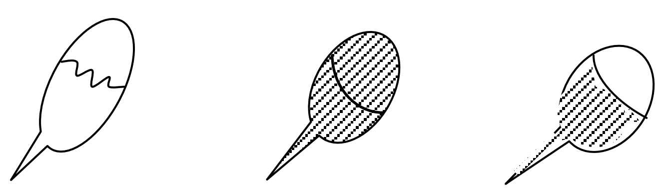
The molecules inside the liquid experience equal forces from neighboring molecules in all directions but molecules on the surface only experience forces from molecules below hence they experience a strong net downward forces which cause the surface of the liquid to contract and behave like elastic skin and put the surface under tension hence surface tension.

Experiment to show surface tension:

1. Using a floating pin [needle]:

- Place a blotting paper on water surface.
- Place carefully a pin [needle] on the blotting paper and observe.
- After some time the blotting paper absorbs water and sinks to the bottom leaving the needle floating on water due to surface tension

2. Using soap film:



- Make a ring of wire and tie a loose thread across it
- Dip the ring inside a soap solution and pull it out so that the ring is filled with soap film.
- Break the soap film at one side of the thread using a pin and note the shape of the thread.
- It is observed that the thread assumes a perfect curve because the thread is being pulled by forces due to surface tension.

Factors affecting surface:

- **Temperature:**
  When the temperature is increased the kinetic energy of the molecules increases which reduced the force of attraction between molecules [cohesion] hence surface tension is reduced.
- **Impurities:**
  Addition of detergents like soap solution weakens the force of attraction between molecules [cohesion] which reduces surface tension of the liquid.

Applications of surface tension:

- Small insects walking on water surface without sinking.
- Small pin floating on water surface without sinking.
- Shape of a small drop out of the tape is due to surface tension.
- Dirt gets removed when detergents are added while washing clothes because surface tension of water is reduced.
- Lubricating oil spread easily on all parts because of their low surface tension.
- Antiseptics like Dettol have low surface tension, so that they spread faster.
- Surface tension prevents water from passing through the pores of an umbrella.
- A duck is able to float on water surface as its feathers secrete oil that lowers the surface tension of water.

Diffusion:

This is the spreading of molecules from a region of higher concentration to a region of lower concentration.

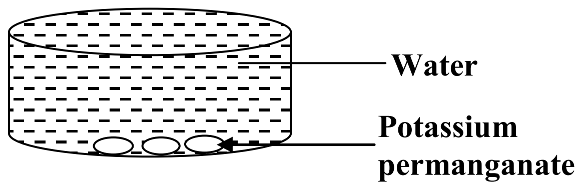
Factors affecting the rate of diffusion:

- **Concentration:**
  The rate of diffusion is directly proportional to the concentration of the liquid that is the more the concentration the higher the rate of diffusion
- **Temperature.**
  The rate of diffusion is directly proportional to the temperature that is the higher the temperature the higher the rate of diffusion.
- **Density of the gas.**
  The rate of diffusion is inversely proportional to the density that is the higher the density the lower the rate of diffusion.
- **Size of the diffusing molecules.**
  Smaller/lighter molecules diffuse faster than larger/heavier molecules. This is because large molecules occupy more space than smaller molecules.

  Note:
  Diffusion is extremely slower in solids than in liquids and very fast in gases

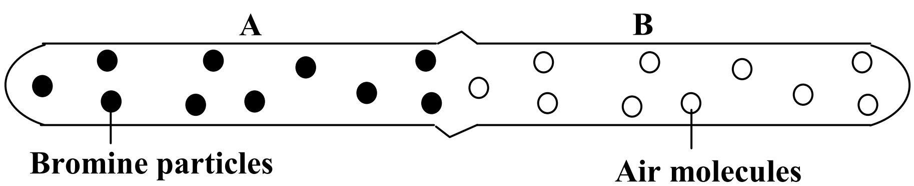
Experiment to show diffusion in liquids:

- Place crystals of coloured substance like potassium permanganate (purple) at the bottom of the beaker containing clean water and then observe.
- It is observed that crystals dissolve and they spread throughout the water in beaker forming a purple solution.



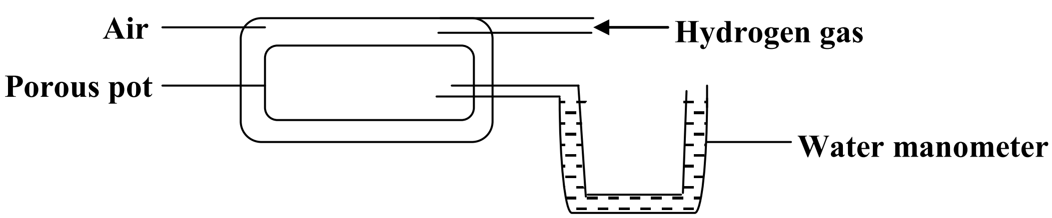
Experiment to show diffusion in gases:

1. Using bromine gas.



- A gas jar containing bromine gas (brown) is placed in contact with an open end of a gas jar of the same diameter containing air (colourless).
- It is observed that after some time brown bromine gas spreads into gas jar B at a greater speed than it returns to gas jar A because of high concentration of bromine particles.
- Likewise air spreads into gas jar A at greater rate than it returns to gas jar B because of high concentration of air particles in gas jar B.

2. Using hydrogen gas.

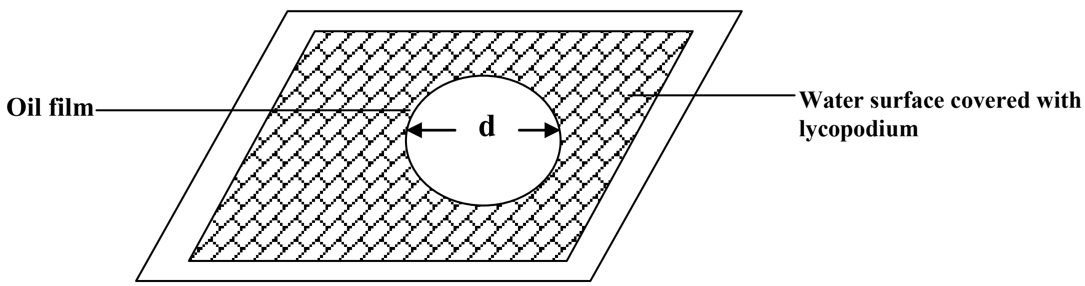


- Connect a water manometer to a porous pot containing air.
- Pass hydrogen into the air enclosed in a porous pot as shown above.
- It is observed that the level of water in left arm falls and in the right arm rises.
- This is because hydrogen molecules diffuse through the porous material into the air which increases the pressure in the porous pot and this pressure acts on the water surface in the left arm hence pushing the water level downwards.

Size of a molecule:

The size of a molecule is too small to be measured accurately and therefore the approximate size can only be estimated using the experiment below;

- Dissolve a known volume of oil in a known volume of a liquid to make a solution.
- Pour clean water in a beaker and sprinkle lycopodium powder on the surface of water.
- A drop of solution of known volume is dropped on water surface covered with lycopodium powder and an oil film is formed on the surface of water.
- Measure the diameter, d of the oil film formed on the water surface.



Volume of the oil film formed = volume of the oil drop.
If t is the thickness of oil film then;

$$V = A \text{ x } t$$

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

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

Where r is the radius and d is the diameter of the oil film formed.

Assumptions made when estimating the size of a molecule

- Each molecule is assumed to be a perfect sphere.
- The oil film is assumed to be one molecule thick.
- The spaces between the molecules in the oil film are negligible.
- The volume of drop is assumed to be equal to volume of the oil film.

Examples:

1. An oil drop of volume 10^{-3} cm^3 forms a patch on water surface of area 0.785cm^2. What is the size of oil molecule?

$V = A \text{ x } t$

$10^{-3} = 0.785 \text{ x } t$

$t = \frac{10^{-3}}{0.785}$

$t = 1.274 \text{ x } 10^{-3}\text{cm}$

2. In an oil drop experiment, the diameter of the oil film formed on water surface is 5cm and volume of the drop used is 0.005 cm^3. Find the thickness of the oil molecules.

$V = A \times t$

$0.005 = \frac{\pi d^2 t}{4}$

$t = \frac{0.005}{\frac{22 x 5^2}{7x4}}$

$t = 6.36 \times 10^{-5} cm$

3. In an oil drop experiment, the area of the oil film formed on water surface is 0.655cm^2 and volume of the drop used is 0.0015 cm^3. Find the thickness of the oil molecules.

$V = A \times t$

$0.0015 = 0.655t$

$t = \frac{0.0015}{0.655}$

$t = 0.00229cm$

4. A solution was made by dissolving 1cm^3 of cooking oil in 199cm^3 of methanol. When 0.004cm^3 of the solution is dropped on the surface of water, an oil film of diameter 12cm is obtained. Calculate

i) The volume of cooking oil and the thickness of the molecule in cooking oil

ii) The number of molecules in the oil film

Solution:

i) volume of cooking oil dissolved = 1cm^3.

$\text{volume of methanol used} = 199cm^3.$

$\text{volume of solution made} = 1 + 199.$

$= 200 \ cm^3.$

$200cm^3 \text{ of solution contain } 1 \ cm^3 \text{ of cooking oil}.$

$0.004cm^3 \text{ of solution contain } \frac{1}{200} x \ 0.004 \ cm^3.$

$= 0.00002cm^3.$

iii) $V = A \times t.$

$0.00002 = \frac{\pi d^2 t}{4}.$

$t = \frac{0.00002}{\frac{22X \ 12^2}{7X4}}.$

$t = 1.77x \ 10^{-7} cm.$

iii) $\text{oil film is one molecule thick}$

$\text{thickness of molecule} = \text{diameter of molecule}.$

$\text{number of molecules} = \frac{\text{volume of oil drop}}{\text{volume of molecule}}.$

$= \frac{0.00002}{\frac{4\pi r^3}{3}}.$

$= \frac{0.00002 \ x \ 3 \ x \ 7}{4 \ x \ 22 \ x \ (8.85x \ 10^{-8})^3}.$

= 6.886 x 10^{15} molecules.

Trial Exercise 7:

1. If 1.8 x 10^{-4} cm^3 of oil spreads to form a patch of area $150cm^2$. Calculate the thickness of the film and the number of molecules in the drop.
   Ans: 1.2 x 10^{-6}cm, 1.989 x 10^{14}molecules
2. An oil drop of volume 1 x $10^{-9}m^3$ spreads on the water surface to form a patch of area 5 x $10^{-2}m^2$. If the patch is one molecule thick, find
   i) The size of the oil molecule
   ii) The number of molecules in the drop
   Ans: i) 2 x 10^{-8}m ii) 2.386 x 10^{14}molecules
3. $20cm^3$ of oil were dissolved in $980cm^3$ of ethanol to form a solution. $2cm^3$ of the resultant was dropped on the water surface sprinkled with lycopodium powder. A roughly circular patch of diameter 18cm was formed. Find the
   i) Volume of oil drop
   ii) Thickness of the oil molecule
   iii) Number of molecules in the oil drop
   Ans: i) $0.04cm^3$ ii) 1.57 x 10^{-4}cm iii) 1.97 x 10^{10}molecules
4. 1 cm^3 0f oil is dissolved in $999cm^3$of ether to form a solution. Then 1 cm^3 of the solution is dropped on to a water surface sprinkled with lycopodium powder. The ether evaporated leaving a patch of diameter 14cm. calculate the thickness of oil molecule
   Ans: 6.494 x 10^{-6}cm
5. How would surface tension of water be increased?
6. Explain how it is possible to compress gases but not solids or liquids
7. In terms of cohesive forces and inter-particle distances of particles in matter, distinguish between the three states of matter.
8. Explain each of the following using the behavior of molecules;
   a) A steel needle placed carefully on the surface of water does not sink
   b) When a small drop of detergent is placed on water, the needle moves rapidly away from it and sinks when more detergent is added
   c) Water wets clean surfaces of glass but not waxed ones
   d) Water rises up in a narrow tube but mercury which is also a liquid falls in a narrow tube to the level below the outside surface.
9. Explain how diffusion supports the idea that matter is made up of particles
10. Explain why the smell of rotten eggs broken at one end of the room soon spreads throughout the room.

Multiple-choice Exercise:

1. A string increases in length from 10cm to 25cm when a force is applied. Find the tensile strain
   A. 1.5 B. 2.5 C. 15 D. 35
2. Which one of the following quantities is the odd one out?
   A. wood B. glass C. concrete D. steel
3. A long piece of chalk is
   A. stiff and brittle B. ductile but not stiff
   C. ductile and stiff D. brittle but not stiff

4. Surface tension of a liquid
A. reduces with increase in temperature
B. reduces with drop in temperature change
C. is not affected by temperature changes
D. increases with increase in temperature

5. Paraffin moves up the wick of a lamp by a process called
A. transpiration B. osmosis C. surface tension D. capillarity

6. A force of 20N extends a spring by 10mm. Find extension in mm caused by a mass of 0.5kg
A. 0.25 B. 1.00 C. 2.50 D. 10.00

7. A material that can be rolled into sheets or drawn into wires without breaking is said to be
A. strong B. elastic C. ductile D. brittle

8. Reinforced concrete is stronger than ordinary concrete because concrete and steel are
A. both brittle materials
B. both ductile materials
C. strong in compression and tension respectively
D. strong in tension and compression respectively

9. When smoke is introduced in a smoke cell and observed under a microscope, it is observed as particles moving at random. This is mainly because the particles
A. are hot
B. collide with one another
C. collide with air molecules
D. collide with walls of the smoke cell

10. Which of the following is a brittle material?
A. rubber B. plastic C. glass D. copper

11. A 2kg mass extends a spring by 20cm. Find the extension in cm, caused by a mass of 0.5kg
A. 0.2 B. 0.5 C. 2.5 D. 5.0

12. A drop of oil of volume 0.00008cm^3 spread out and covered an area of 320cm^2. The thickness of the oil drop on the water was
A. 1.28x10^{-2}cm B. 4.0x10^{-7} cm C. 5.0x10^{-7}cm D. 2.5x10^{-7} cm

13. Which of the following statements is true about concrete?
A. it is both brittle and ductile
B. concrete in tension is weak and strong in compression
C. it is a ductile material
D. concrete in tension is strong and weak in compression

14. Which of the following substances is not elastic?
A. glass B. rubber C. plasticine D. copper

15. A mass of 500g produces an extension of 10cm in a spring. Find the force that will produce an extension of 25cm
A. 0.5N B. 12.5N C. 50.0N D. 200.0N

16. Notches and cracks spread more rapidly when brittle material are under
A. strain B. tension C. compression D. extension

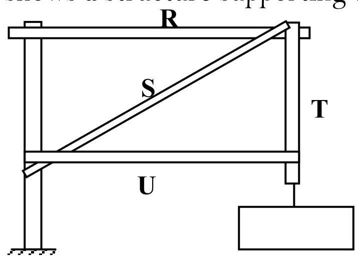
17. Strain by definition is the ratio of
A. force to original length
B. extension to force
C. extension to original length
D. force to change in length

18. 1.8 x 10^{-4}cm^3 of oil spreads to form a patch of area 150cm^2. Calculate the thickness of the film
A. 1.2 x 10^{-6}cm B. 2.7 x 10^{-2}cm C. 8.3 x 10^{5}cm D. 2.5 x 10^{13}cm

19. In an oil drop experiment, the diameter of the oil film formed on water surface is 5cm and the volume of the drop used is $0.005cm^3$. Find the thickness of the oil molecule.

A. 2.55×10^{-4}cm B. 6.36×10^{-5}cm C. 1.00×10^{3}cm D. 1.96×10^{1}cm

20. The figure below shows a structure supporting a load



Which of the girders R, S, T and U is under compression?

A. U and R B. T and R C. S and U D. S and T

Answers:

1	A	5	D	9	C	13	B	17	C
2	D	6	C	10	C	14	A	18	A
3	A	7	C	11	D	15	B	19	A
4	A	8	C	12	D	16	B	20	A

MOTION IN A STRAIGHT LINE:

Motion is change of position with time.

Terms used in motion:

1. Distance. This is the length between two points. The SI unit of distance is a metre (m)

2. Displacement.

This is the distance moved in a specified direction. The SI unit of displacement is a metre (m)

NB: The difference between distance and displacement is that displacement is a vector quantity while distance is a scalar quantity.

3. Speed.

This is the rate of change of distance moved with time.

$$\text{Speed} = \frac{\text{Distance}}{\text{time}}$$

The SI unit of speed is metre per second, ms^{-1}(m/s).

4. Velocity.

This is the rate of change of distance in a specific direction.

OR. It is the rate of change of displacement. Therefore velocity is speed in a specific direction.

$$\text{Velocity} = \frac{\text{Displacement}}{\text{time}}$$

The SI unit of velocity is ms^{-1}(m/s).

NB:

1. **The** difference between speed and velocity is that velocity is a vector quantity while speed is a scalar quantity.
2. The other common unit of velocity and speed is kilometer per hour (kmh^{-1})

Converting units

1. Convert 108 kmh^{-1} to ms^{-1}

$$1\text{ km} = 1000\text{m}$$
$$108\text{ km} = (108 \times 1000)\text{m}$$
$$1\text{ h} = 3600\text{ s}$$
$$108\text{ kmh}^{-1} = \frac{108000}{3600}$$
$$= 30\text{ ms}^{-1}$$

2. Convert 60 ms^{-1} to kmh^{-1}

$$1\text{ km} = 1000\text{m}$$
$$60\text{ m} = \frac{60}{1000}\text{km}$$
$$1\text{ h} = 3600\text{ s}$$
$$1\text{ s} = \frac{1}{3600}\text{h}$$
$$60\text{ ms}^{-1} = \frac{0.06}{1/3600}\text{ kmh}^{-1}$$
$$= 0.06 \times 3600$$
$$= 216\text{ kmh}^{-1}$$

5. Uniform velocity.

This is the constant rate of change of displacement.

6. Uniform speed.

This is the constant rate of change of distance.

7. Acceleration.

This is the rate of change of speed in a specific direction

OR. It is the rate of change of velocity.

$$\text{Acceleration} = \frac{\text{change in velocity}}{\text{time}}$$

$$a = \frac{v - u}{t}$$

Where v is the final velocity, which is the velocity at the end of the motion while u is the initial velocity which is the velocity at the start of motion.

The SI unit of acceleration is metre per second squared, ms^{-2}(m/s^2). Acceleration is a vector quantity.

8. Uniform acceleration.

This is a constant rate of change of velocity moved with time

Note

In motion when a body starts from rest its initial velocity is zero (u = 0) and when body is coming or brought to rest its final velocity is zero (v = 0).

Examples:

1. A car changes its velocity from $10ms^{-1}$ to $50ms^{-1}$ in 8s. Find the acceleration of the car

$$a = \frac{v - u}{t}$$
$$= \frac{50 - 10}{8}$$
$$= 5ms^{-2}$$

2. A body was accelerated at a rate of $6ms^{-2}$ to acquire a velocity of $40ms^{-1}$ in 4s. Calculate the initial velocity of the body

$$a = \frac{v - u}{t}$$

$$6 = \frac{40 - u}{4}$$

$$40 - u = 6 \times 4$$

$$u = 40 - 24$$

$$= 16ms^{-1}$$

3. A car starts from rest and acquire a velocity of $60ms^{-1}$ in 30s. Find the acceleration of the car.

$$a = \frac{v - u}{t}$$

$$= \frac{60 - 0}{30}$$

$$= 2ms^{-2}$$

8. Deceleration [Retardation]:

This is the rate of change of decrease of velocity with time. When a body is moving with decreasing velocity then a body is decelerating [retarding] and acceleration obtained is negative. Hence deceleration or retardation is the negative acceleration.

9. Uniform deceleration:

This is a constant of rate of change of decrease of velocity moved with time.

Examples:

1. A car moving with a velocity of $35ms^{-1}$ is brought to rest in 5s. Find the acceleration of the car

$$a = \frac{v - u}{t}$$

$$= \frac{0 - 35}{5}$$

$$= -7ms^{-2}$$

2. A body moving with a velocity of $60ms^{-1}$ is brought to rest in 12s. Find the deceleration of the car

$$a = \frac{v - u}{t}$$

$$= \frac{0 - 60}{12}$$

$$= -5ms^{-2}$$

$$\text{Deceleration} = 5ms^{-2}$$

3. A body moving with a velocity of $60ms^{-1}$ chages to $40ms^{-1}$ in 2s. Find the deceleration of the car

$$a = \frac{v - u}{t}$$

$$= \frac{40 - 60}{2}$$

$$= -10ms^{-2}$$

$$\text{Deceleration} = 10ms^{-2}$$

Equations of uniformly accelerated motion:

Uniformly accelerated motion is the type of motion in which the rate of change of velocity moved with time is constant.

When a body starts with an initial velocity of ums^{-1} and accelerated uniformly at a rate of a ms^{-2} to a acquire a final velocity of vms^{-1} in time t s and covers a distance of s m, then the equations of motion of a body are;

First Equation:

$v = u + at$

Second Equation:

$s = ut + ½at^2$

Third Equation:

$v^2 = u^2 + 2as$

Examples:

1. A car accelerated from a velocity of $10ms^{-1}$ to $30ms^{-1}$ in 4s. Calculate

i) Acceleration of the car

ii) Distance moved by the car

i) From

$v = u + at$

$30 = 10 + 4a$

$4a = 30 - 10$

$4a = 20$

$a = 5ms^{-2}$

ii) From

$s = ut + ½at^2$

$s = 10 \times 4 + ½ \times 5 \times 4^2$

$s = 40 + ½ \times 80$

$s = 40 + 40$

$s = 80m$

2. A body starts from rest and accelerates uniformly to a velocity of $15ms^{-1}$ at a rate of $5ms^{-2}$. Calculate the distance moved by the body.

$v^2 = u^2 + 2as$

$15^2 = 0^2 + 2 \times 5 \times s$

$225 = 10s$

$s = 22.5m$

3. A body moving with a velocity of $20ms^{-1}$ accelerates to a velocity of $30ms^{-1}$ in 5 seconds. Calculate

i) The acceleration of the body

ii) The distance moved by the body

Solution

i) From

$v = u + at$

$30 = 20 + 5a$

$5a = 30 – 20$

$5a = 10$

$a = 2ms^{-2}$

ii) From

$s = ut + ½at^2$

$s = 20 \times 5 + ½ \times 2 \times 5^2$

$s = 100 + ½ \times 50$

$s = 100 + 25$

$s = 125m$

4. A body starts from rest and accelerates uniformly to a velocity of $25ms^{-1}$ at a rate of $2.5ms^{-2}$. Calculate the distance moved by the body.

$v^2 = u^2 + 2as$

$25^2 = 0^2 + 2 \times 2.5 \times s$

$625 = 5s$

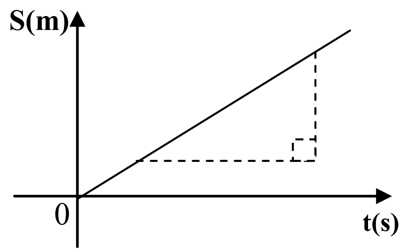
$s = 125m$

Motion graphs:

a) Displacement – time graphs for a body moving with uniform acceleration:

On displacement – time graphs the displacement is on the vertical axis and the time is on the horizontal axis.

1. Uniform velocity

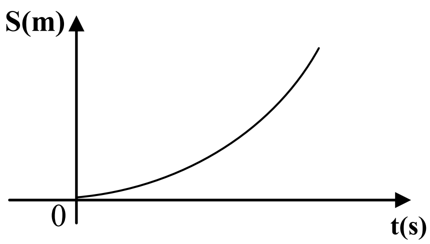


Slope/gradient $= \frac{\text{Change in displacement}}{\text{Change in time}}$

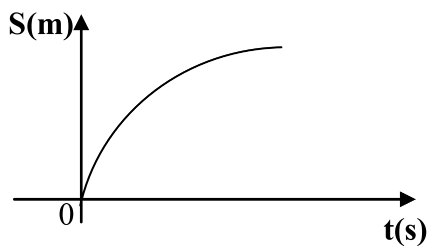
$\frac{\text{Change in displacement}}{\text{Time}} = \text{velocity}$

Therefore the gradient of a displacement – time graph is the velocity of the body

2. Uniform acceleration



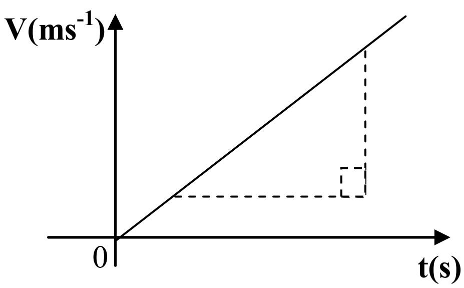
3. Uniform deceleration



b) Velocity – time graph for a body moving with uniform acceleration

On velocity – time graphs the velocity is on the vertical axis and the time is on the horizontal axis.

1. Uniform acceleration

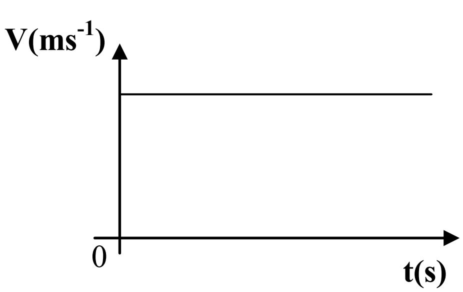


Slope/gradient $= \frac{\text{Change in velocity}}{\text{Change in time}}$

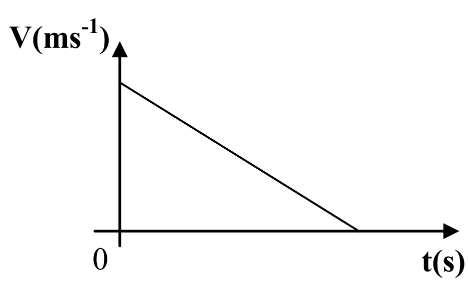
$\frac{\text{Change in velocity}}{\text{Time}} = \text{acceleration}$

Therefore the gradient of a velocity – time graph is the acceleration of the body

2. Uniform velocity



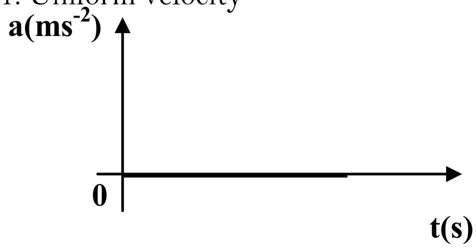
3. Uniform Deceleration



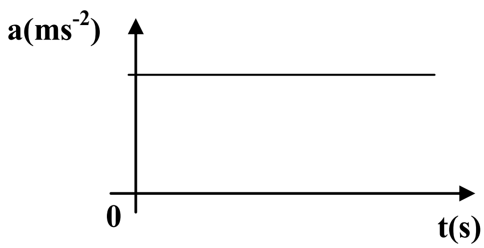
c) Acceleration – time graph:

On acceleration – time graphs the acceleration is on the vertical axis and the time is on the horizontal axis.

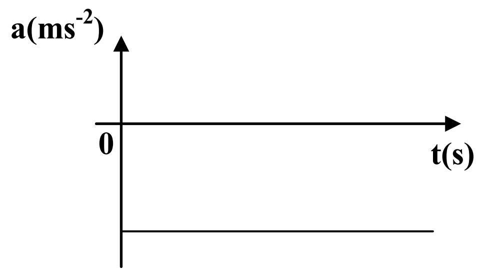
1. Uniform velocity



2. Uniform acceleration



3. Uniform Deceleration

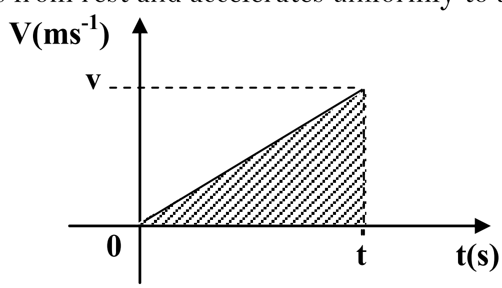


NOTE:

- ❖ All acceleration – time graphs have no gradient, there fore the slope of acceleration – time grap is zero.
- ❖ The area under acceleration – time graphs is equal to the velocity of the body.

Distance covered from velocity – time graph:

Consider a body that starts from rest and accelerates uniformly to a velocity, vms^{-1} in time, t s.



Distance moved = Average velocity x time

$= \frac{(0 + v)}{2} \times t$

$= \frac{1}{2} vt$

$\frac{1}{2} vt$ = Area under the graph

$\therefore$ Distance covered = Area under the graph

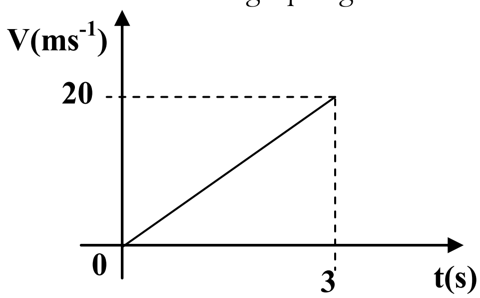
Average velocity $= \frac{\text{Total distance}}{\text{Total time}}$

$= \frac{\text{Area under the graph}}{\text{Total time}}$

Examples:

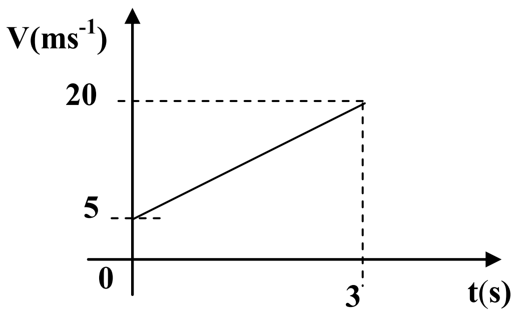
1. Describe the motion of a car for the graphs given below

a)



A car starts from rest or with a velocity of $0ms^{-1}$ and accelerates uniformly to a velocity of $20ms^{-1}$ in 3seconds

b)



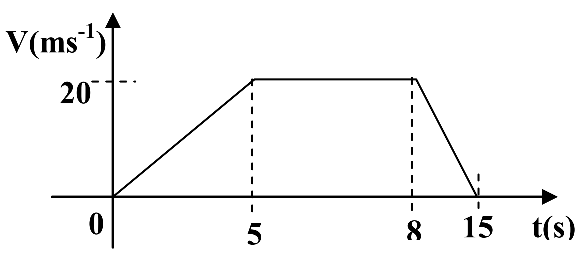
A car starts with a velocity of $5ms^{-1}$ and accelerates uniformly to a velocity of $20ms^{-1}$ in 3seconds with acceleration

$$a = \frac{v - u}{t}$$

$$= \frac{20 - 5}{3}$$

$$= 5ms^{-2}$$

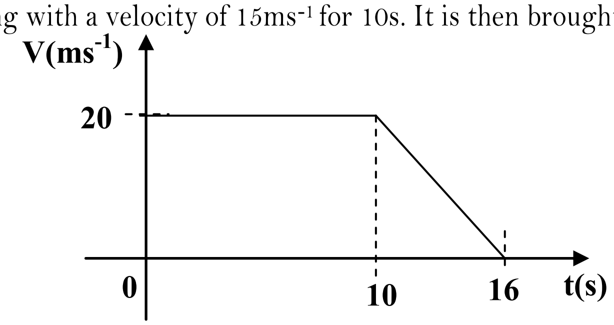
c)



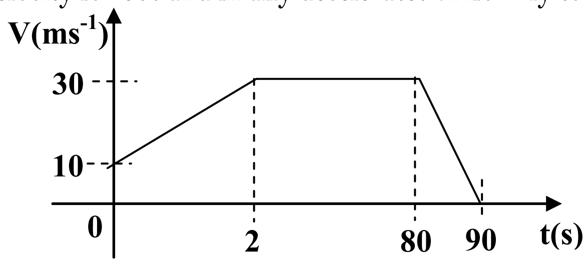
A body starts from rest and accelerates uniformly to velocity of $20ms^{-1}$ in 5s. It maintains this velocity for 3s and it then finally decelerates uniformly to rest in another 7s.

2. Sketch a velocity-time graph for

a) A car moving with a velocity of $15ms^{-1}$ for 10s. It is then brought to rest in 6s

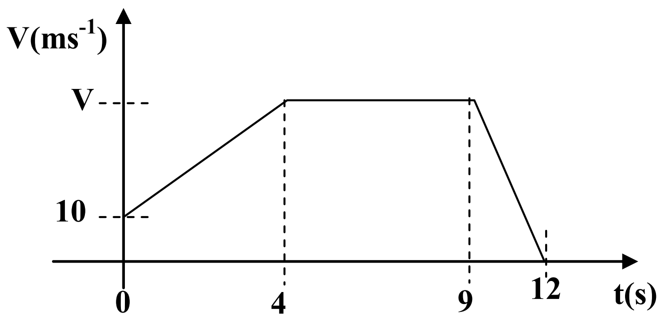


b) A car starts with a velocity of $10ms^{-1}$ and accelerates uniformly for 20s to a velocity of $30ms^{1}$. It then maintains this velocity for 60s and finally decelerates uniformly to rest for 10s.



3. A car traveling at $10ms^{-1}$ is uniformly accelerated for 4s at $2ms^{-2}$ to a maximum speed. It then moves with this maximum speed for 5s after it is uniformly brought to rest in another 3s.
i) Draw a velocity-time for the motion of the car
ii) Calculate the maximum speed
iii) Calculate the deceleration of the car

Solution:
i)



ii) For accelerating car

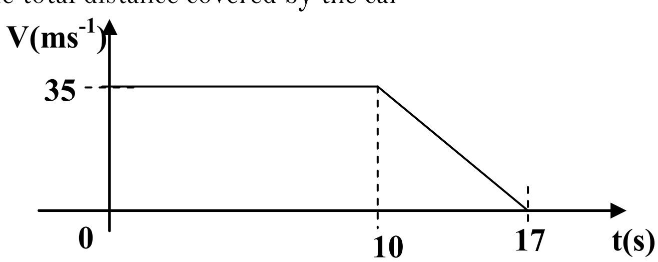
v	= u + at
	= 10 + 4 x 2
	= $18ms^{-1}$

iii) For decelerating car

v	= u + at
0	= 18 – a x 3
18	= 3a
a	= $6ms^{-1}$

4. A car moving with a velocity of $35ms^{-1}$ for 10s is then uniformly brought to rest in 7s
i) Draw a velocity-time for the motion of the car
ii) Calculate the deceleration of the car
iii) Calculate the total distance covered by the car

Solution:
i)



ii) For decelerating car

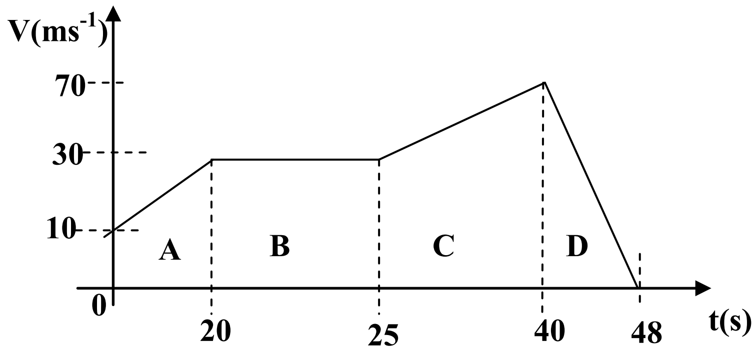
v	= u + at
0	= 35 – a x 7
35	= 7a
a	= $5ms^{-2}$

iii) distance = area under the graph
= ½ h(a + b)
= ½ x 35(10 + 17)
= ½ x 945
= 472.5m

5. A car accelerated uniformly from velocity of $10ms^{-1}$ to a velocity of $30ms^{-1}$ in 20s. It then moved with a constant velocity for 5s. It accelerates uniformly again to a velocity of $70ms^{-1}$ in 15s. The brakes are then applied and it comes to rest uniformly in a further 8s.
i) Draw a velocity – time graph for the motion of the car
ii) Calculate the distance covered by the car
iii) Calculate the average velocity of the car

Solution:

i)



ii) Distance covered = Area under the graph
= Area A + Area B + Area C + Area D
= ½h(a + b) + (lw) + ½h(a + b) + ½bh
= ½ x 20(10 + 30) + 5 x 30 + ½ x 15(30 + 70) + ½ x 8 x 70
= 400 + 150 + 75 + 280
= 905m

iii) Average velocity = $\frac{\text{Total distance}}{\text{Total time}}$
$= \frac{905}{48}$
$= 18.85ms^{-1}$

MOTION UNDER GRAVITY:

When a body is moving under gravity it acted upon by a constant acceleration called acceleration due to gravity, g [$g = 10ms^{-2}$].

Acceleration due to gravity is the rate of change of velocity for freely falling body under the force of gravity.

When a body is moving vertically downwards under the force of gravity its velocity keeps on increasing and acceleration due to gravity acting is positive and the equations of motion of the body are as follows;

1. $v = u + gt$
2. $s = ut + ½gt^2$
3. $v^2 = u^2 + 2gs$

When a body is moving vertically upwards under the force of gravity, its velocity keeps on decreasing until it reaches maximum height when the velocity is zero. The acceleration due to gravity is negative and the equations of motion of the body are as follows

1. $v = u - gt$
2. $s = ut - ½gt^2$
3. $v^2 = u^2 - 2gs$

At maximum height H, v = 0

From $v^2 = u^2 - 2gs$

$0^2 = u^2 - 2gH$

$u^2 = 2gH$

$H = \frac{u^2}{g}$

From $v = u - gt.$

$0 = u - gt.$

$u = gt.$

$t = \frac{u}{g}.$

Where H is the maximum height reached and t is the time to reach the maximum height

Examples:

1. A stone is thrown vertically upwards with a velocity of $15ms^{-1}$. Calculate

i) The maximum height by the stone

ii) The time to reach maximum height

i) $H = \frac{u^2}{2g}$

$= \frac{15^2}{2x10}$

$= \frac{225}{20}$

$= 11.25m$

ii) $t = \frac{u}{g}$

$= \frac{15}{10}$

$t = 1.5s$

2. A body at a height of 20m above the ground falls freely under gravity to the ground. Calculate

i) The time taken by the body to reach the ground

ii) The velocity with which it hits the ground

i) From $s = ut + \frac{1}{2} gt^2$

$20 = 0 \times t + \frac{1}{2} \times 10 \times t^2$

$20 = 5t^2$

$t^2 = 4$

$t = 2s$

ii) From $v = u + gt$

$= 0 + 10 \times 2$

$= 20ms^{-1}$

3. A ball is thrown vertically upwards and reaches a maximum height of 31.25m. Find

i) The initial velocity of the ball

ii) The time taken to return to the hands of the thrower

i) From $H = \frac{u^2}{2g}$

$31.25 = \frac{u^2}{2x10}$

$u^2 = 625$

$u = \sqrt{625}$

$= 25ms^1$

ii) From $t = \frac{u}{g}$

$= \frac{25}{10}$

$t = 2.5s$

Time $= 2.5 \times 2$

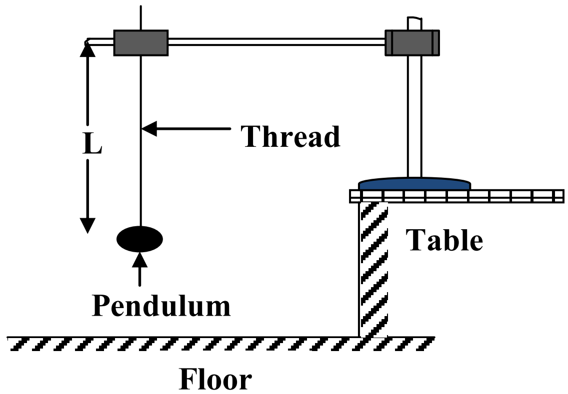
$= 5s$

Note:

When a body is thrown vertically upwards the time taken to reach the maximum height is equal to the time taken for the body to fall from maximum height to the point of projection.

Experiment to determine acceleration due to gravity using a simple pendulum:

a) Suspend the pendulum bob from a retort stand using a piece thread provided as shown in the figure below.



b) Starting with length, L of the thread. Displace the pendulum bob through a small angle and release it to oscillate.
c) Measure the time for 20 oscillations of the pendulum bob.
d) Determine the time, T for one oscillation.
e) Repeat procedure (b) to (d) for different values of L.
f) Tabulate you results including values of T^2.
g) Plot a graph of T^2 against L and determine the slope, S of your graph.
h) Determine the acceleration due to gravity, g from, $g = \frac{4\pi^2}{S}$.

Acceleration due to gravity changes from place to place because of the following reasons;

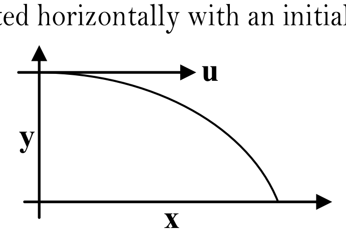
- **The earth is not a perfect sphere:** The earth is not a perfect sphere that is the equatorial radius is greater than the polar radius. Hence the acceleration due to gravity at the poles is slightly greater than the acceleration due to gravity at the equator.
- **Rotation of the earth:** As the result of rotation of the earth, acceleration due to gravity changes. The gravitational pull on the body (mg) at the equator has to provide a centripetal acceleration as the earth rotates about its axis hence there is resultant force on the body towards the Centre of the earth which reduces the acceleration due to gravity.

PROJECTILES:

When a body is moving under the influence of gravity, it follows a path called **trajectory**. Therefore a body projected upwards with an initial velocity describes a projectile motion.

In projectiles the horizontal velocity of the body in motion remains the same throughout while acceleration due to gravity continues to act on the body vertically downwards and it does not affect the horizontal motion of the body.

Consider a body projected horizontally with an initial velocity ums^{-1} from a point above the ground



Horizontal motion

$a_x = 0$

$u_x = u$

From $s = ut + ½ gt^2$

$\mathbf{x = ut}$

Vertical motion

$a_y = g$

$u_y = 0$

From $s = ut + ½ gt^2$

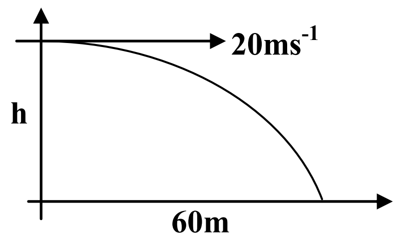
$\mathbf{y = ½gt^2}$

Examples:

1. A ball is thrown from the edge of the cliff with a horizontal velocity of $20ms^{-1}$ and hits the surface at a distance of 60m from the base of the cliff. Calculate

i) The time it takes to reach the surface

ii) Height of the cliff



i) x = ut

60 = 20t

t = 3s

ii) y = ½ gt^2

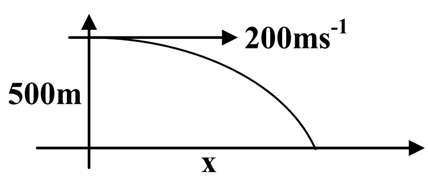
h = ½ x 10 x 3^2

= 45m

2. An object is released from aircraft traveling horizontally with a velocity of $200ms^{-1}$ a height of 500m. Find

i) how long it takes the object to reach the ground

ii) the horizontal distance covered by the object



i) y = ½ gt^2

500 = ½ x 10 x t^2

t^2 = 100

t = √100

= 10s

ii) x = ut

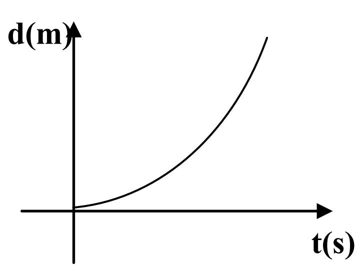
x = 200 x 10

x = 2000m

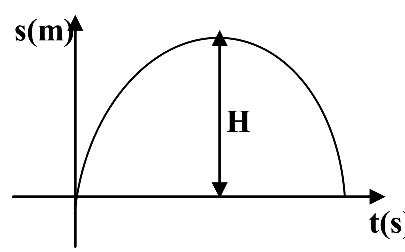
Motion graphs for a body under gravity:

When a body is thrown vertically upwards the following graphs describe the motion of the body

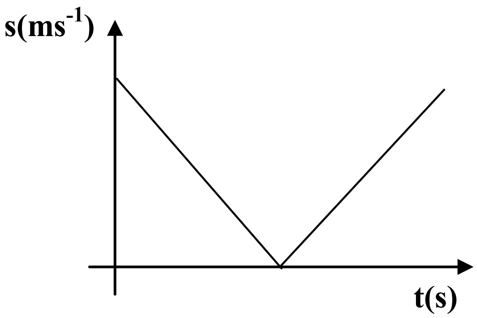
1. Distance – time graph



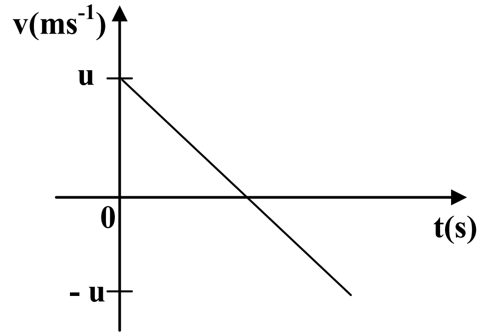
2. Displacement – time graph



3. Speed – time graph



4. Velocity – time graph



TICKER TIMER:

This is a device that is used to investigate velocity, speed and acceleration of a body in a laboratory. It has an arm which vibrates regularly due to changing current of the a.c mains supply. As it vibrates it makes dots on the ticker tape.

Definitions:

- **Period, T**
  This is time taken to print any two successive dots. Its SI unit is second (s)
- **Frequency, f**
  This is the number of dots printed per second. Its SI unit is a hertz (Hz)

$$f = \frac{1}{T}$$

To calculate the velocity:

Note the distance, s between the reference dots and find the time taken to print the dots.

$$\text{time taken} = \text{period x number of spaces between the dots}$$

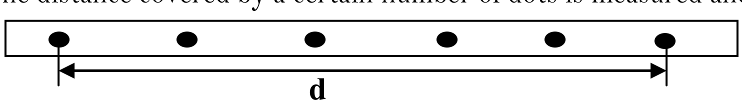
$$\text{period} = \frac{1}{f}$$

$$\text{time taken} = \frac{1}{f} \text{ x number of spaces between the dots}$$

Number of spaces between the dots = number of dots – 1

Experiment to determine uniform velocity using a ticker timer

- The ticker tape is tied on the moving object.
- The electrical vibrator of known frequency, f moves the pin up and down when switched on.
- The time taken for one complete vibration is determined from $T = \frac{1}{f}$ (periodic time)
- If the ticker tape is pulled with uniform velocity then the dots printed are equally spaced out.
- The moving object is made to run on a runway compensated for friction.
- The distance covered by a certain number of dots is measured and noted.



- The uniform velocity is calculated from the formula

$$\text{Velocity} = \frac{\text{Distance covered}}{\text{Time taken}}$$

- Time taken = Number of spaces between the dots x Periodic time

Examples:

1. A ticker-timer vibrates at a frequency of 50Hz. If the distance between two consecutive dots is 2cm. Find the time that elapses between two consecutive and average speed of the tape.

$$f = \frac{1}{T}$$

$$50 = \frac{1}{T}$$

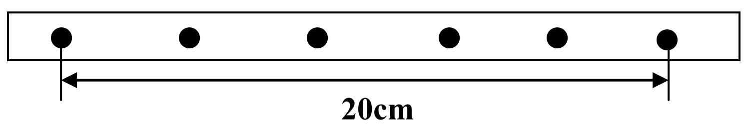
$$\text{time} = 0.02s$$

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

$$\text{speed} = \frac{0.02}{0.02}$$

$$\text{speed} = 1ms^{-1}$$

2. The ticker tape below was pulled by ticker timer. If its frequency is 50Hz. Calculate the speed at which the tape is pulled.



$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

$$\text{distance} = 20cm = 0.2m$$

$$\text{time} = T \text{ x number of spaces}$$

$$\text{time} = \frac{1}{f} \text{ x number of spaces}$$

$$t = \frac{1}{50} \text{ x } 5$$

$$t = 0.1s$$

$$\text{speed} = \frac{0.2}{0.1}$$

$$\text{speed} = 2ms^{-1}$$

To calculate the acceleration:

Note the initial distance in its initial time t_1 and determine the initial velocity, u the note the final distance in its final time t_2 and determine the final velocity, v.

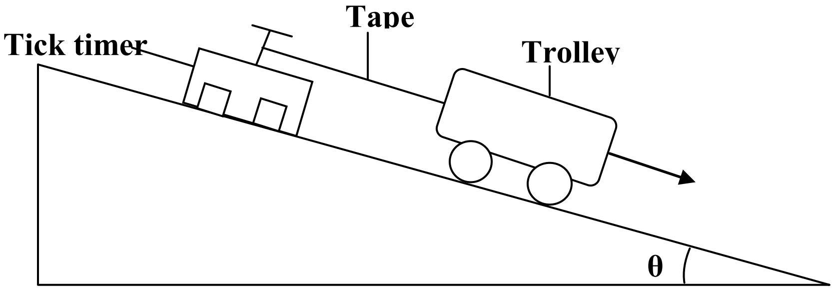
$$\text{acceleration} = \frac{\text{change in velocity}}{\text{time}}$$

$$\text{time} = \text{period x number of spaces between the dots}$$

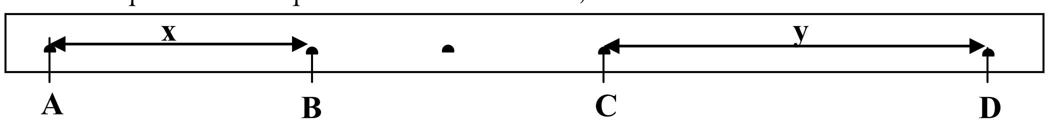
NB: Spaces for acceleration are from the middle of initial distance to the middle of the final distance.

Experiment to determine acceleration of an object using a ticker timer

- Using the arrangement below, the compensated run way is adjusted so that the trolley moves with uniform acceleration.



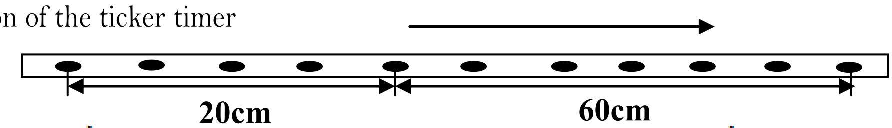
- The trolley pulls the tape through the ticker timer of frequency, f and dots are made on the tape. The dots printed are spaced as shown below;



- Dots between A and B are chosen and distance, x between them is measured. The distance, y between dots C and D is also measured.
- If there are N_1 dots between A and B, then the time taken to make them = $(N_1 - 1)\frac{1}{f}$.
- The initial velocity, u is then calculated = $\frac{xf}{N_1 - 1}$.
- If there are N_2 dots between C and D, then the time taken to make them = $(N_2 - 1)\frac{1}{f}$.
- The final velocity, v is then calculated = $\frac{xf}{N_2 - 1}$.
- Acceleration of the trolley can be calculated from, a = $\frac{v - u}{t}$.
- Where t is the time taken from mid of AB and mid of CD.

Examples:

1. The figure below shows a dots printed by a ticker timer. If the frequency of a ticker timer is 100Hz, calculate the acceleration of the ticker timer



initial speed, $u = \frac{\text{distance}}{\text{time}}$.

$\text{time} = \frac{1}{f}$ x number of spaces .

$\text{time} = \frac{1}{100} \times 4$.

$t = 0.04s$.

$u = \frac{0.2}{0.04} = 5ms^{-1}$.

final velocity, $v = \frac{\text{distance}}{\text{time}}$

$\text{time} = \frac{1}{f}$ x number of spaces

$\text{time} = \frac{1}{100} \times 6$

$t = 0.06s$

$v = \frac{0.6}{0.06} = 10ms^{-1}$

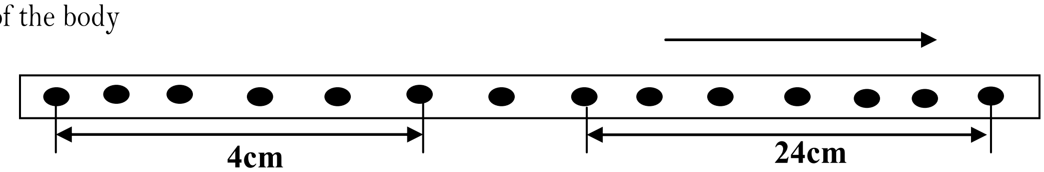
acceleration $= \frac{v - u}{t}$, $t = \frac{1}{f}$ x number of spaces

$t = \frac{1}{100} \times 5$

$t = 0.05s$

$$\text{acceleration} = \frac{10 - 5}{0.05}$$
$$\text{acceleration} = \frac{5}{0.05}$$
$$\text{acceleration} = 10\text{ms}^{-2}$$

2. The figure below shows a dots printed by a ticker timer. If the frequency of a ticker timer is 100Hz, describe the motion of the body



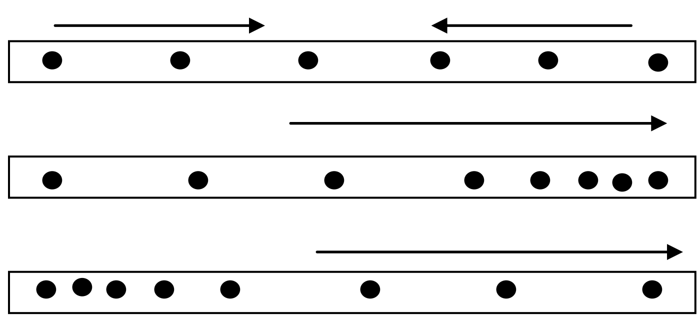
$$\text{initial speed, u} = \frac{\text{distance}}{\text{time}}.$$
$$\text{time} = \frac{1}{f} \text{ x number of spaces}.$$
$$\text{time} = \frac{1}{100} \text{ x } 5.$$
$$t = 0.05\text{s}.$$
$$u = \frac{0.4}{0.05} = 8\text{ms}^{-1}.$$

$$\text{final velocity, v} = \frac{\text{distance}}{\text{time}}$$
$$\text{time} = \frac{1}{f} \text{ x number of spaces}$$
$$\text{time} = \frac{1}{100} \text{ x } 6$$
$$t = 0.06\text{s}$$
$$v = \frac{0.24}{0.06} = 4\text{ms}^{-1}$$

$$\text{acceleration} = \frac{v - u}{t}$$
$$t = \frac{1}{f} \text{ x number of spaces}$$
$$t = \frac{1}{100} \text{ x } 7.5$$
$$t = 0.075\text{s}$$
$$\text{acceleration} = \frac{4 - 8}{0.075}$$
$$\text{acceleration} = -0.533\text{ms}^{-2}$$

In the first 0.05s it was travelling at 8ms^{-1} and then decelerated at 0.533ms^{-2} in the next 0.06s

Note that for ticker tapes showing dots for bodies in motion



Uniform velocity

Uniform acceleration

Uniform deceleration

Trial Exercise 8:

Where necessary use acceleration due to gravity, $g = 10ms^{-2}$

1. Convert the following to ms^{-1}

   i) $36kmh^{-1}$ ii) $720kmh^{-1}$

   Ans: i) $10ms^{-1}$ ii) $200ms^{-1}$

2. Convert the following to kmh^{-1}

   i) $18ms^{-1}$ ii) $22\ ms^{-1}$

   Ans i) $64.8kmh^{-1}$ ii) $79.2kmh^{-1}$

3. A boy runs at a constant speed of $6ms^{-1}$. How far does the boy travel after 4 minutes?

   Ans: 1440m

4. A car starts from rest with uniform acceleration of $5ms^{-2}$. How long does it take to cover a distance of 4km?

   Ans: 40s

5. A body moving with uniform acceleration of $10ms^{-2}$ covers a distance of 320m. If its initial velocity was $60ms^{-1}$, calculate its final velocity

   Ans: $100ms^{-1}$

6. A body whose initial velocity is $30ms^{-1}$ moves with a constant retardation of $3ms^{-2}$. Calculate the time taken for the body to come to rest

   Ans: 10s

7. A car starts with initial velocity of $10ms^{-1}$ and accelerates uniformly at $2ms^{-2}$ for 5 seconds, then slows down uniformly to rest in 10 seconds. Draw a velocity-time graph for the motion of the car and use it to calculate the maximum velocity attained by the car and how far does the car travel

   Ans: $20ms^{-1}$, 175m

8. A car travelling at $30\ ms^{-1}$ is brought to rest after covering a distance of 90m. What was the acceleration of the car and how long does it take to stop

   Ans: $-5ms^{-2}$, 6s

9. The pendulum of a large block takes 4 seconds to make one complete swing. A man walks 100m in a straight line while the pendulum makes 20 complete swings. What is the average velocity of the man?

   Ans: $1.25ms^{-1}$

10. A car starts from rest and accelerates uniformly at $2ms^{-2}$ for 5 seconds. It then travels at the velocity attained for the next 3 seconds before accelerating at $2.5ms^{-2}$ for 2 seconds. The car then uniformly comes to rest after another 2 seconds. Draw a velocity-time graph for this motion and use it to calculate

    i) the velocity after 5s

    ii) the velocity after 10s

    iii) the total distance covered by the car.

    Ans: i) $10ms^{-1}$ ii) $15ms^{-1}$ iii) 95m

11. A child throws a ball with initial velocity of $10ms^{-1}$ and hits the ceiling 5m high. How long did the ball take to reach the ceiling?

    Ans 1s

12. A bullet shot vertically upwards rises to a maximum height of 80m. Find the initial velocity of the bullet and the time of flight of the bullet

    Ans: $40ms^{-1}$, 8s

13. A stone is dropped vertically downwards from a high cliff. Calculate its velocity after 4 seconds and how far it has travelled after 4 seconds

Ans: **$40ms^{-1}$, 80m**

14. A body is projected vertically upwards with initial velocity, u and returns to the same point of projection after 8 second. Calculate the initial velocity, u and the maximum height reached by the body.

Ans: **$40ms^{-1}$, 80m**

15. A ball is thrown horizontally at $10ms^{-1}$ from a point 20m above the horizontal surface. Calculate the time taken to reach the surface and the horizontal distance travelled in that time

Ans: **2s, 20m**

16. An arrow is shot horizontally from the top of a building and lands 200m from the foot of the building after 10 seconds. Calculate the initial velocity of the arrow and the height of the building

Ans: **$20ms^{-1}$, 50m**

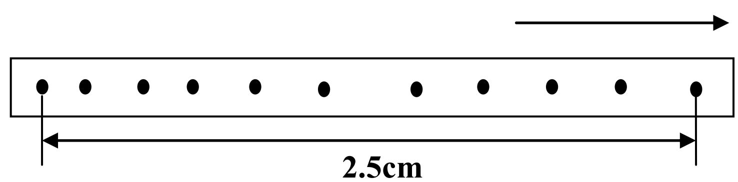
17. A particle is projected horizontally with a velocity of $100ms^{-1}$. Calculate the horizontal and vertical displacements 10 seconds after projection

Ans: **1000m, 500m**

18. A tape was pulled through a ticker-timer which made one dot every second. If it made three dots and the distance between the three dots is 16cm, find the velocity of the tape.

Ans: **$0.08ms^{-1}$**

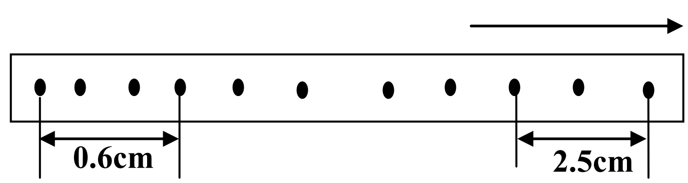
19. The figure below shows a piece of tape pulled through a ticker-timer by a trolley down an inclined plane. The frequency of the ticker-timer is 50Hz.



Calculate the average velocity of the trolley.

Ans: **$0.125ms^{-1}$**

20. The figure below shows a piece of tape pulled through a ticker-timer by a trolley down an inclined plane. The frequency of the ticker-timer is 50Hz.

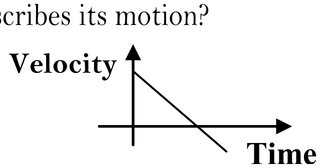


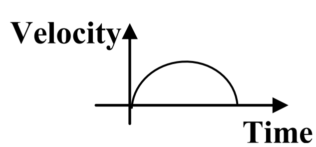
Calculate the acceleration of the trolley.

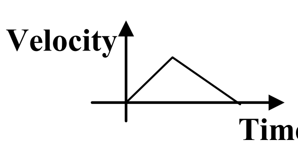
Ans: **$3.5ms^{-2}$**

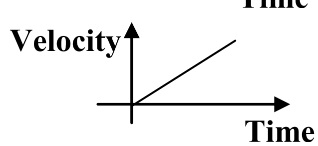
Multiple-choice Exercise:

1. A 5kg mass is projected vertically upwards with a speed of $15ms^{-1}$. To what height does the mass rise?
   A. 3.00m B. 8.00m C. 11.25m D. 25.00m
2. A body is accelerated uniformly from rest at $10ms^{-2}$. What is its velocity after 6s?
   A. $16ms^{-1}$ B. $20ms^{-1}$ C. $36ms^{-1}$ D. $60ms^{-1}$
3. An object moving with a velocity of $10ms^{-1}$ is accelerated uniformly at $2ms^{-2}$. Find its velocity when it has traveled 24m.
   A. $14ms^{-1}$ B. $16ms^{-1}$ C. $18ms^{-1}$ D. $24ms^{-1}$
4. A car is travelling at $72kmh^{-1}$ and when the brakes are applied it experiences a uniform retardation of $2ms^{-2}$. How long does it take the car to stop?
   A. 5s B. 10s C. 15s D. 100s
5. A ball is thrown vertically upwards with a velocity of $15ms^{-1}$. Calculate the time it takes to rise and fall back to the ground level
   A. 1.5s B. 3.0s C. 4.5s D. 6.0s
6. A stone is thrown downwards from the top of a building with a velocity of $4ms^{-1}$ and reaches the ground in 2 seconds. Find the height of the building
   A. 56m B. 28m C. 16m D. 12m
7. The rate at which distance covered by a body in a particular direction changes with time is called
   A. speed B. velocity C. acceleration D. displacement
8. A straight line through the origin of a velocity – time graph shows that the
   A. velocity is uniform B. distance is increasing uniformly
   C. acceleration is uniform D. motion is retardation
9. A cyclist traveling at a constant acceleration of $2ms^{-2}$ passes through two points A and B in a straight line, if the speed of the cyclist at A is $10ms^{-1}$ and the points are 75m apart. Find the speed at B
   A. $15.8ms^{-1}$ B. $17.3ms^{-1}$ C. $20.0ms^{-1}$ D. $400.0ms^{-1}$
10. A body falls freely from a height of 10m to the ground. Calculate its velocity as it hits the ground
    A. $4.47ms^{-1}$ B. $10.00ms^{-1}$ C. $14.14ms^{-1}$ D. $25.00ms^{-1}$
11. A ball thrown vertically upwards returns to the point of projection 12 seconds later. Calculate the speed with which the ball was thrown
    A. $10ms^{-1}$ B. $30ms^{-1}$ C. $60ms^{-1}$ D. $120ms^{-1}$
12. A car starts from rest and gains a speed of $80ms^{-1}$ in 5 seconds. Calculate acceleration of the car
    A. $400ms^{-2}$ B. $85ms^{-2}$ C. $75ms^{-2}$ D. $16ms^{-2}$
13. A body initially travelling at $10ms^{-1}$ is given a retardation of $2ms^{-2}$ in 3s, its velocity is
    A. $4ms^{-1}$ B. $15ms^{-1}$ C. $16ms^{-1}$ D. $60ms^{-1}$
14. A stone thrown vertically upwards returns to the ground after sometime. Which of the following graphs describes its motion?

A. 

B. 

C. 

D. 

15. The gradient of displacement-time graph represents the

A. acceleration of the body B. speed of the body

C. velocity of the body D. distance covered by the body

16. The slope of a velocity-time graph is the

A. speed of the body B. velocity of the body

C. acceleration of the body D. distance travelled by the body

17. A car accelerates from $4ms^{-1}$ to $20ms^{-1}$ in 8 seconds. How far does it travel in this time?

A. 32m B. 96m C. 128m D. 160m

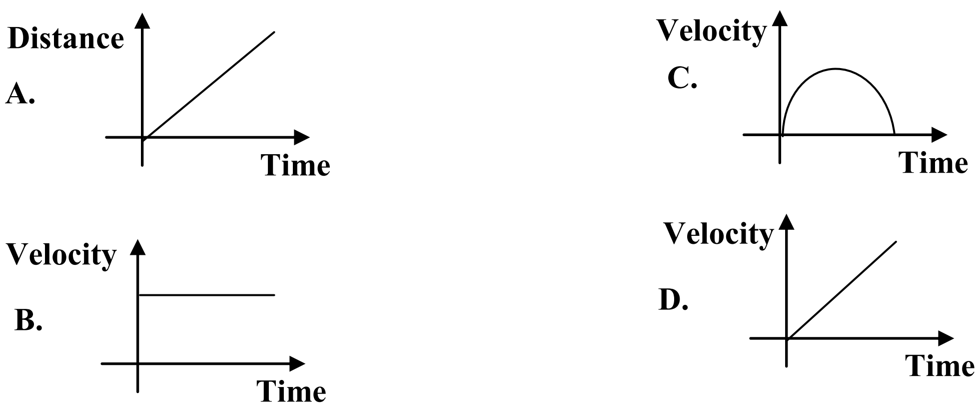
18. A body of mass 2kg is projected vertically upwards with a velocity of $10ms^{-1}$. Find the maximum height reached

A. 0.5m B. 5.0m C. 10.0m D. 50.0m

19. A body starts from rest accelerates at $2ms^{-2}$ for 6 seconds, it then travels at constant speed for 10 seconds then decelerates uniformly to rest in 4 seconds. How far did it travel?

A. 36m B. 80m C. 180m D. 600m

20. Which of the following graphs describes uniformly accelerated motion?



Answers:

1	C	5	B	9	C	13	A	17	B
2	D	6	B	10	C	14	A	18	B
3	A	7	B	11	C	15	C	19	C
4	B	8	C	12	D	16	C	20	D

NEWTON'S LAWS OF MOTION:

First law:

It states that everybody continues in its state of rest or uniform motion in a straight line unless acted upon by an external force. This law is sometimes referred to as **the law of Inertia.**

Inertia is the tendency of a body to remain at rest or keep moving with a uniform velocity. That is the reluctance of a body to start moving or stop moving.

This law is experienced by a passenger in a moving car when the car stops suddenly he experiences a forward jerk and a backward jerk when the car starts moving. A person riding a bicycle a long a level road doesn't come to rest immediately when he stops pedaling.

Second law:

It is states that the rate of change of momentum of a body is directly proportional to the force applied and takes place in the direction of force.

$$\text{Force} \propto \text{rate of momentum}$$

$$F \propto \frac{\text{Change of momentum}}{\text{Time}}$$

$$F \propto \frac{mv - mu}{t}$$

$$F \propto \frac{m(v-u)}{t}$$

$$F = \frac{km(v-u)}{t}$$

$$F = kma$$

Where k is a constant. The SI unit of force is a Newton which is a force required to give a mass of 1kg an acceleration of $1ms^{-2}$. When F = 1N, m = 1kg, a = $1ms^{-2}$ then k = 1

$$F = ma$$

Examples:

1. Calculate the acceleration produced by a force of 25N on an object of mass 100kg

$$F = ma$$

$$25 = 100 \times a$$

$$a = 0.25ms^{-2}$$

2. Calculate the force needed to make a mass of 4kg accelerate at $5ms^{-2}$

$$F = ma$$

$$= 4 \times 5 = 20N$$

3. A resultant force of 40N acts for 4s on a mass of 500g initially at rest. Calculate

i) Acceleration on the mass

ii) Final velocity of the mass

i) $F = ma$

$40 = 0.5a$

$a = 80ms^{-2}$

ii) $v = u + at$

$= 0 + 80 \times 4$

$= 320ms^{-1}$

4. What force is needed to stop a 500kg car moving at $10ms^{-1}$ to cover a distance of 40m?

$F = ma$

$v^2 = u^2 + 2as$

$0^2 = 10^2 + 2 \times a \times 40$

$100 = -80a$

$a = -1.25ms^{-2}$

$F = 500 \times -1.25$

$= -625N$

Third law:

It states that every action there is always an equal but opposite reaction

MOTION IN A LIFT:

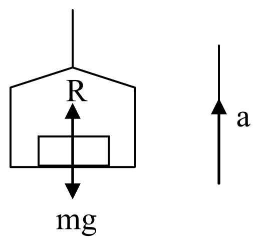
Consider an object of mass, m standing on the floor of a lift which is moving with an acceleration, a with respect to the surrounding

i) If the motion of the lift is upwards

$R - mg = ma$

$R = ma + mg$

$R = m(a + g)$

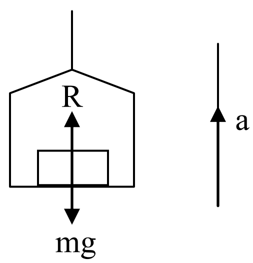


ii) If the motion of the lift is downwards

$mg - R = ma$

$R = mg - ma$

$R = m(g - a)$

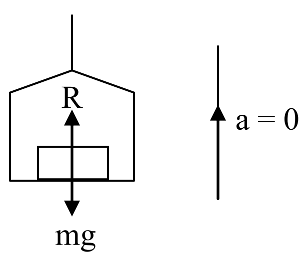


iii) If the motion of the lift has uniform velocity

$mg - R = m \times 0$

$mg - R = 0$

$R = m\,g$



Note: If the object was resting on a weighing scale inside a lift, the reading on the scale would vary. It would read the exact weight of the object when the lift moves with uniform velocity, it reads more than the weight of the object when moving upwards and reads less than the weight of the object when moving downwards.

If the cable of the lift breaks, the lift moves downwards with acceleration due to gravity, g and the object in the lift has the acceleration equal to acceleration due to gravity, g

$mg - R = mg$

$R = 0$

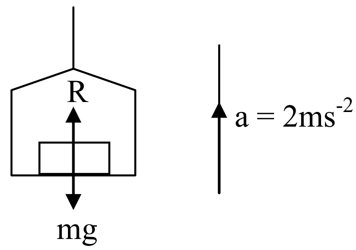
The machine indicates no reading, hence the object is weightless

Examples:

1. A man of mass 80kg stands in a stationary lift on earth. Calculate his apparent weight when the lift
i) Accelerates upwards at $2ms^{-2}$
ii) Falls freely under gravity

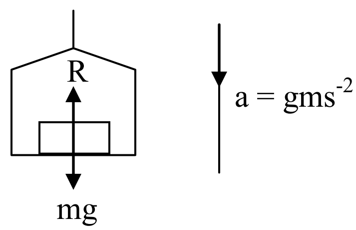
Solution

i) If the motion of the lift is upwards



$R - mg = ma$
$R = 80 \text{ x } 2 + 80 \text{ x } 10$
$R = 160 + 800$
Apparent weight $= 960N$

ii) If the motion of the lift falls freely

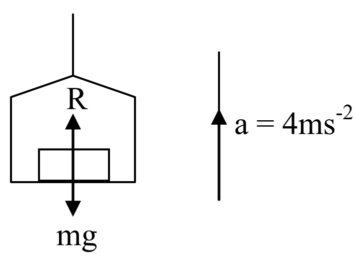


$mg - R = mg$
$R = mg - mg$
$R = 0$
Apparent weight $= 0N$

2. A man of mass 75.0kg stands in a stationary lift on earth. Calculate his apparent weight when the lift
i) Accelerates upwards at a rate of $4ms^{-2}$
ii) Accelerates downwards at a rate of $4ms^{-2}$
iii) Falls freely under gravity

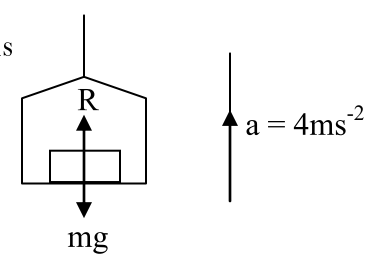
Solution

i) If the motion of the lift is upwards



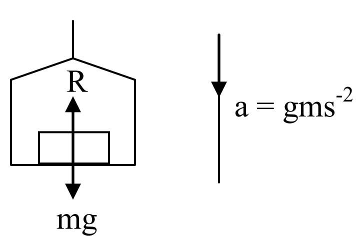
$R - mg = ma$
$R = 75.0 \text{ x } 4 + 75.0 \text{ x } 10$
$R = 300 + 750$
Apparent weight $= 1050N$

ii) If the motion of the lift is downwards



$mg - R = ma$
$R = 75.0 \text{ x } 10 - 75.0 \text{ x } 4$
$R = 750 - 300$
Apparent weight $= 450N$

iii) If the motion of the lift falls freely



$mg - R = mg$
$R = mg - mg$
$R = 0$
Apparent weight $= 0N$

MOMENTUM:

This is the product of mass and its velocity

Momentum = mass x velocity

The SI unit of momentum is $kgms^{-1}$(kgm/s). Momentum is a vector quantity whose direction is the direction of velocity.

Examples:

1. A car of mass 1000kg travels with a velocity of $50ms^{-1}$. What is the momentum of the car?

Momentum $= mv$

$= 1000 \times 50$

$= 50{,}000kgms^{-1}$

2. An object has a mass of 200kg and a momentum of $3800kgms^{-1}$. At what velocity is it moving?

Momentum $= mv$

$3800 = 200 \times v$

$v = \frac{3800}{200}$

$= 19ms^{-1}$

3. A body has a mass of 10kg and momentum of $200kgms^{-1}$. Calculate the kinetic energy of the body

K.E $= \frac{1}{2} mv^2$

Momentum $= mv$

$200 = 20v$

$V = 20ms^{-1}$

K.E $= \frac{1}{2} \times 10 \times 20^2$

$= 2000J$

The principle of conservation of linear momentum:

It states that when two or more bodies collide their total linear momentum remains constant provided no external force is acting.

Collision:

This is when two or more bodies come into contact. There are two types of collision and these are

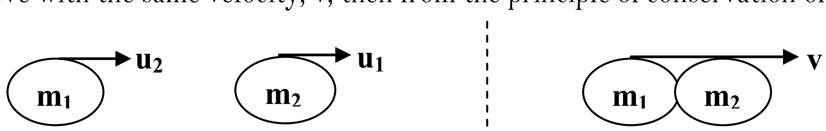
i) Elastic collision.

ii) Inelastic collision.

Inelastic collision:

This is a type of collision where the colliding bodies stay together after collision and move with the same velocity. Momentum of the bodies is conserved but kinetic energy is not conserved.

Consider two bodies of masses m_1 and m_2 moving with velocities of u_1 and u_2 respectively. After collision the bodies move with the same velocity, v, then from the principle of conservation of momentum.



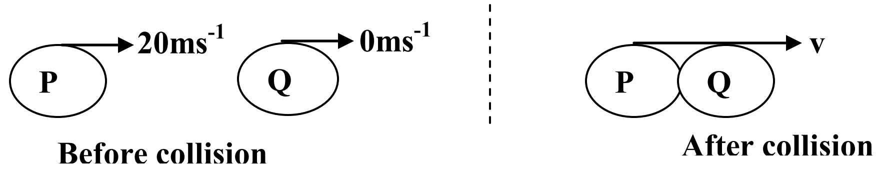
Before collision After collision

Total momentum before collision = Total momentum after collision

$$m_1u_1 + m_2u_2 = [m_1 + m_2] v$$

EXAMPLES:

1. A trolley P of mass 150g moving with a velocity of $20ms^{-1}$ collides with another stationary trolley Q of mass 100g. If the two trolleys move together after collision calculate their common velocity



$$m_1u_1 + m_2u_2 = [m_1 + m_2]\ v$$
$$150 \text{ x } 20 + 100 \text{ x } 0 = [150 + 100]v$$
$$3000 = 250v$$
$$v = 12ms^{-1}$$

2. An object of mass 2kg moving at $5ms^{-1}$ collides with another of mass 3kg which is at rest. Find the

i) Velocity of the two bodies if they stick together after collision

ii) Loss in kinetic energy

Solution:

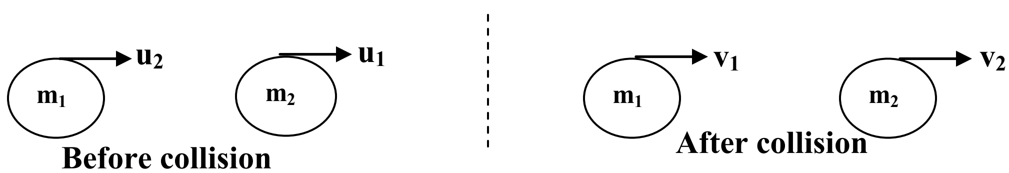
i)
$$m_1u_1 + m_2u_2 = [m_1 + m_2]\ v$$
$$2 \text{ x } 5 + 3 \text{ x } 0 = [2 + 3]v$$
$$10 = 5v$$
$$v = 2ms^{-1}$$

ii)
$$\text{Loss in K.E} = K.E_{before} - K.E_{after}$$
$$= [\tfrac{1}{2} m_1u_1^2 + \tfrac{1}{2} m_2u_2^2] - [\tfrac{1}{2}(m_1 + m_2)v^2]$$
$$= [\tfrac{1}{2} \text{ x } 2 \text{ x } 5^2 + \tfrac{1}{2} \text{ x } 3 \text{ x } 0^2] - [\tfrac{1}{2}(2 + 3)2^2]$$
$$= 25 - 10$$
$$= 15J$$

Elastic collision:

This is a type of collision where the colliding bodies separate after collision and move with different velocities. Both momentum and kinetic energy of the bodies are conserved.

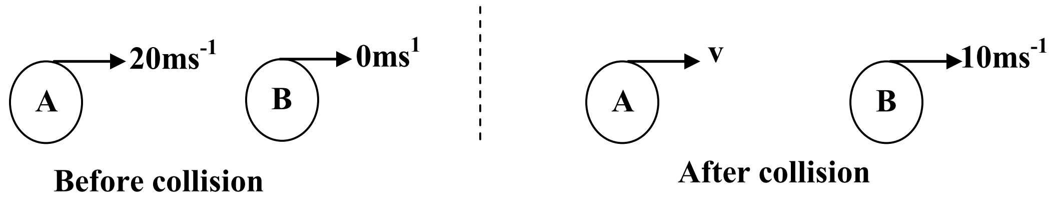
Consider two bodies of masses m_1 and m_2 moving with velocities of u_1 and u_2 respectively. After collision the velocities are v_1 and v_2 respectively, then from the principle of conservation of momentum.



$$\text{Total momentum before collision} = \text{Total momentum after collision}$$
$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

Example:

1. Ball A of mass 400g moving with a velocity of 20ms^{-1} collided with ball B of mass 50g at rest. If ball B moves with a velocity of 10ms^{-1} after collision in the direction of ball A. find the velocity of ball A after collision.



From $m_A u_A + m_B u_B = m_A v_A + m_B v_B$

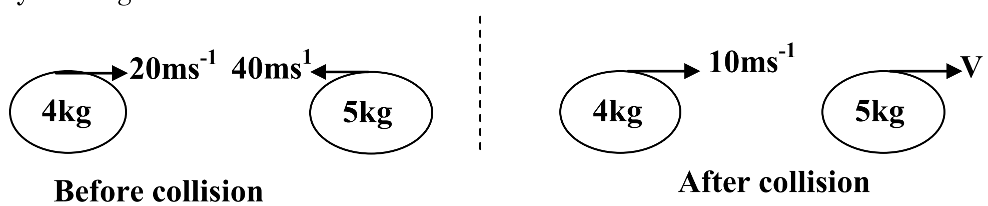
$400 \times 20 + 50 \times 0 = 400 \times v + 50 \times 10$

$8000 = 400v + 500$

$7500 = 400v$

$v = 18.75ms^{-1}$

2. A body of mass 4.0kg moving with a velocity of 25ms^{-1} collided with another body of mass 6.0kg moving with a velocity of 40ms^{-1} from the opposite direction. If 4.0kg mass moves with a velocity of 10ms^{-1} after collision, find the velocity of 5.0kg mass after collision.



From $m_1u_2 + m_1u_2 = m_1v_1 + m_2v_2$

$4 \times 20 + 5 \times -40 = 4 \times 10 + 5 \times v$

$80 - 200 = 40 + 5V$

$-120 = 40 + 5V$

$-160 = 5V$

$V = -32 \text{ ms}^{-1}$

Differences between elastic and inelastic collision:

Elastic collision	Inelastic collision
1. Bodies separate after collision	Bodies stay together after collision
2. Both K.E and momentum are conserved	K.E is not conserved but Momentum is conserved
3. Bodies move with different velocities after collision	Bodies move with a common velocity after collision.

IMPULSE:

This is the product of force and time for which it acts. Impulse is a vector quantity

$\text{Impulse, } I = \text{Force x time}$

$I = Ft$

The SI unit is newton second (Ns)

$\text{But } F = ma$

$F = m\left(\frac{v - u}{t}\right)$

$Ft = mv - mu$

$Ft = I = \text{change in momentum}$

Therefore impulse is the change in momentum of the body

The other unit of impulse is $kgms^{-1}$

Examples:

1. A body of mass 2kg changes its velocity from $10ms^{-1}$ to $45ms^{-1}$ after a period of time. Calculate the impulse on the body.

$I = mv - mu$

$I = 2 \text{ x } 45 - 2 \text{ x } 10$

$I = 90 - 20$

$I = 70kgms^{-1}$

2. A body of mass 4.5kg accelerates uniformly at $2ms^{-2}$ for 5 seconds. Calculate the impulse on the body

$I = F \text{ x } t$

$F = ma = 4.5 \text{ x } 2 = 9N$

$I = 9 \text{ x } 5$

$I = 45 \text{ Ns}$

3. An object is acted upon by a force of 50N for 2minutes. Calculate the impulse on the object.

$I = F \text{ x } t$

$F = 50N$

$t = 2 \text{ x } 60 = 120s$

$I = 50 \text{ x } 120$

$I = 6{,}000 \text{ Ns}$

Applications of the principle of conservation of momentum:

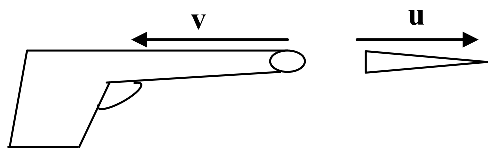
The principle of conservation of momentum is applied in the following cases;

a) **Rockets:** The propulsion of rockets is an application of the law of conservation of momentum that is when the fuel explodes (burns) in the rocket engine gases escape through the nozzle with a large velocity hence large momentum. The escaping gases in turn impart an equal but opposite momentum to the rocket which propels the rocket to move forward with a very high velocity.

b) **Jet planes**: The movement of jet planes is an application of the law of conservation of momentum that is when the fuel explodes (burns) in the jet engine gases escape through the exhaust pipe with a large velocity hence large momentum. The escaping gases in turn impart an equal but opposite momentum to the jet plane which causes the jet plane to move forward with a very high velocity.

c) **Explosion of a bomb:** If the bomb is at rest before it explodes then its total momentum is zero and when it explodes, it breaks into many parts and each part having a particular momentum. A part moving in one direction with a particular momentum has another part moving in opposite direction with the same momentum. If the bomb explodes into two equal parts, then they will move in exactly opposite directions with the same speed since they have the same mass.

d) **Recoil of the gun:** Momentum is conserved in firing a gun. Before firing, the gun and the bullet are at rest and after firing, the bullet receives an equal but opposite momentum to that of the gun. When the gun is fired, the bullet moves forward with a velocity, u and the gun moves backwards with a velocity, v.



$$0 = mu + M(-v)$$
$$Mv = mu$$
$$v = \frac{mu}{M}$$

Where m is the mass of the bullet and M is mass of the Gun

Examples:

1. A bullet of mass 50g is fired from a gun of mass 0.2kg with a velocity of 250ms^{-1}. Calculate the recoil velocity of the gun.

$$Mv = mu$$
$$0.2 \times v = 0.05 \times 250$$
$$v = \frac{0.05 \times 250}{0.2}$$
$$= 62.5ms^{-1}$$

2. A bullet of mass 20g is fired from a gun of mass 0.4kg if the gun recoils with a velocity of 40ms^{-1}. Calculate the velocity of the bullet.

$$Mv = mu$$
$$0.4 \times 40 = 0.02 \times u$$
$$u = \frac{0.4 \times 40}{0.02}$$
$$= 800ms^{-1}$$

3. A bullet of mass 200g is fired from the gun of mass 4kg. If the velocity of the bullet is 400ms^{-1}, calculate

i) the recoil velocity of the gun
ii) the kinetic energy gained by the gun

Solution:

i)
$$Mv = mu$$
$$4 \times v = 0.2 \times 400$$
$$v = \frac{0.2 \times 400}{4}$$
$$= 20ms^{-1}$$

ii)
$$K.E = \tfrac{1}{2} Mv^2$$
$$= \tfrac{1}{2} \times 4 \times 20^2$$
$$= 2 \times 400$$
$$= 800J$$

Trial Exercise 9:

1. A trolley of mass 2kg is pulled from rest by a horizontal force of 5N for 1.2 seconds. If there is no frictional force between the horizontal surface and the wheels of the trolley, calculate the
i) Acceleration and velocity after 1.2 seconds
ii) Distance covered by the trolley and kinetic energy gained by the trolley
Ans: i) 2.5ms^{-2}, 3ms^{-1} ii) 1.8m, 9J
2. A car travelling at a speed of 20ms^{-1} is uniformly stopped after 8 seconds by applying brakes. If the car and its occupants have a mass of 1250kg, calculate the
i) Acceleration and braking force
ii) Distance moved and the work done by the braking force to stop the car.
Ans: i) – 2.5ms^{-2}, 3125N ii) 80m, 250,000J
3. A rally car of mass 700kg starts from rest and travels a distance of 12m in 2 seconds. Calculate
i) Acceleration
i) The force applied on the car
Ans: i) 6ms^{-2} ii) 4200N
4. A bus of mass 7500kg travelling at 30 ms^{-1} collides in-elastically with a van, which is approaching from the opposite direction at 32ms^{-1}. If the van has a mass of 2500kg, at what velocity do the bus and the van travel after collision?
Ans: 14.5ms^{-1}
5. An object of mass 10kg acquires a velocity of 20ms^{-1} from 8ms^{-1} in 4seconds. What is
i) The acceleration and the force acting on the object
ii) The distance and the work done by this force?
Ans: i) 3ms^{-2}, 30N ii) 56m, 1680J
6. A radioactive nucleus emits a beta particle of mass, mkg with a velocity of 2.2 x 10^{8}ms^{-1}. If the mass of the recoiling nucleus is 44000mkg, find the recoil velocity.
Ans: 5 x 10^{3}ms^{-1}
7. Car A of mass 20,000kg travelling at 0.5ms^{-1} collides with another car B of half the mass of A moving in opposite direction with a velocity of 0.4ms^{-1}. If the trucks stay together on collision, calculate the common velocity with which they move.
Ans: 0.2ms^{-1}
8. A bullet of mass 1.5 x 10^{-2}kg is fired from a riffle of mass 3kg with a muzzle velocity of 180kmh^{-1}. Calculate the recoil velocity of the riffle
Ans: 0.25ms^{-1}
9. A car of mass 1000kg travelling at 72kmh^{-1} on a horizontal road is brought to rest in a distance of 40m by action of the brakes. Find
i) The acceleration and the average stopping force
ii) The time taken to stop the car.
Ans: - 5ms^{-2}, 5000N ii) 4s
10. A body of mass 2kg initially moving with a constant velocity is subjected to a force of 5N for 2 seconds. Find the change in momentum of the body.
Ans: 10kgms^{-1}

Multiple-choice Exercise:

1. A car of mass 500kg starts from rest and gains a speed of $80ms^{-1}$ in 5 seconds. Calculate the force applied on the car
A. 16N B. 500N C. 800N D. 8000N
2. When a car is suddenly brought to rest, a passenger jerks forward because of
A. inertia B. friction C. gravity D. momentum
3. A 1.5kg mass accelerates across a smooth table at $15ms^{-2}$. What is the net force applied to the mass
A. 0.1N B. 10.0N C. 15.0N D. 22.5N
4. A bullet of mass 3g travelling at $100ms^{-1}$ penetrates deeply into a fixed target and is brought to rest in 0.01 seconds. Calculate the average retarding force exerted on the bullet
A. 3N B. 30N C. 300N D. 3000N
5. A railway truck of mass 1800kg moving at $4ms^{-1}$ collides with a truck of mass 1200kg moving in the same direction at $3ms^{-1}$, if they move together, what is their combined velocity just after collision
A. $3.5ms^{-1}$ B. $3.6ms^{-1}$ C. $7.0ms^{-1}$ D. $8.2ms^{-1}$
6. A man of mass 70kg stands in a lift. What will he weigh if the lift accelerates at $0.5ms^{-2}$ upwards?
A. 665N B. 686N C. 700N D. 735N
7. A block of mass 10kg accelerates uniformly at a rate of $3ms^{-2}$ along a horizontal table when a force of 40N acts on it. Find the frictional force between the block and the table
A. 10.0N B. 13.3N C. 30.0N D. 70.0N
8. When a steadily increasing force is applied to a moving object all the following change except
A. acceleration B. momentum C. speed D. mass
9. An object of mass 2kg moving at $5ms^{-1}$ collides with another object of mass 3kg at rest. Find the velocity of the two bodies if they stick together after collision
A. $1ms^{-1}$ B. $2ms^{-1}$ C. $2.5ms^{-1}$ D. $5ms^{-1}$
10. A bullet of mass 0.02kg is fired with a speed of $40ms^{-1}$. Calculate its kinetic energy
A. 0.4J B. 0.8J C. 16J D. 32J
11. A bullet of mass 30g is fired with a speed of $400ms^{-1}$ from the riffle. The riffle recoils with a speed of $4ms^{-1}$. Find the mass of the riffle
A. 0.6kg B. 0.3kg C. 6.0kg D. 3.0kg
12. A boxer while training notices that a punch bag is difficult to set in motion and difficult to stop. What property of the punch bag accounts for both these observations?
A. friction B. inertia C. volume D. density
13. Two forces of 24N and 32N act at right angles on a body of mass 2kg. Calculate the acceleration of the body in ms^{-2}
A. 40 B. 20 C. 10 D.6
14. The product of mass and acceleration is
A. force B. inertia C. velocity D. momentum
15. A body continues in its of rest or uniform motion in a straight line unless acted upon by external force is a statement of
A. newton's second law of motion B. newton's first law of motion
C. newton's third law of motion D. newton's law of gravitation

16. When two bodies collide elastically

A. only momentum is conserved
B. both momentum and kinetic energy are conserved
C. only kinetic energy is conserved
D. both momentum and kinetic energy are not conserved

17. Eggs packed in a soft, shock-absorbing box are placed in a car. When the car suddenly starts or stops moving, the eggs do not crack because:

A. the force acting on them causes fast change in momentum.
B. no force acts on them.
C. the force acts on them for only a short time.
D. the force on them is small and acts for a longer time.

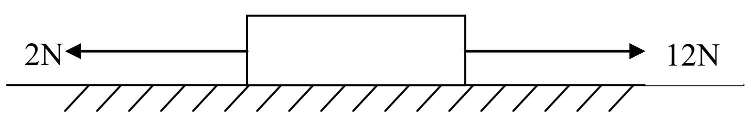
18. A body of mass m travelling with speed 5u collides with and adheres to a body of mass 5m travelling in the same direction with speed u. The speed with which the two travel together in the original direction is

A. 0
B. $\frac{8}{10}u$
C. $\frac{6}{5}u$
D. $\frac{10}{6}u$

19. A body of mass 4kg initially at rest is acted upon by a force of 10N for 10 seconds. Find the final velocity of the body.

A. $2.5ms^{-1}$
B. $20ms^{-1}$
C. $25ms^{-1}$
D. $80ms^{-1}$

20. The figure below shows a wooded block of mass 4.0kg acted upon by forces of 12N and 2N.



The acceleration of the block is

A. $2.5ms^{-2}$
B. $10.0ms^{-2}$
C. $3.5ms^{-2}$
D. $40.0ms^{-2}$

Answers:

1	D	5	B	9	B	13	B	17	D
2	A	6	D	10	C	14	A	18	D
3	D	7	A	11	D	15	B	19	C
4	B	8	D	12	B	16	B	20	A

MACHINES:

This is device that enables the force applied at one point to overcome another force at some other point. That is the device that simplifies work. The force applied is called the Effort [E] and the force which the machine must overcome is called the Load [L]. The SI unit of effort and load is a newton [N]. The following are examples of simple machines;

i) The levers.
ii) The pulley systems.
iii) The inclined plane.
iv) The screw.
v) The wheel and axle.
vi) The gears.
vii) The hydraulic press.

Terms used:

1. Mechanical advantage [M.A]

This is the ratio of load to effort.

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

$$= \frac{L}{E}$$

Mechanical advantage has no SI unit.

2. Velocity ratio [V.R]

This is the ratio of the distance moved by the effort to the distance moved by the load.

$$V.R = \frac{\text{Effort Distance}}{\text{Load Distance}}$$

$$= \frac{E.D}{L.D}$$

The velocity ratio has no SI unit.

3. Efficiency [η]

This is the ratio of useful work done by the machine to the work put into the machine expressed as a percentage.

$$\text{Efficiency} = \frac{\text{Work done by machine}}{\text{Work put into the machine}} \times 100\%$$

$$\eta = \frac{\text{Load x load distance}}{\text{Effort x effort distance}} \times 100\%$$

$$= \frac{L \times L.D}{E \times E.D} \times 100\%$$

$$= \frac{L}{E} \times \frac{L.D}{E.D} \times 100\%$$

$$= M.A \times \frac{1}{V.R} \times 100\%$$

$$\eta = \frac{M.A}{V.R} \times 100\%$$

Examples:

1. A simple machine raises a load of 3000N through a distance of 0.5m when an effort of 150N is applied through a distance of 12.5m. Calculate

i) Mechanical advantage

ii) Velocity ratio

iii) Efficiency of the machine

Solution

i) M.A $= \frac{L}{E} = \frac{3000}{150} = 20$

ii) V.R $= \frac{E.D}{L.D} = \frac{12.5}{0.5} = 25$

ii) $\eta = \frac{M.A}{V.R} \times 100\% = \frac{20}{25} \times 100\% = 80\%$

2. A load of 100N is raised through 6m when an effort of 40N moves through a distance of 24m. Calculate

i) Mechanical advantage

ii) Velocity ratio

iii) Efficiency of the machine

Solution

i) M.A $= \frac{L}{E} = \frac{100}{40} = 2.5$

ii) V.R $= \frac{E.D}{L.D} = \frac{24}{6} = 4$

ii) $\eta = \frac{M.A}{V.R} \times 100\% = \frac{2.5}{4} \times 100\% = 62.5\%$

Note:

- In practice the efficiency of any machine is less than 100% because of the following;

i) Some of the energy is wasted in overcoming friction.

ii) Some of the energy is wasted in lifting useless loads

- However the efficiency of the machine can be increased by;

i) Reducing friction through oiling, lubricating, ball bearings.

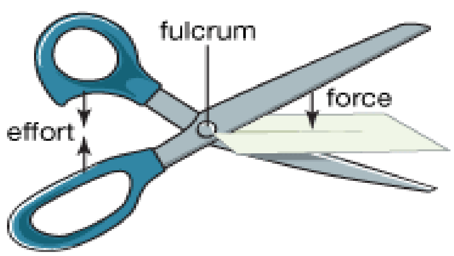
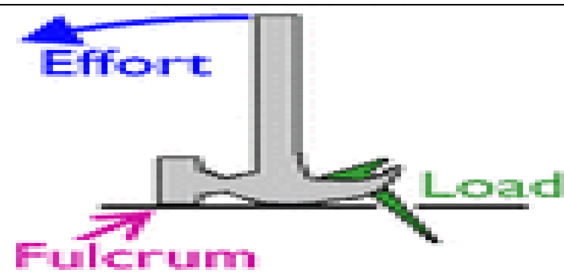
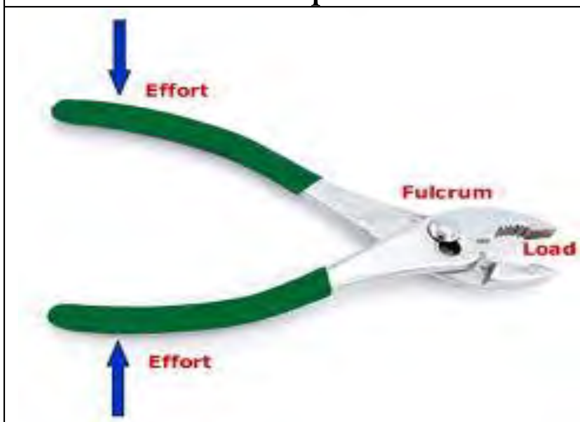
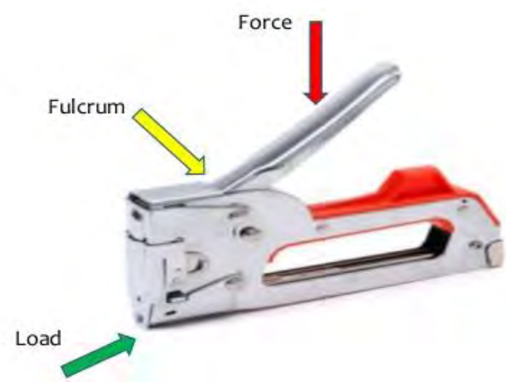
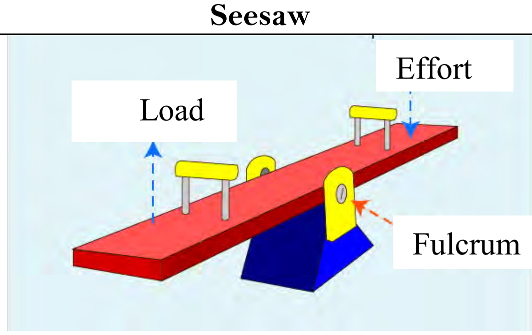
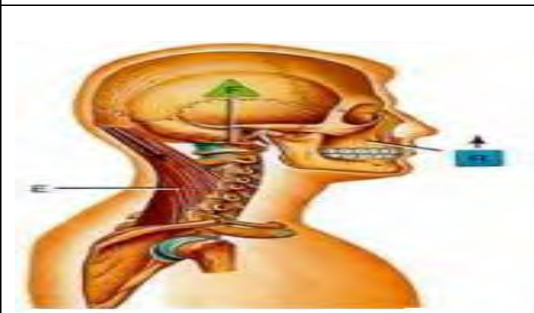
ii) Using light materials for the useless loads.

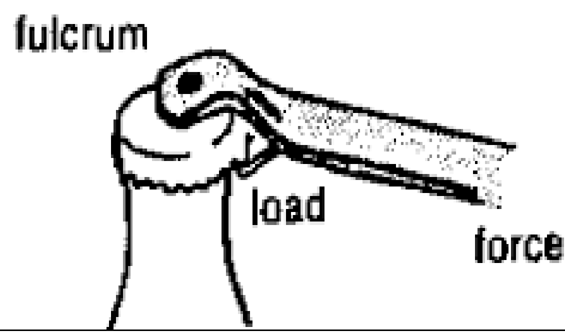
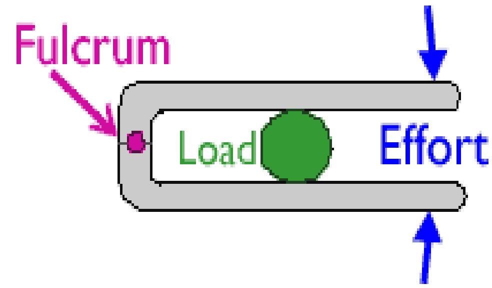
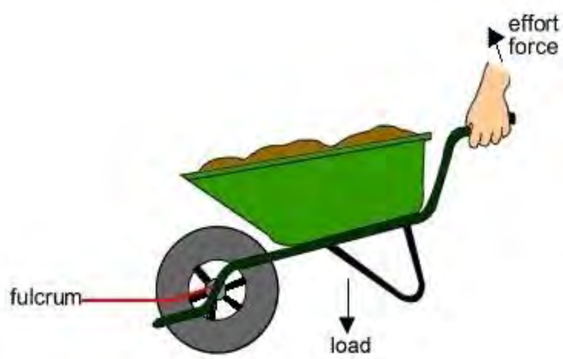
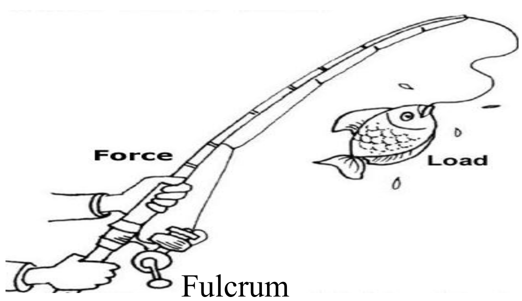
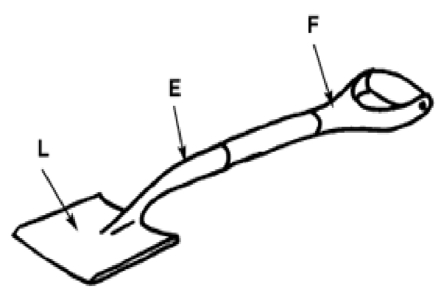
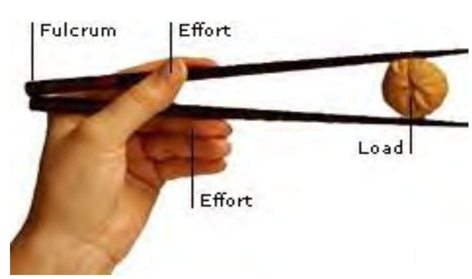
LEVERS:

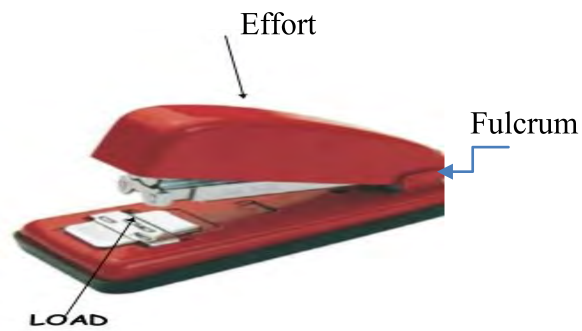
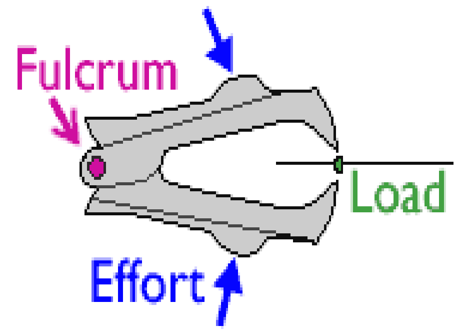
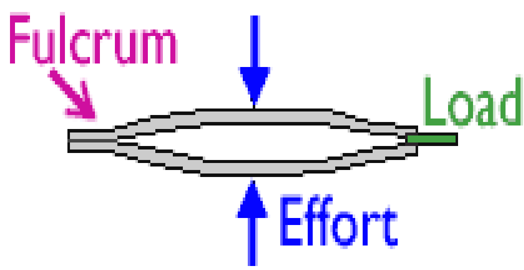
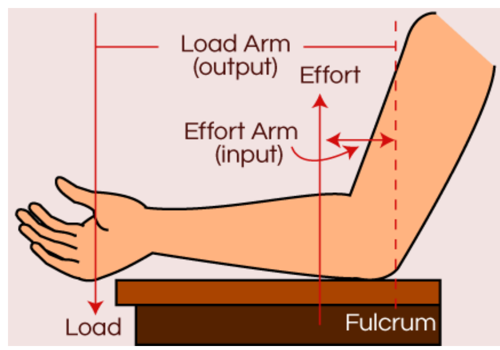
This is a type of machine with a rigid body capable of turning about a fixed point. This fixed point about which a lever turns is called the pivot [fulcrum]. The lever has three major parts i.e the effort, the pivot and the load. The class of the lever depends on the relative position of the parts. There are three classes of levers and these are;

i) First class levers.
ii) Second class levers.
iii) Third class levers

First class levers are type of levers where the pivot is between the effort and the load, Second class levers are type of levers where load is between the effort and the pivot and Third class levers are type of levers where effort is between the load and the pivot. The table below shows different types of levers;

FIRST CLASS LEVERS	
Pair of scissors	**Claw hammer**
	
Pair of pliers	**Gun Stapler**
	
Seesaw	**Head**
	

<table>
<tr><th colspan="2">SECOND CLASS LEVERS</th></tr>
<tr><th>Bottle opener</th><th>Nut cracker</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><th>Wheel barrow</th><th>Leg</th></tr>
<tr><td>
</td><td></td></tr>
<tr><th colspan="2">THIRD CLASS LEVERS</th></tr>
<tr><th>Fishing rod</th><th>Spade</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><th>Fork/spoon</th><th>Pair of tongs</th></tr>
<tr><td>
</td><td>
</td></tr>
</table>

Stapler	Staple remover
	
Pair of tweezers	**Arm**
	

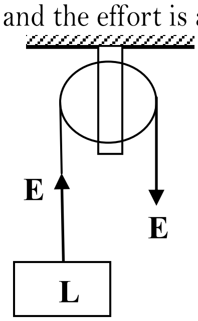
PULLEY SYSTEM:

A Pulley is a wheel with a grooved rim. There are three types of pulley systems and these are;

i) Single fixed pulley
ii) Single movable pulley
iii) Block and tackle pulley

Single fixed pulley.

This is a simple pulley with a fixed wheel and has a rope passing around the groove in its rim. In a single fixed pulley the load is tied to one end and the effort is applied to another end.



If there is no friction and the rope is weightless then at equilibrium

$$L = E$$

$$M = \frac{L}{E}$$

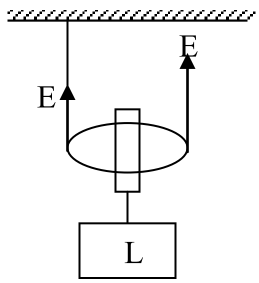
$$M.A = 1$$

In practice the rope has weight and there is friction in the groove, therefore the effort is always greater than the load. Hence mechanical advantage is always less than 1.
However the distance moved by the effort is always equal to the distance moved by the load

Thus $V.R = \frac{E.D}{L.D}$

$= 1$

Single movable pulley:
This is a simple pulley with a rope passing around the groove of a movable wheel. In a single movable pulley one end of the rope is fixed and the effort is applied on the other end but the load is tied to the wheel.



If there is no friction and the rope is weightless then at equilibrium

$L = 2E$

$M.A = \frac{L}{E}$

$M.A = 2$

In practice the rope has weight and there is friction in the groove, therefore the effort is always greater than the load. Hence mechanical advantage is always less than 2.
However the distance moved by the effort is always twice to the distance moved by the load

Thus $V.R = \frac{E.D}{L.D}$

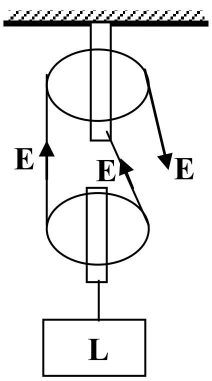
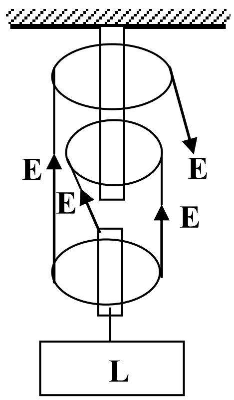
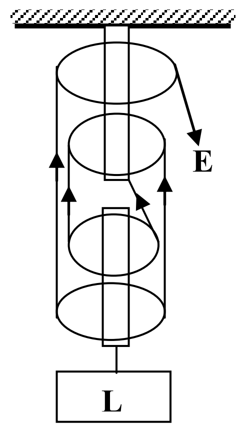
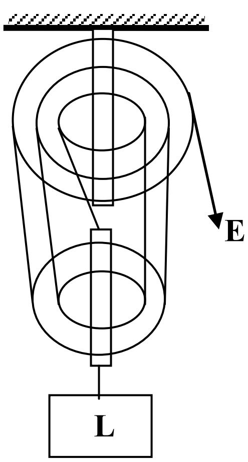
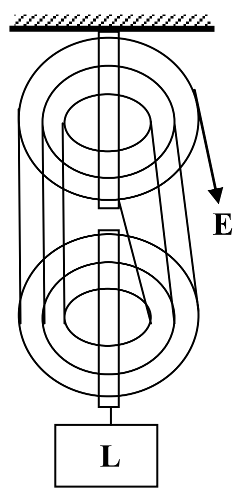
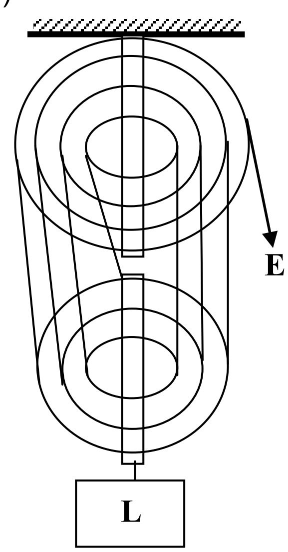
$= 2$

Block and tackle pulley system:
This is a system where two or more pulleys are combined to form a machine of larger velocity ratio and higher mechanical advantage. It uses very little effort hence difficult tasks can be completed by this machine. In a block and tackle pulley system two or more pulleys are mounted on the same axle to form a block. One set of the block is fixed and the other set of the block is movable. These blocks are joined by a single rope called tackle passing through each pulley in turn. If the number of pulleys is odd then the fixed block has more by one pulley than the movable block and when the pulleys are even the blocks have the same number of pulleys. The velocity ratio is equal to number of strings supporting the movable block which is equal to the number of pulleys of the pulley system.

Uses of pulley systems:
- Construction pulleys lift heavy materials from the ground.
- Curtains at the theatre are moved using pulley systems.
- Flag poles use pulleys in order to raise or bring down the flag.
- A crane is a pulley system used in construction.

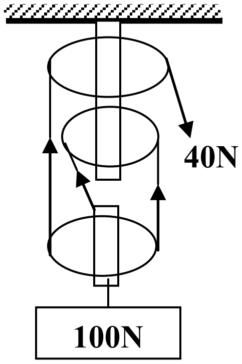
- Engines utilize pulley systems in order to function.
- Fans with chains use pulley systems in order to be turned on or off.
- Timing belts in cars use pulley systems.
- Escalators utilize pulley system to function.
- A lift uses pulley system to move items to higher floors.
- Bulldozer uses a pulley system.
- Rock climbers use pulley systems.
- Oil derricks use pulley systems.
- Garage doors close and open using pulley systems.

NOTE: The table below show different pulley systems with different velocity ratios;

i) V.R = 2 	**ii) V.R = 3** 	**iii) V.R = 4** 
iv) V.R = 5 	**v) V.R = 6** 	**vi) V.R = 7** 

Examples:

1. The minimum effort required to raise a load of 100N is 40N as shown in diagram below.



Calculate

i) The mechanical advantage

ii) Efficiency

iii) Work done by the load if it is raised through 6m.

i) M.A $= \frac{L}{E}$

$= \frac{100}{40}$

$= 2.5$

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

$= \frac{2.5}{3} \times 100\%$

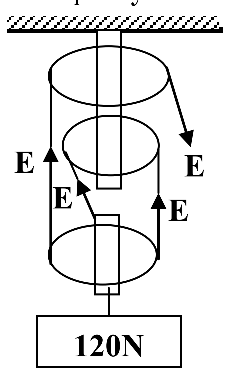
$= 83.3\%$

ii) Work done = load x load distance

= 100 x 6

= 600J

2. In the pulley system below each pulley has a mass of 0.6kg



Calculate the

i) Effort, E

ii) Mechanical advantage

iii) Efficiency

i) $E + E + E = 120 + 0.6 \times 10$

$3E = 126$

$E = \frac{126}{3}$

$= 42N$

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

$= \frac{2.86}{3} \times 100\%$

$= 95.2\%$

ii) M.A $= \frac{L}{E}$

$= \frac{120}{42}$

$= 2.86$

3. A block and tackle pulley system with a velocity ratio of 5 and 60% efficiency is used to a lift a load of mass 60kg through a vertical height of 2m. What effort must be exerted?

$$\eta = \frac{M.A}{V.R} \times 100\%$$

$$60 = \frac{M.A}{5} \times 100\%$$

M.A = 3

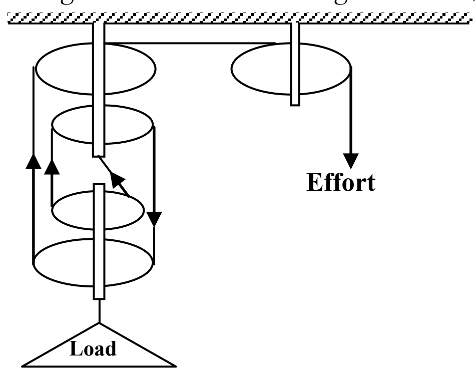
$$M.A = \frac{L}{E}$$

$$3 = \frac{600}{E}$$

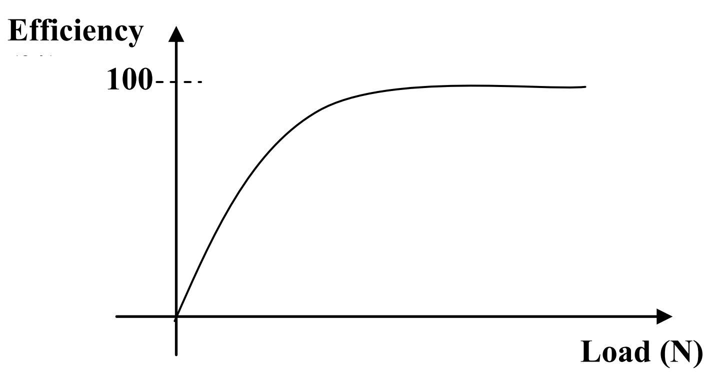
E = 200N

Experiment to measure the efficiency of the pulley system:

- The apparatus is arranged as shown in the diagram below;



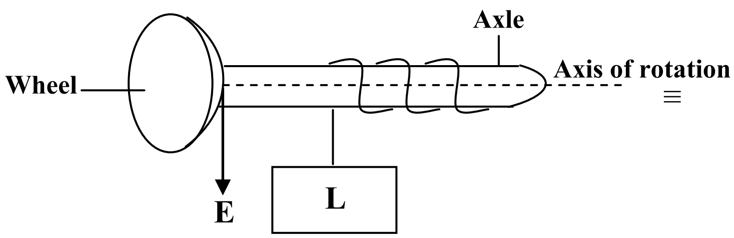
- A known load is placed on the scale pan and known weights are added to the effort pan until the load just starts to move upwards.
- The experiment is repeated with different loads and different efforts noted.
- The results are then tabulated including the values of mechanical advantage.
- Note that the velocity of the above pulley system is 4.
- A graph of efficiency against load is as shown below;

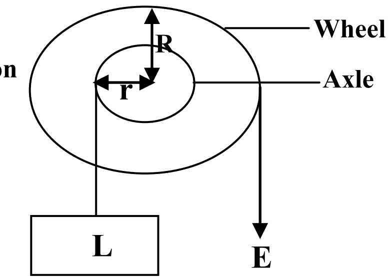


When the load is small, large proportion of the applied effort is used to overcome weight of moving parts and friction. This leads to small mechanical advantage and efficiency for small loads. As the load increases, the portion of the effort that does useful work increases, while that which does work against friction and raising the moving parts decreases. Hence mechanical advantage and efficiency increases with the load.

WHEEL AND AXLE:

The wheel and axle has a common axis of rotation. When the effort is applied to the string attached to the wheel, the load is raised by a string wound around the axle.





After a complete turn the effort, E moves through a distance equal to circumference of a circle described by the wheel = $2\pi R$ and the load, L moves through a distance equal to the circumference of a circle described by the axle = $2\pi r$.

$$V.R = \frac{\text{Effort distance}}{\text{Load distance}} = \frac{2\pi R}{2\pi r} = \frac{R}{r} = \frac{\text{Radius of the wheel}}{\text{Radius of the axle}}$$

Examples:

1. A machine consisting of a wheel of radius 50cm and axle of radius 10cm is used to lift a load of 400N with an effort of 100N. Calculate

i) Its velocity ratio

ii) Its mechanical advantage

iii) The efficiency of the incline

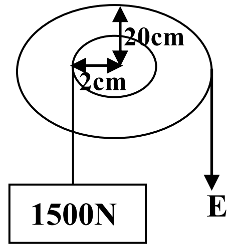
Solution:

i) $$V.R = \frac{\text{Radius of the wheel}}{\text{Radius of the axle}} = \frac{50}{10} = 5$$

ii) $$M.A = \frac{L}{E} = \frac{400}{100} = 4$$

iii) $$\eta = \frac{M.A}{V.R} \times 100\% = \frac{4}{5} \times 100\% = 80\%$$

2. The efficiency of the machine below is 75%.



Calculate
i) Its velocity ratio
ii) Its mechanical advantage
iii) The effort applied

i) $V.R = \frac{\text{Radius of the wheel}}{\text{Radius of the axle}}$

$= \frac{20}{2}$

$= 10$

iii) $\eta = \frac{M.A}{V.R} \times 100\%$

$75 = \frac{M.A}{10} \times 100\%$

$M.A = 7.5$

ii) $M.A = \frac{L}{E}$

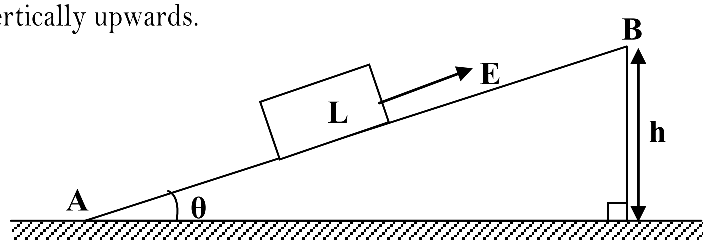
$7.5 = \frac{1500}{E}$

$E = \frac{1500}{7.5}$

$= 200N$

THE INCLINED PLANE:

An inclined plane is a slope which allows a load to be raised more gradually by using a smaller effort than if it was lifted vertically upwards.



Note:

The distance moved by the Effort, E is equal to the length, d of the plane AB and the load is raised through a vertical height, h.

$V.R = \frac{\text{Effort distance}}{\text{Load distance}}$

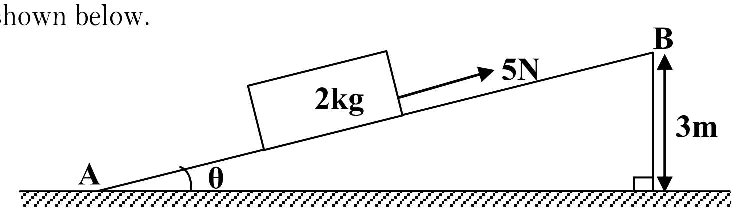
$= \frac{d}{h}$

But $\sin\theta = \frac{h}{d}$

$V.R = \frac{1}{\sin\theta}$

Examples:

1. A brick of mass 2kg is lifted to a height of 3m a long a smooth inclined plane 15m long by applying an effort of 5N as shown below.



Calculate

i) its velocity ratio

ii) its mechanical advantage

iii) the efficiency of the incline

Solution

i) $V.R = \frac{\text{Effort distance}}{\text{Load distance}}$

$= \frac{d}{h}$

$= \frac{15}{3}$

$= 5$

ii) $M.A = \frac{L}{E}$

$= \frac{20}{5}$

$= 4$

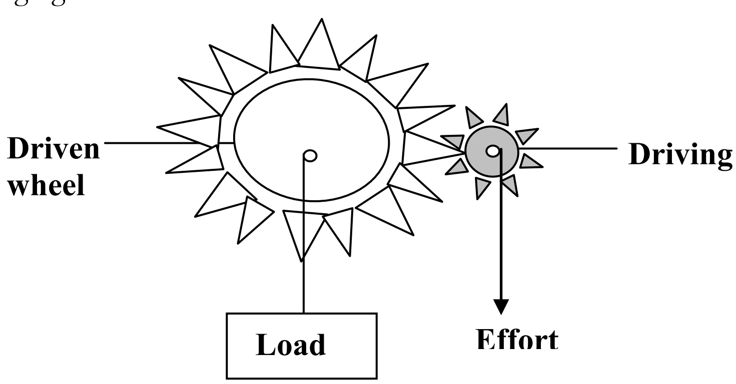
iii) $\eta = \frac{M.A}{V.R} \times 100\%$

$= \frac{4}{5} \times 100\%$

$= 80\%$

THE GEARS:

Gears are rigidly fixed to the axis and turned with their axis. If the effort is applied on a small gear, it drives a large gear which has a load attached on it.



$$\text{Velocity ratio} = \frac{\text{Number of teeth of the driven wheel}}{\text{Number of teeth of the driving wheel}}$$

$$V.R = \frac{N}{n}$$

Example:

1. A driving wheel of 25 teeth engages with a second wheel of 100 teeth and has an efficiency of 85%. Calculate

i) The velocity ratio

ii) The mechanical advantage of the machine

Solution:

i) $V.R = \dfrac{\text{No of teeth of the driven wheel}}{\text{No of teeth of the driving wheel}}$

$= \dfrac{100}{25}$

$= 4$

ii) $\eta = \dfrac{M.A}{V.R} \times 100\%$

$85 = \dfrac{M.A}{4} \times 100\%$

$M.A = 3.4$

2. A driving wheel of 25 teeth engages with a second wheel of 100 teeth and has an efficiency of 85%. Calculate

i) The velocity ratio

ii) The mechanical advantage of the machine

Solution:

i) $V.R = \dfrac{\text{No of teeth of the driven wheel}}{\text{No of teeth of the driving wheel}}$

$= \dfrac{100}{25}$

$= 4$

ii) $\eta = \dfrac{M.A}{V.R} \times 100\%$

$85 = \dfrac{M.A}{4} \times 100\%$

$M.A = 3.4$

3. A certain gear has 60 teeth and drives another gear with 150 teeth. How many revolutions will the driven gear make when the driving gear makes 200 revolutions?

Solution:

$V.R = \dfrac{N}{n}$

$V.R = \dfrac{150}{60}$

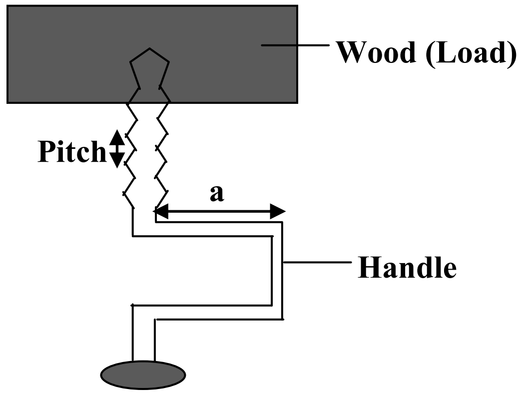
$V.R = 2.5$

$\text{Revolutions} = \dfrac{200}{2.5}$

$= 80$ revolutions

THE SCREW:

The screw is used for the purpose of holding things together. The distance between successive threads of the screw is called **the pitch**. When the effort is applied on the screw by means of the handle, it enters the wood [Load] by a distance equal to the pitch after turning the handle through one complete turn. Therefore the effort moves a distance equal to the circumference of the circle described by the handle and the load moves a distance equal to the pitch, P.



$$V.R = \frac{\text{Effort distance}}{\text{Load distance}}$$

$$= \frac{2\pi a}{\text{Pitch}}$$

$$= \frac{2\pi a}{P}$$

Example:

A screw of pitch 5cm is used to lift a load of 890.8N in a car jerk. The lever makes a circle of circumference 10cm and has an efficiency of 85%. Find

i) Its velocity ratio

ii) Its mechanical advantage

iii) The effort applied to the handle

i) $V.R = \frac{2\pi a}{P}$

$= \frac{10}{5}$

$= 2$

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

$85 = \frac{M.A}{2} \times 100\%$

$= 1.7$

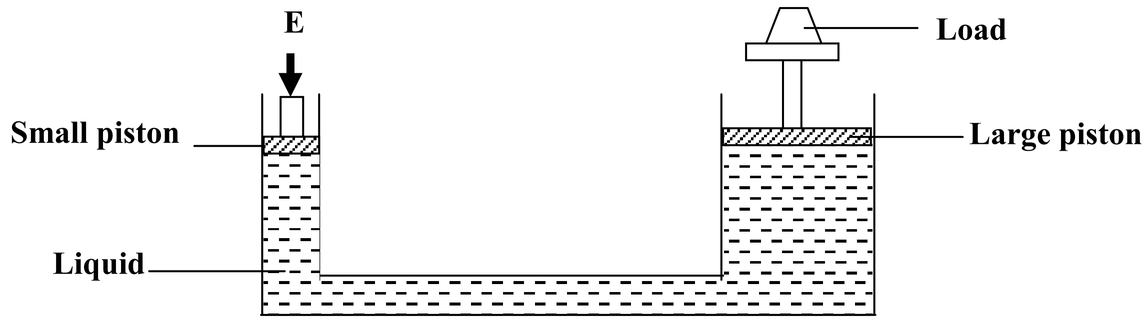
ii) $M.A = \frac{L}{E}$

$1.7 = \frac{890.8}{E}$

$E = 524N$

Hydraulic press/lift:

When a force is applied on small piston of cross sectional area A_1 the pressure exerted by the force is transmitted throughout the liquid to the large piston of cross sectional area A_2 that is when the effort, E is applied on the small piston of radius, r then pressure exerted on the liquid is transmitted by the liquid to the large piston of radius, R to overcome the load on large piston.



Let X be the distance moved by the small piston and Y be the distance moved by the large piston then the volume of the liquid that leaves the small cylinder is equal to the volume that enters the large piston

$X \times A_1 = Y \times A_2$

$\frac{X}{Y} = \frac{A_2}{A_1}$

X is the distance moved by the effort and Y is the distance moved by the load

$V.R = \frac{X}{Y} = \frac{A_2}{A_1}$

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

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

Example:

The radius of the effort piston of a hydraulic lift is 1.4cm while that of the load piston is 7.0cm. This machine is used to raise a load of 120kg at a constant velocity through a height of 2.5m. Given that the machine is 80% efficient. Calculate

i) Velocity ratio

ii) Mechanical advantage

iii) The effort needed

Solution:

i) $V.R = \frac{R^2}{r^2}$

$= \frac{7^2}{1.4^2}$

$= 25$

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

$80 = \frac{M.A}{25} \times 100$

M.A = 25 x 0.8 = 20

iii) $M.A = \frac{L}{E}$.

$20 = \frac{1200}{E}$.

$E = \frac{1200}{20} = 60N$

Trial Exercise 10:

Where necessary use acceleration due to gravity, g = 10ms^{-2} and take $\pi = \frac{22}{7}$

1. In a certain machine the load moves 2m when the effort moves 8m. If an effort of 20N is used to raise a load of 60N. Calculate mechanical advantage, velocity ratio and efficiency of the machine?
   Ans: 3, 4 and 75%
2. A block and tackle pulley system is used to lift a mass of 200kg. If this machine has a velocity ratio of 5 and an efficiency of 80%, sketch a possible arrangement of the pulleys. Calculate the mechanical advantage and the effort applied
   Ans: 4 and 500N
3. A man uses the inclined plane to lift a 72kg load through a vertical height of 4m. The inclined plane makes an angle of 30^o with the horizontal. If the efficiency of the inclined plane is 72%, calculate the
   i) Velocity ratio and mechanical advantage
   ii) Effort needed to move the load up the inclined plane at a constant velocity and the work done against friction in raising the load through a vertical height of 4m.
   Ans: i) 2, 1.44 ii) 500N, 2880J
4. A certain gear has 30 teeth and drives another gear with 75 teeth. How many revolutions will the driven gear make when the driving gear makes 100 revolutions?
   Ans: 40 revolutions.
5. An effort of 125N is used to lift a load of 500N through a height of 2.5m using a pulley system, if the distance moved by the effort is 15m, calculate the work done on the load, work done by the effort and efficiency of the pulley system
   Ans: 1250J, 1875J and 66.7%
6. A screw jack of pitch 2.5cm is operated by a force of 100N acting at a distance of 7cm from the axis about which a handle rotates and lifts a car weighing 79.2kg. Calculate the velocity ratio, mechanical advantage and efficiency.
   Ans: 17.6, 7.92 and 45%
7. A bicycle has a chain wheel with 32 teeth, the driven wheel having 80 teeth. If the efficiency is 88%, find the velocity ratio and mechanical advantage of the machine.
   Ans: 2.5, 2.2
8. The area of the effort piston of a hydraulic lift is 56cm^2 while that of the load piston is 224cm^2. This machine is used to raise a load of 300kg at a constant velocity through a height of 2.5mm. Given that the machine is 75% efficient. Calculate velocity ratio, mechanical advantage, the effort needed and effort distaance
   Ans: 4, 3, 1000N and 10mm
9. A man using a pulley system lifts a load of 200kg at a steady speed through a distance of 20m in 20seconds. If the efficiency of the system is 80%, calculate the power at which the man is working.
   Ans: 2500J
10. A screw jack with a lever arm of 56cm and a pitch of 2.5cm is used to raise a load of 8800N, if its efficiency is 25%, find the velocity ratio, mechanical advantage of the machine and effort needed.
    Ans: 140.8, 35.2 and 250N.

HEAT ENGINES:

A heat engine is a machine which converts heat energy to kinetic energy. There are two types of heat engines that is;

i) Internal combustion engine.

ii) External combustion engine.

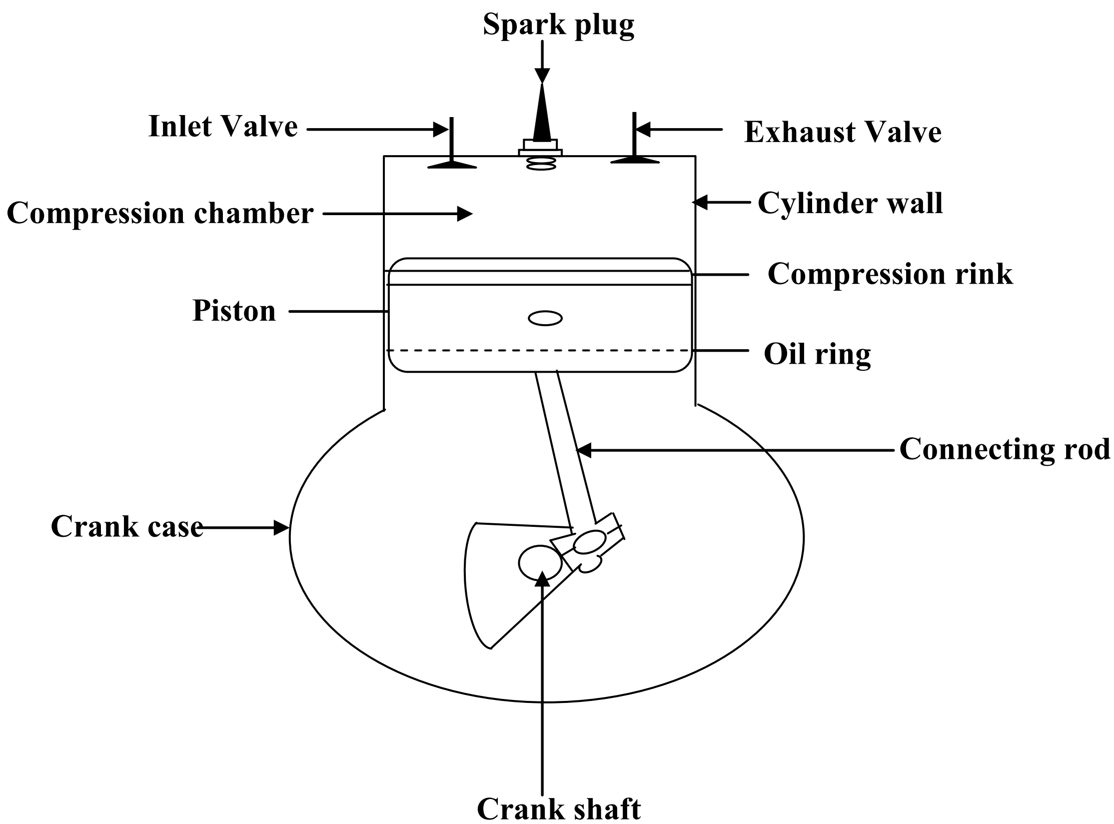
INTERNAL COMBUSTION ENGINE:

In this type of engine fuel is burnt in the cylinder or chamber and energy changes occur in the cylinder which is not the case in external combustion engine. It consists of a piston which moves up and down the cylinder or chamber. The cylinder has two valves;

i) Intake (inlet) valve: This allows a mixture of petrol vapour and air to pass through the cylinder.

ii) Exhaust (outlet) valve: This allows the waste gases to be pushed out from the cylinder by raising the piston.

The structure of internal combustion engine:



FUNCTIONS OF THE PARTS

- **Spark plug:** This provides a spark at the right moment to ignite the compressed gasses in the compression chamber.
- **Cylinder head:** This is at the top of the cylinder and has the following functions;
  - It seals the engine block.
  - It forms the combustion chamber where ignition occurs.
  - It houses the valves , injector nozzle and spark plug.
  - It provides passage for cooling materials to circulate in cooling the engine.

- **Cylinder wall:** This has the following functions;
  - It provideas space in which the piston opertaes to cause compression.
  - It stores fuel-air mixture temporally before its compressed and ignited.
  - It forms basic support unit of the engine block.
- **Piston head:** This has the following functions;
  - It draws in and compresses air-fuel mixture in the engine.
  - It initiates the movement of the engine.
  - It transmits power to the crank shaft as a result of explosion.
  - It avoids friction in between while allowing compression.
- **Piston rings:** These have the following functions;
  - They maintain compression.
  - They maintain piston clearance area that is the area between the piston and the cylinder wall.
  - They prevent cylinder and piston surfaace wear.
  - They minimize oil distribution and prevents unnecessary oil consumption.
  - They help to dispate heat away from the cylinder.
- **Piston (Gudgeon) pin:** This has the following functions;
  - It fastens the piston rod to the piston.
  - It connects the piston to the connecting rod.
- **Piston (connecting) rod:** This connects the crank shaft to the piston.
- **Crank shaft:** This has the following functions;
  - It transmitts power from the connecting rod to the other parts of the vehicle.
  - It drives the crank shaft, fuel pump, water pump and injector pump.
  - It converts the reciprocating movement of the piston to rotary energy.
- **Inlet valve:** This controls the inlet of air and fuel into the engine.
- **Outlet valve:** This controls the outlet of burnt gases and water vapour into the atmosphere.
- **Cam shaft:** This controls the closing and opening of the valves.
- **Fly wheel:** This has the following functions;
  - It smoothens out speed of the crank shaft
  - It stores energy for momentum between power strokes.
  - It transmits power to the engine.

THE FOUR STROKE CYCLE:

A stroke is the movement of the piston from the bottom dead centre (BDC) to the top dead centre (TDC) or from the TDC to the BDC. Bottom dead centre is the minimum point a piston reaches on its downward movement and Top dead centre is the maximum point reached by the piston on its upward movement. Internal combustion engine works on the four stroke principles;

i) Intake (inlet) stroke

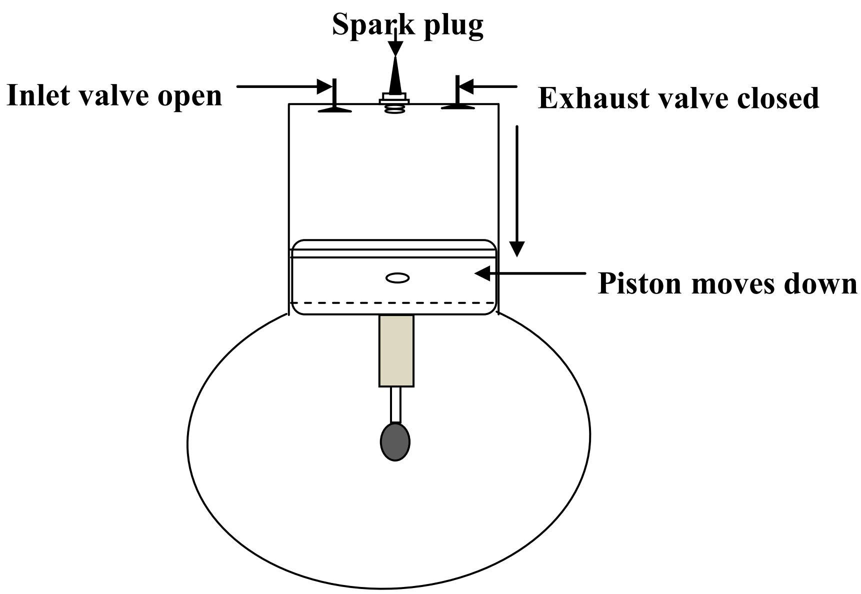
ii) Compression stroke

iii) Power stroke

iv) Exhaust (outlet) stroke

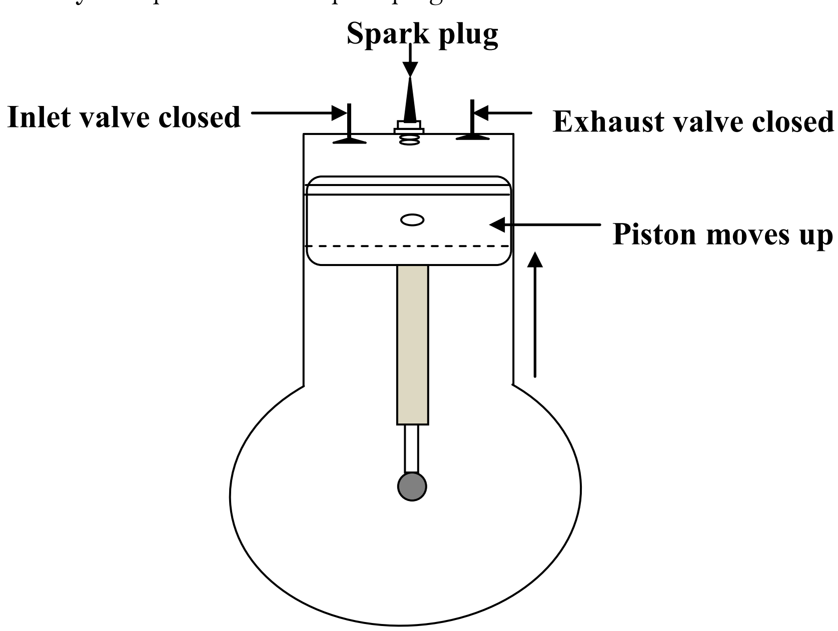
During the intake stroke

- The piston moves down causing partial vacuum in the chamber and reducing on the pressure in the cylinder because the starter motor in a car or the kick start in a motor cycle turns the crankshaft.
- The intake (inlet) valve opens.
- The air-fuel mixture from the carburetor is forced into the cylinder by atmospheric pressure.
- Exhaust valve closes.



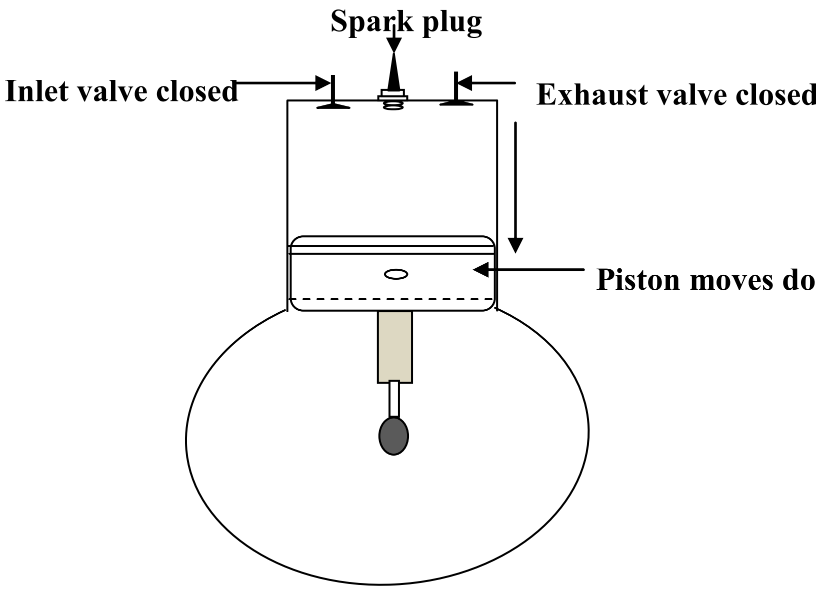
During the compression stroke

- Both valves close.
- The piston moves up.
- The air-fuel mixture is compressed to its minimum volume and near the top of the stroke the mixture is ignited by the spark from the spark plug.



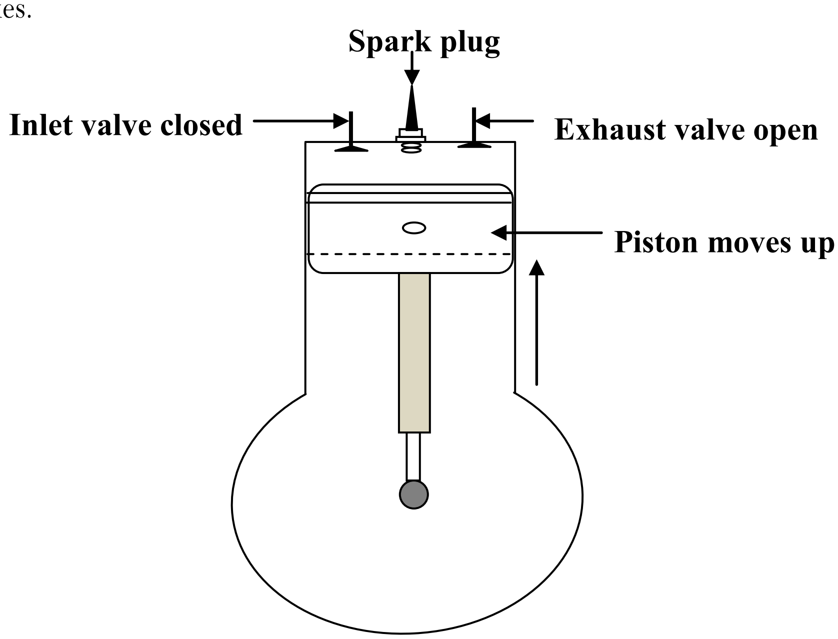
During the power stroke

- The air-fuel mixture explodes because a spark jumps across the points of the sparking plug.
- Both inlet and exhaust valves remain closed.
- Ignited air- fuel mixture expands and forces the piston downwards.



During the exhaust stroke

- The outlet (exhaust) valve opens.
- The inlet valve closes.
- The piston rises pushing the exhaust gases out of the cylinder.
- Near the top of the stroke the exhaust valve closes and the engine is ready to repeat the cycle of four strokes.



Diesel Engine

The operation of diesel engine on two-stroke or four-stroke is similar to that of a petrol engine. Diesel is used in diesel engines instead of petrol. In diesel engine there is no spark plug and the carburetor is replaced by fuel injector.

Four stroke cycle in a diesel engine:

During induction (down) stroke: The piston admits air only into the cylinder.
During the compression (up) stroke: The air is compressed to its minimum volume and the temperature of air increases and air becomes very hot.
During the power stroke: Fuel is pumped into the cylinder by the fuel injector and compressed air ignites automatically causing increase in pressure which force the piston to move downwards.

DIFFERENCES BETWEEN DIESEL AND PETROL ENGINES:

Diesel Engine	Petrol Engine
Uses diesel as fuel	Uses petrol as fuel
Fuel is ignited through compression	Fuel is ignited through electric sparks
No carburetor	Has a carburetor
No spark plug	Has a spark plug
High compression ratio of 16: 1	Low compression ratio of 8:1
Produces a lot of smoke	Produces little smoke
Expensive	Cheap
Uses less fuel	Uses a lot of fuel
Fewer starting problems	Many starting problems
Has an injector	No injector

Advantages of diesel engines over petrol engines

- Diesel engines are more efficient than petrol engines.
- Diesel engines consume less fuel than petrol engines.
- Diesel engines are less expensive to operate than petrol engines.
- Diesel fuel costs less compared to petrol fuel.
- Diesel engine has fewer starting problems than petrol engine.
- Diesel engine operates for a longer time without servicing.
- Diesel fuel is safer.
- Diesel engine has low maintenance costs.
- Diesel engine is more reliable than petrol engine.
- There is no sparking as fuel ignites.

Disadvantages of diesel engines over petrol engines

- Diesel engines produce sooty and smelly smoke.
- Diesel engines are slower.
- Diesel engine is heavy compared to petrol engine.
- Diesel engines are expensive to service.
- Diesel engine affects the environment.

Two stroke engine:

This type of engine is commonly found in small machines used on light jobs like motorcycles, water pumps, small electric generators, hand operated chain saws, small boats etc. valves are replaced by ports on the side of the cylinder which are opened and closed by the piston as it moves. The mechanism of a two stroke engine works in such a way that all elements that is induction, compression, ignition and exhaust are completed in two strokes of the piston.

When the piston is at the top of the cylinder, the mixture is compressed and fresh mixture enters the crank case through the inlet port and the spark ignites the compressed mixture and the piston moves down.

When the piston is near the bottom, the mixture passes through the transfer port into the cylinder, the exhaust port opens and the burnt gases are pushed out as the piston moves up again.

Advantages of a four stroke engine over a two stroke engine

- It produces a lot of power and can do heavy work
- It is efficient in fuel and oil consumption.
- It performs a wide range of operations.
- It is cooled efficiently by water.
- It can absorb vibration of engine better because it is heavy.
- Exhaust gases are sufficiently expelled from the cylinders.
- It is more reliable.
- It lasts longer.
- It pollutes less than two stroke engine.
- It is not noisy like two stroke engine.

Disadvantages of four stroke engines over two stroke engines

- They have high initial cost.
- They are very expensive to maintain.
- They need very skilled operators and support services.
- Their use is limited in hilly areas.
- They are complicated to construct because of valves.
- They are larger in size.
- They are heavy.
- They are slow compared to two stroke engines.

MOMENTS:

Moment is a turning effect of the force about the fixed point. The fixed point is known as the pivot [Fulcrum]

Moment of a force:

This is the product of the force and the perpendicular distance of the line of action of the force from the pivot.

Moment of a force = Force x Its perpendicular distance

The SI unit of moment of the force is newton metre [Nm]. Moment of a force is the vector quantity whose direction is the direction of force.

The moment of the force depends on the following factors

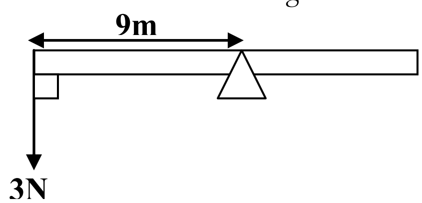
i) the magnitude of the force.

ii) the perpendicular distance from the pivot

Examples:

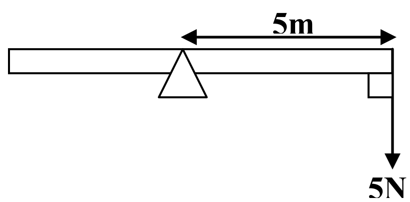
1. Find the moments of the following forces

a)



Moment of a force = F x d
= 3 x 9
= 27Nm

b)

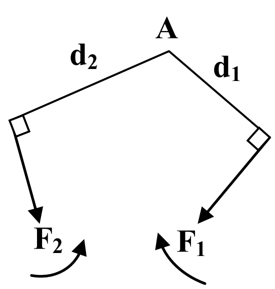


Moment of a force = F x d
= 5 x 5
= 25Nm

The principle of moments:

It states that when a body is in equilibrium the sum of clockwise moments about any point is equal to the sum of anticlockwise moments about the same point. Therefore the algebraic sum of the moments about the fixed point is equal to zero.

Consider forces F_1 and F_2 acting on a body at distances d_1 and d_2 respectively from point



Taking moments about point A

Clockwise moments $= F_1 \times d_1$

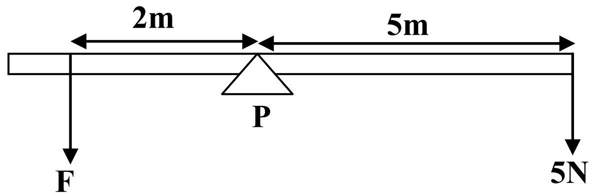
Anticlockwise moments $= F_2 \times d_2$

Note

When calculating moments about a point [pivot] all distances should be measured from that point and should be at right angles to the force.

Examples:

1.



Forces of 5N and F act of the body which is in equilibrium. Calculate the value of F

Taking moments about point P

Clockwise moments = 5 x 5

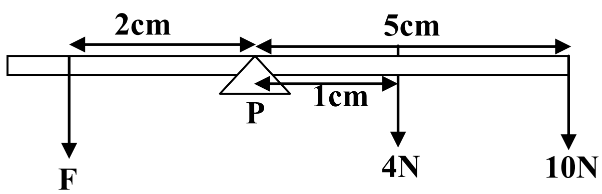
Anticlockwise moments = F x 2

At equilibrium clockwise moments = anticlockwise moments

25 = 2F

F = 12.5N

2.



If the above body is in equilibrium, calculate the value of F

Taking moments about point P

Clockwise moments = 10 x 5 + 4 x 1

Anticlockwise moments = F x 2

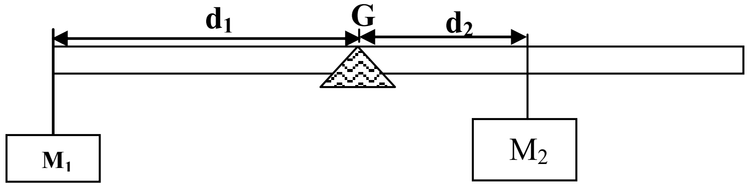
At equilibrium clockwise moments = anticlockwise moments

54 = 2F

F = 27N

Experiment to verify the principle of moments:

- Balance a metre rule horizontally on the knife edge and mark point, G where the metre rule balances horizontally and this is its centre of gravity.
- A mass M_1 is suspended at one end of the metre rule and is balanced with mass, M_2 at point from the other end of the metre rule as shown in the figure below.



- Length, d_1 of the mass, M_1 from knife edge is noted and the length, d_2 of the mass, M_2 from the knife is also noted.
- The experiment is repeated with different masses and different distances d_1 and d_2 are obtained and noted.
- Taking moments about the knife edge then clockwise moments = anticlockwise moments ($M_1gd_1 = M_2gd_2$).
- It is noted that clockwise moments are always equal to anticlockwise moments hence verifying the principle of moments.

CENTRE OF GRAVITY:

This is the point of application of the resultant force due to the earth's attraction on it. This is where the resultant force of gravity [mg] on the body is acting. Hence it is the point on the body where gravity seems to act **OR** it is a point on the body where its mass/weight is concentrated.

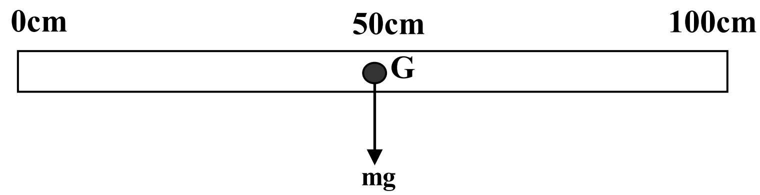
Finding the centre of gravity:

a) Regular object

The mass/weight of a regular object is evenly distributed and therefore its centre of gravity is at its centre [middle].

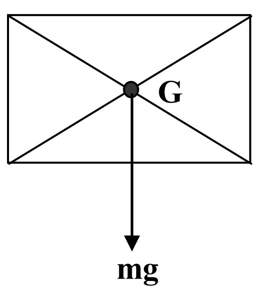
i) Uniform metre rule

Its centre of gravity, G is at 50cm mark



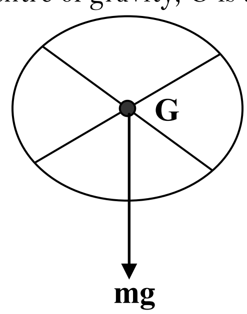
ii) Square

Its centre of gravity, G is in the middle

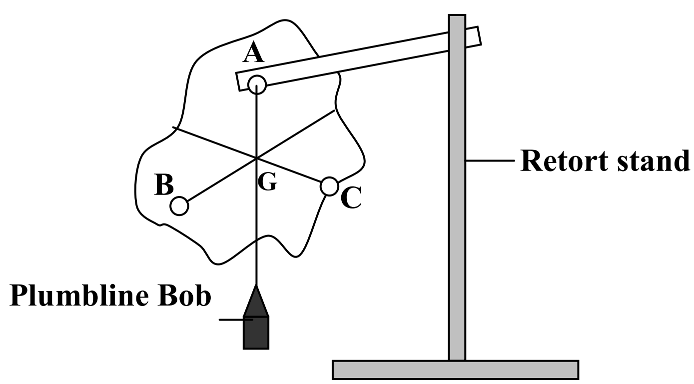


iii) Circle

Its centre of gravity, G is at its centre



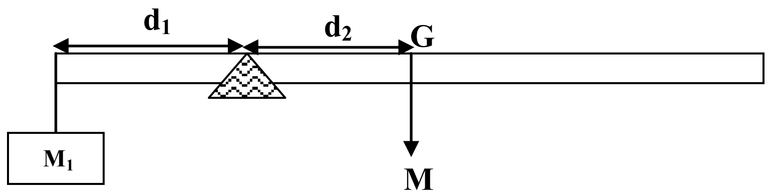
b) Irregular object:



- To determine center of gravity of irregular object three holes A, B and C are made on an irregular object in different corners.
- The object and plumbline bob are made to swing through hole A and when swinging stops a line is marked along the string on the object
- The experiment is repeated with holes B and C and where the three lines meet is the Centre of gravity, G of the object.

Experiment to measure the mass of a uniform body by moments:

- Balance a metre rule horizontally on the knife edge and mark a point, G where the metre rule balances which is the centre of gravity of the metre rule.
- A mass M_1 is suspended at one end of the metre rule and the metre rule is balanced again at point as shown in the figure below.
- Length, d_1 of the mass, M_1 from the knife edge is noted and length, d_2 of the centre of gravity, G from the knife edge is also noted.



- Taking moments about Q then

  Sum of clockwise moments = sum of anticlockwise moments

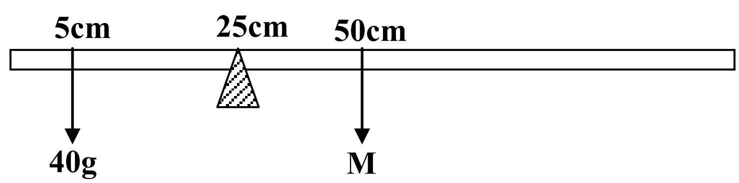
  $$M \times d_2 = M_1 \times d_1$$

  $$M = \frac{M_1 \times d_1}{d_2}$$

- Hence mass M of the metre rule can be calculated

Examples:

1. A uniform metre rule is pivoted at 25cm mark and balances horizontally when a body of mass 40g is hung at 5cm mark. Calculate the mass of the metre rule



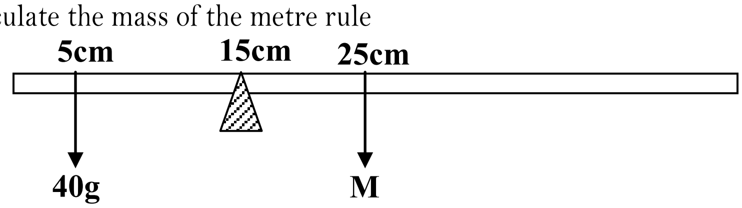
Taking moments about point P

Clockwise moments = anticlockwise moments

$$M \times 25 = 40 \times 20$$

$$M = 32g$$

2. A uniform half metre rule is pivoted at 15cm mark and balances horizontally when a body of mass 30g is hung at 3cm mark. Calculate the mass of the metre rule



Taking moments about point P

Clockwise moments = $M \times 10$

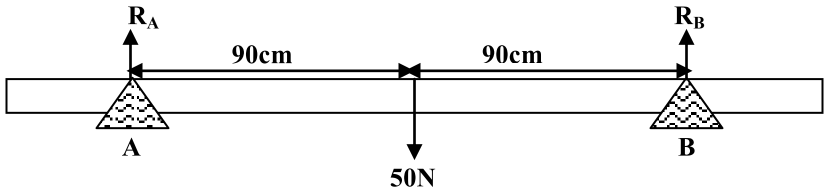
Anticlockwise moments = 40×12

At equilibrium clockwise moments = anticlockwise moments

$$10M = 480$$

$$M = 48g$$

3. Two laborers A and B carry a uniform pole of weight 50N. If the pole is 2m long. Find the reactions at A and B. Given that each labourer is 10cm from each end



Sum Upward forces = sum down ward forces

$R_A + R_B = 50$ ....[1]

Taking moments about A

$R_B \times 180 = 50 \times 90$

$= 25N$

From [1] $R_A = 50 - 25$

$= 25N$

EQUILIBRIUM AND STABILITY:

The body is said to be in equilibrium if forces act on it and the body does not move. Therefore the resultant force on the body is zero. Hence the body is in a state of stability.

Conditions for a body in equilibrium:

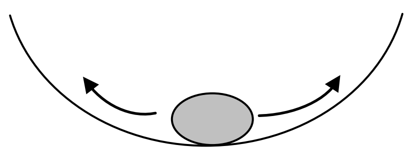
i) the sum of the forces in one direction is equal to the sum of the forces in opposite direction
ii) the sum of clockwise moments about any point is equal to the sum of anti-clockwise moments about the same point

TYPES OF EQUILIBRIUM:

There are three states of equilibrium;

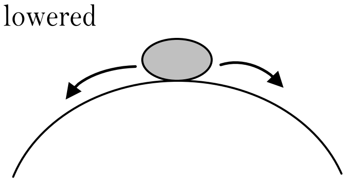
1. Stable equilibrium:

When a body is slightly displaced and then released, the body returns to its original position and its centre of gravity of the body is raised.



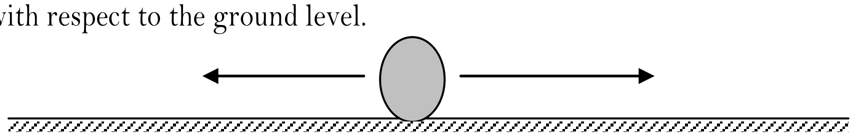
2. Un-stable equilibrium:

When a body is slightly displaced and then released, the body moves farther away from its original position and its centre of gravity of the body is lowered



3. Neutral equilibrium:

When a body is slightly displaced and then released, the body moves but the centre of gravity of the body does not change with respect to the ground level.



The stability of the body can be increased by;

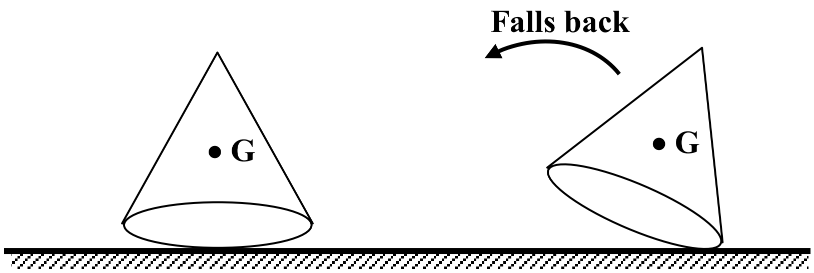
i) Lowering its centre of gravity

ii) Increasing the area of the base of the body

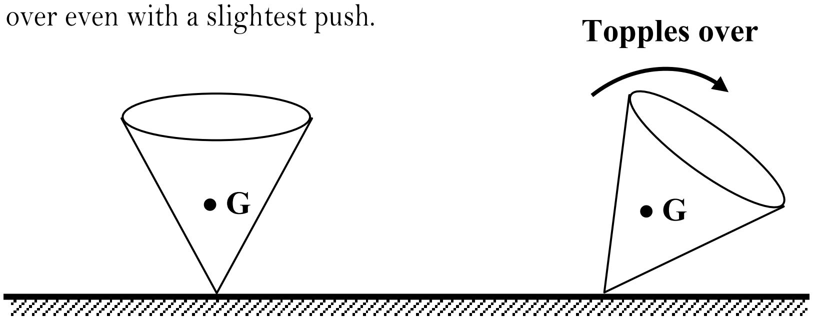
This explains why a bus carrying luggage on its roof racket wobbles more than a bus when its luggage is below its seats.

NOTE:

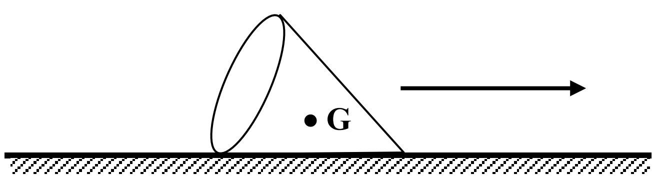
A cone standing on its base is said to be in stable equilibrium because when the cone is tilted from its position through a small angle, the vertical line through its centre of gravity will still fall within its base and therefore the force of gravity pulls back the cone to its initial position as shown below



A cone standing on its tip is said to be in unstable equilibrium because when the cone is given a slight push, the cone topples over even with a slightest push.



A cone lying on its one side is said to be in neutral equilibrium because when the cone is pushed so that it rolls on the bench, its centre of gravity remains at the same level and the line through it continues to pass through the same point in the base and the cone remains at equilibrium at its new position.



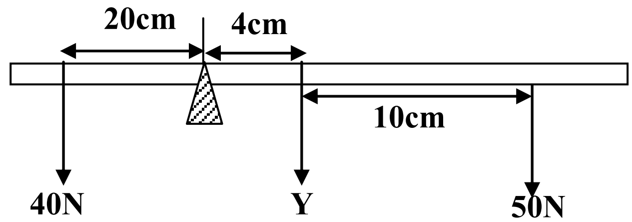
Comparison of states of equilibrium

Stable Equilibrium	**Un-stable Equilibrium**	**Neutral Equilibrium**
• Wide base • Low centre of gravity • When pushed centre of gravity is raised from the base • When pushed slightly it falls back to its initial position	• Narrow base • High centre of gravity • When pushed the centre of gravity is lowered. • When pushed slightly it falls	• Base is a straight line • Cenetre of gravity at its lowest point • When pushed the centre of gravity remains at the same level • When pushed it remains at rest in its new position

Trial Exercise 11:

Where necessary use acceleration due to gravity, g = 10ms^{-2}.

1. A metre rule of mass 120g is pivoted at the 60cm mark. At what point, on the metre rule should a mass of 50g be suspended for the rule to balance horizontally.
   Ans: 84cm mark
2. Given that the system below is in equilibrium. Calculate the value of Y



   Ans: 25N
3. A uniform metre rule of mass 150g is pivoted freely at the 0cm mark. What force, applied vertically upwards at the 60cm mark, is needed to maintain the rule horizontally?
   Ans: 1.25N
4. A uniform half metre rule is pivoted at 15cm mark and balances horizontally when a body of mass 70g is hung at 3cm mark. Calculate the mass of the metre rule
   Ans: 24g
5. A man weighing 80kg walks along a uniform plank resting on two supports 1m from each end. Plank is 10m long and weighs 50kg. Find the force on each support when the man is at one end of the plank
   Ans: 1150N, 150N
6. A uniform bridge AB, 30m long weighing 2×10^5N rests on supports at each end. Find the forces on the supports when a car of weight 1×10^4N is 4m from A and a lorry of weight 1×10^5N is 10m from B.
   Ans: 1.42 x10^{5}N, 1.68x 10^{5}N
7. A uniform log of wood AB is 9m long and weighs 320N. It is supported horizontally at two points P and Q. P is 3m from end A while Q is 2m from end B. Calculate the reactions at points P and Q
   Ans: 200N, 120N
8. A uniform metal rod of length 80cm and mass 3.2kg is supported horizontally by two vertical spring balances at C and D. Balance C is 20cm from one end while balance D is 30cm from the other end. Find the reading on each balance
   Ans: 10.7N, 21.3N
9. A uniform metal rod of length 5m is suspended horizontally from two vertical strings P and Q. String P is attached at 0.8m from one end while Q is attached at 2m from the other end. Given that the weight of the metal rod is 110N, calculate the tension in each of the strings.
   Ans: 25N, 85N
10. A uniform rod AB of length 5cm is suspended at 2cm from end A. If the mass of the rod is 10kg, calculate the mass of the body which must be suspended at 1cm from end A so as for the rod to balance horizontally and tension in the string.
   Ans: 30kg, 400N

Multiple-choice Exercise:

1. 60J of useful work is done by a machine when 75J of energy is supplied, what is the efficiency of the machine

A. 60% B. 75% C. 80% D. 125%

2. Find the velocity ratio of an inclined plane of length 12m if the height from the ground is 3m

A. 6 B. 4 C. 3 D. 2

3. A single movable pulley has an efficiency of 85%. What load can be raised by an effort of 400N?

A. 340N B. 480N C. 680N D. 800N

4. The efficiency of a machine is

A. the ratio of useful work done by the machine to the total work put into the machine

B. the ratio of velocity ratio to mechanical advantage

C. ratio of work input to work out put

D. ratio of distance moved by the load to distance moved by the effort in the same time

5. A uniform metre rule is pivoted at its mid-point,. 0.6N weight is suspended from one end. How far from the other end must a 1N weight be suspended for the metre rule to balance?

A. 20cm B. 25cm C. 40cm D. 80cm

6. A plank AB 5m long weighs 68kg and its Centre of gravity is 2m from A. It rests on two bars one 0.5m from A, the other 0.6m from B. Find the reaction at the bar near A

A. 180N B. 240N C. 300N D. 480N

7. An object in unstable equilibrium continues to fall when slightly displaced because its

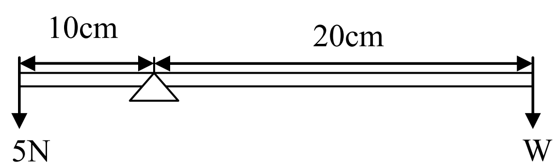
i) Centre gravity is lowered ii) centre of gravity is raised

iii) Potential energy is reduced iv) potential energy is increased

A. (iv) only correct B. (i), (ii) and (iii) correct

C. (ii) and (iv) correct D. (i) and (iii) correct

8.



Two weights are balanced on a rod of negligible mass. What is W

A. 2.5N B. 10.0N C. 30.0N D. 40.0N

9. A bus carrying a heavy load on its rack is more un-stable when moving because

A. its centre of gravity is raised B. the friction on the ground is increased

C. its total weight is increased D. the pressure on the tyres is increased

10. This consists of simple machines only.

A. Lever, hydraulic press, gears, wedge. B. Lever, wheel and axel, generator.

C. Gears, screw, wedge, generator. D. Gears, pulley, screw, motor.

11. An object in stable equilibrium comes back to its original point when slightly displaced and released because its

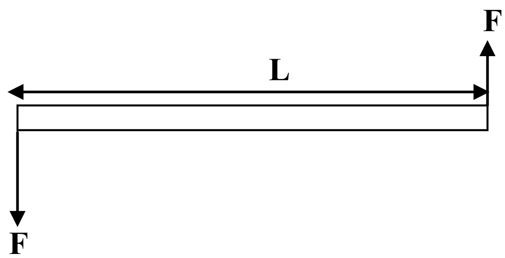
i) Centre gravity is lowered ii) centre of gravity is raised

iii) Potential energy is reduced iv) potential energy is increased

A. (iv) only correct B. (i), (ii) and (iii) correct

C. (ii) and (iv) correct D. (i) and (iii) correct

12. Which of the following statements are true about two equal forces F acting on of length, L as shown below?



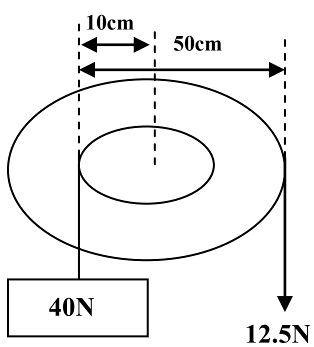
i) The bar is in equilibrium
ii) The forces cause a rotational effect
iii) The forces produce different turning effects

A. (i) only correct B. (i), (ii) and (iii) correct
C. (i) and (ii) correct D. (i) and (iii) correct

13. A machine consisting of a wheel of radius 15cm and axel of radius 2.5cm is used to lift a load of mass 6kg with an effort of 20N. The efficiency of the machine is

A. 75% B. 50% C. 80% D. 60%

14. The diagram below shows the forces acting on a wheel and axle



The efficiency of the machine is

A. 20% B. 80% C. 100% D. 125%

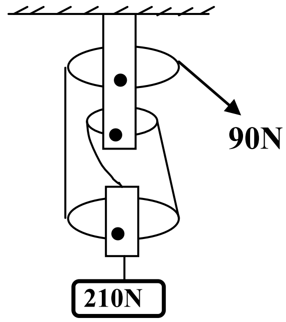
15. The turning effect of a force depends upon
A. centre of gravity and the moment of the force.
B. the force and the perpendicular distance from the force to the fulcrum.
C. the force and the centre of gravity that the force acts on.
D. the fulcrum and the force.

16. How can the mechanical advantage of a wedge be increased?
A. make it thicker B. make it longer
C. make it shorter D. make it out of steel

17. A pulley that is 80.0% efficient and has mechanical advantage of 4.0 does 560J of work in lifting a bale of papers. How much work did the worker do pulling out the rope from the pulley to raise the bale?

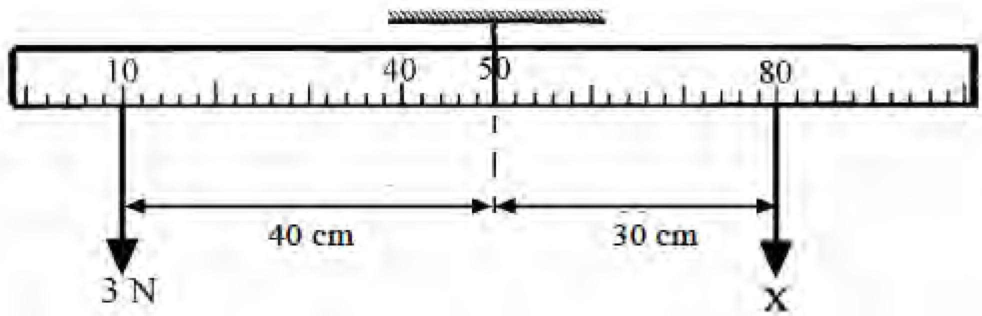
A. 140J B. 448J C. 700J D. 2240J

18. Calculate the efficiency of the pulley system shown in the figure below, if the minimum effort needed to raise a load of 210N is 90N.



A: $\frac{90}{210\times 3\times 100}$ B: $\frac{90\times 3}{210\times 100}$ C: $\frac{210\times 3\times 100}{90}$ D: $\frac{210\times 100}{90\times 3}$

19. A uniform metre-stick, suspended at its mid-point is balanced as shown.



What is the force X?

A. 4 N B. 1.5 N C. 10 N D. 0.375 N

20. Machines increase the amount of work done on them by

A. increasing the effort exerted on them B. increasing the power exerted on them

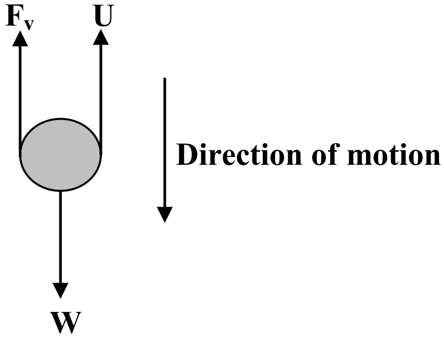
C. reducing friction acting on the machine D. not increasing the work done on them

Answers:

1	C	5	A	9	A	13	B	17	C
2	B	6	D	10	A	14	B	18	D
3	C	7	D	11	C	15	B	19	A
4	A	8	A	12	C	16	B	20	C

MOTION OF A BODY IN FLUIDS:

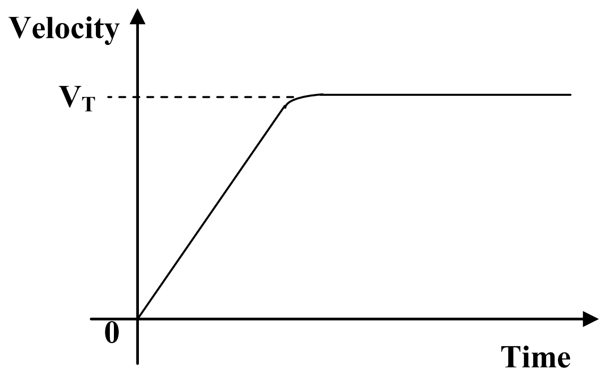
When a body falls vertically through a fluid it will be acted on by the following forces as shown in the diagrm below;



U – Up-thrust acting upwards
W – Weight acting down wards
F_v – Viscous drag acting upwards

The body accelerates uniformly until it attains a uniform velocity called terminal velocity when the weight of the body balances with the viscous drag and up-thrust that is $U + F_v = W$.

The graph of velocity against time for a body falling in a fluid is as shown below;



V_T – Terminal velocity.

DEFINITIONS:

- **Terminal velocity:**

The constant velocity attained by the body falling in a fluid when the resultant force on the body is zero.

- **The viscous drag:**

This is the force that opposes motion of a body in a fluid.

- **Up-thrust:**

This is the upward force acting on a body immersed in a fluid.

FLUID FLOW:

There are two types of fluid flow and these are;

i) Streamline flow.
ii) Turbulent flow.

Streamline flow:

This is the type of fluid flow where the fluid flows slowly and at uniform velocity

Turbulent flow:

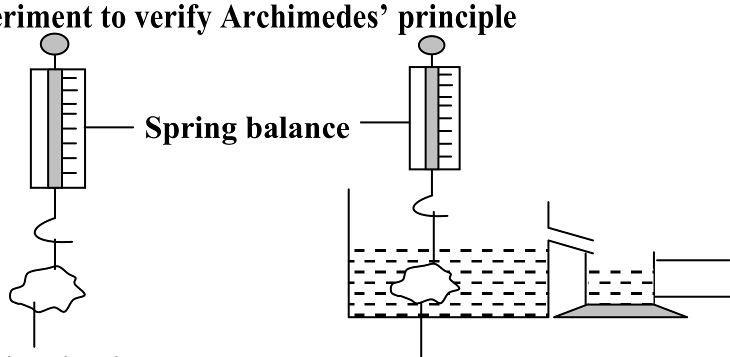
This is the type of fluid flow where the fluid flows fast and at different speeds

ARCHIMEDES' PRINCIPLE:

It states that when a body is wholly or partially immersed in a fluid it experiences an up-thrust equal to the weight of the fluid displaced. When a body is totally or partially immersed in a fluid it appears to weigh less because it experiences an up-thrust from the fluid.

Up-thrust = weight of the fluid displaced

Experiment to verify Archimedes' principle



- Weigh the object in air using a spring balance and record its weight, W_a.
- Weigh the object when completely immersed in water using a spring balance and record its weight, W_w.
- Weigh the displaced water in the beaker using a spring balance and record its weight, W.
- It is noted that the weight of displaced water, $W = W_a - W_w$.
- Up-thrust is equal to apparent loss in weight, $U = W_a - W_w$.
- This shows that up-thrust is equal to the weight of water displaced hence Archimedes' principle.

Note:

Up-thrust = weight of the liquid displaced

$= m_l g$

$= \rho_l V_l g$

Where ρ_l is density of the liquid displaced and V_l is volume of the liquid displaced.

Examples

1. A glass block weighs 25N. When completely immersed in water the glass block appears to weigh 10N. Calculate

i) Up-thrust on the block

ii) Volume of the water displaced

i) Up-thrust = apparent loss in weight

$= W_a - W_w$

$= 25 - 10$

$= 15N$

ii) Weight of water displaced = up-thrust

$= 15N$

$Mg = 15$

$\rho V g = 15$

$1000 \times V \times 10 = 15$

$V = 1.5 \times 10^{-3} m^3$

2. An object weighs 20N in air and 15N when completely immersed in water. Calculate

i) Up-thrust on the object

ii) Volume of the object

iii) Density of the object

i) Up-thrust = apparent loss in weight

$= W_a - W_w$

$= 20 - 15 = 5N$

ii) Volume of the object = volume of the water displaced

Weight of water displaced = up-thrust

$= 5N$

$Mg = 5$

$\rho Vg = 5$

$1000 \times V \times 10 = 5$

$V = 5 \times 10^{-4}\,m^3$

Volume of the object $= 5 \times 10^{-4} m^3$

iii) Density of the object $= \frac{mass}{Volume}$

$= \frac{2}{5 \times 10^{-4}}$

$= 4000kgm^{-3}$

3. A solid of volume $800cm^3$ is totally immersed in oil of density $0.8gcm^{-3}$. Calculate the

i) Mass of oil displaced

ii) up-thrust on the solid.

i) Mass $= \rho \times v$

v = volume of a solid since it completely immersed

$= 0.8 \times 800$

$= 640g$

Up-thrust = weight of oil displaced

$= m_o g$

$= 0.64 \times 10$

$= 6.4N$

Measuring density of a solid using Archimedes' principle:

- Measure the solid in air and record its weight, W_a.
- Measure the solid when completely immersed in water and record its weight, W_w.
- Relative density of a solid $= \frac{\text{weight of solid}}{\text{weight of unequal volume of water}}$

$$= \frac{W_a}{W_a - W_w}$$

$$R.D = \frac{\rho_s}{\rho_w} = \frac{W_a}{W_a - W_w}$$

$$\text{Density of a solid, } \rho_s = \frac{W_a}{W_a - W_w} \times \rho_w$$

Measuring density of a liquid using Archimedes' principle:

- Measure the solid in air and record its weight, W_a.
- Measure the solid when completely immersed in water and record its weight, W_w.
- Measure the solid when completely immersed in a liquid and record its weight W_l.
- Relative density of a liquid $= \frac{\text{weight of liquid}}{\text{weight of unequal volume of water}}$

$$= \frac{W_a - W_l}{W_a - W_w}$$

$$R.D = \frac{\rho_l}{\rho_w} = \frac{W_a - W_l}{W_a - W_w}$$

$$\text{Density of a liquid } \rho_l = \frac{W_a - W_l}{W_a - W_w} \times \rho_w$$

Where ρ_w is the density of water.

Examples:

1. A solid weighs 24N in air and 16N when completely immersed in water. Calculate

i) The relative density of a solid

ii) Density of a solid

Solution:

i) Relative density of a solid $= \frac{\text{weight of solid}}{\text{Weight of unequal volume of water}}$

$$= \frac{W_a}{W_a - W_w}$$

$$= \frac{24}{24 - 16}$$

$$= \frac{24}{8}$$

$$= 3$$

ii) R. D $= \frac{\rho_s}{\rho_w}$

$$3 = \frac{\rho_s}{1000}$$

$$\rho_s = 3000\text{kgm}^{-3}$$

2. A metal weighs 25N in air. When completely immersed in a liquid it weighs 15N and it weighs 20N when completely immersed in water. Calculate

i) The relative density of the liquid

ii) The density of the liquid

SOLUTION:

i) Relative density of a liquid $= \frac{\text{weight of a liquid}}{\text{Weight of unequal volume of water}}$

$$= \frac{W_a - W_l}{W_a - W_w}$$

$$= \frac{25 - 15}{25 - 20} = 2$$

ii) R. D $= \frac{\rho_l}{\rho_w}$

$2 = \frac{\rho_s}{1000}$

$\rho_s = 2000kgm^{-3}$

Application of Archimedes' Principle:

1. Submarine:

A submarine has a large ballast tank, which is used to control its position and depth from the surface of the sea. A submarine submerges by letting water into the ballast tank so that its weight becomes greater than the up-thrust on it. Otherwise, it floats by reducing water in the ballast tank.-thus its weight is less than the up-thrust.

2. Hot Air balloon:

The atmosphere is filled with air that exerts up-thrust force on any object. A balloon rises and floats when the up-thrust force is greater than its weight. It descends when the balloon's weight is higher than the up-thrust force. It becomes stationary when the weight equals the up-thrust force.

3. Hydrometer:

A hydrometer is an instrument to measure the relative density of liquids. It consists of a tube with a bulb at one end. Lead shots are placed in the bulb to weigh it down and enable the hydrometer to float vertically in the liquid. In a liquid of less density, a greater volume of liquid must be displaced for the up-thrust force to be equal to the weight of the hydrometer so it sinks lower. Hydrometer floats higher in a liquid of higher density.

4. Ship:

A ship floats on the surface of the sea because the volume of water displaced by the ship is enough to have a weight equal to the weight of the ship. A ship is constructed in a way so that the shape is hollow, to make the overall density of the ship less than the density of water. Therefore, the up-thrust force acting on the ship is large enough to support its weight. The **plimso-line** marked on the body of the ship acts as a guideline to ensure that the ship is loaded within the safety limit. A ship submerges lower in fresh water as fresh water density is less dense than sea water. Ships will float higher in cold water as cold water has a relatively higher density than warm water.

5. Fishes:

Certain group of fishes uses Archimedes' principles to go up and down the water. To go up to the surface, the fishes will fill its swim bladder (air sacs) with gases. The gases diffuse from its own body to the bladder and thus making its body lighter. This enables the fishes to go up. To go down, the fishes will empty their bladder, this increases its density and therefore the fish will sink.

FLOATATION:

When a body is placed on fluid it sinks if its weight is greater than the up-thrust and it floats if the up-thrust is equal to its weight, however when a cork is held below the surface of liquid it rises on release because the up-thrust on the cork is greater than its weight. A body sinks if its density is greater than the density of the fluid and it floats if its density is less than the density of the fluid

The law of floatation:

It states that a floating body displaces its own weight of the fluid on which it floats.

$$
\begin{aligned}
\text{Weight of the body} &= \text{weight of the displaced fluid}\\
W_b &= W_l\\
M_b g &= M_l g\\
M_b &= M_l\\
\rho_b V_b &= \rho_l V_l
\end{aligned}
$$

Where ρ_l is density of the liquid displaced, V_l is volume of the liquid displaced, ρ_b is density of the body and V_b is volume of the body.

Examples:

1. A piece of wood of density $2.5gcm^{-3}$ and volume $100cm^3$ floats on liquid of density $4gcm^{-3}$. Calculate the volume of wood immersed in the liquid.

$$
\begin{aligned}
\text{Volume immersed} &= \text{volume of the liquid displaced}\\
\text{Weight of the body} &= \text{weight of the liquid displaced}\\
M_w g &= M_l g\\
\rho_w V_w &= \rho_l V_l\\
2.5 \times 100 &= 4 \times V_l\\
V_l &= 62.5cm^3
\end{aligned}
$$

2. A piece of cork of density $0.15gcm^{-3}$ and volume $200cm^3$ floats on water of density $1gcm^{-3}$. Calculate the volume of wood out of water

$$
\begin{aligned}
\text{Volume immersed} &= \text{volume of the liquid displaced}\\
\text{Weight of the body} &= \text{weight of the liquid displaced}\\
M_w g &= M_l g\\
\rho_w V_w &= \rho_l V_l\\
0.15 \times 200 &= 1 \times V_l\\
V_l &= 30cm^3\\
\text{Volume immersed} &= 30cm^3\\
\text{Volume out of water} &= 200 - 30\\
&= 170cm^3
\end{aligned}
$$

Experiment to verify the law of floatation:

- A measuring cylinder is half filled with water and the reading, V_1 is noted.
- A test tube with cotton loop attached is then placed in the cylinder.
- Lead shots are then added to the test tube little at a time until the test tube floats vertically.
- The reading V_2 of the measuring cylinder is noted and the difference $V_2 - V_1$ is calculated which is the volume of water displaced by the test tube.
- The mass of water displaced is equal to its volume since the density of water is $1gcm^{-3}$.
- The test is than removed from the cylinder dried and then weighed.
- The experiment is repeated adding extra lead shot each time and the results are tabulated.
- It is noted from the table that the weight of the test tube with lead shots is equal to the weight of water displaced, hence verifying the law of floatation.

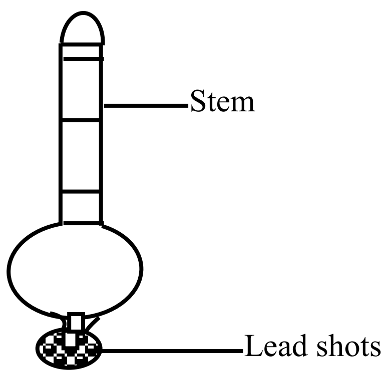
Applications of floatation:

1. Balloons:
A balloon filled with hydrogen rises in air because the density of hydrogen is less than the density of air, hence the weight of air displaced is greater than the weight of the balloon and therefore the resultant upward force acts on the balloon and moves it upwards. Similarly when a cork is held below water and then released it rises because of the same reason.

2. Ships:
A ship floats when the up-thrust on the ship is equal to the weight of water displaced. While a ship being loaded sinks lower and displaces more water to balance the extra load. The loading lines called plimso marks on the sides show the level to which the ship can be safely loaded. Steel will not float on water because it is denser than water, however a ship made of steel floats because it is made hollow and contains air so that the average density of the ship is less than that of water.

3. Submarines:
Submarines consist of ballast tanks which are used to vary its average density. When the ballast tanks are filled with air the average density of the submarine is slightly less than that of water and the submarine floats and when the tanks are filled with water the average density of the submarine is slightly greater that the density of water and the submarine sinks, hence the submarine stays at one depth or rises to the surface.

4. Hydrometer:
This is a device used to determine the density of liquids in which it floats. Lead shots are placed beneath the float to keep the hydrometer upright and the stem graduated to read the relative density of the liquid. The higher the hydrometer float the higher the relative density of the liquid.



Applications of a hydrometer:
To determine the degree of purity of milk
To determine the level of charge of batteries
To determine the level of sugar in some drinks
To determine the alcoholic content of drinks

Qn. A simple hydrometer is made by attaching 1cm^3 of metal of density 1200kgm^{-3} to the end of a wooden rod 25cm long and 4cm^2 cross sectional area.

i) When the hydrometer is floated in water, 10cm of the rod remains above the surface of water. What is the density of wood?

i) When the hydrometer is floated in another liquid, 14cm of the rod remains above the surface of liquid. What is the density of liquid?

i) When the hydrometer is floated in liquid of density 1.5gcm^3, how much of the stem will be submerged.

Solution:

i) Volume of the stem immersed $= (Al + 1)\ cm^3$

$= 4(25 - 10) + 1$

$= 61cm^3$

Weight of water displaced $= mg$

$= \rho vg$

$= \frac{61 \times 1}{1000} \times 10$

$= 0.61N$

Weight of wood $= mg$

$= \rho vg$

$= \frac{\rho \times 4 \times 25}{1000} \times 10$

$= \rho$

Weight of metal $= mg$

$= \rho vg$

$= \frac{1 \times 1.2}{1000} \times 10$

$= 0.012N$

Weight of water = weight of wood + weight of the metal

$0.61 = \rho + 0.012$

$\rho = 0.598gcm^{-3}$

ii) Volume of the stem immersed $= (Al + 1)\ cm^3$

$= 4(25 - 14) + 1$

$= 45cm^3$

Weight of liquid displaced $= mg$

$= \rho vg$

$= \frac{45 \times \rho}{1000} \times 10$

$= 0.45\rho N$

Weight of wood $= mg$

$= \rho vg$

$= \frac{0.598 \times 4 \times 25}{1000} \times 10$

$= 0.598N$

Weight of metal $= mg$

$= \rho vg$

$= \frac{1 \times 1.2}{1000} \times 10$

$= 0.012N$

Weight of liquid = weight of wood + weight of the metal

$0.45\rho = 0.598 + 0.012$

$0.45\rho = 0.61$

$\rho = 1.36gcm^{-3}$

iii) Volume of the stem immersed = (Al + 1)

= 4h + 1

$= (4h + 1)\ cm^3$

Weight of liquid displaced = mg

= ρvg

$= \frac{(4h+1) \times 1.5}{1000} \times 10$

$= 0.015(4h + 1)N$

Weight of wood = mg

= ρvg

$= \frac{0.598 \times 4 \times 25}{1000} \times 10$

$= 0.598N$

Weight of metal = mg

= ρvg

$= \frac{1 \times 1.2}{1000} \times 10$

$= 0.012N$

Weight of liquid = weight of wood + weight of the metal

$0.015(4h + 1) = 0.598 + 0.012$

$0.015(4h + 1) = 0.61$

$15(4h + 1) = 610$

$60h + 15 = 610$

$60h = 595$

$h = 9.92cm$

Trial Exercise 12:

Where necessary assume the following;

Acceleration due to gravity, g = $10ms^{-2}$

Density of water, ρ = $1000kgm^{-3}$

1. A body weighs 100N in air and 80N when submerged in water. Calculate the up-thrust acting on the body.
   Ans: 20N
2. A body weighs 50N in air and 30N when fully immersed in water. Calculate the mass of water displaced
   Ans: 2kg
3. Apiece of metal of density $2500kgm^{-3}$ weighs 1N in air. Find the weight of the metal when completely immersed in water
   Ans: 0.6N
4. A piece of wood of volume $240cm^3$ floats with three-quarters of its volume under water. Calculate the density of wood
   Ans: $750kgm^{-3}$
5. A solid of mass 0.024kg and density $1.2 \times 10^4 kgm^{-3}$ placed in a cylinder containing oil to a level of $51cm^3$. Find the reading of the oil level
   Ans: $53cm^3$
6. A piece of wood of density $5gcm^{-3}$ and volume $200cm^3$ floats on liquid of density $8gcm^{-3}$. Calculate the volume of wood immersed in the liquid.
   Ans: $125cm^3$
7. An object weighs 55N in air. When completely immersed in a liquid it weighs 25N and it weighs 30N when completely immersed in water. Calculate
   i) The relative density of the liquid and the density of the liquid in kgm^{-3}
   ii) Weight of the body in oil of density $800kgm^{-3}$
   Ans: i) 1.2, $1200kgm^{-3}$ ii) 35N
8. A solid weighs 24N in air and 16N when completely immersed in water. Calculate
   i) The relative density and density of a solid
   ii) Volume of the solid
   Ans: i) 3, $3000kgm^{-3}$ ii) $8 \times 10^{-4}m^3$
9. A string supports a solid block of mass 1kg and density $9{,}000kgm^{-3}$ which is completely immersed in water. Calculate the tension in the string.
   Ans: 8.89N
10. An alloy of silver and gold whose densities are $10.5gcm^{-3}$ and $18.9gcm^{-3}$ respectively weighs 35.20g in air and 33.13g in water. If there has been no volume change in the process of processing the alloy, find the composition by mass of the alloy.
    Ans: 29.97g, 5.23g

Multiple-choice Exercise:

1. A body displaces 50cm^3 of water. What is the up-thrust on the body?
   A. 50N B. 5N C. 0.5N D. 0.005N
2. A piece of metal weighs 1N in air and 0.6N in water. What will it weigh in alcohol of relative density 0.8?
   A. 1.20N B. 0.80N C. 0.68N D. 0.48N
3. The principle of floatation states that
   A. a floating body displaces its own mass of the fluid
   B. a floating body displaces its own volume of the fluid
   C. a floating body displaces its own weight of the fluid
   D. a floating body has no weight
4. A block of metal, mass 80g and volume 10cm^3 is suspended from a spring balance and completely immersed in water. What is the reading of the spring balance?
   A. 0.7N B. 0.6N C. 0.5N D. 0.1N
5. A body weighs 100N in air, appears to weigh 50N in a liquid and 70N in water. What is the density of the liquid in gcm^{-3}?
   A. 0.6 B. 1.2 C. 1.7 D. 3.3
6. A hot air balloon is made from very light material. It displaces 360 kg of air and contains 300m^3 of hydrogen of density 0.3 kgm^{-3}. The maximum load the balloon can lift is:
   A. 90 kg B. 270 kg C. 450 kg D. 360 kg.
7. The up thrust on a body partially or wholly immersed in a fluid is equal to the;
   A. Mass of the fluid displaced B. Weight of the fluid displaced
   C. Volume of the fluid displaced D. Density of the fluid displaced
8. A needle floats on the surface of water because of
   A. adhesion B. Surface tension C. Viscosity. D. Capillary attraction.
9. Which of the following is true about a floating body?
   A. it displaces its own volume of the fluid on which it floats
   B. it displaces its own weight of the fluid on which it floats
   C. its density equals that of the fluid on which it floats
   D. the apparent loss in weight on it is zero
10. A body weighs 100N in air, and 60N in water. What is the density of the body in gcm^{-3}?
    A. 0.6 B. 1.2 C. 1.7 D. 2.5
11. The factors affecting up-thrust force on a body are
    A. The volume of the submerged body and the density of the liquid.
    B. The mass of the submerged body and the density of the liquid.
    C. The weight of the submerged body and the density of the liquid.
    D. The area of the submerged body and the density of the liquid.
12. The meaning of the up-thrust force is
    A. the force on an object placed in a fluid
    B. the downward force acting on an object placed in a fluid
    C. the upward force acting on an object placed in a fluid
    D. the force of gravity acting on an object placed in a fluid

13. Archimedes Principle states

A. when a body is partially or wholly immersed in a fluid, it experiences an up-thrust equal to the mass of the fluid displaced.

B. when a body is partially or wholly immersed in a fluid, it experiences an up-thrust equal to the weight of the fluid displaced.

C. when a body is immersed in a fluid, it experiences an up-thrust equal to the weight of the fluid displaced.

D. when a body is partially or wholly immersed in a fluid, it experiences an up-thrust equal to the volume of the fluid displaced.

14. A body weighs 120N in air, and 80N in water. What is the density of the body in kgm^{-3}?

A. 667 B. 1500 C. 2000 D. 3000

15. Why does a mug full of water weigh less inside water?

A. The up-thrust force exerted is responsible for the apparent loss of weight.

B. The weight of the water in the mug is responsible for the apparent loss of weight.

C. The density of water is responsible for the apparent loss of weight.

D. The weight of the mug the water is responsible for the apparent loss of weight.

16. A body weighs 100N in air, appears to weigh 60N in a liquid and 80N in water. What is the density of the liquid in kgm^{-3}?

A. 500 B. 750 C. 1250 D. 2000

17. Any fluid applies an up-thrust force to an object that is partially or completely immersed in it, and the magnitude of the up-thrust force equals the weight of the fluid that the object displaces." This statement is known as

A. Bernoulli's Principle. B. Archimedes' Principle.

C. Pascal's Principle. D. Principle of Superposition.

18. Bernoulli's Principle is a statement of

A. Energy conservation in dynamic fluids.

B. Momentum conservation in dynamic fluids.

C. Hydrostatic equilibrium.

D. Thermal equilibrium in fluids.

19. A body completely immersed in water displaces $50cm^3$ of water. What is the mass of the body if its density is $2.5gcm^{-3}$?

A. 125.0g B. 52.5g C. 20.0g D. 50.0g

20. A body completely immersed in water displaces $40cm^3$ of water. What is the mass of water displaced?

A. 40000.0g B. 40.0g C. 25.0g D. 2.5g

Answers:

1	C	5	C	9	B	13	B	17	B
2	C	6	B	10	D	14	D	18	A
3	C	7	B	11	A	15	A	19	A
4	A	8	B	12	C	16	D	20	B

MISCELLANEOUS EXERCISE 1:

1. a) Define pressure and state its SI units

b) A column of mercury is 700mm high and area of its base is $2cm^2$. Find

i) The pressure it exerts

ii) The force it exerts on the base

Ans: i) 95,200Pa   ii) 19.04N

c) i) State Archimedes' principle

ii) A piece of glass weighs 0.5N in the air and 0.3N in water and 0.32N in benzene. Find the densities of glass and benzene

Ans: $2500kgm^{-3}$, $900kgm^{-3}$

d) A piece of wax of density $550kgm^{-3}$ floats in oil of density $900kgm^{-3}$. If the volume of the wax is $45cm^3$, what volume of oil is displaced?

Ans: $27.5cm^3$

2. a) Define the terms

i) Velocity ratio   ii) Efficiency

b) A pulley system is used to raise a load of 200N through a distance of 7m when an effort of 50N is applied through a distance of 32m. Find

i) The mechanical advantage   ii) The efficiency of the system

Ans: i) 4   ii) 87.5%

c) A uniform beam 4m long and of mass 10kg is placed horizontally and symmetrically on two supports 2.6m apart.

i) Draw a diagram showing the forces acting on the beam

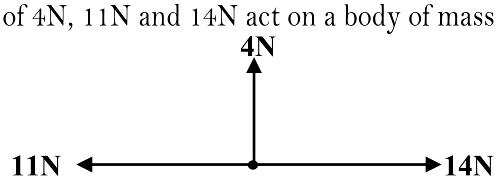
ii) Calculate the reaction on each of the supports

Ans: 50N, 50N.

3. a) What is meant by terms scalar and vector quantities. Give two examples of each

b) i) State the conditions under which a body is said to be in mechanical equilibrium

ii) Forces of 4N, 11N and 14N act on a body of mass 10kg initially at P.



Find the magnitude of the acceleration with which the body moves

Ans: $0.5ms^{-2}$

iii) State two differences between mass and weight of the body

c) What is meant by the terms?

i) Kinetic energy

ii) Potential energy

d) One end of a spring, S is fixed at a point P and the end fixed on the block of mass 1kg which lies on a smooth horizontal plane. The block is pulled to stretch S through an extension of 20cm. If S has a force constant of $100Nm^{-1}$.

i) What is the potential energy stored in S when stretched

ii) With what velocity will the block move when it is first released?

Ans: i) 2J   ii) $2ms^{-1}$

4. a) Define the following terms

i) Joule ii) Power

b) Water pump can raise $0.2m^3$ of water in 20 seconds. Calculate the power of the pump if the water is raised through a height of 25m.

Ans: 2500W

c) i) State Hooke's law

ii) Describe an experiment to verify Hooke's law

d) i) State the factors on which friction in solids depend

ii) State any two reasons why friction should be increased in some cases

5. a) Define work

b) A boy of mass 60kg runs up a flight of 28 steps, each 25cm high in 4.2 seconds. Calculate the power developed by the boy

Ans: 1000W

c) A machine having a velocity ratio of 4 requires 3000J of energy to lift a load of 600N through a perpendicular distance of 2.5m. Calculate

i) The efficiency of a machine

ii) The mechanical advantage

Ans: i) 50% ii) 2

d) Water is pumped from a stream at a rate of 90kg every 30 seconds and sprayed on a lawn from a nozzle at a velocity of $15ms^{-1}$. Calculate

i) The reaction on the nozzle

ii) The power of the pump

Ans: i) 450N ii) 6750W

6. a) What is meant by mechanical advantage and power of a machine

b) Describe an experiment to investigate how the efficiency of a block and tackle pulley system varies with the load it is used to lift. What result would you expect from your experiment?

c) A block and tackle pulley system with a velocity ratio of 5 and 60% efficiency is used to a lift a load of mass 60kg through a vertical height of 2m.

i) What effort must be exerted?

ii) How much work is done in lifting the load?

iii) How much work is done by the effort?

iv) How much energy is wasted? Give reasons

Ans: i) 200N ii) 1200J iii) 2000J iv) 800J

7. a) Define acceleration

b) An object starts from rest and is uniformly accelerated so that its velocity is $20ms^{-1}$ after 20s. It travels at this velocity for 60s and is then brought to rest by a uniform retardation in 10s. Sketch a velocity-time graph and use it to determine

i) Acceleration ii) Retardation iii) The total distance travelled

Ans: i) $1ms^{-2}$ ii) $2ms^{-2}$ iii) 1500m

c) An object of mass 200g moving at $800ms^{-1}$ hits a movable target of mass 12.3kg which is at rest. The target and the object move together after the impact. Find the combined velocity after the impact.

Ans: $12.8ms^{-1}$

8. a) Define the terms

i) Velocity

ii) Acceleration

b) A man with mass of 70kg moves up a stair case in 32 seconds. If there are 20 stairs in all and each is 15cm high, calculate

i) The work done by the man

ii) The power expended by the man

Ans: i) 2100J **ii) 65.625W**

c) A body is fired horizontally with a speed of $20ms^{-1}$ from a cliff 400m above the ground. Calculate

i) The time taken for the body to hit the ground

ii) The horizontal distance travelled

Ans: 8.94s **ii) 178.8m**

9. a) Define the following terms

i) Moment of a force

ii) Centre of gravity

b) With the aid of a labeled diagram, describe an experiment to locate the centre of gravity of an irregular lamina

c) Two labourers A and B are carrying a uniform log of mass 150kg and length 6m on their shoulders, labourer A is at the extreme end and labourer B is 1m from the other end

i) Draw a diagram to show the forces acting on the log

ii) What fraction of the weight of the log is supported by labourer B?

Ans: $\frac{3}{5}$

d) Explain why a bus heavily loaded on its roof rack wobbles more than a coach bus similarly loaded below its seats

10. a) i) Define a vector quantity

ii) Sketch a velocity-time graph for a body moving with uniform acceleration

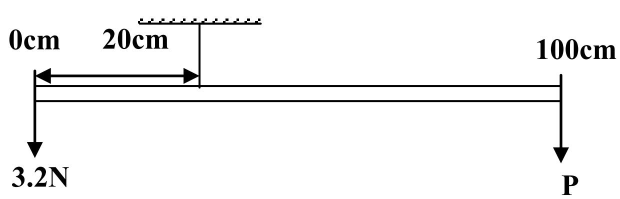
b) i) Write down the equations of motion

ii) A cyclist moving with a constant speed of $10ms^{-1}$ accelerates uniformly at a rate of $2.5ms^{-2}$ for 4 seconds. Calculate the distance travelled during this time

Ans: 60m

c) Describe an experiment to investigate how the efficiency of a block and tackle pulley system varies with the load it is used to lift. What result would you expect from your experiment?

d) A uniform metre rule weighing 1.2N is balanced as shown below.



Find the value of P and the tension in the string holding it

Ans: 0.35N, 4.75N

11. a) i) State Archimedes' principle

ii) Describe an experiment to verify Archimedes' principle

b) A cube of wood of volume $0.2m^3$ and a density of $600kgm^{-3}$ is floated in a liquid of density $800kgm^{-3}$

i) What fraction of volume of the wood would be immersed in a liquid?

ii) What force must be exerted on the cube to make its top surface be at the same level as the liquid surface?

Ans: i) $\frac{3}{4}$ ii) 400N

c) A piece of marble of weight 14N and relative density of 2.8, supported by a light string from a spring balance, is gently lowered in a vessel containing water. If it is fully immersed, what will be the reading of the spring balance?

Ans: 9N

12. a) i) Define capillarity

ii) State any two applications of capillarity

b) Describe an experiment to demonstrate existence of surface tension

c) Explain why a sharpened knife cuts easily

d) A column of mercury is 90cm high and area of its base is $4cm^2$. Find

i) The pressure it exerts

ii) The force it exerts on the base

Ans: i) 122,400Pa ii) 48.96N

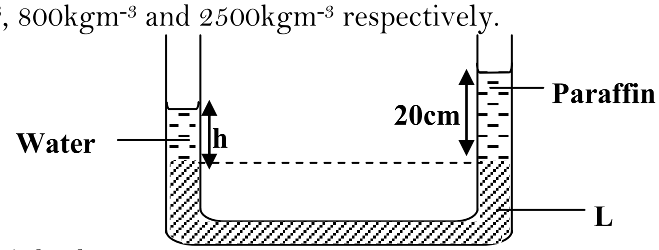
e) A small spherical metallic ball was dropped in oil contained in a vessel. Draw a diagram to show the forces acting on the ball

13. a) Define pressure and give its SI units

b) Explain why it is harder to walk on a soft ground with narrow-heeled shoes than wide-heeled boots

c) Describe an experiment to demonstrate that pressure due to a liquid increases with depth

d) The figure below shows a U-tube containing three liquids water, paraffin and L with densities $1000kgm^{-3}$, $800kgm^{-3}$ and $2500kgm^{-3}$ respectively.



Find the height, h

Ans: 16cm

e) i) State two factors on which the pressure of a liquid depends

ii) Explain why cooking at a high altitude takes longer time than at a lower altitude

14. a) State the differences between mass and weight of the body

b) A man of mass 80kg stands in a stationary lift on earth. Calculate his apparent weight when the lift

i) Accelerates upwards at a rate of $2ms^{-2}$

ii) Falls freely under gravity

Ans: i) 960N ii) 0N

c) A body is fired horizontally with a speed of $30ms^{-1}$ from a cliff 500m above the ground. Calculate

i) The time taken for the body to hit the ground

ii) The horizontal distance travelled

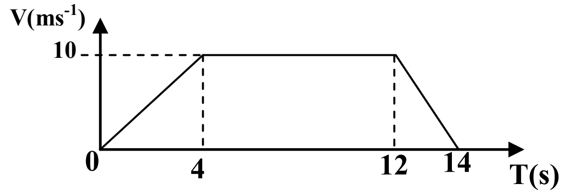
Ans: i) 10s **ii) 300m**

15. a) Define the following terms

i) Displacement

ii) Velocity

b) The diagram shows a velocity-time graph for a particle moving between points A and B



i) Describe the motion of the particle between points A and B

ii) Find the acceleration and retardation of the particle

iii) Find the distance covered during the journey

Ans: ii) 2.5ms^{-2}, 2ms^{-2} **ii) 110m**

c) i) State the law of conservation of linear momentum

ii) A ball A of mass 40g moving with a speed of 5ms^{-1} collides directly with another ball B of mass 30g moving at 2ms^{-1}in opposite direction. Find the speed of the particles after collision if they stick together

Ans: 2ms^{-1}

16. a) i) Define pressure and state its SI units

ii) Describe an experiment to show that the pressure in a liquid increases with depth in the liquid

iii) Find the length of the mercury column in a simple barometer when the barometer is raised from the sea level to a height of 2.5km. Given that the average density of air is 1.2kgm^{-3} and atmospheric pressure at sea level is 76cm of mercury

b) A spring balance reads 2.43N when a metal cube of side 3cm is suspended in air from the spring balance.

i) Find the density of the metal

ii) What will the spring balance read when the metal is completely immersed in a liquid of density of 1200kgm^{-3}?

Ans: i) 9gcm^{-3} **ii) 2.106N**

17. a) i) What is meant by a ductile material

ii) What properties would you look for when selecting a material for overhead cables?

b) i) State the advantage of glass as a construction material

ii) Explain briefly how concrete may be improved so as to withstand tensional forces

c) i) Explain how a plank of wood with cracks on one side may be placed to form a single bridge across a stream

ii) In the construction of bridges or large structures, hollow cubes of strong metals are used instead of solid ones. What advantages do such structures have?

18. a) State Newton's laws of motion

b) A water jet directed to the spot on the ground digs a hole in the ground after some time. Explain

c) A moving ball P of mass 100g collides with a stationary ball Q of mass 200g. After collision P moves backwards with a velocity of 2ms^{-1} while Q moves forward with a velocity of 5ms^{-1}. Calculate

i) The initial velocity of P

ii) The force exerted by P on Q if the collision took 0.004 seconds

Ans: i) 8ms^{-1} ii) -250N

d) Explain the principle of operation of a rocket engine

19. a) i) Define pressure

ii) State any two laws of liquid pressure

b) Explain why a person who has fainted should be left to lie down with his feet raised above the head

c) i) Define the term density

ii) Describe how you would determine the density of glass in form granular form using a density bottle

iii) State one precaution one would take when carrying out the experiment in (b) (ii) above and why

d) In an experiment to determine relative density of a substance, the following measurements were taken

- Mass of an empty density bottle and stopper = 75g
- Mass of density bottle with some glass particles in = 80g
- Mass of density bottle with glass particles topped up with water = 115g
- Mass of density bottle full of water alone = 160g

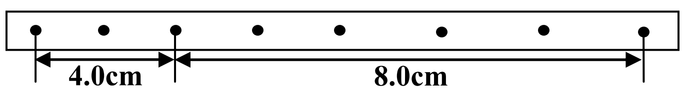
Calculate the relative density of glass substance

Ans: 0.1

20. a) i) Distinguish between centripetal force and centrifugal force

ii) State two applications of centrifugal force in daily life situation

b) The figure below shows dots made on a ticker tape pulled by a trolley through a ticker timer



Describe the motion of the trolley if the frequency is 50Hz

Ans: - 2.86ms^{-2}

c) Explain why the base of a bus is heavily weighted and a large area

d) What do you understand by the following?

i) The velocity ratio of a machine is 3

ii) The relative density of a substance is 2

e) The handle of the screw-jack is 35cm long and the pitch of the screw is 0.5cm. What force must be applied at the end of the handle when lifting a load of 2200N if the efficiency of the jack is 40%?

Ans: 12.5N

L I G H T

Light is a form of energy which is responsible for the sense of sight. Light belongs to a family of electromagnetic waves. Electromagnetic waves do not need a material medium for their transmission hence light can travel through a vacuum and the speed of light in a vacuum is $3 \times 10^8 ms^{-1}$.

SOURCES OF LIGHT:

An object is only seen if light reflected from the object enters our eyes. Most of the objects do not make their own light but reflect light from other sources to our eyes. The following are sources of light;

1. Luminous objects:

These are objects which produce their own light. Examples are the sun, stars, glow worms, electric bulbs etc.

2. Non-luminous objects:

These are objects which do not produce their own light. Examples are the moon, the earth etc.

3. Incandescent objects:

These are luminous objects which give off light when hot. Examples are fire wood, candle, electric lamps etc.

4. Fluorescent objects:

These are luminous objects that produce light without being hot. Examples are glow worms, stars etc.

5. Phosphorescent objects:

These are objects that absorb the incident energy falling on them and emit energy in form of light later. Example is calcium sulphide.

NOTE: A body seen in light of other luminous bodies is referred to as an illuminated body.

TRANSMISSION OF LIGHT:

Light travels from its source to another point through a vacuum or a medium. There are three media through which light travels and these are;

Transparent medium:

This is the type of medium which allows almost all the light to pass through it and objects are seen clearly. Examples are glass, pure or distilled water, paraffin etc.

Translucent medium:

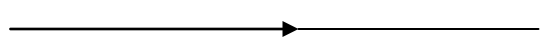
This is the type of medium which allows some of the light to pass through it and objects are not seen clearly. Examples are frosted glass, oily paper, cloudy liquids etc.

Opaque medium:

This is the type of medium which doesn't allow light to pass through it at all and objects are not seen. Examples are walls, wood, stones etc.

RAYS AND BEAMS:

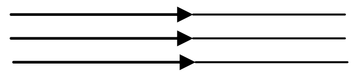
A ray of light is the direction or the path along which light travels. A ray of light is represented by a straight line with an arrow showing the direction in which light is traveling.



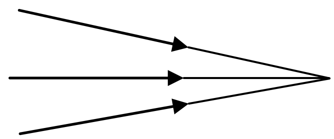
A collection of rays is called **a beam**. There are three types of beams and these are

a) Parallel beam.
b) Convergent beam.
c) Divergent beam

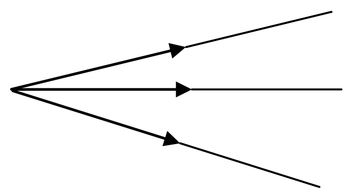
Parallel beam:
This is a collection of rays of light which do not meet or intersect



Convergent beam:
This is a collection of rays originating from different directions and meeting at one point.

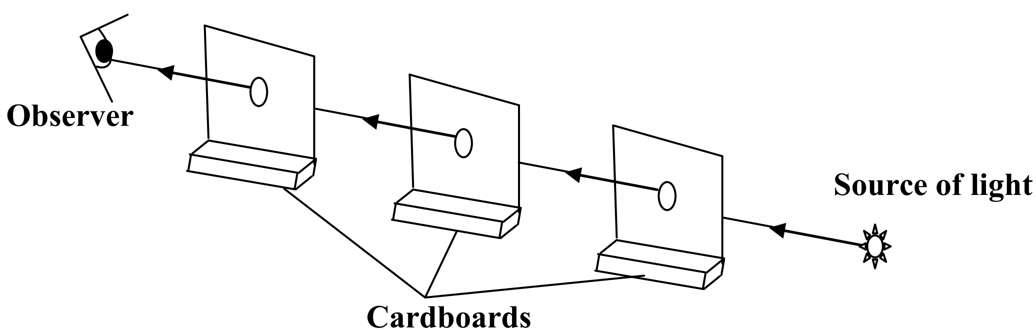


Divergent beam:
This is a collection of rays originating from one point and traveling in different directions



RECTILINEAR PROPAGATION OF LIGHT:
This is a process by which light travels in a straight line when produced from its source.

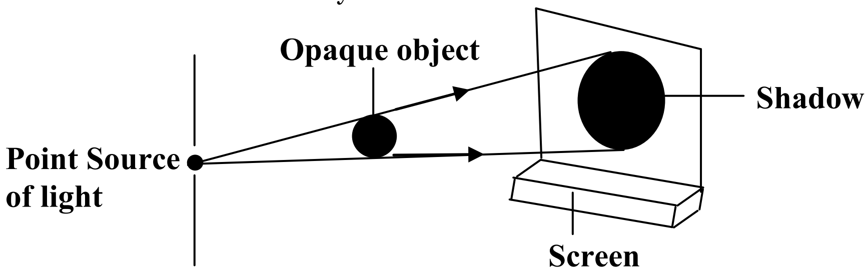
Experiment to show that light travels in a straight line:



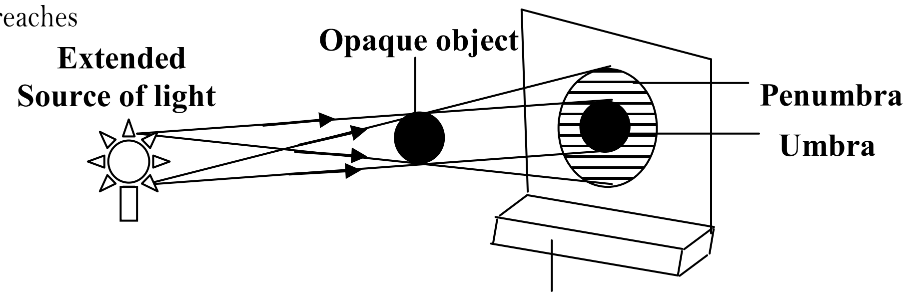
Three cardboards of the same dimensions with a hole at their centre are placed in a straight line as shown above. A source of light is then placed at one end and the observer on the other end. The observer sees light from the source but if one of the cardboards is displaced so that its hole is no longer in line with the other two holes, no light will be seen by the observer indicating that light has been cut off and therefore light travels in a straight line. Rectilinear propagation of light leads to formation of shadows and eclipses.

SHADOWS:
A shadow is an area where light cannot reach. Therefore a shadow is formed when an opaque object obstructs light because light travels in a straight line.

A shadow formed by a point source of light:
A point source of light can be obtained by placing a cardboard with a small hole in front of a lamp. When an opaque object is placed between the screen and the point source of light a sharp shadow is formed on the screen as shown below. The shadow is totally dark and total darkness is known as **Umbra.**

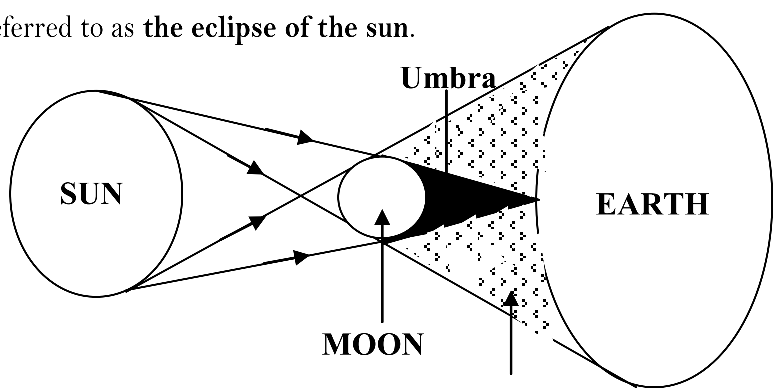


A shadow formed by an extended source of light:
When a cardboard is removed in front of the lamp, it becomes an extended source of light. Two regions of the shadow are formed when an extended source of light is used. These regions are Umbra and Penumbra
Umbra is a region of a shadow where no light reaches at all while **Penumbra** is a region of a shadow where some light reaches



ECLIPSES:
An eclipse occurs when the sun, the moon and the earth are in a straight line. There are two types of eclipses and these are;
i) Solar eclipse (eclipse of the sun)
ii) Lunar eclipse (eclipse of the moon)

Solar eclipse:
This occurs when the moon is between the sun and the earth so that both Umbra and Penumbra reach the Earth. This is because the moon revolves around the earth and the earth revolves around the sun. It is sometimes referred to as **the eclipse of the sun**.



In solar eclipse some areas on earth fall under the moon's shadow and two shadows are formed on earth that is umbra which is formed when the moon blocks the sun completely and the sun is not seen at all and penumbra which is formed when the moon blocks the sun partlyand part of the sun can be seen. Umbra covers a very small area compared to penumbra which covers a large area hence very many people on earth experience partial eclipse rather than total eclipse of the sun. In solar eclipse the area on earth covered by Umbra has total darkness and the sun cannot be seen at all while the area covered by Penumbra has partial darkness and part of the sun can be seen.

Types of solar eclipses:

a) **Partial solar eclipse**: This occurs when the moon and the sun do not come in the same straight line but the moon partly covers the sun hence the sun is visible from a large portion of the earth. In this type of eclipse the umbra of the moon completely misses and therefore no region on earth will experience total solar eclipse but only part of penumbra covers some regions on the earth.

b) **Total solar eclipse**: In this type of eclipse the moon looks as big as the sun hence covering the sun completely and this happens when the earth and the moon are closest to each other. Total solar eclipse is observed by only people in the umbra region.

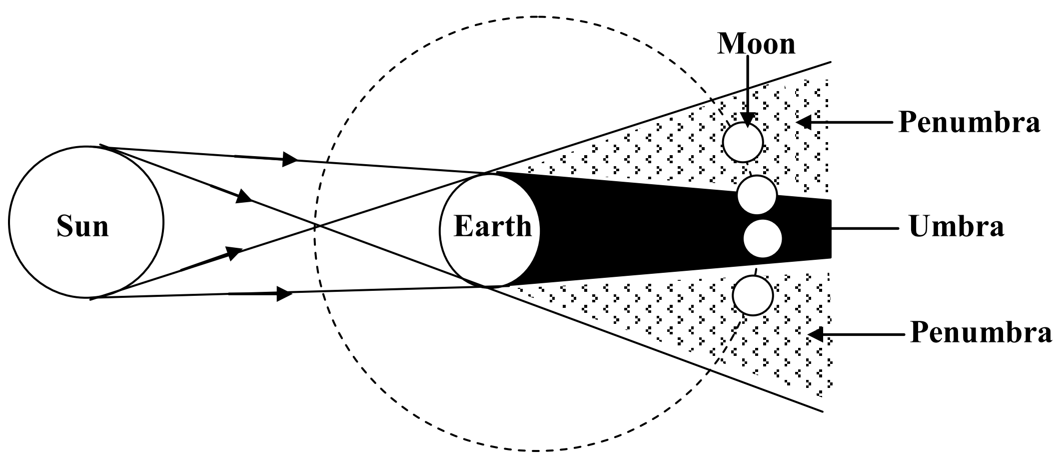
c) **Annular solar eclipse**: This occurs when the sun and the moon are positioned in one straight line but the moon does not completely cover the sun. In this case the moon appears smaller than the sun and a bright ring is visible in the sky. This happens when the earth is furthest from the moon so that the Umbra does not reach the earth but only Penumbra reaches the earth.

NOTE:

Total solar eclipse is a rare event that is on an average itwould repeat itself only once in 370 years. The duration of a total eclipse is really very short that it can not last for more than 7 minutes and 30 seconds. This is because the Moon's umbra is moving at a speed of about 1700kmh^{-1} across the Earth's surface. It is estimated that the longest solar eclipse will occur on July 16, 2186, and will last for a record 7 minutes and 29 seconds only. One of the longest solar eclipses of the 21st century occurred on July 22, 2013, lasting for 6 minutes and 39 seconds.

Lunar eclipse:

This occurs when the earth is between the sun and the moon. It is sometimes referred to as the eclipse of the moon.



In lunar eclipse the shadow of the earth is formed on the moon. Lunar eclipse happens when the moon passes through the earth's shadow. The earth always has a shadow created by the sun and this shadow is composed of two portions that is penumbra where some portion of sun's light rays are blocked and umbra where all the sun's light rays are blocked.

The eclipse of the moon lasts longer than the eclipse of the sun because the earth is larger than the moon in the eclipse of the sun.

Types of lunar eclipses

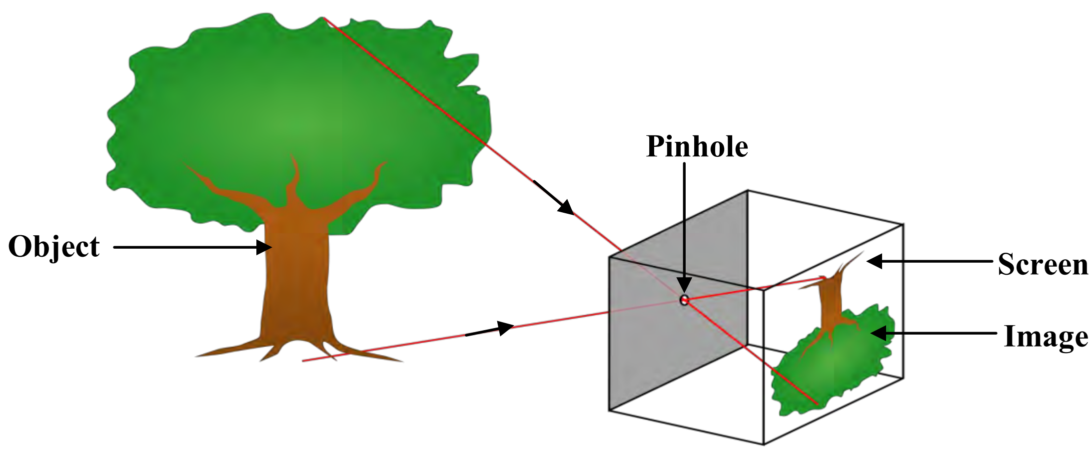
a) Partial lunar eclipse: This occurs when the portion of the moon passes through earth's umbra shadow, this event can easily be seen.

b) Total lunar eclipse: This occurs when entire moon passes through the earth's umbra shadow, during this event the colour of the moon changes and it takes about 90 minutes.

c) Penumbral lunar eclipse: This occurs when the moon passes through the earth's penumbra shadow, this event is quite difficult to observe because the moon,s light is dimmed but does not go dark since the penumbra show is not dark enough to block the sun's light rays. This is some times referred to as appulse eclipse.

PINHOLE CAMERA:

A **pinhole camera** is a simple camera without a lens and with a single small aperture (a pinhole) that is a light-proof box with a small hole in one side. It consists of a light tight box with a hole on one side and a screen on the opposite where the image is formed. Light from a scene passes through this single point and projects an inverted image on the opposite side of the box. When the object is placed in front of a pinhole camera, light rays from the object pass through the pinhole un-deviated and a real, diminished and inverted image is formed on the screen at the back of the pinhole camera.



A pinhole camera is completely dark on all the other sides of the box including the side where the point is created. This part is usually painted black, but black boxes are also used for this purpose. There is also a thin screen which looks like a projector sheet, and is put in between the dark side adjacent to the pinhole.

Effect on image formation in a pin-hole camera:

- When the object is moved closer to the pinhole camera the size of the image increases but becomes less bright because the same amount of light is now spread over a large area of the image.
- When the pinhole is enlarged the image becomes blurred (not clear) and more bright because a large hole will be the same as many pinholes put together each forming its image.
- When the distance between the pinhole and the screen is increased the size of the image increases and image becomes less bright because the same amount of light is now spread over a large area of the image.

MAGNIFICATION:

Magnification is the ratio of the size of the image to the size of the object **OR** it is the ratio of image distance to object distance

$$\text{Magnification} = \frac{\text{height of the image}}{\text{height of the object}}$$

$$\text{Magnification} = \frac{\text{distance of the image}}{\text{distance of the object}}$$

$$\text{Magnification} = \frac{h_1}{h_2} = \frac{v}{u}$$

Examples:

1. An object of height 4cm is placed 25cm from a pinhole camera. The screen is 7cm from the pinhole. Find
i) the magnification of the object
ii) the height of the image

$$\text{Magnification} = \frac{\text{image distance}}{\text{Object distance}} = \frac{7}{25} = 0.28$$

$$\text{Magnification} = \frac{\text{image height}}{\text{object height}}$$

$$0.28 = \frac{h_I}{4}$$

$$h_I = 1.12\text{cm}$$

2. An object 100cm away from a pinhole camera forms an image on the screen. Given that the size of the image is 0.03cm and the size of the object is 0.6cm. Calculate the distance of the screen from the pinhole

$$\text{Magnification} = \frac{h_I}{h_o} = \frac{v}{u}$$

$$\frac{0.03}{0.6} = \frac{v}{100}$$

$$v = 5\text{cm}$$

3. Calculate the height of a building 150cm away from a pinhole camera and produces an image 5cm high when the distance between the screen and the pinhole is 10cm

$$\text{Magnification} = \frac{h_I}{h_o} = \frac{v}{u}$$

$$\frac{5}{h_o} = \frac{10}{1500}$$

$$h_o = 7500\text{cm}$$

REFLECTION OF LIGHT:

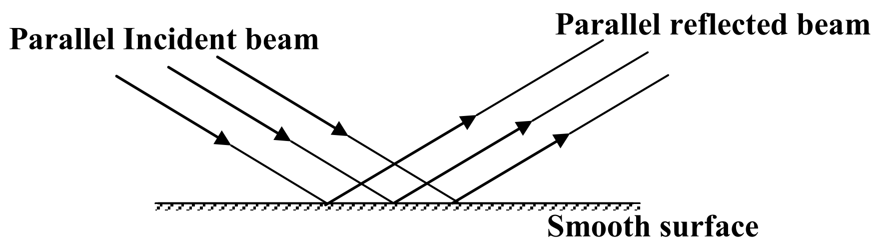
Reflection is a process by which light energy bounces off from the reflecting surface.

The way light is reflected depends on the nature of the surface. There are two types of reflection of light and these are

i) Regular (specular) reflection
ii) Irregular (diffuse) reflection

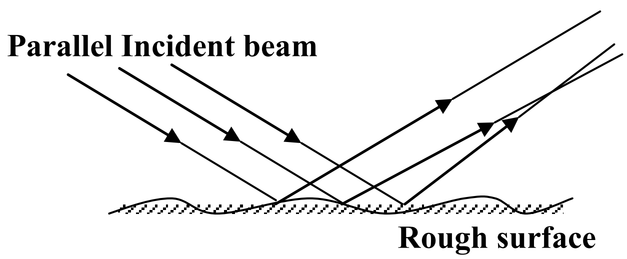
Regular (specular) reflection:

This is a type of reflection when a parallel beam is incident on a smooth surface is reflected as a parallel beam.



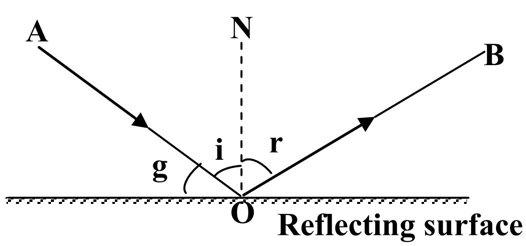
Irregular (diffuse) reflection:

This is a type of reflection when a parallel beam is incident on a rough surface is reflected in different directions.



TERMS USED:

Consider a ray of light AO incident on a smooth reflecting surface and is reflected along OB as shown in the diagram below.



1. Incident ray, AO

This is the ray of light from the light source falling onto the reflecting surface

2. Reflected ray, OB

This is the ray of light which bounces off from the reflecting surface

3. Normal, ON

This is a line at right angle to the reflecting surface

4. Angle of incidence, i

This is the angle between the incident ray and the normal

5. Angle of reflection, r

This is the angle between the reflected ray and the normal

6. Glancing angle, g

This is the angle between the incident ray and reflecting surface

LAWS OF REFLECTION:

First law:

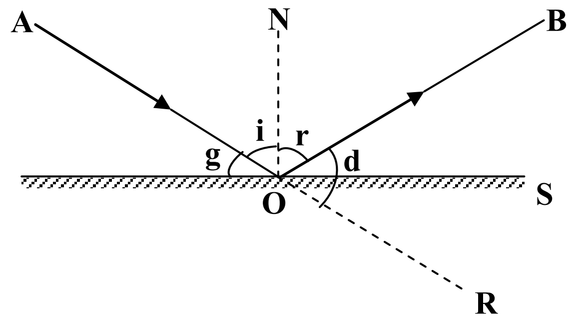
The incident ray, reflected ray and the normal at the point of incidence all lie in the same plane

Second law:

The angle of incidence is always equal to the angle of reflection (i = r)

Deviation and glancing angle:

Deviation is change of direction of the light ray as it strikes the reflecting surface



Angle of deviation, d:

This is the angle between the original direction of the ray and the reflected ray.

d = angle BOS + angle SOR

But angle BOS = g [since i = r]

Angle SOR = g [opposite angles]

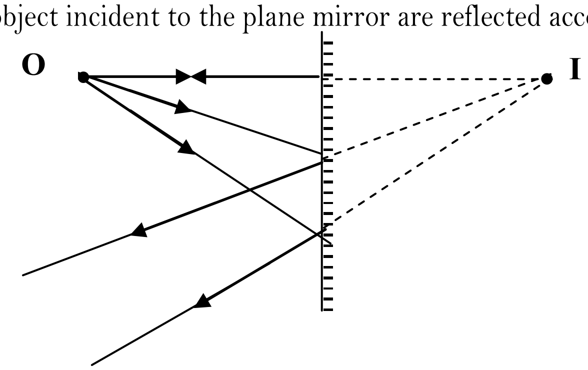
$\therefore$ d = g + g

= 2g

NOTE: The angle of deviation is therefore twice the glancing angle.

Image formed by plane mirror:

Light ray from an object incident to the plane mirror are reflected according to the laws of reflection



The reflected rays appear to come from the image I which is at the same distance behind the mirror as the object O in front of the mirror.

Characteristics of image formed by plane mirror

- The image is virtual (behind the mirror).
- The image is laterally inverted.
- The image is the same size as the object.
- The image is upright (erect).
- The image is the same distance behind the mirror as the object in front of the mirror.

LATERAL INVERSION:

This is the apparent reversal of the mirror image's left and right when compared with the object. Lateral simply means side ways. The image in a plane mirror is said to be laterally inverted because the image right and left are interchanged and this effect occurs whenever an image is formed by one reflection as shown below;

Upright	Inverted (vertical)	Laterally Inverted
image is right-side up	image is upside-down	image is flipped horizontally
MIRROR		

Images formed by two plane mirrors inclined to each other:

When two plane mirrors are inclined at an angle, θ with each other then the number of images formed is given by $\frac{360}{\theta} - 1$

Examples:

1. How many images are formed when two mirrors are inclined at 25° to each other, $\theta = 25°$

$= \frac{360}{25} - 1$

$= 14.4 - 1$

$= 13.4 \quad = 13$ images

2. How many images are formed when two mirrors are inclined at 60° to each other, $\theta = 60°$

$= \frac{360}{60} - 1$

$= 6 - 1 \quad = 5$ images

3. How many images are formed when two mirrors are inclined at 90° to each other, $\theta = 90°$

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

$= 4 - 1$

$= 3$ images

4. How many images are formed when two mirrors are inclined at 60° to each other, $\theta = 120°$

$= \frac{360}{120} - 1$

$= 3 - 1 \quad = 2$ images

5. How many images are formed when two mirrors are parallel to each other, $\theta = 0°$

$= \frac{360}{0} - 1$

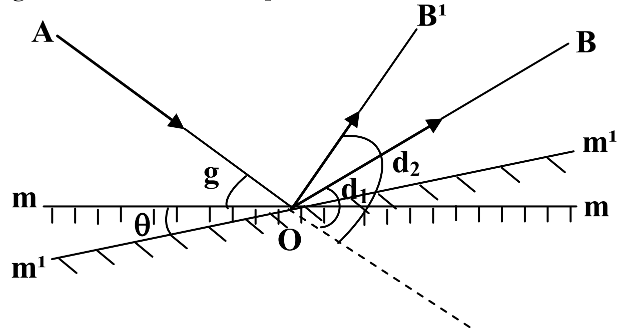
$= \infty$

There is infinite number of images

NOTE: When the angle increases the number of images decrease.

ROTATION OF THE REFLECTED RAY:

Consider a ray of light AO incident on a plane mirror mm as shown below;



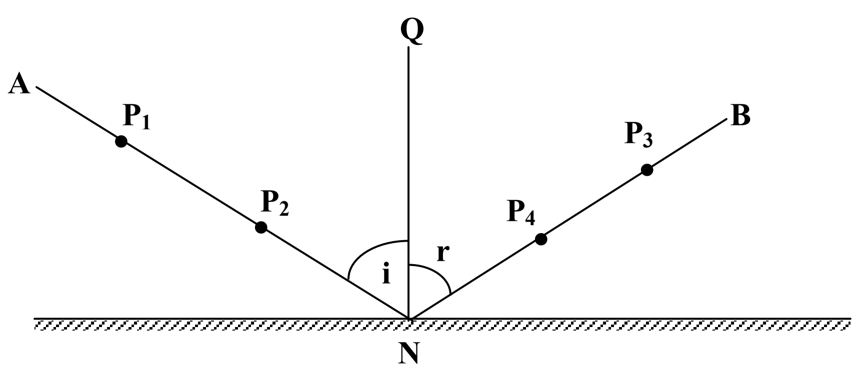
- If the ray of light AO is incident on plane mirror mm at glancing angle, g it is reflected along OB and its angle of deviation $d_1 = 2g$.
- When the mirror is rotated through angle θ to m¹m¹ keeping the incident ray in the same direction the glancing angle increases by θ and it is reflected along OB¹ and its angle of deviation, $d_2 = 2(g + \theta)$.
- The reflected ray rotates through angle B¹OB

$$= d_2 - d_1$$
$$= 2(g + \theta) - 2g$$
$$= 2\theta$$

- The reflected ray rotates through twice the angle of rotation of the mirror

Experiment to verify laws of reflection of light:

a) Fix a white sheet of paper on a soft board using drawing pins.
b) Draw a horizontal line and draw a normal QN to it.
c) Measure angle of incidence, i to the normal and draw the line to meet the line at N.
d) Place a plane mirror vertically along the line.
e) Fix two pins P_1 and P_2 vertically along line AN and locate the images using pins P_3 and P_4 so that they appaear in line with images of P_1 and P_2 as shown in the figure below.



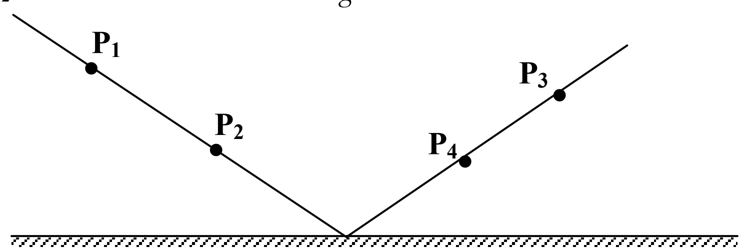
f) Remove the pins and draw line NB through P_3 and P_4 and measure angle, r.
g) Repeat procedure (c) and (f) for different values of i.
h) It is observed that i = r in each case and all the rays lie in the same plane with the normal at the point of incidence hence verifying the laws of reflection of light.

The law of reversibility of light:

It states that light will follow exactly the same path if its direction of travel is reversed.

Experiment to verify the law of reversibility of light:

i) Fix a white sheet of paper on a soft board using drawing pins.
j) Draw a horizontal line and place a plane mirror vertically along the line.
k) Fix two pins P_1 and P_2 vertically in front of the mirror.
l) Viewing from the left hand side fix two other pins P_3 and P_4 such that they appaera in line with images of P_1 and P_2 in the mirror as shown in figure.



m) Viewing from the right hand side images of pins P_3 and P_4 are seen to be in line with pins P_1 and P_2.
n) Therefeore light from the left hand side and light from the right hand side follow the same path.

Applications of plane mirrors:

a) Pointer instruments:

A plane mirror in the scale of the pointer instrument facilitates correct reading.

b) Optical lever:

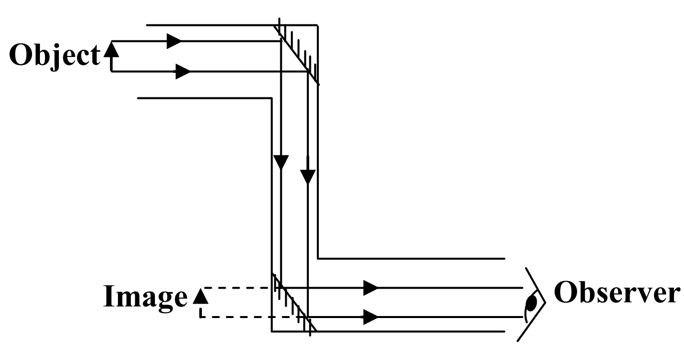
Plane mirrors are attached to the galvanometer so that light falling on the mirror is reflected over the scale as the galvanometer rotates.

c) Kaleidoscope:

A toy which produces beautiful patterns from colored paper, pieces of glass or small colored beads, inclined plane mirrors are used for producing different patterns of objects placed between them in Kaleidoscopes.

d) A periscope:

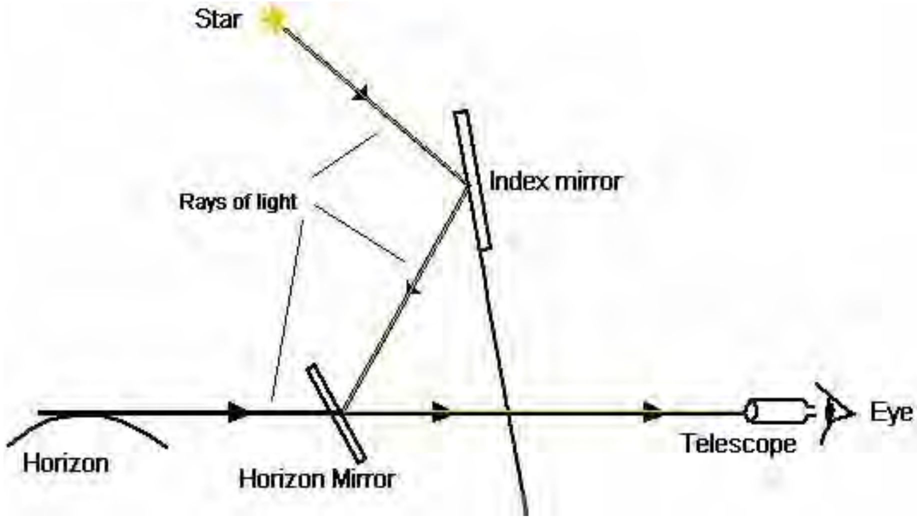
A **periscope** is an instrument for observation over, around or through an object, obstacle or condition that prevents direct line-of-sight observation from an observer's current position.
In its simplest form, it consists of an outer case with mirrors at each end set parallel to each other at a 45-degree angle. This form of periscope, with the addition of two simple lenses, served for observation purposes.



A periscope is used to observe distant objects. The arrangement of a periscope has two plane mirrors inclined at an angle of 45° so that light from the object is turned through 90° at each reflection.

e) Sextant:

The sextant relies on the optical principle that if a ray of light is reflected from two mirrors in succession then the angle between the first and last direction of the ray is twice the angle between the mirrors. To use the sextant the telescope must be focused on the horizon.



Trial Exercise 1:

1. The distance between the pin-hole and the screen of the pin-hole camera is 10cm. The height of the screen is 20cm. At what distance from the pin-hole must a man 1.6m tall stand if a full length image is required

   Ans: 80cm

2. An object of height 5m is placed 10m away from the pin-hole camera. Calculate the size of the image and the length of the pin-hole camera if the magnification is 0.01.

   Ans: 5cm, 10cm

3. The screen of a pin-hole camera is 20cm away from the pin-hole. A student of height 1.6m stands 8m from the pin-hole. Find the height the student's image

   Ans: 4cm

4. A girl stands 2m in front of a plane mirror. Calculate the distance between the girl and her image. If the mirror is moved 0.6m away from the girl, what will be the distance between the girl and her image?

   Ans: 4m, 5.2m

5. Two parallel plane mirrors are placed 30cm apart. An object placed between is 10cm from one mirror. Determine the image distance between the two nearest images formed by the two mirrors.

   Ans: 60cm

6. Two plane mirrors are inclined at an angle of 60^o to each other. A ray of light makes an angle of 40^o with the first mirror and goes on to strike second mirror. Find the angle of reflection on the second mirror and draw a ray diagram.

   Ans: 10^o

7. At what angle would the two mirrors be inclined to form 17 images and 19 images respectively?

   Ans: 20^o, 18^o

8. A pin-hole camera of length 15cm forms an image 3cm high of a man standing 9m in front of the camera. What is the height of the man?

Ans: 180cm.

9. How many images would be seen from two mirrors when reflecting surfaces make an angle of 60^o with each and the practical application of this arrangement?

Ans: 5 images

10. A man stands 300cm from a large wall-mirror. He then walks slowly towards the mirror at a speed of $20cms^{-1}$. What is the distance between the man and his image after 4 seconds?

Ans: 440cm

Multiple-choice Exercise:

1. A pin-hole camera forms an image of a distant objects which is
A. virtual, erect and magnified B. virtual, inverted and diminished
C. real, inverted and diminished D. real, inverted and magnified

2. An object 6cm high is placed 24cm from a tiny hole in a pin-hole camera. If the distance from the hole to the screen is 8cm, find the size of the image on the screen
A. 0.2cm B. 2.0cm C. 18.0cm D. 32.0cm

3. During the eclipse of the sun
A. the sun is between the earth and the moon
B. the earth is in between the sun and the moon
C. the moon is in between the sun and the earth
D. the earth casts the shadow on to the sun

4. Which of the following statements about eclipses is not correct?
A. during the eclipse of the sun, the shadow of the moon falls on the earth
B. during the eclipse of the moon, the earth is between the sun and the moon
C. during the eclipse of the sun the moon is between sun and the earth
D. during the eclipse of the moon, the shadow of the moon falls on the earth

5. The formation of eclipse of the sun can be explained by the fact that light
A. can travel through a vacuum B. can be reflected
C. travels in a straight line D. can be refracted

6. Annular eclipse takes place when
A. the sun is between the earth and the moon
B. the earth is near the moon in lunar eclipse
C. the moon is in between the sun and the earth
D. the earth is in between the sun and the moon

7. The sharpness of the image formed by a pin-hole camera depends on
A. the brightness of the object B. the shape of the pin-hole
C. the size of the object D. the size of the pin-hole

8. During the lunar eclipse
A. light from the sun is reflected by the moon
B. the earth lies between the sun and the moon
C. the moon lies between the earth and sun
D. the sun lies between the moon and the earth

9. The image of a distant object formed by a pin-hole camera is

i) Real ii) Diminished iii) Erect

A. (i), (ii) and (iii) correct B. (i) and (ii) only correct

C. (ii) and (iii) only correct D. (i) only correct

10. The brightness of the image formed by a pin-hole camera depends on

A. the size of the object B. the shape of the object

C. the size of the pin-hole D. the shape of the pin-hole

11. An object is placed 30cm in front of a plane mirror. If the mirror is moved a distance of 6cm towards the object, find the distance between the object and its image

A. 24cm B. 36cm C. 48cm D. 60cm

12. We are able to see objects because of

A. regular reflection B. light from object is reflected into our eyes

C. light travels in a straight line D. diffuse reflection

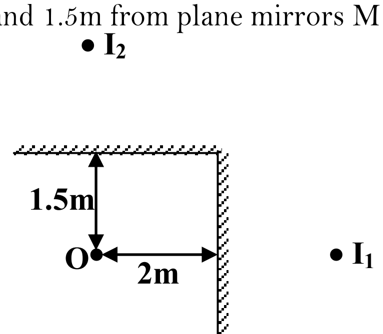
13. Two mirrors inclined at an angle of 60^o forms

A. 6 images B. 5 images C. 4 images D. 3 images

14. What is the number of images formed by plane mirrors inclined at 45^o to each other?

A. 8 B. 7 C. 6 D. 5

15. The images of an object O placed 2m and 1.5m from plane mirrors M_1 and M_2 respectively are I_1 and I_2 as shown below



Find the shortest distance between I_1 and I_2

A. 3.0m B. 3.5m C. 4.0m D. 5.0m

16. Which of the following is not true about the plane mirrors?

A. they form virtual image

B. they form images of the same size as their objects

C. the images formed are laterally inverted

D. the images are closer to the mirrors than the objects are

17. When reflection occurs in a plane mirror

i) The image is real, erect and magnified

ii) The angle of reflection is equal to the angle of incidence

iii) The incident and reflected rays lie in different planes

iv) The object distance and image distance are the same

A. (i), (ii) and (iii) only correct B. (i) and (iii) only correct

C. (ii) and (iv) only correct D. (iv) only correct

18. An object of height 2cm is placed at 16cm from pin-hole camera of the length 4cm. Find the size of the image formed

A. 2.00cm B. 4.00cm C. 0.50cm D. 0.25cm

19. Which of the following is true about the plane mirrors?
A. the images formed are laterally inverted
B. they form images of the different size as their objects
C. they form real image
D. the images are closer to the mirrors than the objects are

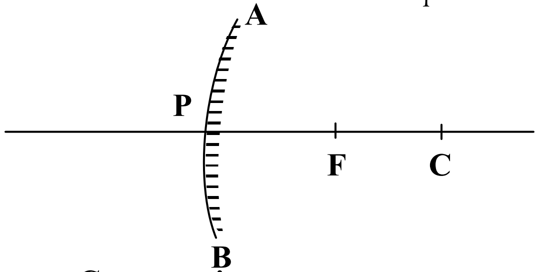
20. Calculate the angle of incline of two plane mirrors in order to produce 8 images
A. 40^o B. 45^o C. 51^o D. 60^o

Answers:

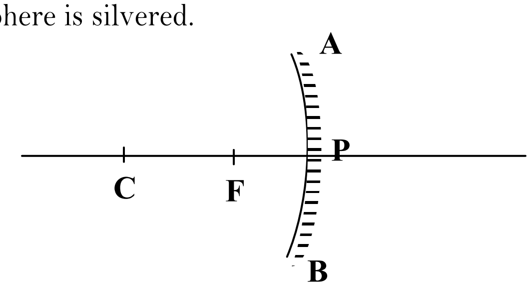
1	C	5	C	9	B	13	B	17	C
2	B	6	C	10	C	14	B	18	C
3	C	7	D	11	C	15	D	19	A
4	D	8	B	12	B	16	D	20	A

REFLECTION AT CURVED MIRRORS:

A curved mirror is formed by cutting part of a sphere. There are two types of curved mirrors namely;
i) Concave (Converging) mirror
ii) Convex (Diverging) mirror
A convex mirror is formed when the outer surface of part of the sphere is silvered while a concave mirror is formed when the inner surface of part of the sphere is silvered.



Convex mirror



concave mirror

Terms used:

1. Centre of curvature, C
This is the centre of the sphere of which the mirror forms a part

2. Aperture, AB
This is the width of the mirror

3. Pole, P
This is the centre point of the mirror

4. Principal axis
This is the line that joins the pole to the centre of curvature of the mirror

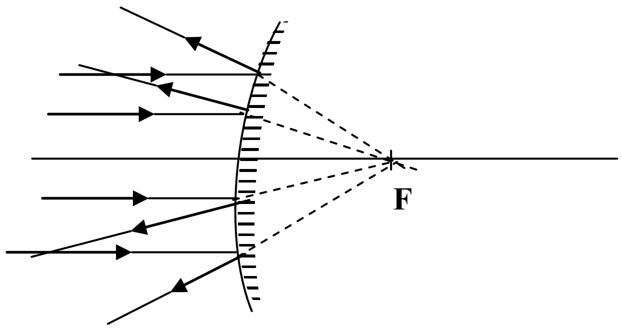
5. Focal length, f
This is the distance between the principal focus and the pole of the mirror

6. Radius of curvature, r
This is the distance between the centre of curvature and the pole of the mirror OR this is the radius of the sphere of which the mirror forms apart.

NB: The radius of curvature is twice the focal length of the mirror, $r = 2f$

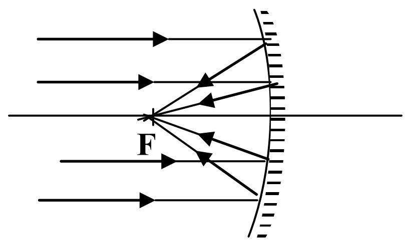
7. Principal focus of a convex mirror, F

It is a point on the principal axis to which all rays parallel and close to the principal axis appear to diverge after reflection



8. Principal focus of a concave mirror, F

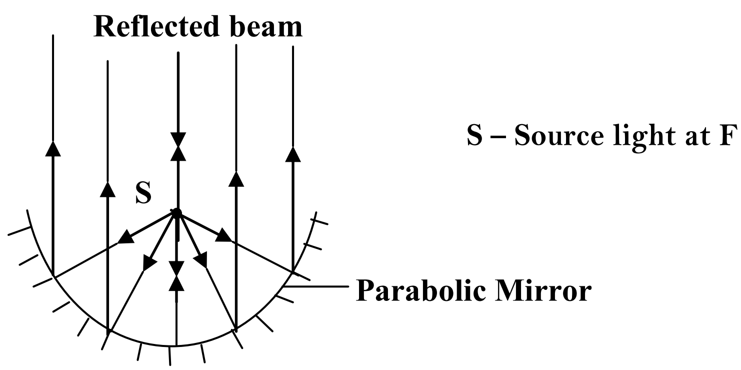
It is a point on the principal axis to which all rays parallel and close to the principal axis converge after reflection



Note: When a wide beam is incident as from a car head lamps to a concave mirror then the rays are reflected at different points on the axis hence the image formed is distorted. Therefore a parabolic mirror can be used on wide beam.

Parabolic Mirror:

A parabolic mirror has the property of reflecting the wide beam of light from a search light at its principal focus, F as a perfectly parallel beam hence the intensity of the reflected beam does not change as the distance from the mirror increases



RAY DIAGRAMS:

Images formed by curved mirrors can be located by drawing any two of the following rays;

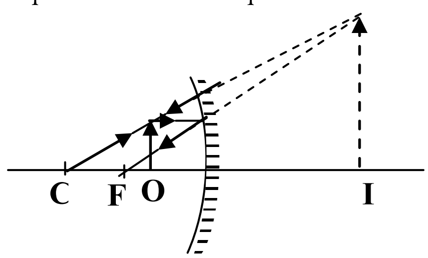
- A ray parallel to the principal axis is reflected passing through the principal focus
- A ray passing through the principal focus is reflected parallel to the principal axis
- A ray passing through the centre of curvature is reflected back along its own path

Images formed by a concave mirror:

Images formed by concave mirrors are real or virtual, diminished or magnified, inverted or upright depending on the position of the object from the mirror.

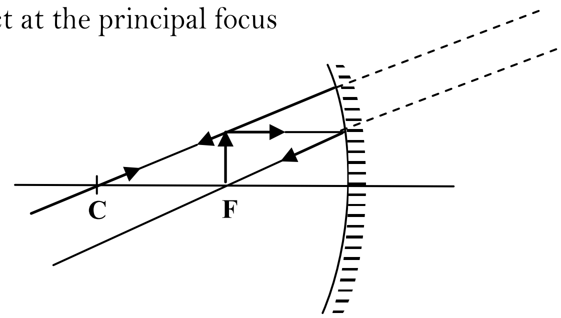
Virtual image is the image formed by apparent intersection of rays [it is not formed on the screen] while **Real image** is the image formed by actual intersection of rays [it is formed on the screen].

1. Object between principal focus and the pole of the mirror



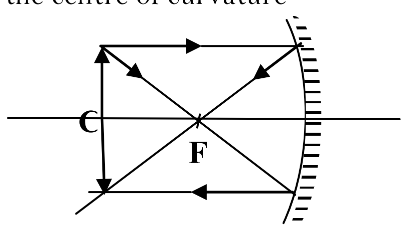
The image is
- Virtual [behind the mirror]
- Magnified [bigger than the object]
- Upright [erect]

2. The object at the principal focus



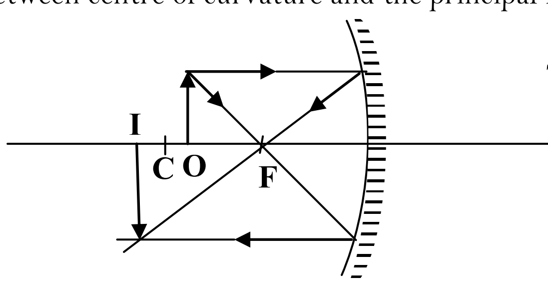
The image is
- Virtual
- Magnified
- Upright
- At infinity

3. The object at the centre of curvature



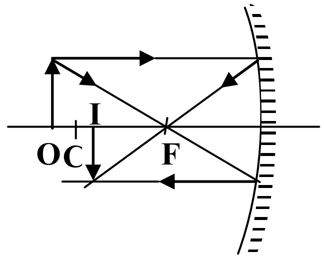
The image is
- Real [on the screen]
- Same size as the object
- Inverted [upside down]
- At centre of curvature

4. Object between centre of curvature and the principal focus



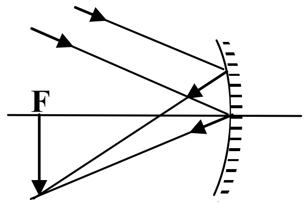
The image is
- Real [on the screen]
- Magnified [bigger than the object]
- Inverted [upside down]
- Beyond centre of curvature

5. Object beyond centre of curvature



The image is
- Real [on the screen]
- Diminished [smaller than the object]
- Inverted [upside down]
- Between C and F

6. The object at infinity

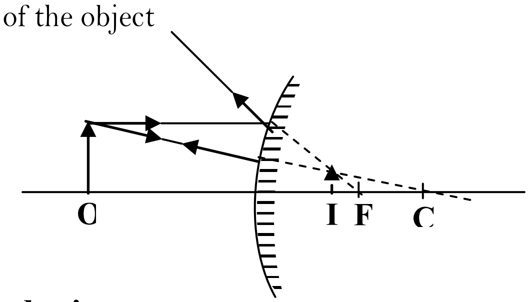


The image is

- Real [on the screen]
- Inverted [upside down]
- Diminished
- At principal focus

Images formed by convex mirror:

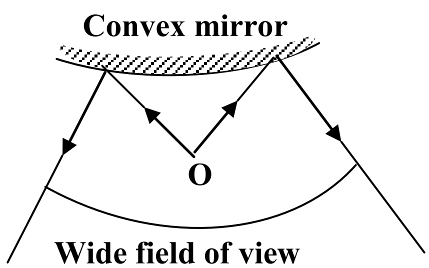
The image formed by a convex mirror unlike by a concave is virtual, diminished and upright irrespective of the position of the object

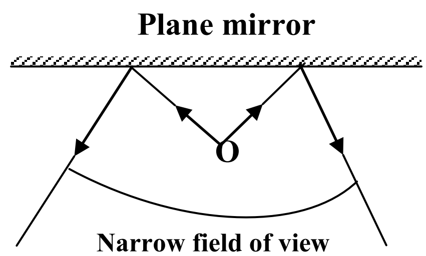


Uses of curved mirrors:

a) Driving mirror:

Convex mirrors are used as driving mirrors because they form only upright images and they have a wide field of view compared to plane mirrors.





b) Reflectors:

When a point source of light is placed at the principal focus of a concave mirror, the reflected beam is parallel; therefore concave mirrors are used as reflectors in torches and car lamps.

c) Shaving mirrors:

If the object is placed between the focal point and pole of the concave mirror a virtual, erect and magnified image is formed. So it is used as magnifying mirror although the view is limited.

d) Telescopes:

Both convex and concave mirrors are used in reflecting telescopes because of their larger aperture as their light energy losses are smaller.

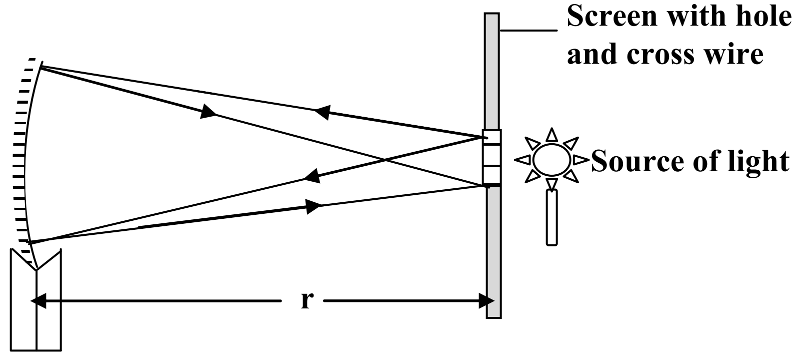
SIGN CONVENTION:

It states that real is positive and virtual is negative. That is distances of real objects and real images are positive distances while distances of virtual objects and virtual images are negative distances and all distances are measured from the mirror as the origin.

NOTE:

A concave mirror has real principal focus and therefore its focal length is positive while a convex mirror has a virtual principal focus and therefore its focal length is negative.

Experiment to measure the focal length of a concave mirror:



- The object used consists of a hole cut in a white screen and illuminated by source of light.
- A concave mirror mounted in a holder and then moved to and fro in front of the screen until a sharp image of the object is formed on the screen adjacent to the object.
- This is achieved when the object and the image coincide that is at the same distance from the mirror.
- Therefore they are both situated in a plane passing through the centre of curvature and at right angles to the axis.
- The distance between the mirror and the screen is then measured and it is the radius of curvature, r of the mirror.
- From r = 2f, the focal length of the mirror can be calculated.

Trial Exercise 2:

1. List the rules followed during the construction of ray diagrams for curved mirrors
2. By means of a ray diagram show how a concave mirror produces an upright and magnified image of an object and state one practical application of the concave mirror when used in this way.
3. With the aid of a well labeled show how a convex mirror is suitable for acting as a driving mirror
4. With the aid of a diagram, explain why a parabolic mirror is suitable for use as in search lights
5. An image 5cm high is formed by a converging mirror. If the magnification is 0.4, find the height of the object

   Ans: 12.5cm
6. An object 2cm high is placed at a distance of 12cm from a concave mirror of focal length 4cm. by scale drawing determine the position, the size and the nature of the image

   Ans: 6cm, 1cm
7. An object 2cm high is placed at a distance of 20cm from a concave mirror of focal length 15cm. by scale drawing determine the position, the size and the nature of the image

   Ans: 60cm, 6cm

8. An object 3 cm high is placed at right angles to the principal axis of a concave mirror of focal length 7.5cm if the object is 30cm from the pole of the mirror, construct a ray diagram to obtain the position and size of the image formed

   Ans: 10cm, 1cm

9. With the aid of a ray diagram find the position and nature of the image of a 3cm object placed 12cm from the pole of a concave mirror of focal length 18cm

   Ans: 36cm

10. An object is placed 15cm from a convex mirror of radius of curvature 20cm. by use of a scale diagram, determine the image position and its magnification

    Ans: 6cm, 0.6

Multiple-choice Exercise:

1. An object is placed at a distance of 20cm from a convex mirror of focal length 10cm. The image formed by a mirror is

   A. virtual B. inverted
   C. magnified D. between the object and the mirror

2. An object is placed at a distance of 30cm from a concave mirror of focal length 15cm. The image formed by the mirror is

   A. real B. virtual C. magnified D. erect

3. Rays of light that pass through the principal focus of a concave mirror after reflection

   A. pass through the pole of the mirror B. pass through the centre of curvature
   C. are parallel to the principal axis D. appear to be coming from the focal point

4. Which of the following is best when shaving?

   A. convex lens B. plane mirror C. concave mirror D. convex mirror

5. Planets are

   A. luminous heavily bodies revolving around a star
   B. non luminous heavily bodies revolving around the sun
   C. luminous heavily bodies revolving around the moon
   D. luminous heavily bodies

6. Rays of light which are close and parallel to the principal axis of a concave mirror after reflection

   A. pass through the pole of the mirror B. pass through the centre of curvature
   C. pass through the focal point D. appear to be coming from the focal point

7. Parallel rays can be obtained practically from a point source of light if the source is placed at;

   A. the centre of curvature of a concave reflector
   B. the centre of curvature of a convex reflector
   C. the principal focus of a concave reflector
   D. the principal focus of a convex reflector

8. An object is placed between the focal point and the centre of curvature of a concave mirror, which of the following fully describes the image formed

   A. virtual, erect and magnified B. virtual, inverted and diminished
   C. real, erect and magnified D. real, inverted and magnified

9. An image 5cm high is formed by a converging mirror. If the magnification is 0.4, find the height of the object

   A. 12.5cm B. 5.4cm C. 2.0cm D. 4.6cm

10. The focal length of a concave mirror is the
A. distance between the pole of the mirror and the focal point
B. distance between the centre of curvature and the mirror
C. distance between the object and the image
D. diameter of the mirror

11. A boy stands straight in front of a mirror at a distance away from it. He sees his erect image whose height is a fifth of his real height. The mirror he is using is
A. plane mirror B. concave mirror C. convex mirror D. Plano-convex mirror

12. The focal length of a concave mirror is 50cm. Where should the object be placed so that its image is two times and inverted
A. 75cm B. 72cm C. 63cm D. 50cm

13. A convex mirror is used to form the image of an object. Then which of the following statements is wrong
A. the image lies between the pole and the focus B. the image is erect
C. the image is diminished in size D. the image is real

14. The focal length of a convex mirror is 20cm, its radius of curvature will be
A. 10cm B. 20cm B. 30cm D. 40cm

15. An object is placed at a distance beyond the focal point of a concave mirror. The image formed by the mirror is
A. real B. virtual C. magnified D. erect

16. An object is placed 15cm from a convex mirror of radius of curvature of 20cm. determine the position of the image
A. 0.6cm B. 1.5cm C. 6.0cm D. 10.0cm

17. A concave mirror with a focal length of 10.0 cm creates a real image 30.0 cm away on its principal axis; the corresponding object is located how far from the mirror?
A. 20.0cm B. 15.0cm C. 7.5cm D. 5.0cm

18. Use of a parabolic mirror, instead of one made of a circular arc surface, can be used to reduce the occurrence of which of the following effects?
A. spherical aberration B. mirages
C. chromatic aberration D. light scattering

19. When the image of an object is seen in a concave mirror the image will
A. always be real B. always be virtual.
C. be either real or virtual D. will always be magnified.

20. Which of the following best describes the image formed by a concave mirror when the object is at a distance further than the center of curvature of the mirror?
A. Virtual, erect and magnified B. real, inverted and diminished
C. virtual, upright and diminished D. real, inverted and magnified

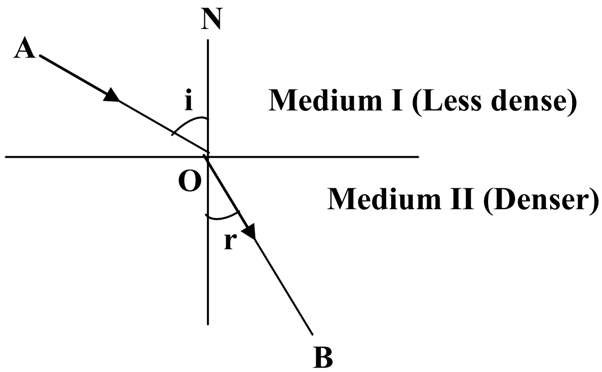
Answers:

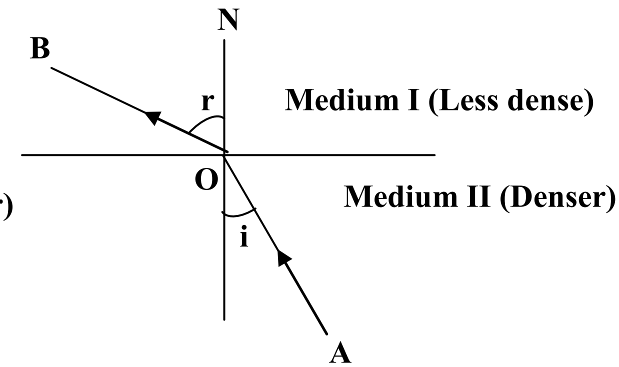
1	A	5	B	9	A	13	D	17	B
2	A	6	C	10	A	14	D	18	A
3	C	7	C	11	C	15	A	19	C
4	C	8	D	12	A	16	C	20	B

REFRACTION OF LIGHT AT PLANE SURFACES:

This is the bending of light ray as it travels from one medium to another of different optical densities. Refraction is caused by difference in speed of light in different media. The speed of light is higher in less dense medium than in denser medium.

When light travels from a less dense medium to a more dense medium then light ray bends towards the normal but when light travels from a denser medium to a less dense medium light ray bends away from the normal.





Terms used:

1. Incident ray, AO

This is the path along which light travels in the first medium before it changes direction

2. Refracted ray, OB

This is the path along which light travels in the second medium after it has changed its direction

3. Angle of incidence, i

This is the angle between the incident ray and the normal at the point of incidence

4. Angle of refraction, r

This is the angle between the refracted ray and the normal at the point of incidence

5. Normal, ON

This is a perpendicular line to the given media

LAWS OF REFRACTION:

First law:

The incident ray, refracted ray and the normal at the point of incidence all lie in the same plane

Second law:

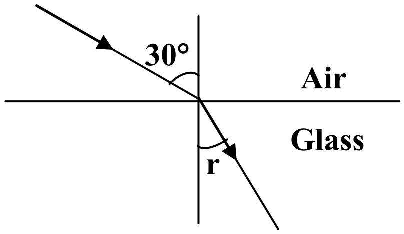
The ratio of sine of angle incidence to sine of angle of refraction is a constant for a given pair of media. This law is referred to as Snell's law and the constant is called the refractive index of the medium in which refraction occurs with respect to the first medium.

The refractive index of glass with respect to air is given by

$$a\cap g = \frac{\text{Sine of angle of incidence in air}}{\text{Sine of angle of refraction in glass}}$$

Examples:

1. A ray of light is incident on air-glass boundary at an angle of 30°. Calculate the refractive index of glass if the angle of refraction is 19.5°



$$a\cap g = \frac{\text{sine of angle of incidence in air}}{\text{sine of angle of refraction in glass}}$$

$$a\cap g = \frac{\sin 30.0°}{\sin 19.5°}$$

$$= \frac{0.500}{0.334}$$

$$= 1.497$$

2. A ray of light is incident on air-water boundary at an angle of 40°. Find the angle of refraction if the refraction index of water is 1.33

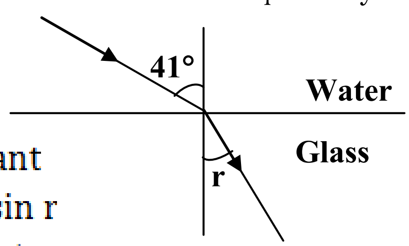
$$a\cap w = \frac{\sin i}{\sin r} = \frac{\sin 40°}{\sin r}$$

$$1.33 = \frac{\sin 40°}{\sin r}$$

$$\text{Sin } r = 0.483$$

$$r = \sin^{-1}(0.483) = 28.9°$$

3. A ray of light is incident on water-glass boundary at an angle of 41°. Calculate the value of r if the refractive indices of glass and water are respectively 1.50 and 1.33



$$n \sin i = \text{a constant}$$

$$n_w \sin 41° = n_g \sin r$$

$$1.33 \sin 41° = 1.5 \sin r$$

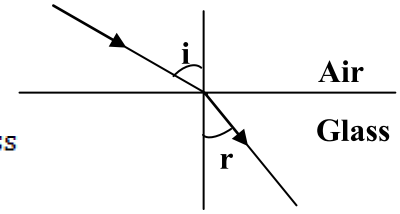
$$\sin r = \frac{0.872}{1.5}$$

$$r = \sin^{-1}(0.581)$$

$$r = 35.5°$$

Relationship between refractive indices:

Consider a ray of light incident on air – glass boundary as shown below;



For a ray moving from air to glass

$$a\cap g = \frac{\sin i}{\sin r}$$

For a ray moving from glass to air

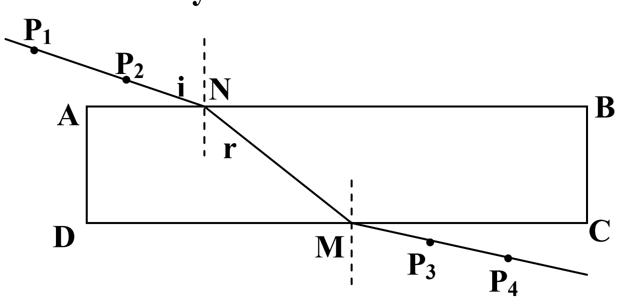
$$g\cap a = \frac{\sin r}{\sin i}$$

$$a\cap g \text{ x } g\cap a = \frac{\sin i}{\sin r} \text{ x } \frac{\sin r}{\sin i}$$

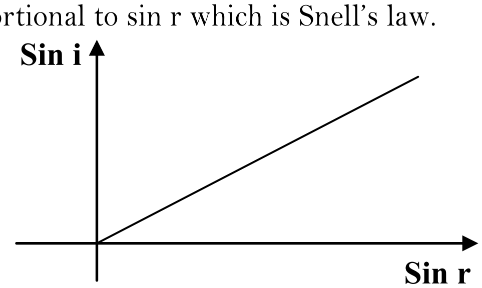
$$a\cap g \text{ x } g\cap a = 1$$

$$a\cap g = \frac{1}{g\cap a}$$

Experiment to verify Snell's law:



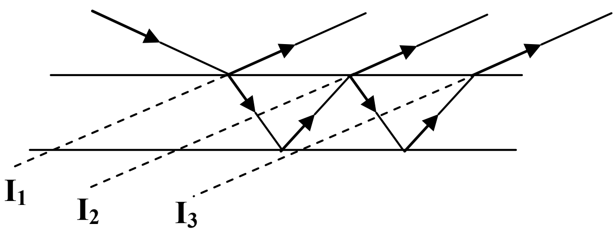
- A glass block is placed on a white sheet of paper and its outline ABCD is drawn.
- A glass block is then removed and the normal is drawn to meet AB at N
- Angle of incidence i is measured from the normal and stick pins P_1 and P_2 along
- Looking through the glass block stick two other pins P_3 and P_4 so that they appear in line with images of P_1 and P_2 in the glass block.
- Join P_3 and P_4 to meet CD at M and join N to M to obtain the refracted ray
- Measure angle of refraction, r
- Repeat procedures above for different angles of incidence and tabulate your results including values of sin i and sin r
- A graph of sin i against sin r is then plotted and straight line graph is obtained showing that sin i is directly proportional to sin r which is Snell's law.



EFFECTS OF REFRACTION:

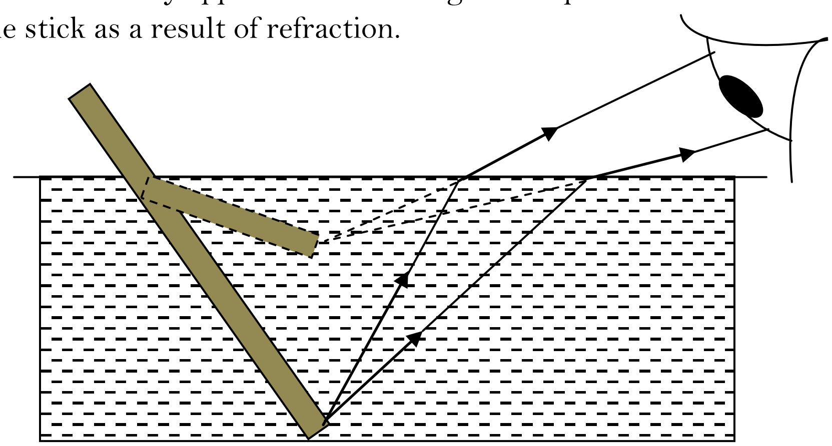
Multiple images in a plane mirror:

A thick plane mirror forms multiple images because it has two surfaces, at the first surface there is reflection and refraction leading to the formation of first image I_1 the refracted light undergoes reflection at the second surface to the first surface and undergoes both reflection and refraction leading to formation of image I_2. The successive reflections at both surfaces bring about formation of multiple images.

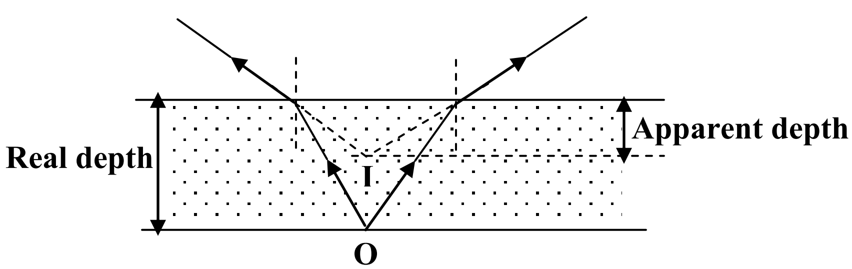


Bending of a stick immersed in water:

When a stick is placed in water it experiences an apparend upward bending. That is the ray of light from one end of the stick through water to air and bends away from the normal since air is less dense than water hence the ray appears to be coming from a point above the end of the stick which is the image of the stick as a result of refraction.



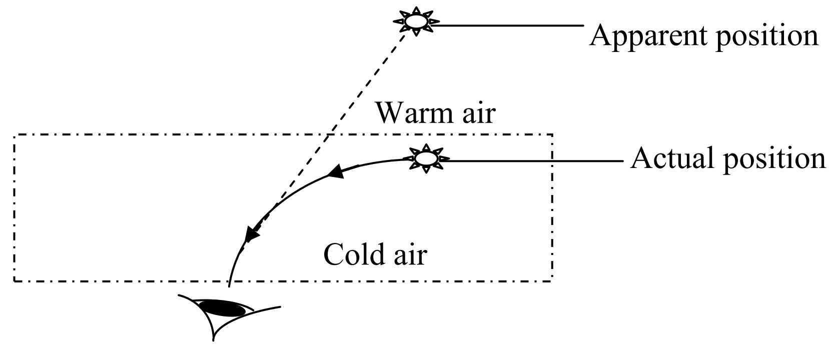
REAL DEPTH AND APPARENT DEPTH:



Water in a swimming pool appears to be shallower than it actually is due to refraction and the depth at which the bottom of the pool appears to be is called apparent depth while its actual depth is called real depth. Therefore the refractive index is given by the ratio of real depth to apparent depth

$$\cap = \frac{\text{real depth}}{\text{Apparent depth}}$$

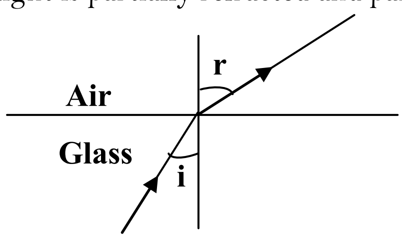
The above explains why a star appears at different location above on the earth than its actual position.



The layers of air near the earth's surface are cooler at night than the layers high above the earth's surface. Therefore the optical density of air near the surface is higher than the optical density of air above the surface hence light from the star bends towards the normal as it moves towards the earth. On entering the eye, the light appears to be coming from a point along the direction light enters his eye thus the star appears higher than its actual position. This is a reason why the sun is seen on the horizon after the sunset and before sunrise.

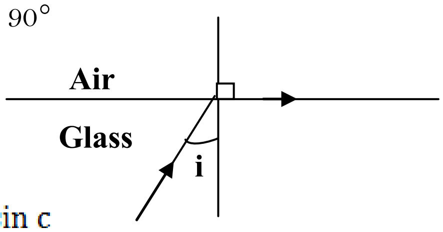
Total internal reflection and critical angle:

When a ray of light travels from a denser medium to a less dense medium and it is incident at a very small angle of incidence then light is partially refracted and partially reflected



When the angle of incidence is increased the angle of refraction also increases and the point is reached when the refracted ray grazes the boundary and at this point the angle of incidence is called the critical angle.

The critical angle therefore is the angle of incidence in a denser medium for which its angle of refraction in a less dense medium is 90°



$$g\cap a = \frac{\sin i}{\sin r} = \frac{\sin c}{\sin 90^\circ}$$

$$g\cap a = \sin C$$

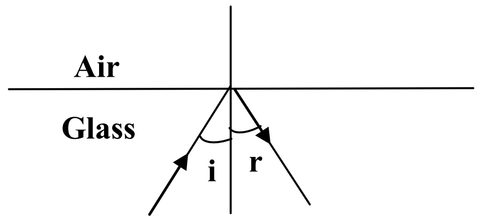
$$\text{but } g\cap a = \frac{1}{a\cap g}$$

$$\sin C = \frac{1}{a\cap g}$$

$$\cap = \frac{1}{\sin C}$$

When the angle of incidence is slightly increased beyond the critical angle, C all the light is reflected back in a more dense medium and total internal reflection is said to have occurred.

Total internal reflection is the phenomenon which occurs when the critical angle has been exceeded and light must be moving from a denser medium to a less dense medium



Conditions for total internal reflection

The following are conditions for total internal reflection to occur

i) the angle of incidence must be greater than the critical angle

ii) light must be moving from a denser medium to a less dense medium

Examples:

1. Find the critical angle for a ray of light traveling from water to air if the refractive index of water is 1.33

$$\text{Sin } C = \frac{1}{\cap} = \frac{1}{1.33}$$

$$C = \sin^{-1}(0.752)$$

$$C = 48.8°$$

2. The critical angle of glass is 42°. Find its refractive index

$$\text{Sin } C = \frac{1}{\cap}$$

$$\text{Sin } 42° = \frac{1}{\cap}$$

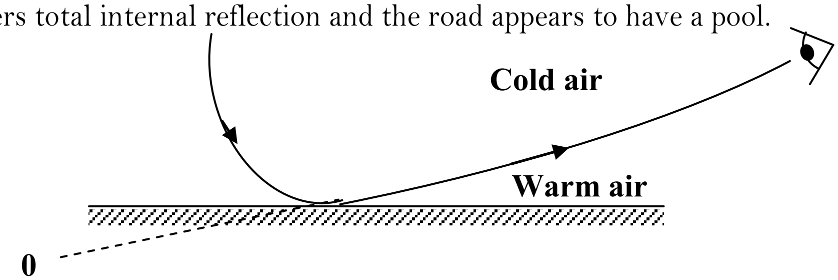
$$\cap = \frac{1}{0.669}$$

$$= 1.49$$

Effects of total internal reflection:

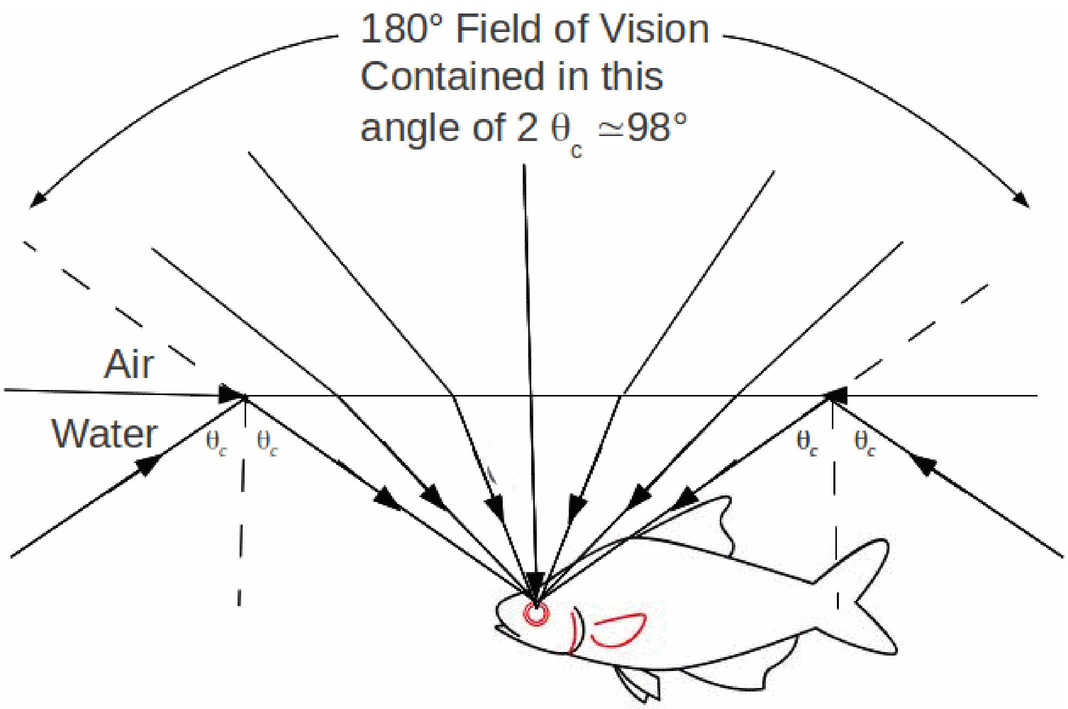
Mirages:

Mirages are common on a hot summer days. On a hot day light from the sky is gradually refracted away from the normal as it passes through layers of warm but less dense air near the hot road. The refractive index of warm air is slightly smaller than that of cool air, so when light meets a layer at critical angle it suffers total internal reflection and the road appears to have a pool.



The fish's eye view:

Though fish lives under water, its view is not restricted to seeing underwater. The fish needs see insects and other animals above the water surface as they are sources of food or potential threats to the fish. The fish sees everything above the water surface, distorted a little, and possibly a lot if the surface is rippled. Its field of view is restricted by the angle at which total internal reflection takes place. If the refractive index of water is n then the critical angle, θ_c is given by $\sin\theta_c = \frac{1}{n}$.

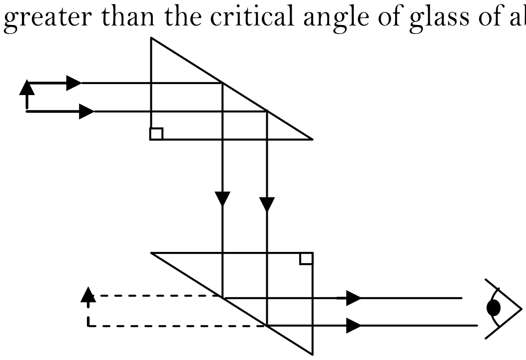


At any depth the fish happens to have a full view of everything above the water surface provided the water surface is unruffled. The figure above explans how the fish enjoys a 180^0 field of view apparently all squeezed into a cone twice the critical angle of water.

Applications of total internal reflection:

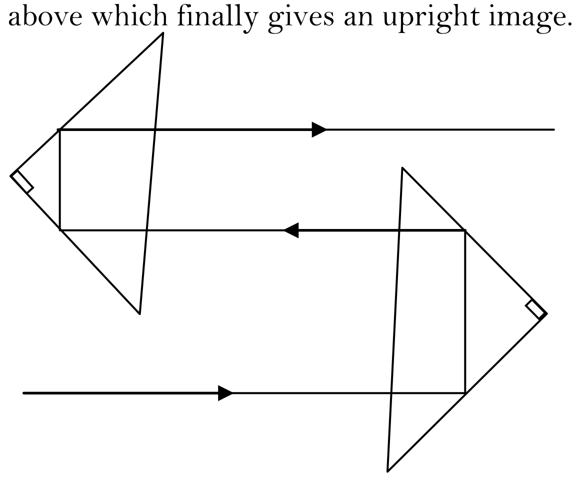
1. Prism periscopes:

It is a combined telescope and periscope. Light enters the sides of the prisms normally and falls on the hypotenuse side internally at angle of incidence of 45°. Total internal reflection occurs since the angle incidence is greater than the critical angle of glass of about 42°



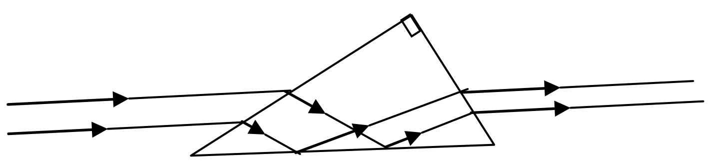
2. Prism Binoculars:

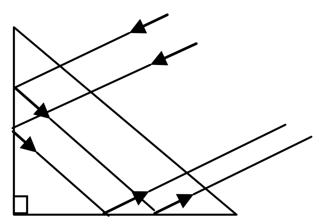
A prism binocular is a simple telescope. If light is incident perpendicular to the hypotenuse face of the nprism it undergoes two internal reflections and emerges out parallel to its original direction as shown in the figure above which finally gives an upright image.



3. Erecting prisms:

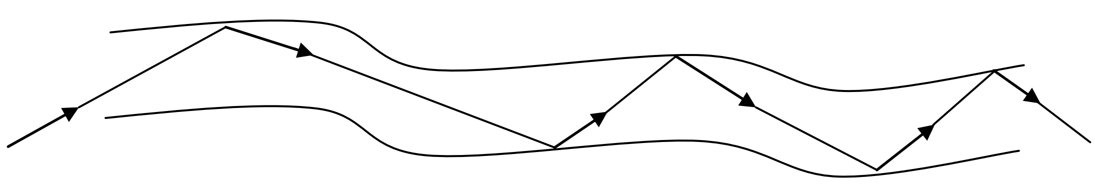
In a projector it is not always possible to obtain an image on the screen. Therefore in order to obtain the image on the screen an erecting right angled prism is placed in front of the projection lens. Light enters the face of the prism approximately parallel to the base and total internal reflection occurs at the base. The critical angle of glass is $42°$ and a ray is incident normally on the prism so that total internal reflection occurs and the ray is turned through $90°$.





4. Optical Fiber:

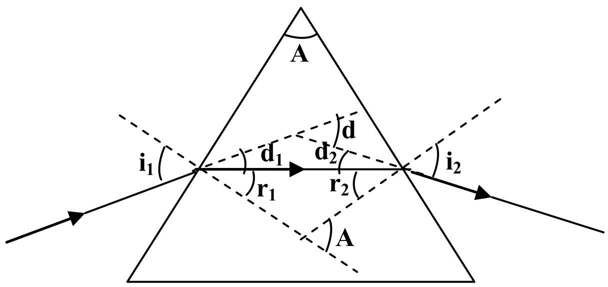
An optical fibre is a thin, transparent fibre, usually made of glass or plastic, for transmitting light. Total internal reflection is a powerful tool since it can be used to confine light. One of the most common applications of total internal reflection is in fibre optics. If light is incident on a cable end with an angle of incidence greater than the critical angle, then the light will remain trapped inside the glass. In this way, light travels very quickly down the length of the cable over a very long distance.



Optical fibers are commonly used in telecommunications, because information can be transported over long distances, with minimal loss of data. Another common use can be found in medicine in endoscopes. The field of applied science and engineering concerned with the design and application of optical fibers are called fiber optics.

REFRACTION THROUGH PRISMS:

A triangular prism is a glass block with a triangular cross section. A prism has two refracting faces. When a ray of light is incident at an angle of incidence i_1, it is refracted through the prism at an angle of refraction r_1 with angle of deviation d_1, the ray then emerges out of the prism at an angle of emergence i_2 with deviation d_2 and angle of refraction r_2



Deviation, $d_1 = i_1 - r_1$

Deviation, $d_2 = i_2 - r_2$

Total deviation, $d = d_1 + d_2$

$= i_1 - r_1 + i_2 - r_2$

$= (i_1 + i_2) - (r_1 + r_2)$

But $r_1 + r_2 = A$

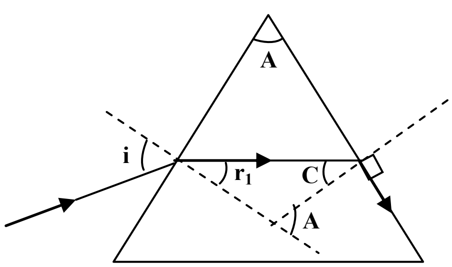
$d = i_1 + i_2 - A$

Where A is the refracting angle and d is angle of deviation.

The refractive index of the prism is given by

$${}_a\cap_g = \frac{\sin i_1}{\sin r_1} = \frac{\sin i_2}{\sin r_2}$$

NB: If the ray of light does not emerge out of the prism but instead grazes one side of the prism, the angle of refraction r_2 becomes the critical angle of the prism



Angle of deviation $d = i_1 + 90^0 - A$

Where $i_2 = 90°$ and $A = r_1 + C$

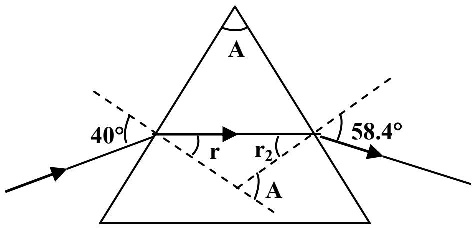
Refractive index ${}_a\cap_g = \frac{\sin i}{\sin r} = \frac{1}{\sin C}$

Examples:

1. A ray of light is incident on a glass prism of refractive index 1.5 at an angle of 40°. Given that the ray emerges out at an angle of 58.4°. Find

i) The refracting angle of the prism

ii) The total deviation



$_a\cap_g = \frac{\sin i_1}{\sin r_1} = \frac{\sin i_2}{\sin r_2}$

$1.5 = \frac{\sin 40}{\sin r_1}$ $\qquad$ $1.5 = \frac{\sin 58.4}{\sin r_2}$

$\sin r_1 = \frac{\sin 40}{1.5}$ $\qquad$ $\sin r_2 = \frac{\sin 58.4}{1.5}$

$r_1 = 25.4°$ $\qquad$ $r_2 = 34.6°$

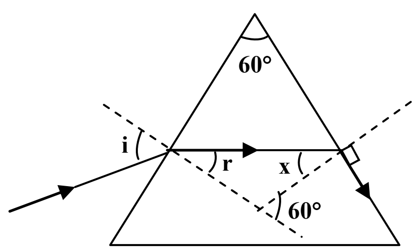
i) Refracting angle $A = r_1 + r_2 = 25.4 + 34.6$

$= 60.0°$

ii) Total deviation, $d = i_1 + i_2 – A = 40 + 58.4 - 60$

$= 38.4°$

2. A ray of light is incident at an angle of incidence i on a triangular prism of refractive index 1.52 as shown below



Find the angles marked x, r and i

From $_a\cap_g = \frac{1}{\sin C}$

$1.52 = \frac{1}{\sin x}$ $\qquad$ $r + x = 60°$

$\sin x = \frac{1}{1.52}$ $\qquad$ $r + 41.1° = 60°$

$x = 41.1°$ $\qquad$ $r = 60° – 41.1°$

$r = 18.9°$

$_a\cap_g = \frac{\sin i}{\sin r}$

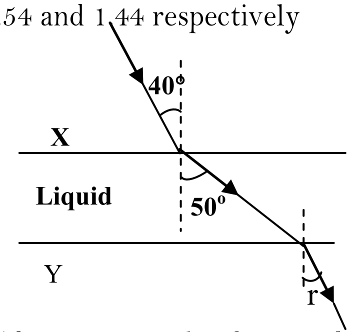
$1.52 = \frac{\sin i}{\sin 18.9°}$

$\sin i = 1.52 \times \sin 18.9°$

$i = 29.5°$

Trial Exercise 3:

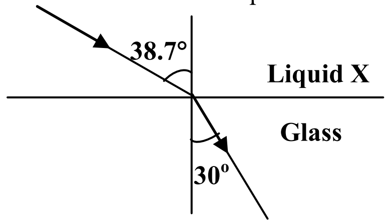
1. The diagram below shows a layer of liquid confined between two transparent plates X and Y of refractive indices 1.54 and 1.44 respectively



A ray of light is incident at an angle of 40° at the interface between medium X and the liquid and refracted as shown above. Find the refractive index of liquid and the angle of refraction, r in medium Y

Ans: 1.29, 32.1°

2. A ray of light moves from liquid x to glass as shown in diagram below. If the refractive index of glass is 1.5, find the refractive index of liquid X

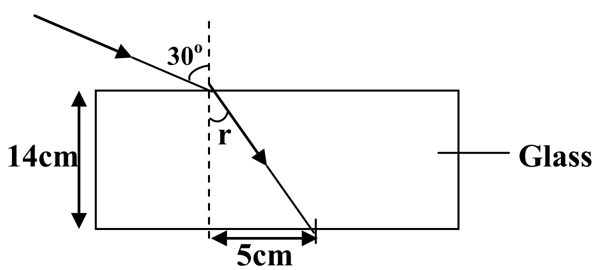


Ans: 1.20

3. A ray of light from air enters a liquid medium at an angle of incidence of 45°. If the angle of refraction is 28°, calculate the refractive index of the liquid

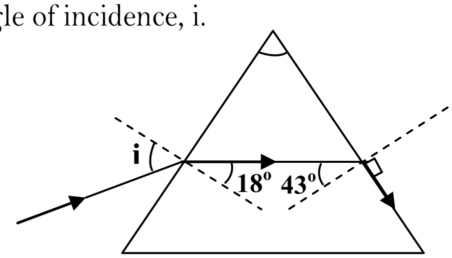
Ans: 1.51

4. A ray of light strikes a glass block as shown in the diagram below. Given that the width of the glass block is 14cm, find the refractive index of glass



Ans: 1.49

5. A ray of light is incident on a glass prism at an angle, i as shown below. Find the refractive index of the prism and angle of incidence, i.



Ans: 1.47, 26.9°

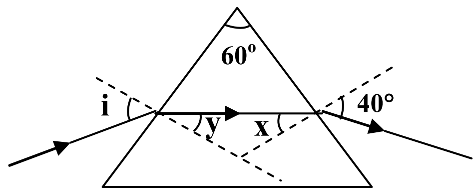
6. A swimming pool contains water to a depth of 2.6m. If the refractive index of water is 1.33, calculate the apparent depth of the surface of the swimming pool.

Ans: 1.95m

7. A ray of light is incident on a glass block at an angle of 45° and refracted at an angle of 21°. Find the critical angle of glass

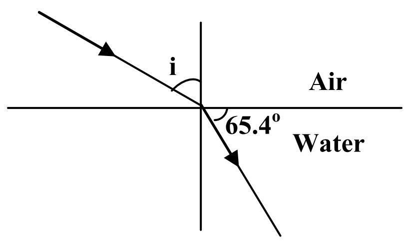
Ans: 30.5°

8. A ray of light is incident on a glass prism at an angle, i as shown below. If the refractive index of the prism is 1.5, find the angles marked x, y and i



Ans: x = 25.4°, y = 34.6° and i = 58.5°

9. A ray of light travels through two different media as shown below calculate the angle of incidence, if the refractive index of water is 1.33.



Ans: 33.6°

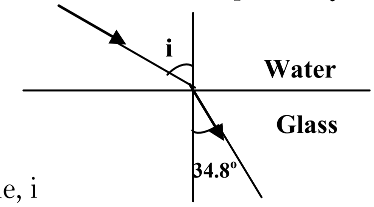
10. With the aid of a diagram explain why a pond appears shallower than it actually is

Multiple-choice Exercise:

1. Total internal reflection occurs when
A. angle of incidence is equal to the critical angle
B. light moves from a denser medium to a dense one
C. light moves from a dense medium to a denser one
D. angle of incidence is smaller than the critical angle

2. Rainbow is produced when sunlight fall on drops of rain. Which of the following physical phenomena are responsible for this?
i) Diffusion ii) Refraction iii) total internal reflection
A. (i), (ii) and (iii) correct B. (i) and (ii) correct
C. (ii) and (iii) correct D. (i) and (iii) correct

3. A ray of light crosses from water to glass as shown below. Given that the refractive indices for water and glass are 1.33 and 1.50 respectively.



Calculate the angle, i
A. 30° B. 49° C. 40° D. 59

4. When a fish in water is viewed by an observer in air, is appears to be at a position different from where it actually is because of

A. reflection B. refraction C. interference D. dispersion

5. Total internal reflection occurs when

i) the angle of incidence is greater than the critical angle

ii) the angle of incidence is less than the critical angle

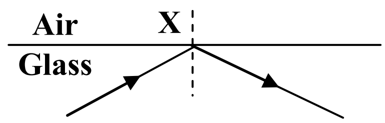
iii) a ray of light travels from a denser medium to a less dense medium

iv) a ray of light travels from a less dense to a denser medium

A. (i), (ii) and (iii) only correct B. (i) and (iii) only correct

C. (ii) and (iv) only correct D. (iv) only correct

6. The diagram below shows a ray of light moving from glass to air.



At point X, the ray has undergone

A. reflection B. refraction C. dispersion D. total internal reflection

7. A ray of light incident on a glass block at an angle of incidence of 40^o and the angle of refraction 21^o. Find the critical angle of the glass

A. 42.0^o B. 40.0^o C. 33.9^o D. 35.0^o

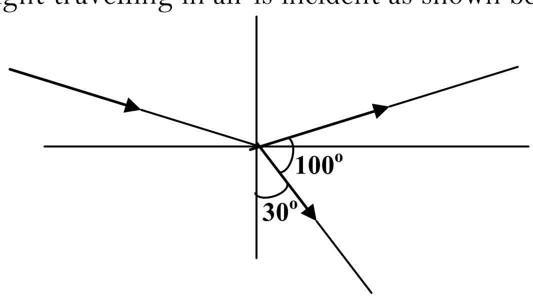
8. A stick with one end immersed in water appears bent at the water surface because of

A. diffraction B. reflection C. interference D. refraction

9. A ray of light incident on a glass block at an angle of incidence of 40^o and the angle of refraction 25^o. Find the refractive index of the glass

A. 2.37 B. 1.56 C. 1.52 D. 0.66

10. A ray of light travelling in air is incident as shown below



The ray is partially reflected and refracted. Calculate the angle of incidence.

A. 30^o B. 45^o C. 50^o D. 80^o

11. In light dispersion, ……………………………………………is deviated least

A. violet B. blue C. red D. green

12. Rainbow is due to

A. absorption of sunlight in minute water droplets

B. diffusion of sunlight through water droplets

C. ionization of water deposits

D. refraction and reflection of sunlight by water droplets

13. White light is separated into its component colours by a prism due to

A. absorption B. dispersion C. reflection D. transmission

14. Mirage is due to
A. unequal heating of different parts of the atmosphere
B. magnetic disturbances in the atmosphere
C. depletion of ozone layer in the atmosphere
D. equal heating of different parts of the atmosphere

15. Optical fibre works on the principle of
A. refraction B. total internal reflection
C. scattering D. interference

16. The best definition of refraction is
A. passing through a boundary B. bouncing off a boundary
C. changing speed at a boundary D. changing direction when crossing a boundary

17. A ray of light in air is incident on an air-to-glass boundary at an angle of 30^o with the normal. If the index of refraction of the glass is 1.65, what is the angle of the refracted ray within the glass with respect to the normal?
A. 56^o B. 46^o C. 30^o D. 18^o

18. Carbon disulfide of refractive index 1.63 is poured into a container made of crown glass of refractive index 1.52. What is the critical angle for internal reflection of a ray in the liquid when it is incident on the liquid-to-glass surface?
A. 89.0^o B. 68.8^o C. 21.2^o D. 4.0^o

19. A light ray in air enters and passes through a block of glass. What can be stated with regard to its speed after it emerges from the block?
A. speed is higher than when in glass B. speed is less than before it entered glass
C. speed is same as that in glass D. speed is the same as that before it entered glass

20. When light from air hits a smooth piece of glass of refractive index 1.5 with the ray perpendicular to the glass surface, which of the following will occur?
A. dispersion B. reflection and transmission at an angle of 0^o
C. all of the above will occur D. refraction at an angle of 41.8^o

Answers:

1	B	5	B	9	C	13	B	17	D
2	C	6	D	10	C	14	A	18	B
3	C	7	C	11	C	15	B	19	A
4	B	8	D	12	D	16	C	20	B

REFRACTION THROUGH THIN LENSES:

Lenses are spherical surfaces of transparent material. The material may be glass, plastics, water etc. There are two types of lenses and these are

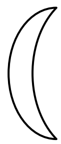
i) Convex (Converging) lenses.

ii) Concave (Diverging) lenses

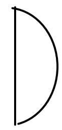
Convex lens:

This is thicker in the middle than at the edges. A convex lens is sometimes referred to as a converging lens because all parallel beams incident to it converge at a point called its principal focus after refraction through the lens.

Biconvex lens



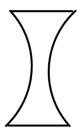
Convex meniscus



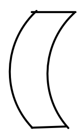
Plano convex

Concave lens:

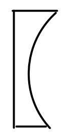
This is thicker at the edges than in the middle. A concave lens is sometimes referred to as a diverging lens because all parallel beams incident to the lens appear to diverge to a point called its principal focus after refraction through the lens



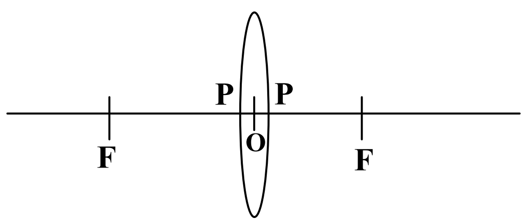
Biconcave lens



Concave meniscus



Plano concave



Terms used:

1. Principal axis

This is a line through the optical centre and principal focus

2. Optical centre, O

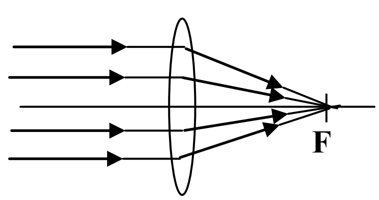
This is the centre between the poles of the lens

3. Poles of the lens, P

Pole of a lens is the centre point of the surfaces of the lens

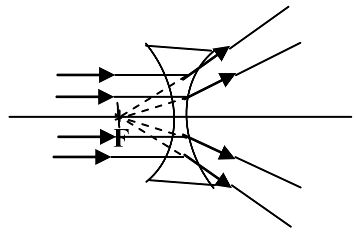
4. Principal focus, F of a converging lens:

This is a point on the principal axis to which all rays parallel and close to principal axis converges after refraction



5. Principal focus, F of a diverging lens:

This is a point on the principal axis to which all rays parallel and close to principal axis appears to diverge after refraction



6. Focal length, f

This is the distance between the optical centre and principal focus

RAY DIAGRAMS:

Images formed by lenses can be located by drawing any two of the following rays

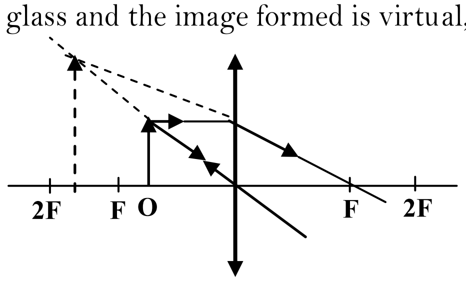
- A ray parallel to the principal axis is refracted passing through the principal focus
- A ray passing through the principal focus is refracted parallel to the principal axis
- A ray passing through the optical centre is un-deviated

Images formed by a convex lens:

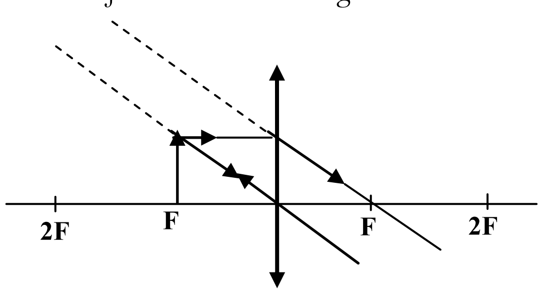
Images formed by convex lens are real or virtual, diminished or magnified, inverted or upright depending on the position of the object from the lens.

1. Object between F and optical centre

When the object is between the principal focus and the optical centre of the lens, the lens acts as a magnifying glass and the image formed is virtual, upright and magnified.



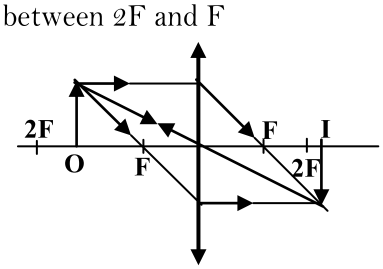
2. When the object is at F the image is formed at infinity.



The image is

- Vitual
- Magnified
- Upright
- At infinity

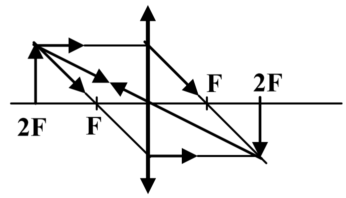
3. The object between 2F and F



The image is

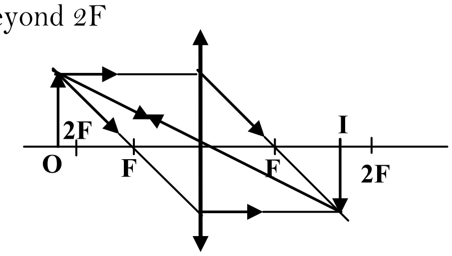
- real
- inverted
- magnified
- beyond 2F

4. The object at 2F



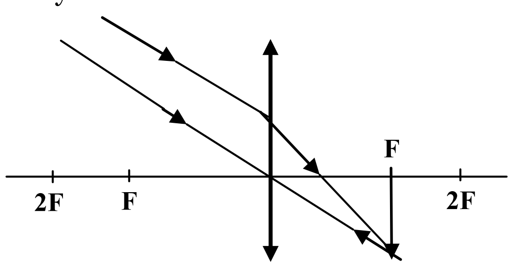
The image is
- real
- inverted
- same size as the object
- at 2F

5. The object beyond 2F



The image is
- real
- inverted
- diminished
- between F and 2F

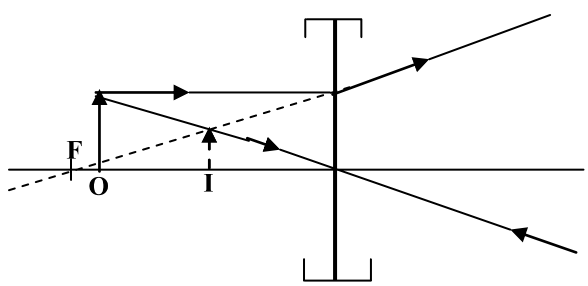
6. Object at infinity



The image is
- real
- inverted
- diminished
- at principal focus

Images formed by a concave lens:

For all positions of the object from a diverging lens, the image formed is always virtual, upright and diminished.



POWER OF THE LENS:

Power of the lens is the reciprocal of its focal length measured in metres.

SI unit is Dioptres (D)

$$\text{Power} = \frac{1}{\text{Focal length}} = \frac{1}{f}$$

Examples:

1. Calculate the power of a converging lens of focal length 10mm

$$\text{Power} = \frac{1}{\text{Focal length}} = \frac{1}{f}$$

$f = 10mm = 0.01m$

$$\text{Power} = \frac{1}{0.01}$$

$\text{Power} = 100D$

2. Calculate the power of a diverging lens of focal length 10mm

$$\text{Power} = \frac{1}{\text{Focal length}} = \frac{1}{f}$$

$f = -10mm = -0.01m$

$$\text{Power} = \frac{1}{-0.01}$$

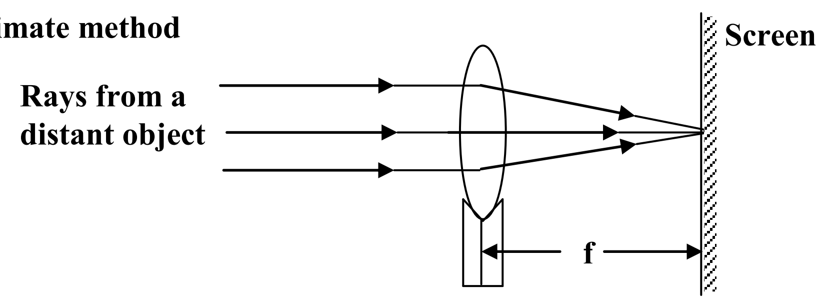
$\text{Power} = -100D$

NOTE:

A diverging lens has a virtual principal focus and therefore its focal length is negative while a converging lens has a real principal focus and therefore its focal length is positive.

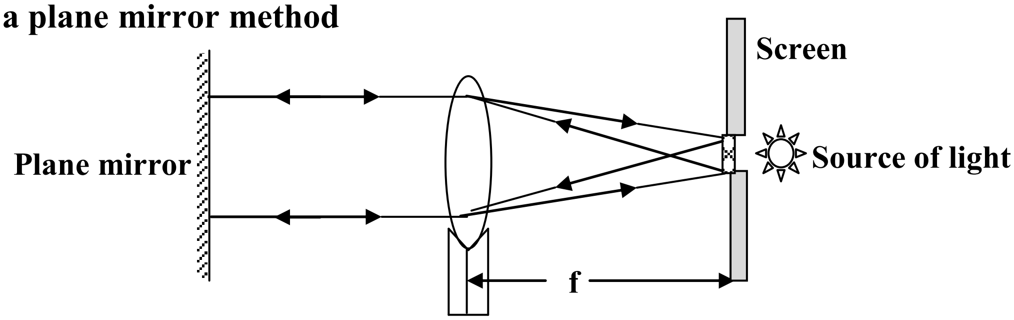
Measurement of focal length of a converging lens:

1. Approximate method



- The approximate focal length of a converging lens can be obtained by focusing a distant object and the screen is moved until a clear image of the object is formed on the screen.
- The distance between the screen and the lens is then measured and it is the focal length, f of the lens

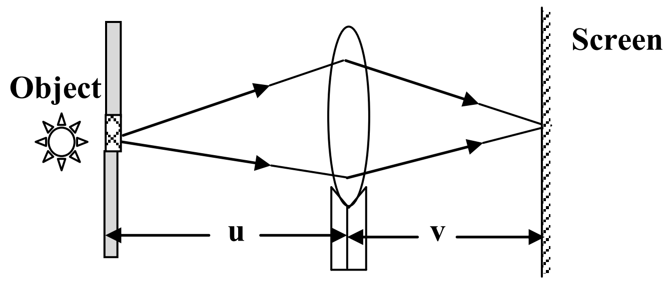
2. Using a plane mirror method



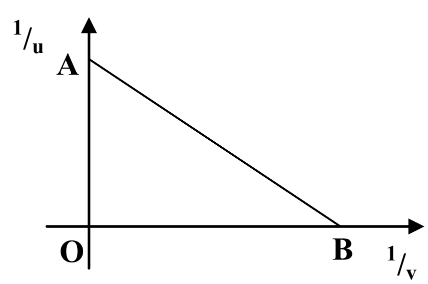
- The apparatus is set up as shown above with a plane mirror placed behind the lens so as to reflect back the light that passes through the lens

- The hole with cross wires acting as the object is made in a white screen and illuminated by a source of light
- The position of the lens is then adjusted until a sharp image is formed on the screen along side the object.
- The object is then at the focal point of the lens and rays from the object emerge from the lens as a parallel beam which are reflected back and brought to focus in the same plane
- The distance between the lens and the screen is then measured and it is the focal length, of the lens.

3. Using object and image distances



- The lens is set up in front of illuminated object so that a real image is formed on the screen.
- The lens is then adjusted until a clear image of the object at a distance, u from the lens is formed on the screen.
- The image distance, v is then measured and recorded.
- The experiment is repeated with the object at different distances, u and the corresponding values of image distances, v measured and recorded.
- The results are then tabulated including values of $\frac{1}{u}$ and $\frac{1}{v}$. The mean value of $\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$ is obtained and focal length, f of the lens can be calculated.
- A graph of $\frac{1}{u}$ against $\frac{1}{v}$ is plotted and from the graph focal length, f is calculated as follows



$$OA = OB = \frac{1}{f}$$

$$f = \frac{1}{OA} = \frac{1}{OB}$$

- The focal length, f of the lens can be calculated

Trial Exercise 4

1. A converging lens focuses an object, which stands vertically upwards on its principal axis 120cm away. The image is formed at 200cm away from the lens. By means of an accurate scale drawing determine the focal length of the lens

   Ans: 75cm

2. An object is placed perpendicular to the principal axis of a convex lens of focal length 12cm so that it forms a real image at a distance of 36cm from the lens, which is 2cm long. Draw a scale diagram clearly showing the image and the object; determine the position of the object and the magnification produced by the lens

   Ans: 18cm, 2

3. An object of height 4cm is placed at a distance of 20cm from a converging lens of focal length 40cm. Find by scale drawing the image position and the height of the image

   Ans: 40cm, 8cm

4. An object of height 4cm is placed at a distance of 60cm from a converging lens of focal length 20cm. Find by scale drawing the image position, the height of the image and the magnification

   Ans: 30cm, 2cm, 0.5

5. An object of height 2cm is placed at a distance of 10cm from a converging lens of focal length 30cm. Find by scale drawing the image position, the height of the image and the magnification.

   Ans: 15cm, 3cm, 1.5

6. An object of height 5cm is placed at a distance of 20cm from a diverging lens of focal length 60cm. find by scale drawing find the image position, the height of the image and the magnification

   Ans: 15cm, 3.8cm, 0.75

7. A converging lens of focal length 20cm is placed in contact with another converging lens of focal length 25cm. find the power of the combination

   Ans: 9D

8. A convex lens of focal length20mm focuses an image on the screen. Calculate the power of the lens?

   Ans: 50D

9. A concave lens of focal length 40cm focuses an image on the screen. Calculate the power of the lens?

   Ans: - 2.5D

10. A converging lens of focal length 10cm is placed in contact with another converging lens of focal length 25cm. Find the power of the combination

    Ans: 14

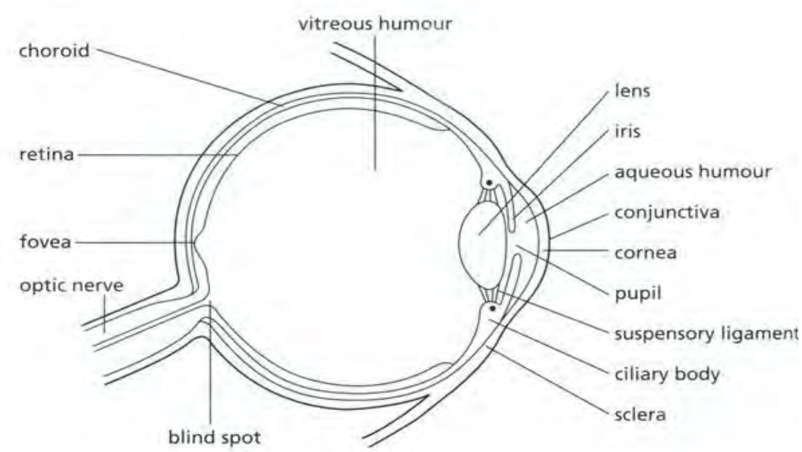
OPTICAL INSTRUMENTS:

Optical instruments are those instruments that change the visual angle. Visual angle is the angle subtended by the object at the eye. That is they help us to see near or far objects and these are

Cameras	Telescopes
Microscopes	Binoculars
Periscopes	Projectors

The eye

In the eye the images are formed on the retina and messages are submitted to the brain by the optical nerves. Light entering the eye is controlled by Iris and the focusing of the image on the retina is affected by changing the focal length of the lens which is referred to as accommodation. The parts of the human eye are shown below;



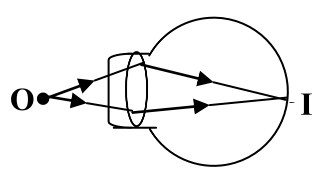
- The eyebrow stops sweat running down into the eye.
- Eyelashes help to stop dust blowing on to the eye.
- Eyelids can close automatically (blinking is a reflex) to prevent dust and other particles getting to the surface of the cornea.
- Blinking also helps to keep the surface moist by moving liquid secretions (tears) over the exposed surface. Tears also contain enzymes that have an antibacterial function.

Defects of vision:

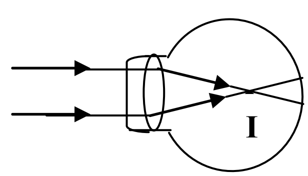
1. Short sight [Myopia]:

A short sighted person can see nearby objects clearly but cannot see far objects. The images of nearby objects are formed on the retina while images of far objects are formed in front of the retina because the eyeball is too long so that the rays from far objects meet in front of the retina.

Nearby object

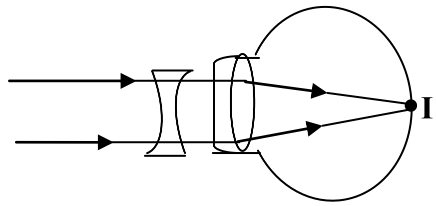


Far object



Correction:

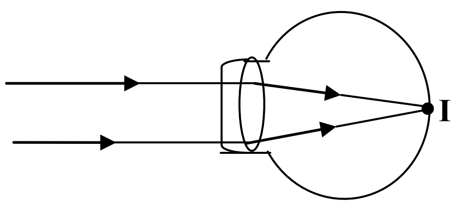
A person suffering from short sightedness is given a diverging [concave] lens so that it can diverge the rays and the convex lens of the eye converge the diverged rays to form the image on the retina and the person will see the object clearly.



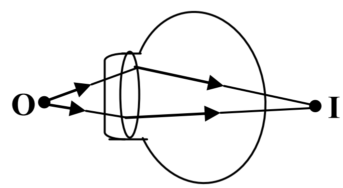
2. Long sight (Hypermetropia):

A long sighted person can see far objects clearly but can not see nearby objects. The images of far objects are formed on the retina while images of nearby objects are formed beyond the retina because the eyeball is too short so that the rays from nearby objects meet beyond the retina.

Far objects

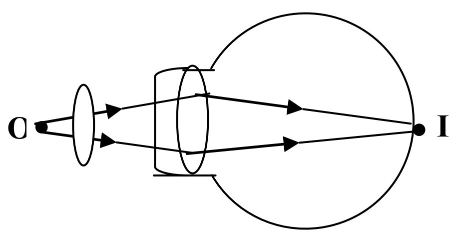


Nearby objects



Correction:

A person suffering from long sightedness is given a converging [convex] lens so that it can converge the rays and the convex lens of the eye converge the converged rays to form the image on the retina and the person will see the object clearly.



3. Astigmatism:

This is the most common vision problem resulting in distorted images as light rays are prevented from meeting at a common focus. This is because light rays fail to come to a single focus on the retina to produce clear vision but instead multiple focus points occur either in front or behind the retina or both in front and behind the retina

A person suffering from a stigmatism faces eye strain and headaches especially after reading or prolonged visual tasks.

Astigmatism is caused by an irregularly shaped cornea that is shaped more like a football.

Types of astigmatism:

There are three types of astigmatism and these are

- Myopic astigmatism
- Hyperopic astigmatism
- Mixed astigmatism

➢ **Myopic astigmatism:** This is where light rays come to two focal points that is before the retina and on the retina.

➢ **Hyperopic astigmatism:** This is where light rays come to two focal points that is on the retina and behind the retina

➢ **Mixed astigmatism:** This is where light ray come to two focal points that is before the retina and behind the retina.

Correction of astigmatism:

It is usually corrected using eyeglasses, contact lenses or refractive surgery. Astigmatism requires an additional "cylinder" lens power to a spherical lens power used in either long sightedness or short sightedness.

4. **Presbyopia:** This occurs when the Centre of the eye lens hardens making it unable to accommodate near vision. This defect normally affects people who are above 50 years of age even if they have myopia.

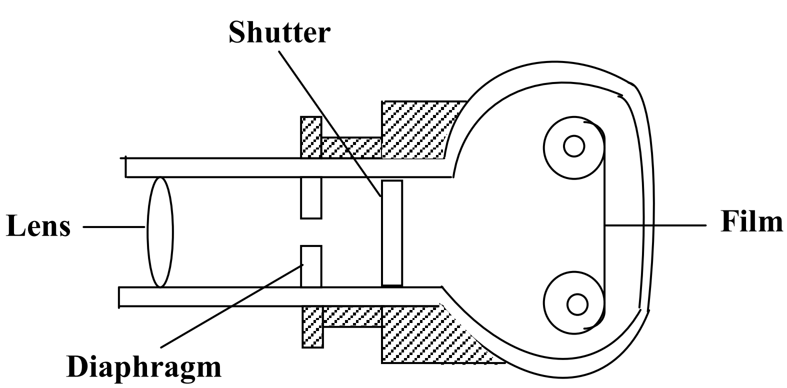
When a person is suffering from presbyopia, he or she develops eyestrain, headaches or feel fatigued. It is caused by age related process which causes gradual thickening and loss of flexibility of natural lens of the eye which makes the lens harder and less elastic over a period of time

Correction of presbyopia:

It is corrected using eye glasses with bifocal lens or progressive addition lenses, contact lenses or refractive surgery. Bifocal means two points of focus that is the near part contains prescription for distance vision while the lower portion of the lens holds prescription for the close wave.

Photographic camera:

The diagram shows the essential parts of a photographic camera.



It consists of a light tight box with a convex lens at the front. At the back of the box is a light sensitive film on which a lens forms a real, inverted and diminished image. The object to be focused is placed at a distance greater than twice the focal length of the lens.

Uses of the parts of a camera:

1. A lens
This is used to focus the object on the film by adjusting the distance between the film and the lens

2. Diaphragm
This controls the amount of light entering the camera and therefore brightness of the image depends on diaphragm

3. Shutter
This controls the amount of light reaching the film

4. Film
This is where a real, inverted and diminished image of the object is formed

Similarities between the eye and the camera

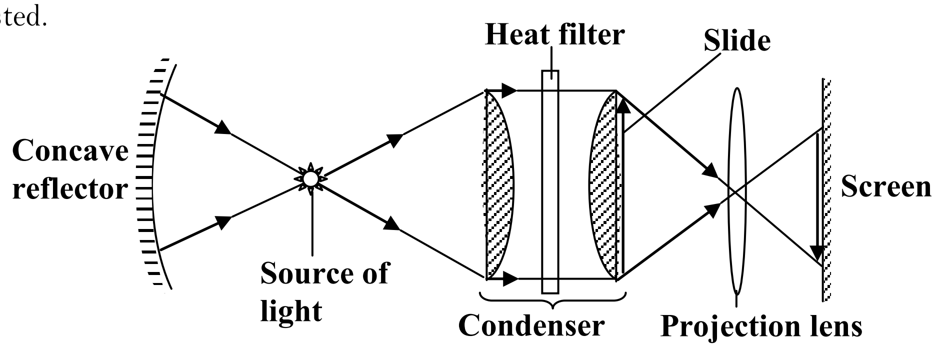
- Both have a convex lens.
- Both form real, inverted and diminished images.
- Both have a light controlling system that is diaphragm for the camera and Iris for the eye.
- Both have a light sensitive part where the images are formed that is retina for the eye and film for the camera.

Differences between the eye and the camera

- In camera the lens is artificial while in the eye the lens is a biological organ.
- The eye lens has a variable focal length while a camera lens has a fixed focal length.
- In a camera the distance between the lens and the film is adjustable while in the eye the distance between the eye lens and the retina is fixed.

THE PROJECTOR:

A projector forms a real image of the slide on the screen. It consists of the source of light which illuminates the whole system and the concave reflector which reflects back light which would have been wasted.



Functions of the parts:

1. Condenser
It is made up of two Plano-convex lenses and it concentrates light on to the slide and evenly distributes light on the screen.

2. Projection lens
It magnifies the image of the slide on the screen

3. Concave reflector
It reflects back the light that would be wasted at the back of the projector

4. The screen

This is where a real image of the slide is formed

5. Slide

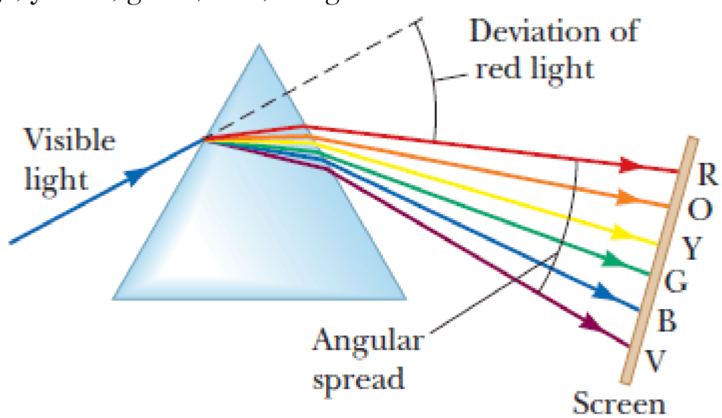
It acts as the object of the image

DISPERSION AND COLOURS:

Dispersion:

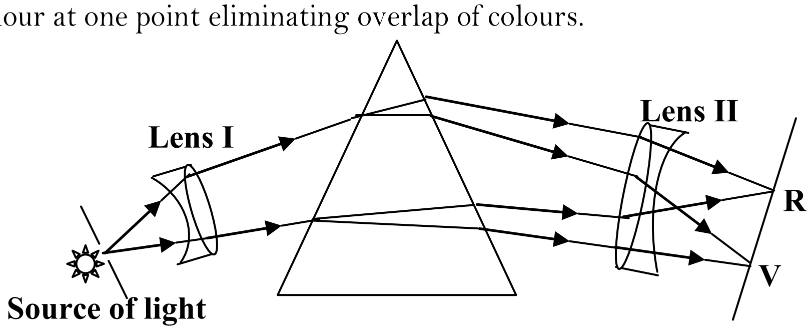
This is the splitting of white light into its constituent colours by the prism. The prism splits white light because the prism has different refractive index for each colour of white light and each colour has different speed in glass and therefore refracted through different angle. The red colour is deviated least and violet colour is deviated most.

The band of the colours on the screen is referred to as the spectrum and these colours are red, orange, yellow, green, blue, indigo and violet.



Pure spectrum:

The spectrum produced by the prism is not a pure spectrum because colours overlap. A better method of obtaining a pure spectrum than the one just described is to use a parallel beam of light as in an instrument called a spectrometer. An illuminated slit is placed at the principal focus of a converging lens so that a parallel beam of light emerges from it and falls on a prism. Refraction through the prism splits up the light into separate parallel beams of different colours, each of which is brought to its own focus in the focal plane of a second lens. Here the spectrum may be formed on a white screen or, alternatively, viewed through a magnifying eyepiece. The combination of slit and first lens is called the collimator (to collimate means to make parallel). The second lens with cross wires in its focal plane together with the eyepiece forms a telescope. To produce a pure spectrum two lenses are used lens I produces a parallel beam incident on the prism and lens II converges light of the same colour at one point eliminating overlap of colours.



Rain bow:

When white light from the sun enters a rain drop it undergoes refraction and then dispersed and the spectrum is totally internally reflected inside the water drops and this is referred to as a rainbow.

A **rainbow** is phenomenon that is caused by reflection, refraction and dispersion of light in water droplets resulting in a spectrum of light appearing in the sky. It takes the form of a multicoloured arc. Rainbows caused by sunlight always appear in the section of sky directly opposite the sun. Rainbows can be full circles; however, the average observer sees only an arc formed by illuminated droplets above the ground and centred on a line from the sun to the observer's eye.

Note:

- In a primary rainbow, the arc shows red on the outer part and violet on the inner side. This rainbow is caused by light being refracted (bent) when entering a droplet of water, then reflected inside on the back of the droplet and refracted again when leaving it.
- In a double rainbow, a second arc is seen outside the primary arc, and has the order of its colours reversed, red facing toward the other one in both rainbows. This second rainbow is caused by light reflecting twice inside the water droplets.

The colour of the object:

The colour of an object depends on the colour of light falling on that object and the colour the object transmits or reflects. Therefore the colour of the object is determined by the colour of light falling on that object. A white object reflects all the colours of the spectrum and therefore appears white in white light while a black object absorbs all the colours of white light and reflects none to the eye and therefore appears black.

Examples:

1. A red flower and a blue cloth both appear completely black in a dark room because there is no light falling on the objects.
2. Green leaves will appear green in white light because green leaves absorb all other colours in white light and reflects only green colour
3. A yellow dress [green + red] appears green in cyan light [green + blue] because a yellow dress absorbs blue colour and reflects green colour.
4. Yellow flowers [green + red] appear black in blue light because blue colour is absorbed and none is reflected.
5. A red shirt with blue strips appears black with blue strips in cyan light [green + blue] because a red shirt absorbs all collours and reflects none and blue strips absorbs green and reflects blue colour.

Types of colours:

There are three types of colours and these are

- Primary colours.
- Secondary colours.
- Complementary colours.

Primary colours:
These are colours that cannot be obtained by mixing any other colours

Examples are Red, Green and Blue

Secondary colours:
These are colours obtained by mixing two primary colours

Examples are

Yellow = Red + Green

Cyan (Peacock Blue) = Blue + Green

Magenta = Red + Blue

Complementary colours:
These are colours when added together a white colour is produced

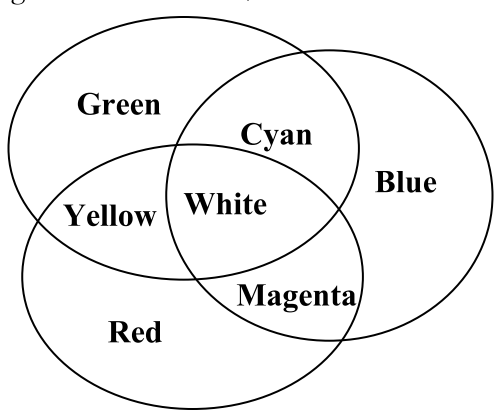
Examples are

Yellow + Blue = White

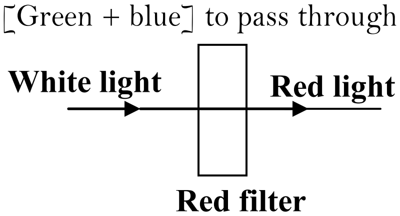
Cyan + red = White

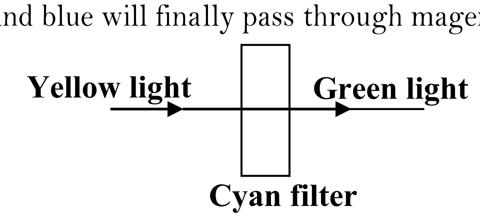
Magenta + Green = White

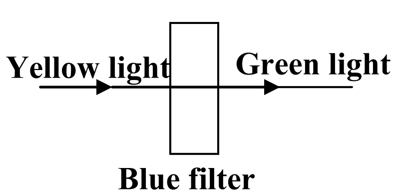
Note: When three primary colours are all added together a white colour is obtained and the above can be summarized in a Venn diagram shown below;

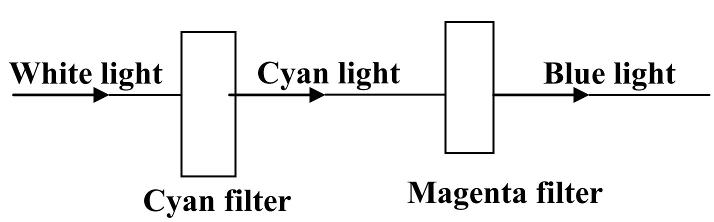


The filters:
These are transparent material treated with various dyes which allow the colour of its own to go through it and absorbs other colours. White light incident on a red filter allows red light to pass through it and absorbs other colours, yellow light incident on a cyan filter allows green light to pass through it and absorbs blue colour while yellow light incident on a blue filter allows blue light to pass through it and absorbs green colour and White light incident on a cyan filter and magenta filter allows cyan light [Green + blue] to pass through cyan filter and blue will finally pass through magenta filter.



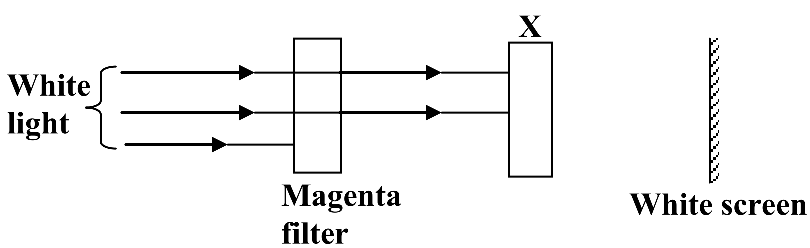






Multiple-choice Exercise:

1. Which of the following is not true, when constructing ray diagrams?
   A. rays through the optical centre are un-deviated
   B. rays through the principal focus emerge parallel to principal axis after refraction through the less
   C. rays parallel to the principal axis pass through the centre of curvature after refraction through the lens
   D. rays parallel to the principal axis pass through the principal focus after refraction through the lens
2. When does a converging lens act as a magnifying glass? When the object is
   A. at the principal focus B. between F and 2F
   C. Beyond 2F D. between the lens and F
3. An object is placed in front of a convex lens at a distance less than the focal length of the lens. The image formed is
   A. virtual, erect and magnified B. virtual, inverted and diminished
   C. real, erect and diminished D. real, inverted and magnified
4. An image 5cm high is formed by a converging lens. If the magnification is 0.2, find the height of the object
   A. 20cm B. 46cm C. 50cm D. 25cm
5. A house is painted green and blue. What colour will it appear when viewed through a magenta filter?
   A. black and blue B. black and green C. green and blue D. black
6. Which of the following make a pair of complementary colours
   A. blue and yellow B. green and red
   C. green and yellow D. yellow and magenta
7. Which of the following are secondary colours only?
   A. red, green and yellow B. blue, yellow and magenta
   C. yellow, cyan and magenta D. red, green and blue
8. The figure shows white light incident on a magenta colour filter.



   What colour filter should X be so that red is seen on the screen?
   A. cyan B. blue C. black D. yellow
9. When a girl wearing a red dress with a white stripes passes under a green street light, her dress appears.
   A. green with no stripes B. red with green stripes
   C. black with green stripes D. black with white stripes

10. When a yellow dress with blue dots is placed in a room lit with pure red light, the dress appears
A. red with black dots B. yellow with blue dots
C. green with red dots D. black with yellow dots
11. An object is placed between a converging lens and its principal focus. The image formed is
A. real, magnified and upright B. real, magnified and inverted
C. virtual, diminished and upright D. virtual, magnified and upright
12. A piece of white cloth viewed through a blue glass looks blue because
A. blue light is absorbed by the glass
B. the glass adds blue light to the light coming from the cloth
C. the glass transmits only blue light and absorbs all other colours
D. the colour of the glass is reflected onto cloth
13. A compound microscope uses
A. a lens B. convex mirrors C. combination of lenses D. plane mirrors
14. An air bubble in water will act like a
A. convex lens B. convex mirror C. concave lens D. concave mirror
15. The formation of brilliant colors in a thin soap film is a consequence of the phenomena of
A. polarization and interference B. diffraction and dispersion
C. multiple refraction and dispersion D. multiple reflection and interference
16. A thin magnifying glass has a focal length of 10 cm. What is the power of the glass is?
A. 0.1 D B. 5.0 D C. 10.0 D D. 20.0 D
17. If the image was formed in front of the retina rather than on the retina, then the person would need to correct the vision problem by using a
A. convex lens B. concave lens C. chromatic lens D. alarm clock
18. Different colors of light correspond to different light …………..in the medium
A. polarities. B. velocities. C. intensities. D. wavelengths.
19. Complementary colors are two colors that
A. look good together. B. are right for each other.
C. are additive primary colors. D. produce white light when added together.
20. A lens is used in optics to
A. disperse light. B. filter light. C. focus light. D. Reflect light

Answers:

1	C	5	A	9	C	13	C	17	B
2	D	6	A	10	A	14	A	18	B
3	A	7	C	11	D	15	C	19	D
4	D	8	D	12	C	16	C	20	C

MISCELLANEOUS EXERCISE 2:

1. a) What is meant by focal length of a lens

b) Where should an object be placed in front of a converging lens in order to obtain

i) Diminished real image

ii) A real image, same size as the object

iii) A magnified real image

iv) A magnified virtual image

c) An object 4cm high is placed perpendicularly on the principal axis 10cm away from a converging lens of focal length 15cm. With the aid of a ray diagram, determine nature, position and magnification of the image formed

Ans: 30cm, 3

d) Mention two applications of the image formed

2. a) Define the following

i) Critical angle ii) Total internal reflection

b) Explain briefly why the sky appears blue

c) State two applications of a concave mirror

d) i) An object 8cm high is placed perpendicularly on the axis and 12cm away from a concave mirror. With the aid of a ray diagram, find the focal length of the mirror if the height of the image formed is 2cm

Ans: 2.4cm

ii) State the nature of the image formed in (i) above

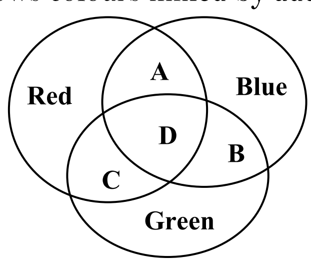
3. a) Explain dispersion as applied to light

b) i) What is a pure spectrum

ii) With the aid of a labeled diagram, describe briefly how a pure spectrum is produced

c) i) Distinguish between a primary and a secondary colour

ii) The figure below shows colours mixed by addition. Name the colours represented by letters labeled A, B, C and D



d) State the colour of a yellow dress in green light

4. a) Define the following as applied to a concave mirror

i) Centre of curvature

ii) Principal axis

b) State and explain one application of

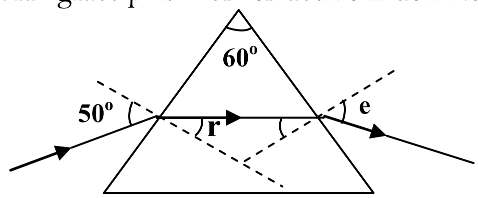
i) Concave mirror ii) Convex mirror

c) Describe an experiment to measure the focal length of a concave mirror

d) An object of height 1cm is placed 15cm in front of a concave mirror of focal length 10cm. If the object is perpendicular to the principal axis, find by construction the position, the size and nature of the image.

Ans: 30cm, 2cm

5. a) The diagram below shows a ray of yellow light incident at an angle of 50° on one side of an equilateral triangular glass prism of refractive index 1.52



i) Calculate the angles marked r and e

Ans: r = 30.3°, e = 48.9°

ii) State and explain what would be observed if the ray above were of white light

b) Explain, with the aid of a diagram, why the writing on a piece of paper placed under a glass block appears raised when observed from above

c) State

i) The conditions necessary for total internal reflection to occur

ii) One application of total internal reflection

6. a) i) State the laws of refraction of light

ii) Describe an experiment to verify the laws of refraction of light

b) An object 5cm tall placed in front of a converging lens, forms an inverted image twice as tall as the object and 30cm from the lens. By construction, find the position of the object, the focal length and power of the lens

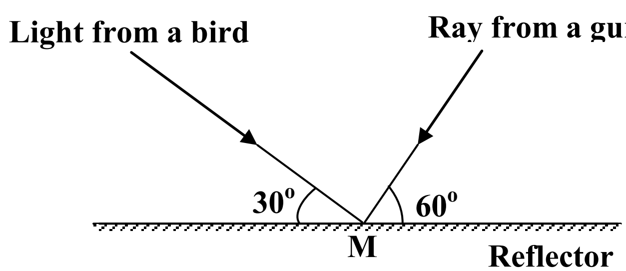
Ans: 15cm, 10cm, 10D

c) A ray of light is incident on glass from air at an angle of 42°. If the refractive index of glass is 1.41, find the angle of refraction

Ans: 28.3°

7. a) With the aid of diagrams, distinguish between diffuse and regular reflection

b)



A ray from a bird makes an angle of 30° with a plane reflector and a ray from the barrel of a gun makes an angle of 60° to the same reflector at the same point, M as shown figure above. Find the angle through which the reflector must be rotated about M such that the ray from the barrel of the gun falls on the bird.

Ans: 15°

c) With the aid of diagram explain why a parabolic mirror is most suitable for use in car headlights

d) List three uses of a concave mirror

8. a) i) State the laws of reflection of light

ii) Describe an experiment to verify the laws of reflection of light

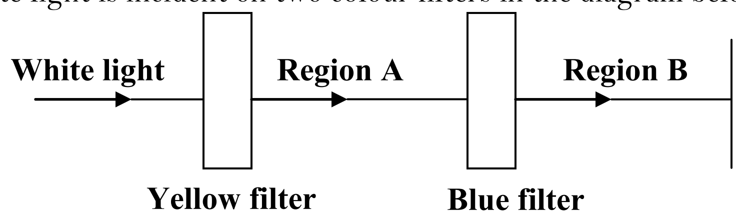
b) i) Define the term critical angle

ii) A ray of light moving from water to air at an angle of incidence of 48.6° has the angle of refraction of 90°. Calculate the refractive index of water

Ans: 1.33

c) Distinguish between primary and secondary colours

d) White light is incident on two colour filters in the diagram below



i) State the colours that will be observed in regions A and B

ii) Explain the observation in (d) (i) above

9. a) Explain the term virtual image as applied to optics

b) With aid of a ray diagram, explain why a convex mirror is used as a driving mirror

c) An object is placed 15cm in front of a concave mirror. An upright image of magnification four is produced. By graphical method, determine the

i) Nature of the image

ii) Focal length of the mirror

iii) Distance of the image from the mirror

Ans: ii) 12cm iii) 60cm

d) Name two applications of a concave mirror

10. a) Explain the following terms as applied to a thin converging lens

i) Principal focus

ii) Focal length

iii) Power

b) An object is placed at right angles to the principal axis of a thin converging lens of focal length 10cm. A real image of height 5cm is formed at 30cm from the lens. Find by construction the position and height of the object.

Ans: 15cm, 2.5cm

c) With the aid of a ray diagram show how a converging lens can be used as a magnifying glass

11. a) With the aid of a diagram, explain briefly how a pure spectrum may be produced

b) i) What are primary colours? Name them

ii) Explain briefly what happens when white light falls on a green body

c) With the aid of a labeled diagram, describe how a lens camera works

12. a) Explain the phenomenon of dispersion as applied to white light

b) Draw a ray diagram to show the dispersion of white light by a glass prism

c) Distinguish between secondary and primary colours. Give one example of each

d) Name the colour that would be obtained when the following coloured lights are mixed

i) Green and red ii) Cyan and red

e) Explain why an object illuminated by white light appears

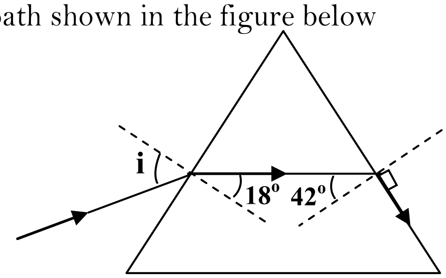
i) Coloured

ii) Black

13. a) Describe a simple method of measuring the refractive index of glass in form a block

b) i) Explain, with the aid of a diagram, the term critical angle

ii) Light of the same wave length is incident at an angle i on glass prism. The light is refracted and follows the path shown in the figure below



Find the refractive index of glass and the angle of incidence, i

Ans: n = 1.49, i = 27.4°

14. a) Define

i) The principal focus of a converging lens

ii) A virtual image

b) With the aid of a labeled diagram, describe a simple to determine the focal length of a converging lens

c) An object of height 4cm is placed perpendicularly on the principal axis at a distance of 45cm from a converging lens of focal length 15cm. By graphical construction, determine

i) The position of the image

ii) The magnification

Ans: i) 22.5cm, 0.5

d) Give one use of converging lenses

15. a) i) Describe a simple experiment to show that light travels in a straight line

ii) An object 3cm high is placed at right angle to the principal axis of a concave mirror of focal length 7.5cm. If the object is 30cm from the pole of the mirror, construct a ray diagram to obtain the position and size of the image formed

iii) State two applications of a concave mirror

Ans: ii) 10cm, 1cm

b) i) State laws of refraction of light

ii) Light of the same wavelength is incident from air on glass of refractive index 1.5. If the angle of incidence is 60°, find the angle of refraction

Ans: ii) 35.3°

16. a) Describe an experiment to demonstrate the laws of reflection of light

b) With the aid of a diagram illustrate how shadows are formed when an opaque object is placed between an extended source of light and the screen

c) An object 10cm high is placed at a distance of 15cm from a convex mirror of focal length 30cm

i) Draw a ray diagram to locate the position of the image

ii) Calculate the magnification

Ans: i) 10cm **ii) 0.67**

d) Give reasons for use of convex mirrors in vehicles

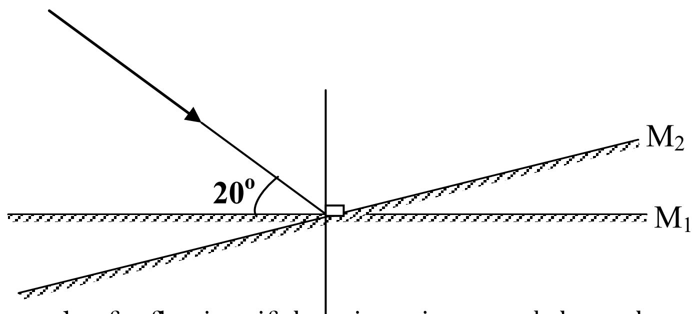
17. a) State the laws of reflection of light

b) Describe an experiment to demonstrate the principal of reversibility of light

c) An object is released from a height of 10m above a plane mirror. What distance must it drop through in order to be 5m away from its image?

Ans: 7.5m

d) An incident ray makes an angle of 20^{o} with a plane mirror in position M_1 as shown in the diagram below;



What will be the angle of reflection, if the mirror is rotated through 6^{o} to position M_2 while direction of incident ray remains the same?

Ans: 64^{o}

e) With the aid of a ray diagram, explain how a thick plane mirror forms multiple images of an object.

18. a) Describe a simple experiment to show that light travels in a straight line

b) An object of height 4cm is placed 35cm away from a pin-hole camera. The screen is 7cm from the pin-hole camera

i) Draw a ray diagram to show the formation of the image by the pin-hole camera

ii) What is the nature of the image formed?

iii) Find the magnification

iv) Explain what happens to the image if the pin-hole is made larger

Ans: iii) 0.2

c) Draw a diagram to show the formation of a solar eclipse

19. a) Use a ray diagram to show how a virtual image is formed in a converging lens

b) A converging lens of focal length 20cm forms a real image 4cm high of an object which is 5cm high. The image is 36cm away from the lens; determine by graphical method the position of the object

Ans: 45cm

c) State two differences between a pin-hole camera and lens camera

d) With the aid of a diagram explain why a pond appears shallower than it actually is

e) Using a labeled diagram show how two right-angled isosceles prisms may be used to produce an erect image of a distant object

20. a) Explain the causes of refraction of light

b) Describe an experiment you would use to measure the refractive index of glass using a glass block

c) i) State the conditions for total internal reflection to occur

ii) State one application of total internal reflection

iii) Calculate the critical angle for an air-glass interface if refractive index of glass is 1.5

Ans: 41.8^{o}

W A V E S

A wave is a disturbance through a medium which transfers energy from one point to another without causing any permanent displacement of medium itself.

Transmission of energy by a wave:

Energy is transmitted from one point to another in form of waves.
When a stone is dropped in still water, ripples spread out in form of concentric circles from the point where the stone enters the water and if a floating body is placed in the ripples it moves up and down, therefore the molecules of water are moving up and down with the energy received from previous molecule and in so doing energy is transferred to the next molecule.

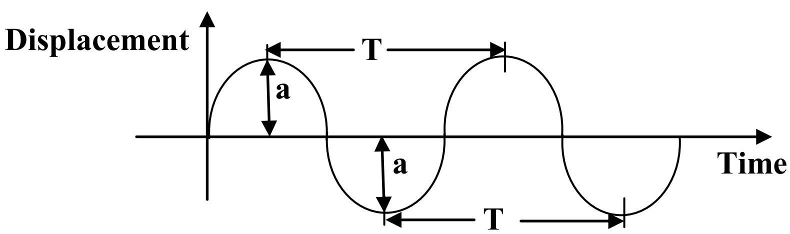
Oscillations:

An oscillation is a to and fro movement **OR** it is a change which keeps on repeating regularly.
Examples that produce oscillations are

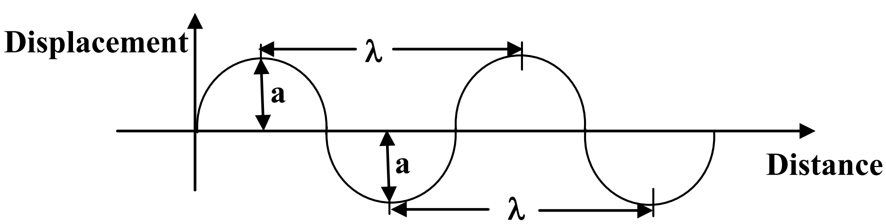
- Swinging a pendulum bob.
- A mass on a spring when pulled and released.
- When a rope is fixed and it is jerked its other end.

Terms used in wave motion:

Displacement – time graph



Displacement – distance graph



1. Amplitude, a

This is the maximum displacement from undisturbed position of the wave

2. Crest

This is a point of maximum displacement from undisturbed position

3. Trough

This a point of minimum displacement from undisturbed position

4. Wave length, λ

This is the distance between two successive crests or two successive troughs

5. Period, T

This is the time taken to complete one oscillation. It is measured in seconds

6. Frequency, f

This is the number of oscillations per second. It is measured in Hertz (Hz)

$$\text{Frequency} = \frac{1}{\text{period}}$$

$$f = \frac{1}{T}.$$

$$T = \frac{1}{f}$$

7. Wave form

This is the shape of the wave

6. Phase

This is the time of the wave in comparison with another wave

WAVE MOTION:

Wave motion is divided into two and these are;

i) Mechanical wave.

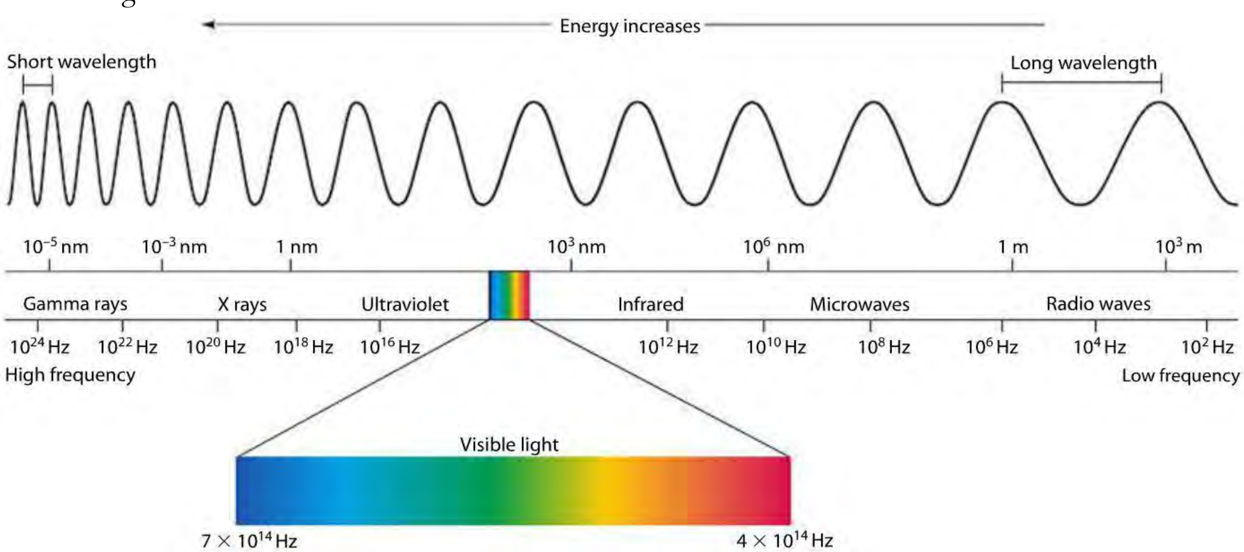
ii) Electromagnetic wave.

Mechanical wave motion:

Mechanical wave motion is a mechanism by which energy is transferred from one point to another through a material medium. In wave motion particles of the medium are temporarily displaced and then return to their original position. Mechanical wave is categorized as transverse wave and longitudinal wave.

Electromagnetic spectrum:

Electromagnetic waves are made up of electric and magnetic vibrations of very high frequency. They do not need a material medium for their transmission and therefore they can travel through a vacuum. They are produced by oscillating electric sparks and very hot bodies. Any particular range of wavelength of electromagnetic waves is called a band



Gamma rays:

Gamma rays have shortest wave length and the highest frequency, therefore greatest penetrating power and high energy. Gamma rays are produced within the nuclei of some radioactive elements. They cause solution to harden and lubricating oil to thicken on exposure but they destroy body tissues on exposure to the body for long time.

X-rays:
They have longer wavelength than gamma rays. They cause certain metals to emit electrons but destroy body tissues on exposure to the body for a long time. X-rays are produced by fast moving electrons on hitting the metal target.

Visible light:
Visible light helps us to see objects. It determines the colour of the object and the appearance of the object.

Ultra-violet [uv] light:
This is a type of radiation with wavelength just shorter than violet. The sun emits much of the energy in form of ultra-violet light but most of it is absorbed by the atmosphere.
Ultra-violet light causes certain metals to emit electrons, they cause photosynthesis in green plants and they cause blindness when too much of it falls into the eyes.

Infrared:
All objects emit infrared radiations. They cause the body temperature to rise because most of the heat in light is carried by infrared. Infrared enables us to get vitamin D.

Radio waves:
Radio waves are produced when electrons are accelerated in an aerial. They have the longest wavelength and lowest frequency. Radio waves can penetrate most materials.

Properties of electromagnetic waves:

- They are transverse waves in nature.
- They travel at a speed of light of $3 \times 10^8 ms^{-1}$ in a vacuum.
- They do not need a material medium.
- They carry energy.
- They have no specific charge

Differences between mechanical waves and electromagnetic waves:

Electromagnetic waves	Mechanical waves
1. They travel through the vacuum	They can not travel through the vacuum
2. They do not require a material medium for their transmission	They require a material medium for their transmission
3. They are transverse	They are longitudinal & transverse
4. Caused by electromagnetic vibrations	Caused by a disturbance in a medium
5. They are faster	They are slower

Similarities between mechanical waves and electromagnetic waves

- Both carry energy from one place to another.
- Both are subject to interference.
- Both can be reflected, refracted and diffracted

Wave equation:

Consider a wave moving with a speed, V

$$\text{Speed, V} = \frac{\text{Distance}}{\text{time}}$$

When distance = wave length, λ

$\text{time} = \text{period, T}$

$$\text{Speed} = \frac{\text{Wave length}}{\text{period}}$$

$$V = \frac{\lambda}{T} \qquad \text{But } f = \frac{1}{T}$$

$$\mathbf{V = \lambda f}$$

Examples:

1. Calculate the frequency of the wave if its velocity and wave are 5ms^{-1} and 0.5m respectively

$V = f\lambda$

$5 = 0.5f$

$f = 10\text{Hz}$

2. A vibrator of frequency 50Hz produces circular waves. If the distance between the two successive crests is 3cm. find the speed of the waves

$V = f\lambda$

$V = 50 \times 0.03$

$f = 1.5\text{ms}^{-1}$

3. A vibrator with a frequency of 20Hz vibrates for a distance of 25cm in 5 seconds. Find

i) The speed of the wave produced

ii) Wave length of the wave produced

i) $\text{Speed} = \frac{\text{Distance}}{\text{time}}$

$V = \frac{0.25}{5} = 0.05\text{ms}^{-1}$

ii) $V = f\lambda$

$0.05 = 20 \times \lambda$

$\lambda = 0.0025\text{m}$

4. A vibrator produces waves which travel a distance of 35cm in 2 seconds. If the distance between two successive crests is 5cm. find

i) The velocity of the waves

ii) The frequency of the waves

i) $\text{Speed} = \frac{\text{Distance}}{\text{time}}$

$V = \frac{0.35}{2} = 0.175\text{ms}^{-1}$

ii) $V = f\lambda$

$0.175 = 0.05 \times f$

$f = 3.5\text{Hz}$

Note that if the distance between n successive crests is d, then wave length, $\lambda = \frac{d}{n-1}$

Example:
If the distance between 9 successive crests is 48cm. Find the wave length of the wave

$\lambda = \frac{d}{n-1}$

$\lambda = \frac{48}{9-1}$

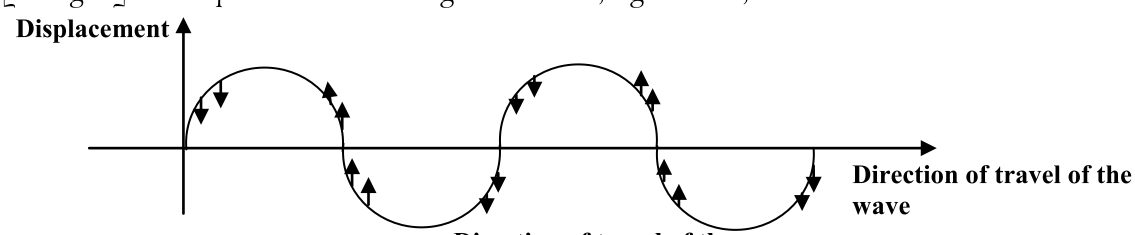
$\lambda = \frac{48}{8}$

$\lambda = 6cm$

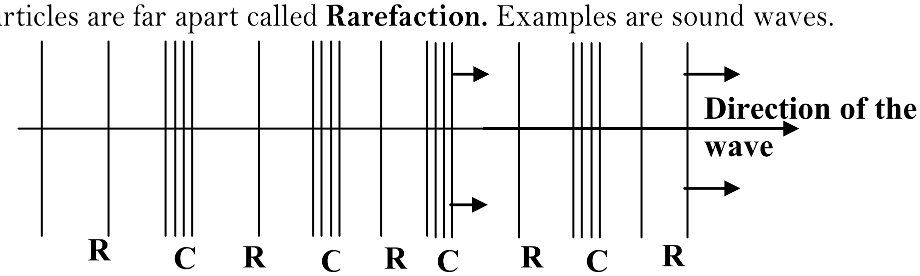
TYPES OF WAVES:
There are two types of waves and these are
i) Progressive waves
ii) Stationary [Standing] waves.

Progressive waves:
Progressive waves are waves which carry energy away from the source. As the wave moves the particles at maximum displacement are in phase and the particles in minimum displacement are in opposite phase.
There are two types of progressive waves and these are
a) Transverse waves.
b) Longitudinal waves.

Transverse wave:
This is a wave in which the direction of travel of the particle is perpendicular to the direction of travel of the wave. It has regions of maximum displacement [crests] and regions of minimum displacement [troughs]. Examples are electromagnetic waves, light wave, water waves and wave from vibrating string.



Longitudinal wave:
This is a wave in which the particles travel in the same direction as the direction of travel of the wave. It has regions in which oscillating particles are close together called **Compression** and regions in which oscillating particles are far apart called **Rarefaction.** Examples are sound waves.



C – Compressions
R – Rarefactions
Note that the distance between two successive compressions or rarefactions is equal to the wave length of the wave.

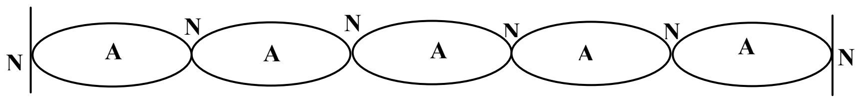
Stationary [standing] waves

This is a wave formed when two transverse waves of the same speed, frequency, wave length and amplitude traveling in opposite direction meet. It has points which are permanently at rest called Nodes and points which vibrate with maximum displacement called Antinodes.

Conditions for stationary wave to be formed:

The following conditions are necessary to form a stationary wave

- The waves have the same frequency.
- The waves have the same speed.
- The waves have the same wave length.
- The waves have the same amplitude.
- The waves are moving in opposite directions.



NOTE:

The distance between two successive nodes or Antinodes is equal to a half wave length (½λ)

Example:

The distance between two successive nodes is 12cm. Find the wave length of the wave

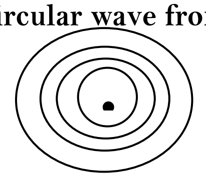
$\frac{1}{2}\lambda = 12$

$\lambda = 24\text{cm}$

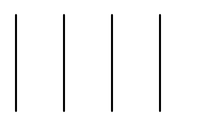
WAVE FRONT:

This is the surface of the wave form on which every particle transmitting the wave is at the same distance from source of the wave and in the same state of disturbance. Wave fronts are either circular or plane wave fronts.

Circular wave front



Plane wave fronts

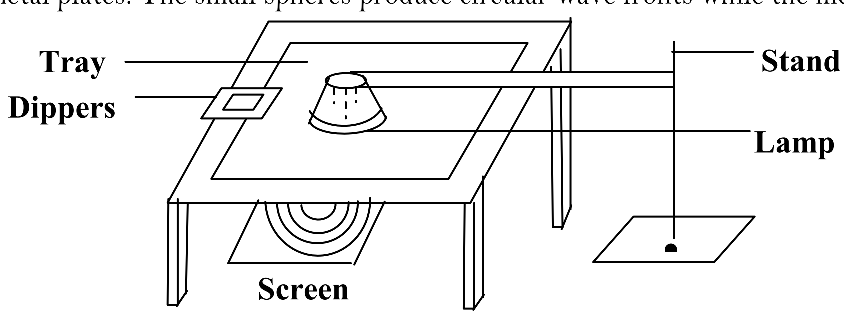


NOTE:

The distance between two successive wave fronts is equal to the wave length, λ

RIPPLE TANK:

This is the instrument used in the laboratory to study the behavior of the water waves. It consists of a transparent tray containing water. In order to observe the wave pattern formed on the water surface, the ripple tank is placed between the source of light and the screen. The images of the waves are then formed on the screen which is placed below the ripple tank. The waves are produced by means of the dippers which are in form of small spheres and metal plates. The small spheres produce circular wave fronts while the metal plates produce plane wave fronts.

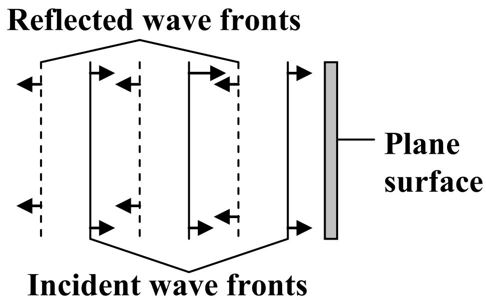


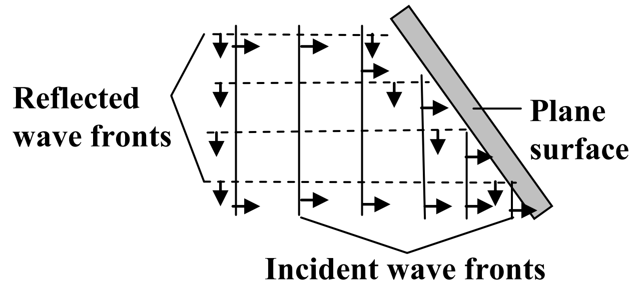
REFLECTION OF WAVES:

This is the bouncing off of waves when they meet a barrier. The waves produced in a ripple tank are reflected when a barrier is placed in their path.

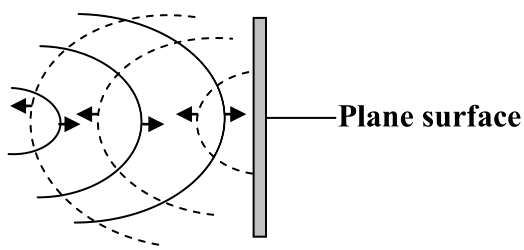
a) Reflection on a plane surface

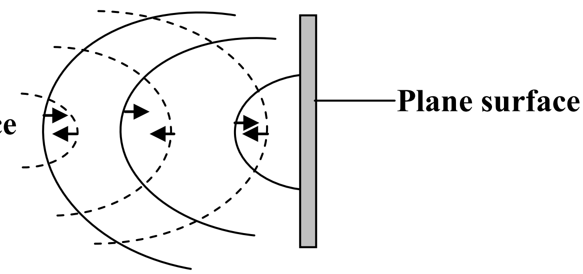
A plane wave front incident on a plane surface is reflected as a plane wave front and if the plane surface is inclined at an angle of $45°$ to the waves, the waves are reflected as shown below





Circular convex wave fronts incident on a plane surface are reflected as circular concave wave fronts and circular concave wave fronts are reflected as convex circular wave fronts.

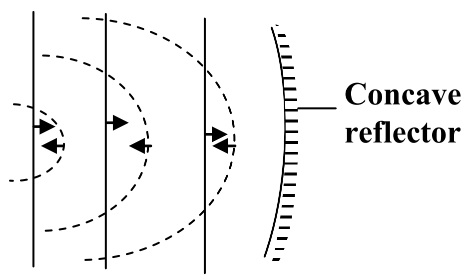




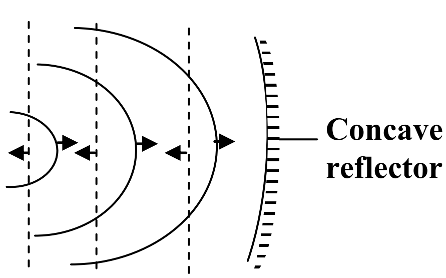
b) Reflection on a curved surface

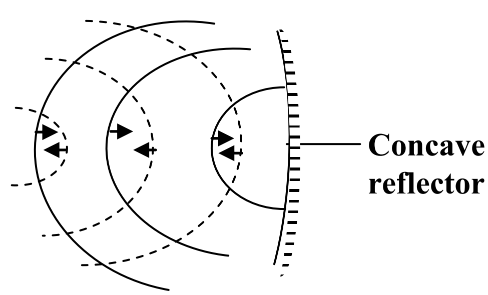
i) Concave reflector

Plane wave fronts incident on a concave reflector are reflected as circular wave fronts.



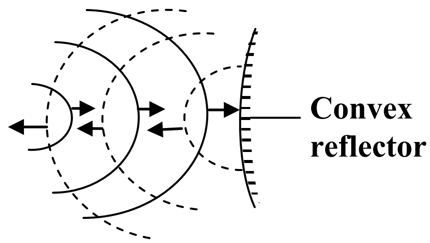
Concave circular wave fronts are reflected as plane wave fronts and convex circular wave fronts are reflected as concave circular wave fronts.



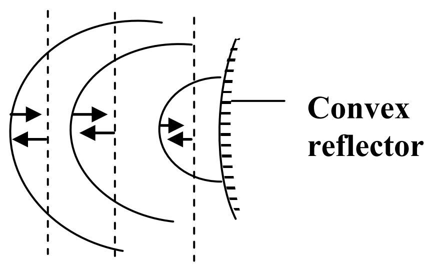


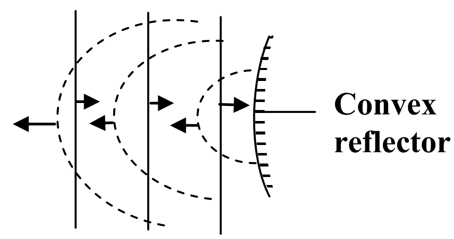
ii) Convex reflector:

Concave circular wave fronts are reflected as convex circular wave fronts



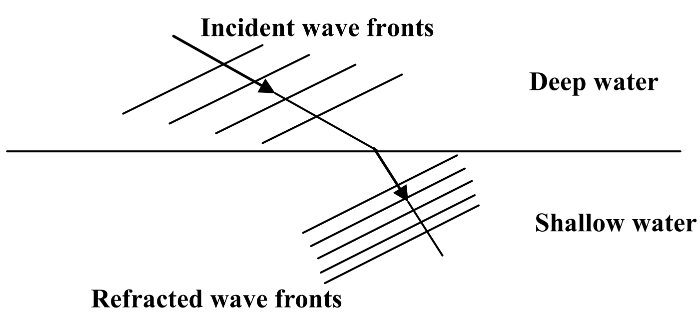
Convex circular wave fronts are reflected as concave circular wave fronts and Plane wave fronts are reflected as circular wave fronts.





REFRACTION OF WAVES:

This is change in direction of the wave when a wave moves from one medium to another of different optical densities. When a wave is refracted there is change in wave length and speed but the frequency remains constant. Waves formed in a ripple tank can be refracted by placing a sheet of glass in water to make it shallow. When a wave moves from deep water to shallow water its wave length and its speed decrease but the frequency does not change. The wave fronts are therefore close to one another in shallow waters than in deep waters as shown below.



$$\cap = \frac{\text{Velocity of wave in the first medium, } V_1}{\text{Velocity of the in the second medium, } V_2}$$

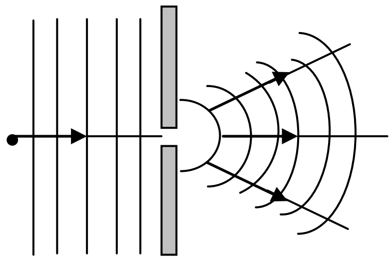
$$= \frac{f\lambda_1}{f\lambda_2}$$

$$\cap = \frac{\lambda_1}{\lambda_2}$$

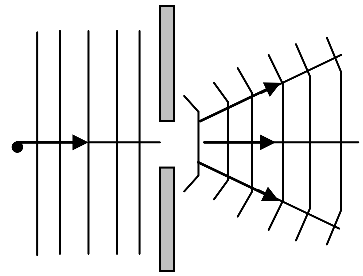
DIFFRACTION OF WAVES:

This is the spreading of waves of the same wave length and frequency around the corner or barrier. In a ripple tank diffraction can be achieved by placing two barriers with a gap between them and plane wave fronts made to pass through the gap. If the gap is made smaller the plane wave fronts emerge with a circular shape and spread out in all directions and if the gap is made wide plane wave fronts emerge bent slightly at the edges as shown below;

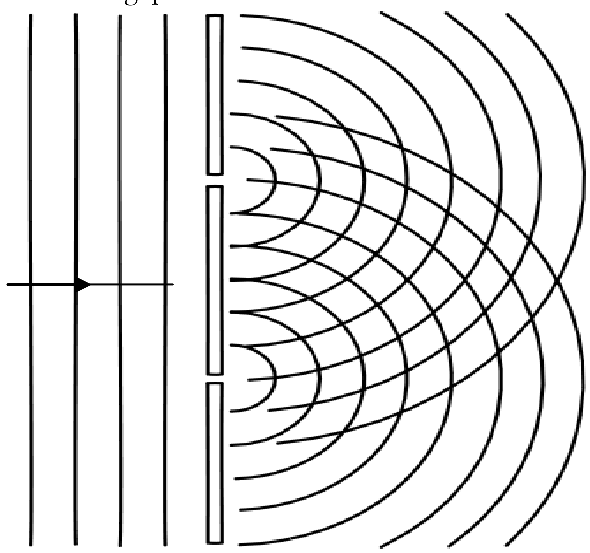
Narrow gap



Wide gap



If there are two or more gaps in a barrier the waves will be diffracted and interference of waves takes place.



INTERFERENCE OF WAVES:

This is the effect which occurs when two waves of the same speed, frequency, wave length and amplitude traveling in the same direction meet. The waves merge and combine and the ability of the waves to combine together is called the principle of super position

Conditions for interference to occur:

For interference to occur the following conditions are important

- The waves have the same frequency.
- The waves have the same speed.
- The waves have the same wave length.
- The waves have the same amplitude.
- The waves are moving in the same direction

Types of interference:

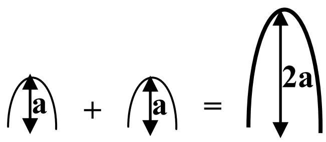
There are two types of interference and these are

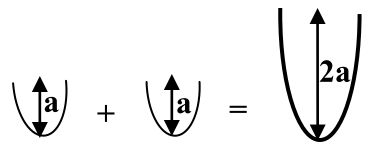
i) Constructive interference.

ii) Destructive interference.

Constructive interference

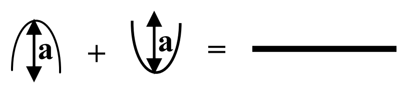
This is when a crest of one wave meets a crest of another wave or a trough of one wave meets a trough of another wave. The amplitude of the resultant wave increases and this effect occurs on the anti-nodal lines.





Destructive interference

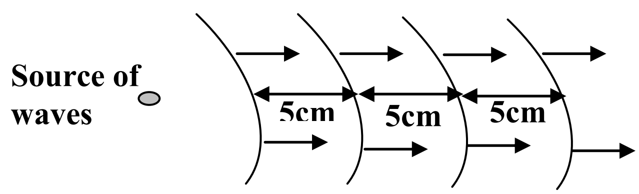
This is when a crest of one wave meets a trough of another wave. The resultant wave has no amplitude and this effect occurs on nodal lines.



Trial Exercise 1

1. The wave length of a radio wave is 10m. Given that the speed of the radio wave is $3 \times 10^8 ms^{-1}$. Find the frequency and period of the wave

   Ans: 3.0×10^7Hz, 3.33×10^{-8}s

2. 

   The frequency of the above circular waves is 32Hz. Calculate the speed of the wave

   Ans: $1.6ms^{-1}$

3. The frequency of a radio wave is 6.0×10^7Hz. Given that the speed of the radio wave is $3 \times 10^8 ms^{-1}$. Find the wave length of the wave.

   Ans: 5m

4. Water waves travel a distance of 36cm in 6 seconds and the separation between two successive troughs is 3.0cm. Calculate the velocity and the frequency of the waves

   Ans: $6 \times 10^{-2} ms^{-1}$, 2Hz

5. A source produces waves which travel a distance of 140cm in 0.08 seconds and the separation between two successive crests is 20cm. Calculate the velocity and the frequency of the waves.

   Ans: $17.5ms^{-1}$, 87.5Hz

6. Water waves of frequency of 6Hz travel a distance of 24m in 10 seconds. Calculate the velocity and wave length of the waves

   Ans: $2.4ms^{-1}$, 0.4m

7. A vibrator in a ripple tank vibrates at 500Hz. If the distance between 10 successive crests is 37.8cm. Calculate the wave length and the velocity of the waves

   Ans: 4.2cm, $21.0ms^{-1}$

8. A vibrator produces waves which travel a distance of 315cm in 20 seconds and the separation between two successive crests is 20cm. Calculate the velocity and the frequency of the waves
Ans: 0.1575ms^{-1}, 0.7875Hz

9. The frequency of a sound wave is 6.8 x 10^5Hz. Given that the speed of the sound wave is 340ms^{-1}. Find the wave length of the wave.
Ans: 5 x 10^{-4}m

10. A vibrator produces waves of frequency 2500Hz and the separation between 11 successive crests is 240cm. Calculate the wave length and the velocity of the waves
Ans: 24cm, 600ms^{-1}

Multiple-choice Exercise:

Assume speed of sound in air = 330ms^{-1} and speed of light in a vacuum = 3x 10^8ms^{-1}

1. Which of the following is the correct order of increasing wavelength of some electromagnetic waves?
A. X-rays, infra red, ultra violet, radio waves
B. infra red, ultra violet, X-ray, radio waves
C. radio waves, infra red, ultra violet, X-rays
D. X-rays, ultra violet, infra red, radio waves
2. The point of maximum energy on a stationary wave is called
A. anode B. a crest C. a trough D. an anti-node
3. Which of the following electromagnetic waves lies between ultraviolet radiation and infrared radiation?
A. gamma rays B. visible radiation C. X-rays D. microwave radiation
4. The basic difference between transverse and longitudinal waves is in
A. amplitude B. direction of vibration
C. wavelength D. medium through which the waves travel
5. Water waves of frequency 6Hz travel 24m in 10s. The wavelength of the waves is
A. 0.4m B. 2.5m C. 14.4m D. 40.0m
6. In a ripple tank constructive interference occurs when
A. the wave is stationary B. a crest overlaps with a trough
C. a crest overlaps with a crest D. a wave strikes a barrier
7. A vibrator produces a sound wave that travels a distance of 900m in 3s. If the wavelength of the wave is 10m, find the frequency of the vibrator
A. 30Hz B. 270Hz C. 300Hz D. 3000Hz
8. The electromagnetic radiation which causes the body temperature to rise is called
A. X-rays B. gamma rays C. infrared D. ultraviolet
9. The number of vibrations a wave makes in one second is called the
A. frequency B. wavelength C. period D. amplitude
10. Which of the following are longitudinal waves?
A. water waves B. light waves C. sound waves D. radio waves
11. Points on a stationary wave which are permanently at rest are called
A. crests B. troughs C. nodes D. anti-nodes

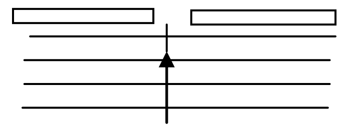
12. A vibrator produces a sound wave that travels 140cm in 0.08s. If the distance between two successive crests is 20cm, find the frequency of the vibrator

A. 7.0Hz B. 11.2Hz C. 87.5Hz D. 250.0Hz

13. Which one of the following shows the order in decreasing frequency, of the members of the electromagnetic spectrum?

A. ultraviolet, x-rays, radio waves, infrared B. radio waves, infrared, x-rays, ultraviolet
C. x-rays, ultraviolet, infrared, radio waves D. gamma rays, ultraviolet, radio waves, infrared

14. The diagram below shows parallel wave fronts approaching a narrow gap.



Waves passing through the gap are likely to undergo

A. reflection B. refraction C. diffraction D. interference

15. Which of the following are transverse waves only?

A. radio waves, sound waves, ultraviolet B. ultraviolet, x-rays, water waves
C. infrared, gamma rays, sound wave D. sound waves, ultraviolet, x-rays

16. A vibrator produces a wave that travels 36cm in 6s. If the distance between successive crests is 3.0cm, find the frequency of the vibrator

A. 2Hz B. 12Hz C. 18Hz D. 72Hz

17. Which of the following does not change when water waves travel from deep to shallow water?

A. frequency B. amplitude C. velocity D. wavelength

18. The particles of the medium through which a longitudinal wave travels

A. vibrate parallel to the direction of propagation of the wave
B. vibrate perpendicular to the direction of the propagation of the wave
C. move along with the wave
D. move in the opposite direction to the wave

19. When sound waves pass through a metal bar, the atoms of the metal

A. rotate in circles B. move along the bar
C. expand and contract D. vibrate about fixed points

20. The components of electromagnetic spectrum have

i) The same velocity
ii) Different wavelength
iii) Different frequencies
iv) The same refractive index for a given medium

A. (i), (ii) and (iii) only correct B. (i) and (iii) only correct
C. (ii) and (iv) only correct D. (iv) only correct

Answers:

1	D	5	A	9	A	13	C	17	A
2	D	6	C	10	C	14	C	18	A
3	B	7	A	11	C	15	B	19	D
4	B	8	C	12	C	16	A	20	A

SOUND WAVES:

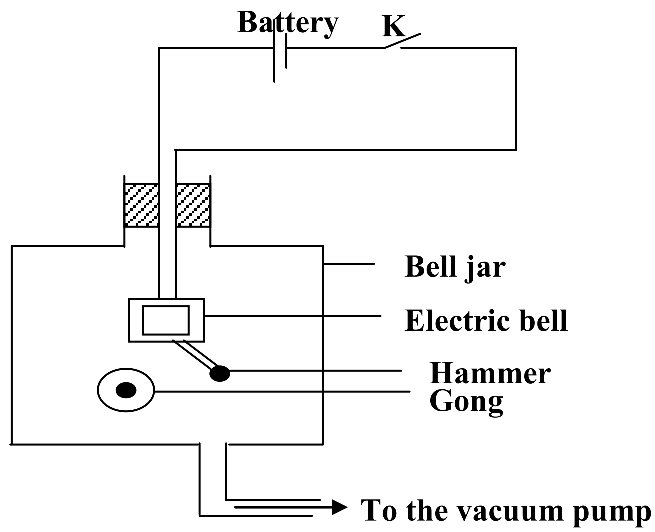
Sound waves are waves produced when particles of the medium are set into vibrations. The medium in which sound waves travel can be a solid, a liquid or gas. In gases (air) sound waves travel forming regions of compressions and rarefactions, hence sound waves cannot travel without a medium.

Properties of sound waves:

Sound waves have the following properties;

- They are longitudinal waves in nature.
- They require a material medium for their transmission.
- They can be reflected, refracted and diffracted.
- There is interference of sound waves.

Experiment to show that sound waves need a material medium for transmission:



When an electric bell inside the bell jar is switched on by closing switch, K a loud sound is heard. When the air inside the bell jar is gradually removed by means of a vacuum pump the loudness of sound heard gradually dies away. No sound is heard when all the air is completely removed from the bell jar even though the hammer is seen hitting the gong showing that sound waves need a material medium for transmission.

Factors that affect the speed of sound in a medium:

The speed at which sound travels is directly influenced by the following factors;

1. Temperature:

Increasing the temperature increases the speed of the molecules of the medium hence increasing the speed of sound in the medium. Decreasing the temperature decreases the speed of the molecules of the medium hence decreasing the speed of sound in the medium.

2. Density:

Speed of sound is higher in a denser medium than in a less dense medium because the particles in a denser medium are closely packed than in a less dense medium hence transfer of sound from one particle to another particle is fast in a denser medium. The compressions and rarefactions of sound waves cause change in wave length and therefore change in speed of sound in the medium. Speed of sound depends on the nature of the material through which sound travels. The speed of sound in solids is higher than in liquids/gases because solids are denser than liquids/gases. Speed of sound in air is about $330ms^{-1}$, in water is about $1500ms^{-1}$ while in steel bar is about $5000ms^{-1}$.

3. Wind:
The speed of sound waves increases if the direction of travel of sound is the same as that of wind because the speed of wind has to be added to that of sound to obtain the speed of sound relative to the ground. However it decreases if the direction of travel of sound is in opposite direction with the direction of travel of wind. Loudness has no effect on the speed of sound in a medium.

4. Humidity:
This is a measure of the amount of water vapour in the air. The density of moist air is less than that of dry air and the speed of sound is higher in dry air (denser medium) than in moist air (less dense medium) hence speed of sound increases with humidity.

5. Altitude:
Sound travels faster at a lower altitude and slower at a higher altitude because temperature is high at lower altitudes than at a higher altitude hence speed of the moleculecules is higher at a lower altitude than at a higher altidude.

REFLECTION OF SOUND WAVES:
Sound waves obey the laws of reflection that is they are reflected in the same way light waves are reflected

Laws of reflection of sound:
1st law

The incident wave, the reflected wave and the normal at the point of incidence all lie in the same plane

2nd law

The angle of incidence of the wave is always equal to the angle of reflection of the wave

THE ECHO:
This is the reflected sound. The speed of the echo is the same as the speed of the original sound. Echoes are often heard in the neighborhood of big houses, high cliffs and in big churches but they are not heard in small rooms because the reflected sound waves return very quickly and mix up with the original sound. The time that elapses between hearing the original sound and the echo depends on the following:

i) The distance from the reflecting surface.
ii) The speed of sound in the medium.

Note:
i) If the time that elapses is less than 0.1 seconds, then you cannot distinguish between the original sound and the echo hence the echo is not heard.

ii) If the time that elapses is 0.1 seconds the original sound appears prolonged and the prolonged sound is called **Reverberation**.

To avoid this effect in churches and concert halls; soft boards, soft materials and clothings (curtains) which absorb some of the sound waves are used.

Applications of echoes:
Echoes can be applied in the following

- Measurement of speed of sound.
- Echo sounding.
- Measurement of distance.
- Measurement of time taken by sound to travel a given distance.

Measuring velocity of sound by echo method:

Two people one to produce the sound and another to carry out the timing stand at a known distance, D from a vertical wall. One claps and the other one starts a stop clock. On hearing the echo a stop clock is stopped and the time is noted. The experiment is repeated and the average time T is calculated.

$$\text{Speed} = \frac{\text{Distance}}{\text{time}} = \frac{2D}{T}$$

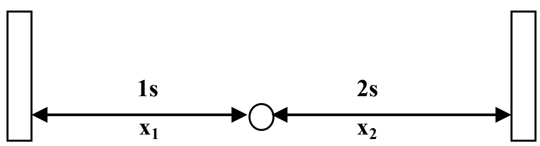
Examples

1. A man stands at 495m away from a cliff and makes a loud sound; he hears the echo after 3 seconds. Calculate the speed of sound

$$\text{Speed} = \frac{\text{distance}}{\text{Time}} = \frac{2D}{T}$$

$$\text{Speed} = \frac{2 \times 495}{3} = 330\text{ms}^{-1}$$

2. A man stands between two cliffs and makes a loud sound. He hears the first echo after 1 second and the second echo after 2 seconds. Find the distance between the two cliffs if the speed of sound in air is 330ms-1



Distance between the cliffs = $x_1 + x_2$

$$\text{Speed} = \frac{\text{distance}}{\text{Time}} = \frac{2x_1}{T_1} \qquad \text{Speed} = \frac{\text{distance}}{\text{Time}} = \frac{2x_2}{T_2}$$

$$330 = \frac{2 \times x_1}{1} \qquad 330 = \frac{2 \times x_2}{2}$$

$$x_1 = 165\text{m} \qquad x_2 = 330\text{m}$$

Distance between the cliffs = 165+ 330 = 495m

Echo sounding:

This is a device used in ships to measure depth of the sea. It consists of a transmitter and a hydrophone (microphone) which is designed to be under water. The transmitter sends out sound of very high frequency at regular intervals and the reflected sound from the sea bed is received by the hydrophone which is connected to an electrical timing circuit. The depth is calculated from plotted graph by the circuit.

In an echo sounder sounds of very high frequency are used because it cannot be confused by sounds of the engine and other sounds by the ship. It can also penetrate a larger distance in the sea without loss of energy by diffraction.

Ultrasonic sounds:

This is the sound of very high frequency which the human ear cannot detect. The human ear has a range of sound frequencies which it can hear and the lowest audibility is about 20Hz the highest limit of audibility for most people is 20 kHz. The sound waves with frequencies above 20 kHz cannot be detected by the human ear and are called ultrasonic sounds.

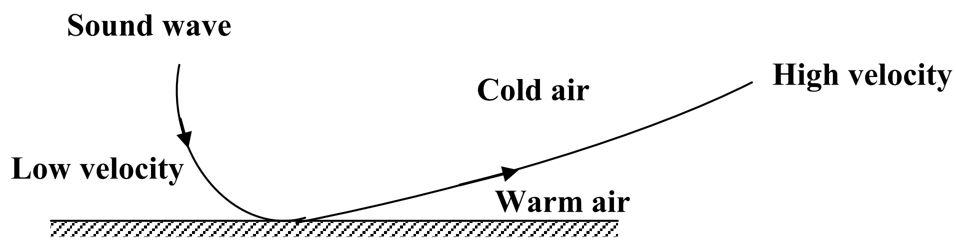
Applications of ultrasonic sounds:

- They enable bats, cats, dogs and dolphins to communicate and navigate that is they send repeated ultrasonic sound, hear and process the echo.
- They are used to distinguish between an obstacle and flying insects.
- They are used to determine the direction, speed and size of the flying insect.
- They are used in medical diagnostic ultrasound scanning.
- They are used in spectacles for blind to judge the distance of an object from the time taken by the reflected wave to return.
- They are used to measure the depth of the sea and to detect shoals of the fish.
- They are used to check flaws in welded joints and ultrasonic drills cut holes in glass and steel.

Refraction of sound waves:

Refraction occurs when the speed of sound waves changes. In air the speed of sound waves is affected by air temperature. Sound waves when passed through layers of air, they move at different rates and they change direction. When the air near the ground is cool at night refraction is towards the earth's surface making it easier to hear distant sounds across the country side.

Sounds are more audible at night than during the day because the speed of sound in warm air exceeds that in cold air and refraction occurs. At night the air near the ground is usually cooler and refraction is towards the earth but during the day the reverse is usually true and this explains why radios are clearer at night than during day time.



Trial exercise 2:

1. Two boys stand 240m from a wall. One boy bangs two pieces of wood together while the second starts a stop watch and stops it when he hears the echo. If the time on stop watch is 1.2 seconds, calculate the speed of sound

   Ans: 400ms^{-1}
2. The ship sends out an ultra sound whose echo is received after 10 seconds. If the wavelength of the ultra sound in water is 5m and the frequency of the transmitter is 50 Hz, calculate the speed of the wave and the depth of the ocean

   Ans: 250ms^{-1}, 1250m
3. The speed of sound in air is 340ms^{-1}. A loudspeaker placed between two walls but nearer to wall A than wall B is sending out constant sound pulses. How far is it from wall B if it is 200m from wall A and the time between two echoes received is 0.176 seconds

   Ans: 229.92m
4. A range of audible frequencies varies from 20Hz to 20 kHz. If the speed of sound is 340ms^{-1}, what is the corresponding range of wavelength?

   Ans: 0.017m to 17m

5. A girl stands 160m away from a high wall and claps her hands at a steady rate so that each clap coincides with the echo of the one before. If she makes 60 claps in one minute, what is the speed of sound?If the girl moves 40m closer to the wall she finds that clapping rate has to be 80 per minute. Calculate the speed of sound.

Ans: 320ms^{-1}, 320ms^{-1}

6. Explain why it is not easy to hear sound from distant sources during the day
7. How is sound produced? Explain why sounds are fainter on high mountains than at sea level
8. Why is the inside of a loudspeaker box covered with cotton material?
9. Frequency, velocity and wavelength are physical properties of a wave. Which of the three properties depends on?

   i) The behavior of the sources of the waves

   ii) The medium through which the waves travel
10. Draw and label the significant points of water waves in a ripple tank for each of the following

    i) Circular waves reflected by a plane surface

    ii) Plane waves reflected by plane surface

    iii) Circular waves reflected by a concave surface

Multiple-choice Exercise:

Assume speed of sound in air = 330ms^{-1} and speed of light in a vacuum = 3x 10^{8}ms^{-1}

1. Sound from a distant source is louder at night than during day due to

   A. refraction B. diffraction C. reflection D. interference
2. A man standing some distance from a vertical wall beats a drum. He hears the echo after 2 seconds. If the speed of sound in air is 330ms^{-1}, calculate the distance between the man and the wall

   A. 82.5m B. 165.0m C. 330.0m D. 660.0m
3. A man standing some distance from a vertical wall makes a loud sound. He hears the echo after 1½ seconds. If the speed of sound in air is 330ms^{-1}, how far is he from the wall?

   A. 110.0m B. 247.5m C. 440.0m D. 990.0m
4. Sound is produced by a source vibrating at a frequency of 50Hz. Given that its speed is 330ms^{-1} in air, its wavelength is

   A. 0.15m B. 6.60m C. 380.00m D. 16500.00m
5. The velocity of sound in air at constant pressure

   A. increases with loudness C. increases with increase in temperature

   B. decreases with loudness D. decreases with increase in temperature
6. The effect produced when many echoes merge into one prolonged sound is known as

   A. noise B. harmonics C. reverberation D. pitch
7. Man standing 85m from a vertical wall makes a loud sound. He hears the echo after 0.5s. Calculate the speed of sound in air

   A. 340ms^{-1} B. 170ms^{-1} C. 85ms^{-1} D. 43ms^{-1}
8. In a sound wave the particles of the medium

   A. are stationary C. vibrate in the same direction as the wave

   B. move along with the wave D. vibrate at right angles to the direction of the wave
9. A girl stands in between two tall cliffs, and claps her hands. She hears the first echo after 1 second and the second echo after 2 seconds. If speed of sound is 300ms^{-1}, the distance between the cliffs is

   A. 300m B. 450m C. 900m D. 1200m

10. Sound waves
A. do not pass through the vacuum
B. travel through solids at a lower speed than in air
C. do not travel through liquids
D. travel at a highest speed in air

11. An echo is produced as a result of sound waves being
A. absorbed by objects
B. transmitted by objects
C. reflected back by objects
D. bent around corners by objects

12. Sound travel much greater through
A. steel B. wood C. water D. nitrogen gas

13. A girl standing 300m away from a high vertical wall makes a loud sound of frequency 60Hz. Calculate the wavelength of sound wave if the girl hears the echo after 2 seconds.
A. 0.2m B. 2.5m C. 5.0m D. 10.0m

14. A sound wave of frequency 250Hz is produced 300m away from a high wall. If an echo is received after 2 seconds the wavelength of sound wave is
A. 2.40m B. 1.20m C. 0.83m D. 0.60m

15. Sound travel much slower through
A. steel B. wood C. water D. nitrogen gas

16. When sound waves pass through a metal bar, the atoms of the metal
A. rotate in circles
B. move along the bar
C. expand and contract
D. vibrate about fixed points

17. Which of the following are longitudinal waves?
A. water waves B. light waves C. sound waves D. radio waves

18. Sound waves in air are
A. transverse B. longitudinal C. electromagnetic D. polarized

19. Sound of frequency below 20Hz is called
A. audio sounds B. infrasonic C. ultrasonic D. supersonics

20. Sound travels with different speed in the media. In what order does the velocity of sound increase in these media
A. water, iron and air
B. iron, air and water
C. air, water and iron
D. iron, water and air

Answers:

1	A	5	C	9	B	13	C	17	C
2	C	6	C	10	A	14	B	18	B
3	B	7	A	11	C	15	D	19	B
4	B	8	C	12	A	16	D	20	C

MUSICAL SOUNDS:

These are sounds composed of uniform and regular vibrations. Musical sounds are referred to as musical notes and a musical note is a sound of regular frequency

MUSIC AND NOISE:

Music is a sound of uniform and regular frequency while noise is the sound produced by sources vibrating with irregular frequency. A combination of musical notes gives music.

Properties of musical notes:

There are three properties of musical notes and these are;

i) Pitch of the sound.
ii) Loudness of sound
iii) Quality of sound.

1. Pitch of sound:

This is the sharpness or mildness of musical notes. This property enables one to differentiate between high musical notes from low musical notes. The pitch depends on the number of vibrations (frequency) that is it increases with increase in frequency of the sound waves and decreases with decrease in frequency of the wave

2. Loudness of sound:

This is the sensation of the musical notes in the mind of an individual. Loudness of sound depends on the amplitude of the vibrations that is a loud note has larger amplitude than a quiet note. Large amplitude of the note is determined by a mass of air set into vibrations. Example a loud sound can be heard from a small radio set when connected to a large loud speaker with a large surface area because a large mass of air is set into vibrations by a large loud speaker.

Loudness of sound depends on the following factors;

i) Varying pressure exerted on the Ear drum.
ii) Sensitivity of the ear to different frequencies.
iii) Intensity of the sound.

Intensity:

This is the rate of flow of energy per unit area perpendicular to the direction of sound. Intensity depends on the following factors;

a) The square of the amplitude.
b) The square of the frequency.
c) The density of the medium.

3. Quality of sound:

This is the property of the musical note that distinguishes it from another note of the same pitch and loudness. The same musical note on different musical instruments sounds differently because no instrument can emit a pure musical note. The musical notes consist of the fundamental note mixed with other notes called Overtones (Harmonics). The fundamental note is the lowest note produced by a musical instrument while the Harmonics are the integral multiples of the fundamental notes. Therefore the number and strength of the harmonics determines the quality of the musical note.

VIBRATING STRING:

The following are factors that affect the frequency of a vibrating string

i) Length of the string.
ii) Tension in the string.
iii) Mass per unit length (thickness).

Length, L:

Increasing the length of the string of constant tension and thickness produces a note of low frequency and decreasing the length gives a note of high frequency. Therefore frequency is inversely proportional to the length of the string.

$$f \propto \frac{1}{L} = K\frac{1}{L}$$

Where k is a constant of proportionality

$fL = K$. Hence $f_1 L_1 = f_2 L_2$

Example

A string has a length of 75cm and a fundamental frequency of 200Hz. Find the new frequency if the length is increased to 100cm.

$$f_1L_1 = f_2L_2$$
$$200 \times 75 = f_2 \times 100$$
$$f_2 = 150Hz$$

Tension, T:

If the length and thickness of the string are kept constant, then the frequency of the note produced by a string increases with increase in tension in the string. Frequency is therefore directly proportional to the square root of tension.

$f \, \alpha \sqrt{T}$ $\qquad f = k\sqrt{T}$

Where k is a constant of proportionality

$f^2 = kT$ $\qquad$ Hence $\frac{f^2{}_1}{T_1} = \frac{f^2{}_2}{T_2}$

Example:

A stretched string produces a note of frequency 260Hz. Find the frequency of the note if the tension in the string is increased 4 times with other factors remaining constant.

$$\frac{f^2{}_1}{T_1} = \frac{f^2{}_2}{T_2}$$
$$\frac{260^2}{x} = \frac{f^2{}_2}{4x}$$
$$f_2 = \sqrt{270400}$$
$$f_2 = 520Hz$$

Mass per unit length [thickness]

Thin wires of constant length and tension emit notes of high frequency but if the wires are made thick, the frequency of the note produced decreases. Therefore frequency is inversely proportional to the square root of mass per unit length [thickness]

$f \alpha \frac{1}{\sqrt{m}}$ $\quad$ $f = \frac{k}{\sqrt{m}}$

Where k is a constant of proportionality

$f^2 m = k$ Hence $f^2{}_1 m_1 = f^2{}_2 m_2$

Example

A stretched string of thickness 45kgm^{-1} produces a note of frequency 40Hz. Find the frequency of the note if the thickness is decreased to 20kgm^{-1}

$f^2{}_1 m_1 = f^2{}_2 m_2$

$40^2 x\ 45 = f^2{}_2\ x\ 20$

$\frac{72000}{20} = f^2{}_2$

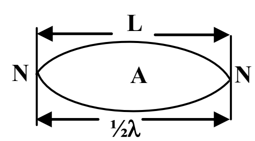
$f_2 = \sqrt{3600}$

$f_2 = 60Hz$

Waves produced by a vibrating string:

When a string is set into vibration, a transverse wave travels along the vibrating string to the fixed end where the wave is reflected back. This results into two transverse waves traveling in opposite directions along the string and a stationary wave is then produced.

If the string of length, L is plucked half way from one end then it produces a fundamental note (first harmonic) with a fundamental frequency, f_o.



The velocity, V of the fundamental note is given by

$V = f_o\lambda$ $\quad$ $f_o = \frac{v}{\lambda}$

But $L = \frac{\lambda}{2}$ $\quad$ $\lambda = 2L$

$f_o = \frac{V}{2L} \ldots\ldots\ldots\ldots\ldots\ldots. [1]$

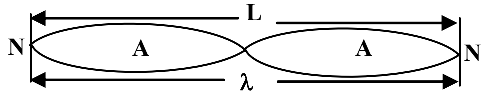
Note:

A fundamental note is the lowest musical note produced by a musical instrument and the fundamental frequency is the frequency of the lowest musical note produced by the musical instrument.

If the frequency of the fundamental note is increased beyond the fundamental frequency overtones are produced.

A harmonic is the simple multiple of a note being produced by the instrument. Thus the fundamental note is the first harmonic.

If the string is plucked a quarter way from one end it produces the second harmonic [first overtone]



$V = f_1\lambda$ $\qquad f_1 = \frac{V}{\lambda}$

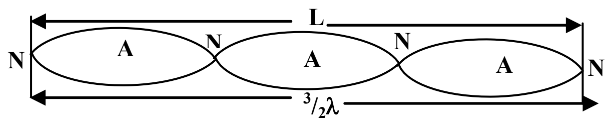
But $L = \lambda$ $\qquad \lambda = L$

$f_1 = \frac{V}{L} \ldots\ldots\ldots\ldots\ldots [2]$

From equation 1 & 2

$$\mathbf{f_1 = 2f_o}$$

If the string is plucked a sixth way from one end it produces the third harmonic [second overtone]



$V = f_2\lambda$ $\qquad f_2 = \frac{V}{\lambda}$

But $L = \frac{3\lambda}{2}$ $\qquad \lambda = \frac{2L}{3}$

$f_2 = \frac{3V}{2L} \ldots\ldots\ldots\ldots\ldots [3]$

From equation 1 & 3

$$\mathbf{f_2 = 3f_o}$$

The harmonics produced by a vibrating string are f_o, $2f_o$, $3f_o$, $4f_o$…Therefore a vibrating string produces all types of Harmonics.

Examples

1. The frequency of the third harmonic produced by a vibrating string is 660Hz. Find the length of the string if the speed of sound is 330ms^{-1}

For the third harmonic frequency $\qquad f_2 = \frac{3V}{2L}$

$660 = \frac{3 \times 330}{2 \times L}$

$L = 0.75m$

2. Find the frequency of the second harmonic produced by a vibrating string whose fundamental frequency is 300Hz.

For the second harmonic $\qquad f_1 = 2f_o$

$= 2 \times 300$

$= 600Hz$

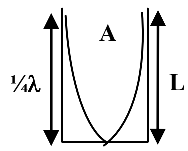
WAVES PRODUCED IN PIPES:

Pipes used are closed and open pipes

1. Closed pipes:

Closed pipes are closed on one end and open on the other. When a vibrating tuning fork is held over the mouth of the closed pipe, the air inside the pipe is set into vibrations and the wave is set down and is reflected from the surface of the pipe producing a stationary wave.

For the first position of resonance a fundamental note [first harmonic] with a fundamental frequency f_o is produced.



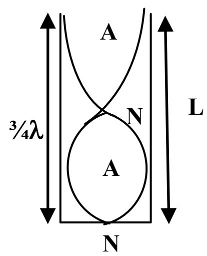
The velocity of the fundamental note is given by

$V = f_o\lambda$ $\quad f_o = \frac{V}{\lambda}$

But $L = \frac{1}{4}\lambda$ $\quad \lambda = 4L$

$f_o = \frac{V}{4}$ ……………………[1]

For the second position of resonance the third harmonic [first overtone] is produced



$V = f_1\lambda$ $\quad f_1 = \frac{V}{\lambda}$

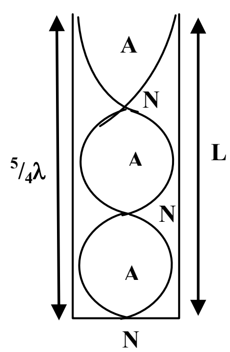
But $L = \frac{3}{4}\lambda$ $\quad \lambda = \frac{4}{3}L$

$f_1 = \frac{3V}{4L}$ ……………………………… [2]

From equations 1 & 2

$\mathbf{f_1 = 3f_o}$

For the third position of resonance the fifth harmonic [second overtone] is produced



$V = f_2\lambda$ $\quad f_2 = \frac{V}{\lambda}$

But $L = \frac{5}{4}\lambda$ $\quad \lambda = \frac{4}{5}L$

$f_2 = \frac{5V}{4L}$ ……………………… [3]

From equations 1 & 3

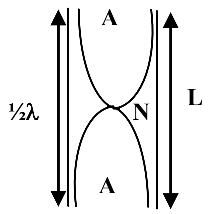
$\mathbf{f_2 = 5f_o}$

The harmonics produced in closed pipes are f_o, $3f_o$, $5f_o$, $7f_o$…Therefore only odd harmonics are possible in closed pipes and less quality sound is produced in closed pipes.

2. Open pipes:

Open pipes are open at both ends. When a vibrating tuning fork is held over the mouth of the closed pipe, the air inside the pipe is set into vibrations and the wave is set down and is reflected from the other end of the pipe producing a stationary wave.

For the first position of resonance a fundamental note [first harmonic] with a fundamental frequency f_o is produced.



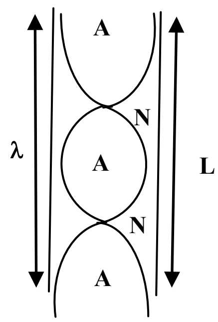
The velocity of the fundamental note is given by

$V = f_o\lambda \qquad f_o = \frac{V}{\lambda}$

But $L = \frac{1}{2}\lambda \qquad \lambda = 2L$

$f_o = \frac{V}{2L}$………[1]

For the second position of resonance the second harmonic [first overtone] is produced



$V = f_1\lambda \qquad f_1 = \frac{V}{\lambda}$

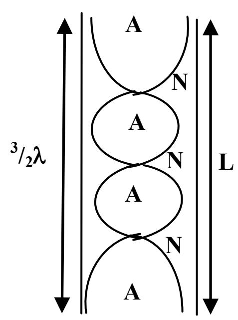
But $L = \lambda \qquad \lambda = L$

$f_1 = \frac{V}{L}$……… [2]

From equations 1 & 2

$\mathbf{f_1 = 2f_o}$

For the third position of resonance the third harmonic [second overtone] is produced



$V = f_2\lambda \qquad f_2 = \frac{V}{\lambda}$

But $L = {}^3/_2\lambda \qquad \lambda = {}^2/_3L$

$f_2 = \frac{3V}{2L}$…… [3]

From equations 1 & 3

$\mathbf{f_2 = 3f_o}$

The harmonics produced in open pipes are f_o, $2f_o$, $3f_o$, $4f_o$…

NOTE:

In open pipes all harmonics are possible and high quality sound (music) is produced that is why open pipes are preferred to closed pipes in producing musical notes.

Examples

1. The frequency of the third harmonic in an open pipe is 750Hz. Find the speed of sound in air if the length of the pipe is 80cm.

The harmonics are $f_o, 2f_o, 3f_o$

For 2nd harmonic $\qquad f_2 = 3f_o = \frac{3V}{2L}$

$750 = \frac{3 \times V}{2 \times 0.8}$

$V = 400ms^{-1}$

2. A pipe closed at one end has a length of 10cm. If the velocity of sound in air is $340ms^{-1}$, find the frequency of
i) Fundamental note
ii) Third harmonic

Solution

i) The harmonics are f_o, $3f_o$, $5f_o$

For the fundamental note $f_o = \frac{V}{4L}$

$= \frac{340}{4 \times 0.1}$

$= 850Hz$

ii) The harmonics are f_o, $3f_o$, $5f_o$

For the third harmonic $f_1 = \frac{3V}{4L} = 3f_o$

$= \frac{3 \times 340}{4 \times 0.1}$

$= 2550Hz$

3. A pipe open at both ends has a length of 40cm. If the velocity of sound in air is $340ms^{-1}$, find the frequency of
i) Fundamental note
ii) First overtone

Solution

i) The harmonics are f_o, $2f_o$, $3f_o$

For the fundamental note $f_o = \frac{V}{2L}$

$= \frac{340}{2 \times 0.4}$

$= 425Hz$

ii) The harmonics are f_o, $2f_o$, $3f_o$…

For the second harmonic (1st overtone), $f_1 = \frac{V}{L} = 2f_o$

$= \frac{340}{0.4}$

$= 850Hz$

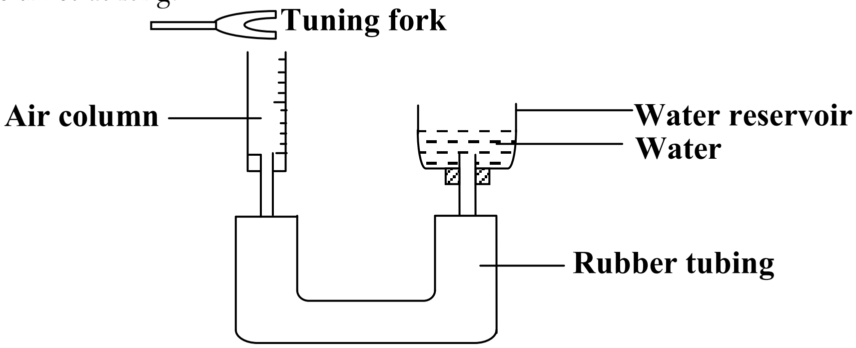
RESONANCE:

This occurs whenever a body or system is set into vibrations with its own natural frequency as a result of impulses received from another system vibrating with the same frequency. The vibrations combine to produce a larger vibration.

Experiment to demonstrate resonance in an air tube:

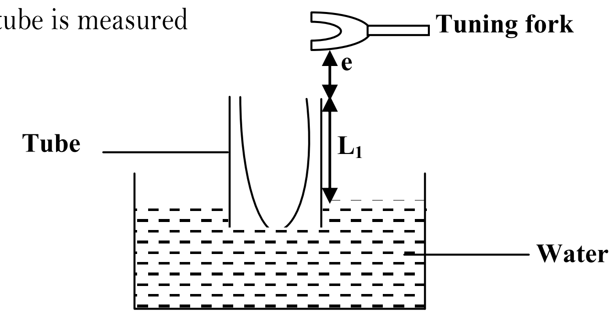
Raising or lowering the water reservoir increases or decreases the effective length of the air column in the tube.
Starting with a very short air column, a vibrating fork is held over the mouth of the tube and the length of the column is then gradually increased.
Strong resonance occurs when the column reaches a certain critical length called the first position of resonance.

If the length of the column is increased a second position of resonance is obtained when the column is approximately three times as long.



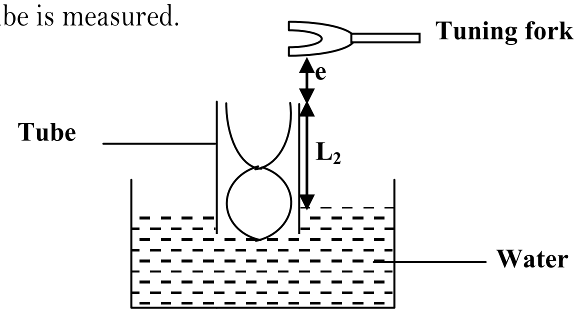
Measuring speed of sound by resonance method:

When a vibrating tuning fork of known frequency, f is held over the mouth of the resonance tube then the air inside the tube is set into vibrations and the wave is set downwards and reflected from the surface of water which is at the lower end of the tube forming a stationary wave. The tube is slowly raised until a loud sound is heard and therefore the air inside is resonating with the tuning fork. This is the first position of resonance and the length, L_1 of the tube is measured



$L_1 + e = \frac{1}{4}\lambda$ ………………………………………… [1]

The tube is again raised further until a second position of resonance is obtained with the same tuning fork and the length L_2 of the tube is measured.



$L_1 + e = \frac{3}{4}\lambda$ ………………………………………… [2]

Where e is the end correction

Subtracting 1 from 2

$L_2 - L_1 \quad = \frac{3}{4}\lambda - \frac{1}{4}\lambda$

$L_2 - L_1 = \frac{1}{2}\lambda$

$\lambda \quad = 2(L_2 - L_1)$

But $V = f\lambda = 2f(L_2 - L_1)$

Hence the velocity, V can be calculated

Examples:

1. A tube is partially immersed in water and a tuning fork of frequency 425Hz is sounded and held above it. If the tube is gradually raised find the length of the tube when resonance first occurs if the speed of sound is $340ms^{-1}$

For the first position of resonance

$l_1 + e = ¼\lambda$

Neglecting end correction, e

$l_1 = ¼\lambda$

$\lambda = 4l_1$

But $V = f\lambda = 4fl_1$

$340 = 4 \times 425 \times l_1$

$l_1 = 0.2m$

2. A tube closed at one end resonates first at length of 28.5cm and again at 88.5cm when a tuning fork of frequency 275Hz is held near the open end. Find the velocity of sound

$V = f\lambda$

where $\lambda = 2(l_2 - l_1)$

$V = 275 \times 2\ (0.885 - 0.285)$

$V = 330ms^{-1}$

Trial exercise 3:

1. A stretched wire adjusted to a length of 48cm produces the same note when plucked as a tuning fork whose frequency is 256Hz. If the wire is then adjusted to 32cm and the tension is kept constant, what frequency of the tuning fork would be in tune with the wire?
   Ans: 384Hz
2. The frequency of a vibrating wire is 280Hz, when its length is 75cm. Find its frequency when the length is reduced to 50cm. Assume that the tension on the wire and its cross sectional area remain constant.
   Ans: 420Hz
3. A guitar has two strings A and B. A has a smaller cross sectional area compared to B
   i) The two wires are under the same tension and have equal length. Compare their frequencies, if they are plucked with the same force
   ii) How can the frequency of string B be increased by keeping its cross sectional area and length constant?
   iii) If string A has a fundamental frequency of 300Hz, what will its frequency become if its tension is increased nine times?
   Ans: 900Hz
4. The frequency of the third harmonic in an open pipe is 590Hz. Find the length of the air column if the speed of sound in air is $330ms^{-1}$
   Ans: 0.84m
5. The length of air column in an open pipe is 1.6m. Find the frequency of the third harmonic if the speed of sound in air is $320ms^{-1}$
   Ans: 300Hz

6. A pipe closed at one end has a length of 10cm. If the velocity of sound in air of the pipe is $340ms^{-1}$, calculate the fundamental frequency and the frequency of the first overtone

Ans: 850Hz, 2550Hz

7. The frequency of the second harmonic produced in a vibrating string is 600Hz. Find the length of the string given that the speed of sound in air is $330ms^{-1}$

Ans: 0.55m

8. Find the frequency of the fourth overtone produced by a vibrating string of length 25cm given that the speed in air is $320ms^{-1}$

Ans: 3200Hz

9. The length of air column in a closed pipe is 150cm. Find the frequency of the third harmonic if the speed of sound in air is $330ms^{-1}$

Ans: 165Hz

10 The frequency of the third overtone in an open pipe is 750Hz. Find the length of the air column if the speed of sound in air is $300ms^{-1}$

Ans: 0.8m

Multiple-choice Exercise:

Assume speed of sound in air = $330ms^{-1}$ and speed of light in a vacuum = $3x\ 10^8ms^{-1}$

1. The difference of pitch between two musical sounds is due to a difference in
A. loudness B. amplitude C. frequency D. phase
2. The sound wave produced by a vibrating tuning fork is longitudinal because the air vibrates in
A. the same direction as that in which the prongs vibrate
B. a direction opposite to that in which the wave is travelling
C. the same direction as that in which the wave is travelling
D. the opposite direction to that in which the prongs vibrate
3. In forced vibrations, resonance occurs when the forcing
A. frequency is equal to the natural wavelength B. velocity is equal to the natural velocity
C. frequency is equal to the natural frequency D. frequency exceeds the natural frequency
4. What occurs when a body is made to vibrate with its natural frequency due to external vibration?
A. echo B. resonance C. refraction D. reverberation
5. The pitch of a note from a guitar string can be made higher by
A. lengthening the string B. tightening the string
C. heating the string D. increasing the thickness of the string
6. Intensity of sound at a point is ---------------its distance from the source
A. directly proportional to C. directly proportional to square of
B. inversely proportional to D. inversely proportional to square of
7. Supersonic plane fly with the speed
A. less than the speed of sound B. of sound
C. greater than the speed of sound D. of light
8. An open pipe and a closed pipe have their first overtone identical in frequency. Their lengths are in the ratio of
A. 1:2 B. 3:4 C. 2:3 D. 4:5

9. If the pressure amplitude in a sound wave is tripled, then the intensity of sound is increased by a factor of

A. 9 B. 6 C. 2 D. $\sqrt{3}$

10. The frequency of the third harmonic in open pipe is 825Hz. Find the length of the air column if the speed of sound in air is 330ms^{-1}

A. 1.8m B. 0.6m C. 0.5m D. 0.1m

11. A stretched string resonates with a tuning fork of frequency 512Hz when the length of the string is 0.5m. The length of the string required to vibrate resonantly with a tuning fork of frequency 256Hz would be

A. 0.25m B. 0.50m C. 1.00m D. 2.00m

12. When a tuning fork A of frequency 385Hz is sounded the first position of resonance occurs when the length of air column is 22.0cm. Find the velocity of the wave produced.

A. 320.0ms^{-1} B. 330.0ms^{-1} C. 338.8ms^{-1} D. 340.0ms^{-1}

13. The frequency of air vibrating in an open pipe is f. When half of the pipe is dipped in water, calculate the frequency of air vibrating in the pipe

A. f B. $\frac{3}{4}$f C. $\frac{1}{2}$f D. ¼f

14. In an open pipe the fundamental frequency is 30 Hz. If the pipe is closed, what is the fundamental frequency?

A. 10Hz B. 15Hz C. 20Hz D. 30Hz

15. If the speed of sound in air is 350ms^{-1}. Calculate the fundamental frequency of air vibrating in an open pipe of length 50cm.

A. 175Hz B. 350Hz C. 500Hz D. 700Hz

16. Standing waves are produced in a 10m long stretched string. If the string vibrates in 5 segments and the wave velocity is 20ms^{-1}. Find the frequency of the wave

A. 2Hz B. 4Hz C. 5Hz D. 10Hz

17. Which one of the following is not produced by sound waves in air?

A. polarization B. diffraction C. refraction D. reflection

18. The fundamental frequency of source is 256Hz. What is the frequency of the first harmonic produced?

A. 768Hz B. 520Hz C. 512Hz D. 256Hz

19. Which of the following emits sound of highest pitch?

A. donkey B. man C. mosquito D. lion

20. The length of the air column in an open pipe is 1.6. Find the frequency of the third harmonic if the speed of sound in air is 320ms^{-1}

A. 512Hz B. 300Hz C. 200HZ D. 100Hz

Answers:

1	C	5	B	9	A	13	A	17	A
2	C	6	C	10	B	14	B	18	D
3	C	7	C	11	C	15	B	19	C
4	B	8	B	12	C	16	C	20	B

MISCELLANEOUS EXERCISE 3:

1. a) Define the following terms;
i) Wavelength
ii) Reverberation
iii) Stationary waves
b) i) What is meant by resonance
ii) State three examples and one hazard caused by resonance
c) Describe an experiment to determine the velocity of sound in air by resonance tube method
d) Calculate the frequency of vibration of the fundamental note and the second overtone in an open tube of 25cm long if the velocity of sound is $330ms^{-1}$
Ans: 660Hz, 1980Hz.
e) Given the factors which affect the frequency of vibrations of a stretched string
2. a) What do you understand by the following terms;
i) Anti-node
ii) Resonance
b) State the factors which affect the frequency of wave produced by a vibrating string
c) A sound wave of frequency 300Hz is produced 160m away from a high wall. Calculate
i) The wavelength of the sound wave.
ii) The time taken for the sound wave to travel to the wall and back to the source.
Ans: i) 1.1m ii) 0.97s
d) A boy standing some distance from a cliff claps his hands and hears an echo after 5 seconds
i) What is distance between the boy and the cliff?
ii) How long would it take the boy to hear the echo if there was a wind blowing towards the cliff at a speed of $20ms^{-1}$
Ans: i) 825m ii) 4.71s
3. a) What is a wave
b) As regards to a wave, what is meant by the following
i) Frequency
ii) Wavelength
c) State four properties of waves
d) Describe how a resonance tube may be used to determine the velocity of sound in air
e) A boy stands between two parallel cliffs but nearer to one of them. When he claps hard once he hears the first echo after 1 second and a second echo 1 second after the first. If the distance between the cliffs is 510m, find the speed of sound.
Ans: $340ms^{-1}$
4. a) Define the following terms as applied to waves
i) Amplitude
ii) Frequency
b) i) What is meant by interference of waves
ii) Using a labeled diagram show how circular waves are reflected from a straight barrier
c) Use a labeled diagram to show the bands of electromagnetic waves.
5. a) i) Define an echo.
ii) State the conditions required for a stationary wave to be formed

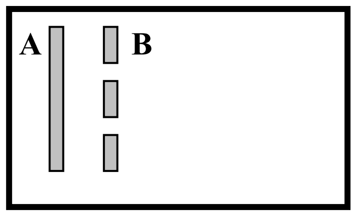
b) List the factors on which the frequency of a wave in a vibrating string depends

c) Describe an experiment to demonstrate resonance in a closed pipe

d) A child stands between two cliffs and makes a loud sound. If he hears the first echo after 1.5 seconds and the second echo after 2.0 seconds, find the distance between the two cliffs, if the speed of sound in air is $330ms^{-1}$.

Ans: 577.5m

6. The diagram below is of a cross section of a ripple tank in which A is a straight dipper and B a barrier with two gaps.



a) Sketch a diagram showing waves produced when A vibrates perpendicular to the water surface

b) What will happen when?

i) The gaps are made narrower

ii) The separation of the gaps is increased

iii) The frequency of the vibrator A is decreased

c) If A vibrates with a frequency of 20Hz and is 25cm from B, find

i) The speed of the wave if the wave front takes 5s from A to B

ii) The wavelength of the waves

Ans: i) $0.05ms^{-1}$ ii) $2.5 \times 10^{-3}m$

d) State differences between water waves and light waves

7. a) Give three similarities and three differences between sound waves and radio waves

b) i) Describe how the speed of sound in air can be determined by an echo method

ii) A student standing between two vertical cliffs produces sound by clapping his hands together. He hears the first echo after 3 seconds and a second echo after 5 seconds. Calculate the distance between the two cliffs

Ans: ii) 1320m

c) A radio station broadcasts at 100m band

i) What is meant by this statement?

ii) Calculate the frequency of the broadcast.

Ans: ii) $3.0 \times 10^{6}Hz$.

8. a) State two differences between sound and light waves

b) i) Describe a simple experiment to determine the velocity of sound in air

ii) Explain why the speed of sound is higher in solids than in air

c) Two people X and Y stand in a line at a distance of 330m and 660m respectively from a high wall. Find the time interval taken for X to hear the first and second sounds when Y makes a loud sound, if speed of sound in air is $330ms^{-1}$

Ans: 2.0s

d) i) What is meant by a stationary wave

ii) Give any two conditions

iii) Name one musical instrument which produces stationary waves

10. a) With aid of a diagram explain the terms amplitude and wavelength as applied to wave motion

b) i) Derive an equation relating velocity, V frequency, f and wavelength, λ of a wave

ii) A radio wave is transmitted at a frequency of 150Hz. Calculate its wavelength

Ans: 2.0 x 10^6Hz.

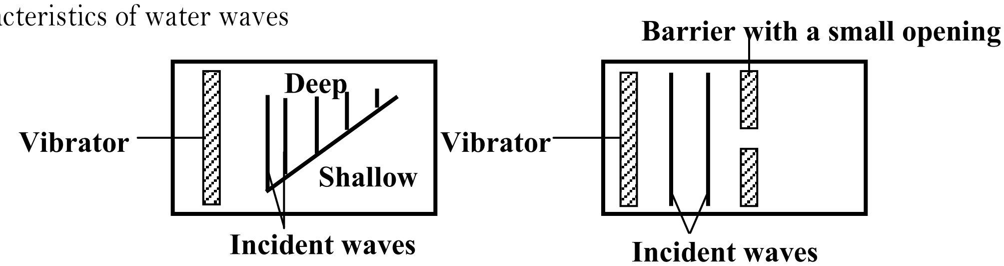
c) i) List four properties of electromagnetic waves

ii) A long open tube is partially immersed in water and a tuning fork of frequency 425Hz is sounded and held above it. If the tube is gradually raised, find the length of air column when resonance first occurs. Neglect end correction and take speed of sound in air = 340ms^{-1}

Ans: ii) 0.2m

9. a) Explain the difference between transverse and longitudinal waves. Give one example of each

b) The diagram in the figure below represents a plane view of horizontal ripple tanks set up to study characteristics of water waves



The vibrators were set up to produce plane waves

i) Draw diagrams to show wave patterns in A and B

ii) Explain what happens to plane waves in each case

c). A vibrator in a ripple tank vibrates at 5Hz. If the distance between 10 successive crests is 37.8cm. Calculate

i) The wave length of the waves

ii) The velocity of the waves

Ans: i) 4.2cm ii) 0.21ms^{-1}

11. a) i) Describe how the speed of waves in a ripple tank can be decreased

ii) Explain the effect of decreasing the speed of the wave in (a) (i) on frequency

b) With the aid of sketch diagrams, explain the effect of size of a gap on diffraction of waves

c) i) Give two reasons why sound is louder at night than during the day

ii) An echo-sounding equipment on a ship receives sound pulses reflected from the sea bed 0.02 seconds after they were sent out from it. If the speed of sound in water is 1500ms^{-1}, calculate the depth of water under the ship.

Ans: ii) 15m

d) Identify two differences between water and sound waves

12. a) Define the following terms as applied to waves;

i) Amplitude

ii) Frequency

b) i) What is meant by interference of waves

ii) Using a labeled diagram show how circular water waves are reflected from a straight barrier

c) i) Use a labeled diagram to show the bands of an electromagnetic spectrum

ii) Calculate the frequency of a radio wave of wavelength 2m

Ans: ii) 1.5 x 10^8Hz

d) i) State any three effects of electromagnetic radiation on matter

ii) State two properties that electromagnetic waves have in common

13. a) Explain each of the following observations;

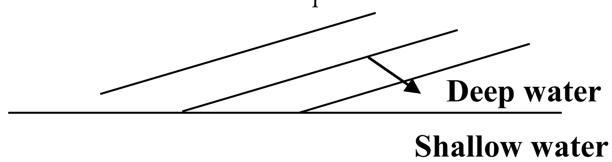
i) Sound from a distant source is louder at night than during day time

b) Describe an experiment to show interference of sound waves

c) A man stands between two cliffs and makes a loud sound. He hears the first echo after 1 second and the second echo after a further 1 second. Find the distance between the cliffs

Ans: 495m

d) Straight water waves travel from deep to shallow water as shown below



Copy and complete the wave front pattern in shallow water

14. a) State differences between sound and light waves

b) i) Explain how stationary waves are formed

ii) State three main characteristics of stationary waves

c) i) Define the terms frequency and wavelength as applied to sound

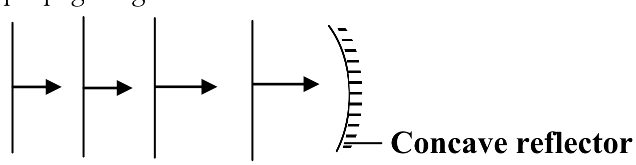
ii) Describe an experiment to demonstrate resonance in sound

d) The velocity and frequency of sound in air at a certain time were $320ms^{-1}$ and 200Hz respectively. At a later time, the air temperature changed and the velocity of sound in air was found to be $340ms^{-1}$. Determine the change in wavelength of sound.

Ans: 0.1m

15. a) List three differences between sound waves and radio waves

b) Figure below shows waves propagating towards a concave reflector



i) Draw a diagram to show how the waves are reflected

ii) If the velocity of the waves is $320ms^{-1}$ and the distance between two successive crests is 10cm, find the period of the waves

Ans: 3.125×10^{-4}s

c) Describe a simple echo method of determining the speed of sound in air.

16. a) What is meant by sound

b) Describe an experiment to show that sound waves require a material medium for transmission

c) Explain briefly the following;

i) A dog is more able than a human being to detect the presence of a thief tiptoeing at night

ii) An approaching train can easily be detected by human ears placed close to the rails

d) A sound frequency 250Hz is produced 120m away from a high wall. If the speed of sound in air is $330ms^{-1}$, calculate the

i) Wavelength ii) Time it takes the sound wave to travel to and from the wall.

Ans: i) 1.32m ii) 0.73s

17. a) i) State two factors which affect the frequency of the note produced by the string

ii) Why does the quality (timbre) of the sound produced by a violin differ from that produced by a piano?

b) Describe an experiment to show that sound waves do not travel through a vacuum

c) A pipe is closed at one end has a length of 10cm. if the velocity of sound in the air of the pipe is 340ms^{-1}. Calculate

i) The fundamental frequency

ii) The first overtone

Ans: i) 850Hz ii) 2550Hz

d) State four differences between sound waves and light waves

18. a) i) Describe a simple experiment to determine the velocity of sound in air

ii) What factors would affect the value of velocity of sound obtained from the experiment in (i) above

b) Explain why a musical note played on a piano sounds different from that played on a guitar

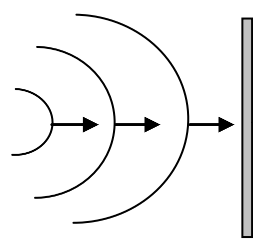
c) i) Calculate the wavelength of sound waves of frequency 3.3kHz and speed 330ms^{-1}

ii) State four differences between sound and radio waves

Ans: i) 0.1m

19. a) List three differences and three similarities between sound waves and light waves

b) The diagram below shows circular waves propagating towards a plane reflector



i) Draw a diagram to show how the waves will be reflected

ii) Calculate the frequency of the waves if their velocity and wavelength are 5.0ms^{-1} and 0.5m respectively

Ans: ii) 10Hz

c) A man stands midway between two cliffs and makes a loud sound. He hears the first echo after 3 seconds. Find the distance between the cliffs, if the velocity of sound in air is 330ms^{-1}.

Ans: 990m

20. a) Define each of the following terms as applied to wave motion

i) Wave front

ii) Wavelength

b) The wavelength of radio wave is 10m. Calculate

i) The frequency

ii) The period of the wave

Ans: i) 3.0 x 10^{7}Hz ii) 3.33 x 10^{-8}s

c) Why does sound travel faster in solids than in gases

d) i) What is meant by the term resonance

ii) The frequency of the third harmonic in a closed pipe is 280Hz. Find the length of the air column in the pipe.

Ans: ii) 075m

H E A T

Heat is form of energy which flows from one point to another due to temperature difference between the two points. Heat flows from a region of high temperature to a region of low temperature and when a body absorbs heat energy, the energy absorbed is used to;

- Increase its temperature so that it becomes hot.
- Change the state of the body.
- Create a chemical change.
- Make it expand.

Hence heat is a measure of total internal energy in a body that is kinetic energy and potential energy of the molecules. The SI unit of heat is a joule [J].

TEMPERATURE MEASUREMENT:

Temperature is a degree of hotness or coldness of a body or a place. Temperature depends on the average kinetic energy of the molecules in a body. Therefore temperature can be defined as the average kinetic energy of molecules in a body. Temperature of a body is measured by a thermometer on the basis of physical property which changes with temperature. The physical property which changes with temperature is referred to as **a thermometric property**.

In order to set up a temperature scale, one selects some physical property, whose value changes with different degree of hotness.

Examples of physical properties used in different thermometers;

i) Length of a liquid column (a liquid–in–glass thermometer).
ii) Electrical resistance of a wire (platinum resistance thermometer).
iii) The pressure of a fixed mass of a gas at constant pressure (constant – pressure gas thermometer).
iv) Volume of the fixed mass of the gas at constant pressure (constant – pressure gas thermometer).
v) E.M.F of a thermocouple (thermocouple thermometer).
vi) Quality (wave length) of electromagnetic radiation emitted by a hot body (Pyrometers).

Qualities of a good thermometric property:

- It should vary continuously and linearly with temperature changes.
- It should change considerably for a small change in temperature.
- It should vary over a wide range of temperatures.
- It should be accurately measurably over a wide range of temperature of fairly simple apparatus.

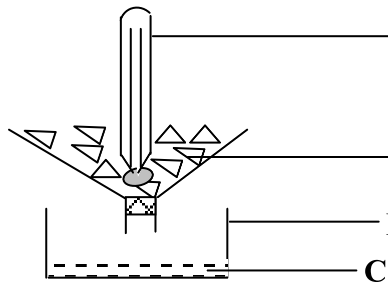
Each value of thermometric property should correspond to one and only one value of the temperature.To measure temperature, a scale of temperature is obtained by choosing the fixed points and dividing the range between them into equal divisions.

FIXED POINTS OF A THERMOMETER:

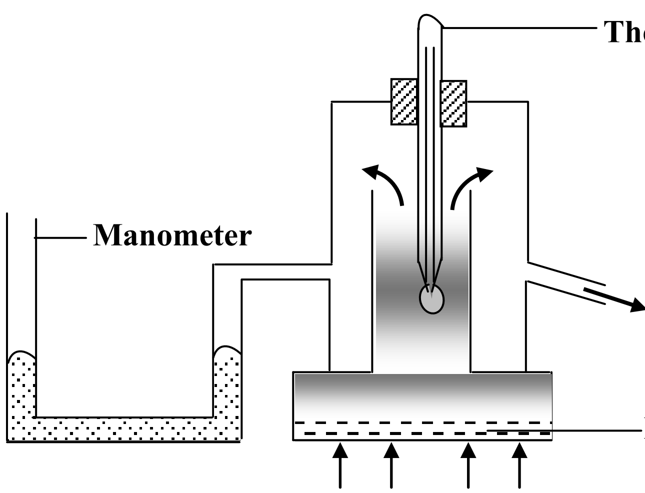
A fixed point is the temperature at which a physicachange takes place. Fixed points are therefore reference points of a thermometer and there are two fixed points and these are;

i) Lower fixed point.
ii) Upper fixed point.

Lower fixed point:
This is the temperature of pure melting ice.
Determining the lower fixed point:
The unmarked thermometer is placed in pure melting ice in a funnel with ice packed around its bulb. The thermometer is left in the ice for some time until the level of mercury remains stationary. This level is then marked and it is the lower fixed point



Upper fixed point:
This is the temperature of pure boiling water.
Determining the upper fixed point:
The thermometer is made to hang in steam above boiling water and kept inside the double walls. The double walls ensure a constant temperature of steam of 100°C and a manometer is attached to the hypsometer to ensure constant pressure of 76cmHg. The thermometer is left in steam for some time until the level of mercury remains stationary. This level is then marked and it is the upper fixed point.



NB: The ineterval between the lower fixed point and the upper fixed point is called the fundamental interval.

SCALES OF TEMPERATURE:

Temperature scale is the scale used to measure the degree of hotness or coldness. There are two scales commonly used and these are;

- The Celsius [centigrade] scale.
- The Kelvin [thermodynamic] scale.

The Celsius scale:

On the Celsius scale the temperature is measured in degrees Celsius [^oC]. On this scale the lower fixed point is melting point of ice which is 0^oC while the upper fixed point is boiling point of water which is 100^oC.

If the temperature on the Celsius scale is θ^oC then its corresponding temperature on the Kelvin scale, T is given by T = [273 + θ] K.

The Kelvin scale:

On the Kelvin scale the temperature is measured in Kelvin [K] which is the SI unit of temperature. On this scale the lower fixed point is melting point of ice which is 273K while the upper fixed point is boiling point of water which is 373K. If the temperature on the Kelvin scale is TK then its corresponding temperature on the Celsius scale, θ is given by θ = [T - 273] ^oC.

EXAMPLES:

1. Covert the following temperature to Kelvin [K]

i) 27^oC ii) – 23^oC

Solution

i) 27^oC	= 273 + 27	ii) – 23^oC	= 273 + (-23)
	= 300K		= 250K

2. Convert the following temperatures to degrees Celsius [^oC]

i) 574K ii) 23K

Solution

i) 574K	= 574 – 273	ii) 23K	= 23 – 273
	= 301^oC		= - 250^oC

3. Convert the following temperatures to degrees Celsius [^oC]

i) 54K ii) 234K

Solution

i) 54K	= 54 – 273	ii) 234K	= 234 – 273
	= 219^oC		= - 39^oC

Obtaining the temperature on an un-calibrated thermometer:

To measure the unknown temperature the length, Y of the mercury thread between the lower fixed point and upper fixed point is measured and noted and the length, X of mercury thread above the lower fixed point to the unknown temperature, θ is measured and noted. The unknown temperature, θ in degrees Celsius is given by

$$\theta = \frac{X}{Y} \text{x } 100\%$$

If L_o is the length of mercury thread at ice point [lower fixed point], L_{100} is the length of mercury thread at steam point [upper fixed point] and L_θ is the length of mercury thread at unknown temperature, θ. The unknown temperature, θ in degrees Celsius is then given by

$$\theta = \frac{L_\theta - L_o}{L_{100} - L_o} \text{x } 100\%$$

Examples:

1. The length of mercury column of a thermometer at ice point and steam point are 22cm and 62cm respectively. Calculate the reading of the thermometer when the mercury column is 42cm long

$$\theta = \frac{L_\theta - L_o}{L_{100} - L_o} x\ 100\%$$

$$\theta = \frac{42 - 22}{62 - 22} x\ 100\%$$

$$\theta = \frac{20}{40} x\ 100\%$$

$$\theta = 50°C$$

2. When a thermometer is inserted in boiling liquid, the mercury thread rises above the lower fixed point by 18.5cm. Find the temperature of the liquid if the fundamental interval is 20cm.

Fundamental interval is the interval between the lower fixed point and the upper fixed point

$$\theta = \frac{x}{Y} x\ 100\%$$

$$\theta = \frac{18.5}{20} x\ 100\%$$

$$\theta = 92.5°C$$

3. The interval between the upper fixed and lower fixed point on a Celsius scale in unmarked mercury in glass thermometer is 35cm. find the temperature if the mercury level is 28cm below the upper fixed point

$$\theta = \frac{x}{Y} x\ 100\%$$

$$X = 35 - 28 = 7cm$$

$$\theta = \frac{7}{35} x\ 100\%$$

$$\theta = 20°C$$

Choice of a liquid in thermometer:

The two liquids mainly used in the thermometer are mercury and alcohol. The choice of the liquid to be used depends on the range of temperature to be measured that is mercury freezes at – 39°C and boils at 357°C while alcohol freezes at – 130°C and boils at 78°C. Hence alcohol is suitable for low temperatures and mercury is suitable for high temperatures

Properties of a liquid that make it suitable for thermometer use:

- It should be opaque so as to be readily seen.
- It should have a regular or uniform expansion that is its expansion per degree should be the same at different points on the temperature scale.
- It should be a good conductor of heat so as to respond rapidly to any change in temperature.
- It should have a high boiling point and a low melting point [wide range] so that both high and low temperatures can be measured.
- It should not wet the glass that is stick to sides of the glass tube.
- It should have a high expansivity.

Reasons why water is not used as a thermometric liquid:

- It does not expand regularly (uniformly).
- It has a small range of expansion that is it freezes at 0^oC and boils at 100^oC.
- It is transparent (colourless).
- It wets the glass.
- Its meniscus is difficult to read.

Advantages of mercury over alcohol as a thermometric liquid:

- It can be used to measure high temperature because of its high boiling point [357^oC].
- It expands regularly.
- It is a good conductor of heat.
- It does not wet the glass.
- It is opaque that is it can be easily seen.
- It vaporizes easily.

Disadvantages of mercury over alcohol as a thermometric liquid:

- It cannot be used to measure very low temperatures because of its high freezing point [$- 39^oC$].
- It has a low expansivity.

Advantages of alcohol over mercury as a thermometric liquid:

- It has a high expansivity that is it expands so much for a small temperature change.
- It can be used to measure very low temperatures because of its low freezing point [$- 130^oC$].

Disadvantages of alcohol over mercury as a thermometric liquid:

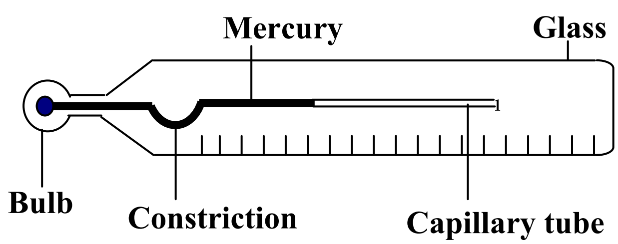
- It cannot be used to measure high temperatures because of its low boiling point [78^oC].
- It is transparent (colourless) and therefore has to be colored before being used.
- It expands irregularly.
- It is a relatively poor conductor of heat.
- It tends to wet the glass that is it tends to stick to the walls of the glass tube.

TYPES OF THERMOMETERS:

The most common type of thermometer found in school laboratories is a liquid-in-glass thermometer other types include platinum resistance thermometer, constant-volume gas thermometer, constant-pressure gas thermometer, thermocouple thermometer and pyrometers.

a) Clinical thermometer:

This is a type of mercury-in-glass thermometer used by doctors in clinics and hospitals for measuring the temperature of the body. It uses a thermometric property of length and consists of tube with a constriction [narrow bent part] just beyond the bulb.



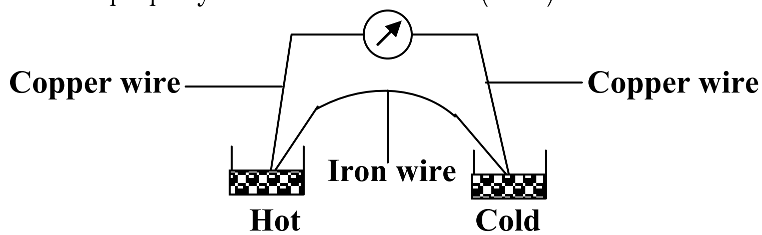
When the thermometer is in use the mercury expands passed constriction and when it is not in use the mercury in the bulb cools and contracts breaking the mercury thread at the constriction. A thermometer is said to be sensitive if it can record very small temperature changes. A clinical thermometer to be sensitive should have the following features;

i) A large bulb: If the bulb is large, the greater the volume the greater the expansion per degree.

ii) A very narrow bore: If the bore is very narrow, a small change in volume fills a greater length of capillary tube.

b) Thermocouple thermometer:

It consists of two wires of different materials joined together and their junctions kept at different temperatures. It uses a thermometric property of electromotive force (e.m.f)



When one junction is at higher temperature than the other junction an electric current flows and a potential difference across the galvanometer is produced.

Thermocouples are used to measure a wide range of varying temperatures up to about 1500°C and an electromotive force (emf).

Trial Exercise 1:

1. Convert the following from Kelvin to °C

   i) 167K ii) 283K iii) 3450K

   Ans: i) – 106°C ii) 10°C iii) 3177°C

2. Convert the following from °C to Kelvin

   i) -23°C ii) 143°C iii) 237°C

   Ans: i) 250K ii) 416K iii) 510K

3. A mercury thermometer reads 10°C when dipped into melting ice and 90°C when in steam at normal atmospheric pressure. What would this thermometer read when dipped into a liquid at 20°C?

   Ans: 12.5°C

4. When marking the fixed points on a thermometer, it is observed that at 0°C, the mercury thread is of length 1cm and 6cm at 100°C. What temperature would correspond to a length of 4cm?

   Ans: 60°C

5. When a Celsius thermometer is inserted in a boiling liquid, the mercury thread rises above the lower fixed point by 19.5cm. Find the temperature of boiling liquid if the fundamental interval is 25cm.

   Ans: 78°C

6. in an un-calibrated mercury thermometer the, length of mercury thread above the bulb is 18mm at a temperature of melting ice and 138mm at a temperature of steam. When placed in a hot liquid the length of mercury thread is 118mm. Calculate the temperature of the liquid

   Ans: 83.3°C

7. The resistance of platinum thermometer is 5.7Ω, 5.5Ω, 5.2Ω at boiling point, unknown temperature, θ, and at the freezing point of water respectively. Determine the unknown temperature in θ°C.

Ans: 60°C

8. The resistance of a platinum resistance thermometer is 4.00Ω at the ice point and 5.46Ω at the steam point. What temperature on the platinum resistance of 9.84Ω?

Ans: 400°C

9. The resistance of platinum wire at the triple point of water is 5.16Ω. What will its resistance be at 100°C?

Ans: 7.05Ω

10. Why is it that boiling water is not used for sterilization of a clinical thermometer and how is a clinical thermometer sterilized.
11. Describe an experiment to determine the fixed points of a thermometer.
12. What is a thermometric property and state any four thermometric properties.
13. What is meant by scale of temperature and how is temperature defined on a Celsius scale.
14. Mention any three reasons for not using water as a thermometric liquid.
15. Name physical properties which change with temperature.

HEAT TRANSFER:

Heat transfer is the transition of heat energy from a hot body to a cold body. There are three ways by which heat can be transferred and these are

- Conduction.
- Convection.
- Radiation.

CONDUCTION:

This is the transfer of heat through matter from a region of higher temperature to a region of lower temperature without the movement of matter as a whole.

Conduction in solids:

Conduction requires a material medium for heat to be transferred. In solids heat is transferred as a result of the following;

- Excess energy of vibrations of atoms being passed from one atom to another.
- Excess energy of free electrons near the source of heat carried to the colder region.

Conduction is faster in good conductors than in bad conductors and different conductors have different rates of conductivity. The rate of heat transfer a long a metal bar depends on the following factors;

- The temperature between the ends of the metal bar.
- The length of the mental bar.
- The cross sectional area of the metal bar.
- The nature of the material of the metal bar.

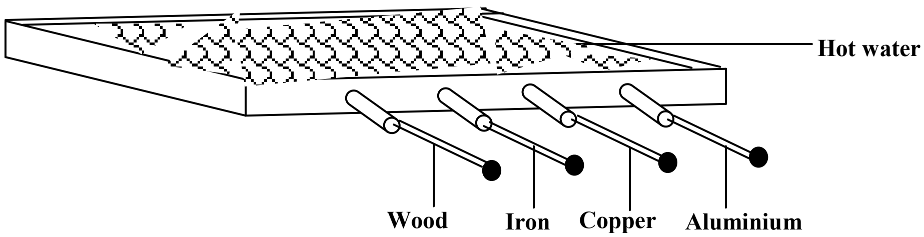
Good conductors of heat:

Good conductors of heat conduct heat easily because they are made up of atoms with freely electrons which are loosely bound. Examples are all metals like aluminium, copper, iron, steel, lead etc. They are used in making cooking utensils like kettle, saucepans, boilers etc.

Bad conductors of heat:

Bad conductors of heat do not conduct heat easily because they are not made up of free electrons. Examples are all non-metals like wood, plastic, wool, glass, cork etc. They are used in making handles of cooking utensils.

Experiment to compare thermal conductivity of different conductors:



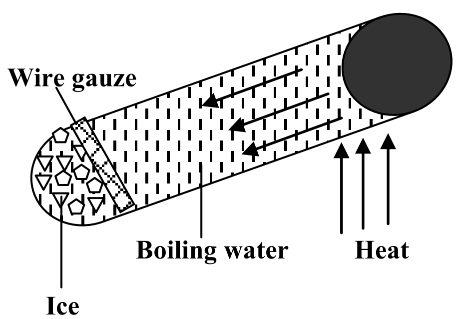
- Identical rods of different materials coated with wax are dipped in hot water.
- After some time the wax begins to melt along the rods.
- The wax on the rods melts to different lengths along the rods.
- The greatest being in copper and least in wood.
- This shows that solids have different rates of conductivity, copper being the best and wood being the worst.

Conduction in fluids:

Liquids and gases conduct heat at a very slow rate and liquids are poor conductors of heat

Experiment to show that water is a poor conductor of heat:

- Place ice in the test tube.
- Metal gauze is used to keep ice down in the test tube.
- Fill the test tube with water.
- Apply heat at the mouth of the test tube as shown below;



- It is observed that water starts to boil before ice at the bottom melts.
- This shows that there is little conduction of heat down the test tube; hence water is a poor conductor of heat.

CONVECTION:

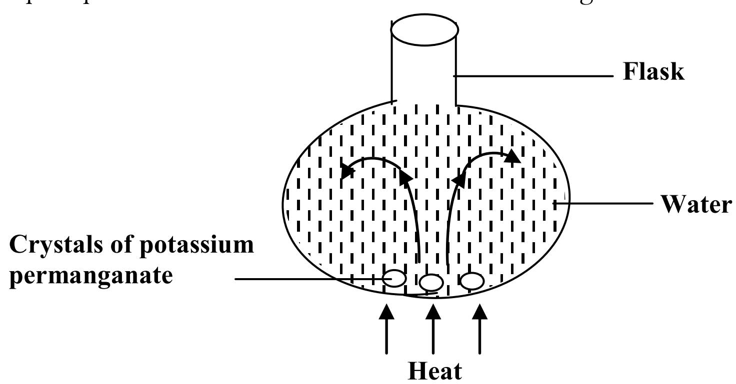
This is the transfer of heat through fluids from a region of higher temperature to a region of lower temperature by the movement of the fluid itself.

Convection in fluids:

When a fluid is heated it expands and becomes less dense than the surrounding cold fluid. The heated fluid is forced upwards by the surrounding cooler fluid which moves under it. As the warm fluid rises it gives heat to the surrounding cooler fluid forming convection currents.

Experiment to show convectional currents in liquids:

- Fill a round bottom flask.
- Place potassium permanganate crystals carefully at the bottom of the flask.
- Gently heat the liquid and observe.
- It is observed that the purple colour of potassium permanganate is seen moving upwards and on reaching the top it spreads and then moves downwards forming convectional currents.



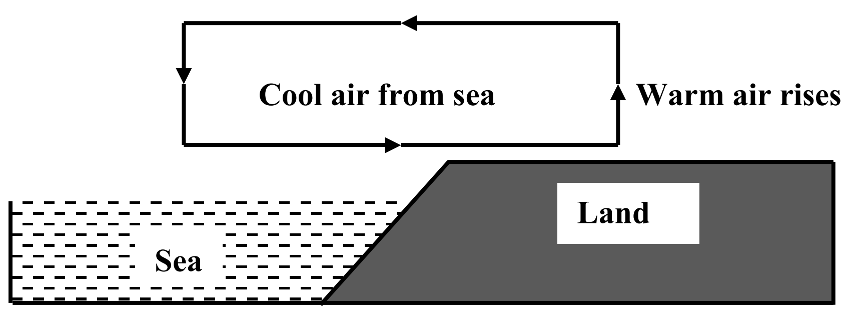
Natural convectional currents:

a) Sea breeze:

This is a cool air that blows inland from the sea during the day time. It occurs during the day when the land is warmer than the surface of the sea water.

Explanation of sea breeze:

- During the day, the land is heated to a higher temperature than the sea by the sun because the specific heat capacity is much smaller than that of water and the surface of the sea is in constant wave motion leading to mixing warm surface water with cold water below the surface.
- The increase in temperature of the land causes the air above the land to expand and rises up as it becomes less dense.
- The space left is occupied by dense air from relatively cooler sea and this result is a sea breeze which blows from the sea towards the land.

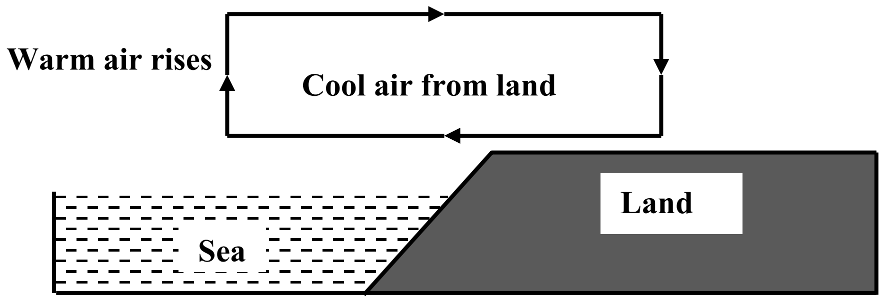


b) Land breeze:

This is a warm air that blows from land to the sea at night. It occurs at night when the land is cooler than surface of sea water.

Explanation of land breeze:

- At night the land is no longer heated by the sun and cools very rapidly because land is a better emitter of heat than the sea as a result the sea is warmer than the land.
- The warm air above the sea expands and rises up as it becomes less dense.
- The space left is occupied by dense air from relatively cooler land and this result is a land breeze which blows from land towards the sea.



c) Ventilation:

- Inside the building warm air which is less dense rises up and flows out through ventilators above the building.
- The space left is replaced by fresh cool air which enters the building through doors and windows.
- This results in a circulation of air which forms convectional currents.

RADIATION:

This is the transfer of heat from one place to another by means of electromagnetic waves.

The following are examples in which energy is transferred by radiation

i) Light from the sun.

ii) Heat energy from a hot body or fire.

When radiation falls on an object it is partly reflected, transmitted and absorbed. The absorbed radiation raises the temperature of the body and the rate at which a hot body radiates heat energy depends on the following factors;

i) Temperature of the body that is a hotter body radiates heat faster

ii) Surface area of the body that is a large surface area allows much energy to be radiated per second

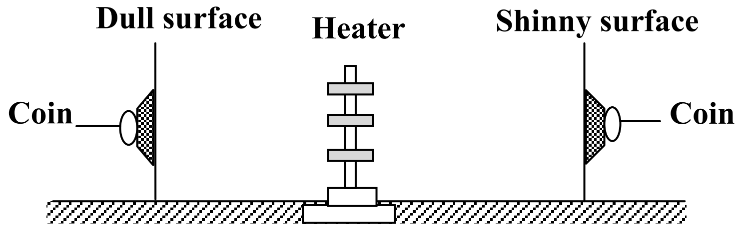
iii) The nature of the surface of the body that is dull surfaces radiate heat energy faster than highly polished surfaces.

Good and bad absorbers of heat:

Good absorbers of heat absorb heat easily and reflect a few while bad absorbers don't absorb heat easily and reflect most of the heat energy. Dull and black surfaces absorb most of the heat while shiny surfaces reflect most of the heat energy. This explains the following

- Buildings in hot countries are painted white and the roof surfaces are shiny.
- Reflectors on electric devices are made up of polished metals.
- Cooling fins on the heat exchanger of refrigerators are painted black
- Tea pots and kettles are polished

Experiment to show absorption of radiation

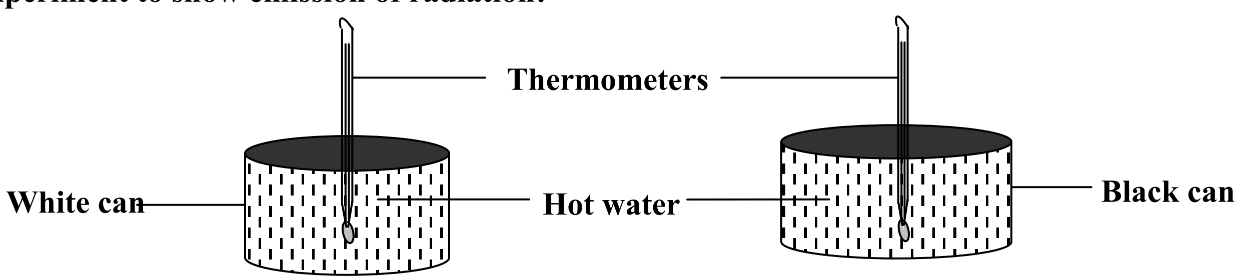


- Two surfaces [a shinny surface and a dull surface] are placed vertically at a distance from each other.
- Stick pieces of candle wax with a coin attached at the back of each surface.
- An electric heater is then placed between the surfaces so that each receives the same amount of radiation.
- It is observed that after some time the wax on the dull surface melts and the coin falls off before the wax on the shinny surface.
- This shows that a dull surface is a good absorber of radiation and a shinny is a good reflector of the radiation.

Good and bad emitters of heat

Good emitters of heat reflect heat easily and absorb a few while bad emitters don't reflect heat easily and absorb most of the heat energy. Dull and black surfaces emit most of the heat while shiny surfaces reflect most of the heat energy. Therefore good emitters of heat are also good absorbers of heat and bad emitters of heat are also bad absorbers of heat. This explains why in the morning a metal [good absorber of heat] feels cold to touch because it emits most of the heat

Experiment to show emission of radiation:

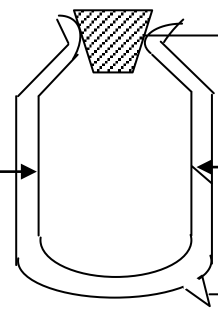


- Two metal cans one painted black and the other white are filled with hot water and then stopped.
- Thermometers are then placed in each can and the temperature of water in each can is noted.
- The temperature of water is then recorded every minute for each can.
- It is noted that the temperature of water in the black can drops faster than the temperature of water in a white can.
- This shows that the black surface radiates heat faster than the white surface

Applications of Radiation:

- Kettles, cooking pans and iron boxes have polished surfaces to reduce on heat loss through radiation.
- Petrol tanks are painted silvery bright to reflect away heat.
- Houses in hot areas have their walls and roofs painted with bright colours to reflect away heat while those in cold regions have walls and roofs painted with dull colours to absorb heat.
- In solar concentrators, electromagnetic waves in form of radiant heat are reflected to a common point by a concave reflector.

- **Solar heater:** It uses solar energy to heat water. It consists of a coiled blackened copper pipe on a blackened insulating surface. The radiant energy from the sun is absorbed by blackened copper pipes that contain water which is then heated up. The temperature of air above the pipe also increases boosting the heating of water in the pipe.
- **The green house effect**: This is used in providing appropriate conditions for plants in cold regions. It is a warming up of the earth because of absorption of solar radiation by the earth caused by re-emission of infra red rays by carbon-dioxide and other gases. Green house gases prevent the escape of heat and keep the temperatures on earth increasing. The radiant energy from the sun passes through the green house and is absorbed by objects in the house which then emit radiation of lower energy and this causes the temperature of the earth to increase substantially.
- **Vacuum flask**: This is a flask with two walls enclosing a vacuum used for keeping the contents at a fairly constant temperature. A vacuum flask keeps hot liquids hot and cold liquids cold. It consists of a double walled glass vessel having a vacuum between the walls and both sides are silvered on the vacuum side.



How heat losses are minimized in a vacuum flask:

i) **The cork:** This is a poor conductor of heat and minimizes heat loss or heat gain by conduction.
ii) **The vacuum:** This lacks the medium and minimizes heat loss or heat gain by conduction and convection.
iii) **Silvered surfaces:** These are highly polished surfaces and minimizes heat loss or heat gain by radiatio

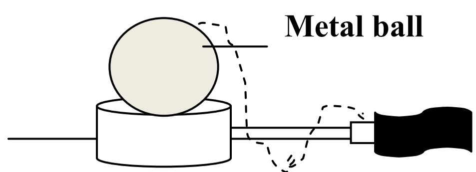
N.B:

- The vacuum flask is rendered useless when the vacuum seal breaks because the vacuum is filled with air and heat is lost by radiation.
- Despite the above attempts to minimize heat loss and heat gain by the vacuum flask, hot contents of the vacuum flask eventually get cold after a long time because little heat escapes by conduction through a thin glass wall at the neck and the poorly conducting cork.

THERMAL EXPANSION:

Expansion is the increase in size of matter in all directions whenever matter is heated. When matter is cooled it decreases in size [contracts].

Experiment to demonstrate expansion in solids:



- A metal ball which just passes through the metal ring when both are at room temperature is used.
- The metal ball is then heated for some time and try to pass it through the ring.

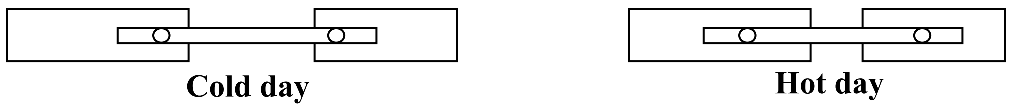
- When the ball is heated it doesn't pass through the ring.
- When the ball cools it will pass through the ring again indicating that the metal contracts on cooling.
- Different metals expand by different amount when equally heated.

APPLICATIONS OF EXPANSION:

The following are applications of expansion;

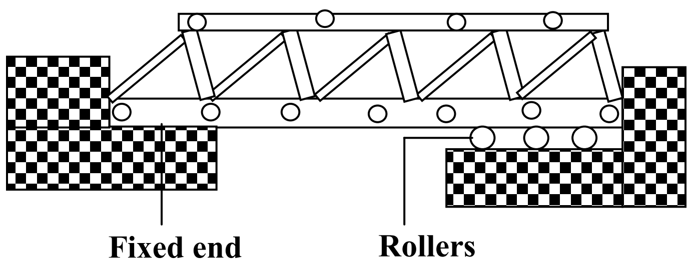
a) Railway lines:

Gaps are left between lengths of the railway to allow for expansion in hot seasons. Railway lines are constructed in sections held together by fish plates. The bolt holes in the rails are oval to allow free expansion and contraction of the rails with changes in temperatures.



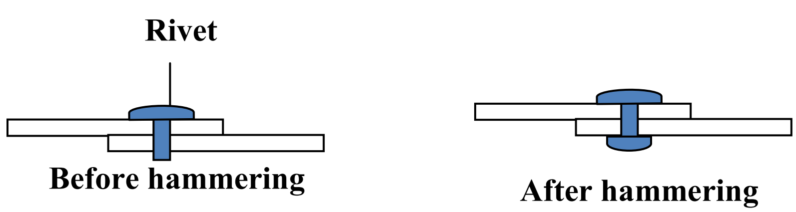
b) Bridges

Bridges are constructed with girders where one end rests on rollers and the other end fixed to allow for expansion.



c) Rivets:

Thick metal plates, sheets and girders in ships are joined together by means of rivets. A white hot rivet is fitted and its end hammered flat, on cooling it contracts and pulls the plates together.



d) Telephone/Electric wires

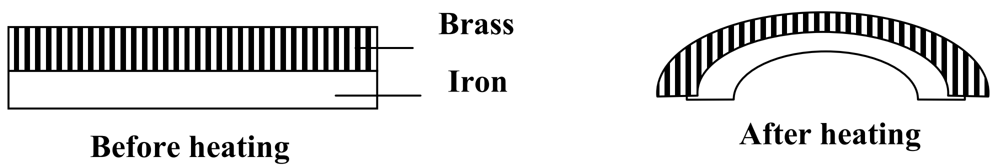
Telephone wires or electric wires are loosely fixed to allow for contraction. During cold weather they contract and when it is warm they expand. The wires appear to be shorter and taut in the morning and in hot afternoons; the wires appear longer and slackened.

e) Steam pipes:

Pipes carrying steam from boilers are fitted with loops or expansion joints. These allow the pipes to expand and contract easily when steam passes through them. Without the loop the force of expansion and contraction can cause breakage of the pipe.

f) Bimetallic strip:

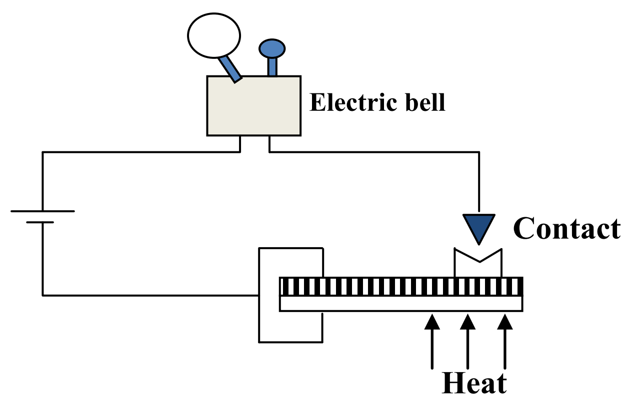
When two metals of different expansivity are riveted together, they form a bimetallic strip. Brass and iron are used to make a bimetallic strip and when heated brass expands more than iron and the strip bends with brass outside.



Uses of bimetallic strip

Bimetallic strips are applied in the following devices

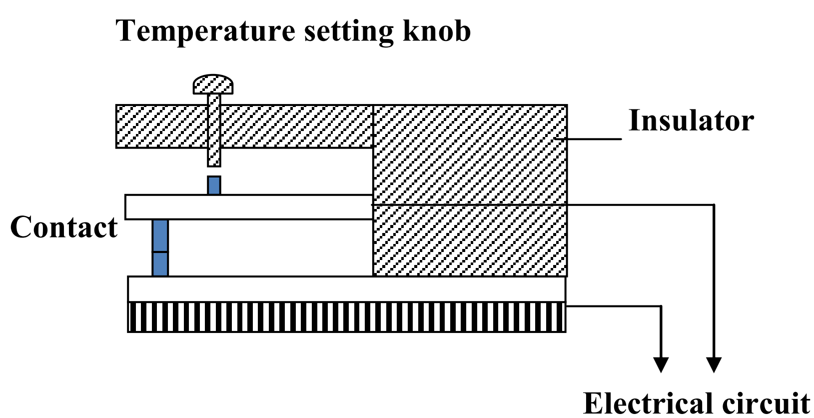
i) Fire alarm



- A bimetallic strip is heated by fire.
- It bends and completes an electrical circuit and an alarm bell is heard

ii) Thermostat

- The temperature required is set by a temperature setting knob.
- The bimetallic strip then bends breaking the contact which switches off the current.
- On cooling the bimetallic strip makes the contact and switches on the current and steady temperature is maintained.



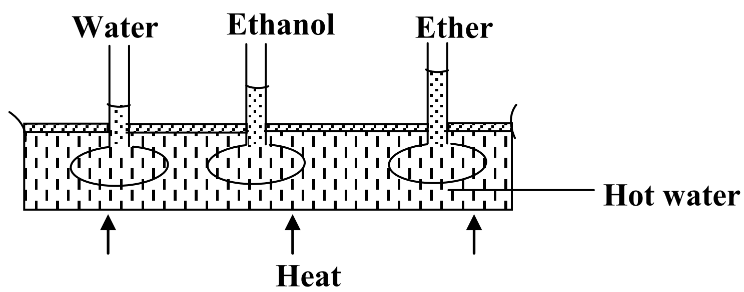
Expansion of liquids:

Liquids expand when they are heated and different liquids expand by different amounts when equally heated. According to the kinetic theory of matter liquid molecules are far apart compared to solid molecules and the intermolecular forces are weaker. Hence when a liquid is heated in a container the vibrations of its molecules become more vigorous and the liquid will then occupy more space. There fore liquids expand much more than solids.

However when glass flask is filled with a liquid and then heated its level falls slightly at first and then starts rising, this is due to the expansion of the glass flask which gets heated first and the liquid starts expanding when heat finally reaches it and the level rises in the flask.

Experiment to compare the expansion of different liquids:

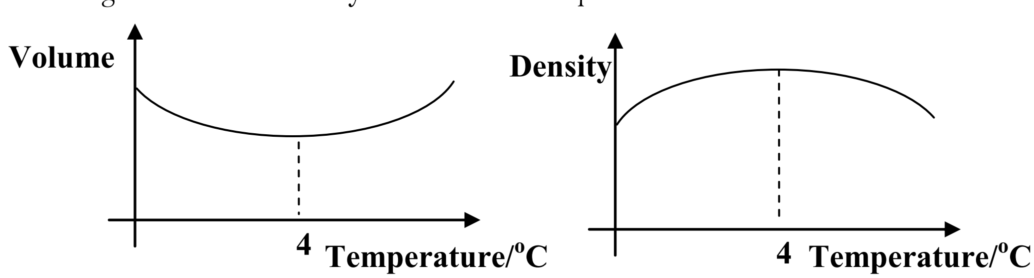
- Different glass tubes are filled with equal amounts of ethanol, water and ether
- The glass tubes are then heated from the same source using the water bath
- The levels of the liquids in tubes rise by different amount as the heating continues with ether expanding more than ethanol and water respectively.



The unusual expansion of water:

When liquids and solids are heated they expand and when cooled they contract. However water shows an unusual behavior in that it contracts when its temperature is raised from 0°C to 4°C, this is referred to as Anomalous expansion of water. Anomalous expansion of water is therefore an abnormal property of water whereby water expands instead of contracting when the temperature goes from 0°C to 4°C and becomes less dense. When ice is heated from -20°C, it expands until its temperature reaches 0°C and then melts with no change in temperature which is accompanied by contraction. The water formed will still contract as its temperature rises from 0°C and the volume of water is minimum at 4°C and therefore it has a maximum density. Water expands with increase in temperature above 4°C.

The changes in volume/density of water with temperature are as shown below



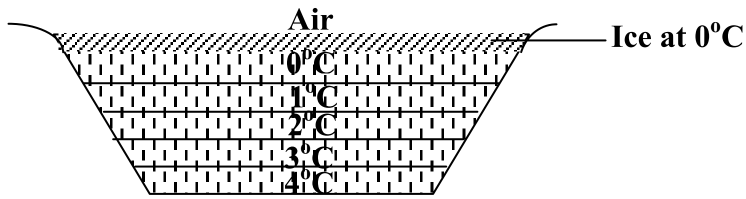
This explains why ice floats when mixed with water because for any given mass of ice at 0°C its volume is greater than that of water and therefore less dense than water hence floats on water.

Effects of anomalous expansion of water

Anomalous expansion of water has the following effects;

i) Freezing of lakes and ponds

This helps to preserve the lives of aquatic animals in water. Water in lakes and ponds usually freezes in winter and ice being less dense than water it floats on water. Since ice is a bad conductor of heat, it insulates the water below against heat losses to the cold air above. Water at 4°C being the most dense keeps at the bottom of lake and ice being less dense than water it floats on the layers of water at different temperatures as shown below



ii) Icebergs:

Density of ice is slightly less than that of water and it floats with its small portion above the water surface and the big portion under the water surface. A big mass below the water surface is known as an ice berg which poses a greater danger to ships as navigators cannot see the submerged part.

iii) Weathering of rocks:

When water in a crack in a rock freezes, it expands which breaks the rock into small pieces

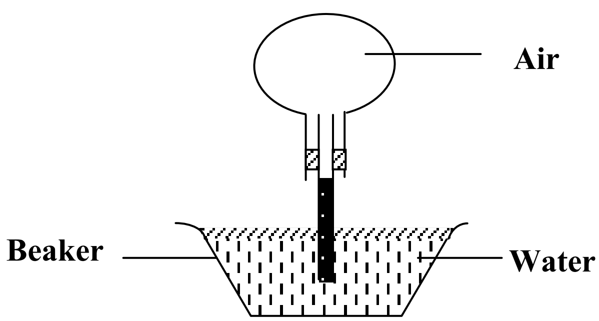
iv) Water pipes:

Water pipes burst when the water flowing through the pipes freezes.

EXPANSION OF GASES:

When gas is heated, the gas molecules gain more energy and move further apart occupying more space.

Experiment to show the expansion of gases:



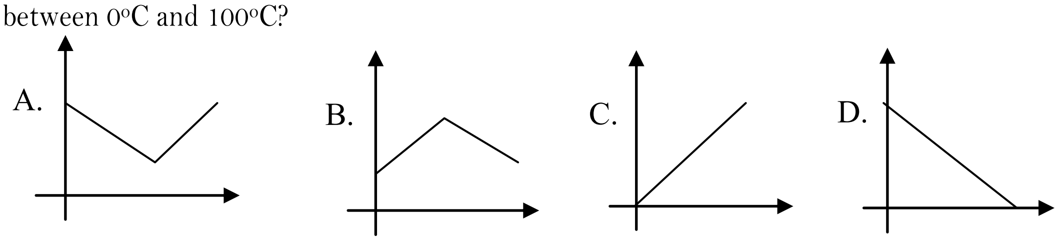
- Invert the flask with the glass tube dipped into the water in the beaker
- The flask is then warmed for some time and the level of water column in the glass tube drops
- This indicates that air expands when the temperature rises, pushes water down the tube and water bubbles are seen at the end of the tube.
- On cooling the flask the air inside contracts and water rises up in the glass tube.

Trial Exercise 2:

1. Distinguish between natural and forced convection
2. Explain why the feet feel colder when a person stands on a cemented floor than on a wooden floor.
3. Explain why many houses in hot areas should be painted white while those in colder areas should be painted with dull colours
4. Why are ventilations for a room put near the roof and not near the floor?
5. Explain the greenhouse effect and how it affects the earth
6. Explain the following observations;
   i) Two thin blankets are warmer than a single thick one
   ii) Flames go upwards
   iii) A person should crawl close to the floor in a smoke-filled room
7. Why is it that a swimmer would prefer to put on a wet cloth before diving into cold water?
8. State and explain the disadvantages of anomalous expansion of water
9. A man wants to fit a brass ring tightly into a steel rod of diameter equal to the inner diameter of the ring. Explain how this can be achieved.
10. Why do gases expand much more than solids for the same temperature change?

Multiple-choice exercise:

1. The ice and steam points on an un-graduated thermometer are 20cm apart. What temperature is recorded in ^oC when mercury thread is 5cm long?
   A. 25.0 B. 33.3 C. 84.7 D. 400.0
2. The distance between the lower fixed point and upper fixed point on a Celsius scale on unmarked mercury-in-glass thermometer is 25cm. If the mercury level is 5cm below the upper fixed point then the temperature is
   A. 5^oC B. 20^oC C. 80^oC D. 95^oC
3. In order to make mercury thermometer more sensitive, the
   A. degree markings must be further apart
   B. diameter of the capillary tube must be reduced
   C. volume of the mercury bulb must be reduced
   D. capillary tube must be open to air
4. Which of the following graphs shows the correct density against temperature relationship of water between 0^oC and 100^oC?



5. A bimetallic strip operates on the principle that metals
   A. are heat controllers B. have different rates of expansion
   C. are good heat conductors D. have the same rates of expansion
6. Which of the following devices does not use a bimetallic strip?
   A. electric flat iron B. gas oven C. car flasher unit D. hot water tanks
7. Which of the following does not change when a metal is heated?
   A. mass B. volume C. length D. density

8. What is the mode of heat transfer from a fire to a person seated beside it?
A. conduction B. convection C. radiation D. evaporation

9. Why is water preferred to ethanol as a coolant?
A. water has a higher density than ethanol
B. water has a higher specific heat capacity than ethanol
C. water is more volatile than ethanol
D. ethanol has a higher density than water

10. Which of the following is/are true about a sea breeze?
i) It takes place during day time
ii) Cooler air blows from the land towards the sea
iii) Warmer air blows from the land towards the sea
iv) Cooler air blows from the sea towards the land
A. (ii) only correct B. (i) and (iv) correct
C. (i), (ii) and (iii) correct D. (i), (iii) and (iv) correct

11. In metals heat is transmitted by
A. conduction and radiation B. convection and radiation
C. conduction only D. convection only

12. Which of the following is not true about a vacuum flask?
A. it controls heat loss by radiation using the vacuum
B. the silvering of the walls on the vacuum side reduces loss or gain of heat by radiation
C. the cork is used to reduce loss of heat by conduction
D. it can be used to keep cold liquids cold

13. On a cool day, a metal feels cold to touch because
A. metals contain less heat
B. the temperature of the metal is the same as that of the surroundings
C. the temperature of the metal is less than that of the surroundings
D. the metal conducts heat away from the hand

14. Metals are good conductors of heat because
A. they are ductile B. they contain free protons
C. they contain free electrons D. their atoms can easily be displaced

15. The transfer of heat by actual movement of molecules of matter takes place
A. only in liquids B. only in gases
C. in solids and liquids D. in liquids and gases

16. The triple point of water is
A. 373.00K B. 273.16K C. 100.00K D. 0.00K

17. What are the missing words from the following sentence? Heat is a form of __________ measured in ______________________
A. energy and joules B. energy and ^oC
C. power and ^oC D. power and joules

18. The unit of heat is the
A. watt B. kilogram C. joule D. newton

19. It is hotter for the same distance over the top of a fire than it is in the side of it, mainly because.
A. air conducts heat upwards
B. convection takes more heat upwards
C. heat is radiated upwards
D. all processes of heat transfer contribute significantly transferring heat upwards

20. The rate of loss of heat from a body cooling under conditions of forced convection is proportional to its
i) heat capacity iii) absolute temperature
ii) surface area iv) excess of temperature over that of surrounding
A. (i), (ii) and (iii) correct B. (ii) and (iv) correct
C. (i) and (iii) correct D. (iv) only correct

Answers:

1	A	5	B	9	B	13	C	17	A
2	C	6	D	10	B	14	C	18	C
3	B	7	A	11	C	15	D	19	D
4	B	8	C	12	A	16	B	20	B

HEAT MEASUREMENT:

Terms used in measurement of heat:

i) Heat capacity, C:

This is the heat required to raise the temperature of a body by 1°C or 1K.

$$\text{Heat capacity} = \frac{\text{Quantity of heat}}{\text{Change in temperature}}$$

$$\text{Heat capacity} = \frac{Q}{\Delta\theta}$$

$$\text{Heat capacity} = \text{mass x specific heat capacity}$$

Heat capacity = mc

The SI unit of heat capacity is joules per Kelvin [J/K or Jk^{-1}]

ii) Specific heat capacity, c:

This is the quantity of heat required to raise the temperature of 1kg mass of a substance by 1°C or 1K.

$$\text{Specific heat capacity} = \frac{\text{Quantity of heat}}{\text{Mass x change in temperature}}$$

$$c = \frac{Q}{m \times \Delta\theta}$$

$$Q = mc\Delta\theta$$

The SI unit of specific heat capacity is Joules per kilogram per Kelvin [J/kgK or $Jkg^{-1}K^{-1}$].

N.B: The specific heat capacity is different for different substances and the table below shows values of specific heat capacities of some common substances.

Substances	Specific heat capacity[J/kgK]
Water	4200
Ice	2100
Aluminium	900
Copper	400
Iron	450

NOTE:

The high specific heat capacity of water makes water a very good liquid for cooling machines and radiators of central heating systems. The specific heat capacity of water is 4200Jkg^{-1}K^{-1}, this means that 1kg mass of water requires 4200J of heat to raise its temperature by 1K.

Examples:

1. How much heat is required to raise the temperature of 5kg of iron from 30^{o}C to 40^{o}C if the specific heat capacity of iron is 440Jkg^{-1}K^{-1}?

$\text{Heat} = mc\Delta\theta$

$\text{Heat} = 5 \times 440\ (40 - 30)$

$= 2200 \times 10$

= 22000Jkg^{-1}K^{-1}

2. How much heat is required to raise the temperature of 50g of copper from 16^{o}C to 116^{o}C if the specific heat capacity of copper is 400Jkg^{-1}K^{-1}?

$\text{Heat} = mc\Delta\theta$

$\text{Heat} = 0.05 \times 400\ (116 - 16)$

= 20 x 100

= 2000Jkg^{-1}K^{-1}

3. When a block of iron of mass 2kg absorbs 19kJ of heat its temperature rises by 10^{o}C. Find the specific heat capacity of iron

$\text{Heat} = mc\Delta\theta$

$19000 = 2 \times c \times 10$

$$c = \frac{19000}{20}$$

= 950Jkg^{-1}K^{-1}

4. When a block of iron of mass 2kg absorbs 3000J of heat its temperature rises by 10^{o}C. Find the heat capacity of iron

$\text{Heat} = C\Delta\theta$

$3000 = C \times 10$

$$C = \frac{3000}{10}$$

= 300JK^{-1}

CALORIMETRY:

This is the method of measurement of heat flow. The instrument used in calorimetry is called copper calorimeter.

Methods of measuring specific heat capacity:

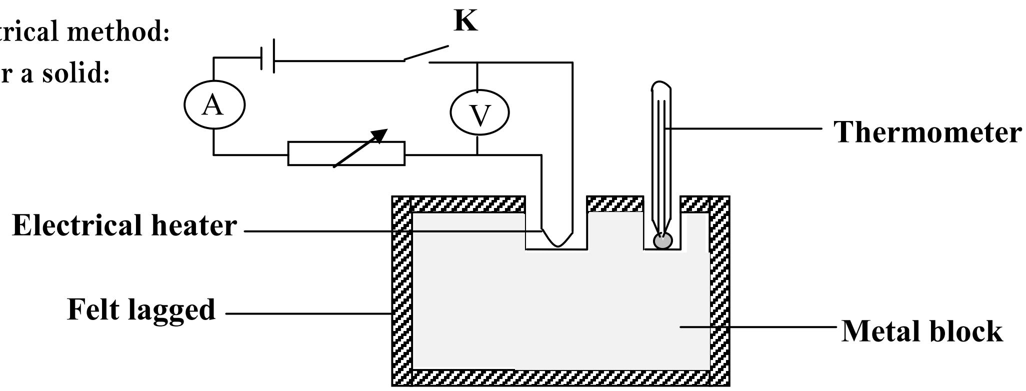
There are two common methods used to measure specific heat capacity of substances and these are

i) The method of mixture.

ii) The electrical method.

Electrical method:

a) For a solid:



- A solid used should be a good conductor of heat.
- A metal block of mass, m with two holes is used .
- The heater is placed in one of the holes and the thermometer in another hole.
- The initial temperature, θ_1 on the thermometer is then recorded.
- The heater is then switched on by closing switch, K until the temperature changes to θ_2, in time, t.
- The ammeter and voltmeter readings I and V respectively are noted and recorded.
- Assuming there are no heat losses

Electrical heat supplied = Heat gained by the solid

$$IVt = mc\Delta\theta$$

$$c = \frac{IVt}{m(\theta_2 - \theta_1)}$$

But IV = Electrical power, P

$$c = \frac{P \text{ x } t}{m(\theta_2 - \theta_1)}$$

- Hence specific heat capacity, c of the solid can be calculated.

Example:

98, 000J of electrical heat are needed to raise the temperature of 2kg of a substance from 51°C to 65°C. Calculate the specific heat capacity of a substance

Electrical heat supplied = Heat gained by the substance

$$IVt = mc\Delta\theta$$

$$P \text{ x } t = mc(\theta_2 - \theta_1)$$

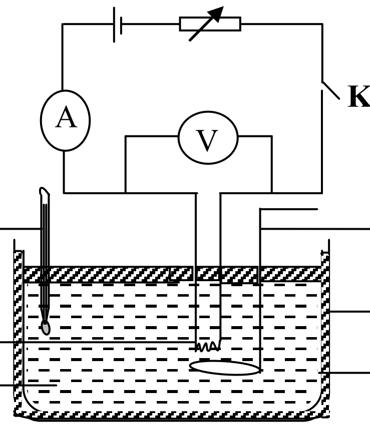
$$98000 = 2 \text{ x } c\,(65 - 51)$$

$$c = \frac{98{,}000}{28}$$

$$c = 3500\text{Jkg}^{-1}\text{K}^{-1}$$

b) For a liquid:

- A liquid of mass, m is poured in a copper calorimeter of mass, m_c and specific heat capacity, c_c.
- The temperature, θ_1 of the liquid is then recorded from the thermometer immersed in the liquid.
- The electrical heater is switched on until the temperature changes to θ_2 in time, t.
- The ammeter and voltmeter readings I and V respectively are noted and recorded.



- Assuming there are no heat losses

Electrical heat supplied = Heat gained by the liquid + heat gained by copper calorimeter

$$IVt = mc\Delta\theta + m_c c_c \Delta\theta$$

$$c = \frac{IVt - m_c c_c(\theta_2 - \theta_1)}{m(\theta_2 - \theta_1)}$$

But IV = Electrical power, P

$$c = \frac{P \text{ x } t - m_c c_c(\theta_2 - \theta_1)}{m(\theta_2 - \theta_1)}$$

- Hence specific heat capacity, c of the solid can be calculated

Example:

An electric heater of 1.8kW was used to heat 5kg of a liquid. It takes 6minutes to raise the temperature of the liquid from 20°C to 110°C. Calculate the specific heat capacity of the liquid

Electrical heat supplied = Heat gained by the liquid

$$IVt = mc\Delta\theta$$

$P \text{ x } t = mc(\theta_2 - \theta_1)$

$1.8 \text{ x } 1000 \text{ x } 6 \text{ x } 60 = 5 \text{ x } c\,(110 - 20)$

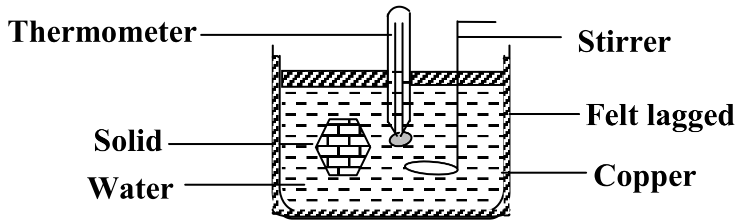
$648{,}000 = 5 \text{ x } c \text{ x } 90$

$$c = \frac{648{,}000}{450}$$

$c = 1440 Jkg^{-1}K^{-1}$

Method of mixtures:

a) For a solid



- A solid of mass, m_s whose specific heat capacity, c is required is heated to a temperature, θ_3.
- A solid is then transferred quickly to a copper calorimeter of mass, m_c and specific heat capacity c_c containing water of mass, m_w at a temperature, θ_1.
- The mixture is well stirred until a maximum temperature, θ_2 is reached.
- Assuming there are no heat loses during the experiment

  Heat lost by the solid = Heat gained by water + Heat gained by a calorimeter

$$m_s c\Delta\theta = m_w c_w \Delta\theta + m_c c_c \Delta\theta$$

$$c = \frac{m_w c_w(\theta_2 - \theta_1) + m_c c_c(\theta_2 - \theta_1)}{m_s(\theta_3 - \theta_2)}$$

- Hence specific heat capacity, c of a solid can be calculated

Example

A piece of metal of mass 0.5kg is heated to 100°C and then placed in 0.4kg of water at 10°C, if the final temperature of the mixture is 30°C. Calculate the specific heat capacity of the metal.

Heat lost by the solid = Heat gained by water

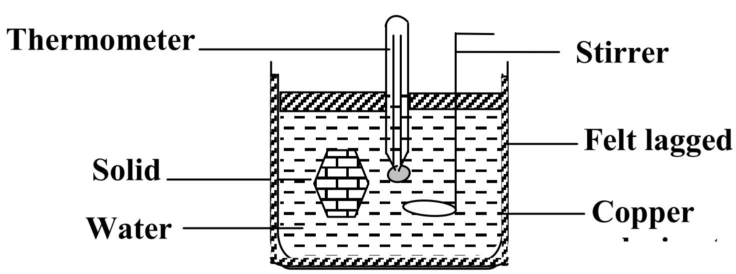
$$m_s c\Delta\theta = m_w c_w \Delta\theta$$

$$0.5 \text{ x } c \text{ x} (100 - 10) = 0.4 \text{ x } 4200 \text{ x } (100 - 10)$$

$$45c = 36 \text{ x } 4200$$

$$c = 3360 \text{Jkg}^{-1}\text{K}^{-1}$$

b) For a liquid:



- A solid of mass, m_s and specific heat capacity, c_s is heated to a temperature, θ_3.
- A solid is then transferred quickly to a copper calorimeter of mass, m_c and specific heat capacity c_c containing a liquid of mass, m_l whose specific heat capacity, c_l is required at a temperature, θ_1.
- The mixture is well stirred until a maximum temperature, θ_2 is reached.

- Assuming there are no heat loses during the experiment

  $\text{Heat lost by the solid} = \text{Heat gained by liquid} + \text{Heat gained by a calorimeter}$

  $$m_s c_s \Delta\theta = m_l c_l \Delta\theta + m_c c_c \Delta\theta$$

  $$c_l = \frac{m_s c_s(\theta_3 - \theta_2) - m_c c_c(\theta_2 - \theta_1)}{m_1(\theta_2 - \theta_1)}$$

- Hence specific heat capacity, c_l of a liquid can be calculated

Examples:

1. 450g of water at 60°C is to be cooled to 35°C by addition of cold water at 20°C. Calculate the mass of cold water added.

$\text{Heat lost by the hot water} = \text{Heat gained by cold water}$

$$m_w c_w \Delta\theta = m_c c_w \Delta\theta$$

$$0.45 \text{ x } 4200 \text{ x}(60 - 35) = \text{m x } 4200 \text{ x } (35 - 20)$$

$$\mathbf{11.25 = 15m}$$

$$m = 0.75\text{kg}$$

2. A copper metal of mass 250g is heated to 145°C and then placed in a copper calorimeter of mass 250g which contains 250cm^3 of water at 20°C. Calculate the maximum temperature attained by water [specific heat capacity of water is 4200Jkg^{-1}K^{-1} and specific heat capacityof copper is 400Jkg^{-1}K^{-1}]

$\text{Heat lost by the copper metal} = \text{Heat gained by liquid} + \text{Heat gained by a calorimeter}$

$$m_s c_s \Delta\theta = m_w c_w \Delta\theta + m_c c_c \Delta\theta$$

$0.25 \text{ x } 400 \text{ x } (145 - \theta) = 0.25 \text{ x } 4200 \text{ x } (\theta - 20) + 0.25 \text{ x } 400(\theta - 20)$

$14500 - 100\theta = 1050\theta - 21000 + 100\theta - 2000$

$37500 = 1250\theta$

$\theta = 30^oC$

LATENT HEAT:

This is the heat required to change the state of substance without change in temperature.

There are two types of latent heat and these are

i) Latent heat of fusion
ii) Latent heat of vaporization

Latent heat of fusion:

This is the heat required to change the state of a substance from solid to liquid without change in temperature.

Latent heat of vaporization:

This is the heat required to change the state of a substance from liquid to vapour without change in temperature.

N.B:

According to the kinetic theory when a substance is changing in state there is no change in temperature because the heat supplied is being used by molecules to break away the intermolecular forces holding them in one state.

Specific latent heat, L:

This is the heat required to change the state of 1 kg mass of substance without change in temperature.

The SI unit of specific latent heat is joule per kilogram, Jkg^{-1}.

$\text{Heat required} = \text{mass x specific latent heat}$

$\text{Heat} = mL$

There are two types of specific latent heat and these are

i) Specific latent heat of fusion.

ii) Specific latent heat of vaporization

Specific latent heat of fusion, L_f:

This is the heat required to change the state of 1kg mass of substance from solid to liquid without change in temperature. The SI unit of specific latent heat of fusion is Jkg^{-1}

Heat required = mass x specific latent heat of fusion

Heat = ml_f

Examples

1. How much heat is needed to melt 10g of ice at 0^oC?

[Specific latent heat of fusion of ice = 3.36×10^5kg]

Heat = ml_f

$$\text{Heat} = \frac{10}{1000} \times 3.36 \times 10^5$$
$$= 3.36 \times 10^3 J$$

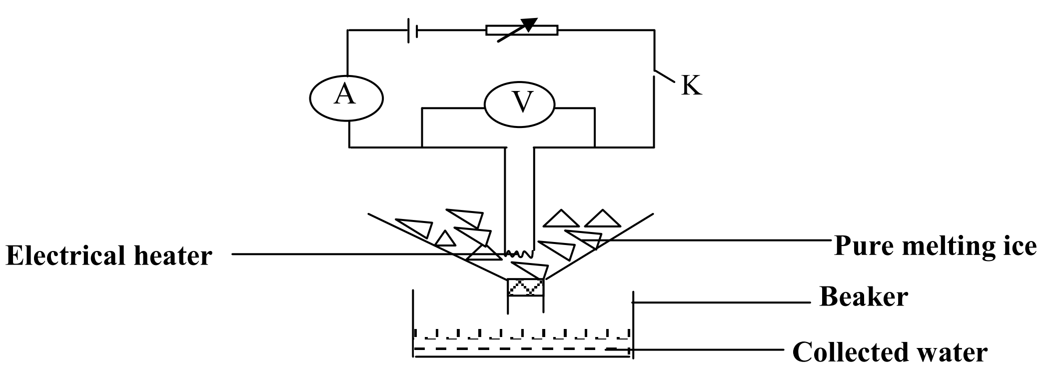
2. How much heat is needed to melt 10g of ice at -10^oC to water at 0^oC?

[Specific latent heat of fusion of ice = 3.36×10^5kg and specific heat capacity of ice = $2100Jkg^{-1}K^{-1}$]

$$\text{Heat} = mc\Delta\theta + mLf$$
$$\text{Heat} = \frac{10}{1000} \times 2100[0-(-10)] + \frac{10}{1000} \times 3.36 \times 10^5$$
$$= 0.21 \times 10^3 + 3.36 \times 10^3$$
$$= 3.57 \times 10^5 J$$

Determining specific latent heat of fusion of ice:

a) **Electrical method:**



- An electrical heater is placed in a funnel.
- Small pieces of ice are packed around it.
- The heater is then switched on for some time, t.
- The ammeter and voltmeter readings I and V are respectively noted and recorded.
- The mass, m of collected water from melted ice is measured and recorded
- Assuming there are no heat losses

  Heat supplied by the heater = heat gained by ice in melting

$$IVt = mL_f$$

$$Lf = \frac{IVt}{m}$$

But Power, $P = IV$

$$Lf = \frac{P \text{ x } t}{m}$$

- Hence specific latent heat of fusion, L_f can be calculated.

Example:

Qn. A 3kW electrical heater is left for 2 minutes in a container packed with ice at 0°C. If 100g of ice melted into water, calculate the specific latent of fusion of Ice.

$$IVt = m$$

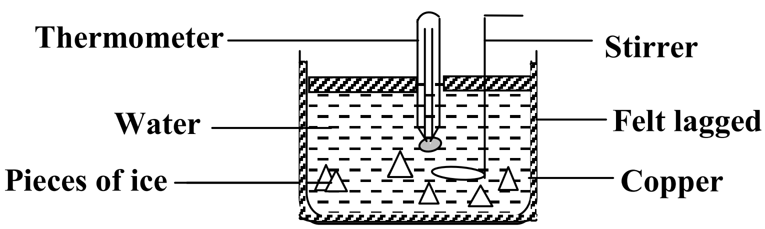
$$Lf = \frac{IVt}{m}$$

But Power, $P = IV = 3 \text{ x } 1000W$

$$Lf = \frac{3 \text{ x } 1000 \text{ x } 2 \text{ x } 60}{0.1}$$

$$= 3.6 \text{ x } 10^5 Jkg^{-1}$$

b) **Method of mixtures:**



- Small pieces of ice at 0°C are placed in copper calorimeter of mass, m_c and specific heat capacity, c_c containing hot water of mass, m_w at a temperature, θ_2.
- Stir the mixture gently until all the ice melts and record the temperature, θ_1 of the mixture from the thermometer.
- Weigh the calorimeter and its contents and determine the mass, m_i of melted ice.
  $m_i = \text{Total mass} - m_c$
- Assuming there are no heat losses

Heat gained by ice and melted ice = Heat lost by hot water and calorimeter

$$m_i L_f + m_i c_w \Delta\theta = m_w c_w \Delta\theta + m_c c_c \Delta\theta$$

$$L_f = \frac{m_c c_c \Delta\theta + m_w c_w \Delta\theta - m_i c_w \Delta\theta}{m_i}$$

$$L_f = \frac{m_c c_c (\theta_2 - \theta_1) + m_w c_w (\theta_2 - \theta_1) - m_i c_w \theta_1}{m_i}$$

Specific latent heat of vaporization, L_v:

This is the heat required to change the state of 1kg mass of substance from liquid to vapour without change in temperature. The SI unit of specific latent heat of vapourization is Jkg^{-1}.

$$\text{Heat required} = \text{mass x specific latent heat of vaporisation}$$

$$\text{Heat} = mLv$$

Examples

1. How much heat is needed to change 10g of water at 100°C to steam at constant temperature?
[Specific latent heat of vaporization of water = 2.3 x 10^6kg]

$$\text{Heat} = mLv$$

$$\text{Heat} = \frac{10}{1000} \text{ x } 2.3 \text{ x } 10^6$$

$$= 2.3 \text{ x } 10^4 J$$

2. How much heat is needed to melt 10g of ice at -10°C to steam at 100°C?
[Specific latent heat of fusion of ice = 3.36 x 10^5kg, specific heat capacity of ice = $2100Jkg^{-1}K^{-1}$, specific heat capacity of water = $4200Jkg^{-1}K^{-1}$, specific latent heat of vaporization of water = 2.3 x 10^6Jkg^{-1}]

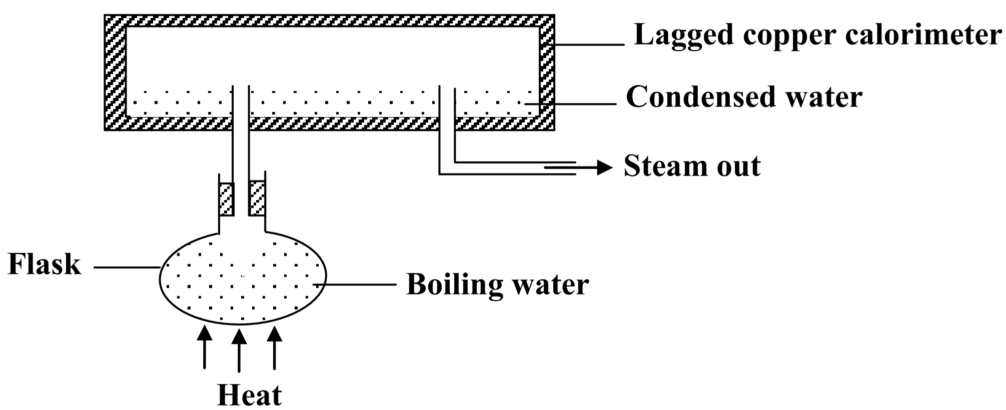
$$\text{Heat} = mici\Delta\theta + miLf + micw\Delta\theta + miLv$$

$$\text{Heat} = \frac{10}{1000} \text{x}2100 \text{ x } 10 + \frac{10}{1000} \text{ x } 3.36 \text{ x } 10^5 + \frac{10}{1000} \text{ x } 4200 \text{ x } 100 + \frac{10}{1000} \text{ x } 2.3 \text{ x } 10^6$$

$$= 0.21 \text{ x } 10^3 + 3.36 \text{ x } 10^3 + 4.2 \text{ x} 10^3 + 23 \text{ x} 10^3$$

$$= 3.077 \text{ x } 10^4 J$$

MEASURING SPECIFIC LATENT HEAT OF VAPORIZATION:



- Water in the flask is heated to a temperature of 100°C until steam comes out.
- Steam is then condensed into water in a well lagged copper calorimeter of mass, m_c and specific heat capacity, c_c at a temperature, θ.
- The calorimeter and its contents are measured to determine the mass, m of condensed water

  $$\mathbf{m = Total\ mass - m_c}$$

- Assuming there is no heat loss during the experiment

  Heat given out by steam = Heat gained by copper calorimeter

  $$mL_v = m_c c_c(100 - \theta)$$

  $$\mathbf{L_v = \frac{m_c c_c(100-\theta)}{m}}$$

- **Hence the specific latent heat of vaporization L_v can be calculated.**

Example:

1. The temperature of water of mass 2kg and specific heat capacity of $4200Jkg^{-1}K^{-1}$ is raised from 20^oC to 80^oC by steam at 100^oC. Calculate the mass of steam needed if the specific latent heat of vaporization of water is $2.3x10^6Jkg^{-1}K^{-1}$.

Heat lost by steam and condensed water = Heat gained by water

$$mL_v + mc_w(100 - \theta_2) = m_w c_w(\theta_2 - \theta_1)$$

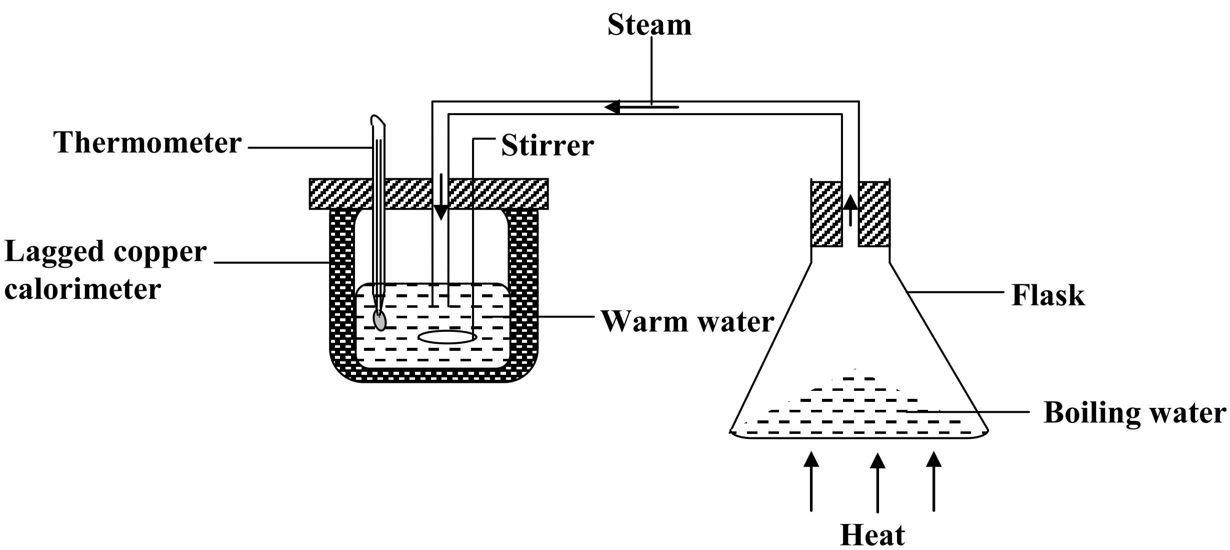
$$m = \frac{m_w c_w(\theta_2 - \theta_1)}{L_v + c_w(100 - \theta_2)}$$

$$m = \frac{2 \text{ x } 4200\ (80 - 20)}{2.3 \text{ x } 10^6 + 4200(100 - 80)}$$

$$m = \frac{504000}{2308400}$$

$$m = 0.218kg$$

Measuring specific latent heat of vaporization by method of mixtures



- Water in the flask is heated to a temperature of 100^oC until steam comes out.
- Steam is then passed through a cold water of mass, m_w at a temperature, θ_1 in a copper calorimeter of mass, m_c and specific heat capacity, c_c.
- The mixture is well stirred until a constant temperature, θ_2 is noted and recorded from the thermometer.
- The calorimeter and its contents are measured to determine the mass, m of condensed steam.
- $m = Total\ mass - (m_c + m_w)$.
- Assuming there is no heat loss during the experiment

  Heat lost by steam and condensed water = Heat gained by calorimeter and cold water

  $$mL_v + mc_w(100 - \theta_2) = m_w c_w(\theta_2 - \theta_1) + m_c c_c(\theta_2 - \theta_1)$$

  $$L_v = \frac{m_w c_w(\theta_2 - \theta_1) + m_c c_c(\theta_2 - \theta_1) - mc_w(100 - \theta_2)}{m}$$

- **Hence the specific latent heat of vaporization L_v can be calculated**

Example:
A calorimeter of mass 35.0g and specific heat capacity of 840Jkg^{-1}K^{-1} contains 143.0g of water at 7°C. Dry steam at 100°C is passed through the water in the calorimeter until the temperature of water rises up to 29°C. If the mass of steam which condenses is 5.6g, calculate
i) The heat gained by water and calorimeter
ii) Specific latent heat of vaporization of water
Solution:
i) $\text{Heat} = m_w c_w(29-7) + m_c c_c(29-7)$

$\text{Heat} = 0.143 \times 4200 \times 22 + 0.035 \times 840 \times 22$

$= 13860\text{J}$

ii) heat lost by steam and condensed water = heat gained by calorimeter and cold water

$mL_v + mc_w(100-29) = 13860$

$0.0056L_v + 0.0056 \times 4200 \times 71 = 13860$

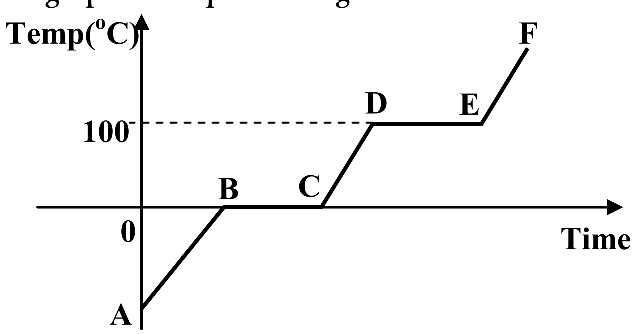
$0.0056L_v = 13860 - 1669.92$

$L_v = \frac{12190.08}{0.0056}$

$L_v = 2{,}176{,}800\text{Jkg}^{-1}$

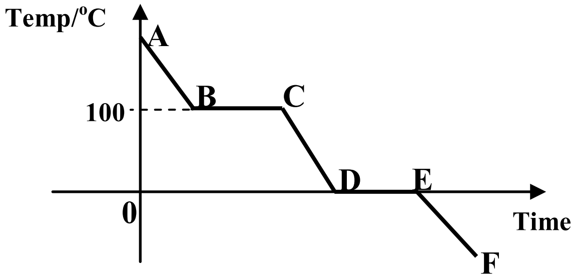
Change of state of a substance:
When a solid is heated it changes to a liquid at its melting point and when a liquid is cooled it changes to a solid at its freezing point. When a liquid is heated it changes to a gas (vapour) at its boiling point and when a liquid is cooled it condenses and changes to a liquid.

The graph of temperature against time when ice below its melting point is heated.



Explaining the shape of the graph
AB: temperature of ice is increasing
BC: ice is changing to water at 0°C
CD: the temperature of water is increasing
DE: water is changing to steam at 100°C
EF: temperature of steam is increasing
The states of water along different regions are;
AB – solid state (ice)
BC – solid state and liquid state (water + ice)
CD – liquid state (water)
DE – liquid state and gaseous state (water + vapour)
EF – gaseous state (steam or vapour)

The graph of temperature against time when water above its boiling point is cooled



Explaining the shape of the graph

AB: temperature of steam is decreasing

BC: steam is changing to water at 100°C

CD: the temperature of water is decreasing

DE: water is changing to ice at 0°C

EF: temperature of ice is decreasing

The states of water along different regions are;

EF – solid state (ice)

DE – solid state and liquid state (water + ice)

CD – liquid state (water)

BC – liquid state and gaseous state (water + vapour)

AB – gaseous state (steam or vapour)

NOTE:

When a solid is heated, the particles obtain energy and vibrate at a faster rate. As the temperature increases, the vibration of the particles increases until they reach the melting point where the particles obtain enough energy to overcome the forces that hold them in their fixed positions. The solid then changes into a liquid. During melting, the temperature remains constant. This is because the heat energy is taken in by the particles to overcome forces between them instead of being used to raise the temperature. When a liquid is heated further, the particles gain energy and move faster. As heat energy is keep on supplying to the liquid, the particles will eventually obtain enough energy to completely break the forces in between molecule. The liquid then changes into a gas and particles are now able to move freely and are far apart. The temperature remains constant during boiling because heat energy that is absorbed by the particles is used to break the forces holding them together.

The process in which a liquid changes to a solid is called **freezing**. Energy is taken away during freezing. The temperature at which a liquid changes to a solid is its freezing point. The process in which a solid changes to a liquid is called **melting**. Energy is added during melting. The melting point is the temperature at which a solid changes to a liquid. If water gets hot enough the particles of liquid water gain enough energy to completely overcome the force of attraction between them and changes to the gaseous state. The process in which a liquid boils and changes to a gas is called **vaporization**. The temperature at which a liquid boils is its **boiling point**. A liquid can also change to a gas without boiling. This process is called **evaporation**. It occurs when particles at the exposed surface of a liquid absorb just enough energy to pull away from the liquid and escape into the air. Energy is added during evaporation and vaporization. The process in which a gas changes to a liquid is called **condensation.** Energy is removed during condensation.

Trial Exercise 3:

Where necessary assume the following

Specific heat capacity of water	$= 4200Jkg^{-1}K^{-1}$
Specific heat capacity of copper	$= 400\ Jkg^{-1}K^{-1}$
Specific heat capacity of iron	$= 450\ Jkg^{-1}K^{-1}$
Specific heat capacity of aluminium	$= 880\ Jkg^{-1}K^{-1}$
Specific heat capacity of ice	$= 2100\ Jkg^{-1}K^{-1}$
Specific latent heat of fusion of ice	$= 336{,}000\ Jkg^{-1}$
Specific latent heat of vaporization of water	$= 2{,}250{,}000\ Jkg^{-1}$

1. How much heat is required to raise the temperature of 50g of aluminium from -100°C to 120°C?
   Ans: 9,680J
2. If 98,000J of heat are needed to raise the temperature of 2kg of a substance from 51°C to 65°C. What is the specific heat capacity of a substance?
   Ans: 3500Jkg^{-1}K^{-1}
3. An electric fire has a power of 1,800W. When used to heat a liquid of 5kg, it takes 6 minutes to raise the temperature by 90°C. What is the specific heat capacity of the liquid?
   Ans: 1440Jkg^{-1}K^{-1}
4. A 30g block of copper is heated from -20°C to 180°C. How much heat does it absorb during heating?
   Ans: 2400J
5. How much heat energy is needed to melt 0.01kg of ice at 0°C?
   Ans: 3360J
6. How much heat energy is needed to change 0.2kg of ice at 0°C into steam at 100°C?
   Ans: 601,200J
7. An electric heater marked 225,000W keeps water boiling at 100°C. What mass of water evaporates in a second?
   Ans: 0.1kg
8. An electric heater was used to heat 2kg of water from 20°C to 50°C in 25 minutes. If the voltage across the heater was 24V, what was the current through the heater?
   Ans: 7.0A
9. 5kg of ice cubes are removed from the freezing compartment of a refrigerator into a home freezer. The refrigerator's freezing compartment is kept at -40°C the home freezer is kept at -17°C. How much heat does the freezer's cooling system remove from the ice cubes?
   Ans: 241,500J
10. What is the heat capacity of 5.5kg of aluminium?
    Ans: 4,840Jk^{-1}

Multiple-choice Exercise:

1. How much heat is evolved when 100g of copper are cooled from 90°C to 10°C?
A. 3,200,000J B. 38,000J C. 8,000J D. 3,200J

2. The amount of heat used to raise the temperature of 5kg of water from 5°C to 30°C is the same amount used to heat 2kg of iron at 5°C. What is the final temperature of iron?
A. 30.0°C B. 62.5°C C. 583.3°C D. 588.3°

3. Calculate the amount of heat needed to change 3kg of ice at -10°C to water at 90°C
A. 2.27×10^6J B. 2.21×10^6J C. 9.10×10^5J D. 6.3×10^4J

4 A 1200W kettle contains 2kg of water at 25°C. How long would it take to heat the water to 85°C if 80% of electrical energy supplied is absorbed by the water?
A. 5.60minutes B. 7.00minutes C. 8.75minutes D. 420.00minutes

5. A block of iron of mass 25g at 100°C is immersed in water of mass 100g at 20°C. What is the final temperature of the water?
A. 100.0°C B. 60.0°C C. 22.1°C D. 20.0°C

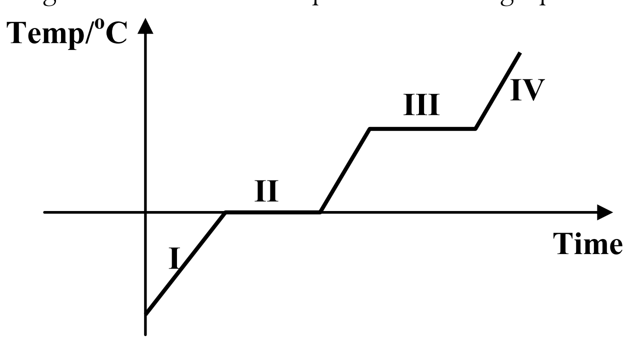
6. 500g of water at 100°C are added to a thick copper calorimeter of mass 1000g at 15°C. What is the final temperature of water and the calorimeter?
A. 16.9°C B. 57.5°C C. 85.0°C D. 86.4°C

7. 1kg of water at 40°C was placed in a metal can of mass 500g at 18°C. The temperature of water fell by 2 degrees. What is the specific heat capacity of the material of the metal?
A. $924{,}000Jkg^{-1}K^{-1}$ B. $840Jkg^{-1}K^{-1}$ C. $185Jkg^{-1}K^{-1}$ D. $0.84Jkg^{-1}K^{-1}$

8. Ice cubes of mass 500g at 0°C are mixed with 3kg of water at 0°C. How much heat is needed to convert the mixture to water at 10°C?
A. 168,000J B. 315,000J C. 147,000J D. 126,000J

9. Which of the following is not a method of minimizing heat loss in a calorimeter experiments?
A. insulating the calorimeter
B. covering a calorimeter with a card board
C. enclosing the calorimeter in a vacuum
D. painting a calorimeter with a dull black surface

10. The diagram below shows temperature – time graph of a certain substance



What state is the substance in stages I, II, III and IV

	I	II	III	IV
A.	solid	solid	liquid	gas
B.	liquid	liquid + solid	gas	gas
C.	solid	solid + liquid	liquid + gas	gas
D.	liquid	solid	solid	liquid

11. When 1 kg of certain liquid is heated for 10s its temperature rises by 25°C. If the power supplied is 1000W. Find the specific heat capacity of the liquid

A. 2,500$Jkg^{-1}K^{-1}$ B. 1,000$Jkg^{-1}K^{-1}$ C. 400$Jkg^{-1}K^{-1}$ D. 40$Jkg^{-1}K^{-1}$

12. The process of using a material of low thermal conductivity to prevent heat loss is called

A. cooling B. lagging C. absorption D. contraction.

13. 450g of water at 60°C is to be cooled to 35°C by addition of cold water at 20°C. How much cold water is to be added

A. 0.169kg B. 0.270kg C. 0.281kg D. 0.750kg

14. The specific heat capacity of a substance is the quantity of heat

A. needed to change 1kg mass from solid to liquid

B. needed to change 1kg mass from liquid to gas

C. needed to change the temperature of 1kg mass by 1K

D. given out when 1kg mass changes from solid to liquid

15. 50g of water at 60°C is to be cooled by addition of 20g of cold water at 20°C. Find the maximum temperature of the mixture.

A. 3.0°C B. 30.0°C C. 48.6°C D. 80.0°C

16. If ice of mass 0.5g at – 10°C is added to 40g of water at 15°C. Calculate the temperature of the mixture

A. 13.8°C B. 13.0°C C. 12.0°C D. 10.0°C

17. 10g of steam passes over an ice block. What amount of ice will melt?

A. 8g B. 18g C. 45g D. 67g

18. Specific heat capacity of a body does not depend on

A. heat supplied B. rise in temperature

C. mass of the body D. nature of the material

19. To raise the temperature of 100g of ice at 0°C to 10°C by a heater of 420W, the time required is

A. 90.0min B. 1.5min C. 21.2min D. 12.7min

20. Two bodies at different temperatures are mixed in a calorimeter, which of the following quantities remain constant

A. internal energy of each body B. total internal energy of the two bodies

C. total heat of the two bodies D. sum of the temperatures of the two bodies

Answers:

1	D	5	C	9	D	13	D	17	D
2	D	6	D	10	C	14	C	18	D
3	B	7	B	11	C	15	C	19	B
4	C	8	B	12	B	16	A	20	B

GAS LAWS:

A gas is a substance possessing a perfect molecular mobility and has a property of indefinite expansion as opposed to a solid or a liquid.

There are three gas laws namely;

i) Boyle's law.
ii) Pressure law.
iii) Charles' law.

Boyle's law:

It states that the volume of a fixed mass of a gas at constant temperature is inversely proportional to its pressure.

$$\text{Pressure} \propto \frac{1}{\text{Volume}}$$

$$P \propto \frac{1}{V} \qquad P = K\frac{1}{V} \qquad PV = K$$

Where K is constant of proportionality and if the volume of gas changes from V_1 to V_2 and its pressure changes from P_1 to P_2.

then $P_1V_1 = P_2V_2$

Examples:

1. The volume of a fixed mass of a gas at constant temperature is $250cm^3$ when the pressure is 720mmHg. Find the pressure when the volume is increased to $600cm^3$.

$P_1V_1 = P_2V_2$

$P_1 = 720mmHg \; V_1 = 250cm^3 V_2 = 600cm^3$

$720 \times 250 = P_2 \times 600$

$$P_2 = \frac{720 \times 250}{600}$$

$P_2 = 300mmHg$

2. The volume of a fixed mass of a gas at constant temperature is $2.0 \times 10^{-5}m^3$ when the pressure is 7.2×10^6Pa, find the pressure when the volume is increased to $6.0 \times 10^{-4}m^3$.

$P_1V_1 = P_2V_2$

$P_1 = 7.2 \times 10^6 V_1 = 2.0 \times 10^{-5}m^3 V_2 = 6.0 \times 10^{-4}m^3$

$7.2 \times 10^6 \times 2.0 \times 10^{-5} = P_2 \times 6.0 \times 10^{-4}$

$$P_2 = \frac{7.2 \times 10^6 \times 2.0 \times 10^{-5}}{6.0 \times 10^{-4}}$$

$P_2 = 2.4 \times 10^5 Pa$

3. The volume of a fixed mass of a gas at constant temperature is $4cm^3$ when the pressure is 6 atmospheres, find the volume when the pressure is increased to 12 atmospheres.

$P_1V_1 = P_2V_2$

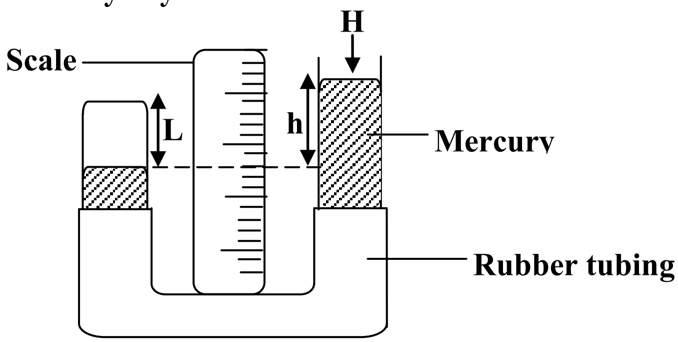
$P_1 = 6 \text{ atm } V_1 = 4cm^3 P_2 = 12 \text{ atm}$

$6 \times 4 = V_2 \times 12$

$$V_2 = \frac{24}{12}$$

$V = 2 \text{ cm}^3$

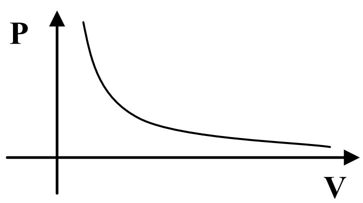
Experiment to verify Boyle'slaw



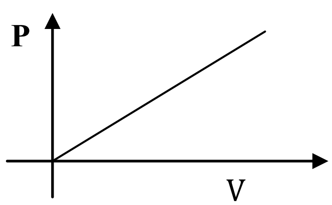
- Dry air is trapped by mercury in a closed limb of the tube of uniform cross sectional area, A.
- The pressure of the gas is due to height, h and its volume is due to length, L of the tube.
- The pressure, P of the gas and its volume, V are adjusted by raising and lowering the tube.
- The pressure, P of the gas is given by $P = H + h$ and the volume, V of the gas is given by $V = AL$ where H is the atmospheric pressure.
- The results are then tabulated in table below

Length, L	Height, h	Volume, V	Pressure, P

- A graph of P against V is then plotted and the shape below is obtained



- A graph of P against $\frac{1}{V}$ is also plotted and the shape below is obtained



Note: From the above graphs it shows that pressure is inversely proportional to volume which is Boyle's law.

Pressure law:

It states that the pressure of a fixed mass of a gas at constant volume is directly proportional to its absolute temperature.

$\text{pressure} \propto \text{temperature}$

$P \propto T$

$P = KT$

Where K is constant of proportionality. If the temperature of gas changes from T_1 to T_2 and its pressure changes from P_1 to P_2.

then $\frac{P_1}{T_1} = \frac{P_2}{T_2}$

Example:

The pressure of a fixed mass of a gas at 127°C is 600mmHg. Calculate its pressure at constant volume if the temperature reduces to 27°C

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

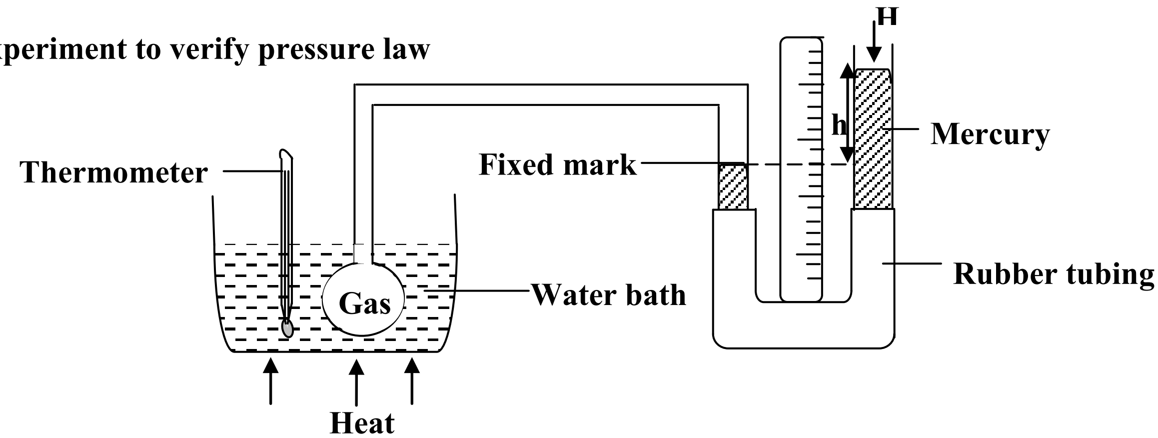
$P_1 = 600\text{mmHg}$ $P_2 = ?$

$T_1 = 127 + 273 = 400K$ $T_2 = 27 + 273 = 300K$

$$\frac{600}{400} = \frac{P_2}{300}$$

$P_2 = 450\text{mmHg}$

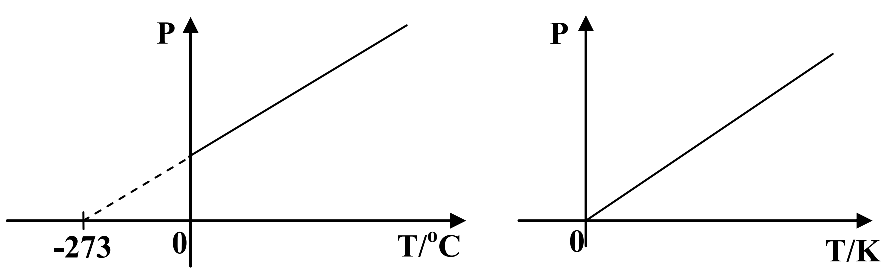
Experiment to verify pressure law



- Dry gas in the bulb is heated using a water bath.
- The pressure of the gas is due to height, h which is measured when the mercury level is at the fixed mark in the tube.
- The temperature of the gas is recorded and noted from the thermometer.
- The pressure, P of the gas is adjusted by increasing the temperature of the water bath and the pressure, P of the gas is given by P = H + h.
- The results are then tabulated in table below

Temperature, T	Height, h	Pressure, P

- The graph of pressure against temperature is then plotted



Note: From the above graphs it shows that pressure is directly proportional to the temperature which is pressure law and the temperature -273°C (0K) is called **absolute zero temperature.**

Absolute zerotemperature is the temperature at which the molecules of a gas have minimum kinetic energy.That is the temperature at which the volume of the molecules of the gas reduces to zero.

Charles' law:

It states that the volume of a fixed mass of a gas at constant pressure is directly proportional to its absolute temperature.

volume α temperature

$V \alpha T$

$V = KT$

Where K is constant of proportionality. If the temperature of gas changes from T_1 to T_2 and its volume changes from V_1 to V_2.

then $\frac{V_1}{T_1} = \frac{V_2}{T_2}$

Example:

1. The volume of a fixed mass of a gas at 127°C is 300cm³. Calculate its volume at constant pressure if the temperature reduces to 27°C

$\frac{V_1}{T_1} = \frac{V_2}{T_2}$

$V_1 = 300cm^3 V_2 = ?$

$T_1 = 127 + 273 = 400K \quad T_2 = 27 + 273 = 300K$

$\frac{300}{400} = \frac{V_2}{300}$

$V_2 = 225cm^3$

2. The volume of a fixed mass of a gas at 17°C is 5.0 x 10^{-4}m³. Calculate its temperature at constant pressure if the volume reduces to 2.0 x 10^{-4}m³

$\frac{V_1}{T_1} = \frac{V_2}{T_2}$

$V_1 = 5.0 \text{ x } 10^{-4} \text{ m}^3 V_2 = 4.0 \text{ x } 10^{-4} \text{m}^3$

$T_1 = 17 + 273 = 290K \quad T_2 = ?$

$\frac{5.0 \text{ x } 10^{-4}}{290} = \frac{2.0 \text{ x } 10^{-4}}{T_2}$

$T_2 = \frac{2 \text{ x } 290}{5}$

$T_2 = 116K$

3. The volume of a fixed mass of a gas at 27°C is 400cm³. Calculate its volume at constant pressure if the temperature reduces to -123°C

$\frac{V_1}{T_1} = \frac{V_2}{T_2}$

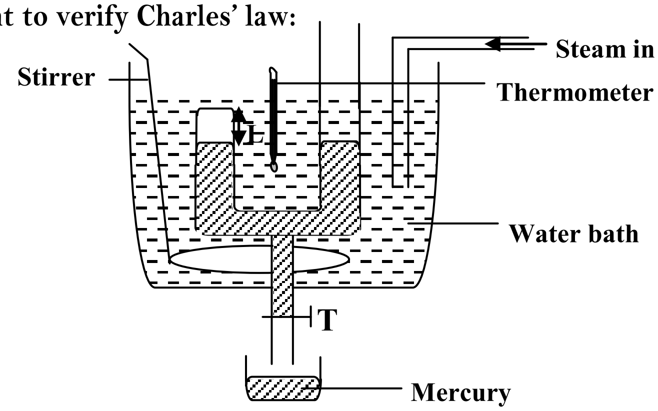
$V_1 = 400cm^3 V_2 = ?$

$T_1 = 27 + 273 = 300K \quad T_2 = -123 + 273 = 150K$

$\frac{400}{300} = \frac{V_2}{150}$

$V_2 = 200cm^3$

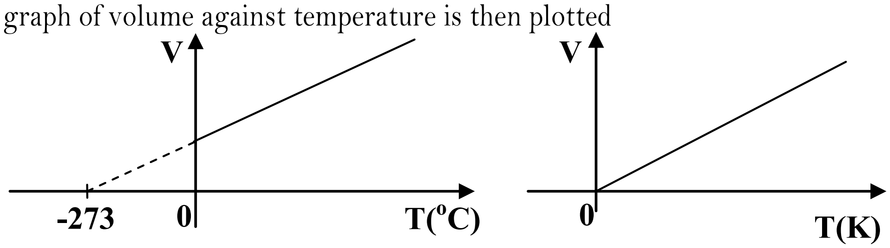
Experiment to verify Charles' law:



- Dry air is trapped in a closed limb of uniform cross sectional area, A by mercury.
- The tube is immersed in a water bath and is well stirred to ensure a uniform temperature.
- The mercury in the limbs is maintained at the same level by opening tap, T so that the pressure of the gas is kept constant.
- The temperature, T of the gas is adjusted by passing steam through the water bath and the volume of the gas depends on the length, L of the tube.
- The volume, V of the gas is given by V = AL.
- The results are then tabulated in table below

Temperature, T	Length, L	Volume, V

- The graph of volume against temperature is then plotted



Note: From the above graphs it shows that volume is directly proportional to the temperature which is Charles' law and the temperature -273°C (0K) is called **absolute zero temperature.**

Equation of state for an ideal gas:

This is sometimes referred to as ideal gas equation. It is a combination of the three gas laws

$\text{Boyle's law } PV = K$

$\text{Pressure law } \frac{P}{T} = K$

$\text{Charle's law } \frac{V}{T} = K$

Combining the above three laws

$\text{then } \frac{PV}{T} = K$

Therefore if the volume of the gas changes from V_1 to V_2, its pressure from P_1 to P_2 and its temperature from T_1 to T_2

$$\textbf{then } \frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

Examples

1. In an experiment 500cm^3 of a gas was collected at a temperature of 97^{o}C and a pressure of 3.7 x 10^6 Pa. Find the volume the gas if the pressure changes to 6.0 x 10^6 Pa at a temperature of 27^{o}C.

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

$$\frac{3.7 \text{ x } 10^6 \text{ x } 500}{97 + 273} = \frac{V_2 \text{ x } 6.0 \text{ x } 10^6}{27 + 273}$$

$$V_2 = \frac{3.7 \text{ x } 300 \text{ x } 500}{370 \text{ x } 6}$$

$$V_2 = 250\text{cm}^3$$

2. In an experiment 58cm^3 of a gas was collected at a temperature of 17^{o}C and a pressure of 8.0 x 10^4 Pa. Find the volume the gas at s.t.p

Note: S.T.P is standard temperature and pressure and the standard temperature = 273K and standard pressure = 76cmHg = 760mmHg = 1.013 x 10^{5}Pa.

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

$$\frac{8.0 \text{ x } 10^4 \text{ x } 58}{17 + 273} = \frac{V_2 \text{ x } 1.013 \text{ x } 10^5}{273}$$

$$V_2 = \frac{8 \text{ x } 273 \text{ x } 58}{290 \text{ x } 10.13}$$

$$V_2 = 43.12 \text{ cm}^3$$

Kinetic theory and Gas laws:

It states that matter is made up of small particles that are in a constant random motion and possess energy. Therefore the speed of the particles is proportional to temperature and the pressure exerted by the gas is due to collision of gas molecules with the walls of the container

Boyle's law:

When the volume of the fixed mass of a gas is reduced at constant temperature the speed of the gas molecules increases hence the rate of collision with the walls of the container increases thus the pressure of the gas increases since the temperature is constant. However increasing the volume reduces the pressure of the gas since the speed of the molecules of the gas reduces hence reducing on the rate of collision with the walls of the container.

Charles' law:

When the temperature of the fixed mass of a gas is increased at constant pressure the speed of the molecules of a gas increases and the rate of collision with the walls of a container increases hence the volume of the gas increases to keep the pressure constant.

Pressure law:

When the temperature of the fixed mass of a gas is increased at constant volume the speed of the molecules of a gas increases and the rate of collision with the walls of a container increases hence the pressure of the gas increases to keep the volume constant.

VAPOURS:

This is the mass of small liquid drops in air. Example of a vapour is steam [water vapour]. There are two types of vapours and these are

i) Saturated vapour

ii) Unsaturated vapour

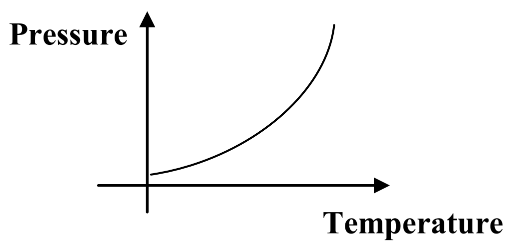
Saturated vapour:

This is the vapour that is in dynamic equilibrium with its own liquid. The pressure exerted by a vapour in dynamic equilibrium with its own liquid (saturated vapour) is called **saturated vapour pressure.**

Effect of temperature on saturated vapour:

When a saturated vapour is heated the average kinetic energy of the molecules increases that increases the rate of evaporation and rate of condensation and eventually its saturated vapour pressure increases. The mass of the saturated vapour changes with change in temperature the density of the vapour changes with temperature. Therefore a saturated vapour does not obey the gas laws [Charles' law].

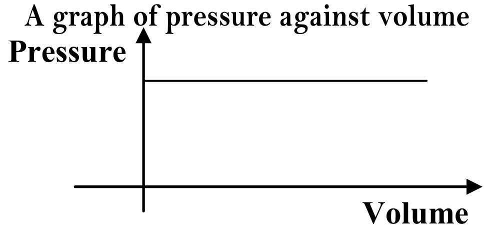
A graph of pressure against temperature:



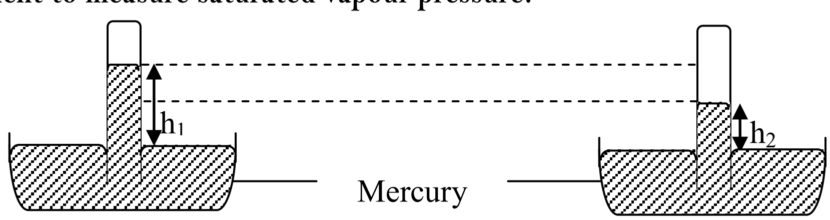
Effect of pressure on saturated vapour:

At constant temperature the saturated vapour pressure is not affected by changes in volume of the vapour because decrease in volume of the vapour increases its density which increases the rate of condensation but the rate of evaporation remains constant hence the rate of condensation exceeds the rate of evaporation until the density of the vapour falls to its original value to restore the equilibrium position with the saturated vapour pressure having its original value. Therefore a saturated vapour does not obey the gas laws [Boyle's law].

A graph of pressure against volume



Experiment to measure saturated vapour pressure:



Before saturation **After saturation**

- Set up te barometer and wait for the mercury column to become constant.
- Read and record the atmospheric pressure, h_1.
- Squirt a few drops of the liquid into the barometer tube by means of a pipette.

- The liquid rises to the top of merry and wait until the mercury column becomes constant.
- Read and record the new atmospheric pressure, h_2.
- Saturated pressure is given by the difference between h_1 and h_2 which can be calculated.

$$\text{Saturated vapour pressure} = h_1 - h_2$$

N.B

Some of the liquid will evaporate in the tube to evaporate to fill the terrecillian vacuum above the mercury column and the vapour pressure exerted forces the mercury column down wards.

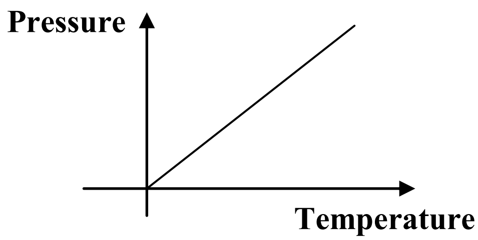
Unsaturated vapour:

This is the vapour that is not in dynamic equilibrium with its own liquid. The pressure exerted by a vapour that is not in dynamic equilibrium with its own liquid (unsaturated vapour) is called **unsaturated vapour pressure.**

Effect of temperature on unsaturated vapour:

When an unsaturated vapour is heated the average kinetic energy of the molecules increases which increases the rate of evaporation that exceeds the rate of condensation and eventually the unsaturated vapour pressure increases. The mass of the unsaturated vapour is fixed. Therefore a saturated vapour obeys the gas laws [Charles' law]

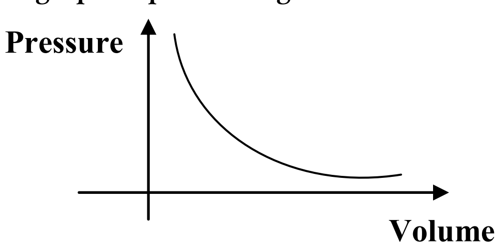
A graph of pressure against temperature



Effect of pressure on unsaturated vapour:

At constant temperature, unsaturated vapour pressure decreases with increase in volume of the vapour. Therefore a saturated vapour does not obey the gas laws [Boyle's law].

A graph of pressure against volume



Differences between saturated vapour and unsaturated vapour

Saturated vapour	Unsaturated vapour
✓ Exists at a fixed temperature ✓ Can only exist when the liquid is present ✓ It is the vapour in equilibrium with its own liquid ✓ It doesn't obey gas laws	✓ Exists at any temperature ✓ Does not need the presence of the liquid ✓ It is the vapour not in equilibrium with its own liquid ✓ It obeys gas laws

EVAPORATION:

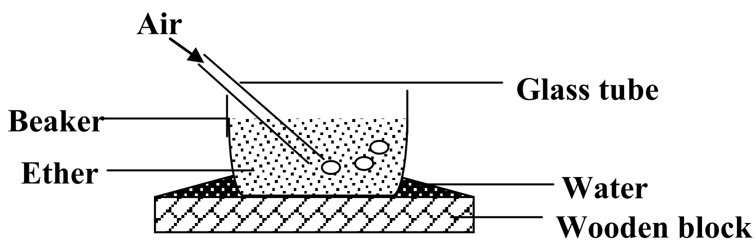
This is the escape of molecules of a liquid from its surface. It is a gradual change of state from liquid to gas that occurs at the surface of the liquid.

Kinetic theory explanation:

Molecules of a liquid are in a state of continuous constant random motion moving at different speeds. The average speed of the molecules depends on the temperature of the liquid. Molecules with most kinetic energy overcome the force of attraction and escape from the liquid surface causing evaporation. The remaining liquid molecules have the least kinetic energy and therefore the liquid cools as it evaporates. Cooling as a result of evaporation is seen in panting of dogs and making of ice by evaporation of volatile liquid

Experiment to make ice by evaporation of a volatile liquid:

- Place a beaker/metal can filled with ether [volatile liquid] on a film of water on a wooden block and blow air though a glass tube



- Ether will evaporate when it gets the necessary heat from water under the beaker and loss of heat makes the water to freeze.
- It is then observed that water under the beaker turns into a solid [ice] because as evaporation of ether takes place the temperature of the liquid falls which causes heat to flow from the water through the beaker to ether, this in turn causes the water to freeze.

Factors that affect the rate of evaporation:

Rate of evaporation is the number of molecules that escape per second. The following factors affect the rate of evaporation;

i) Surface area:

Increasing the surface area increases the rate of evaporation because a large surface area exposes many energetic molecules to escape while small surface exposes fewer molecules to escape

ii) Temperature:

Increasing temperature increases the rate of evaporation and decreasing the temperature decreases the rate of evaporation because at high temperature more molecules will move faster to escape from the liquid surface but at low temperature fewer molecules move faster to escape from the liquid surface.

iii) Wind [air current]:

The rate of evaporation increases if there is too much wind blowing because wind blows away more energetic molecules which have already escaped from the liquid so that they can not return back to the liquid.

iv) Nature of the liquid:

The nature of the liquid will determine the rate of evaporation that is a liquid of high concentration will evaporate slowly because of strong intermolecular force to be overcome and the liquid of low concentration will evaporate quickly because of weak intermolecular forces to be overcome.

v) Pressure:

At high pressure the rate of evaporation decreases and at low pressure the rate of evaporation increases because there is high exertion on the liquid surface at high pressure hence preventing molecules from escaping and there is low exertion on the liquid surface at low pressure hence allowing molecules to escape.

The total atmospheric pressure has no effect on the rate of evaporation of water. The atmospheric pressure is the total pressure pushing down on the surface of a liquid. If the temperature remains constant, it is the partial pressure of the water vapour in the air that determines the rate of evaporation. Suppose that a closed container contains water and dry air. The water will evaporate at a normal rate until the partial pressure of water molecules above the surface equals the equilibrium vapour pressure of water. The rate of evaporation will decrease as equilibrium is approached. At that point, it will appear to stop, because the rate of condensation will be equal the rate of evaporation.

BOILING:

This is the process that occurs when the atmospheric pressure is equal to the saturation vapour pressure of the liquid. Boling takes place at a particular temperature called the boiling point and at boiling the bubbles of the vapour form throughout the liquid.

Factors that affect boiling point of a liquid:

Boiling point of a liquid is the temperature at which its saturation vapour pressureis equal to the atmospheric pressure. The following factors affect the boiling point of a liquid.

i) Pressure:

The lower the atmospheric (surrounding) pressure, the lower the temperature needed to boil a liquid. This is because if the atmospheric pressure is decreased, then the liquid will boil more easily.
Increase in external pressure increases the boiling point of a liquid and decrease in pressure decreases the boiling point of a liquid because boiling to take place external pressure must be equal to internal therefore at high external pressure the boiling point is high and at low external pressure boiling point is low. This explains why;

Food cooks more quickly in pressure cooker because the pressure of steam above water in the cooker can rise to twice the normal atmospheric pressure.

Cooking takes longer at a very high altitude because external pressure is low at a high altitude and therefore water boils at low temperature which may take long for food to cook or may not cook.

If you put a glass of water in a vacuum chamber and begin to remove the air (i.e. you reduce the pressure above the water), although the water is not hot, it begins to boil. The reason is that water molecules are leaving the surface so rapidly in an attempt to maintain the equilibrium vapour pressure.

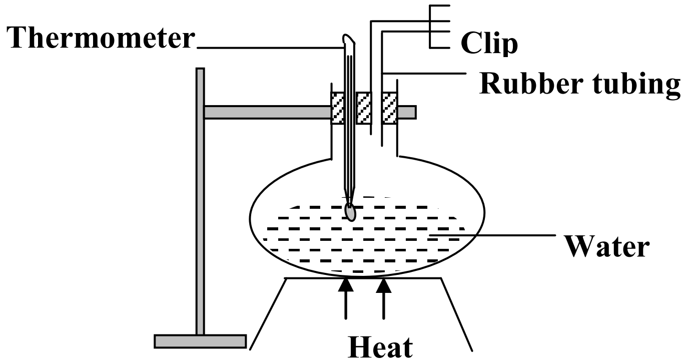
ii) Impurities:

Addition of impurities like salt lowers the freezing point of liquid but raises the boiling point of liquid. Actually, impurities in water raise the boiling point of it. This is a colligative property known as boiling point elevation. Salts in the water will cause the water molecules to be more attracted to the salts, and thus it will cause more heat (and thus a higher temperature) for the water to boil.

In general, adding impurities to compounds elevates their boiling points and lowers their freezing points. You can think of this as extending the liquid range in both directions. There are some examples where this does not hold true. For example, if you add a small amount of water as an impurity to ethanol and heat it, you will get a mixture of 95% ethanol and 5% water that boils over and actually has a slightly lower boiling point than pure ethanol.

Experiment to study the effect of pressure on boiling point:

A round bottomed flask is filled with distilled water and closed with a stopper having two holes. A thermometer is inserted into one hole while the other carries rubber tubing with a clip



With the clip open, the flask is heated until water boils and its boiling point is noted. The clip is then closed to prevent steam from escaping then stop heating.

The water will have to be heated again before it boils because the steam accumulating in the flask exerts pressure on the surface of water which increases the pressure, hence increasing the boiling point.

Boiling under reduced pressure:

A round bottomed flask is filled with distilled water and then heated until it boils. The steam is let to escape so as to drive out all the air from the flask. When all the air has been driven out, the heating is stopped and the mouth of the flask is closed with a stopper having a thermometer, the water will stop boiling. The flask is inverted on a ring stand and then cooled by pouring cold water on it using a wet cloth

It is observed that water in the flask starts to boil even though no heat is supplied and the temperature of water drops. The pressure on the water surface as the steam condenses into a liquid due to cooling

This shows that when pressure is reduced the boiling point of a liquid reduces. This explains why at high altitudes water boils at low temperature hence food will not be cooked easily and properly. This can be achieved using a pressure cooker.

Pressure cooker:

The pressure cooker has a lid that prevents steam from escaping. As water inside is heated, steam pressure increases causing boiling point of water to rise above 100°C. This results in food being cooked quickly thereby saving time and cost of fuel

Differences between boiling and evaporation

Boiling	Evaporation
✓ It occurs at a particular temperature ✓ It takes place throughout the liquid ✓ The temperature of the liquid remains constant during boiling ✓ It is vigorous and visible	✓ it occurs at any temperature ✓ it takes place at the surface of the liquid ✓ the liquid cools during evaporation of the liquid ✓ it is calm and invisible

Freezing point and melting point:

Freezing is the process by which a substance changes from liquid state to solid state. Freezing occurs at constant temperature called freezing point. The process by which a substance changes from solid state to liquid state is called melting. Melting occurs at a constant temperature called melting point. Therefore

Freezing point is the temperature at which a substance changes from liquid state to solid state while **Melting point** is the temperature at which a substance changes from solid state to liquid state.

Factors that affect freezing and melting points:

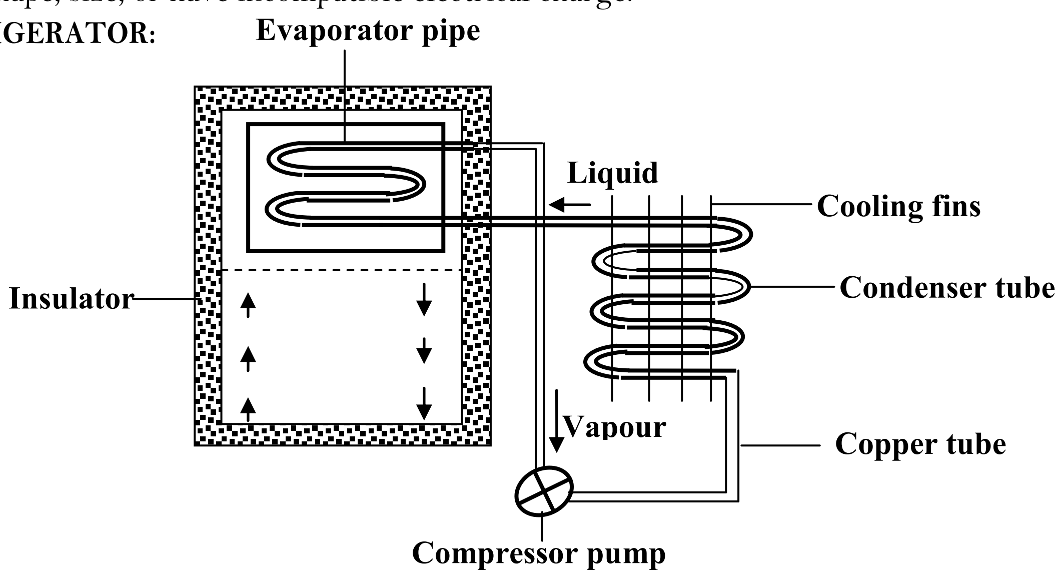
i) Pressure:

Normal solids, e.g. iron, copper and wax, expand when they change into liquids. When pressure is incresed on the surface of a normal solid, expansion is suppressed and melting is delayed. Thus, the melting point of a normal solid is raised. Abnormal solids, like ice and bismuth, contract on melting into liquids. When pressure is applied on the surface of such a solid, the change into the liquid is assisted. Thus, the melting point of ice is lowered by increase in pressure.

ii) Impurities:

The presence of impurities lowers the freezing point of a liquid because impurities lower the vapour pressure of the liquid so that it can melt at a lower temperature. In substances, such as water, impurities like salt usually decrease the freezing point, requiring a lower temperature since bonds between molecules are disrupted more and more at higher salt concentrations. Other substances also experience a decreased melting point because of impurities. In general, freezing points are decreased by impurities when the impurities are miscible in the substance because impurities obstruct the proper formation of the solid structure since an impurity can impede its formation because it is the wrong shape, size, or have incompatible electrical charge.

A REFRIGERATOR:



Mode of operation:

The copper tube contains a highly volatile liquid and as it enters the evaporator pipes in the freezing compartment it evaporates rapidly under reduced pressure which causes the remaining liquid to cool. The latent heat is taken from and refrigerator contents. In the cooling compartment, the vapour formed is compressed into the condenser tube and loses its latent heat and turns into a liquid and the heat is taken to the tube by conduction and is lost through cooling fins by convection and radiation. The liquid formed goes back to the freezing compartment and process is repeated. The heat exchange between the inside and outside of refrigerator is prevented by the insulator.

Functions of the parts:

i) Compressor pump:

This removes the vapour formed in the freezer and forces the vapour to condenser tube

ii) Condenser tube [Heat exchanger]:

This where the vapour is compressed and liquefies giving out latent heat of vaporization to the surrounding air

iii) Cooling fins:

These give out latent heat of vaporization to the surrounding air. They are painted black because black surfaces are good emitters of heat radiations.

iv) Insulator:

This prevents the heat exchange between the inside and outside the refrigerator.

v) Evaporator pipe:

This cools the liquid by evaporating volatile liquid under reduced pressure in the pipe

Trial Exercise 4:

1. 200litres of a gas at 0°C are kept under a pressure of 150kPa. If the temperature is raised to 273°C, its pressure is raised to 400kPa. Calculate its volume

   Ans: 150 litres
2. The density of argon gas at 27°C is 0.27kgm^{-3}. A volume of 50m^{3} of argon gas is kept under constant pressure at 27°C. What will be the density of argon if its temperature is raised to 51°C?

   Ans: 0.25kgm^{-3}
3. The volume of a fixed mass of a gas at constant temperature is 150cm^{3} when the pressure is 76cmHg. Calculate the volume when the pressure is 38cmHg.

   Ans: 300cm^{3}
4. The volume of a fixed mass of a gas at constant pressure is 400cm^{3} at a temperature of 27°C. Calculate the volume when the temperature is raised to 78°C.

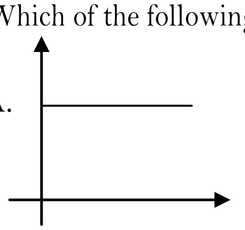
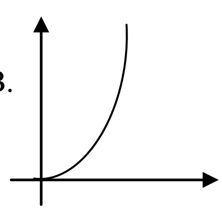
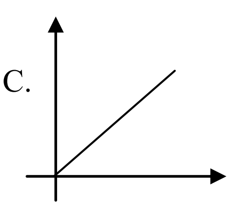
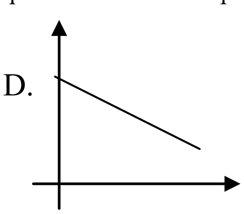
   Ans: 468cm^{3}
5. The pressure of a fixed mass of a gas at constant volume is 600mmHg at a temperature of 127°C. Calculate the pressure when the temperature falls to 27°C.

   Ans: 450mmHg
6. Air in a 2.5litre vessel at 127°C exerts a pressure of 3 atmospheres. Calculate the pressure that the same mass air would exert if contained in a 4litre vessel at -73°C

   Ans: 0.9375atmospheres.
7. State differences between boiling and evaporation
8. Distinguish between saturated vapour and un-saturated vapour
9. What are the factors that affect the rate of evaporation of a liquid and how
10. Use the kinetic theory to explain effect of increasing temperature of the gas at constant pressure

Multiple-choice exercise:

1. Which of the following does not require absorption of heat?
   A. evaporation B. boiling C. sublimation D. condensation
2. At a pressure of 1 atmosphere, a mass of a gas has a volume of $5m^3$ and temperature 102^oC. What will be the new volume if the temperature is lowered to 27^oC and the pressure is raised to 2 atmospheres?
   A. $7.40m^3$ B. $2.00m^3$ C. $0.66m^3$ D. $0.18m^3$
3. Which of the following is correct?
   A. increase in pressure decreases saturated vapour pressure
   B. a liquid boils when its saturated vapour pressure is equal to atmospheric pressure
   C. saturated vapours obey gas laws
   D. external pressure has no effect on the boiling point of the liquid
4. A pressure cooker, cooks food quickly because
   A. it retains heat energy using its heavy cover
   B. it has a safety valve that regulates temperature
   C. it loses no heat energy to the surrounding
   D. boiling takes place at a higher temperature due to raised pressure
5. The volume of a fixed mass of a gas is 3litres when a pressure of 50kPa is applied to it. What pressure should be applied to the gas to reduce its volume to 2litres at the same temperature?
   A. 75Pa B. 7,500Pa C. 33,000Pa D. 75,000Pa
6. A gas in a sealed container has a temperature of 100^oC and a pressure of $100Nm^{-2}$. To what temperature must the gas be heated for its temperature to become $120Nm^{-2}$
   A. 447.6K B. 393.0K C. 174. 6K D. 32.2K
7. What is the effect of pressure on the melting point of pure ice?
   A. increase in pressure raises the melting point
   B. changes in pressure have no effect on the melting point of ice
   C. increase in pressure lowers the melting point
   D. decrease in pressure raises the melting point
8. A gas of mass 2kg and density $1.6kgm^{-3}$ is heated from -23^oC to 127^oC at constant pressure. What is the density of the gas at 127^oC?
   A. 0.3 kgm^{-3} B. 1.0 kgm^{-3} A. $2.0kgm^{-3}$ A. $4.0kgm^{-3}$
9. Which of the following graphs shows the correct variation saturated vapour pressure with temperature?

A.  B.  C.  D. 

10. If a fixed mass of a gas is kept at constant temperature
   A. the volume increases with decrease in pressure
   B. the volume remains constant
   C. density remains the same when pressure is varied
   D. density is inversely proportional to the pressure

11. Air in a 3litre vessel at 27^{o}C exerts a pressure of 2Nm^{-2}. Calculate the pressure that the same mass of air would exert if it is contained in a 2litre vessel at -33^{o}C

A. 1.1 Nm^{-2} B. 2.4 Nm^{-2} C. 3.7 Nm^{-2} D. 20.0 Nm^{-2}

12. The volume of a fixed mass of a gas at 27^{o}C and pressure of 750mmHg is 300cm^3. What is its volume when the pressure is raised to 900mmHg and the temperature is 327^{o}C?

A. 125cm^3 B. 180cm^3 C. 500cm^3 D. 720cm^3

13. A given mass of a gas occupies a volume of 200cm^3 at a temperature of 27^{o}C and a pressure of 1 atmosphere. Find the volume when its temperature rises to 54^{o}C at constant pressure

A. 654.0K B. 218.0K C. 54.5K D. 32.7K

14. If a fixed mass of a gas is kept at constant pressure

A. the volume increases with increase in temperature

B. the volume remains constant

C. density remains the same when temperature is varied

D. density is inversely proportional to the temperature

15. Which of the following statements about boiling and evaporation is correct?

A. boiling takes place at all temperatures while evaporation does not

B. evaporation takes place throughout the liquid while boiling takes place at the bottom

C. boiling takes place throughout the liquid while evaporation takes place at the surface

D. evaporation takes place at a lower temperature than boiling does

16. The rate of evaporation of a liquid increases when

i) temperature increases ii) pressure increases iii) its surface area increases

A. (i), (ii) and (iii) correct B. (i) and (iii) correct

C. (ii) and (iii) correct D. (i) and (ii) correct

17. A domestic refrigerator uses a volatile liquid. Which of the following represents the order of the process the liquid undergoes?

A. evaporation, compression, condensation and evaporation

B. cooling, condensation, evaporation, compression and evaporation

C. compression, evaporation, condensation, cooling and evaporation

D. condensation, cooling, evaporation, compression and evaporation

18. Which of the following can produce a cooling effect?

(i) Compression of a gas (ii) expansion of a gas (iii) evaporation of a liquid

A. (i), (ii) and (iii) correct B. (i) and (iii) correct

C. (ii) and (iii) correct D. (iii) only correct

19. It takes much longer to cook food in the hills than in the plains because

A. in the hills the atmospheric pressure is lower than that in the plains and therefore water boils at a temperature lower than 100^{o}C causing an increase in cooking time

B. due to lower atmospheric pressure on the hills, water boils at a temperature higher than 100^{o}C and therefore takes longer to boil.

C. in the hills the atmospheric density is low and therefore a lot of heat is lost to the atmosphere.

D. in the hills humidity is high and therefore a lot of heat is absorbed by the atmosphere leaving very little for cooking

20. Of the four locations mentioned below the highest inside temperature will be attained in the pressure cooker operated with the pressure valve open

A. at sea level

B. at the top of Mt. Everest

C. at the place in a valley below sea level

D. in an aeroplane flying at a height of 10,000m with inside pressure maintained at sea level.

Answers:

1	D	5	D	9	B	13	A	17	D
2	B	6	A	10	A	14	A	18	C
3	B	7	C	11	B	15	C	19	A
4	D	8	B	12	C	16	B	20	C

MISCELLANEOUS EXERCISE 4:

1. a) Define specific heat capacity

b) 0.05kg of water at 80°C is mixed with 0.06kg of water at 10°C contained in a vessel of heat capacity $28Jkg^{-1}$. What is the final temperature of the mixture?

Ans: 40°C

c) i) Define specific latent heat of fusion

ii) Describe a simple method to determine the specific latent heat of fusion of ice

d) When 0.005kg of ice at 0°C is added to 0.02kg of warm water at 30°C the final temperature attained is 8°C. Find the specific latent heat of fusion of ice.

Ans: 336,000Jkg^{-1}

2. a) i) State Boyle's law

ii) With the aid of a labeled diagram describe the experiment to show the relationship between the volume and the temperature of a fixed mass of a gas at atmospheric pressure.

b) A cylinder with a movable piston contains $0.1m^3$ of air at a temperature of 27°C. Calculate the volume of the gas if it is cooled to -33°C at constant pressure.

Ans: 0.08m^3

c) Define the term specific heat capacity

d) A copper block of mass 200g is heated to a temperature of 145°C and then dropped into a well lagged copper calorimeter of mass 250g which contains $300cm^3$ of water at 25°C

i) Calculate the maximum temperature attained by the water

ii) Sketch a graph to show the variation of temperature of water with time

Ans: i) 31.7°C

3. a) i) Define heat capacity of a substance

ii) Describe an experiment to determine specific heat capacity of a substance by method of mixtures

iii) State the precautions necessary for accuracy during the experiment above

b) A well lagged copper calorimeter of mass 85g contains 80g of water at 60°C. Dry ice at 0°C is added to the calorimeter and after stirring the mixture attains a steady temperature of 20°C. Find the mass of ice added

Ans: 35.2°C

c) i) Describe an expiration to show that evaporation produces cooling.

ii) Explain why evaporation produces cooling.

iii) State one application of cooling by evaporation.

4. a) i) What is a saturated vapour?

ii) Explain why the boiling point of a liquid depends on altitude.

b) i) Define specific heat capacity.

ii) Describe an experiment to determine the specific heat capacity of a solid

c) A copper block of mass 250g is heated to a temperature of 145°C and then transferred to a cooper calorimeter of mass 250gwhich contains 250cm^{3}of water at 20°C

i) Calculate the maximum temperature attained by water

ii) Sketch the graph to show the variation of temperature with time

Ans: i) 30^{o}C

d) i) What is meant by the term temperature

ii) Give two physical properties which change with temperature

5. a) Define the following terms as used in heat

i) Specific heat capacity

ii) Latent heat of vaporization

b) Describe an experiment to determine the specific heat capacity of a liquid

c) Steam from boiling water is bubbled through 1.5kg of water at 20^{o}C. After this process, the mass of water was found to be 1.54 kg. What is the new temperature of water?

Ans: 35.99^{o}C

d) State four ways in which heat losses can be minimized in a calorimetry experiment

6. a) Define specific latent heat of fusion

b) Describe an experiment to determine the specific latent heat of fusion of ice

c) A copper block of mass 300g is heated to a temperature of 245^{o}C and then dropped into a well lagged copper calorimeter of mass 350g containing 400g of water at 35^{o}C. Calculate the maximum temperature attained by the water.

Ans: 43.3^{o}C

d) i) What is meant by absolute zero temperature

ii) A sealed flask contains gas at a temperature of 27^{o}C and a pressure of 900Pa. if the temperature rises to 127^{o}C. What will be the new pressure?

Ans: ii) 1200Pa

7. a) i) Define temperature.

ii) The fundamental interval of a mercury-in-glass thermometer is 192mm. Find the temperature in degrees Celsius when mercury thread is 67.2mm long

b) With the aid of a labeled diagram describe the experiment to show the relationship between the volume and the pressure a fixed mass of a gas at constant temperature.

c) A copper block of mass 150g is heated to a temperature of 95^{o}C and then dropped into a well lagged copper calorimeter of mass 200g containing 250g of water at 15^{o}C. Calculate the maximum temperature attained by the water.

Ans: 19.0^{o}C

d) State any two differences between boiling and evaporation

8. a) Define specific latent heat of vaporization

b) A calorimeter of mass 35g and specific heat capacity 840Jkg^{-1}K^{-1} contains 143g of water at 7^{o}C. Dry steam at 100^{o}C is bubbled through water in the calorimeter until the temperature of the water rises to 29^{o}C. If the mass of steam which condenses is 5.6g,

i) Calculate heat gained by the water and calorimeter

ii) Obtain an expression for the heat lost by the steam in condensing at 100^{o}C and in cooling to 29^{o}C.

iii) Find the specific latent heat of vaporization of water

Ans: i) 13860J ii) 0.0056L_v + 1669.92 iii) 2,176,800

c) Explain in terms of molecules what is meant by a saturated vapour?

d) Describe briefly one application of vaporization

9. a) i) Describe the fixed points of a Celsius scale of temperature

ii) Give two advantages of mercury over alcohol as thermometric liquid

iii) Convert -200^{o}C to Kelvin

Ans iii) 73^{o}C

b) Use the kinetic theory to explain the following

i) Cooling by evaporation

ii) Why the temperature of a gas contained in a cylinder increases when it is compressed

c) Explain briefly the transfer of thermal energy by conduction in metals

d) A battery of e.m.f 12V and internal resistance 1Ω is connected for 3minutes a cross a heating coil of resistance 11Ω immersed in a liquid of mass 0.2kg and specific heat capacity 2.0 x 10^{3}Jkg^{-1}K^{-1}. Find the rise in temperature of the liquid. State clearly any assumptions made.

Ans: 4.95^{o}C

10. a) With the aid of a labeled diagram, describe the experiment to show the relationship between temperature and pressure a fixed mass of a gas at constant volume.

b) A gas of volume 1000cm^3 at a pressure of 4.0 x10^5 Pa and temperature of 17^{o}C is heated to 89.5^{o}C at constant pressure. Find the new volume of the gas.

Ans: 1250cm^3

c) A balloon is filled with 50cm^3 of hydrogen and tied to the ground. The balloon alone and the container it carries have a mass of 2kg. If the densities of hydrogen and air are 9.0 x 10^{-2}kgm^{-3} and 1.29kgm^{-3} respectively, how much load can the balloon lift when released

11. a) What is meant by conduction

b) Draw a labeled diagram of a thermos flask and explain how it is able to keep a liquid cold for a long time

c) With the aid of a diagram, describe how you would determine the upper fixed point of un-calibrated thermometer

d) Explain the following observations;

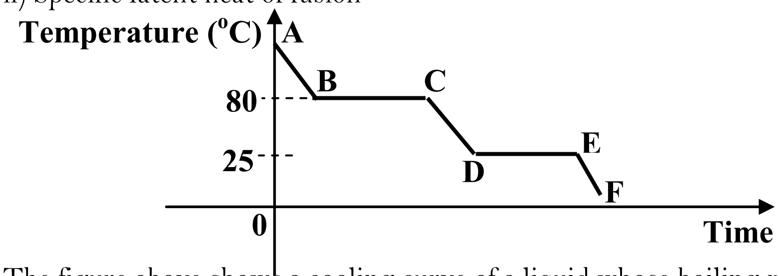
i) A bare cement floor feels colder than a carpeted one

ii) A beam with a notch that is used for constructing a bridge lasts longer when the notch is on its top surface than when the notch is on its lower surface

12. a) Define the following terms

i) Specific heat capacity

ii) Specific latent heat of fusion



The figure above shows a cooling curve of a liquid whose boiling point is 80°C and freezing point is 25°C.

i) Give the states over regions AB, BC, DE and EF

ii) What is happening over region BC?

iii) Use the kinetic theory to explain the differences in states over regions AB and EF

c) An iron rod of mass 0.8kg is pushed into an insulator solid substance through a distance of 2.3m against frictional force of 400N. The temperature of iron rises by 2.5°C. Calculate the specific heat capacity of iron

Ans: 460Jkg^{-1}K^{-1}

d) i) Explain why when water in a saucepan is heated, the level first falls and then rises after some time

ii) The length of mercury thread of un-calibrated thermometer is 10cm when the bulb is in pure melting ice and rises to 20cm in steam. What is the reading of the thermometer when the mercury thread is 18cm?

Ans: ii) 80°C

13. a) Define specific latent heat of vaporization

b) Describe an experiment to determine specific latent heat of vaporization of steam

c) A copper calorimeter of heat capacity 60Jkg^{-1} contains 0.5kg of water at 20°C. Dry steam at 100°C is passed into the water in the calorimeter until the temperature of the water and the container reaches50°C. Calculate the mass of steam condensed

Ans: 4.61kg

d) i) What is meant by saturated vapour pressure

ii) Explain what may happen when one is to cook food from a very high altitude

14. a) i) Define latent heat of fusion.

ii) Describe with the aid of a labeled diagram, an experiment to show the effect of increase in pressure on the melting point of ice

b) If the melting point of lead is 327°C, find the amount of heat required to melt 200g of lead initially at 27°C given that specific latent heat of fusion of lead is 2.5 x 10^{6}Jkg^{-1} and specific heat capacity of lead is 660Jkg^{-1}K^{-1}.

Ans: 539,600J

c) What is meant by the terms?

i) Temperature

ii) Heat

d) State two physical properties which change with temperature.

15. a) Describe an experiment to determine the specific latent heat of fusion of ice
b) 2 kg of ice initially at -10°C is heated until it changes to steam at 100°C
i) Sketch the graph to show how temperature changes with time
ii) Calculate the energy required at each end of the graph
Ans: 42,000J 672,000J 840,000J 4,500,000J

16. a) Differentiate between conduction and convection
b) Describe an experiment which can be performed to show convection in a liquid
c) i) Draw a labeled diagram of a vacuum flask
ii) Explain how a vacuum flask minimizes heat losses
d) Why is a car radiator made of fins and painted black

17. a) State the kinetic theory of matter
b) i) State the law of volume and temperature
ii) The volume of a fixed mass of a gas at a given pressure is $1.5m^3$ at 300K. at what temperature will the volume of the gas be at the same pressure
c) Describe an experiment to determine the fixed points of a thermometer
d) i) Mention any three reasons for not using water as a thermometric liquid
ii) When a Celsius thermometer is in a boiling liquid, the mercury thread rises above the lower fixed point by 19.5cm. Find the temperature of boiling liquid if the fundamental interval is 25cm.
Ans: 78°C

18. a) What is meant by latent heat of vaporation
b) With the aid of a labeled diagram describe how a refrigerator works
c) The cooling system of a refrigerator extracts 0.7kW of heat. How long will it take to convert 500g of water at 20°C into ice?
Ans: 300s
d) Explain how evaporation takes place

19. a) What is meant by conduction
b) Draw a labeled diagram of a vacuum flask and explain how it is able to keep a liquid hot a long time
c) With the aid of a labeled diagram describe an experiment to determine the upper fixed points of an un-calibrated thermometer
d) Explain the following observation a bare cement floor feels colder than a carpeted one

20. a) i) Define latent of fusion
ii) Describe with the aid of a labeled diagram, an experiment to show the effect of increase in pressure on the melting point of ice
b) What is meat by the terms?
i) Temperature
ii) Heat
c) The fundamental interval of mercury in glass is 192mm. find the temperature in degrees Celsius when the mercury thread is 67.2mm below the upper fixed point.
Ans: 65°C
d) State two physical properties which change with temperature

E L E C T R I C I T Y

There are two branches of electricity namely;

i) Electrostatic electricity.

ii) Current electricity.

ELECTROSTATIC ELECTRICITY:

Electrostatic electricity is the study of electric charges at rest. An electric charge is a deficiency or surplus of electrons and therefore electric charges are either positive or negative.

Origin of charge:

Matter is made up of atoms and an atom has three particles namely;

- Protons.
- Neutrons.
- Electrons.

The protons are positively charged and are located in the nucleus of an atom, the neutrons are neutral (no charge) and are also located in the nucleus of the atom while the electrons are negatively charged and they move around the nucleus. Therefore the nucleus has positive charge due to the charge on the protons and the total number of protons in nucleus is equal total number of electrons around the nucleus, hence the atom has no charge (neutral)

Any material that gains electrons becomes negatively charged and any material that loses electrons becomes positively charged, this is the origin of electric charges.

Note:

- The charge is neither created nor destroyed during charging but can be transferred from one body to another this is the principle of conservation of charge.
- A negatively or a positively charged atom is called an ion.

The law of charges:

It states that like charges repel each other and unlike charges attract each other.

Conductors and insulators:

- **Conductors**

A conductor is a substance in which electrons are free to move and conducts heat and electricity easily. Examples are all metals and carbon in form of graphite.

Properties of conductors:

- They have free electrons which are loosely held by the nucleus.
- They are good conductors of heat and electricity.
- They can lose or gain electrons.
- Loss of electrons leaves a conductor positively charged.
- Gain of electrons leaves a conductor negatively charged.

- **Insulators:**

An insulator is a substance in which electrons are not free to move and does not conduct heat and electricity easily. Examples are all non-metals like ebonite, fur, plastic, polythene and rubber.

Properties of insulators:

- They don't have free electrons; electrons are tightly held by the nucleus.
- They don't conduct heat and electricity.
- They can lose or gain electrons.
- Loss of electrons leaves an insulator positively charged.
- Gain of electrons leaves an insulator negatively charged.

Methods of charging:

a) Charging by rubbing [friction]:

- When two insulators are rubbed together, there is transfer of electrons.
- The insulator that gains electrons becomes negatively charged and an insulator that loses electrons becomes positively charged.
- The two insulators will therefore acquire equal but opposite charges.

Example:

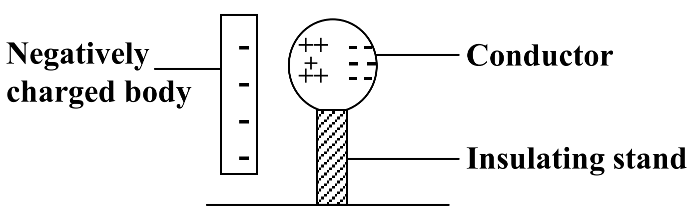
When glass and silk are rubbed together the glass atoms lose electrons to silk atoms, as a result the silk acquires a negative charge due to excess electrons and the glass acquires a positive due to excess protons. The resulting electric force can attract small pieces of paper.

b) Electrostatic induction:

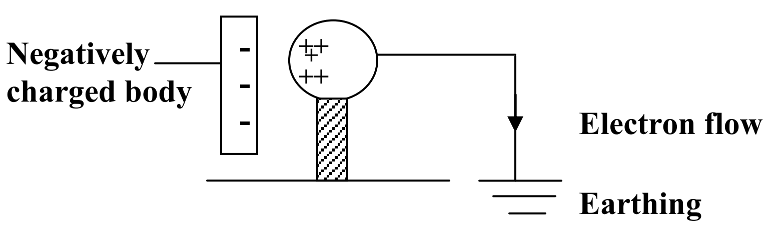
This is the method of charging a conductor without touching it with the charged body

i) Charging a conductor positively by induction:

- Bring a negatively charged body near one side of the conductor supported on an insulator.
- Positive charges are induced on the side near the body and the negative charges are repelled to the other side.

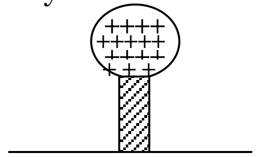


- With the negatively charged body still in place, the other side of the conductor is then earthed by connecting an earth wire to the ground or by touching with a finger, electrons will then flow to the ground leaving positive charges.



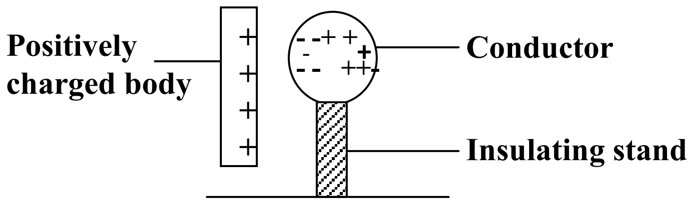
- With the negatively charged body still in its position, remove the earth wire and the positives will distribute themselves over the whole conductor

- The negatively charged body is finally removed and the conductor is left with a net positive charge.

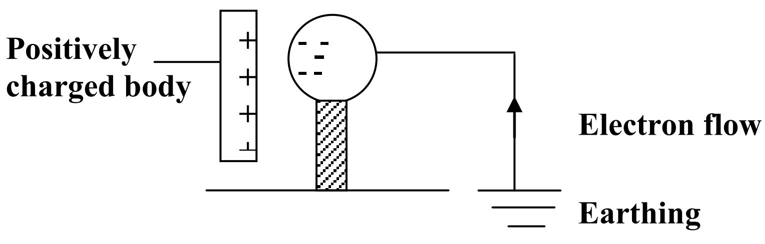


ii) Charging a conductor negatively by induction:

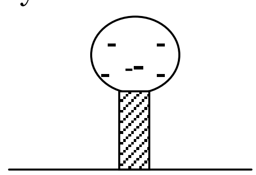
- Bring a positively charged body near one side of the conductor supported on aninsulator
- Negative charges are induced on the side near the body and the positive charges are repelled to the other side



- With the positively charged body still in place, the other side of the conductor is then earthed by connecting an earth wire to the ground or by touching with a finger, electrons will then flow from the ground and neutralize the positive on the conductor leaving only negative charges



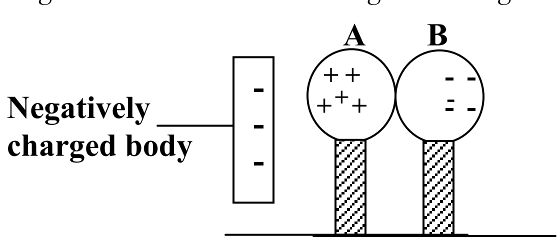
- With the positively charged body still in its position, remove the earth wire and the negatives will distribute themselves over the whole conductor.
- The positively charged body is finally removed and the conductor is left with a net negative charge.



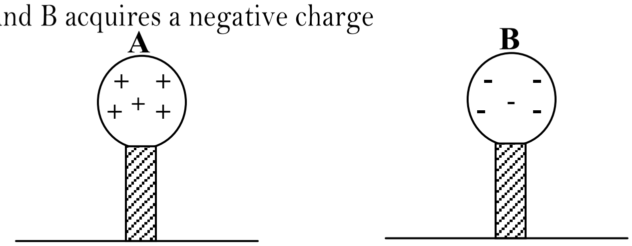
Note: Charging by induction is more successful than charging by contact because when a body touches another the points of actual contact are extremely few and therefore transfer of charge by contact is limited to only these few points where as in induction it is the nearness of the body that matters

iii) Charging two conductors simultaneously by induction:

- Place two metal spheres A and B on insulator supports and in contact.
- Bring a negatively charged body near sphere A.
- Positive charges are induced on A and negative charges are repelled to B.



- With the negatively charged body still in place the two spheres are separated and sphere A acquires a positive charge and B acquires a negative charge



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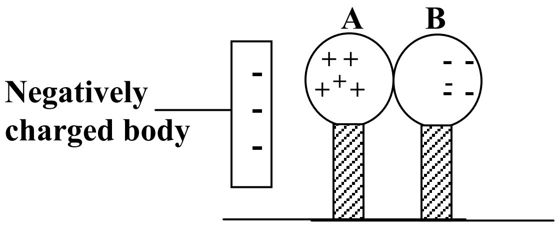
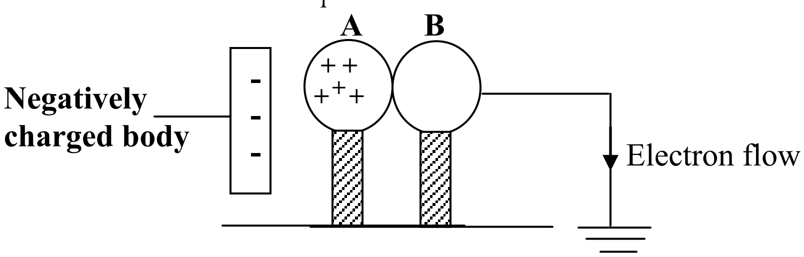
iv) Charging simultaneously two conductors positively by induction:

- Place two metal spheres A and B on insulator supports and in contact.
- Bring a negatively charged body near sphere A.
- Positive charges are induced on A and negative charges are repelled to B.



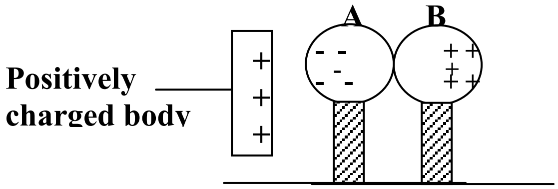
- With the negatively body still in place sphere B is earthed and electrons flow to the ground and positive charges on A redistribute themselves over spheres A and B



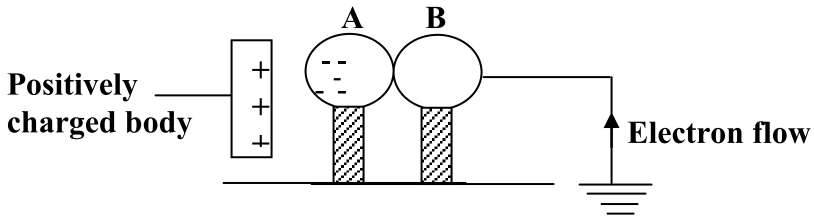
- With the negatively charged body still in place the two spheres are separated and both spheres A and B acquire a positive charge.

v) Charging simultaneously two conductors negatively by induction:

- Place two metal spheres A and B on insulator supports and in contact.
- Bring a positively charged body near sphere A.
- Negative charges are induced on A and negative charges are repelled to B



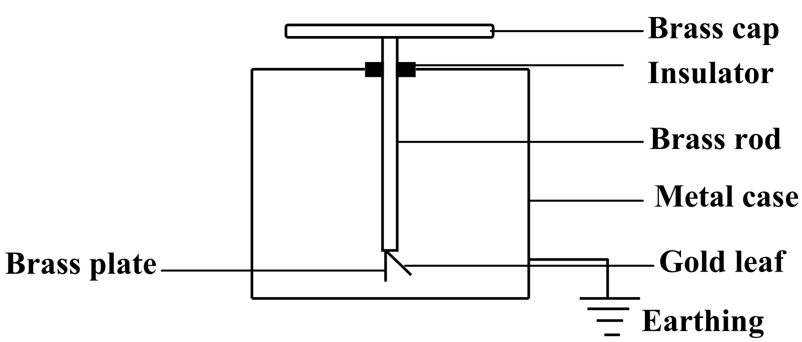
- With the positively charged body still in place sphere B is earthed and electrons flow from the ground to neutralize positive charges on sphere B and negative charges on A redistribute themselves over spheres A and B.



- With the positively charged body still in place the two spheres are separated and both spheres A and B acquire a negative charge.

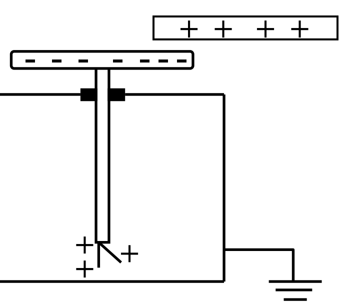
THE GOLD LEAF ELECTROSCOPE:

- This is an instrument which works on the principle of electrostatic charges to detect the presence of the charge and differentiate between the charges.
- It consists of a metal case with glass windows to protect it from draught.
- It consists of a metal cap joined to the metal rod which is supported by an insulator so that charges are not conducted to the metal case.
- The rod is joined to agold leaf on a plate and the metal case is earthed by a wire.

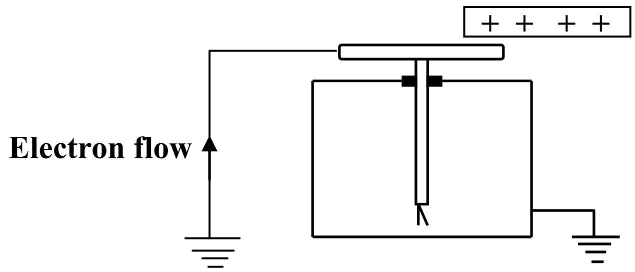


Charging a gold leaf electroscope negatively by induction:

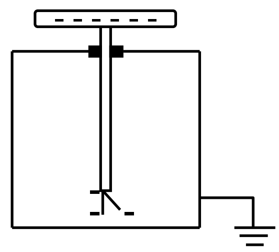
- Bring a positively charged rod near the cap of uncharged gold leaf.
- Negative charges are induced on the cap and positive charges are repelled down to the plate and the gold leaf and an increase in divergence of the leaf is observed because of like charges on the plate and the leaf.



- With the charged rod still in place the cap is earthed by connecting the earth wire to the cap or touching the cap with a finger and the negative charges (electrons) flow from the earth through the earth wire or the body to neutralize the positive charges and a decrease in divergence of the gold leaf is observed.

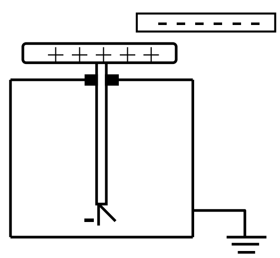


- The earthing is removed and subsequently the charged rod is removed and the negative charge on the cap redistributes onto the plate and the gold leaf and as a result the leaf diverges and the electroscope acquires a negative.

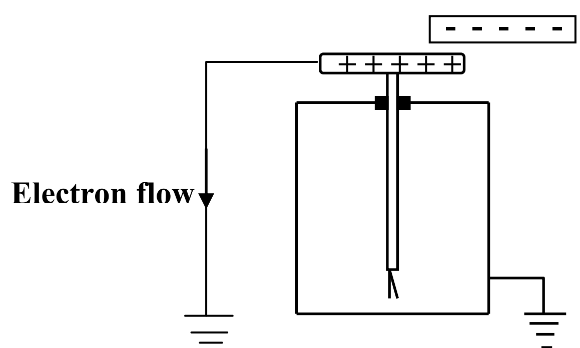


Charging a gold leaf electroscope positively by induction:

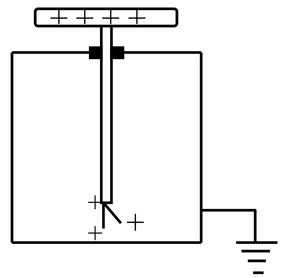
- Bring a negatively charged rod near the cap of uncharged gold leaf.
- Positive charges are induced on the cap and negative charges are repelled down to the plate and the gold leaf and an increase in divergence of the leaf is observed because of like charges on the plate and the leaf.



- With the charged rod still in place the cap is earthed by connecting the earth wire to the cap or touching the cap with a finger and the negative charges (electrons) flow to the earth through the earth wire or the body and a decrease in divergence of the gold leaf is observed.



- The earthing is removed and subsequently the charged rod is removed and the positive charge on the cap redistributes onto the plate and the gold leaf and as a result the leaf diverges and the electroscope acquires a positive charge.



Uses of the gold leaf electroscope:

The following are uses of gold leaf electroscope;

1. To detect the presence of charge on a body:

When a charged body is brought near the cap of an uncharged electroscope, the gold leaf is seen to diverge indicating that a charge has been induced on the plate and the leaf which results into repulsion between them. If the body is not charged there is no divergence of the gold leaf.

2. To test the sign of the charge on the body:

A charged electroscope is used to test the sign of the charge on the body.

- When a negatively charged body is brought near the cap of a negatively charged electroscope an increase in divergence of the leaf is observed and if a positively charged body is used a decrease in divergence of the leaf is observed.
- When a positively charged body is brought near the cap of a positively charged electroscope an increase in divergence of the leaf is observed and if a negatively charged body is used a decrease in divergence of the leaf is observed.
- When an uncharged body is brought near the cap of a negatively or positively charged electroscope a decrease in divergence of the leaf is observed.
- This shows that the only sure of confirming the kind of charge on a body is by an increase in divergence of the leaf.
- The table below shows a summary of the results obtained when we test the sign on a charged body using different charged electroscopes

Charge on electroscope	Charge on th body	Effect on the divergence
+	+	Increase
-	-	Increase
+	-	Decrease
-	+	Decrease
+ or -	No charge	Decrease

3. To test for insulation and conduction properties:

A body is brought in contact with a cap of a charged electroscope;

- If the leaf collapses immediately then the body is a conductor like copper, iron, aluminium, zinc and graphite because conductors have free electrons hence there is rapid loss of electrons.

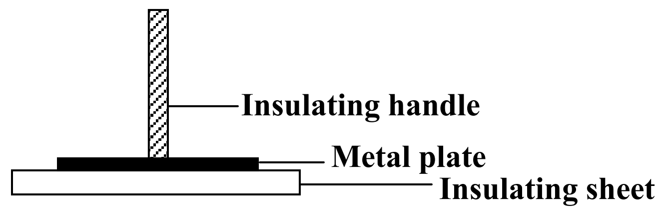
- If the there is no change in divergence of the leaf then the body is an insulator like plastic, glass, cotton, wood and paper because they do not allow electrons to flow between the earth and the electroscope.
- If the leaf collapses slowly then the body is a semi conductor like silicon and germanium since their conductivity is between the conductivity of insulators and conductors.

4. **To test the magnitude of the charge on a body:**

Two spherical balls of different sizes are charged simultaneously and then each is brought near the cap of the charged electroscope. It is observed that the small ball shows a slight change in divergence of the leaf and the large ball shows a greater change in divergence of the leaf.

ELECTROPHORUS:

This is a device for producing charges by electrostatic induction and it is used in transfer of charge. It consists of a circular metal plate with an insulating handle placed on an insulating sheet previously charged by rubbing.

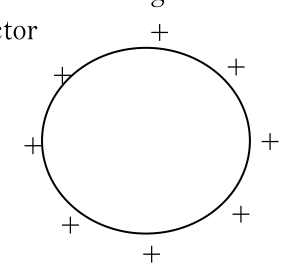


When the plate is earthed by touching with a finger and then removed it acquires a charge opposite to that on insulating sheet. This charge can be transferred to another conductor and the electrophorus recharged again as before.

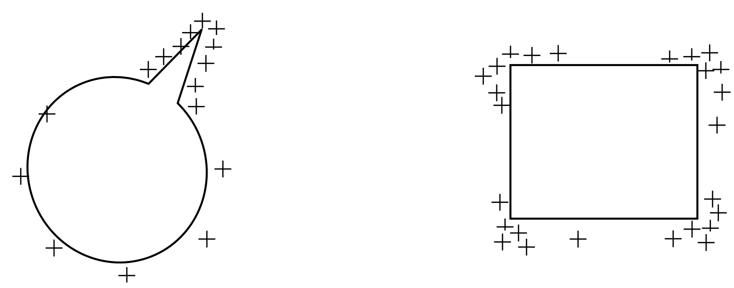
Distribution of charge on a conductor:

The distribution of charge on the surface of the conductor depends on the shape of the conductor that is charge is concentrated at pointed edges of the conductor hence there is high charge density at sharp edges of the conductor. The high charge density causes ionization of air where the ions opposite to the charge are attracted and neutralize the charge hence loss charge by the process called corona discharge (charge leakage). Charge density is amount of charge per unit area.

- For a uniform spherical conductor the charges are evenly distributed and therefore the charge density is uniform for a spherical conductor

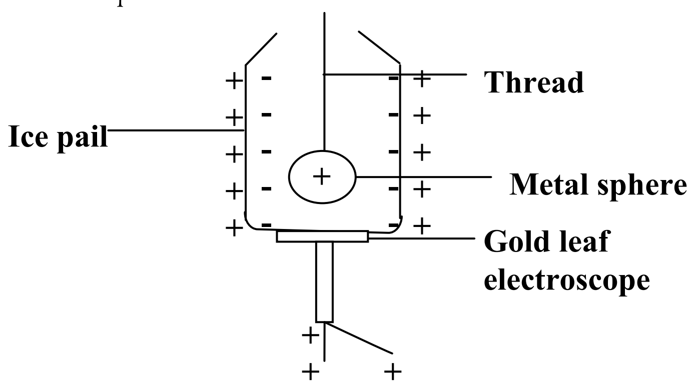


- For pointed conductors there are more charges at the sharp points and therefore the charge density is high at sharp points.



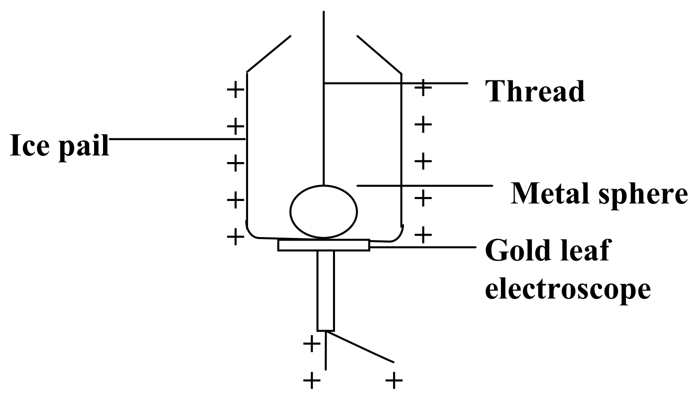
FARADAY'S ICE PAIL EXPERIMENT:

Ice pail is placed on top of the cap of a charged electroscope so as to detect any presence of charge on the outside of the pail. A positively charged metal sphere attached to an insulating thread is then lowered into the pail without allowing it to touch the pail. The gold leaf is seen to diverge indicating that a charge has been induced on the outside of the pail.



The magnitude of the divergence does not change when the sphere is moved in different positions inside the pail and when the sphere is removed and tested for the charge it had its charge.

The sphere is again lowered in the pail and allowed to touch the pail and the magnitude of divergence remains the same as before but when removed and tested for charge it had no charge.



Conclusion:

The above experiment shows there is no charge residing inside the hollow conductor or the sphere induced a charge of equal in magnitude inside the pail but opposite to the charge on the sphere.

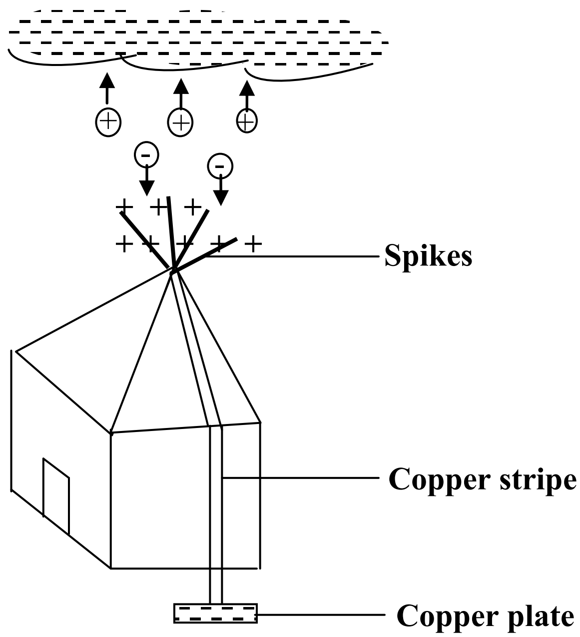
Action of pointed ends:

The sharp points of a conductor have high charge density which results in production of strong electric fields. The strong electric field causes the air around the sharp point to be ionized and the attraction between the positive and negative ions results in partial neutralizing hence charge leakage [corona discharge].

LIGHTENING:

This is a result of sudden neutralizing of electric charges which occurs between the clouds and the earth when charges build up in the clouds. Lightening occurs when a negatively charged cloud meets a positively charged cloud resulting in a spark which is seen as lightening.

Lightening conductor:



Lightening conductors are used to protect buildings from being struck by lightening. It consists of a thick copper stripe with spikes at the top and copper plate which is buried in the earth

- When a negatively charged cloud passes over a lightening conductor positive charges are induced on the spikes and negative charges are repelled to the plate.
- Due to high charge density on the spikes the air around the spikes is ionized and the negative ions are attracted to the spikes and neutralize some of the charges and the positive ions are repelled to the cloud and neutralize some of the charges on the cloud.
- This charge leakage reduces the chance of a negative cloud meeting a positive cloud hence lightening

ELECTRIC FIELD:

This is an area around a charge where an electric force can be experienced. The electric field is represented by electric field lines [lines of force]. An electric field line is a line drawn such that its direction at any point is the direction of the electric field at that point.

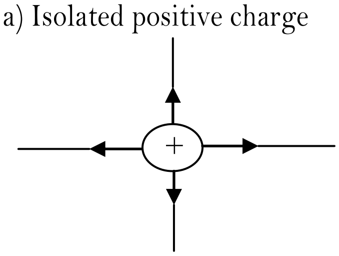
Properties of electric field lines:

- They do not intersect or cross or touch each other.
- They originate from the positive charge to the negative charge.
- They are in a state of tension.
- They form like charges which repel each other.

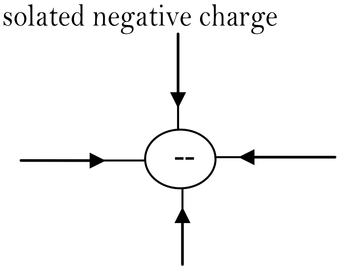
Representing electric fields:

An electric field is represented by lines with an arrow showing the direction of the field. The following are examples of electric field patterns.

a) Isolated positive charge

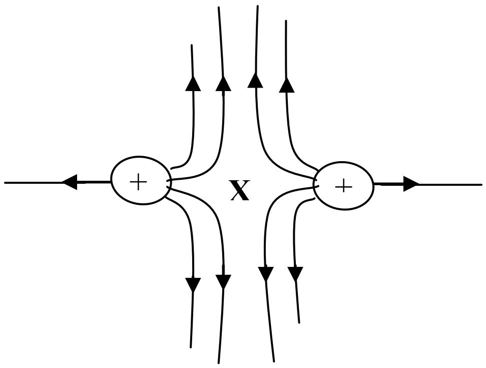


b) Isolated negative charge

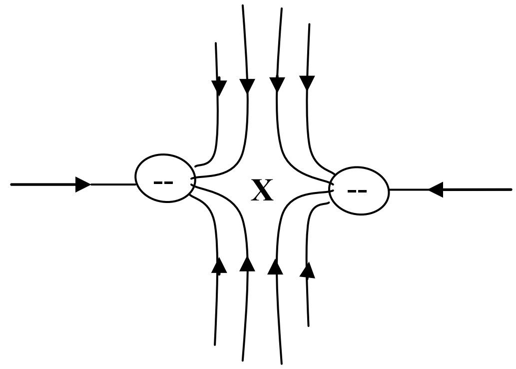


c) Like charges near each other

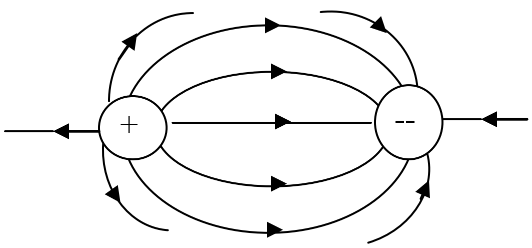
i) Positive – positive



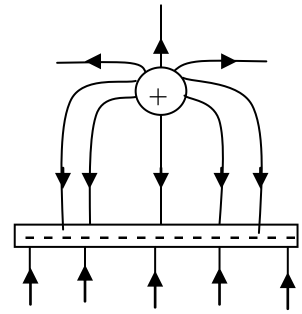
ii) Negative – negative



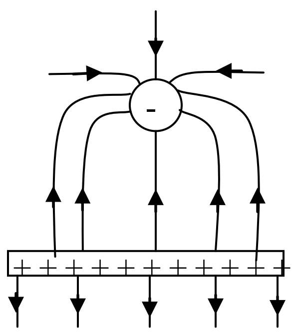
d) Unlike charges near each other



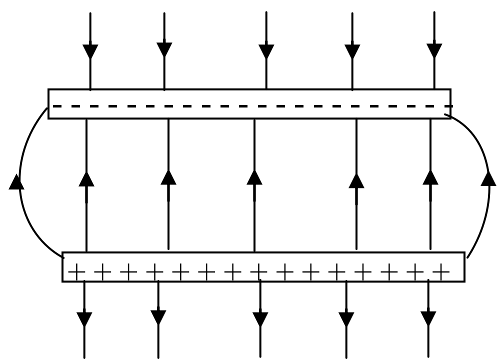
e) A positive charge near a negative plate



f) A negative charge near a positive plate



g) Two oppositely charged plates



Note: X is a neutral point which is the area with no electric field lines that is the resultant electric force is zero

ELECTRIC CELLS:

An electric cell is a device that is capable of driving an electric charge around a circuit in form of current. Therefore electric cells are sources of electricity (electrical energy). Other sources of electrical energy include batteries, generators, solar panels, thermocouples and some crystals under pressure. Electrical energy is used in producing heat, light, sound and operating electronic devices like radios, televisions, telephones etc. Currently the major sources of electricity are chemical cells, generators and solar panels

Chemical cells:

They produce electromotive force (e.m.f) as a result of a chemical reaction. There are two types of chemical cells namely;

i) Primary cells.

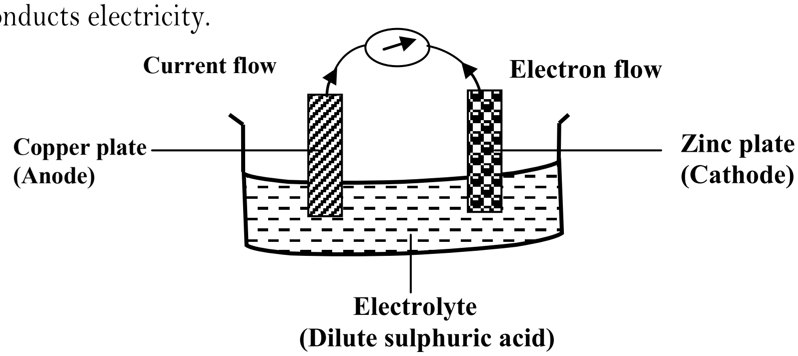
ii) Secondary cells.

PRIMARY CELLS:

These are chemical cells that can not be renewed (recharged) once the chemicals are exhausted. They produce current as a result of irreversible chemical reaction that is chemical energy is converted to electrical energy examples of primary cells include simple cell and Leclanche' cells.

Simple cell:

It consists of two electrodes of different metals in an electrolyte. The electrodes commonly used are copper and zinc with dilute sulphuric acid as an electrolyte. An electrolyte is a substance when in solution or molten form conducts electricity.



Action of a simple cell:

- When two electrodes are dipped in dilute sulphuric acid, they carry electric charges into and out of the electrolyte. A more reactive metal (iron) is the cathode and the less reactive metal (copper) is the anode. Dilute suphuric acid exists in form of ions and ionizes as follows;

$$H_2SO_{4(aq)} \longrightarrow 2H^+_{(aq)} + SO_4{}^{2-}{}_{(aq)}$$

- When the zinc plate is joined to the copper plate by a wire, the zinc metal dissolves in the acid to form zinc ions and electrons liberated electrons flow through the connecting wire as shown above to the copper plate.

$$Zn_{(s)} \longrightarrow Zn^{2+}_{(aq)} + 2e^-$$

- As the zinc ions enter the solution the hydrogen ions move to the copper plate and acquire electrons hence hydrogen gas bubbles are produced around the copper plate.

$$2H^+_{(aq)} + 2e \longrightarrow H_{2(g)}$$

- By loosing electrons to hydrogen ions makes a copper plate positive and the zinc plate negative. Conventionally the direction of current is from the positive plate to the negative plate

Defects in a simple cell:

A defect is anything that reduces the amount of current produced by a simple cell. There are two defects in a simple cell namely;

i) Polarization.
ii) Local action.

POLARIZATION:

This is the accumulation of hydrogen bubbles around the copper plate. This defect provides insulation to the flow of current and sets up local cells with copper plate whose electron flow tends to oppose the flow of electrons from the zinc plate. This effect increases the internal resistance of the cell hence reduces the flow of current. This defect can be reduced by removing hydrogen bubbles [depolarization]. Depolarizer (potassium dichromate) which is an oxidizing agent is added and oxidizes hydrogen ions to water which boosts the current flow but the electrolyte gets more diluted

$$H^+_{(aq)} + OH^-_{(aq)} \longrightarrow H_2O_{(l)}$$

LOCAL ACTION:

This is when the zinc plate is eaten away as it reacts with dilute sulphuric acid. The zinc used is impure which results into wearing off of the zinc plate. This defect can be reduced by cleaning zinc plate with concentrated sulphuric acid or using pure zinc plate or coating zinc plate with mercury to form zinc amalgam (amalgamation) which covers the impurities and prevent them from being in contact with an electrolyte.

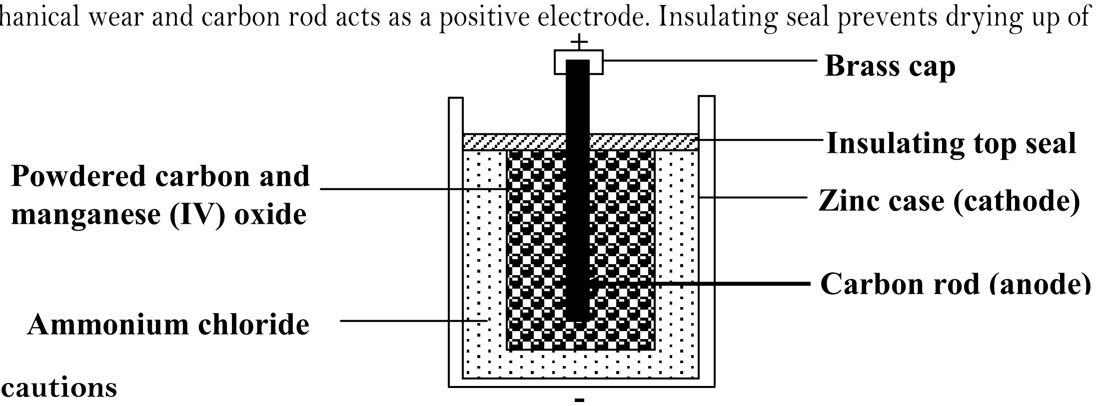
The Leclanche' cells:

These are cells in which local action and polarization are eliminated. There are two types of Laclanche' cells namely;

i) Dry laclanche'e cell.
ii) Wet laclanche' cell.

Dry Lachanche' cell:

This type of cell has no liquid hence dry cell. The electrolyte used is ammonium chloride jelly instead of a solution. Manganese (IV) oxide acts as depolarizer so that the hydrogen produced is oxidized to water which makes the cell wet after being used up. Powdered carbon reduces the internal resistance of the cell. The zinc case acting as a negative electrode reacts with ammonium chloride and an emf is step up from the produced electrons of zinc, this emf keeps on reducing due to the local action which is still a defect in this cell. Brass cap prevent mechanical wear and carbon rod acts as a positive electrode. Insulating seal prevents drying up of the jerry.



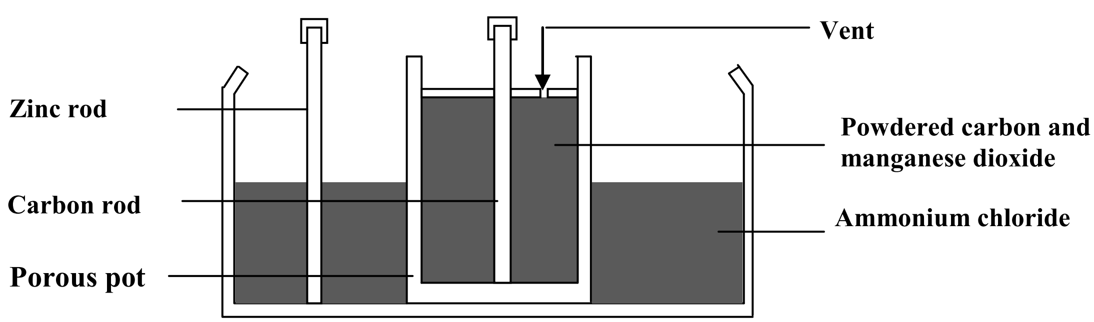
Precautions

- Large currents should not be drawn from the dry cell with in a short time.
- Short circuiting its terminal can ruin it.
- The cell should be stored in dry places.

Advantages of dry lachanche' cell over wet lachache' cell

- It gives large amount of current compared to wet lachanche' cell.
- It is portable since its size is quite small.
- It uses a jelly as electrolyte instead of a solution.

Wet Lachanche' cell



The electrolyte is ammonium chloride. The anode is carbon rod contained in porous pot surrounded by manganese dioxide so as to depolarize the carbon rod and the cathode is zinc rod. The carbon powder increases the conducting surface area of the carbon rod. When the carbon rod is connected to the zinc rod by a conductor, current flows from carbon to zinc outside but from zinc to carbon inside. As zinc reacts with ammonium chloride, electrons flow from zinc to carbon.

$$Zn + 2NH_4Cl \longrightarrow ZnCl_2 + 2NH_3 + H_2$$

The polarization caused by hydrogen is prevented by manganese dioxide which oxidizes hydrogen to water. However the depolarization action slow and hence a cell polarizes when a large current is taken from the cell. If the cell is allowed to rest for some time, the depolarization action continues to completion and original current is restored. Hence the cell is not suitable for sustaining a steady current over a long period of time but can be used where current stopping at intervals is required. When a large current is taken from the cell, manganese dioxide cannot oxidize hydrogen as faster as hydrogen is formed so polarization takes place resulting in e.m.f to fall.

SECONDARY CELLS:

Secondary cell is a cell which can be recharged when it runs down by passing current backwards through it. The chemical process which occurs in secondary cells when delivering current can be reversed by applying a direct current to the terminals. There are two types of secondary cells called accumulators (batteries) namely;

i) Lead acid accumulator.
ii) Nickel alkaline cell.

Lead acid accumulator:

A battery or an accumulator is a combination of cells usually packed in a single container. Lead acid accumulator is the most reliable, long lasting and cost effective of the secondary cells. Lead is a negative electrode and lead dioxide is positive electrode. At the positive electrode, a sulphate ion reacts with the lead to form lead sulphate and hydrogen ions react with oxygen in the lead (IV) oxide to form water.

$$2PbO_{2(s)} + 2H_2SO_{4(aq)} \longrightarrow 2PbSO_{4(aq)} + 4H_2O_{(l)}$$

At the cathode lead reacts with sulphuric acid to form lead sulphate and hydrogen gas

$$Pb_{(s)} + H_2SO \longrightarrow {}_{4(aq)}PbSO_{4(s)} + H_{2(g)}$$

During these processes electrons are amassed at the negative electrode while positive charges at the anode. This generates an emf between the anode and the cathode. When it is fully charged the cell has an emf of 2.2V and the relative density is about 1.25 while when discharged the emf is about 2.0V and the relative density is about 1.15 because lead sulphate forms on the plates which leads to formation of water.

Nickel alkaline (Nife) cell:

The electrolyte in this cell is an alkaline solution like potassium hydroxide. The common types are nickel cadmium and nickel iron accumulators. Nickel hydroxide is the anode (positive) electrode and iron cadmium is the cathode (negative) electrode.

Advantages of alkaline accumulators over lead acid accumulators:

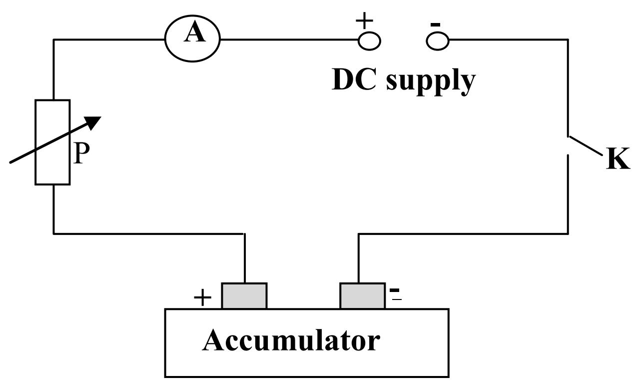
- They are not affected by over-charging and over-discharging.
- They deliver large amounts of current.
- They are portable compared to lead acid accumulators.
- They require very little attention to maintain.
- They have longer life time than lead acid accumulators.
- They can stay un-discharged for a long time compared to lead acid accumulators.

Disadvantages of alkaline accumulators over lead acid accumulators:

- They are very expensive compared to lead acid accumulators.
- They have a lower emf compared to lead acid accumulators.
- They have high internal resistance.
- They are less efficient than lead acid accumulators.

Charging an accumulator:

An accumulator is recharged using a direct current supply. When recharging a direct is passed through the cell in opposite direction to that during discharging that is the accumulator is connected in such a way that the positive terminal of the accumulator is connected to the positive terminal of the electrical source and the negative terminal to the negative terminal of the electrical source so that the process that takes place during discharging is reversed during charging.



The rheostat, P is necessary to adjust the current to the required value and before charging, an accumulator should be topped up with distilled water.

Care and maintenance of accumulators:

- The level of the electrolyte should be checked regularly and maintained above the plates by using distilled water but not the acid.
- The accumulator should be charged when the emf of the cell drops below 1.8V and relative density of the acid falls below 1.12.
- Large amounts of current should not be drawn from the accumulator for a long time.
- The accumulator should not be left discharged for a long period of time.
- The accumulator should not be over-charged or over-discharged.
- The terminals should be always kept clean and greased.
- The positive terminal should never be connected directly to the negative terminal to avoid short circuiting.

Trial Exercise 1:

1. Write down advantages of charging by induction over charging by contact
2. Explain why the leaf of uncharged gold-leaf electroscope diverges as a charged body is brought near its cap
3. Explain why when a conductor is brought near the cap of a charged gold-leaf electroscope the divergence of the leaf decreases.
4. Distinguish between an electric cell and a battery
5. Give reasons why lead acid battery may be preferred to dry cells
6. Give differences between primary and secondary cells
7. In making a simple cell the two electrodes used are not of the same kind. Explain why
8. Why is it possible to start a car with the lead-acid battery but not with dry cells in series giving the emf equal to that of a battery?
9. What are the defects and their remedies in the working of a dry cell?
10. Explain the following;
    a) A glass window when wiped with a dry cloth on a dry day soon becomes dusty
    b) A nylon dress sticks on the body and crackles when removed

Multiple-choice Exercise:

1. If rubbing together materials P and Q makes P acquire a positive charge and Q a negative charge, then during the process
   A. Q loses protons to P B. Q gains electrons from P
   C. P loses protons to Q D. P gains electrons from Q
2. Charging by rubbing is possible with insulators and not with conductors because
   A. electrons move freely through conductors
   B. molecules of an insulator vibrate less violently
   C. conductors repel charge while insulators attract it
   D. electric charge lowers the temperature of an insulator
3. Electrostatic induction occurs due to shifting of
   A. protons of atoms B. nuclei of the atoms
   C. neutrons of the atoms D. electrons of the atoms
4. The energy transformation that takes place when an electrophorus is used to charge bodies is
   A. kinetic to potential B. mechanical to electrical
   C. mechanical to heat D. heat to mechanical
5. The energy transformation that takes place when a cell is producing electricity is
   A. chemical to electrical B. mechanical to electrical
   C. heat to electrical C. electrical to heat
6. What is true?
   A. the emf of a cell depends on the size of the cell
   B. the lead-acid cell has higher internal resistance than the dry Leclanche cell
   C. Manganese (IV) oxide in a dry cell prolongs its life
   D. the emf of the battery depends on the number of cells in it.
7. When identical cells are connected in parallel
   A. the effective internal resistance is reduced B. the total emf is greater
   C. the effective internal resistance is increased D. the total emf is smaller

8. Which of the following gives a defect and its cause in a simple cell?

Defect	Cause
A. local action	presence of zinc amalgam
B. polarization	hydrogen remaining in gaseous form
C. local action	adding oxidizing agent
D. polarization	use dilute electrolyte

9. A dry cell in use depreciates with time due to
A. polarization B. disintegration of the carbon rod
B. local action D. hardening of ammonium chloride jelly

10. When lead-acid cell is left in a discharged state for long
A. the electrolyte slowly turns into water C. the plates disintegrate
B. the lead sulphate becomes inconvertible D. the electrolyte solidifies

11. If a battery is to be recharged, then
A. it is connected in series with the charging source
B. the charging p.d must be lower than that of a battery
C. the electrolyte must be replaced first
D. it is connected in parallel with the charging source

12. When the terminals of a cell are joined directly, the cell heats up because
A. the emf is increased B. a high current is drawn from the cell
C. there is friction between the terminal D. the internal resistance is increased

13. When a plastic rod is rubbed with dry piece of cloth, the rod and piece of cloth will
A. both acquire negative charges B. both acquire positive charges
C. acquire opposite charges D. have no charge

14. Which of the following statements is true about good insulator?
A. it acquires electric charge when rubbed with suitable materials
B. all its electrons are loosely bound to its atoms
C. electric charge easily flows on its surface
D. some of its electrons are free to move about

15. A body can only be confirmed to be electrically charged when
A. another charged body attracts it
B. it does not affect a leaf of a charged electroscope
C. it is repelled by another charged body
D. it is found to have less protons than electrons

16. Which of the following objects can be charged by friction?
A. safety pin B. copper plate C. razor blade D. plastic ruler

17. An electroscope is negatively charged by
A. gaining electrons B. gaining protons C. losing electrons D. losing protons

18. Which one of the following actions will cause the leaf of a negatively charged electroscope to fall?
i) Bringing a positively charged rod near the cap
ii) Bringing a negatively charged rod near the cap
iii) Connecting the can to the earth
A. (i) and (ii) correct B. (i) and (iii) correct
C. (ii) and (iii) correct D. (i), (ii) and (iii) correct

19. When a charged body is brought near a cap of a negatively charged gold leaf electroscope, the
A. the divergence of the leaf does not change
B. leaf falls if the body is negatively charged
C. leaf diverges if the body is positively charged
D. leaf diverges if the body is negatively charged

20. The leaf of a charged gold leaf electroscope gradually collapses with time due to
A. leakage to surroundings B. surrounding magnetic field
C. pressure variations in the surroundings D. similar charges from the surrounding

21. A charged conductor usually loses charge gradually by a process called
A. induction B. conduction C. insulation D. leakage

22. In a simple cell
A. polarization is caused by impure zinc
B. potassium dichromate is used to prevent polarization
C. the formation of hydrogen bubbles on the copper plate causes local action
D. hydrogen is produced on the zinc plate and causes polarization

23. The negative plate of a simple cell gradually goes into the solution because of
A. polarization B. local action C. charging D. gassing

24. When brass is to be copper plated, the suitable electrolyte to be used is
A. distilled water B. sulphuric acid C. lead (IV) oxide D. copper sulphate

25. The law of electrostatic induction states that
A. likes poles repel and unlike poles attract
B. unlike poles repel and like poles attract
C. likes charges repel and unlike charges attract
D. unlike charges repel and like charges attract

Answers

1	B	6	C	11	D	16	D	21	D
2	A	7	A	12	B	17	A	22	B
3	D	8	B	13	C	18	B	23	B
4	B	9	B	14	A	19	D	24	C
5	A	10	A	15	C	20	A	25	C

C U R R E N T E L E C T R I C I T Y

This is the study of electric charges in motion. **Charge** is the quantity of electricity which passes any section of a conductor. The S.I unit of charge is a coulomb [C].

A coulomb is a quantity of electricity which passes any point of a conductor in a one second when a current of one ampere is flowing through a conductor.

Electric current is the rate of flow of charge.

$$\text{Current} = \frac{\text{charge}}{\text{time}}$$

$$I = \frac{Q}{t}$$

$$Q = It$$

The S.I unit of current is an ampere [A]

An ampere is a constant current which when flowing in two long straight parallel conductors placed one metre apart in a vacuum produces a force of 2×10^{-7}N per metre length between them.

Other small units of current which can be used are

$1\text{mA} = 1 \times 10^{-3}\text{A}$

$1\mu\text{A} = 1 \times 10^{-6}\text{A}$

Examples:

1. Find the quantity of electricity used when a current of .5A is passed through a solution for 25 minutes

$$Q = It$$

$$Q = 0.5 \times 25 \times 60$$

$$Q = 750C$$

2. A charge of 2550C flows past a point in a circuit in 25minutes. Find the current flowing

$$\text{Current} = \frac{\text{Charge}}{\text{time}}$$

$$I = \frac{2550}{25 \times 60}$$

$$I = 1.7A$$

3. A current of 6mA flows for 2 hours in a circuit. Calculate the quantity of electricity that flows in the circuit

$$Q = It$$

$$Q = 6 \times 10^{-3} \times 2 \times 3600$$

$$Q = 43.2C$$

Resistance of a conductor:

This is the opposition to the flow of current within a conductor. The SI unit of resistance is an Ohm (Ω)

An Ohm is the resistance of a conductor in which a current of one ampere flows when a potential difference of one volt is applied across its ends.

Potential difference (p.d):

This is work done in joules when one coulomb of electricity moves from one point to another in a circuit. The SI unit of p.d is a volt (V).

A volt is the potential difference between two points in a circuit when one joule of work is done to move one coulomb of electricity between the two points.

Factors that affect resistance of a conductor:

1. Length: The resistance of a conductor is directly proportional to the length of conductor that is resistance increases with increase in length of the conductor ($R \propto L$).

2. Cross section: The resistance of conductor is inversely proportional to cross sectional area that is resistance of conductor decreases as cross sectional area of conductor increases$\left(R \propto \frac{1}{A}\right)$.

3. Temperature: The resistance of a pure conductor like copper increases with increase in temperature while resistance of a semi-conductor like silicon increases with decrease in temperature.

4. Nature of the conductor: Different conductors have different resistances due to different conductivities.

OHM'S LAW:

It states that the current flowing through a conductor is directly proportional to the potential difference across its ends provided temperature and other physical conditions are kept constant.

$V \propto I$

$V = RI$

$V = IR$

Where R is constant called resistance of a conductor

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

Therefore resistance is the ratio of potential difference to current flowing through a conductor.

Examples

1. Calculate the p.d across a 10Ω resistor carrying a current of 2A.

$V = IR$

$V = 2 \text{ x } 10$

$V = 20V$

2. The p.d across a 2Ω resistor is 4V. What is the current flowing?

$V = IR$

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

$I = \frac{4}{2}$

$I = 2A$

3. Find the p.d across a conductor of resistance 2Ω if the charge of 180C flows for 2 minutes

$V = IR$

$I = \frac{Q}{t}$

$V = \frac{QR}{t}$

$V = \frac{180 \text{ x } 2}{2 \text{ x } 60}$

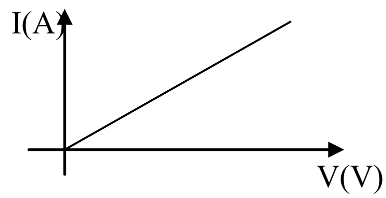
$V = 3V$

LIMITATIONS OF OHM'S LAW:

Ohm's law applies only to metals and only obeyed when the temperature is constant but it does not apply to certain materials.

Ohmic conductors:

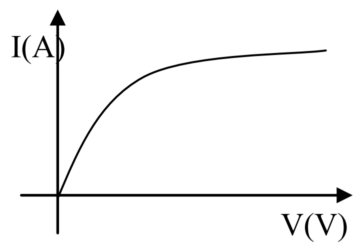
These are conductors which obey ohm's law e.g. metals like copper, iron, zinc e.t.c. The graph of current against p.d for ohmic conductors is straight line graph passing through the origin showing that current is directly proportional to the voltage as shown below.



Non-ohmic conductors:

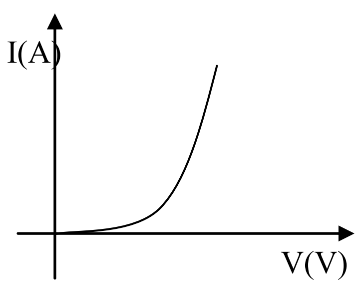
These are conductors which don't obey ohm's law. Examples of non-ohmic conductors and their graphs of current against voltage are as shown below.

a) Filament lamp

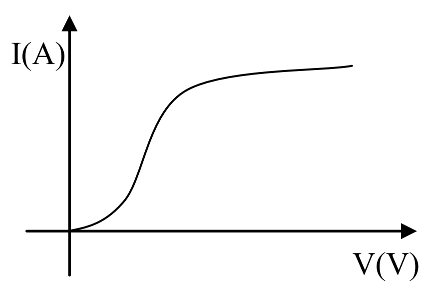


The graph shows that a given change in V causes a small change in current that is the resistance of the filament lamp increases as temperature increases.

b) Semi-conductor diode

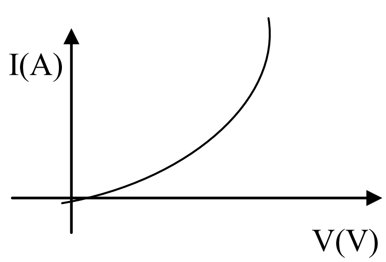


c) vacuum diode



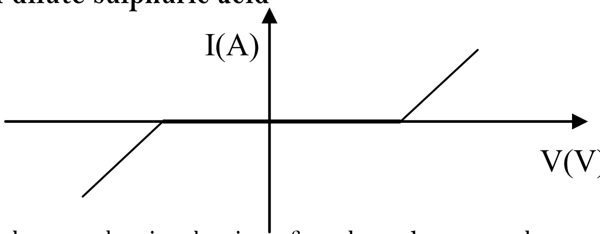
The graphs show that current flows when the p.d is applied in one direction but almost zero when it acts in opposite direction. A diode has small resistance when the p.d is applied in forward direction but large resistance when applied in a reverse direction.

d) Thermistor



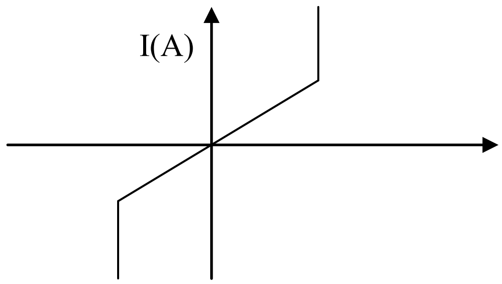
The graph shows that the resistance increases sharply as the temperature rises

e) Electrolysis of dilute sulphuric acid

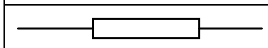
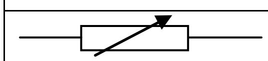
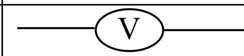
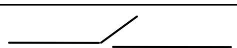
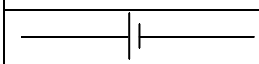
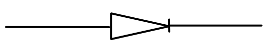
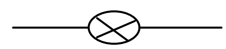
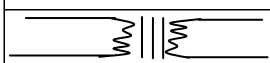
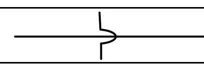


The graph shows that conduction begins after the voltage reaches a certain value

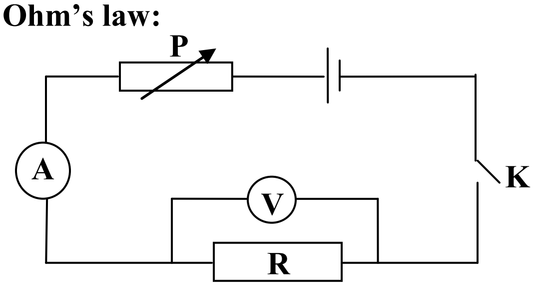
f) Inert gases (Neon)



Circuit symbols commonly used:

Symbol	Name	Symbol	Name
	Standard resistor		Ammeter
	Variable resistor or Rheostat		Voltmeter
	Switch		Galvanometer
	Cell		a.c supply
	Diode		Capacitor
	Battery or accumulator		Filament lamp
	Transformer		Crossing wires

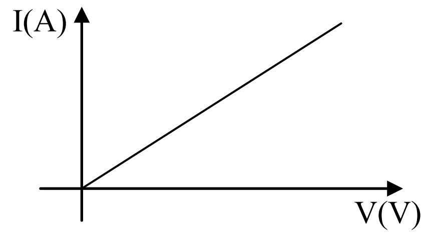
Experiment to verify Ohm's law:



Cell, switch, K, ammeter, A, and rheostat, P, are connected in series with a standard resistor, R across which a voltmeter, V is connected. Switch K is then closed and ammeter and voltmeter readings I and V are respectively noted and recorded. The rheostat is then adjusted for different ammeter and voltmeter readings and results are tabulated.

V(V)	I(A)

A graph of I against V is plotted



A straight line graph is obtained showing that I is directly proportional to V hence verifying Ohm's law

Arrangement of resistors

Resistors in a circuit can be connected in series or in parallel

Series arrangement

Resistors are said to be in series if they are connected end to end so that the same current passes through them.

Consider three resistors R_1, R_2 and R_3 connected in series across a p.d V

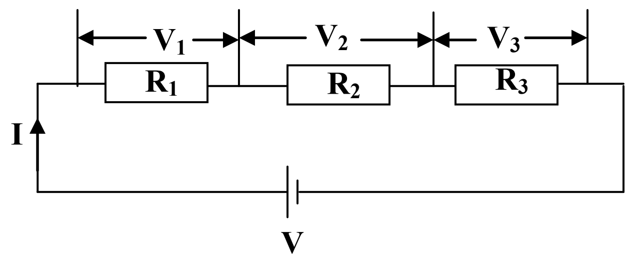
$V = V_1 + V_2 + V_3$

But $V = IR$

$V_1 = IR_1, V_2 = IR_2, V_3 = IR_3$

$IR = IR_1 + IR_2 + IR_3$

$R = R_1 + R_2 + R_3$



This is the effective (total) resistance for three resistors in series and for n-resistors in series

$\mathbf{R = R_1 + R_2 + \ldots + R_n}$

Parallel arrangement

Resistors are said to be in parallel if they are connected side by side so that the same p.d is across each resistor.

Consider three resistors R_1, R_2 and R_3 connected in parallel across a p.d V

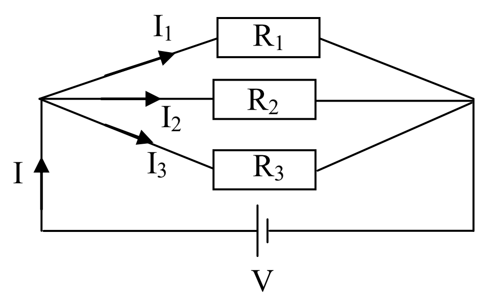
$I = I_1 + I_2 + I_3$

But $I = \frac{V}{R}$

$I_1 = \frac{V}{R_1}, I_2 = \frac{V}{R_2}, I_3 = \frac{V}{R_3}$

$\frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$

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



This is the effective (total) resistance for three resistors in parallel.

For two resistors connected in parallel.

$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$

$\frac{1}{R} = \frac{R_2 + R_1}{R_1 R_2}$

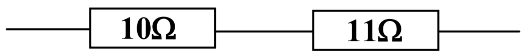
$\mathbf{R = \frac{R_2 R_1}{R_1 + R_2}}$

$\mathbf{R = \frac{product}{sum}}$

Examples:

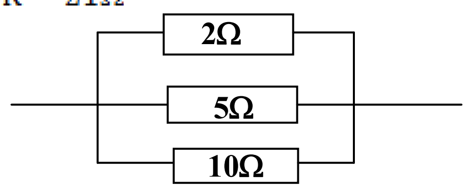
1. Find the effective resistance in circuit diagrams below

a)



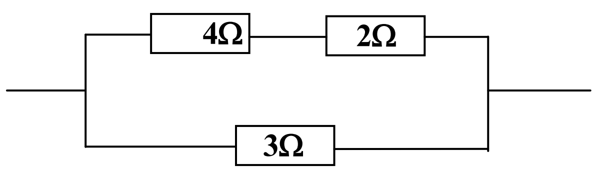
$$R = R_1 + R_2$$
$$R = 10 + 11$$
$$R = 21\Omega$$

b)



$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$
$$\frac{1}{R} = \frac{1}{2} + \frac{1}{5} + \frac{1}{10}$$
$$\frac{1}{R} = \frac{5 + 2 + 1}{10}$$
$$\frac{1}{R} = \frac{8}{10}$$
$$R = \frac{10}{8}$$
$$R = 1.25$$

c)



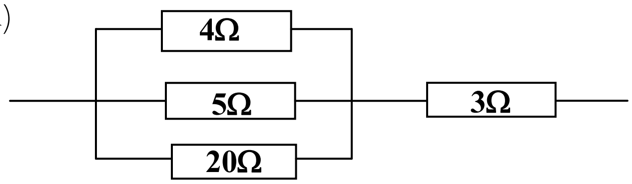
For series arrangement

$$R = R_1 + R_2$$
$$R = 4 + 2$$
$$R = 6\Omega$$

For parallel arrangement

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$
$$\frac{1}{R} = \frac{1}{6} + \frac{1}{3}$$
$$\frac{1}{R} = \frac{1 + 2}{6}$$
$$\frac{1}{R} = \frac{3}{6}$$
$$R = \frac{6}{3}$$
$$R = 2\Omega$$

d)



For parallel arrangement

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

$$\frac{1}{R} = \frac{1}{4} + \frac{1}{5} + \frac{1}{20}$$

$$\frac{1}{R} = \frac{5 + 4 + 1}{20}$$

$$\frac{1}{R} = \frac{10}{20}$$

$$R = \frac{20}{10}$$

$$R = 2\Omega$$

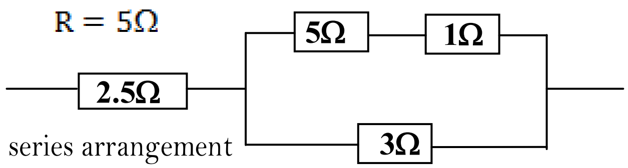
For series arrangement

$$R = R_1 + R_2$$

$$R = 3 + 2$$

$$R = 5\Omega$$

e)



For series arrangement

$$R = R_1 + R_2$$

$$R = 5 + 1$$

$$R = 6\Omega$$

For parallel arrangement

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$\frac{1}{R} = \frac{1}{6} + \frac{1}{3}$$

$$\frac{1}{R} = \frac{1 + 2}{6}$$

$$\frac{1}{R} = \frac{3}{6}$$

$$R = \frac{6}{3}$$

$$R = 2\Omega$$

For series arrangement

$$R = R_1 + R_2$$

$$R = 2 + 2.5$$

$$R = 4.5\Omega$$

E.m.f and internal resistance of resistance of a cell:

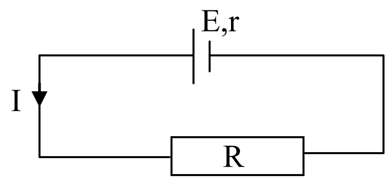
The electromotive force (E.m.f) of the cell is the work done in joules to move one coulomb of electricity in a circuit in which a cell is connected.

The internal resistance of the cell is the opposition to flow of current through a cell.

Consider a cell of e.m.f, E and internal resistance, r connected in series to external resistor, R

$E = IR + Ir$

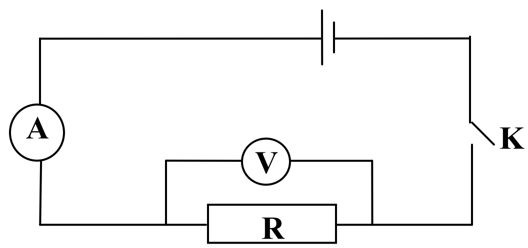
$I = \dfrac{E}{R + r}$



Experiment to determine the internal resistance of the cell:

1. Using the voltmeter and an ammeter:

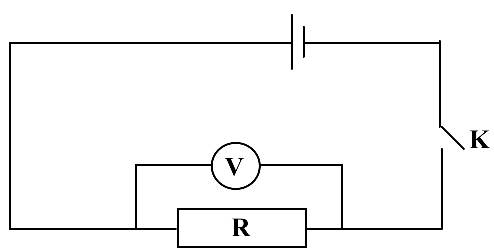
- Measure the e.m.f, E of the cell by connecting the terminals of the cell direct to the voltmeter.
- Connect a cell in series with a switch, K an ammeter, A and a standard resistor, R across which a voltmeter, V is connected as shown below.



- Switch, K is then closed and ammeter and voltmeter readings I and V respectively are noted and recorded.
- From $E = IR + Ir$
- Internal resistance $r = \frac{E - IR}{I}$ can be calculated

2. Using the voltmeter:

- Measure the e.m.f, E of the cell by connecting the terminals of the cell direct to the voltmeter.
- Connect a cell in series with a switch, K and a standard resistor, R across which a voltmeter, V is connected as shown below.



- Switch, K is then closed voltmeter reading V is noted and recorded.
- From $E = V + Ir$.
- But $I = \frac{V}{R}$.
- Internal resistance $r = \frac{E - V}{I} = \frac{R(E-V)}{V}$ can be calculated.

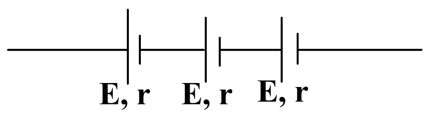
Arrangement of cells:

When cells are connected together they form a battery. Cells can be connected in series and in parallel.

a) Series arrangement:

Cells are said to be in series if the positive terminal of one cell is connected to the negative terminal of another cell and so on and the total e.m.f is the sum of e.m.fs of each of the cells.

Consider three cells each of e.m.f E and internal resistance r connected in series as shown below.



Total emf, E = E + E + E

= 3E

Total internal resistance, r = r + r + r

= 3r

For n-cells in series

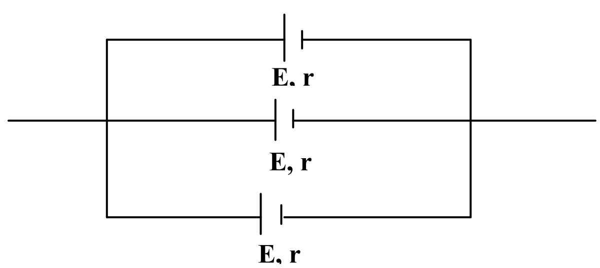
Total emf, E = nE

Total internal resistance, r = nr

b) Parallel arrangement:

Cells are said to be in parallel if the positive terminals of cells are connected to one point and the negative terminals of cells are connected to another point and the total e.m.f is the e.m.f of one of the cells and therefore cells must be having the same e.m.f

Consider three cells each of e.m.f E and internal resistance r connected in parallel as shown below.



Total e.m.f E = E [e.m.f of one of the cells]

Total internal resistance, $\frac{1}{r} = \frac{1}{r} + \frac{1}{r} + \frac{1}{r}$

$r = \frac{r}{3}$

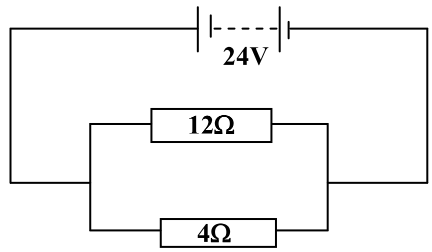
For n-cells in parallel

Total e.m.f, E = E [e.m.f of one of the cells]

Total internal resistance, r = $\frac{r}{n}$

Examples:

1. A battery of e.m.f 3V and negligible internal resistance is connected across two resistors as shown below



Calculate the current

i) Supplied by the battery

ii) Through 4Ω resistor and 12Ω resistor

Solution:

i) Current $I = \frac{E}{R}$

Where $R = \frac{R_1 R_2}{R_1 + R_2}$

$R = \frac{12 \times 4}{16}$

$R = \frac{48}{16}$

$R = 3\Omega$

$I = \frac{24}{3}$

$I = 8A$

ii) Current through 4Ω

$I = \frac{E}{R_4}$

$I = \frac{24}{4}$

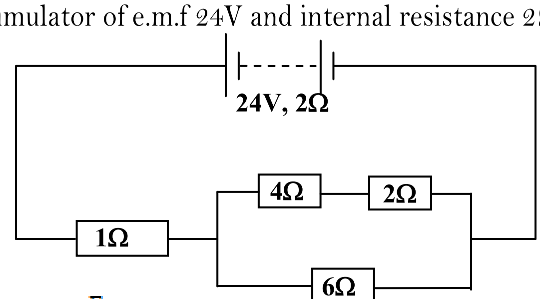
$I = 6A$

Current through 12Ω

$I = 8 - 6$

$I = 2A$

2. Four resistors are connected across an accumulator of e.m.f 24V and internal resistance 2Ω as shown below.



Calculate the current

i) Supplied by the battery

ii) Through 4Ω resistor

Solution:

For series arrangement

$R = R_1 + R_2.$

$R = 2 + 4.$

$R = 6\Omega.$

For parallel arrangement

$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}.$

$\frac{1}{R} = \frac{1}{6} + \frac{1}{6}.$

$\frac{1}{R} = \frac{1+1}{6}.$

$\frac{1}{R} = \frac{2}{6}.$

$R = \frac{6}{2}.$

$R = 3\Omega.$

For series arrangement

$R = R_1 + R_2.$

$R = 1 + 3 = 4\Omega$

i) Current $I = \frac{E}{R}$

$I = \frac{E}{R+r}$

$I = \frac{24}{4+2}$

$I = 4A$

ii) p.d across parallel arrangement

$V = IR$

$V = 4 \times 3$

$V = 12V$

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

$I = \frac{12}{6}$

$I = 2A$

ELECTRICAL ENERGY AND POWER:

Electrical energy is the work done on an electrically charged particle by an electric field. This energy is changed into internal energy in a conductor hence rise in temperature of a conductor forming heat energy. SI unit of electrical energy is a joule [J]

$\text{work done} = \text{charge x p.d.}$

$W = Q \times V.$

But $Q = It.$ But $V = IR$ But $I = \frac{V}{R}$

$W = IVt.$ $W = I^2Rt$ $W = \frac{V^2t}{R}$

Electrical power is the rate of changing electrical energy. SI unit of electrical power is watts [W]

$$\text{Electrical power} = \frac{\text{electrical energy}}{\text{time}} = \frac{IVt}{t} = \frac{I^2Rt}{t} = \frac{V^2t}{Rt}.$$

$P = IV.$ $P = I^2R$ $P = \frac{V^2}{R}$

Note:

An electrical appliance rated 240V, 60W means that when the appliance is connected to a 240V main supply consumes or supplies energy of 60J every second.

Examples:

1. How much energy is consumed by a 0.5kW electrical iron in 30minutes?

$\text{Electrical Energy} = IVt$

$\text{But Power} = IV$

$\text{Electrical Energy} = P \times t$

$E = 0.5 \times 1000 \times 30 \times 60$

$E = 900{,}000J$

2. How much energy is consumed by a 60W lamp in 10hours?

$\text{Electrical Energy} = IVt$

$\text{But Power} = IV$

$\text{Electrical Energy} = P \times t$

$E = 60 \times 1000 \times 10 \times 60 \times 60$

$E = 2{,}160{,}000J$

3. An electrical iron is marked 200V, 500W and it is connected to a 200V mains.

i) How much current does it take?

ii) What is the resistance of the heating coil of the electrical iron?

i) $P = IV.$

$500 = 1 \times 200.$

$I = 2.5\ A.$

ii)$P = I^2R$

$500 = 2.5^2 \times R$

$R = 80\Omega$

4. A battery of e.m.f 24V is connected in series with a resistor, R and a lamp rated at 10V, 20W. Find

i) The p.d across the resistor, R

ii) The value of R

iii) Power dissipated in the resistor, R

Solution:

i) p.d across R = 24 – 10 ii) P = IV   V = IR

= 14V   20 = I x 10   14 = 2 x R

I = 2A   R = 7Ω

ii) Power = I^2R

= 2^2 x 7

= 28W

COMMERCIAL ELECTRICITY:

The commercial unit of electricity is kilowatt hour [kWh]. The kilowatt hour is the rate of working of 1000W for one hour. Energy consumed by 1 unit [kWh] of electricity is

1kWh = 1 kW x 1 h

= 1000 x 60 x 60

= 3,600,000J

Unit of electricity = power (kW) x time (hours)

Cost of electricity = unit x unit cost

Examples

1. How much will it cost to run four bulbs rated at 40W for 2days, if the cost of each unit of electricity is shs.30?

Units = power (kW) x time (hours)

Power = 40 x 4

= 160W

= 0.16kW

Time = 2 x 24

= 48hours

Units = 0.16 x 48

= 7.68kWh

1 kWh costs shs. 30

7.68kWh cost 30 x 7.68

= shs. 230.4

2. How much will it cost to run two bulbs rated at 60Wand an electric iron rated at 120W for 35minutes, if the cost of each unit of electricity is shs.415?

Units = power (kW) x time (hours)

Power = 60 x 2 + 120

= 240W

= 0.24kW

Time = $\frac{35}{60}$hours

Units = $0.24 \times \frac{35}{60}$

= 0.14kWh

1 kWh costs shs. 415

0.14kWh cost 415 x 0.14

= shs. 58.1

Electric Heating:

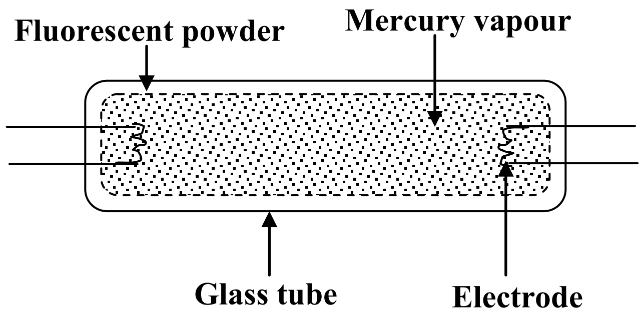
The effect of electrical heating is that electrical energy is converted to heat energy in a resistor which is used in most electrical devices. The heating elements are made from nichrome wire (an alloy of nickel and chromium) because nichrome is not oxidized and becomes brittle when it is red hot that is oxides of metals are poor conductors. Examples of devices which have nichrome wire are filament lamp, hot plates, electric kettles and electric flat iron e.t.c

Filament Lamp:

Filament is a small coil tungsten wire which becomes white hot when current flows through it. The temperature of the filament rises rapidly until it becomes white hot and emits heat and light. The filament is made of tungsten because of its high melting point. In order to avoid oxidation of the filament, air is removed from the bulb. Filament lamps contain inert gas (nitrogen or argon) at a low pressure which reduces the evaporation of the filament which leads to darkening of the bulb and raises the operating temperature. The filament is made of the tungsten because the temperature of filament is so high that requires high melting point material

Fluorescent Tubes:

Fluorescent tube is a gas discharge lamp that uses electricity to excite mercury vapour. It has electrodes at the ends and the inside wall is coated with fluorescent substance.



When current flows, the filament becomes white hot and emits electrons. The electrons are attracted to the anode, the electrons collide with mercury atoms and excite the atoms which produce ultra-violet light that causes the substance to produce visible light.

Advantages of fluorescent tubes over filament lamps:

- They are more efficient.
- They have cheap running costs.
- They don't produce a lot of heat.
- They are long lasting

Disadvantages of fluorescent tubes over filament lamps:

- They need high installation costs.
- They may not start when the supply voltage is low

ELECTRICAL INSTALLATION:

Electrical power from the source is taken to a house or a factory by thick wires or cables known as the mains. The cable contains two wires one of which is live cable and the other is neutral cable. The neutral wire is connected to the earth at the local sub-station and the house so that it is at zero potential. The power usually transmitted is alternating current (a.c) that is flowing backwards and forward rapidly with a frequency of about 50Hz because it can be easily stepped up or down.

House wiring:

In wiring house the following should be included in the circuit

Switch:

This is always connected to the live wire for cutting off the current whenever it is not required and connecting it when needed. This ensures there is no electric shock when power is switched off. If the switch is put on the earth wire, appliance will be permanently connected to the live wire and touching any faulty appliance, one would get an electric shock

Fuse:

A fuse wire is a safety device which cuts off current if too high current is being used. When current is too high the fuse wire melts and the circuit is broken. The fuse is used to safe guard appliances from being brown when current exceeds the rated value. Fuse wire is made to carry current up to a certain definite value of 2A, 5A, 10A, 13A, 15A 30A and when the current exceeds the stated value it blows

Earthing:

The earth wire conducts any stray electric current that is it provides alternative path to current when there is a fault there by preventing electric shock. It is connected to the metal frame so that one may not get electric shock as the live wire may touch the earth wire of the appliance. The three wires, the live wire, neutral wire and the earth wire have specific colour codes. That is live wire is brown or red, the neutral wire is blue or black and the earth wire is yellow with green strips.

Safety precautions taken when wiring a house:

- The colour codes must be followed.
- All switches should be connected to the live wire.
- Wires should be insulated.
- An earth wire and fuses should be installed to safe guard various components.

All house connections are connected in parallel because of the following:

- To ensure that all appliances are at the same potential difference.
- It enables switching on and off lights of appliances independently.
- Series connection can cause dimming of lights.
- If one appliance develops a fault the other appliances continue working.

Trial exercise 2:

1. a) A charge of 180C flows through a lamp every minute. Calculate the current flowing through the lamp.
   b) Calculate the number of electrons involved if the charge on an electron is 1.6×10^{-19}C
   Ans: a) 3A b) 1.875×10^{19} electrons
2. A battery circulates charge round a circuit for 1.5 minutes. If the current is held at 2.5A, what quantity of charge passes through the wire?
   Ans: 225C
3. A current of 10mA flows for 4 hours in a circuit. Calculate the quantity of electricity that flows in the circuit
   Ans: 144C

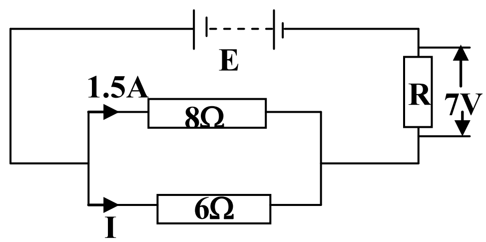
4. When a resistance of 2Ω is connected a cross a battery a current of 1A flows. When the 2Ω resistor is replaced with a 4Ω resistor the current becomes 0.6A. Find

i) the internal resistance of the battery

ii) the emf of the battery

Ans: i) 1Ω ii) 3V

5. In the circuit diagram below, the battery has emf, E and negligible internal resistance



Calculate;

i) Current, I

ii) The resistance, R

iii) The emf, E

Ans: i) 2A ii) 2Ω iii) 19V

6. A kettle is marked "2500W, 240V". What do these markings mean and what current does the kettle draw when connected to a 200V source.

Ans: 12.5A

7. Calculate the power used in 100Ω connected to a source of emf 12V

Ans: 1.44W

8. Two appliances are rated 240V, 2kW and 240V, 500W. Find the cost of running them for three hour if the cost of one unit of electricity is 670/=

Ans: shs. 5,025/=

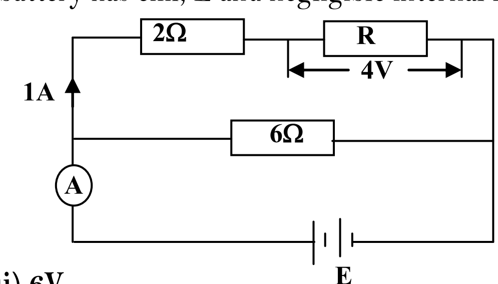
9. In the circuit diagram below, the battery has emf, E and negligible internal resistance

Find;

i) Ammeter, A reading

ii) The resistance, R

iii) The emf, E



Ans: i) 2A ii) 4Ω iii) 6V

10. The table below shows a number of appliances and how they are used in Mr. Kato's house

Appliance	Number	Rating	Time per day
Bulbs	4	100W	4hours
Bulbs	5	60W	3hours
Cooking plate	1	1500W	3hours
Flat iron	1	750W	30minutes
Kettle	1	2.7kW	30minuts
Oven	1	2.8kW	1½hours

If a unit costs 550/= calculate Mr. Kato's April bill

Ans: shs. 213,262.5

Multiple-choice Exercise:

1. An alternative unit that could be used for current is

A. joule per second B. joule per coulomb

C. coulomb per second D. volt per metre

2. Ohm's law relates

A. current, resistance and p.d B. temperature, current and p.d

C. length, current and p.d D. current, resistance and temperature

3. When the temperature of the wire is raised, its resistance

A. increases B. remains constant

C. decreases D. increase and then decreases

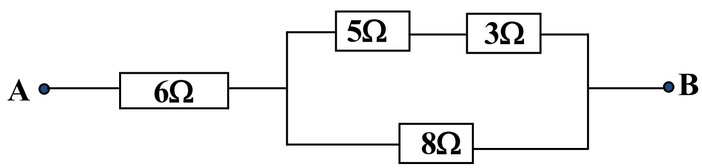
4. A uniform wire of length 10cm has a resistance of 1.2Ω. What resistance will 2m of the wire have?

A. 24.00Ω B. 2.40Ω C. 0.60Ω D. 0.24Ω

5. If the cross-sectional area of the wire in question 16 is doubled and the length tripled what will be the resistance of the resulting wire

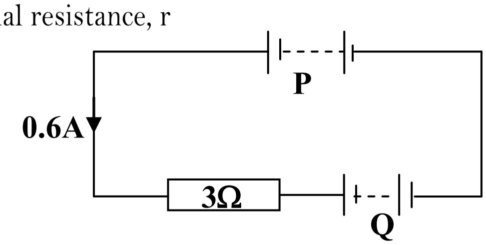
A. 7.2Ω B. 1.8Ω C. 0.8Ω D. 0.2Ω

6. Find the resistance between points A and B



A. 22Ω B. 14Ω C. 11Ω D. 10Ω

7. In the circuit diagram below, battery P has internal resistance of 0.5Ω and emf of 6V while Q has emf of 3V and internal resistance, r



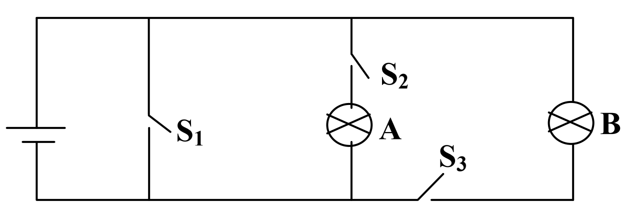
If the current flowing is 0.6A, find the internal resistance of cell Q

A.0.5Ω B. 1.5Ω C. 2.9Ω D. 11.0Ω

8. A current of 2A flows in a conductor. How much charge flows past a section of the conductor in 3 minutes?

A. 0.67C B. 6C C. 90C D. 360C

9. In the circuit below, A and B are bulbs, S_1, S_2 and S_3 are witches



What is true about the circuit?

A. if all the switches are closed, all the bulbs light up

B. if all the switches are closed no bulb will light up

C. if only switches S_1 and S_2 are closed only bulb A will light up

D. as long as switch S_1 is open no bulb will light up even if S_2 and S_3 are closed

10. A device connected to a source of 60V consumes electrical energy at a rate of 300W. If it is connected to a source of 36V it will draw a current of

A. 3A B. 5A C. 33A D. 500A

11. Two bulbs, each marked 100W, 240V are connected in series and the combination is connected across a supply of 240V. The power consumed by each bulb is

A. 25W B. 50W C. 100W D. 200W

12. The commercial unit of electrical energy is

A. kilowatt B. kilojoules C. mega joule D. kilowatt hour

13. A suitable material for the filament of a bulb should have

A. high melting point and low resistance B. low melting point but high resistance

C. high melting point and high resistance D. low melting point and low resistance

14. A lighting circuit is supplied through a 5A fuse. What is the maximum number of 75W, 240V bulbs that can be fixed in the circuit?

A. 10 B. 16 C. 48 D. 3600

15. The purpose of a fuse in a circuit is to

A. limit the current in the circuit B. stop the current in case too much of it flows

C. protect the appliance D. reduce the voltage to a safe value

16. Switches are connected on the live and not the neutral

A. because the live is stronger

B. so that the appliances do not remain live when the switch is off

C. because no current flows in the neutral

D. because if it is in the neutral the appliance would not respond to it

17. The purpose of earthing appliances having metallic bodies is

A. to protect the appliance from being blown up

B. to avoid damage due to lightening

C. to protect the user from shock should the live touch the body of the appliance

D. to prevent the short circuit

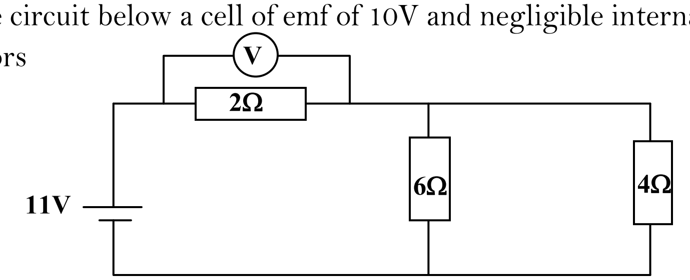
18. If the cost per unit of electrical energy is 170/=, what is the cost of operating 6 bulbs each rated at 75W, 220V for 8 hours

A. 612/= B. 792/= C. 612,000/= D. 792,000/=

19. The most appropriate fuse for a 1600W, 220V heater among these is

A. 20A B. 15A C. 10A D. 5A

20. In the circuit below a cell of emf of 10V and negligible internal resistance is connected to three resistors



What is the reading of the voltmeter, V in circuit diagram?

A. 2V B. 4V C. 5V D. 10V

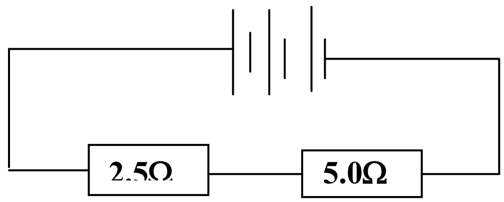
21. A p.d of 20V is applied across two resistors of 4Ω and 6Ω connected in series. Determine the p.d across the 6Ω resistor

A. 1.0V B. 2.0V C. 3.3V D. 12.0V

22. The rate at which electric charge flows past a point in a circuit is measured in

A. watts B. volts C. amperes D. coulombs

23. In the circuit diagram, each cell has an internal resistance of 0.5Ω



Find the resistance in the circuit

A. 1.25Ω B. 7.50Ω C. 8.00Ω D. 9.00Ω

24. The resistance of the wire increases when its

A. length increase C. temperature is reduced

B. length decreases D. cross sectional area is doubled

25. Alternating current is preferable to direct current for the transmission of power because

A: it can be rectified B: it is easier to generate

C: thinner conductors can be used. D: it is safer

Answers:

1	C	6	D	11	A	16	B	21	D
2	A	7	B	12	D	17	C	22	C
3	A	8	D	13	A	18	A	23	D
4	A	9	A	14	B	19	C	24	A
5	B	10	B	15	B	20	C	25	A

MISCELLANEOUS EXERCISE 5:

1. a) State what happens when each of the following is brought near the cap of a positively charged electroscope

i) A glass rod rubbed with silk

ii) An uncharged metal rod

iii) An ebonite rod rubbed with fur

b) Describe how a conductor can be charged negatively by induction

c) i) What is a neutral point as applied to an electric field

ii) Draw a diagram of electric field pattern when a negative charge is placed near a positive plate

c) List four features of electric field

2. a) i) What is meant by electrical resistance

ii) State factors that determine the resistance of a metallic wire

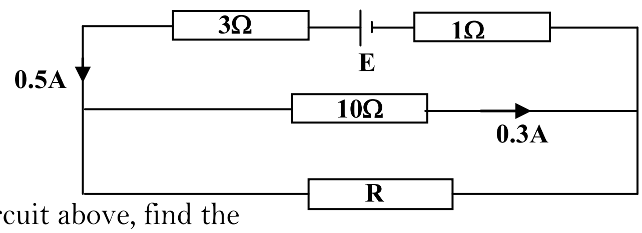
b) Three identical bulbs, each rated at 6V, 3W are used to investigate the various combinations of them when connected to a 6V source

i) How many combinations of three bulbs are possible?

ii) Find the minimum and maximum power consumption during these investigations

Ans: i) 4 ii) Maximum = 9W, Minimum = 1W

c)



In the circuit above, find the

i) Resistance, R

ii) E.m.f, E of a cell of negligible internal resistance.

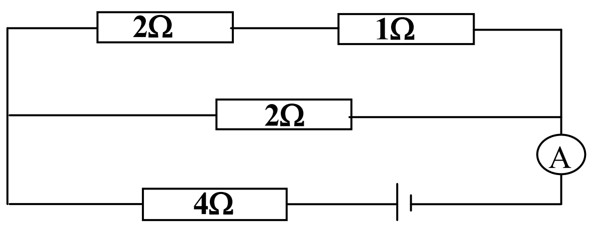
Ans: i) 15Ω ii) 5.0V

3. Define the following terms;

i) A volt

ii) Internal resistance of a cell

b) The circuit diagram below shows a cell of emf 3.6V and internal resistance 2Ω connected to network of resistors



Calculate;

i) Total resistance

ii) Ammeter, A reading

iii) The p.d across 1Ω resistor

Ans: i) 7.2Ω, ii) 0.5A iii) 0.2A

c) Draw a labeled diagram of a simple cell

d) i) Define the term electric field

ii) Draw an electric field pattern between a positive charge and a negative plate

4. a) Draw sketch graphs of p.d, V against current, I for following

i) A wire

ii) An electrolyte

iii) A semi-conductor diode

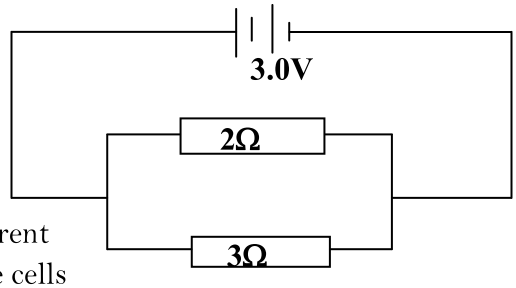
b) Explain the differences between a voltmeter and an ammeter in terms of their

i) Construction

ii) Use

c) State three physical properties that affect the resistance of a solid conductor

d) Two cells each of emf 1.5V and negligible internal resistance are connected in series across two resistors of 2Ω and 3Ω as shown below



Calculate the current

i) Supplied by the cells

ii) That passes through a 3Ω resistor

Ans: i) 2.5A ii) 1.0A

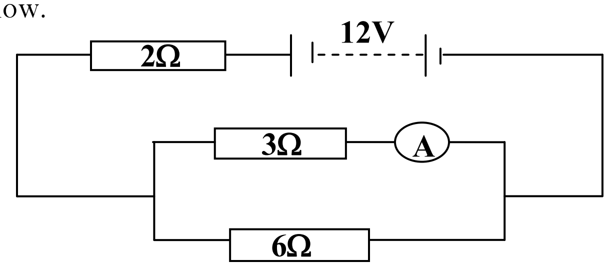
5. Define the following terms;

i) A volt

ii) Electrical resistance

b) List ways by which the life of an accumulator can be prolonged

c) A battery of e.m.f 12V and negligible internal resistance is connected to resistances of 2Ω, 3Ω and 6Ω as shown below.



Find

i) The reading of the ammeter, A

ii) Current passing through 6Ω resistor

Ans: i) 2A ii) 1A

d) State three advantages of an alternating current over a direct current in power transmission

e) Sketch the current versus voltage variation for a semi-conductor diode

6. a) i) Draw a well labeled diagram of a gold leaf electroscope

ii) Describe how electroscope can be charged positively by induction

b) Sketch the electric field patterns for the following

i) Two negatively point charges close to each other

ii) A positively charged hollow conducting sphere

iii) Two positively charged parallel plates

c) Explain how a lightening conductor safeguards a house against lightening

7. a) Describe how you would use a gold leaf electroscope to determine the sign of the charge on a given charged body

b) Explain how an insulator gets charged by rubbing

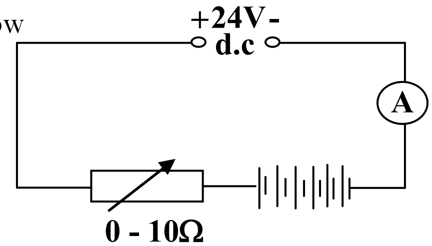
c) Sketch the electric field pattern between a charged point and a metal plate

d) Describe how a lightening conductor safeguards a tall building from being struck by lightening

8. a) i) What is meant by the e.m.f of a source of electrical energy

ii) Draw a labeled diagram to show the structure of a dry cell

b) Six accumulators each of e.m.f 2V and each of internal resistance 0.1Ω are charged from a 24V a.c supply as shown below



i) Explain why it is necessary to include a rheostat in the circuit

ii) What will the ammeter, A read if the rheostat is set at 5.4Ω

iii) Find the rate at which electrical energy is converted to chemical energy in (ii) above

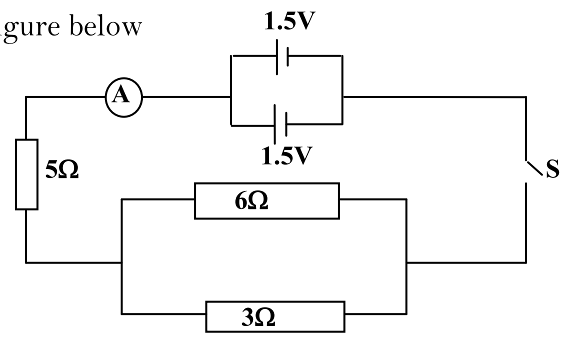
9. Name one instrument that turns

i) Chemical energy to electrical energy

ii) Heat energy to electrical energy

b) With the help of a well labeled diagram describe how dynamo generates an electromotive force (e.m.f)

c) Two cells each of internal resistance 1Ω are connected to a circuit which includes switch, S as shown in the figure below



i) What is the reading of the ammeter, A when the switch, S is closed

ii) Calculate the power developed in the 5Ω resistor when switch, S is closed

Ans: i) 0.2A ii) 0.2W

10. a) What is meant by a conductor and an insulator. Give an example of each

b) Explain how an insulator gets charged by rubbing

c) i) Explain briefly how you can charge a conductor negatively by induction

ii) Describe how it can be confirmed that the conductor in (b) (i) is negatively charged

d) Explain the action of a lightening conductor

e) i) Explain what is meant by polarization as applied to a simple cell

ii) State how polarization can be minimized in a simple cell

11. a) What happens when a glass rod is rubbed with

i) Silk

ii) An identical glass rod

b) Describe how a gold leaf electroscope may be used to test the nature of the charge on an object

c) Draw an electric field patterns for;

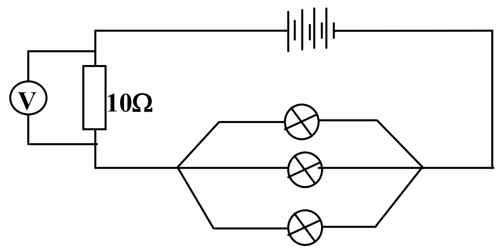
i) An insulated negative charge

ii) Two oppositely charged parallel plates at a small distance apart

d) Explain why it is not advisable to touch the copper strip of a lightening conductor when it is raining

12. a) Sketch the current and p.d variation for a semi-conductor diode

b) Four identical cells each of internal resistance 0.2Ω are connected to form a battery. Three identical lamps each marked 3W and a 10Ω resistor are connected to the battery as shown below



If the current through each lamp is 0.5A, find

i) The resistance of each lamp

ii) The reading of the voltmeter, V

iii) The effective resistance in the circuit

iv) The energy delivered by the battery per second

Ans: i) 12Ω ii) 15V iii) 14.8Ω iv) 33.3W

c) Calculate the cost of running an electric fire for 2½ hours, if an electric fire draws a current of 13A on a 100V supply and each unit costs shs. 400/=

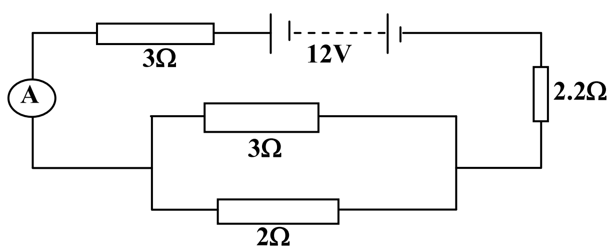
Ans: shs. 1300/=

13. a) i) Draw a diagram to show the structure of a simple cell

ii) Give one defect of a simple cell and state how it is minimized

b) Explain how a lead acid accumulator can be recharged when it has run down

c) Four resistors are connected across a 12V battery of negligible internal resistance as shown below



Determine

i) The reading of the ammeter, A

ii) The p.d across the parallel combination of resistors.

Ans: i) 1.875A ii) 2.25V

d) When two identical heating elements of a kettle are connected in series to a 240V supply, the power developed is 400W. Find

i) The resistance of either element

ii) The power developed when the element of a kettle are connected in parallel to the same supply

Ans: i) 36Ω ii) 3200W

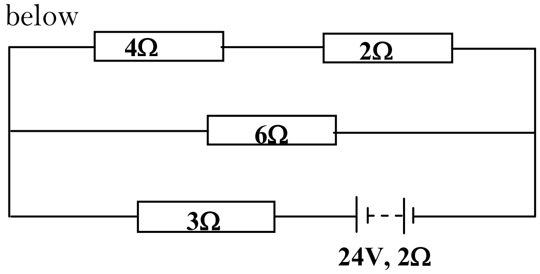
14. a) i) Draw a labeled diagram of a lead acid accumulator

ii) List three precautions necessary to prolong the life of an accumulator

iii) State two advantages of a Nife cell over a lead acid cell

b) What is meant by the following?
i) Electromotive force
ii) Internal resistance of a cell
c) Explain the differences between a voltmeter and an ammeter in terms of their
i) Construction
ii) Use
d) State three physical properties that affect resistance of a solid conductor

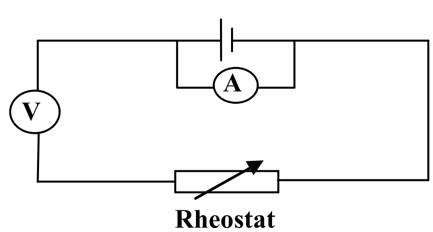
15. a) Define the volt
b) Draw a circuit diagram which can be used to investigate the p.d-current relationship for a wire
c) Sketch a graph of current against p.d for
i) A carbon resistor
ii) A semi-conductor diode
c) An accumulator of e.m.f 24V and internal resistance of 2Ω is connected to 3Ω, 4Ω, 2Ω and 6Ω resistors as shown below



Calculate
i) Current through the 6Ω resistor
ii) The total power expended
Ans i) 1.5A ii) 72W
e) State two precautions which must be taken to protect an accumulator

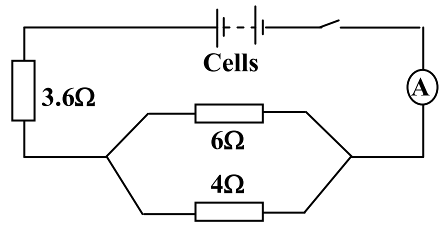
16. a) Describe the structure and action of a fluorescent tube
b) Give one advantage of fluorescent tube over a filament lamp
c) Describe the functions of;
i) A fuse
ii) An earth wire
d) Describe briefly how power is transmitted from a power station to a home
e) Find the cost of running two 60W lamps for 20 hours if the cost of each unit is shs. 400/=
Ans: shs. 480/=

17. a) An ammeter, A and a voltmeter, V are connected as shown in the circuit below



What can you say about the above connections?

b) Three resistors of 6Ω, 4Ω and 3.6Ω are connected to eight identical cells of negligible internal resistance as shown below



If the ammeter, A reads 2A, when the switch is closed, determine

i) Current through a 4Ω resistor

ii) E.m.f of each cell

Ans: i) 1.2A ii) 1.5V

c) Swithen paid an electricity bill of shs. 1800/= after using two identical bulbs for 2 hours every day for ten days at a cost of shs. 600/= per unit

i) Determine the power consumption by each of the bulbs

ii) State the energy changes that occur in the bulb

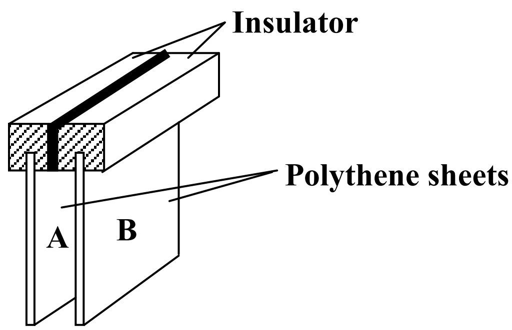
Ans: i) 75W

18. a) i) What is a conductor

ii) Give two examples of conductors

b) Describe how a gold leaf electroscope can be positively charged by electrostatic induction

c) Two polythene sheets A and B are both negatively charged with equal amounts of charge. One end of each polythene sheet is fixed into an insulator and the two sheets brought near each other as shown below



i) Describe and explain what happens

ii) Describe and explain what happens if an earthed sheet of metal is inserted between the polythene sheets without touching them

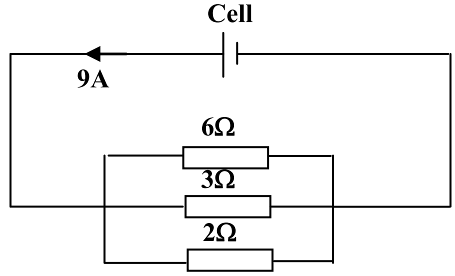
d) Explain how thunder is produced during rainstorm

19. a) Sketch the current versus p.d variation for

i) Metal wire

ii) Semi-conductor diode

b) The figure below shows a cell of negligible internal resistance connected to a system of resistors.



Calculate

i) E.m.f of the cell

ii) The current through the 3Ω

iii) Power dissipation in the 3Ω

Ans: i) 9V ii) 3A iii) 27W

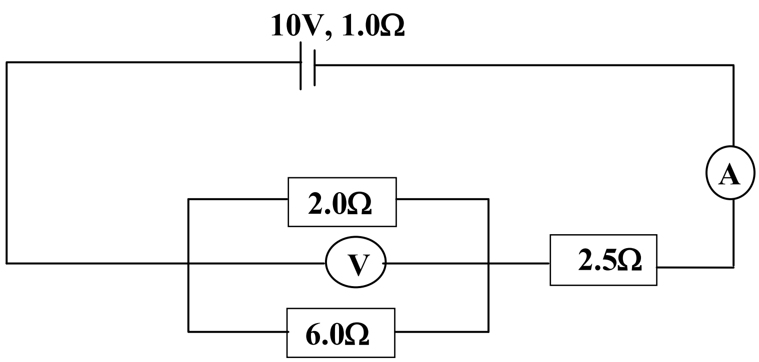
c) Describe the energy changes which occur from the time an electric bulb is switched on

20. a) Define the following terms

i) Potential difference

ii) Electromotive force

b) A battery of emf 10V and internal resistance 1.0Ω is connected to resistors 6.0Ω, 2.0Ω and 2.5Ω as shown in the figure below



i) Calculate the ammeter and voltmeter readings

ii) Calculate the current through the 2.0Ω resistor

iii) Find the rate at which the electrical energy is converted to heat energy in the 6.0Ω resistor.

Ans: 2A ii) 1.5A iii) 1.5W

c) i) What is a short circuit

ii) Briefly explain how a galvanometer can be turned into an ammeter

d) State **two** ways of increasing the sensitivity of electrical meters

M A G N E T I S M

A **magnet** is a piece of material that attracts other materials while **Magnetism** is the force exerted by a magnetic field. There are different magnetic materials and these include the following;

i) **Ferro magnetic materials:**

These are magnetic materials that are strongly attracted by a magnet. Ferro magnetic materials are capable of being made into a magnet and retain magnetic properties when the external field is removed.

ii) Diamagnetic materials:

These are magnetic materials that are slightly repelled by a magnetic field. A diamagnetic material does not retain the magnetic properties when the external field is removed. Diamagnetic properties arise from the realignment of the electron paths under the influence of an external magnetic field.

iii) Paramagnetic materials:

These are materials that are slightly attracted by a magnetic field and the material does not retain the magnetic properties when the external field is removed. Paramagnetic properties are due to the presence of some unpaired electrons, and from the realignment of the electron paths caused by the external magnetic field.

iv) Non-Ferro magnetic materials:

These are magnetic materials that are not attracted by a magnet at all. Non-Ferro magnetic materials can not be made into a magnet.

The table below shows examples of different magnetic materials;

Diamagnetic	**Paramagnetic**	**Ferromagnetic**	**Non - Ferromagnetic**
Copper Silver Stainless steel Gold Brass	Magnesium Lithium	Cobalt Iron Nickel Steel	Rubber Plastic Leather Mica Feather Paper

Polarity of a magnet:

A pole of a magnet is an area on a magnet where the magnetic force is strongest. A magnet has two poles and these are the North Pole and the South Pole. Poles of a magnet are found at the ends of a magnet and they occur in pairs of equal strength.

Note:

i) When a magnet is freely suspended it always comes to rest in the North-South direction. The pole that points towards the northern hemisphere (south pole) of the earth is the north pole of the magnet and the pole that points towards the southern hemisphere (north pole) of the earth is the south pole of the magnet because the south pole of the earth is in northern hemisphere and the north pole of the earth is in the southern hemisphere.

ii) When a magnet is dipped in iron fillings, the iron fillings are seen to concentrate at the ends of a magnet which shows that the magnetic attraction is strongest at the ends of the magnet.

Law of magnets:

It states that like poles repel each other and unlike poles attract each other.

Testing for the polarity of a magnet

A known pole of a magnet is brought near the ends of a magnet with unknown poles and if repulsion occurs then that end of a magnet is a like pole. The poles of a given magnet therefore can only be tested by repulsion since attraction can either result from unlike poles or a magnetic substance. The results obtained during testing can be summarized in the table below;

	North pole	South pole	Magnetic substance
North pole	Repulsion	Attraction	Attraction
South pole	Attraction	repulsion	Attraction
Magnetic substance	Attraction	Attraction	No effect

Magnetic fields:

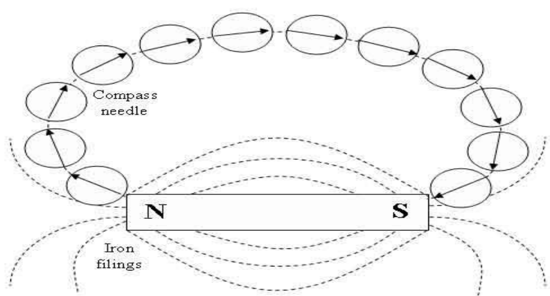
Magnetic field is an area or a region around a magnet where the magnetic effect is felt. The magnetic field is represented by the magnetic field lines or lines of force which start from the North Pole and end up in the South Pole in air. **Magnetic field line** is the path a magnetic pole would follow if it is placed in a magnetic field and the number of field lines is called **Magnetic flux**. The direction of the field lines at any point is the direction of the magnetic field at that point. The magnetic field is stronger where there are many field lines which are closer to each other.

Properties of magnetic field lines:

- They do not intersect or cross or touch each other.
- They can pass through none magnetic substances.
- They form like poles which repel each other.
- They seek the path of least resistance between opposite magnetic poles.
- They all have the same strength.
- Their density decreases with increasing distance from the poles.
- They flow from the South Pole to the North Pole within a material and North Pole to South Pole in air.

Magnetic field pattern by use of iron fillings

- A bar magnet is placed on a table and then covered with a smooth stiff paper.
- Iron fillings are then uniformly sprinkled on the paper and tap the paper gently.
- The iron fillings become magnetized by induction and arrange themselves in curved lines which are magnetic lines of force.



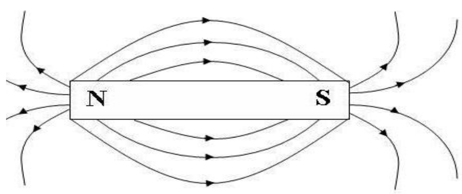
Magnetic field pattern by use of plotting compass method

- A bar magnet is placed on a sheet of paper fixed on a soft board.
- Its outline is marked and its poles indicated on the paper.
- A plotting compass is then brought near North Pole of the magnet.
- The direction pointed by the north pole of the plotting compass is marked with pencil dots.

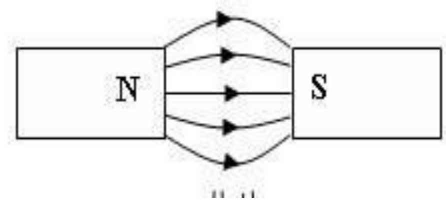
- The compass is moved until its south pole coincides with the dot marked.
- The procedure is repeated so that a series of dots is obtained.
- Join the dots by a smooth curve which represents a magnetic field lines

Representation of magnetic fields

1. Isolated bar magnet

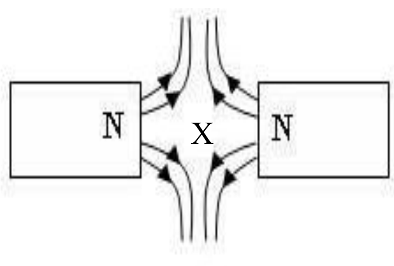


2. Two unlike poles near each other

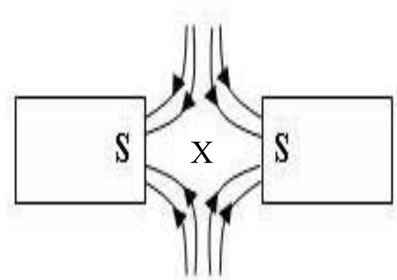


3. Two like poles near each other

i) North – North Pole



ii) South – South Pole

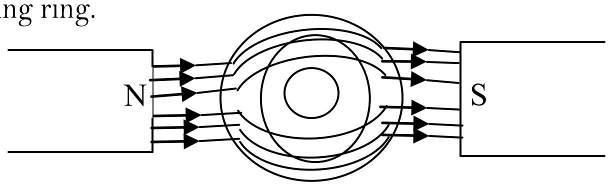


Note:

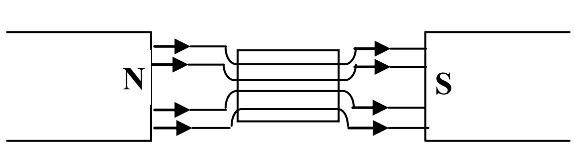
Points marked x are called **Neutral points**. A Neutral point is an area in a magnetic field where the resultant magnetic force is zero. There are no magnetic fields at the neutral point.

MAGNETIC SHIELDING [SCREENING]:

Soft iron ring concentrates the magnetic lines of force a long its length which prevents lines from passing through the surrounding ring and the neutral point and there the neutral point is shielded by the ring from the magnetic fields. Iron in form of a ring causes the lines of force to pass through its walls and no magnetic flux passes the surrounding ring.

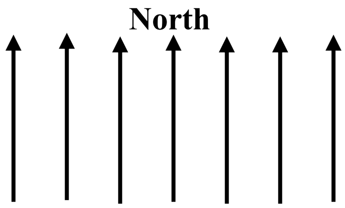


The space inside the ring is said to be shielded or screened from magnetic flux.This property of iron is utilised for protecting delicate instruments which are easily affected by magnetic fields. If a soft iron piece is used, the following pattern is obtained.



Earth's magnetic field:

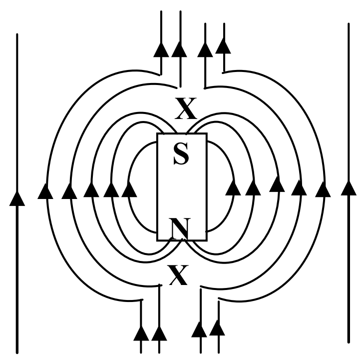
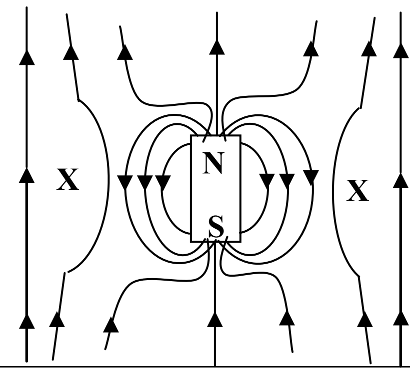
The earth behaves as though it contains a bar magnet inclined at an angle to its axis of rotation and its field lines are parallel lines pointing towards the north.



The earth contains the south pole with in the Northern hemisphere (Geographic North) and the North Pole in the southern hemisphere (Geographic south).

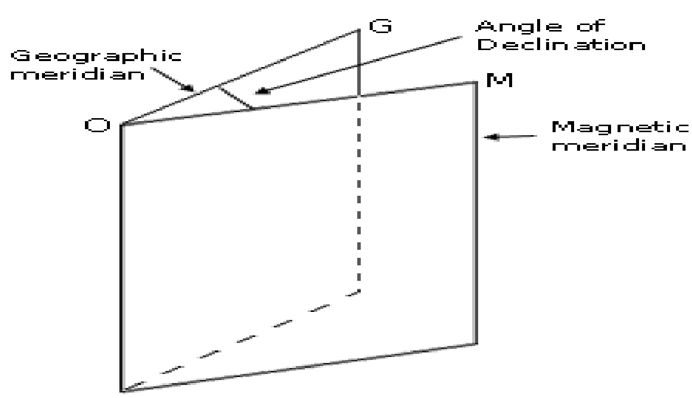
Effect of magnetic field of a bar magnet on the earth's magnetic field:

When a bar magnet is placed horizontally on the earth's surface, the field around the magnet will be a combination of the two field and the resulting pattern depends on the direction of the bar magnet

North pole pointing south of the earth's field	**North pole pointing north of the earth's field**
	

Note: X is a neutral point where the earth's magnetic field and magnet's field are exactly equal

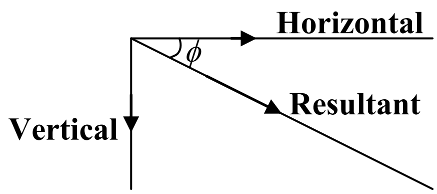
Terms used in the earth's magnetic field:



- **Geographic meridian:**
  This is the vertical plane which passes through the earth's geographic poles
- **Magnetic meridian**:
  This is the vertical plane in which a freely suspended magnetic needle sets itself.

- **Angle of declination, GOM:**
  This is the angle between the geographic meridian and the magnetic meridian.
- **Angle of dip[inclination]:**
  This is the angle between horizontal and the magnetic axis of a magnet free to swing in the magnetic meridian about the horizontal axis.

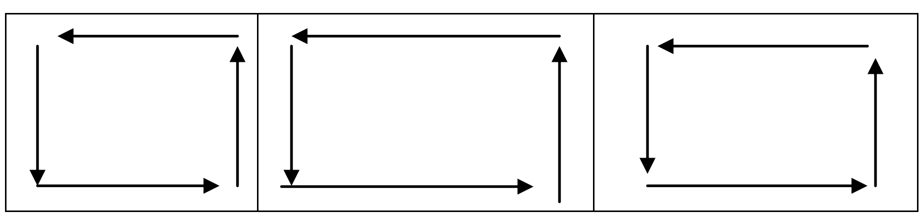
  NOTE:
  - The angle of dip increases from 0^o at the equator to 90^o at the poles.
  - The earth's magnetic field has two components that is the horizontal component and the vertical component



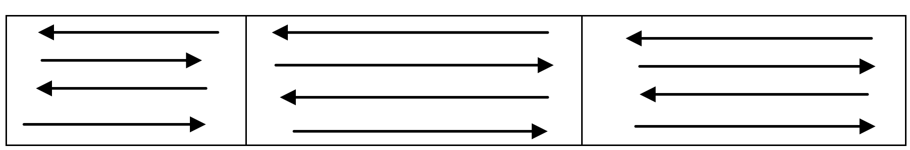
$\phi =$ **Angle of dip**

Domain theory of magnetism:

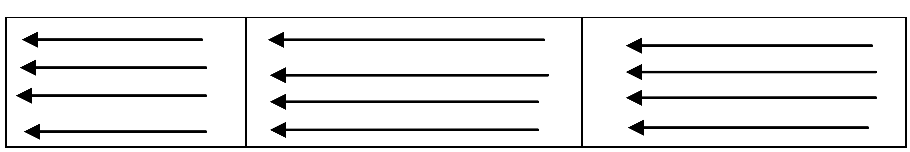
The theory of magnetism states that all magnetic substances are composed of tinny magnets which are divided into regions called domains. Each domain has millions of tinny magnets called Dipoles lined up with their north poles in one direction. The tinny magnets do not act individually but act in a group to form a domain. The tinny magnets point in different directions in an un-magnetized magnetic material where the north pole of one is neutralized by the south pole of the other. In an un-magnetized substance the domains are so arranged that the dipoles tend to link up in closed loops.



When an un-magnetized steel bar is placed in weak magnetic field, the dipoles in some of the domains turn to point in the direction of the field. The closed loop is then broken forming a weak magnet.



When the magnetic field is strong enough all the dipoles in all the domains turn to point in the direction of the field and in this case the substance can't be magnetized further, the material is then said to be magnetically saturated and no further magnetization can take place.



Note:

The point where a magnetic substance cannot be magnetized any more is called **magnetic saturation**

Soft and hard magnetic materials:

- **Soft magnetic materials** are magnetic materials which are magnetized easily but do not retain their magnetism. E.g. iron, nickel.
- **Hard magnetic materials** are magnetic materials which are difficult to magnetize but retain their magnetism for a long time. E.g. steel

Properties of iron:

- Iron is easily magnetized.
- Iron is easily demagnetized.
- Iron keeps its magnetism for a short time.
- Iron is used for making electromagnets.

Properties of steel:

- Steel is not easily magnetized.
- Steel is not easily demagnetized.
- Steel keeps its magnetism for a long time.
- Steel is used for making permanent magnets.

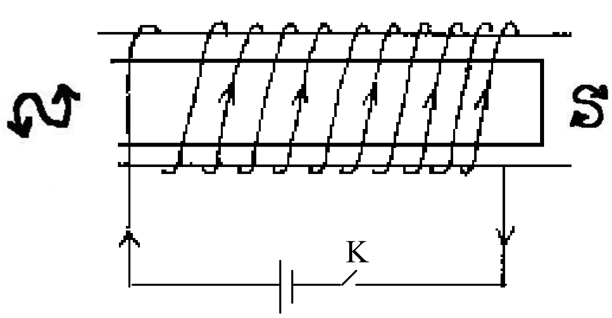
MAGNETIZATION:

This is a process by which randomly arranged molecular magnets of a ferromagnetic substance are arranged to point in one direction. Magnetization is a process of making a magnet from a ferromagnetic substance. The following are methods used in magnetization;

i) Stroking method.
ii) Electrical method.
iii) Hammering in the earth's field.

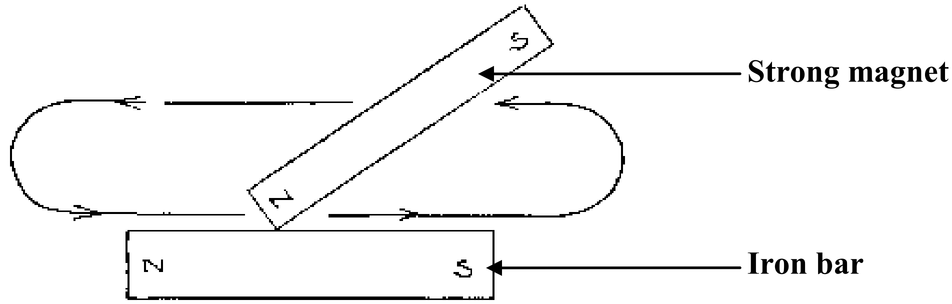
Electrical method:

- A coil of insulated copper wire of many turns called solenoid is used.
- Place a steel bar inside the solenoid connected to direct current.
- Switch on the current and then switch it off.
- The steel bar will be magnetized and the polarity of the magnet depends on the direction of current. That is if on viewing the bar the current flows in clockwise direction then that end will be south pole and if the current flows in anticlockwise direction it will be the north pole



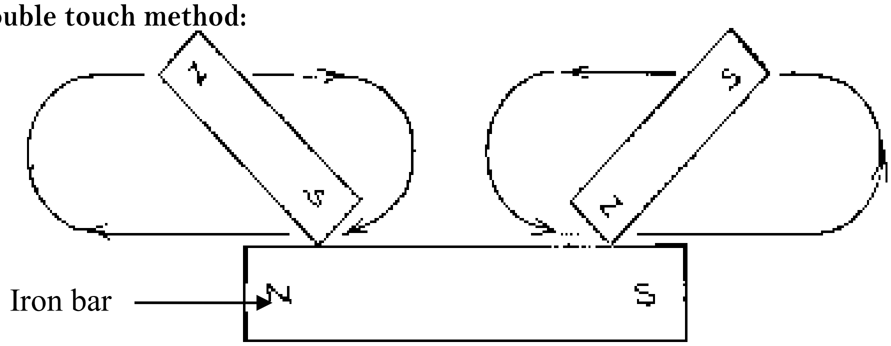
Stroking method:

a) Single touch method:



- Get an iron bar and a strong magnet.
- Place the iron bar on the table and drag a pole of the magnet along the bar from one end to another and lift away.
- Repeat the procedure several times keeping the inclination of the magnet the same.
- The end of the bar where the magnet finishes stroking acquires an opposite pole to that of the stroking magnet.
- This method produces a magnet with one pole nearer to the end compared to the other pole.

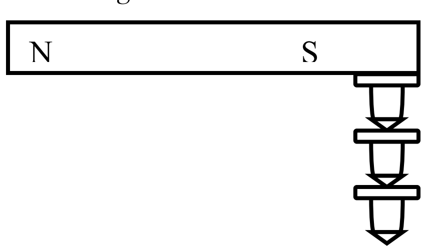
b) **Double touch method:**



- Stroke the iron bar from the centre repeatedly in opposite directions using opposite poles of two bar magnets and lift away**.**
- The end of the bar where the magnet finishes stroking acquires an opposite pole to that of the stroking magnet.
- This method produces a magnet with both poles at the ends of bar.

Induced magnetism:

A piece of un-magnetized magnetic material in contact or near the pole of a permanent magnet will attract pieces of iron. The material has been magnetized by induction. This is referred to as induced magnetism. Induced magnetism can be used to form a magnetic chain as shown bellow



The iron nail attached to the magnet becomes magnetised. Each nail added to the chain magnetises the next one by induction. In each case, the induction of magnetism in the nails takes place first and then the attraction occurs between their adjacent unlike poles.

DE-MAGNETIZATION:

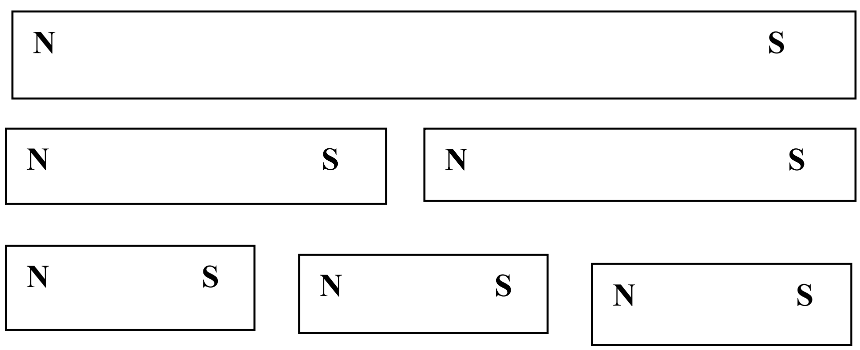
This is a process by which a magnet losses its magnetism. The order of tinny magnets called dipoles is destroyed during demagnetization.

The following are methods of demagnetization;

- **Heating:**
  A magnet is heated until it becomes hot. On cooling it has lost its magnetism.
- **Hammering/Dropping/Throwing:**
  When a magnet is hammered/dropped/thrown several times, upon testing it has lost its magnetism.
- **Using alternating current:**
  A magnet is placed in a solenoid connected to an a.c supply. Switch on and off and upon removing the magnet it has lost its magnetism

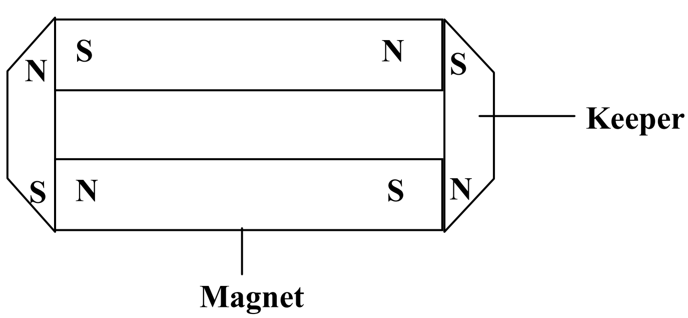
Breaking a magnet:

Every molecule in a magnet is its self a permanent magnet and when a magnet is broken into two portions both will have two unlike poles which appear at opposite ends of each piece. The cutting of a magnet does not separate the two poles of a magnet no matter how many times the magnet is broken



Storing magnets:

Magnets tend to become weaker with time due to self demagnetization. This is caused by the poles at the end repelling each other and disorganizing the alignment of the domains inside the magnet. To prevent this, magnets are stored in pairs with unlike poles adjacent to one another and with small pieces of soft iron bars called keepers placed across their ends. The keepers are magnetized by induction so that the atomic dipoles in both magnets and keepers form closed loop with no free poles.



Trial exercise 1:

1. Describe two methods of magnetizing a steel rod
2. Compare magnetic properties of steel and iron
3. Explain why a magnetic material is attracted by a magnet
4. Explain why iron filings are not suitable for plotting lines of force of a weak magnet field
5. Explain why soft iron can not be used to make permanent magnet
6. Describe how you would verify the basic law of magnetism
7. Explain the meaning of the following magnetic field and magnetic lines of force
8. Describe how you would shield a magnetic material from a magnetic field and state one application of magnetic shielding
9. Describe the methods of demagnetizing a permanent magnet
10. Use domain theory to explain the difference between magnetic and non-magnetic materials

Multiple-choice Exercise:

1. Magnetism at the Centre of a bar magnet is

   A. minimum B. maximum C. zero D. minimum or maximum
2. The shape of a magnetic field around a long straight current carrying wire is:

   A. curve B. square

   C. circular D. varies depending on the magnitude of the current
3. Which of the following statements is not true about magnets?

   A. magnetic poles can be separated

   B. a paramagnetic material is a material from which strong magnet can be made

   C. the neutral point in a magnetic field is a point where there is no force experienced

   D. heating a magnet can reduce its magnetism
4. Permanent magnets are made from

   A. diamagnetic materials B. ferromagnetic materials

   C. paramagnetic materials D. dielectric materials
5. Which of the following can be deflected by magnetic fields?

   (i) Gamma rays (ii) Cathode rays (iii) X-rays (iv) beta particles

   A: (i) and (ii) only B: (i) and (iii) only C: (ii) and (iii) only D: (ii) and (iv) only
6. Which of the following statements is/are correct?

   (i) An electromagnet is a temporary magnet because it can be activated and deactivated

   (ii) The strength of the magnetic field increases as the current through a wire decreases

   (iii) The strength of an electromagnet decreases with decrease of the number of turns around the core.

   (iv) The magnetic field lines form concentric circles about the conductor

   A. (i), (ii) and (iii) only correct B. (i) and (iii) only correct

   C. (ii) (iii) and (iv) only correct D. (iv) only correct
7. A beam of electrons directed to pass between two poles of a magnet would be

   A. deflected according to Fleming's left hand rule

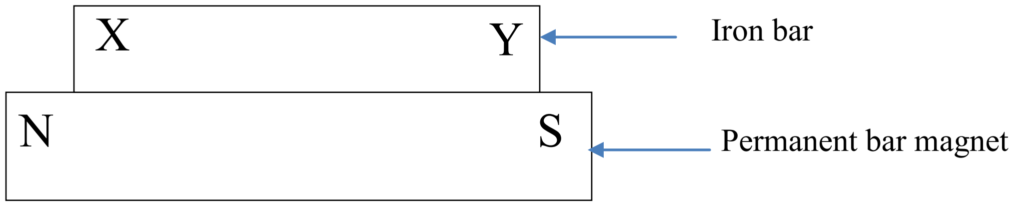
   B. slowed down

   C. deflected according to Fleming's right hand rule

   D. directed towards the North Pole

8. Which of the following statements are true about magnets?
(i) Magnets always have opposite polarities
(ii) A magnet can be used as a compass
(iii) Repulsion is the only sure test for a magnet
(iv) Magnets attract all metals
A. (i), (ii) and (iii) only correct B. (i) and (iii) only correct
C. (ii) and (iv) only correct D. (iv) only correct

9. An iron bar XY was placed on the middle part of a permanent bar magnet as shown in the diagram below;



The iron bar was later found to have acquired magnetism temporarily, which of the following would be the possible induced polarities

	INDUCED POLARITIES	
	X	Y
A	NORTH	NORTH
B	NORTH	SOUTH
C	SOUTH	NORTH
D	SOUTH	SOUTH

10. The magnitude of the force on a conductor carrying electric current in a magnetic field does not depend on the
A. length of the conductor B. magnitude of the current
C. magnetic field D. direction of the current

11. When the north poles of two bar magnets are brought close together, there will be
A. a downward force B. a force of attraction
C. no force D a force of repulsion

12. When the speed at which a conductor is moved through a magnetic field is increased, the induced voltage
A. increases B. decreases C. remains constant D. reduces to zero

13. When the current through the coil of an electromagnet reverses, the
A. magnetic field collapses
B. direction of the magnetic field remains unchanged
C. direction of the magnetic field reverses
D. magnetic field expands

14. A material which is slightly repelled by a magnetic field is known as
A. ferromagnetic material B. diamagnetic material
C. paramagnetic material D. conducting material

15. In the left hand rule, forefinger always represents
A. current B. voltage C. magnetic field D. force
16. Indicate which of the following material does not retain magnetism permanently
A. Soft iron B. Stainless steel C. Hardened steel D. None of the above
17. The direction of magnetic lines of force is
A. from South Pole to north pole B. from North Pole to South Pole
C. from one end to another end D. none of the above.
18. Which electromagnetic device uses brushes and a commutator?
A. speaker B. DC generator C. Relay D. solenoid
19. What are the effects of moving a closed wire loop through a magnetic field?
A. A voltage is induced in the wire
B. A current is induced in the wire.
C. The polarity across the wire depends on the direction of motion.
D. All of the above
20. What do you call the characteristic of a magnetic material whereby a change in magnetization lags the application of a magnetizing force?
A. Hysteresis B. Induction C. leakage D. Reluctance

Answers

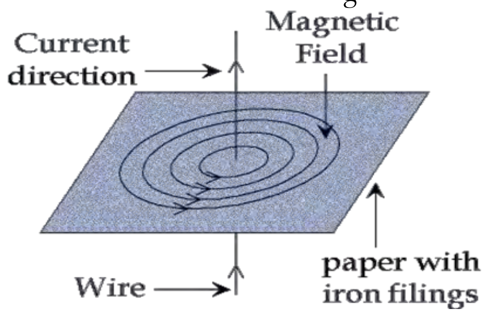
1	A	5	D	9	C	13	C	17	B
2	C	6	C	10	D	14	B	18	B
3	A	7	C	11	D	15	C	19	D
4	B	8	A	12	A	16	A	20	A

MAGNETIC EFFECT OF AN ELECTRIC CURRENT:

When current flows in a conductor it generates a magnetic field around the conductor. This was discovered when a current carrying conductor was able to deflect a pivoted magnetic needle.

Experiment to show the magnetic effect of an electric current using a compass needle:

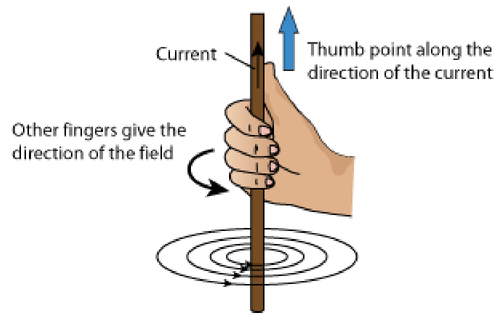
- Support a stiff card board horizontally with a coil of several turns of insulated copper wire with both sides of the wire passing through the centre of the card board.
- Sprinkle iron fillings thinly and evenly over the card board and switch on the current and tap the card gently.
- Draw the pattern assumed by iron fillings and place a plotting compass at various positions around the wire on the card board and note the direction of the magnetic field.
- The card is again gently tapped and the iron fillings settle in series of concentric circles and therefore a conductor carrying current has an associated magnetic field which is concentric.



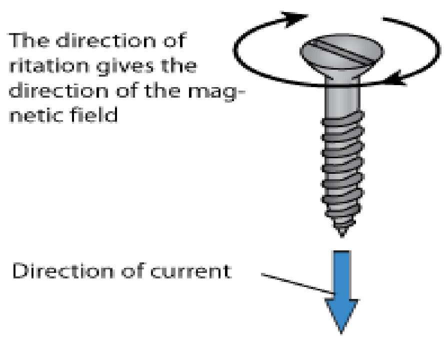
Direction of the magnetic field:
The direction of the field around a straight conductor and the direction of current is usually determined by the following rules;

- Maxwell's cork screw rule.
- Right hand grip rule.

Right hand grip rule:
It states that if the wire is grasped in the right hand with the thumb pointing in the direction of current then the other fingers point in the direction of the field.



Maxwell's corkscrew rule:
It states that if the right hand is used to screw a cork screw along the wire in the direction of the current, the direction of rotation of the screw gives the direction of the field



Magnetic field patterns:
Magnetic fields associated with conductors carrying current have different shapes for different conductors and different fields are as shown in the diagram below

i) Straight conductor carrying current:
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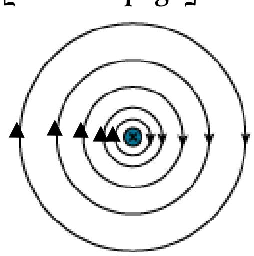
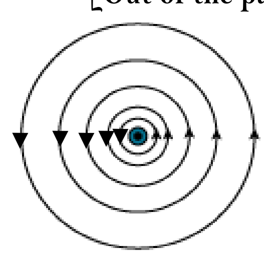
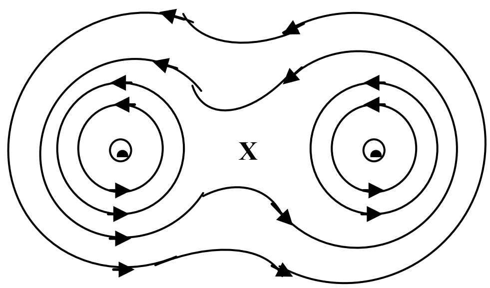


ii) Straight conductor carrying current:
[Out of the page]

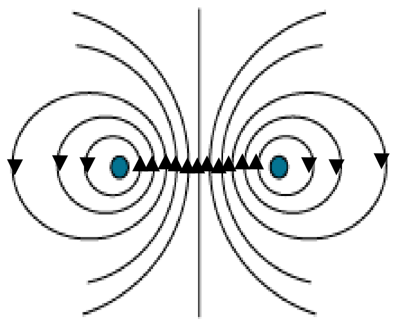


iii) Two straight conductors with currents in the same direction:



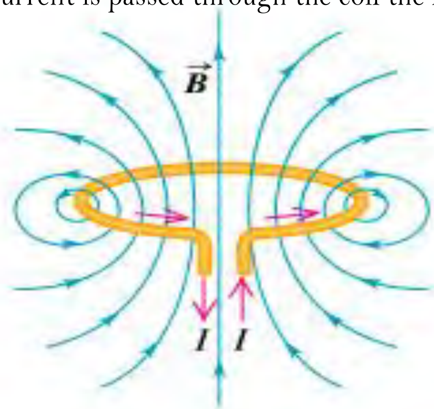
X is a neutral point

iv) Two straight conductors with currents in opposite directions:



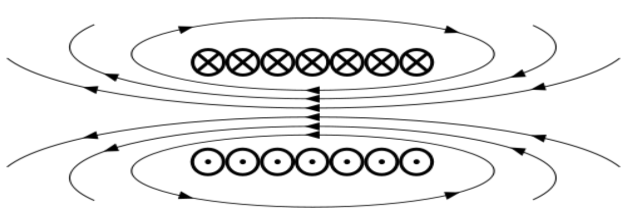
v) Current in a circular coil:

A circular coil can be made by winding an insulated copper wire around a cylindrical pipe and then removing the coil obtained. When a direct current is passed through the coil the field pattern is as shown below



vi) Current in the solenoid:

A solenoid is made by winding an insulated copper wire around a cylindrical pipe and then mounted on a stiff card board. When a direct current is passed through the solenoid the field pattern is like that of a bar magnet.



NOTE:

- The polarity of the ends of the solenoid can be determined by the clock rule which states that if by looking at the side of the solenoid the current flows in clockwise direction then that side is the south pole and if the current flows in an anticlockwise direction that side is the north pole.

Force on a conductor carrying current:

A current carrying conductor in a magnetic field experiences a force. This force is a result of interaction between the magnetic field around a conductor and magnetic field in which it is situated.

Factors that affect the force on a current carrying conductor placed in a magnetic field:

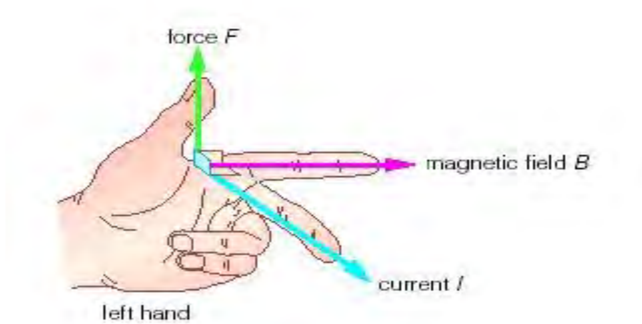
- **Current.**
  The force on current carrying conductor increases with increase in current and decreases with decrease in current, therefore force is directly proportional to the current flowing.
- **Strength of the magnetic field.**
  The force increases with increase in the strength of the magnetic field.
- **Length of the conductor.**
  The force increases with increase in length of the conductor.
- **Angle of incline with the field.**
  When the angle is decreased from 90^o, the force decreases and becomes zero [minimum] when the conductor is parallel to the field but maximum when the conductor is perpendicular to the field.
- **Area of conductor in the field.**
  The larger the area in the field the larger the force on the conductor

DIRECTION OF THE FORCE:

Experiments show that the force is always perpendicular to the plane which contains both current and external magnetic field. The direction of the force can be determined by Fleming's left hand rule.

Fleming's left hand rule:

It states that if the left hand is held with the thumb and the first two fingers mutually at right angles with the first finger in the direction of the field, the second finger in the direction of current then the thumb will point in the direction of motion [force]. Fleming's left-hand rule is for motors, when current flows in a wire, and an external magnetic field is applied across the wire, the wire experiences a force perpendicular to both the field and the direction of the current flow. A left hand can be held, as shown in the in the diagram below

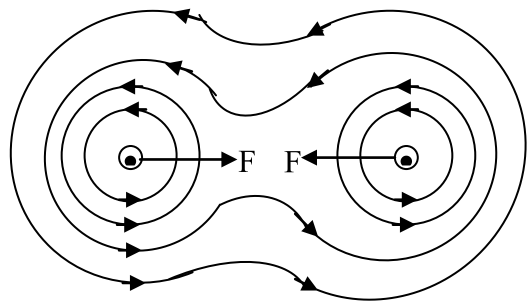


The Thu**m**b represents the direction of force. The **F**irst finger represents the direction of the field (North to South) and the Se**c**ond finger represents the direction of current flowing.

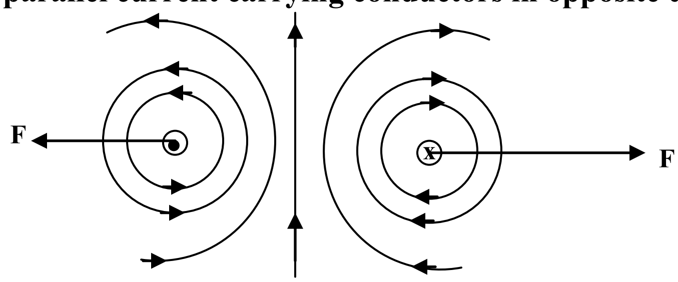
Force due to magnetic field produced by current carrying conductor

When the magnetic field of a bar magnet interacts with magnetic field due to a current carrying conductor, the magnetic field lines repel one another sideways and tend to shorten. They exert a force on a conductor which moves towards the region with fewer field lines.

Force between two parallel current carrying conductors in opposite direction



Force between two parallel current carrying conductors in opposite direction



It is noted that for parallel two current carrying conductors

- They attract each other when currents in them flow in the same direction.
- They repel each other when currents flow in opposite directions.

ELECTRO-MAGNETS:

This is the magnet produced by an electric current flowing in a solenoid with soft iron core. The core is placed inside the solenoid where the magnetic field is strongest. The magnetism in an electromagnet is temporary since it is lost when an electric current is switched off. Due to the magnetism induced, electromagnets have the ability to attract magnetic materials.

Factors that affect the strength of electromagnet:

- **Number of turns:**

Increasing the number of turns on the core increases the strength of the electromagnet

- **Current through the coil:**

Increasing the current increases the strength of electro-magnet

- **Nature of the core:**

Soft iron core increases the strength of electromagnet because iron can easily be magnetized and easily demagnetized.

- **Shape of the core:**

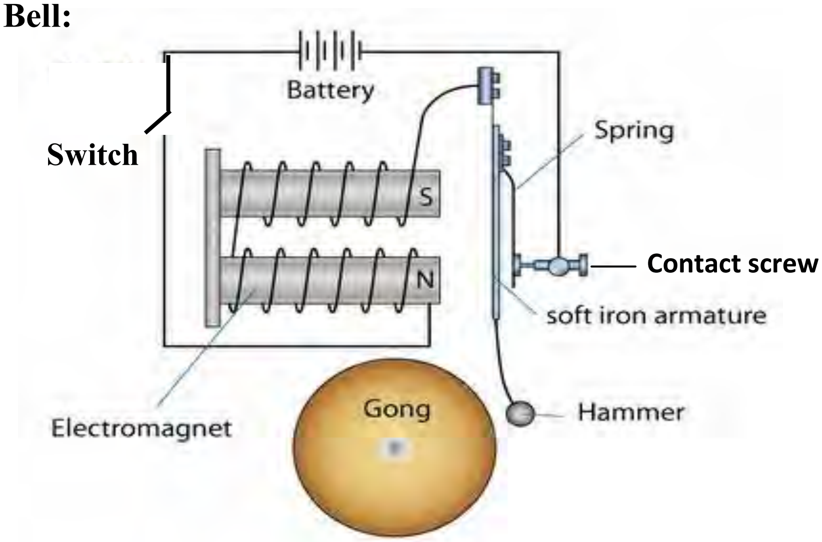
Core shape which brings both magnetic poles close together increases the strength of electromagnet.

Applications of electromagnets:

Electromagnets are commonly used in various industrial and domestic instruments or devices and these are;

Electric bell	Telephone receiver
Lifting magnets (Cranes)	Loudspeakers
Ammeters and voltmeters	Magnetic relays

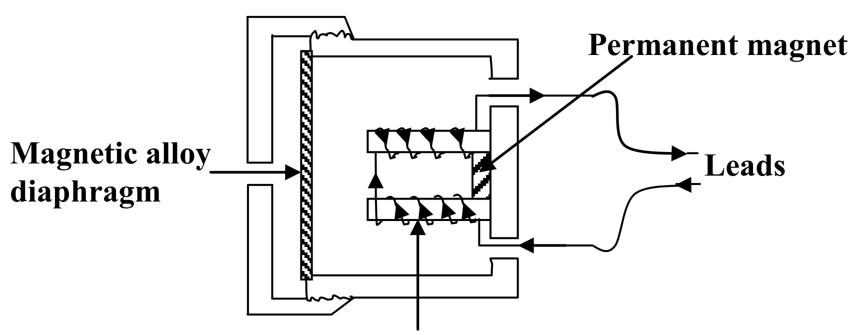
Electric Bell:



Mode of operation:

- When the switch is closed current flows in the circuit and magnetizes the soft iron core which becomes an electromagnet.
- The electromagnet attracts the soft iron armature and then the hammer hits the gong and a loud sound is heard.
- When the armature is attracted the contact between the spring and the contact screw is broken and current is cut off, then electromagnet loses its magnetism and returns to its original position which makes the contact again.
- As long as the switch is closed the process is repeated and the hammer hits the gong repeatedly making continuous ringing sound

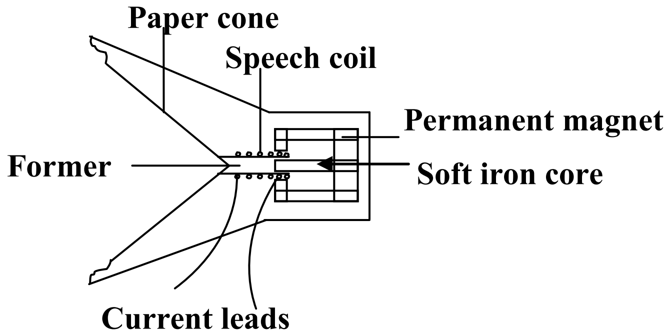
The telephone receiver:



Mode of operation:

- When a person speaks into a microphone at the end of the line, a varying electric current is set up having the same frequency as the sound produced by the person that is sound energy changes to electrical energy.
- The electric current then passes through the solenoid in the earpiece which magnetizes the electromagnet and produces a corresponding variation in the pull of the diaphragm.
- The diaphragm then vibrates and reproduces the sound produced by the person through the microphone.

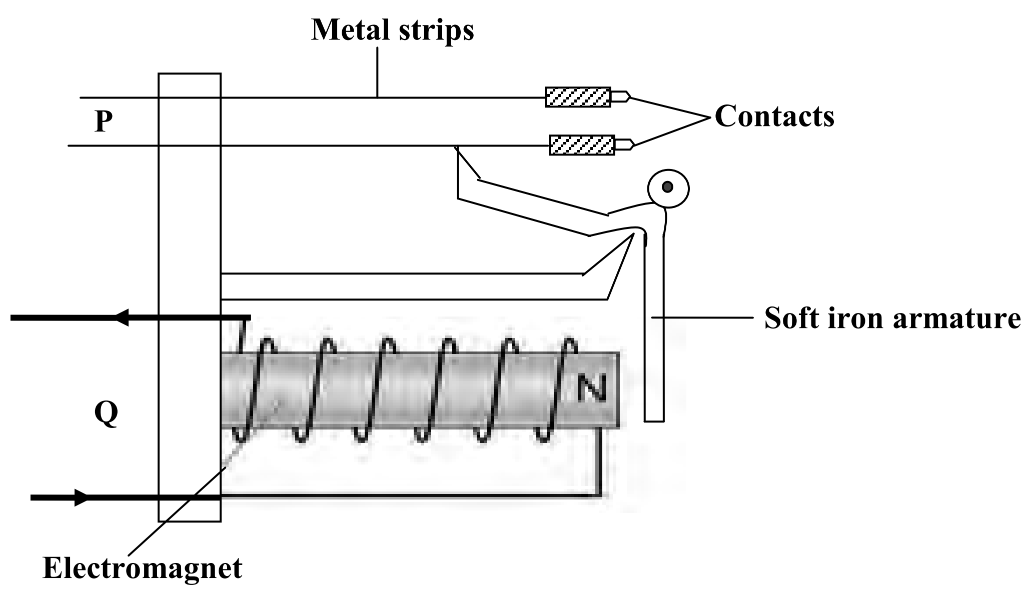
Moving coil loud speaker



Mode of operation

- When an alternating current flows into the coil which is at right angle to the radial magnetic field, the coil experiences a force and moves in and out.
- This sets the cone paper and the coil to vibrate with the same frequency as the current in the speech coil.
- The motion of the cone paper sets the air in contact with the cone into vibration and a loud sound is heard from the speaker.

Magnetic relays:

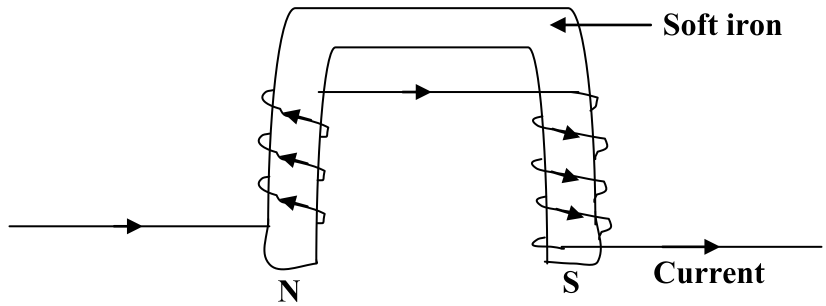


Mod of operation:

- When circuit Q supplies very small current, the electromagnet attracts the soft iron armature and this closes the contact in circuit P by pushing the spring metal strip.
- When current in Q is switched off the electromagnet loses its magnetism and armature goes to its original position thus switching off the current in circuit P.
- Several sets of contacts can be operated by the same armature lever which are widely used in telephone circuits, in traffic light circuit and car ignition circuit

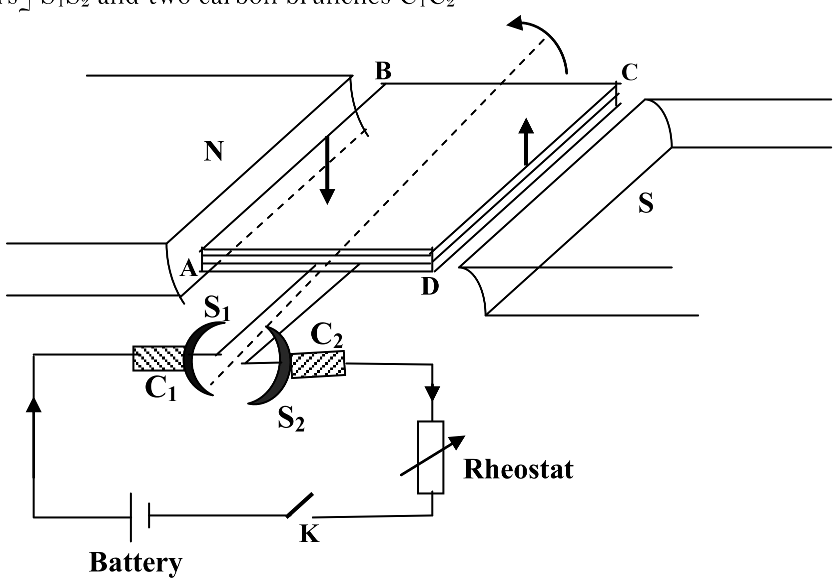
Lifting magnets (Cranes):

They are mainly used for lifting and transporting heavy steel from one point to another in a factory. The coils are made of insulated copper wire wound on a u-shaped soft iron so that opposite polarity is produced. The opposite adjacent poles increase the lifting power of the electromagnet. The coil is wound in opposite directions on each side of the soft iron.



Electric motor [D.C motor]:

This is a device that converts electrical energy into mechanical energy. It consists of the coil ABCD, two halves split rings [commutators] S_1S_2 and two carbon brunches C_1C_2



Mode of operation:

- When switch K is closed current flows into the coil ABCD and the side near the South Pole CD experiences an upward force and the side near the North Pole AB experiences a down ward force.
- The two forces are equal in magnitude and therefore constitute a couple which causes the rotation of the coil in anticlockwise direction.
- The coil rotates until it reaches its vertical position where the carbon brunches miss contact and current is cut off.
- However the momentum of the coil carries it past this position and two split rings exchange the carbon brunches which reverses the direction of current through thus reversing the direction of the force on each side of the coil.
- Therefore as long as the current is flowing, the coil continues rotating in the same direction

Back e.m.f in an electric motor:

When a conductor is moved in a magnetic field an e.m.f is induced. Since the armature rotates in a magnetic field an e.m.f called back e.m.f, E_b is induced in the coil which opposes the e.m.f, E applied to the motor to drive it.

$$I_a = \frac{E - E_b}{R_a}$$

$$E = E_b + I_aR_a$$

I_a is the current flowing through the armature of resistance, R_a

The efficiency of the electric motor

The efficiency of the motor depends on the design to reduce energy losses

$$\text{Effeciency} = \frac{\text{power output}}{\text{power input}} \text{ x } 100\%$$

$$\eta = \frac{IE_b}{IE} \text{ x } 100\%$$

$$\eta = \frac{E_b}{E} \text{ x } 100\%$$

Examples:

A motor whose armature resistance is 2Ω is operated on a 240V mains supply. Given that the back e.m.f in the motor is 220V. Calculate

i) The armature current

ii) The efficiency of the motor

i) Current I_a

$$I_a = \frac{E - E_b}{R_a}$$

$$= \frac{240 - 220}{2}$$

$$= \frac{20}{2}$$

$$= 10A$$

ii) Efficiency

$$\eta = \frac{E_b}{E} \text{ x } 100\%$$

$$= \frac{220}{240} \text{ x } 100\%$$

$$= 91.7\ \%$$

Energy losses in an electric motor:

i) Energy loss due to friction between carbon brunches and commutators which can be minimized by lubrication [oiling, greasing etc].

ii) Energy loss due to eddy currents which can be minimized by using laminated iron core.

iii) Energy loss due to the heating effect as a result of resistance of the coil which can be minimized by using thick copper wires of low resistance.

EDDY CURRENTS:

These are currents induced whenever the magnetic flux linking the coil changes. Eddy currents lead to loss of energy as thermal energy and can reverse the direction of motion of the coil. The change in magnetic flux linked with the coil may be brought about by the following

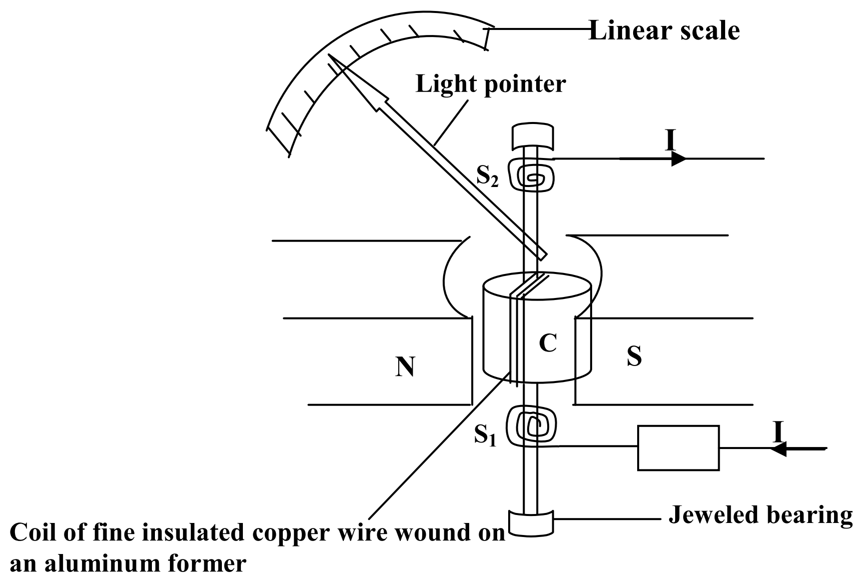
- Moving a coil in a constant magnetic field.
- Subjecting a coil to a varying magnetic field.

Uses of eddy currents:

- They are used to detect cracks in metals.
- They are used in damping in a moving coil galvanometer.
- They are used in electromagnetic brakes.
- They are used in sorting metallic objects out of solid waste.
- They are used in induction furnaces.

Moving coil galvanometer:

This is used to detect small currents and potential differences. It consists of a rectangular coil which rotates in a radial magnetic field provided by pole pieces of permanent magnet. Radial magnetic field ensures that the coil is always at a right angle and experiences a constant torque.



Mode of operation:

- A moving coil galvanometer works on the principle that when current carrying conductor is placed in a magnetic field a force acts on it.
- When the current flows through the coil each vertical side of coil experiences a force.
- The two forces constitute a couple which causes the rotation of the coil until it is stopped by hair springs S_1S_2.
- This causes in turn the pointer to move along the scale and the coil finally comes to rest when the couple due to current balances with the couple due to the spring.
- The deflection by the pointer is directly proportional to the current flowing hence a linear scale.

Sensitivity of a galvanometer:

There are two types of sensitivity;

- Current sensitivity: This is the deflection per unit current.
- Voltage sensitivity: This is the deflection per unit voltage.

Factors that affect sensitivity of a galvanometer:

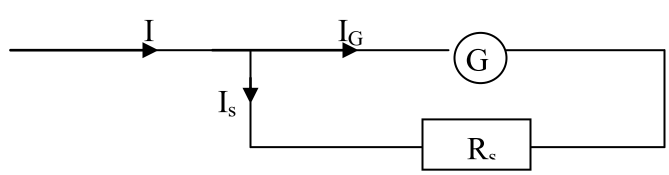
- **Strength of a magnet:**
  Strong magnet increases the sensitivity of the galvanometer and weak magnets reduces the sensitivity of the galvanometer.
- **Number of turns:**
  Increasing the number of turns on the coil increases the sensitivity of the galvanometer and decreasing the number of turns reduces the sensitivity of the galvanometer.
- **Cross sectional area of the coil:**
  Large cross sectional area of the coil increases the sensitivity of the galvanometer and small cross section reduces the sensitivity of the galvanometer.
- **Hair springs:**
  Weak hair springs increases the sensitivity of the galvanometer and strong hair spring reduces the sensitivity of the galvanometer.

Advantages of a moving coil galvanometer:

- It can be used to measure both a.c and d.c.
- It has linear scale.
- It is portable.
- It is simple and cheap.
- It is not affected by external magnetic field.

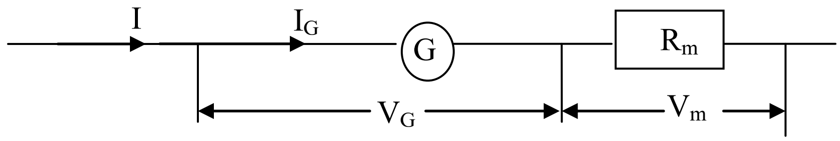
Converting a galvanometer into an ammeter:

A galvanometer is designed to read very small currents in mili-amperes but can be made to read large currents in amperes by connecting a resistor of low resistance in parallel with the galvanometer. The resistor with low resistance is known as a shunt resistor



$$\mathbf{I = I_G + I_s}$$
$$\mathbf{I_s = I - I_G}$$
but p.d across galvanometer = p.d across the shunt
$$\mathbf{V_G = V_S}$$
$$\mathbf{I_sR_s = I_GR_G}$$
$$\mathbf{R_s = \frac{I_GR_G}{I - I_G}}$$

Converting a galvanometer into a voltmeter:
A galvanometer is designed to read very small voltages in mili-volts but can be made to read large voltages in volts by connecting a resistor of high resistance in series with the galvanometer. The resistor with high resistance is known as a multiplier.



$\mathbf{V = V_G + V_m}$

$\mathbf{V_m = V - V_G}$

$\mathbf{but\ current\ through\ galvanometer = current\ through\ the\ multiplier}$

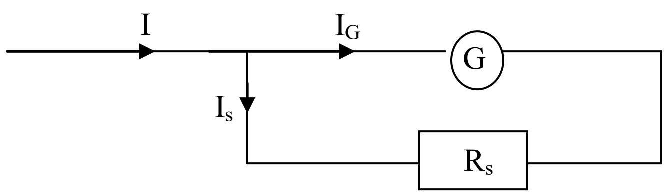
$\mathbf{I_G = I_m}$

$\mathbf{I_G R_m = V - I_G R_G}$

$$\mathbf{R_m = \frac{V - I_G R_G}{I_G}}$$

Examples:

1. A moving coil galvanometer of resistance 20Ω gives a full scale deflection of 5mA. How can it be converted to an ammeter which can measure a maximum current of 2A?



$\mathbf{I = I_G + I_s}$

$\mathbf{I_s = I - I_G}$

$\mathbf{but\ p.d\ across\ galvanometer = p.d\ across\ the\ shunt}$

$\mathbf{V_G = V_S}$

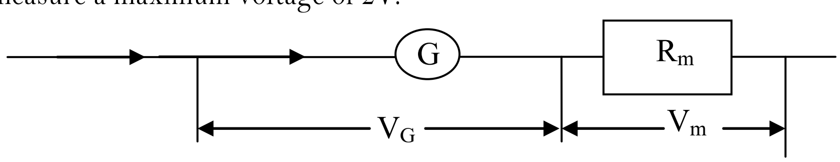
$\mathbf{I_s R_s = I_G R_G}$

$$\mathbf{R_s = \frac{0.005 \times 20}{2 - 0.005}}$$

$\mathbf{= 0.05\Omega}$

Connect a shunt resistor of resistance 0.05Ω in parallel with the galvanometer

2. A moving coil galvanometer of resistance 6Ω gives a full scale deflection of 15mA. How can it be converted to voltmeter which can measure a maximum voltage of 2V?



$\mathbf{V = V_G + V_m}$

$\mathbf{V_m = V - V_G}$

$\mathbf{but\ current\ through\ galvanometer = current\ through\ the\ multiplier}$

$\mathbf{I_G = I_m}$

$\mathbf{I_G R_m = V - I_G R_G}$

$$\mathbf{R_m = \frac{2 - 0.015 \times 6}{0.015}}$$

$\mathbf{= 127.33\Omega}$

Connect a multiplier of resistance 127.33Ω in series with the galvanometer

Trial exercise 2:

1. A moving coil galvanometer of resistance 4Ω gives a full scale deflection of 1.5mV. How can it be converted to voltmeter which can measure a maximum voltage of 2V?

   Ans: By connecting a 5329.3Ω multiplier in series with a galvanometer.
2. A moving coil galvanometer of resistance 10Ω gives a full scale deflection of 25mA. How can it be converted to an ammeter which can measure a maximum current of 2.5A?

   Ans: By connecting a 0.101Ω shunt resistor in parallel with a galvanometer.
3. A moving coil galvanometer of resistance 50Ω gives a full scale deflection of 5mV. How can it be converted to an ammeter which can measure a maximum current of 2A?

   Ans: By connecting a 0.0025Ω shunt resistor in parallel with a galvanometer.
4. Draw the magnetic field patterns around the a circular coil and a solenoid carrying currents
5. Draw the magnetic field patterns around a straight current carrying conductor
6. State and explain the effect on an electromagnet of replacing the iron core with a steel core
7. i) Draw a labeled diagram of a simple d.c electric motor

   ii) State and explain three ways in which the forces on the coil and hence the speed of the motor can be increased

   iii) What factors make the efficiency of the motor less than100% and how is each factor minimized
8. i) Draw a labeled diagram of an electric bell and state the function of each part

   ii) State with a reason whether the electric bell works on d.c only or on a.c as well
9. Describe with the aid of a diagram the structure and mode of operation of a moving coil galvanometer
10. Differentiate between a shunt resistor and a multiplier

Multiple-choice Exercise:

1. A moving coil galvanometer has a resistance of 4Ω and gives a full scale deflection of 2.5mA. Find the value of the resistor required to convert it to a voltmeter measuring up to 20V.

   A. $5.0 \times 10^{-3}\Omega$ B. $5.0 \times 10^{-4}\Omega$ C. $7.966 \times 10^{3}\Omega$ D. $7.996 \times 10^{3}\Omega$
2. The direction of induced current in a conductor moving in a magnetic field can be predicted by applying

   A. faraday's law B. Maxwell's screw rule

   C. Fleming's left hand rule D. Fleming's right hand rule
3. A moving coil galvanometer can be used to

   A. detect the presence current and voltage

   B. convert alternating current into direct current

   C. convert direct current into alternating current

   D. measure the peak value of an alternating current
4. Which of the following factors affect the magnitude of force on a current – carrying conductor in a magnetic field?

   (i) The direction of current (ii) The amount of current

   (iii) The direction of the magnetic field (iv) The strength of the magnetic field

   A. (i) and (ii) only correct B. (ii) and (iii) only correct

   C. (i) and (iii) only correct D. (ii) and (iv) only correct

5. The strength of the magnetic field between the poles of an electromagnet remains the same if the

(i) Current in the electromagnet windings is doubled

(ii) Direction of the current in the electromagnet windings are reversed

(iii) The number of turns are halved

A. (i) only correct B. (ii) only correct

C. (i) and (ii) only correct D. (ii) and (iii) only correct

6. The sensitivity of a moving coil galvanometer can be increased by using

A. smaller coil B. weaker magnet

C. weaker hairspring D. fewer turns of the wire on the coil

7. Which of the following factors affect the strength of an electromagnet?

(i) Changing the magnitude of the current

(ii) Changing direction of the current

(iii) Doubling the number of turns

A. (ii) only correct B. (i) and (ii) only correct

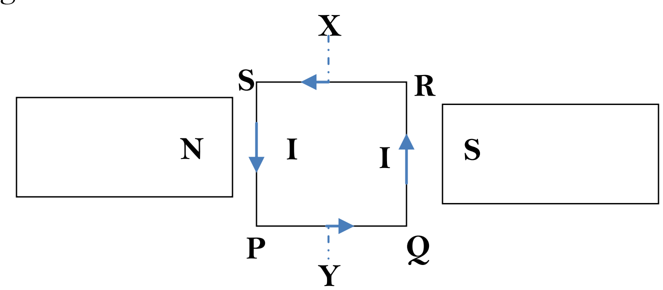
C. (i) and (iii) only correct D. (ii) and (iii) only correct

8. Which of the following statements are true about an electric motor? It changes

A. kinetic energy to electrical energy B. electrical energy to light energy

C. electrical energy to kinetic energy D. chemical energy to electrical energy

9. The figure below shows a current carrying coil PQRS pivoted about XY between two magnets.



Which of the statements are true about the coil?

(i) The sides PS and QR shall experience force

(ii) As seen from X the coil will rotate anticlockwise

(iii) The force on the coil can be increased by increasing the number of turns

(iv) The coil will come to rest with PQ at right angles to magnetic field

A. (i), (ii) and (iii) correct B. (i) and (iii) correct

C. (ii) and (iv) correct D. (iv) only correct

10. A moving iron meter

A. measures only direct current C. measures only alternating current

B. has a permanent magnet D. has the pointer attached to the soft iron

11. A galvanometer reads 0.05A at full scale deflection and has resistance of 2.0Ω. Calculate the resistance that should be connected in series with it to convert it to a voltmeter which reads 15V at full scale deflection

A. 10Ω B. 280Ω C. 298Ω D. 980Ω

12. Electromagnets are used in the following **except** the
A. Telephone receiver B. Moving coil loud speaker
C. Moving coil galvanometer D. Electric bell.

13. Which of the following statements are correct?
(i) The particles of magnetic materials are tiny magnets
(ii) The particles in un-magnetized iron arrange themselves in closed chains
(iii) The particles in a magnet are arranged in open chains with N-pole of one particle against the S-pole of its neighboring particle
(iv) Groups of atoms form a magnetic domain
A. (i), (ii) and (iii) correct B. (i), (iii) and (iv) correct
C. (ii) and (iv) correct D. (iv) only correct

14. The magnitude of the force on the coil of a d.c motor depends on
(i) the strength of the magnetic field (ii) the number of turns on the coil
(iii) the current through the coil (iv) the mass of the coil support
A. (i), (ii) and (iii) only correct B. (i) and (iii) only correct
C. (ii) and (iv) only correct D. (iv) only correct

15. An electric motor is connected by cable to a 240V supply. The p.d across the motor is 239V when the current flowing is 5A. The resistance of the cable is
A. 0.2Ω B. 5.0Ω C. 47.8Ω D. 48.0Ω

16. The current sensitivity of a moving coil galvanometer can be increased by
A. Increasing the magnetic field of the permanent magnet
B. Increasing the number of turns in the coil
C. Increasing the area of the deflecting coil
D. All of the above

17. A small cylindrical soft iron piece is kept in a galvanometer so that
A. a radial uniform magnetic field is produced
B. There is a steady deflection of the coil
C. A uniform magnetic field is produced
D. All of the above

18. The polarity of induced voltage while a field is collapsing is
A. independent of the force creating the field
B. opposite to the force creating the field
C. identical to the force creating the field
D. present only if the force is stationary

19. Which electromagnetic device has a flexible cone?
A. speaker B. DC generator C. Relay D. solenoid

20. The induced voltage across a stationary conductor in a stationary magnetic field is
A. increased B. decreased C. reversed in polarity D. zero

Answers

1	D	5	B	9	B	13	A	17	A
2	D	6	C	10	C	14	A	18	B
3	A	7	C	11	C	15	A	19	A
4	D	8	C	12	C	16	D	20	D

ELECTROMAGNETIC INDUCTION:

This is the process by which an electric current is induced in a coil due to change in magnetic flux linking the coil. Whenever the magnetic flux linking the coil changes an e.m.f is induced in the coil, the induced e.m.f causes current to flow in the coil.

Factors that determine the magnitude of induced e.m.f:

- The number of turns on the coil.
- The strength of the magnet.
- The speed of the relative motion between the magnet and the coil.
- Area of the coil in the magnetic field

Laws of electromagnetic induction:

A detailed investigation of electromagnetic induction leads to two laws of electromagnetic induction and these are;

i) Faraday's law.
ii) Lenz's law.

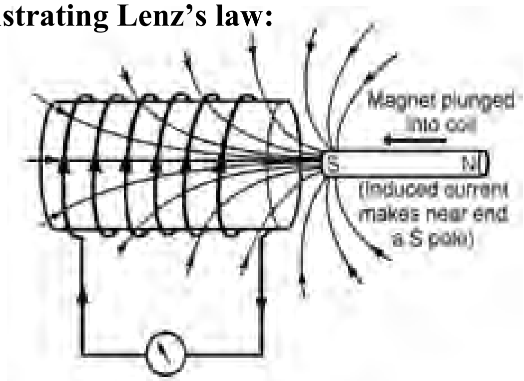
Faraday's law of electromagnetic induction:

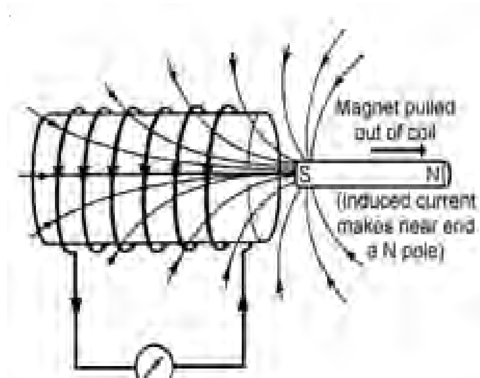
It states that the induced e.m.f in a coil is directly proportional to the rate of change of magnetic flux linked with the coil

Lenz's law of electromagnetic induction:

It states that the induced e.m.f flows in a direction so as to oppose the effect producing it

Illustrating Lenz's law:



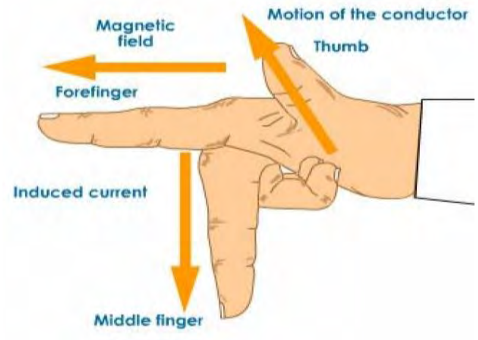


- When the magnet is plunged into the solenoid an e.m.f is induced in the solenoid. The induced current flows in such direction so as the side near the magnet is South Pole hence repulsion is experienced.
- When the magnet is pulled out of the solenoid an e.m.f is induced in the solenoid. The induced current flows in such direction so as the side near the magnet is North Pole hence attraction is experienced.

Fleming's right hand rule

It states that if the right hand is held with the thumb and the first two fingers mutually at right angles with the thumb pointing in the direction of motion, first finger in the direction of the field then the second finger will point in the direction of current. Fleming's right-hand rule is for generators shows the direction of induced current when a conductor moves in a magnetic field. The Thu**m**b represents the direction of **M**otion of the conductor. The **F**irst finger represents the direction of the **F**ield (North to South) and the Se**c**ond finger represents the direction of the induced or generated **C**urrent (the direction of the induced current will be the direction of conventional current from positive to negative).

The right hand is held with the thumb, the first finger and the second finger mutually perpendicular to each other (at right angles), as shown in the diagram.



Self induction and mutual induction:

Self induction:

This is a process by which an e.m.f is induced in the coil due to changing current in the coil itself. The induced e.m.f tends to oppose the flow of current in the coil and this is experienced in generators

GENERATORS:

A generator is a device that converts mechanical energy into electrical energy. There are two types of generators namely;

i) A.C generator.

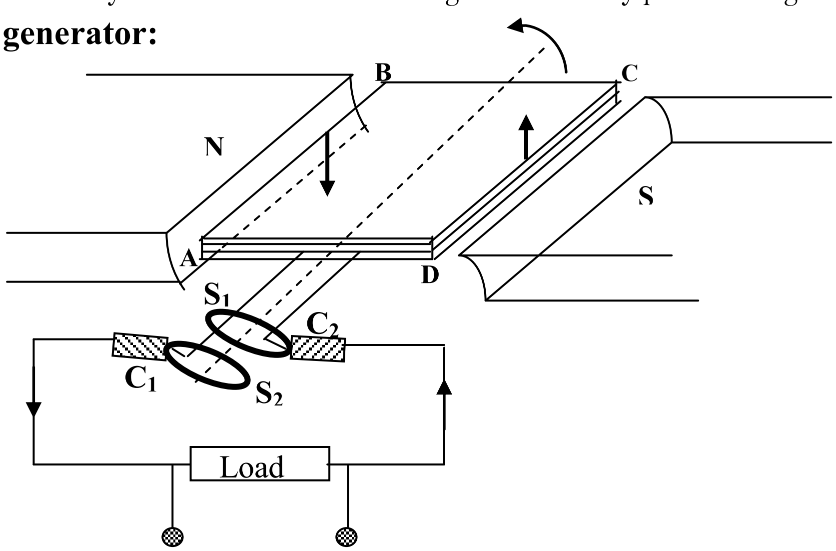
ii) D.C generator

The simple A.C Generator:

It consists of the following;

- A permanent magnet that provides a strong magnetic field.
- A rectangular coil that brings about electromagnetic induction in a generator.
- Slip rings where current is tapped by carbon brushes.
- Carbon brushes that convey current between the moving and stationary parts of the generator.

Structure of A.C generator:

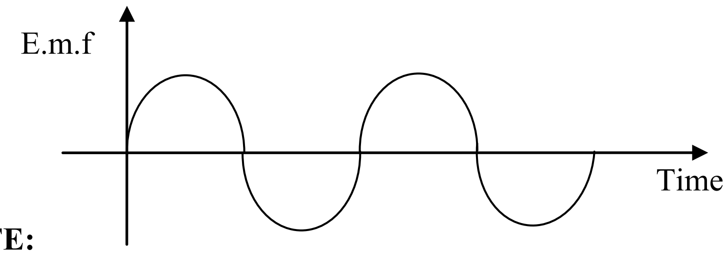


Mode of operation:

- When the rectangular coil ABCD rotates about its axis, the magnetic flux linked with it changes and an e.m.f is induced in the coil in the direction determined by Fleming's right hand rule.

- When the coil reaches the vertical position the slip rings S_1S_2 miss contacts with the carbon brushes C_1C_2 and the induced e.m.f is cut off.
- As the coil moves further past the vertical position the induced e.m.f reverses direction.
- This result into change in current in the load resistor hence an alternating current is obtained across the load resistor.

Variation of e.m.f generated with time:



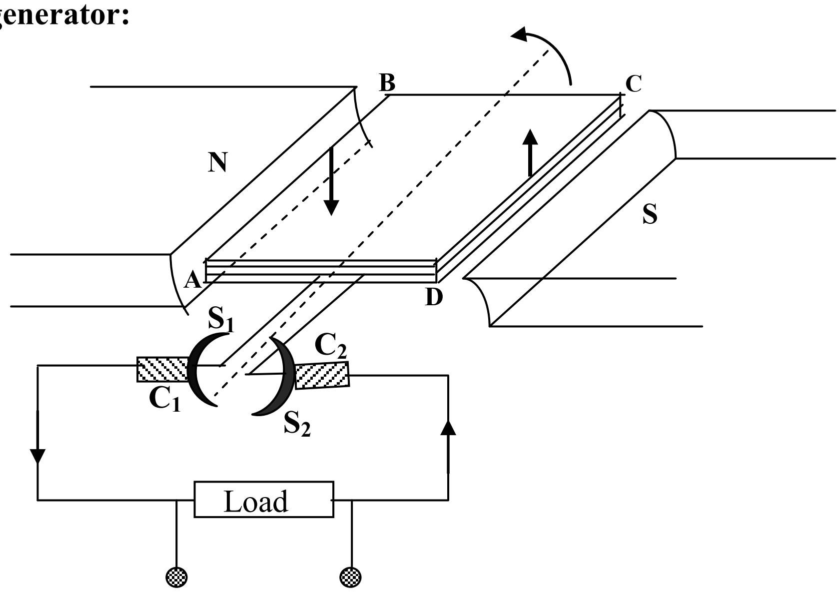
NOTE:

- The induced e.m.f is a maximum when the coil is in the horizontal position that is the coil is perpendicular to the direction of the magnetic field.
- When the coil rotates beyond the horizontal position the induced e.m.f reduces steadily to zero when the coil is in vertical position.
- Beyond the vertical position the whole process is repeated as shown above.

The simple D.C Generator:

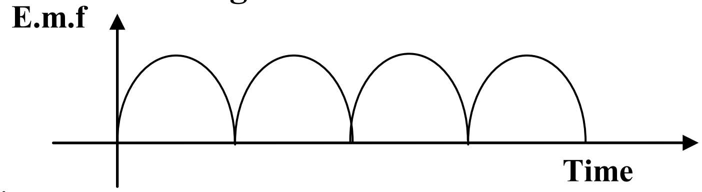
When the slip rings of an A.C generator are replaced by split rings [commutators] the A.C generator becomes a D.C generator

Structure of D.C generator:



- When the rectangular coil ABCD rotates about its axis, the magnetic flux linked with it changes and an e.m.f is induced in the coil.
- When the coil reaches the vertical position the split rings S_1S_2 change contacts with the carbon brushes C_1C_2 and the e.m.f in the coil reverses.
- This makes the direction of the current to remain the same.

Variation of e.m.f generated with time:



Note:

In practice the e.m.f generated by a D.C or A.C generator is very low. To increase on the magnitude of the induced the following should done

- Increase the speed of rotation of the coil through the magnetic field.
- Increase the number of turns in the coil.
- Use a strong magnet.
- Increase the area of the coil.
- Wind the rectangular coil on soft iron core.

Mutual induction:

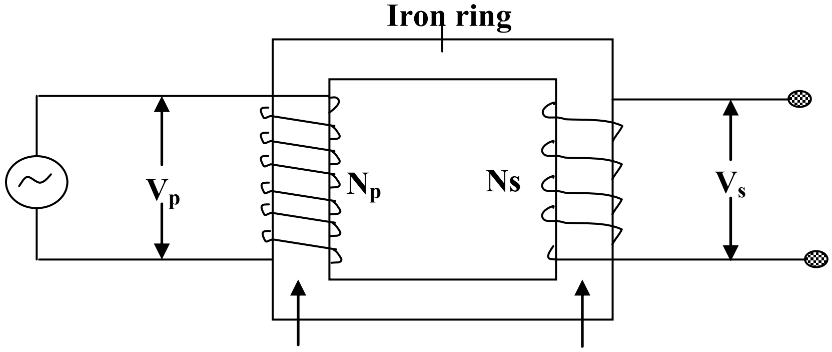
This is a process by which an e.m.f is induced in the coil (secondary) due to change in current in a nearby coil (primary). This can be experienced in a transformer.

A.C Transformer:

This is an electrical device that is used to increase or decrease an alternating voltage

Structure of an A.C transformer:

It consists of an iron ring around which primary and secondary coils are wound. Ideally the primary coil has zero resistance and the secondary coil has very high resistance.



Mode of operation:

- When an alternating voltage, V_p is applied to the primary coil, the magnetic flux linked with the secondary coil changes due to induced current in the primary coil.
- The change in magnetic flux induces the voltage V_s in the secondary coil which causes current to flow in the secondary coil.
- The induced e.m,f is directly proportional to the number of turns on the secondary and the rate of change of magnetic flux.

Types of transformers:

There are two types of transformers namely;

i) Step up transformer.

ii) Step down transformer.

Step up transformer:
This is a type of transformer in which the number of turns in the secondary is greater than the number of turns in the primary. This increases the voltage and as a result the voltage in the secondary is greater than the voltage in the primary.

Step down transformer:
This is a type of transformer in which the number of turns in the primary is greater than the number of turns in the secondary. This reduces the voltage and as a result the voltage in the primary is greater than the voltage in the secondary.

Transformer equations:

$$\frac{\textbf{Voltage in primary coil, } \mathbf{V_p}}{\textbf{Voltage in secondary coil, } \mathbf{V_s}} = \frac{\textbf{Number of turns in primary coil, } \mathbf{N_p}}{\textbf{Number of turns in secondary coil, } \mathbf{N_S}}$$

$$\frac{V_p}{V_s} = \frac{N_p}{N_s} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

For an ideal transformer where there are no energy loses then;

Power output = Power input

Power in secondary coil = Power in the primary coil

$$I_sV_s = V_pI_p$$

$$\frac{V_s}{V_p} = \frac{I_p}{I_s} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .. (2)$$

From (1) and (2)

$$\frac{I_p}{I_s} = \frac{N_s}{N_p} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .. (3)$$

Efficiency of a transformer

This is the ratio of power output to power input expressed as a percentage

$$\eta = \frac{\text{Power output}}{\text{Power input}} \text{ x } 100\%$$

$$\eta = \frac{I_sV_s}{I_pV_p} \text{ x } 100\%$$

Energy [power] losses in a transformer

- Energy loss due to heating effect (I^2R) the coil because of its resistance, this can be minimized by using low resistance thick copper wires.
- Energy loss due to eddy currents, this can be minimized by using laminated soft iron core so that the current can pass through them.
- Energy loss due to hysteresis losses, this can be minimized by using soft iron core where the coils are wound.
- Energy loss due to flux linkage, this can be minimized by using an E-shaped core where the secondary coil is wound over the primary coil

Example:

1. An A.C transformer of efficiency 80% is connected to a 240V main. The voltage across the secondary coil of 960 turns is 20V. Calculate

i) The number of turns in the primary coil

ii) The current in primary if a resistor of 40Ω is connected across the secondary coil

i) From $\frac{V_s}{V_p} = \frac{N_s}{N_p}$

$$\frac{20}{240} = \frac{960}{N_p}$$

$$N_p = 11520\text{turns}$$

ii) $\text{Efficiency} = \frac{\text{power output}}{\text{power input}} \text{ x } 100\%$

$$= \frac{I_sV_s}{I_pV_p} \text{ x } 100\%$$

$$= \frac{{V_s}^2}{RI_pV_p} \text{ x } 100\%$$

$$80 = \frac{20^2}{40 \text{ x } 240\ I_p} \text{ x } 100$$

$$I_p = 4.1A$$

2. A 3Ω resistor is connected to a secondary coil of 60 turns, if the primary coil has 1200 turns and is connected to 240V a.c supply. Calculate

i) The p.d across the secondary coil

ii) The current through a 3Ω resistor

i) From $\frac{V_s}{V_p} = \frac{N_s}{N_p}$

$$\frac{V}{240} = \frac{60}{1200}$$

$$V = 12V$$

ii) $V = IR$

$$12 = 3 \text{ x } I$$

$$I = 4A$$

Trial Exercise 3:

1. A transformer has 800 turns in its primary coil and 3200 turns in its secondary coil. If its connected to an alternate voltage of 240V. What is the out put voltage?
   Ans: 960V.
2. If one wishes to step down voltage from 240V to 10V, determine the number of turns in the secondary if the primary coil has 4800 turns.
   Ans: 200 turns.
3. Find the ratio of number of turns of the primary to the number of turns in the secondary, if the voltage of 12V is stepped up to 18V.
   Ans: 2: 3

4. A step up transformer is 80% efficient if the number of turns of the coil is 2400 turns and 500 turns. Given that the input voltage and the output current are 240V and 0.25A. Calculate the output voltage and input current.
Ans: 1152V, 0.015A
5. A 3V, 6W bulb is connected to the secondary coil of a transformer whose input voltage is 12V. Given that the transformer is 90% efficient and the bulb works at full capacity. Calculatethe current in the secondary coil and the current in the primary coil
Ans: 2A, 1.8A
6. An electric power is generated at 11kV. Transformers are used to raise the voltage to 440V for transmission over long distances using cables. The output of transformers is 19800W and they are 90% efficient. Find the input current to the transformer and the output current to the cables
Ans: 45A, 2A
7. A transformer is designed to produce an output of 240V when connected to a 25V supply. If the transformer is 80% efficient, calculate the input current when the output is connected to a 240V, 75W lamp.
Ans: 0.3125A, 0.0375A
8. a) i) What is a transformer
ii) Describe the structure and action of a transformer
b) Distinguish between connections in a step up transformer from that of a step – down transformer.
c) Why is it that a transformer doesn't use direct current (d.c) but alternating current (a.c).
9. a) Briefly explain how power is transported from a dam to a home
b) State why a.c is preferred to d.c in power transmission
c) Explain the causes of energy losses in a transformer and how they be minimized.
10. a) Practical generators have;
i) The coil of wire wound on the soft iron
ii) Rectangular coils wound in different planes.
State the effect of each of the above.
b) How can you modify an a.c generator to be a d.c generator?
c) Draw a graph for the variation of emf with time of
i) A d.c generator
ii) An a.c generator

Multiple-choice exercise:

1. Large transformers, when used for some time, become very hot and are cooled by circulating oil. The heating of the transformer is due to
A. the heating effect of current alone.
B. hysteresis loss alone
C. both the heating effect of current and hysteresis loss
D. intense sunlight at noon.
2. A high alternating voltage may be obtained from a low alternating voltage by use of
A. a dynamo B. an induction coil C. a generator D. a transformer

3. The production of an e.m.f in a given coil due to the change of e.m.f in a nearby coil is called
A. mutual induction B. self-induction
C. electromagnetic induction D. electrostatic induction

4. Power loss due to eddy currents in the core of a transformer can be minimized by
A. laminating the core
B. using thick copper wires in the windings
C. using a soft iron core
D. winding the secondary coil on top of the primary coil

5. A transformer connected to 240V a.c mains is used to light a 12V, 36W lamp. What current does the lamp draw?
A. 0.05A B. 0.15A C. 0.33A D. 3.00A

6. A 240V mains transformer has 1000 turns in the primary. The number of turns in the secondary if it is used to supply a "12V, 24W" lamp is
A. 2.0×10^4 B. 5.0×10^2 C. 5.0×10^1 D. 2.0×10^1

7. A transformer is used to step down an alternating voltage from 240V to 12V. Calculate the number of turns on the secondary coil if the primary coil has 1200 turns
A. 3 B. 5 C. 60 D. 100

8. A magnetic material can be magnetized by
(i) Stroking with a permanent magnet
(ii) Using a direct current
(iii) By induction
A. (i) only correct B. (i) and (ii) only correct
C. (ii) and (iii) only correct D. (i), (ii) and (iii) correct

9. The induced current in a generator
A. is a maximum when the coil is vertical
B. is a minimum when the coil is horizontal
C. changes direction when the coil is horizontal
D. increases when the speed of rotation increases

10. The transformer cores are laminated to
A. reduce eddy currents
B. distribute the voltage output equally within the transformer
C. decrease the resistance of the coils
D. determine the energy lost by the transformer

11. A transformer cannot function normally with d.c because a d.c
A. has extremely high heating effect
B. cannot provide high voltage required for power transmission
C. cannot produce a changing magnetic field
D. reduces the efficiency of the transformer

12. A transformer has twice as many turns in the secondary coil as in the primary coil. The a.c input to the primary is 4V. What is the output voltage
A. 2V B. 4V C. 8V D. 16V

13. Which of the following statements describes an electric generator?
A. Magnet is rotated through a coil of wire to produce an electric current.
B. Electric potential in a rotating coil of wire creates a permanent magnet.
C. An electrical current causes a coil of wire to rotate in a magnetic field.
D. Forces from a permanent magnet allow a coil of wire to rotate.

14. The main function of a step-up transformer is to
A. change a.c to d.c B. change d.c to a.c
C. increase current D. increase voltage

15. An a.c input voltage of 250V is connected to a transformer with 1000 turns. Calculate the number of turns of the secondary coil if an output of 15V is required
A. $\frac{1000}{(250-15)}$ B. $\frac{1000}{(250+15)}$ C. $\frac{1000 \times 15}{250}$ D. $\frac{(1000 \times 250)}{15}$

16. Which one of the following would **not** reduce the energy losses in a transformer?
A**:** using thinner wire for the windings
B**:** using a laminated core instead of a solid core
C**:** using a core made from iron instead of steel
D**:** using a core that allows all the flux due to the primary coil to be linked to the secondary coil

17. Which one of the following would be suitable to use in the construction of transformer core
A. lead B. copper C. soft iron D. aluminium

18. An engineering student made a transformer and he found that the output voltage is higher than expected which of these could be the reason.
A. Using bare wire for the secondary coil.
B. Using d.c instead of an a.c.
C. Putting too many turns on the secondary coil.
D. Putting too many turns on the primary coil.

19. The efficiency of a d.c motor can be increased by
i) Using thick copper coil of low resistance to reduce the heating effect
ii) Using a core of hard magnetic material to retain induced magnetism
iii) Laminating the core to reduce eddy currents
iv) Filling the gaps between the commutators with insulating material
A. (i) and (iii) only correct B. (ii) and (iv) only correct
C. (i), (ii) and (iii) only correct D. (ii), (iii) and (iv) only correct

20. Find the root mean square value in each cycle of an alternating current whose peak value is 220V
A. 311.13V B. 176.75V C. 169.68V D. 155.56V

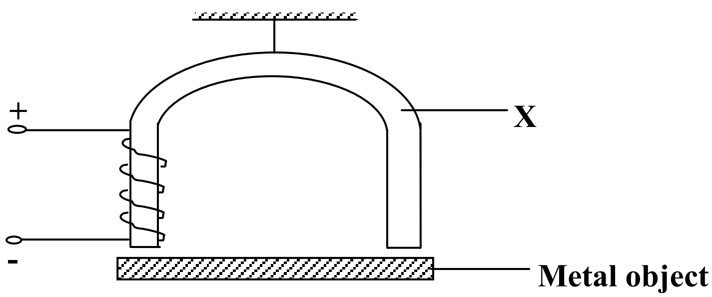
Answers

1	C	5	D	9	D	13	D	17	C
2	D	6	C	10	A	14	D	18	C
3	A	7	C	11	C	15	C	19	C
4	A	8	B	12	C	16	A	20	A

MISCELLANEOUS EXERCISE 6:

1. a) i) Define the term neutral point as applied to magnetism
ii) Briefly explain how a rod of steel can be magnetized using the single touch stroking method
b) Briefly explain how the soft iron core causes power loss in a transformer
c) i) What is a magnetic field
ii) Draw a diagram of the magnetic field pattern when a bar magnet is placed in the earth's magnetic field with its south pole facing the geographical north
d) List four features of magnetic flux

2. a) Define the following terms as applied to magnetism
i) Ferromagnetic material
ii) Neutral point
b) The figure below shows an electromagnet made by a pupil in the laboratory. The electromagnet is to pick up and release a metal object



i) Name a suitable material for X and explain why it is made from this material
ii) Name two metals which a magnet will not attract
iii) State two changes which a student could make so that a heavier metal object could be lifted by the electromagnet
c) A galvanometer of resistance 5Ω gives a full scale deflection for a current of 15mA. How may it be converted into?
i) An ammeter reading up to 3A
ii) A voltmeter reading up to 6V
Ans: i) $2.51 \times 10^{-2}\Omega$ ii) 395Ω

3. a) i) What is a magnetic field
ii) State the law of magnetism
b) i) Explain with the aid of diagrams, how a steel bar can be magnetized by the single touch method
ii) Sketch the magnetic field pattern around two bar magnets whose north poles face each other
c) With the aid of a labeled diagram, describe how a simple a.c generator works

4. a) Describe briefly the structure and action of an a.c transformer
b) i) State any three causes of energy losses in a transformer
ii) How are these losses reduced in a practical transformer?
c) Explain why it is an advantage to transmit electrical power at high voltage
d) An electric power is generated at 11kV. Transformers are used to raise the voltage to 440kV for transmission over large distances using cables. The output of transformers is 19.8MW and they are 90% efficient. Find;

i) The input current to the transformer

ii) The output current to the cables

Ans: i) 2kA ii) 45A

5. a) Explain how a piece of iron can be magnetized by the single touch method. Illustrate your answer with a diagram

b) How can you determine the polarity of a magnet?

c) Explain why a magnet loses its magnetism when placed in a coil of a wire carrying an alternating current

d) Describe the motion of a beam of electrons directed midway between the north and south poles of a permanent magnet

6. a) Describe with the aid of a labeled diagram, the structure and principle of operation of an a.c generator

b) An electric power generator produces 24kW at 240V a.c. The voltage is stepped up to 4000V for transmission to a factory, where it is then stepped down to 240V. The total resistance of the transmission wires is 0.5Ω.

i) What is the ratio of the number of turns in the primary to the number of turns in the secondary of the step down transformer?

ii) Find the power lost in the transmission lines assuming both transformers are 100% efficient

Ans: i) 50:3 ii) 18W

c) i) What power would have been lost if the same electric power had been transmitted directly to the factory through the same transmission wires without use of transformers

ii) Comment on differences between the power losses in (b) (ii) and (c) (i) above

Ans: i) 15kW

7. a) i) Draw a labeled diagram to show essential parts of a d.c motor

ii) Describe briefly how a d.c motor works

b) State three ways of increasing the torque of the motor

c) i) What factors make the efficiency of a motor less than 100%

ii) How is each factor in (c) (i) above minimized

d) An electric motor of efficiency 90% operates a water pump. The pump raises 0.9kg of water through 10m every second

i) What is meant by the term efficiency?

ii) State the energy changes which take place

iii) Find the electrical power supplied to the motor

Ans: iii) 100W

8. a) i) What is a magnetic field

ii) Draw a diagram of the magnetic field pattern between the north poles of two bar magnets placed near each other

b) Describe how you can plot the magnetic field around a wire carrying a current perpendicular to the plane of the paper

c) Draw a diagram to show what happens when two straight conductors placed vertically near each other carry a current in

i) The same direction

ii) The opposite direction

d) Describe briefly two methods of magnetizing an iron rod

e) A transformer is designed to produce an output of 220V when connected to a 25V supply. If the transformer is 80% efficient, calculate the input current when the output is connected to a 220V, 75W lamp.

Ans: 3.75A

9. a) State three factors on which the magnitude of the force exerted on a wire carrying a current in a magnetic field depends

b) With the aid of a labeled diagram, describe the action of a moving coil galvanometer

c) A moving coil galvanometer has a coil of resistance 4Ω and gives a full scale deflection when a current of 25mA passes through it. Calculate the value of the resistance required to convert it to an ammeter which reads 15A at full scale deflection.

Ans: $6.68 \times 10^{-3}\Omega$

10. a) With the aid of a diagram explain, the use of keepers to store magnets

b) i) Describe using a labeled diagram how a telephone receiver works

ii) State two ways by which the strength of an electromagnet can be increased

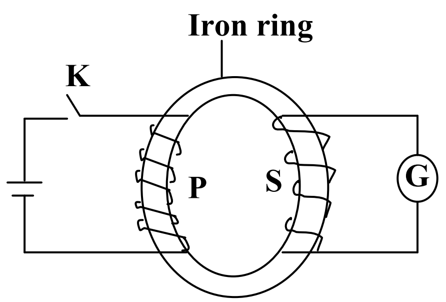
c) i) A part from electrical method mention two other methods of demagnetization

ii) Explain how the above methods mentioned lead to magnetization

d) Describe how you would demagnetize a bar magnet by the electrical method.

11. a) What is a transformer

b) The diagram below shows a model of a transformer in which the primary coil is connected to d.c and the secondary coil, S is connected to the galvanometer, G



i) What is observed just as the switch, K is closed

ii) What wiil be the effect of closing switch, K very fast in (i) above

iii) What is observed when the switch is left closed?

iv) What is observed as the switch is opened

v) When is observed if the d.c source is replaced by an a.c source of low frequency

c) A transformer of efficiency 80% is connected to a 240V a.c supply to operate a heater of resistance 240Ω. If the current flowing in the primary circuit is 5A

i) Calculate the potential difference across the heater

ii) If the heater is cooled by oil of specific heat capacity 2,100$Jkg^{-1}K^{-1}$ and the temperature of oil rises by 20° in 3 minutes, find the mass of oil used in cooling.

Ans: i) 48V **ii) 4.11kg**

12. a) i) What is meant by a magnetic field

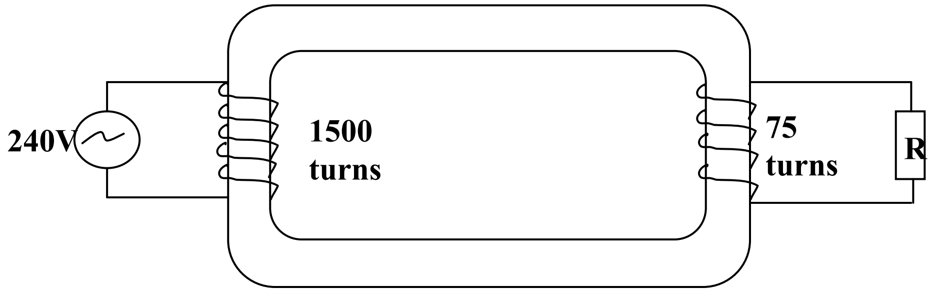
ii) Suggest any three characteristics of the magnetic field

b) i) Describe in details how an iron bar can be magnetized by electrical method

ii) A galvanometer has resistance of 2Ω and gives a 50mA full scale deflection. Calculate the value of resistance that is used so that the meter reads current up to 2A

Ans: ii) $5.13 \times 10^{-2}\Omega$

d) The diagram below is a transformer, study it and answer the questions that follow



i) Find the potential difference across R

ii) If the current in the mains is 0.55A. What is the current in the secondary coil?

iii) With a reason name the type of the transformer

Ans: i) 12V ii) 11A

13. a) State any two factors which determine the magnitude of a force exerted on a current carrying conductor

b) With the aid of a well labeled diagram, describe the structure and mode of action of a moving coil loud speaker

c) State the factors which determine the pitch and loudness of the sound produced by a moving coil loud speaker.

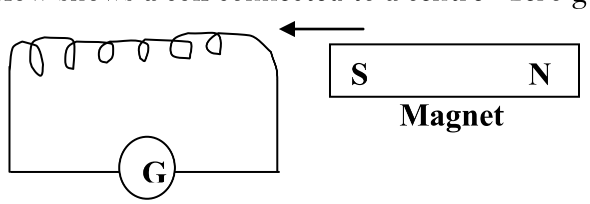
d) A D.C motor has an armature resistance of 4Ω. If it draws a current of 10A when connected to a supply of 200V, calculate the

i) Power wasted in the windings

ii) Efficiency of the motor

Ans: i) 400W ii) 80%

14. a) The diagram below shows a coil connected to a centre –zero galvanometer, G



State and explains the deflection of the galvanometer needle when the magnet is

i) Held stationary at one end of the coil

ii) Moved slowly towards the coil

iii) Left at rest inside the coil

iv) Moved away from the coil

v) Moved quickly in an out of the coil about twice per second

b) i) State four ways in which power is lost in a transformer

ii) How can the power loss be minimized in each case

c) Distinguish between a d.c motor and a d.c generator

d) An electric motor taking a current of 5A at 240V is connected by cable to a generator some distance away. If the p.d at the terminals of the generator is 250V, calculate

i) The resistance of the cable

ii) The power supplied by the generator and loss of power in the cable.

15. a) A bar magnet is placed with its axis along the magnetic meridian with its south pole pointing north.

i) Sketch the magnetic flux pattern near the magnet in the earth's field.

ii) With reference to the sketch, explain what is meant by a neutral point in a magnetic field

b) i) Describe an experiment to determine the magnetic field pattern of a bar magnet using iron fillings.

ii) State one advantage and one disadvantage of the method in (b) (i).

c) Describe how the earth's magnetic meridian may be determined.

d) A galvanometer has a coil of resistance 8Ω and gives a full scale deflection when a current of 0.5mA is supplied. Calculate the resistance that can be used to convert it into an ammeter measuring up to 5A.

Ans: $8.0 \times 10^{-4}\Omega$.

16. a) i) What is a magnetic field

ii) State the law of magnetism

b) i) Explain with the aid of a diagram how a steel bar can be magnetized by the single touch method.

ii) Sketch the magnetic field paatern around two bar magnets whose north poles face each other.

c) With the aid of a labeled diagram describe how a simple ac generator works

d) Explain with the aid of a diagram what happens when two vertical, parallel conductors are placed near one another and carry current in

i) The same direction

ii) The opposite direction

e) i) Describe with the aid of a diagram, how a direct current generator works

ii) State three ways of increasing the e.m.f produced by the generator

17. a) What is meant by magnetic saturation

b) Explain why freely suspended bar magnet swings until it points North South

c) With the aid of a diagram explain the use of magnetic keepers

d) State any two factors which determine the magnitude of the emf induced in a coil rotating in magnetic field

d) i) Draw a diagram to show the construction of a step – down transformer

ii) A transformer is used to step–up an alternating voltage from 20V to 240V. Calculate the number of turns in the primary coil if the secondary coil has 1200 turns.

Ans: 100 turns

M O D E R N P H Y S I C S

This deals with nuclear model of an atom.

The structure of an atom:

An atom is the smallest particle of an element that can take part in a chemical reaction. An atom consists of three subatomic particles and these are;

i) Neutrons.

ii) Protons.

iii) Electrons.

An atom is made of a central part called the nucleus around which electrons rotate. The nucleus is positively charged because it consists of protons which are positively charged and neutrons which have no charge. The properties of the subatomic particles of an atom are as shown in the table below.

Name	Symbol	Mass	Charge
Protons	P	1	Positive
Neutrons	n	1	No charge
Electrons	e	0	Negative

Note:

The number of protons in the nucleus is equal to the number electrons around the nucleus and since they have opposite charges the atom has no charge.

Atomic number, z:

This is the number of protons in the nucleus of an atom

Atomic number, z = Number of protons

Mass number [atomic mass], A:

This is the total number of protons and neutrons in the nucleus of an atom

Mass number = Number of protons + Number of neutrons

A = z + n

If an atom of an element X is represented as $^{A}_{z}X$

Then z = Atomic number and A = Atomic mass

Example:

Given the chloride atom $^{35}_{17}Cl$. Find the number of neutrons and electrons in the atom

A = z + n

Where A = 35 and z = 17

n = 35 – 17

= 18 neutrons

Number of electrons = Number of protons

= Atomic number, z

= 17 electrons

ISOTOPES:

These are atoms of the same element with the same atomic number but different mass numbers. Therefore isotopes of an element have the same number of protons and electrons and different number of neutron.

Examples of isotopes are;

i) Chlorine;	$^{35}_{17}Cl$	$^{36}_{17}Cl$	$^{37}_{17}Cl$
ii) Carbon;	$^{12}_{6}C$	$^{13}_{6}C$	$^{14}_{6}C$
iii) Oxygen;	$^{16}_{8}O$	$^{17}_{8}O$	$^{18}_{8}O$
iv) Hydrogen;	$^{1}_{1}H$	$^{2}_{1}H$	$^{3}_{1}H$

RADIOACTIVITY:

This is the spontaneous disintegration of unstable nucleus to form a stable nucleus with emission of radiations. Radioactivity is not affected by eternal factors like temperature and pressure. There are three radiations emitted by radioactive nucleus and these are;

i) Alpha particles, α.
ii) Beta particles, β.
iii) Gamma rays, γ

Alpha particle, α:

Alpha particle is a high speed helium nucleus ($^{4}_{2}He$)
Alpha particles have a mass number of 4 and atomic number of 2 and carry a positive charge.

Properties of alpha particles:

- They are slightly deflected by both magnetic and electric fields because of their large mass.
- They are positively charged.
- They have the greatest ionizing power.
- They have the least penetrating power.
- They are stopped by a thick sheet of paper.
- They have very short range in air.
- They affect the photographic films.
- They have speed less than the speed of light.
- They produce flashes when incident on fluorescent substance.

Beta particle, β:

A beta particle is a high speed electron emitted from the nucleus of a radioactive atom. Beta particles have no mass number and carry a negative charge ($^{0}_{-1}e$). A beta particle is produced as a result of one of the neutrons changing to a proton $^{1}_{0}n \longrightarrow {}^{1}_{1}P + {}^{0}_{-1}e$

Properties of beta particles:

- They are negatively charged.
- They are easily deflected by both magnetic and electric fields because they are lighter.
- They have greater penetrating power than alpha particles because of their high speed.
- They have less ionizing power than alpha particle.
- They can be stopped by a thin sheet of aluminium.
- They have a greater range in air than alpha particles.
- They produce flashes when incident on fluorescent substance

Gamma rays, γ:

Gamma ray is high energy electromagnetic radiation of very short wave length emitted from the nucleus of the radioactive substance. Gamma rays have no mass number and carry no charge.

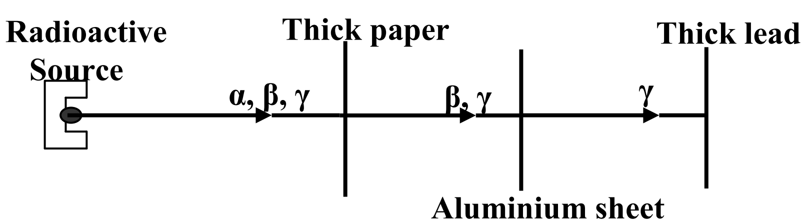
Gamma rays are produced when an excited atomic nucleus loses energy and the energy is given out as gamma rays.

Properties of gamma rays:

- They are not charged.
- They travel at a speed of light since they are electromagnetic radiations.
- They are not deflected by both magnetic and electric fields since they are not charged.
- They have the least ionizing power.
- They have the greatest penetrating power.
- They undergo interference and diffraction.
- They cause fluorescence when incident on fluorescence substances.

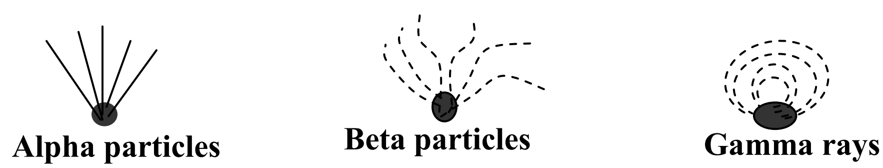
Penetrating power of the radiations:

Alpha particles have the least penetrating power and can be stopped by a thick sheet of paper. Beta particles have greater penetrating power than alpha particles and can be stopped by a thin sheet of aluminium while gamma rays have the greatest penetrating power and can be stopped by thick block of lead



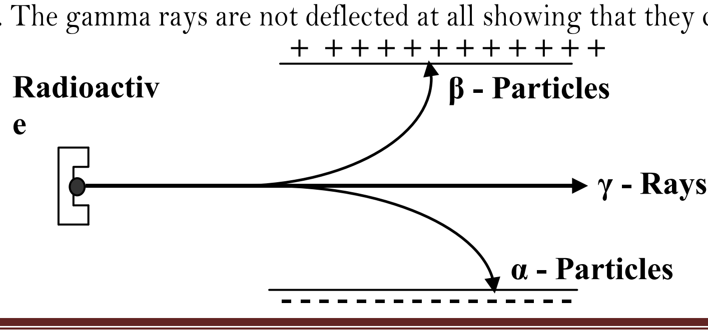
Ionizing power of the radiations:

Alpha particles produce straight traces because they are heavy and they cause greater ionization of the gases through which they pass. Beta particles produce irregular and light traces while gamma rays do not produce any trace when the radiations are in a cloud chamber detector.



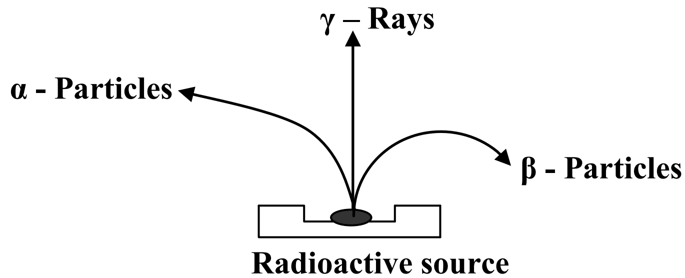
Deflection of the radiations in an electric field:

When the radiations from a radioactive nucleus are passed through a strong electric field the beta particles are deflected towards a positive plate showing that they carry a negative charge. Alpha particles are deflected towards a negative plate in the direction opposite to that of beta particles showing that alpha particles carry a positive plate. The gamma rays are not deflected at all showing that they carry no charge.



Deflection of the radiations in a magnetic field:

When the radiations from a radioactive nucleus are passed through a strong magnetic field the beta particles are deflected according to Fleming's right hand rule showing that they carry a negative charge. Alpha particles are deflected to the direction opposite to that of beta particles showing that alpha particles carry a positive charge but heavier than beta particles. The gamma rays are not deflected at all showing that they carry no charge.



Radioactive decay:

This is the process of spontaneous break down of radioactive nuclide. A radioactive nuclide is an atomic species of a radioactive substance which continuously breaks down with emission of radiations.

Types of radioactive decay:

a) Alpha decay:

When a nuclide undergoes an alpha decay, it loses two protons and two neutrons. Therefore its mass number reduces by four and its atomic number reduces by two and the daughter nuclide is two steps to the left in the periodic table.

Given that a radioactive element, $^{A}_{z}X$ undergoes an alpha decay to form element **Y**. Then the nuclear reaction equation is given by

$$^{A}_{z}X \longrightarrow {}^{A-4}_{z-2}Y + {}^{4}_{2}He + \text{energy}$$

Examples:

1. Radium [Ra] decays to become radon [Rn] according to the equation

$$^{226}_{88}Ra \longrightarrow {}^{222}_{86}Rn + {}^{4}_{2}He$$

2. Uranium [U] decays to become thorium [Th] according to the equation

$$^{238}_{92}U \longrightarrow {}^{234}_{90}Th + {}^{4}_{2}He$$

b) Beta decay:

When a nuclide undergoes beta decay its mass number does not change but its atomic number increases by one and the daughter nuclide is one step to the right in the periodic table. This is because electrons do not exist inside the nucleus but can be produced when a neutron changes into a proton and an electron, the proton then remains in the nucleus hence increasing the atomic number and an electron is lost from the nucleus.

Given that a radioactive element, $^{A}_{z}X$ undergoes a beta decay to form element **Y**. Then the nuclear reaction equation is given by

$$^{A}_{z}X \longrightarrow {}^{A}_{z+1}Y + {}^{0}_{-1}e + \text{energy}$$

Example:

Carbon -14 decays to become Nitrogen according to the equation.

$$^{14}_{6}C \longrightarrow {}^{14}_{7}N + {}^{0}_{-1}e$$

c) Gamma decay:

Gamma rays are not particles, therefore when nuclide emits gamma rays its atomic number and its mass number do not change but the nucleus becomes more stable.

Given that a radioactive element, $^{A}_{Z}X$ undergoes a gamma decay to form a stable element **X**. Then the nuclear reaction equation is given by

$$^{A}_{Z}X \longrightarrow {}^{A}_{Z}X + \gamma + \textbf{Energy}$$

Note:

The change of an element to another element is called **Transmutation**

Uses of radioactivity:

a) Medical uses:

- Radiations are used in radiotherapy [in treatment of cancerous cells] that is gamma rays are usually used to destroy cancer cells.
- Medical instruments are sterilized using gamma rays.
- Radiations are used to detect brain tumours.
- Radiations are used to detect lung and heart problems.
- Radiations destroy germs.

b) Industrial uses:

- Radioactive elements are used to measure fluid flow in pipes in industries.
- Radioactive elements are used to provide source of energy [electricity].
- Radioactive elements are used in hardening polythene and petroleum.
- Radioactive elements are used in food preservation.
- Radioactive elements are used as tracers in identifying oil leakages in oil pipes.
- Radioactive elements are used to measure the thickness of the metal sheet.
- Radioactive elements are used as level indictor that is to check the filling packets of soap powders.

c) Agricultural uses:

- Radioactive elements produce varieties of plants with new characteristics.
- Radioactive elements are used as tracers to study the uptake of fertilizers by plants.
- Radioactive elements can be used in pest control.

d) Carbon dating:

- Carbon dating forms a radioactive carbon-dioxide which is taken up by plants in the manufacture of carbohydrates by photosynthesis. When plants are cut down the atoms will start to decay by emission of beta particles and by measuring the residue and half life the age of the ancient containing carbon can be estimated.

Health hazards of radioactivity:

- Radiations cause blood cancer.
- Radiations cause radiation burns.
- Radiations cause sterility [inability to produce].

- Radiations cause low body resistance to normal diseases.
- Radiations cause genetic changes [mutation].
- Radiations destroy body cells.
- Radiations damage eye sight and body tissues.

Safety precautions when handling radioactive elements:

- They should be handled using long pair of tongs.
- They should be transported in thick lead containers.
- You should avoid unnecessary exposure to the radiations.
- You should wear protective clothing when handling radioactive elements.
- You should not eat or drink where radioactive sources are in use.
- You should cover any wound before using radioactive source.

Background radiations:

These are ionizing radiations from a variety of natural and artificial sources and are always present in the environment. Background radiation is all around us, most background radiation comes from natural sources, while most artificial background radiation comes from medical examinations, such as x-ray photographs.

Natural sources:

Natural sources of background radiation include the following:

Cosmic Radiation:

These are radiations that reach the Earth from space. The sun is a major source of 'cosmic radiation'. The sun and stars send a constant stream of cosmic radiation to Earth. Cosmic rays originating from the sun, stars and other major events in outer space are continuously striking the Earth. The majority of these cosmic rays are absorbed by the Earth atmosphere but the more energetic radiations interact with the atoms in the atmosphere creating energetic neutrons. Other energetic rays such as gamma rays can make it through the atmosphere to the Earth's surface.

Terrestrial Radiation:

The Earth itself is a source of terrestrial radiation. Radioactive materials (including uranium, thorium, and radium) exist naturally in soil and rock. Some rocks are radioactive and give off radioactive radon gas. Essentially all air contains radon. In addition, water contains small amounts of dissolved uranium and thorium, and all organic matter (both plant and animal) contains radioactive carbon and potassium. Some of these materials are ingested with food and water, while others (such as radon) are taken in. The Earth contains radioactive rocks. Radioisotopes with long half-lives such as Uranium-235, Uranium-238 and Thorium-232 still remain along with the radioisotopes formed from the decay of the long lived isotopes. During the radioactive decay of Uranium, Radon gas is produced which passes through rocks underground and introduced into the atmosphere. Radon gas is radioactive and accounts for a large proportion of the natural background radiation.

Internal Radiation:

Small traces of radioactive materials are present in the human body. These come from natural radioactive sources such as Carbon-14 in the air we breathe. Fruits and crops take in radioactive materials from the soil as well as Carbon-14 from the air. These are introduced into the body when they are eaten or via the food chain when meat or milk from animals grazing on the crops is consumed. Therefore all people have internal radiation, mainly from radioactive potassium- 40 and carbon-14 inside their bodies from birth and, therefore, are sources of exposure to others. And living things like plants absorb radioactive materials from the soil and these pass up the food chain

Artificial sources:

Human activity has added to background radiation by using artificial sources of radiation which include the following;

Nuclear power stations:

Major incidents from nuclear power stations have released radiations into the environment. Nuclear waste from power station also accounts for a proportion of artificial background radiation

Nuclear weapons:

Nuclear weapon testing resulted in an increase of radiation in the environment because of **radioactive fallout** from nuclear weapons testing.

Medical sources:

Humans are exposed to radiations by medical procedures such as x-rays and radiotherapy. Nearly all artificial background radiation comes from medical procedures such as receiving x-rays for x-ray photographs.

Detecting the radiation:

The following can be used to detect radiations;

Photographic film:

Photographic film goes darker when it absorbs radiation, just like it does when it absorbs visible light. The more radiation the film absorbs, the darker it is when it is developed. People, who work with radiation, wear film badges which are checked regularly to monitor the levels of radiation absorbed.

Geiger-Muller tube and Cloud Chamber:

The Geiger-Muller tube or cloud chamber detects radiation and each time it absorbs radiation, it transmits an electrical pulse to a counting machine. This makes a clicking sound or displays the count rate. The greater the frequency of clicks, the higher the count rate and the more radiation the Geiger-Muller tube or cloud chamber is absorbing.

NUCLEAR REACTIONS:

This is a process in which energy is produced. There are two types of nuclear reactions and these are

i) Nuclear fusion.

ii) Nuclear fission.

Nuclear fusion:

This is a process by which two light nuclei combine to form a heavy nucleus with release of energy. It takes place at the sun, stars and in the hydrogen bomb.

Example

Two Deuterium nuclei combine to form Helium -3 and a neutron with release of energy

$$ {}^{2}_{1}H + {}^{2}_{1}H \longrightarrow {}^{3}_{2}He + {}^{1}_{0}n + \text{Energy} $$

Conditions for nuclear fusion:

i) It occurs at very high temperature of about 10^8K.
ii) Presence of two light nuclei.
iii) It requires high speed moving nuclei.

Nuclear fission:

This is the splitting of a heavy nucleus into two nuclei with release of energy. It takes place in nuclear reactors and in the atomic bombs.

Example

Splitting of uranium-236 $^{236}_{92}U$ to form Barium (Ba) and Krypton (Kr) with release of energy

$$^{236}_{92}U \longrightarrow {}^{141}_{56}Ba + {}^{92}_{36}Kr + 3\,{}^{1}_{0}n + \text{Energy}$$

Conditions for nuclear fission:

i) It occurs at very low temperature.
ii) Presence of energetic slow moving neutron.
iii) Presence of a heavy nucleus,

Examples:

1. $$^{235}_{92}U + {}^{1}_{0}n \longrightarrow {}^{236}_{92}U \longrightarrow {}^{144}_{x}Ba + {}^{y}_{36}Kr + 2\,{}^{1}_{0}n$$

Find the values of x and y in the above nuclear fission reaction

236	= 144 + y + 2	92	= x + 36 + 0
236	= 146 + y	92	= x + 36
y	= 90	x	= 56

2. $$^{235}_{92}U + {}^{1}_{0}n \longrightarrow {}^{144}_{56}Ba + {}^{90}_{36}Kr + 2X$$

Identify X in the above nuclear fission reaction

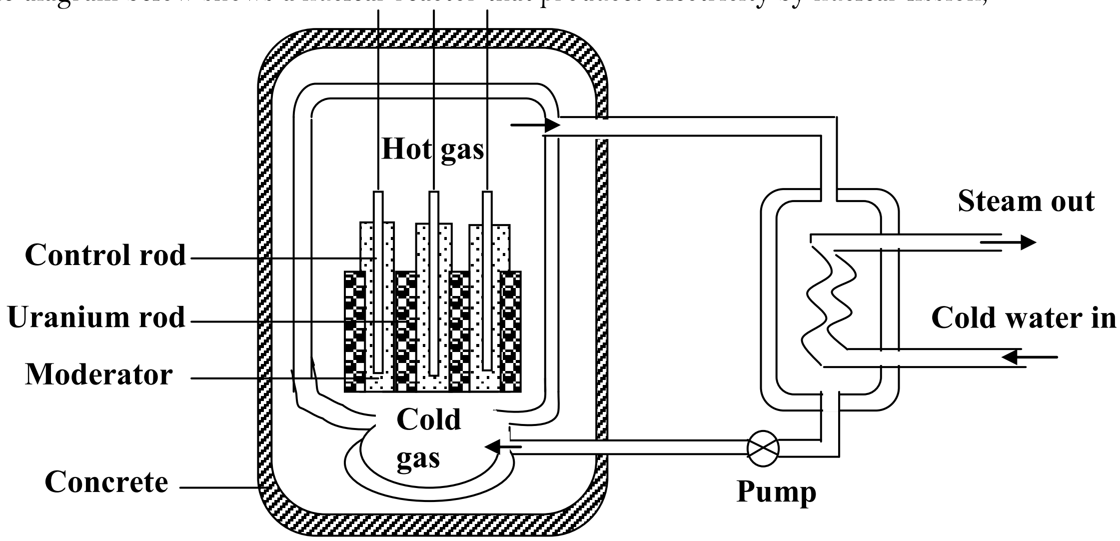
235 + 1	= 144 + 90 + 2A	92 + 0	= 56 + 36 + 2z
236	= 234 + 2A	92	= 92 + 2z
2	= 2A	0	= 2z
A	= 1	z	= 0

X is a neutron

NB: The number of radioactive nuclei that decay per unit time is called **activity**

NUCLEAR REACTOR:

The diagram below shows a nuclear reactor that produces electricity by nuclear fission;



How electricity is produced from the nuclear reactor:

The uranium rod undergoes fission and fast neutrons are produced as a result. The neutrons collide with other atoms and the energy possessed by the neutrons changes to heat energy. The heat energy is then absorbed by the coolant and is made to heat water to produce steam. The steam then drives the turbines connected to a generator and electricity is produced.

Functions of the parts:

i) Control rods are made of boron or cadmium and they control the fission rate that is they absorb neutrons that would initiate a fission reaction.

ii) The moderator is made of graphite or heavy water at very high pressure and it is used to slow the neutrons there by making them to be absorbed by the uranium atoms

iii) Coolant is made of water at very high pressure, liquid sodium or carbon-dioxide and is used to absorb heat from the reactor core.

iv) Uranium rods are made of uranium and they are as fuel which contains uranium-235. The atoms of uranium undergo fission and produce energy

v) The concrete shield absorbs any radiation from the fission fragments or from the fuel directly.

NOTE:

Heavy water at very high pressure is used instead of ordinary water as a moderator because heavy water does not absorb the neutrons since it contains deuterium atoms $\left({}^{2}_{1}\mathrm{H}\right)$ and high pressure prevents it from boiling and thus not turning into a vapour.

Uses of nuclear reactors:

i) they used to produce new elements.

ii) they are used to produce nuclear fuel.

iii) they are used to produce power that it acts as source of energy.

Problems nuclear power station face:

i) There may be an explosion due the radiations from the environment.

ii) There may be fuel leakage.

iii) Global warming due to the heat given out.

iv) Dangers from radioactive waste.

HALF LIFE:

This is the time taken for a radioactive element to decay to half its original value. Half life is measured in seconds, minutes, hours, days, weeks, months and years.

Half life is not affected by physical factors like temperature and pressure and half life is different for different radioactive nuclides.

If N_o is the original value of a radioactive element and N_T is the mass of a radioactive element at any time, t, then

$$\frac{N_o}{N_T} = 2^{t/T_{1/2}}$$

Where $T_{1/2}$ is the half life of a radioactive element

Alternatively

Mass	Number of half life	Time
N_o	0	0
$\frac{N_o}{2}$	1	$1T_{1/2}$
$\frac{N_o}{4}$	2	$2T_{1/2}$
$\frac{N_o}{8}$	3	$3T_{1/2}$
$\frac{N_o}{16}$	4	$4T_{1/2}$

Examples:

1. Radioactive element of mass 8g has half life of 8days. Find

i) Mass of the element after 24days

ii) Mass decayed after 24days

i)

$$\frac{N_o}{N_T} = 2^{t/T_{1/2}}$$

$$\frac{8}{N_T} = 2^{24/8}$$

$$8 = 2^3 N_T$$

$$8 = 8N_T$$

$$N_T = 1g$$

ii) Mass decayed $= 8 - 1$

$= 7$days

Alternatively:

Mass(g)	Number of half life	Time(days)
8	0	0
4	1	8
2	2	16
1	3	24

i) Mass of an element after 24 days = 1g

ii) Mass decayed after 24 days = 8 – 1 = 7g

2. A radioactive element of mass 9.6g has a mass of 0.15g after 24hours

$$\frac{N_o}{N_T} = 2^{t/T½}$$

$$\frac{9.6}{0.15} = 2^{24/T½}$$

$$64 = 2^{24/T½}$$

$$2^6 = 2^{24/T½}$$

$$6 = 24/T½$$

$$T½ = 4\text{hours}$$

Alternatively

Mass(g)	Number of half life	Time(hours)
9.60	0	0
4.80	1	1T½
2.40	2	2T½
1.20	3	3T½
0.60	4	4T½
0.30	5	5T½
0.15	6	6T½

$$6T½ = 24$$

$$T½ = 4\text{hours}$$

3. A radioactive element of mass 12g has a half life of 7years. Find the time taken for the element to decay to 0.75g

$$\frac{N_o}{N_T} = 2^{t/T½}$$

$$\frac{12}{0.75} = 2^{t/7}$$

$$16 = 2^{t/7}$$

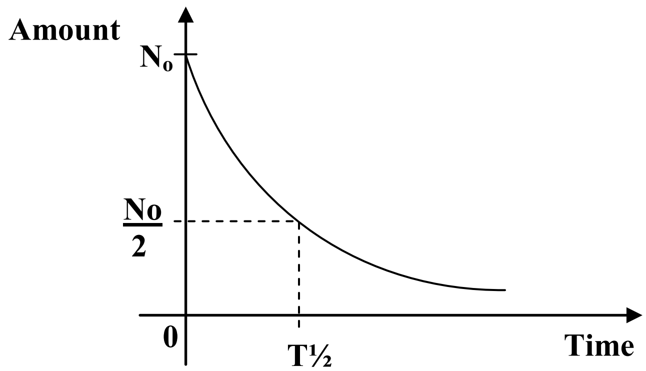
$$2^4 = 2^{t/7}$$

$$4 = {}^{t}/_{7}$$

$$t = 28\text{years}$$

Half life from the graph:

- The graph of amount of an element, N against time, t is plotted.
- Draw a horizontal line from half of the original amount to meet the curve.
- Draw a vertical line from the point on the curve to meet the time axis.
- Read the half life from where the vertical line meets the time axis.



Qn. The following figures were obtained from the reading of a rate metre for the alpha particle emission from Thoron – 220

Time(s)	0	20	40	60	80	100	120	140
Average Counts	96	72	55	45	36	26	20	15

Plot a suitable graph from the readings and obtain the half-life of Thoron – 220

Trial Exercise 1:

1. a) Define the following terms
i) Atomic number
ii) Mass number
b) State the composition of elements $^{222}_{86}X$ and $^{224}_{86}Y$
c) i) What is meant by the term radioactivity
ii) Name the radiations emitted by radioactive materials
iii) State the properties of the radiations named in (b) (ii) above
d) What dangers may a rise when one is exposed to radioactive materials?
2. a) What is a radioactive nuclide
b) State the changes that take place in the nucleus of an atom if it emits
i) Alpha particle ii) Beta particle iii) Gamma ray
c) Explain the origin of beta particles and gamma rays.
d) Explain why
i) Alpha particles are more ionizing than beta particles
ii) Alpha particles have a short range in air than beta particles
iii) Beta particles are deflected more than alpha particles by the same magnetic field
3. a) The nuclide $^{226}_{89}X$ decays to nuclide Y by emission of alpha particle.
i) Write the equation for the decay.
ii) State the atomic number and mass number of Y.
Ans: Mass Number = 222, Atomic Number = 87

b) The nuclide $^{24}_{11}A$ decays to nuclide P by emission of beta particle.
i) Write the equation for the decay.
ii) State the atomic number and mass number of P.
Ans: Mass Number = 24, Atomic Number = 12
c) The nuclide $^{214}_{82}X$ decays to nuclide M by emission of beta particle and gamma ray.
i) Write the equation for the decay.
ii) State the atomic number and mass number of M.
Ans: Mass Number = 214, Atomic Number = 83
d) The nuclide $^{226}_{88}Ra$ decays to nuclide Y by emission of two alpha particles and one beta particle.
i) Write the equation for the decay.
ii) State the atomic number and mass number of Y.
Ans: Mass Number = 218, Atomic Number = 85

4. X decays to P according to the equation below

$$^{A}_{Z}X \longrightarrow {}_{Z+1}^{A}P + k$$

Indentify k

5. Given that R and H decay as shown below

i) $^{232}_{92}R \longrightarrow {}^{224}_{91}Y + m\propto + n\beta$

ii) $^{222}_{86}H \longrightarrow {}^{218}_{84}P + D$

Find m, n and indentify particle D
Ans: m = 2, n = 3

6. Given that Ra decays to Y according to the equation

$$^{226}_{88}Ra \longrightarrow {}^{A}_{Z}Y + 2\propto + \beta$$

Find the values of A and Z.
Ans: A = 218, Z = 85

7. a) Define the term half life
b) A radioactive sample of mass 60g has half life of 8 minutes. Determine how much of it remains after 40 minutes
Ans: 1.875g
c) An element X of mass 64g decays to 4g in 96 days. Calculate
i) The half life of X
ii) Themass that decays in 120 days
iii) How long dose it take for ¾ of the sample to decay
Ans: i) 24 days **ii) 2g** **iii) 48 days**

8. a) Define the terms
i) Nuclear fusion
ii) Nuclear fission
b) i) State the conditions necessary for each to take place
ii) Give two examples where each takes place
c) i) $^{235}_{92}U + {}^{1}_{0}n \longrightarrow {}_{56}^{x}Ba + {}^{92}_{y}Kr + 3\,{}^{1}_{0}n$
Find the values of x and y
ii) $^{2}_{1}H + {}^{3}_{1}H \longrightarrow Q + {}^{1}_{0}n$

Find the atomic number and mass number of Q

Ans: i) x = 141, y = 36 ii) Mass Number = 4, Atomic Number = 2

9. a) What is background radiation

b) i) Describe the structure and action of Geiger-Muller tube

ii) Describe the structure and action of diffusion cloud chamber.

c) Draw diagrams to show tracks of each of the radioactive radiations appear in the Geiger-Muller tube

10. a) Explain why heavy water at very high pressure is used as a moderator instead of ordinary water

b) State the problems a nuclear power station faces

c) i) Briefly explain why it is difficult to construct a reactor that utilizes fusion reaction

ii) What advantage would a rise from such reactor as compared to the one of fission?

d) Give uses of a nuclear reactor.

Multiple-choice Exercise:

1. The mass of a radioactive material falls to ¼ of its original mass after 10days. What is its half-life?

A. 2.5 days B. 5.0 days C. 20.0 days D. 40.0 days

2. Which of the following emissions will cause no change in the nucleus of radioactive element?

A. neutron emission B. beta emission C. gamma emission D. alpha emission

3. Which of the following particles are added to the atom of an element to form an isotope of the element?

A. electron B. proton C. alpha particle D. neutron

4. A radioactive substance has a half-life of 2days. After 14 days only 1g remained. What was the initial mass of a radioactive substance?

A. 128g B. 64g C. 32g D. 2g

5. If $^{a}_{b}Z$ stands for the symbol of an element, which of the following statements are correct

i) Z has 'b' protons in its nucleus

ii) the atom of the element Z has 'a' electrons

iii) the mass number of Z is 'a – b'

iv) the atomic number of Z is 'b'

A. (i) and (iv) correct B. (i), (ii) and (iii) correct

C. (ii) and (iv) correct D. all are correct

6. The half-life of radioactive substance is 4minutes. How long will it take 32g to reduce to 2g

A. 16minutes B. 8minutes C. 4minutes D. 2minutes

7. If X is an isotope of Y, then the

A. atomic mass of X is equal to that of Y

B. atomic mass of X is equal to atomic number of Y

C. atomic number of X is equal to that of Y

D. atomic number of X is equal to atomic mass of Y

8. An atom contains 3 electrons, 3 protons and 4 neutrons. Its nucleon number is

A. 3 B. 4 C. 6 D. 7

9. An isotope of nuclide $^{35}_{17}X$ has

A. 18 protons and 17 neutrons B. 17 electrons and 18 neutrons

C. 17 protons and 20 neutrons D. 18 protons and 18 neutrons

10. Radioactive elements A and B are of half-lives 400seconds and 800seconds respectively. Starting with 64g of A and 16g of B, how long will it be before the same mass of each remains

A. 2000s B. 1600s C. 1200s D. 800s

11. A radioactive substance has a half-life of 1000years. After 5000years what fraction of its initial mass of a radioactive substance will have decayed?

A. $\frac{1}{32}$ B. $\frac{1}{5}$ C. $\frac{4}{5}$ D. $\frac{31}{32}$

12. A radioactive nucleus $^{235}_{92}U$ loses two alpha particles and one beta particle to be isotope $^{a}_{b}P$. What are the values of a and b

	a	b
A.	243	95
B	227	89
C.	231	91
D.	235	92

13. A nuclear reaction of a radioactive element is given by the equation

$$^{232}_{92}X \longrightarrow {}^{224}_{91}Y + a\,{}^{4}_{2}He + b\,{}^{0}_{-1}e.$$

Find the values of a and b

	a	b
A.	2.0	0
B	3.0	2
C.	0.5	6
D.	2.0	3

14. Isotopes are nuclides with the same number of

A. protons but different number of electrons B. protons but different number of neutrons

C. neutrons but different number of protons D. electrons but the same number of neutrons

15. Given that $^{120}_{80}X$ is the symbol for a nuclide, the number of neutrons is

A. 40 B. 80 C. 120 D. 200

16. The process by which a substance emits radiations spontaneously on its own is called

A. radiation B. photoelectric effect C. radioactivity D. thermionic emission

17. When the nucleus of a radioactive atom loses an alpha particle, the atomic number

A. remains the same B. decreases by two

C. increases by one D. decreases by four

18. Which one of the following radiations is from the nucleus of a radioactive atom?

A. cathode rays B. infra-red rays C. gamma rays D. ultraviolet rays

19. Which of the following radiations are attracted towards the negative plate in an electric field?

A. beta particles B. alpha particles C. gamma rays D. neutron

20. In the equation $^{234}_{90}X \longrightarrow {}^{234}_{91}Y + P$. P is likely to be

A. an alpha particle B. a beta particle C. a gamma ray D. a neutron

Answers

1	B	5	A	9	B	13	D	17	B
2	C	6	A	10	B	14	B	18	C
3	D	7	C	11	D	15	A	19	B
4	A	8	D	12	B	16	C	20	B

THERMIONIC EMISSION:

This is the process by which electrons are emitted from the metal surface by application of heat energy.

Applications of thermionic emission:

Thermionic emission can be applied in the following devices;

- Diode valves.
- Cathode ray tube.
- Cathode ray oscilloscope.
- X-ray tube.

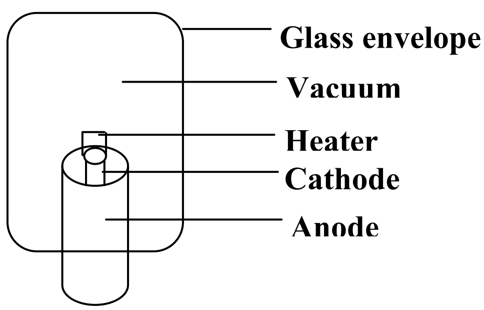
The diode valve:

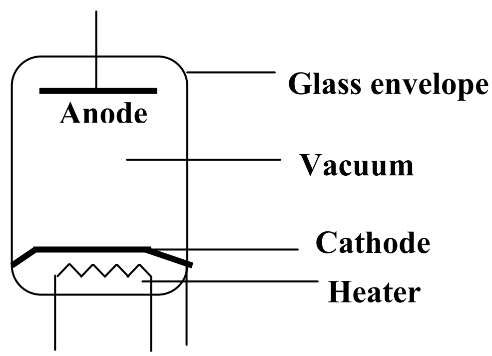
This is an electrical device that conducts electricity in one direction only. There are two types of diodes and these are

i) Semi-conductor diode.
ii) Vacuum diode.

Thermionic diode valve:

This is an electrical device that uses the principle of thermionic emission. This is some times referred to as vacuum diode.

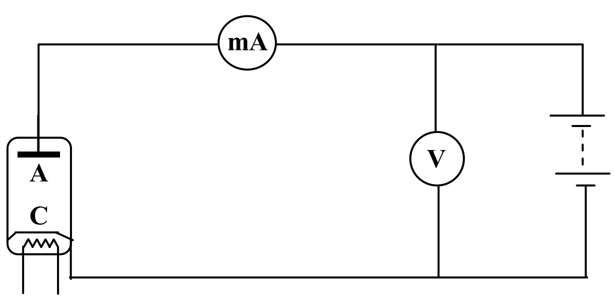




It consists of the following;

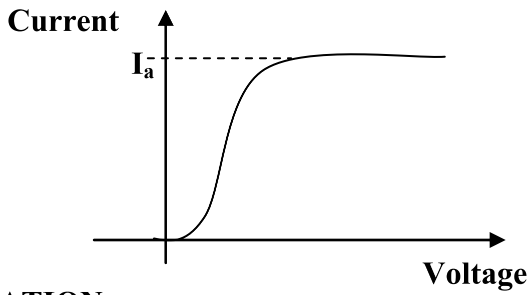
i) Evacuated glass envelope to prevent electrons from colliding with air molecules.
ii) The anode which accelerates electrons emitted from the heated cathode.
iii) The cathode which emits electrons thermionically.
iv) The heater which heats the cathode electrically.

Action of a diode:



- When the cathode, C is heated, it emits electrons by thermionic emission.
- When no voltage is applied across the anode and the cathode, the emitted electrons stay around the cathode.
- If the anode, A is positive with respect to the cathode, C, the electrons from the space charge are attracted to the anode and this causes the flow of current.

- The number of electrons emitted from the cathode depends on the voltage, that is the higher the voltage the higher the temperature and more electrons are emitted hence the higher the current in the circuit. When the voltage increases the current increases until its maximum value, I_a where any increase in voltage will not increase the current. This maximum value is called **saturation current.**

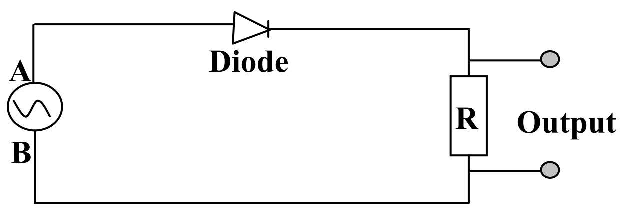


RECTIFICATION:

This is a process of changing an alternating current to direct current by use of a diode. There are two types of rectification and these are;

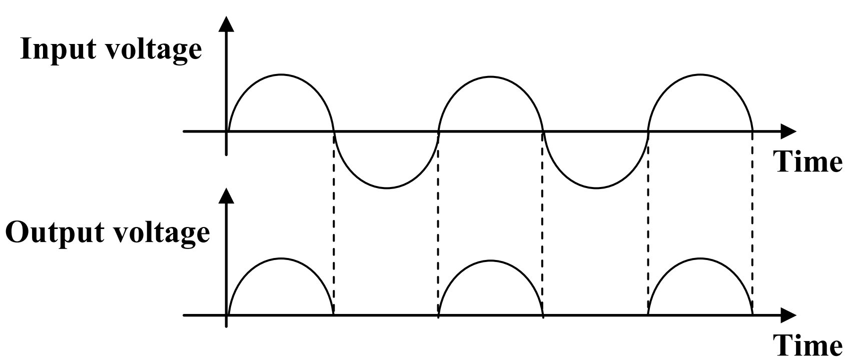
i) Half wave rectification
ii) Full wave rectification

Half wave rectification:



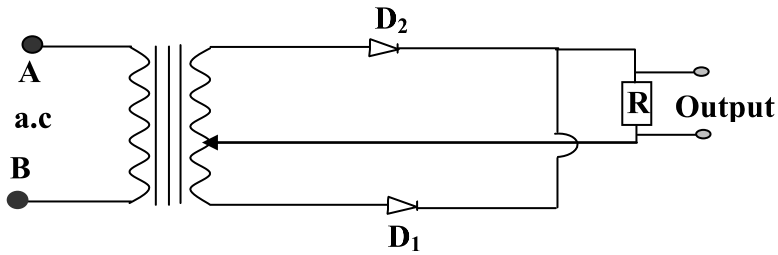
- During the first half of the cycle when A is positive with respect to B, the anode is positive with respect to the cathode and diode conducts.
- Electrons are attracted to the anode and current flows through R.
- During the next half of the cycle when B is positive with respect to A, the anode is negative with respect to the cathode and the diode does not conduct.
- No electrons are attracted to the anode and therefore no current flows through R.
- Hence current flows through R during only one half of the cycle when A is positive with respect to B.

The graph of voltage against time for half wave is as shown below.



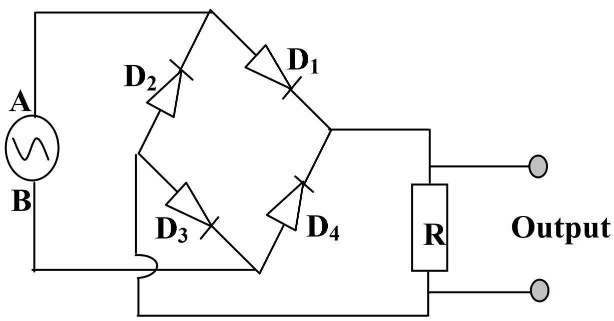
Full wave rectification:

a) Using two diodes:



- During the first half of the cycle when A is positive with respect to B, diode D_2 conducts and diode D_1 does not conduct but current flows through R.
- During the next half of the cycle when B is positive with respect to A diode D_1 conducts and diode D_2 does not conduct but current flows through R.
- Hence current flows through R during both cycles and therefore both cycles are rectified giving a full wave rectification.

b) Using four diodes:



- During the positive half of the cycle when A is positive with respect to B diodes D_1 &D3 conducts and diodes D_2 &D_4 do not conduct but current flows through R.
- During the negative half of the cycle when B is positive with respect to A diodes D_2 &D_4 conduct and diodes D_1&D_3 do not conduct but current flows through R.
- Hence current flows through R during both cycles and therefore both cycles are rectified giving a full wave rectification.
- The graph of voltage against time for full wave is as shown below.

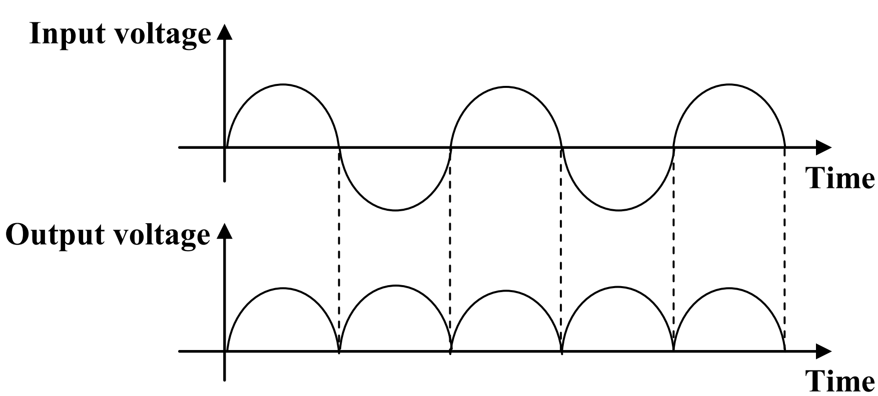


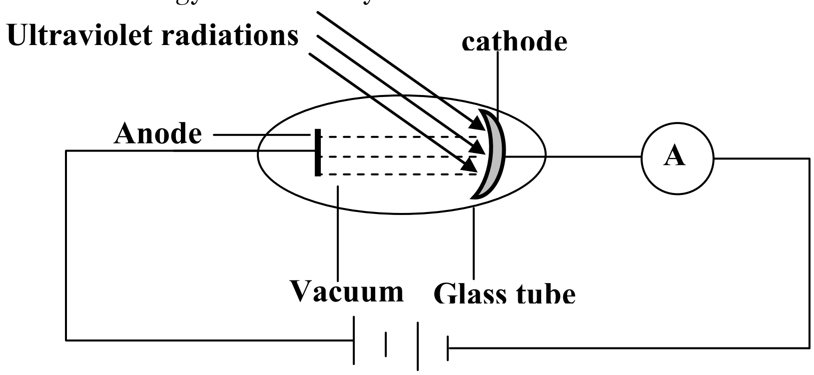
Photo electric emission:

This is the process by which electrons are emitted from the metal surface when exposed to electromagnetic waves of high frequency and shortwave length.

Photo electric emission occurs in phototubes [photoelectric cells]. The electrons emitted are referred to as photoelectrons and the electromagnetic waves used are ultra violet radiations.

Photoelectric cell:

Photoelectric cell is composed of the cathode and the anode enclosed in a vacuum tube. The glass tube is evacuated in order to avoid collision of cathode rays with air molecules which may lead to low current flowing due to loss in kinetic energy of cathode rays.



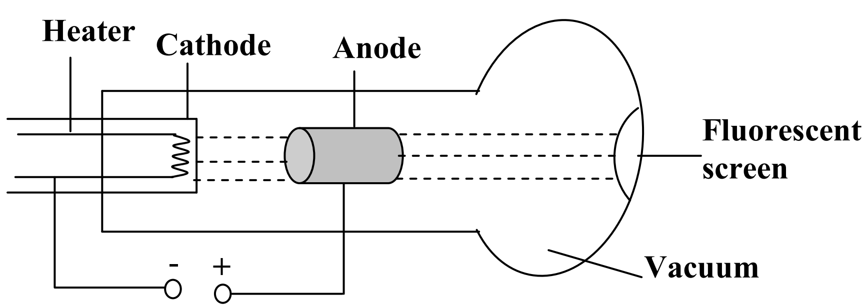
Mechanism of a photoelectric cell:

Electromagnetic radiation is directed on to the cathode and supplies sufficient energy that causes the liberation of electrons. The electrons emitted are then attracted to the anode and the flow of electrons generates a current around the circuit and the ammeter deflects. The amount of the current is proportional to the intensity of the radiation. The stream of electrons flowing from the cathode to the anode is referred to as cathode rays.

CATHODE RAYS:

These are streams of electrons moving at a very high speed. They are produced from the cathode by thermionic emission. Cathode rays carry energy since they posses speed

Production of cathode rays:



- Cathode rays are produced when the metal cathode is electrically heated using low voltage.
- The cathode rays are then accelerated by the anode which is at a positive potential with respect to the cathode.
- Some of the electrons pass through the anode and a parallel beam of electrons is obtained which is received as spot on the fluorescent screen.
- The tube is evacuated to prevent cathode rays from colliding with air particles hence free movement of cathode rays.

Properties of cathode rays:

- They travel in straight lines.
- They are negatively charged since they are streams of electrons.
- They produce X-rays when stopped by a heavy metal.
- They are deflected by both magnetic and electric fields.
- They possess momentum and energy.
- They cause other materials to give off light [fluorescence].

Applications of cathode rays:

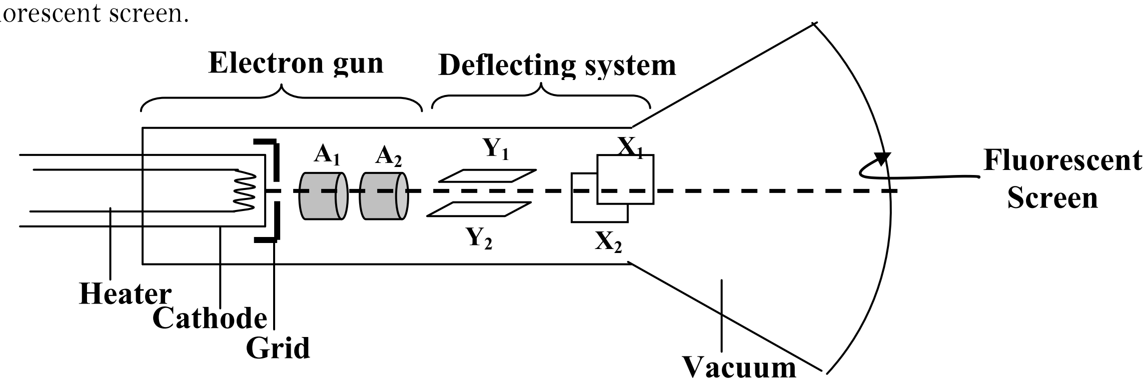
Cathode rays are applied in the following devices;

- Cathode ray oscilloscope.
- X – ray tube.
- Diode.

Cathode Ray Oscilloscope [C.R.O]:

It is an instrument used to study current and voltage wave forms. It has three main parts and these are

i) Electron gun.
ii) Deflecting system.
iii) Fluorescent screen.



A_1A_2 – Anodes X_1X_2 – X – Plates Y_1Y_2 – Y – Plates

Functions of the parts:

1. Electron gun:

It consists of a heater, cathode, grid and Anodes

i) The heater:

This heats the cathode electrically

ii) The cathode:

It emits electrons when heated electrically by the heater

iii) The grid:

It controls the number of electrons reaching the anode and therefore controls the brightness of the spot on the screen. The grid is at a negative potential with respect to the cathode

iv) The anodes:

These are used to accelerate the electrons produced by the cathode. The anodes are at a positive potential with respect to the cathode.

2. Deflecting system:

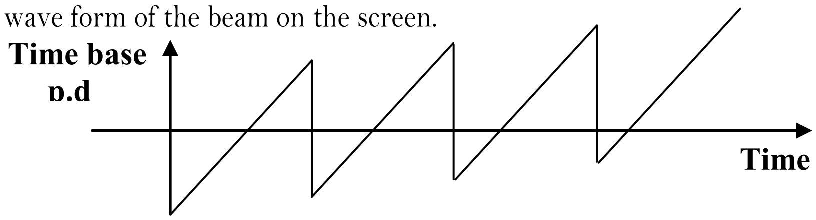
It consists of two pairs of metal plates and these are X – plates and Y – plates. The Y – plates are horizontal and deflect the beam of electrons vertically while the X – plates are vertical and deflect the beam of electrons horizontally.

3. Fluorescent screen:

This is where the spot of electrons is received

4. Time base:

This is a special circuit that generates p.d which rises steadily to a certain value and falls rapidly to zero. This provides a saw-toothed voltage to X-plates. Hence the time base is used to generate a saw-toothed voltage. Vertical motion of the beam causes the beam to travel across the screen and horizontal motion of the beam provides the wave form of the beam on the screen.

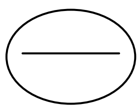
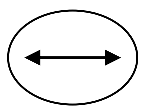


Note:

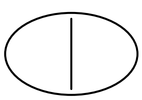
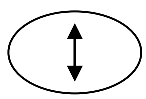
The time base is connected to the X – plates and causes the spot to move from left to right called linear sweep and the spot returns to the left before it starts the next sweep called fly back.

Wave forms on C.R.O

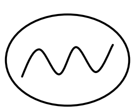
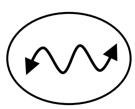
i) A.C on the X-plates and time base off

 **OR** 

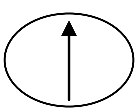
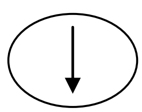
ii) A.C on the Y-plates and time base off

 **OR** 

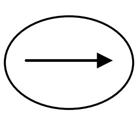
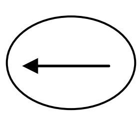
iii) A.C on the Y-plates and time base on

 **OR** 

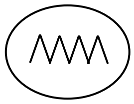
iv) D.C on the Y-plates only and time base off

 **OR** 

v) D.C on the X-plates only and time base off

 **OR** 

iv) D.C on the Y-plates and time base on



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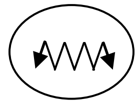
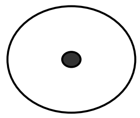


vii) No potential difference is applied to the Y-plates and time base off



Uses of C.R.O:

- It is used to measure potential difference.
- It is used to study wave forms.
- It is used to measure the frequency of the wave.
- It is used to measure the wave length of the wave.
- It is used to measure phase difference between two voltages.
- It is used as a timing device.
- It is used to measure the peak value of alternating and direct current.

Advantages of C.R.O over ordinary ammeter or voltmeter:

- It has infinite resistance therefore draws no current from the circuit.
- It is not affaected by high voltages/currents.
- It measures both alternating and direct voltages.
- It is very accurate.
- It has no coil to burn out.
- It has instantaneous response.

Disadvantages of C.R.O over ordinary ammeter or voltmeter:

- It is bulky.
- It requires skilled personel.
- It is expensive.
- It takes a lot of time to measure voltages.
- It does not give direct reaings.

Advantages of voltmeter or ammter over C.R.O:

- It is portable.
- It does not require skilled personel.
- It is cheap.
- It takes a short time to measure voltages/currents.
- It gives direct reaings.

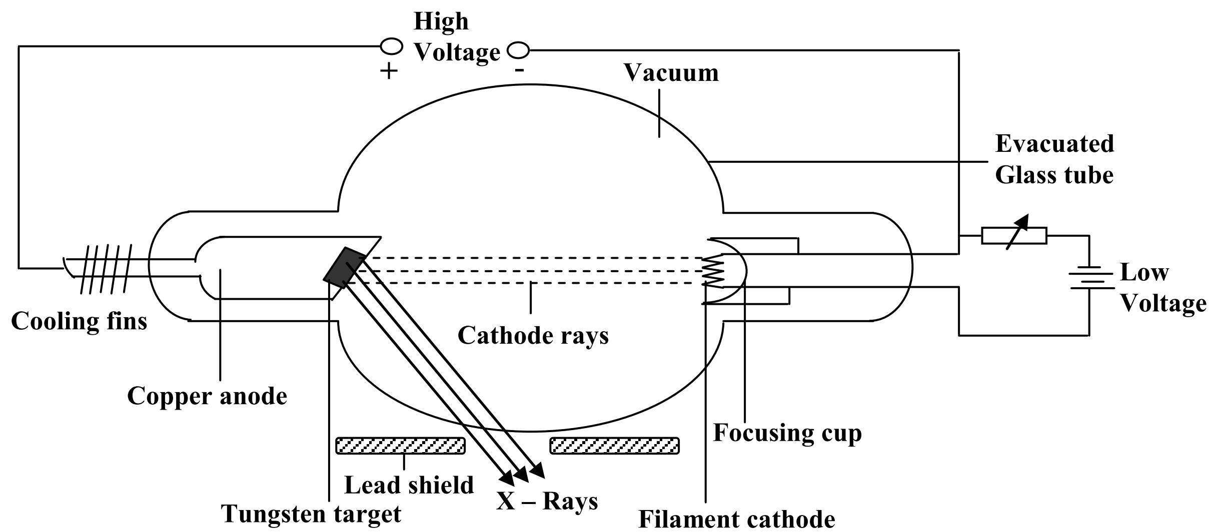
Dadvantages of voltmeter or ammeter over ordinary C.R.O:

- It draws current from the circuit.
- It is affaected by high voltages/currents.
- It measures only direct voltages/currents.
- It is not very accurate.
- It has coil that burns out.

X – RAYS:

These are short wave length electromagnetic waves which are produced when cathode rays are stopped by a heavy metal.

Production of X – Rays [X – Ray Tube]:



Mode of operation:

- A low voltage is applied across the cathode and electrons are emitted thermionically and a concave focusing cathode focuses the electrons onto the target.
- The high potential difference applied across the cathode and the anode accelerates electrons across the vacuum and on reaching the target, 99% of the kinetic energy of electrons is converted into heat while 1% of kinetic energy of elections is turned into X–rays.
- The heat generated at the target is cooled by means of copper cooling fins or running water and then conducted away by conduction and radiation.
- The X – ray tube is evacuated to prevent cathode rays from colliding with air particles [air resistance] hence allowing free movement of electrons in the tube.
- The tungsten is used because it has a high melting point that can withstand the heated generated when electrons hit the target.
- In the X – ray tube the following energy changes take place;

  Electrical energy $\longrightarrow$ Heat energy $\longrightarrow$ Kinetic energy $\longrightarrow$ Electromagnetic energy

Intensity of X- Rays [Quantity]:

Intensity is the strength or power of X – rays. The intensity of X – rays in an X – ray tube is proportional to the number of electrons reaching the target. The number of electrons produced is determined by the filament current. Therefore the higher the filament current the higher the intensity of the X – rays since more electrons are emitted with high filament current.

Penetration power of X – Rays [Quality]:

Penetration power is the ability to enter matter. The penetration power of X – Rays depends on the kinetic energy of electrons reaching the target. The penetration power of X – Rays is determined by the high potential difference across the X – Ray tube. The higher the accelerating voltage the faster the electrons produced and the greater the kinetic energy of electrons hence the higher the penetration power of X–Rays produced.

Types of X- Rays:

There are two types of X – rays and these are

i) Soft X – rays.

ii) Hard X – rays.

Soft X– Rays:

These are types of X – rays produced when a low potential difference is used.

Properties of soft X – Rays:

- They produced by low voltages.
- They have low penetration power.
- They have low energy.
- They have long wave length.
- They are used in X – ray photography for human body.

Hard X – Rays:

These are types of X – rays produced when a high potential difference is used.

Properties of hard X – rays:

- They produced by high voltages
- They have high penetration power.
- They have high energy.
- They have short wave length.
- They are used to destroy cancer cells.

Properties of X – rays:

- They carry no charge.
- They are not deflected by both magnetic and electric fields.
- They readily penetrate matter. Penetration is least with materials of high density.
- They cause ionization of gases.
- They affect photographic paper.
- They travel in straight lines at a sped of light.
- They under go reflection, refraction and diffraction by atoms.
- They are electromagnetic waves of very short wave length.
- They cause other materials to give off light [fluorescence].
- They can produce photoelectric emission

Uses of x – rays:

Uses of X-Rays can be characterized as medical uses and industrial uses

Medical uses:

- They are used to investigate the broken bones in X – ray photography.
- They are used to treat cancerous diseases and other malignant growth in the human body.
- They used to detect the complicated organs of the body.
- They are used to detect tuberculosis of the lungs.
- They are used to diagnose stomach ulcers.

Industrial uses:

- They are used to detect cracks in metal castings and welded joints.
- They are used to study the structure of crystals [crystallography].
- They are used to detect faults in motor tyres.
- They are used to detect defects in paints.

Safety precautions taken when using x – rays:

- A void unnecessary exposure to X – rays.
- The X – ray apparatus should shielded using thick lead.
- The person should wear protective clothing made of thick lead.
- Keep large distance between X-Ray source and people.
- Soft X – rays should always be used on human tissues

Dangers of x – rays:

- They destroy living cells in the body.
- They damage blood cells and eye sight.
- They cause genetic changes [mutation].
- They can cause deep seated burns due to their greater penetration power.

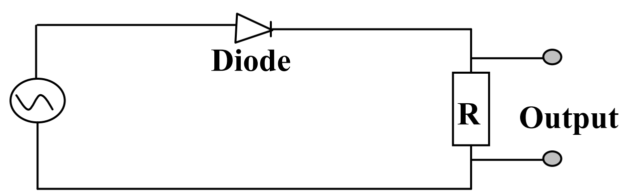
Trial Exercise 2:

1. a) What is a diode?

   b) Draw a graph of current against p.d across the diode and explain the features of your graph.

   c) What is rectification?

   d)



   The diagram above shows a diode in a circuit that can be used to change a.c to d.c. draw a graph for the variation of

   i) Input voltage with time ii) Output voltage with time

   e) What is meant by the term photo electric emission?

   f) Give applications of photo cells

2. a) What are cathode rays

   b) Give the properties of cathode rays

   c) Draw a well labeled diagram of cathode ray oscilloscope (C.R.O) and give the function of each part.

   d) Draw traces that appear on the screen of C.R.O when

   i) The C.R.O is just switched on ii) d.c is connected to the Y-plates

   iii) d.c is connected to the X-plates iv) a.c is connected to the Y-plates

   v) a.c is connected to the X-plates vi) a.c is on the Y-plates and time base on the X-plates

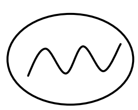
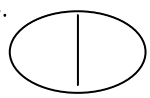
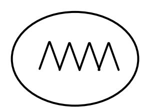
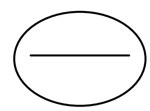
   vii) Time base only connected to X-plates

3. a) i) Draw a well labeled diagram of an X-ray tube and describe how X-rays are produced.
ii) State the energy changes the take place in an X-ray tube
b) State the effect on X-rays produce when
i) The filament current is increased ii) The anode is made more positive
c) Explain how the intensity and penetrating power of X-rays in an X-ray tube may be varied.

4. a) i) State and explain what happens when X-rays are passed above the cap of a positively charged gold leaf electroscope.
ii) Would your observation and explanation in (a) (i) above be different if the gold leaf electroscope is negatively charged.
b) Briefly explain how X-rays may be used to locate the broken part of a bone.
c) State and explain what happens when X-rays are directed into a metal block like that of lead.

Multiple-choice Exercise:

1. By what process are electrons emitted from the cathode ray oscilloscope
A. thermionic emission B. photoelectric emission
C. secondary emission D. field emission

2. Which of the following diagrams shows the correct display on the screen of the C.R.O when a direct p.d is connected across the y-plates and the time base is switched on?
A.  B.  C.  D. 

3. Which of the following is not true about cathode rays?
A. they are fast moving electrons
B. they are not affected by electric and magnetic fields
C. they carry a charge
D. they are deflected by electric and magnetic fields

4. Which of the following is used to control the brightness of the spot on the screen of a C.R.O?
A. x-plates B. anode C. grid D. cathode

5. The number of rectifiers used in full wave rectification is
A. 1 B. 3 C. 4 D. 5

6. What device could be connected to the secondary of a transformer in order to get a d.c in the output?
A. diode B. resistor C. rheostat D. thermostat

7. Rectification of alternating current means
A. stepping up alternating current by a transformer
B. converting alternating current into direct current
C. stepping down alternating current by a transformer
D. generating alternating current from a dynamo

8. The brightness on the screen of a T.V is determined by
A. darkness in the room B. the size of the screen
C. the direction of the aerial D. the number of electrons reaching the screen

9. The phenomenon by which electrons are released from a metal surface when radiation falls on it is known as
A. radioactivity B. thermionic emission
C. photoelectric effect D. reflection

10. Streams of electrons moving at high speed are called

A. x-rays B. gamma rays C. cathode rays D. alpha particles

11. Which of the following are properties of cathode rays?

i)they travel in straight lines ii) they can penetrate thick sheet of paper

iii) they affect the photographic plate iv) they are deflected by a magnetic field

A. (i), (iii) and (iv) correct B. (i), (ii) and (iv) correct

C. (i), (ii) and (iii) correct D. (iv) only

12. The particles that are emitted from a hot metal surface are called

A. electrons B. neutrons C. protons D. alpha

13. Thermionic emission occurs when

A. fast moving electrons hit the metal B. a metal surface is given heat energy

C. metal surface receives light energy D. a substance undergoes radioactive decay

14. The difference between x-rays and ultraviolet rays is that x-rays have

i) a greater velocity ii) a shorter wave length

iii) a higher frequency iv) more energy

A. (i), (ii) and (iii) correct B. (i) and (ii) correct

C. (ii), (iii) and (iv) correct D. (i), (ii) and (iii) correct

15. The difference between hard and soft x-rays is that

A. hard x-rays travel faster than soft x-rays

B. hard x-rays penetrate more than soft x-rays

C. hard x-rays are less dangerous than soft x-rays

D. soft x-rays are produced at very high potential difference

16. Absorbed electrons from the anode to the cathode produce

A. Voltages B. Energy C. Current D. Explosion of sub-particles

17. The x-plates and y-plates in a C.R.O make up

A. electron gun B. deflection system

C. focusing system D. accelerating system

18. The following are uses of x-rays except

A. treatment of cancer B. preservation of food

C. archeological dating D. detection of flaws in welded joints

19. Rectifiers are used to convert

A. direct current to alternating current

B. alternating current to direct current

C. high voltage to low voltage

D. low voltage to high voltage.

20. The higher the frequency of light,

A. The more electrons ejected C. The faster the electrons are ejected

B. The fewer electrons ejected D. The larger the electrons are ejected

Answers

1	A	5	C	9	C	13	B	17	B
2	C	6	A	10	C	14	C	18	B
3	B	7	B	11	A	15	B	19	B
4	C	8	D	12	A	16	C	20	A

MISCELLANEOUS EXERCISE 7:

1. a) What is meant by the following;

i) Radioactivity

ii) Half-life

b) The following figures were obtained from the reading of a rate metre for the alpha particle emission from Thoron – 220

Time(s)	0	20	40	60	80	100	120	140
Average Counts	96	72	55	45	36	26	20	15

Plot a suitable graph from the readings and obtain the half-life of Thoron – 220

Ans: 52 seconds

c) i) Distinguish between soft x-rays and hard x-rays

ii) Mention two uses of x-rays and briefly describe how they are applied.

2. a) Define the following terms

i) Atomic number

ii) Mass number

b) When lithium is bombarded by Neutrons, a nuclear reaction occurs which is represented by the following reaction.

$$^{6}_{3}Li \quad + \quad ^{1}_{0}n \longrightarrow \; ^{3}_{1}H \quad + \quad P$$

Complete the equation and name P

c) i) Describe the application of radioactivity in determining the age of foils

ii) Give two harmful effects of radioactivity.

d) The half-life of Uranium is 24 days. Calculate the mass of Uranium which remains after 120 days if the initial mass is 64g

Ans: 2g

e) State three differences between alpha particles and gamma rays

3. a) Draw a labeled diagram of x-ray tube

b) i) Using the diagram in (a) above, explain how x-rays are produced

ii) What adjustments will you make while using the x-ray tube to obtain hard x-rays instead of soft x-rays?

c) i) Explain the use of a cooling system in an x-ray tube

ii) What special property has a metal target in the x-ray tube and why

iii) Why are x-rays used in study of crystals?

d) If x-rays have wave lengths ranging from 10^{-8}m and 10^{-10}m. What is the frequency of the hardest x-rays that can be obtained?

Ans: 3×10^{18}Hz

4. a) Give two methods of producing electrons from the metal surface

b) State the effect of each of the following on a fine beam of electrons

i) Electric field

ii) Magnetic field

c) i) Explain briefly how x-rays are produced (diagram not necessary)

ii) Distinguish between soft x-rays and hard x-rays

iii) What precaution should be taken in order to minimize x-rays health hazards

5. a) Define radioactivity

b) i) Name any two particles emitted by radioactive nuclides

ii) State the three differences between the two particles named in (b) (i) above

c) The table below gives the count produced by a radioactive isotope at different times during an experiment

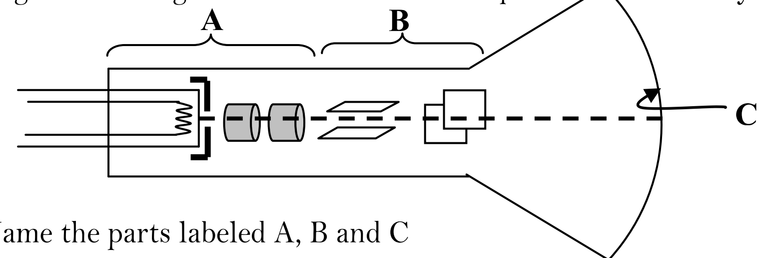
Time(hour)	0.0	1.0	1.8	2.5	3.0	3.8	4.5	5.5
Counts rate(min^{-1})	1816	1376	1096	896	776	616	516	416

i) Given that a back ground count of 16 counts per minute was recorded throughout the experiment, plot a suitable graph and use it to determine the half-life of the isotope

ii) What is the count rate after 9.6 hours?

Ans: i) 2.6 hours ii) 125 per minute

6. The diagram in the figure below shows the main parts of a cathode ray oscilloscope (C.R.O)



a) i) Name the parts labeled A, B and C

ii) Why is a C.R.O evacuated?

b) i) Describe briefly the principle of operation of C.R.O

ii) How is the bright spot formed on the screen of a C.R.O?

c) Use diagrams to show what is observed on the screen of a C.R.O when

i) The C.R.O is switched on and no signal is applied on the Y-plates

ii) The time base is switched on and no signal is applied to the Y-plates

iii) An alternating signal is applied to the Y-plates while the time base is switched off

d) Give two uses of C.R.O

7. a) i) State the necessary conditions for production of x-rays

ii) Distinguish between hard x-rays and soft x-rays

b) i) Draw a labeled diagram of an x-ray tube

ii) Describe how the penetration power of the x-rays produced by the tube may be adjusted

iii) Mention two applications of x-rays

c) What is meant by the following?

i) Radioactivity

ii) Half-life

d) A radioactive substance is found to have a half-life of 5 days. If after 15 days, 125g of it is remaining, what amount was present at the beginning?

Ans: 1000g

8. a) What are x-rays

b) With the aid of a labeled diagram, describe the structure and operation of x-ray tube

c) Explain briefly how each of the following can be increased in an x-ray tube

i) Intensity of x-rays

ii) Penetrating power of x-rays

d) State four ways in which x-rays are similar to gamma rays

e) Give two biological uses of x-rays

9. a) i) Distinguish between nuclear fission and nuclear fusion

ii) State one example where nuclear fusion occurs naturally

b) State one use of nuclear fission

c) The following nuclear reaction takes place when a neutron bombards a sulphur atom

$$^{34}_{6}S \quad + \quad ^{1}_{0}n \longrightarrow \ ^{a}_{b}Y$$

i) Describe the composition of the nuclide, Y formed

ii) The nuclide, Y decays by emission of an α-particle and a γ-ray. Find the changes in mass number and atomic number of the nuclide, Y

iii) State two properties of α-particles

d) The half-life of the isotope, Cobalt-60, is 5 years. What fraction of the isotope remains after 15 years?

Ans: $\frac{1}{8}$

e) State i) One medical use of radioisotopes

ii) Two ways of minimizing the hazardous effects of radiation from radioactive materials

10. a) Define half-life of a radioactive substance

b) The mass of a radioactive substance decays to $\frac{1}{16}^{th}$ of its original mass after 16 days. What

i) Is its half-life

ii) Fraction of the original mass will have decayed after 20 days

Ans: i) 4 days ii) $\frac{31}{32}$

c) Given the reaction $^{232}_{90}X \xrightarrow[A]{} \ ^{228}_{88}Y \xrightarrow[B]{} \ ^{228}_{89}Z \xrightarrow[C]{} \ ^{228}_{89}Z$

i) Indentify the particles or radiations A, B and C emitted in the decay process shown above

ii) State two differences between radiations A and B

iii) Name two health hazards of radioactivity

d) What is the difference between nuclear fission and nuclear fusion?

11. a) Define the following terms

i) Atomic number ii) Mass number iii) Isotopes

b) A radioactive nucleus decays by emission of alpha particles

i) What is an alpha particle?

ii) What changes occur in mass number and atomic number when an alpha particle is emitted?

iii) State any three differences between alpha particles and beta particles

c) The table shows the count rates of a certain radioactive material

Time(hour)	0	1	3	4	7	9
Counts rate(min^{-1})	6400	5380	3810	2700	1910	1350

Plot a suitable graph and use it to find half-life of the material.

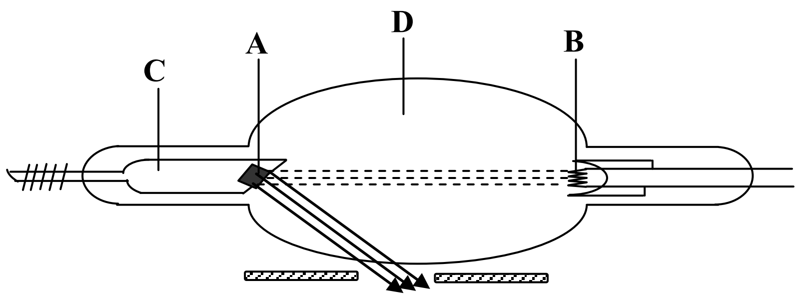
Ans: 3.2 hours

12. a) What is meant by the terms;

i) Isotopes
ii) Atomic number
b) i) Name and state the nature of emissions from radioactive nuclides
ii) What effect does each of the emissions have on the parent nuclide?
c) A radioactive sample has a half-life of 3×10^3 years
i) What does the statement half-life of 3×10^3 years mean?
ii) How long does it take for three-quarters of the sample to decay?
Ans: ii) 6.0×10^3 years
d) Give two uses of radioactivity.

13. a) A radioactive nuclide decays by emission of two alpha particles and two beta particles to nuclide, Y
i) What is meant by radioactive nuclide?
ii) Give three differences between alpha and beta alpha particles
iii) State atomic number and mass number of Y
b) What precautions would have to be taken when handling radioactive materials?
c) A certain radioactive material contains 2.7×10^{24} atoms. How many atoms will have decayed after 32000 years if the half- life of the material is 800years?
Ans: 2.53125×10^{24} atoms.
d) Explain briefly one industrial application of radioactivity.

14. The figure below shows the main parts of an x-ray tube



a) Name the parts labeled A, B, C and D
b) List in order the energy changes which occur in the x-ray tube
c) Describe one industrial use of x-rays
d) i) What is meant by the half-life of a radioactive material
ii) The activity of a radioactive source decreases from 4000 counts per minute to 250 counts per minute in 40 minutes. What is the half-life of the source?
iii) A carbon source of half life 6 days initially contains 8×10^6 atoms. Calculate the time taken for 7.75×10^6 atoms to decay.
Ans: ii) 10 minutes **iii) 30 days**

15. a) Define the following terms as used in nuclear reactions
i) Fusion
ii) Fission
iii) Activity
b) Describe a simple model of an atom
c) Uranium, U has a mass number of 238 and atomic number of 92. It undergoes radioactive decay by emission of an alpha particle to form element X.

i) Write down a nuclear equation reaction that takes place

ii) State the mass number and atomic number of X

Ans: ii) Mass Number = 234, Atomic Number = 90

d) i) What is meant by half life of radioactive substance

ii) The count rate of a radioactive isotope fall from 600 counts per second to 75 counts per second in 75 minutes. Calculate the half-life of the radioactive isotope.

Ans: ii) 25 minutes

16. a) A radio active nuclide $^{236}_{92}U$ decays by emission of two alpha particles and two beta particles to a nuclide Y

i) What is meant by a radioactive nuclide?

ii) State the mass number and atomic number of Y

iii) Give four differences between alpha and beta particles

Ans: ii) Mass Number = 234, Atomic Number = 90

b) State four precautions that would have to be taken when handling radioactive materials

c) A certain mass of radioactive material contains 2.4×10^{12} radioactive atoms. How many atoms will have decayed after 3200yearsif the half life of the material is 800 years?

Ans: 2.25×10^{12} atoms

d) Explain briefly one industrial application of radioactivity

e) Briefly describe how full wave rectification can be achieved

17. a) i) What is meant by cathode rays

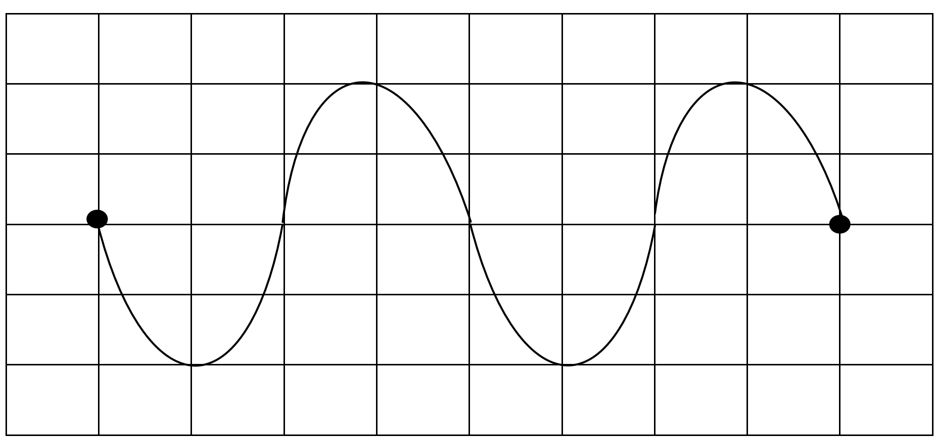
ii) With the aid of a labeled diagram, describe how cathode rays are produced by thermionic effect

b) With reference to the cathode ray oscilloscope, describe

i) The function of the time base

ii) How the brightness is regulated

c) A cathode ray oscilloscope (C.R.O) with time base switched on is connected across a power supply. The waveform shown in the figure below is obtained



The distance between the lines is 1cm

i) Indentify the voltage generated by the power supply

ii) Find the amplitude of the voltage generated if the voltage gain is $5Vcm^{-1}$

iii) Calculate the frequency of the power source if the time base setting on the C.R.O is $5.0 \times 10^{-3}scm^{-1}$

Ans: i) 10V ii) 30Hz

18. a) Describe a simple model of the atom

b) Define the following

i) Isotopes of an element

ii) Atomic number

c) State two differences between an alpha particle and a beta particle

d) i) What is meant by nuclear fission and nuclear fusion

ii) Give one example of where each one occurs

e) The half-life of radioactive substance is 24 days. Calculate the mass of the substance which has decayed after 72 days if the original mass is 0.64g.

Ans: 0.56g

19. a) Define the following terms

i) Atomic number

ii) Mass number

b) A radioactive nuclide $^{42}_{19}Y$ decays by emission of both alpha & gamma radiations to a nuclide X

i) Write a balanced equation for the nuclear reaction

ii) Give three differences between beta and alpha particles

c) The table below shows the count rate of a certain radioactive material

Time(hour)	0	1	3	4	7	9
Counts rate(min^{-1})	6400	5380	3810	2700	1910	1350

Plot a suitable graph and use it to find

i) Half-life of the material

ii) The count rate after 6 days

Ans: i) 3.2 hours ii) 1745 per minute

d) State conditions required for each of the following to occur

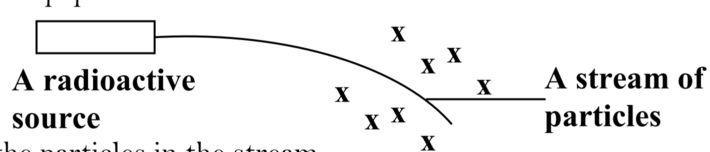
i) Fission

ii) Fusion

20. a) i) Name the particles emitted by radioactive nuclides

ii) Give two properties common to the particles named in (i) above

b) A stream of particles from a radioactive source passes through a magnetic field directed into the plane of the paper as show below



i) Indentify the particles in the stream

ii) Sketch a diagram to show the path of the particles in an electric field

c) i) Define half life

ii) x grams of a radioactive material of half life of 3 weeks, decays and 5.12g remains after 15 weeks. Determine the value of x

Ans: 163.84g

d) i) Distinguish between the terms fusion and fission.

ii) State two conditions necessary for each to occur.

SCIENTIFIC DEFINITIONS:

MECHANICS DEFINITIONS:

- **Physics:** This is the branch of science that deals with matter in relation to energy.
- **Matter:** This is anything that occupies space and has weight.
- **Energy:** This is the ability to do work.
- **Fundamental quantities:** These are quantities which cannot be expressed in terms of other quantities.
- **Derived quantities:** These are quantities which can be expressed in terms of fundamental quantities of mass, length and time.
- **Scalar Quantities:** These are quantities that have magnitude only but no direction.
- **Vector Quantities:** These are quantities that have both magnitude and direction.
- **Length:** This is the distance between two points irrespective of the path taken.
- **Time:** This is the measure of duration of an event.
- **Mass:** This is the quantity of matter contained in an object.
- **Area:** This is the measure of the surface of an object.
- **Volume:** This is the amount of space occupied by an object.
- **Weight:** This is the force a body exerts on anything that freely supports it.
- **Density:** This is mass per unit volume of an object.
- **Relative Density:** This is the ratio of density of a substance to density of water.
- **Force:** This is a push or a pull that changes a body's state of rest or uniform motion in a straight line.
- **A newton:** This is a force that gives a body of mass one kilogram an acceleration of one metre per second squared.
- **Centripetal force:** This is the force that keeps a body moving in a circle and is directed towards the centre of the circle.
- **Up-thrust:** This is the upward force acting on a body immersed in a fluid.
- **Magnetic force:** This is a push or a pull exerted by a magnet.
- **Cohesion:** This is the force of attraction or repulsion between molecules of the same substance.
- **Electrostatic force:** This is a push or pull exerted by charged bodies.
- **Adhesion:** This is the force attraction or repulsion between molecules of different substances.
- **Viscous drag:** This is the force that opposes motion of a body in a fluid.
- **Gravitational force:** This is the force that pulls bodies towards the centre of earth.
- **Resultant force:** This is a single force that has the same effect as two or more force acting on a body.
- **Friction:** This is the force that opposes relative motion between two surfaces in contact.
- **Static friction:** This is the frictional force between bodies tending to slide against one another.
- **Dynamic friction:** This is the frictional force between two bodies moving relative to one another.
- **Coefficient of friction:** This is the ratio of limiting frictional force to the normal reaction on the body.

- **Limiting friction:** This is the frictional force between two bodies that are about to slide over each other.
- **Work:** This is the product of force and distance moved in the direction of force.
- **A joule:** This is the work done when a force of one newton moves a body through a distance of one metre in the direction of force.
- **Renewable sources of energy:** These are sources of energy that can be re-used to produce other forms of energy.
- **Non-renewable sources of energy:** These are sources of energy that cannot be re used to produce other forms of energy.
- **Kinetic energy:** This is the energy possessed by a body by virtue of its motion.
- **Potential energy:** This is the energy possessed by a body by virtue of its position in the gravitational field.
- **Mechanical energy:** This is the energy possessed by a body by virtue of its motion and its position in the gravitational field.
- **Power:** This is the rate of doing work.
- **Watt:** This is the rate of working of one joule in one second.
- **Pressure:** This is the force acting normally per unit area
- **Pascal:** This is the pressure exerted when a force of one newton is acting normally on an area of one metre squared.
- **Atmospheric pressure:** This is the force acting normally per unit area exerted against a surface by the weight of the air above that surface.
- **Strength:** This is the ability of the material to withstand the applied force before breaking.
- **Stiffness:** This is the ability of the material to resist change of size or shape.
- **Ductility:** This is the ability of a material to be hammered, moulded, bent, stretched and rolled into different shapes without breaking.
- **Brittleness:** This is the ability of a material to break just after elastic limit is reached.
- **Elasticity:** This is the ability of a material to regain its original size or shape when the applied force has been removed.
- **Plasticity:** This is the ability of the material not to regain its original size or shape when the applied force has been removed.
- **Strong material:** This is the material that withstands any applied force without breaking.
- **Stiff material:** This is the material that resists change of size or shape.
- **Ductile material:** This is the material that can be hammered, moulded, bent, stretched and rolled into different shapes without breaking.
- **Brittle material:** This is the material that breaks just after elastic limit is reached.
- **Elastic material:** This is the material that regains its original size or shape when the applied force has been removed.
- **Plastic material:** This is the material that cannot regain its original size or shape when the applied force has been removed.
- **Elastic limit:** This is a point beyond which a material cannot regain its original shape or size.

- **Proportional limit:** This is the point beyond which force applied is not directly proportional to the extension.
- **Yield point:** This is the point corresponding to the maximum stress for plastic deformation.
- **Plastic deformation:** This is the type of deformation in which the material cannot regain its original shape or size.
- **Elastic deformation:** This is the type of deformation in which the material regains its original shape or size.
- **Stress:** This is the ratio of force applied to cross sectional area of the material.
- **Strain:** This is the ratio of extension to original length of the material.
- **Young's modulus:** This is the ratio of tensile stress to tensile strain.
- **Compressional forces:** These are forces that bring about particles of matter to be pressed more closely.
- **Tensional forces:** These are forces that bring about particles of matter to be pulled further apart from one another.
- **A Structure:** This is a makeup which consists of materials joined together in a particular form.
- **A Beam:** This is a large straight piece of material used as a support in a structure.
- **A girder:** This is a piece of material that strengthens a structure.
- **Strut:** This is the girder under compression.
- **Tie:** This is the girder under tension.
- **Shear force:** This is the force needed to fracture the material in a direction parallel to the applied force.
- **Notch:** This is a cut or a weak point in a given material.
- **Concrete:** This is a stone like material which is obtained by carefully proportioned mixture of cement, sand, gravel and water and is left to harden.
- **Reinforced concrete:** This is the concrete combined with steel rods, sisal fibre, bamboo stripes and wood strands.
- **Capillarity:** This is the action by which the surface of a liquid where it is in contact with a solid is elevated or depressed depending on the adhesive and cohesive properties of the liquid.
- **Meniscus:** This is curve formed on a liquid in a capillary tube.
- **Surface tension:** This is the force acting normally per unit length on an imaginary line drawn tangentially on the surface of the liquid.
- **Diffusion:** This is the spreading of molecules from a region of higher concentration to a region of lower concentration.
- **Angle of contact:** This is the angle between the tangent to the surface and the solid surface measured through the liquid.
- **Brownian motion:** This is the random motion of molecules of the fluid.
- **Crystal:** This is a solid substance having a regular form with arranged plane faces.
- **Crystal Cleavage:** This is the tendency of a crystal material to split a long a definite structural planes.
- **Distance:** This is the length between two points.

- **Displacement:** This is the length between two points in a given direction.
- **Speed:** This is the rate of change of distance moved with time.
- **Velocity:** This is the rate of change of displacement moved with time.
- **Uniform speed:** This is the constant rate of change of distance moved with time.
- **Uniform velocity:** This is the constant rate of change of displacement moved with time.
- **Acceleration:** This is the rate of change of velocity moved with time.
- **Uniform acceleration:** This is the constant rate of change of velocity moved with time.
- **Deceleration:** This is the rate of decrease of velocity moved with time
- **Uniform deceleration:** This is the constant rate of decrease of velocity moved with time.
- **Acceleration due to gravity:** This is the rate of change of velocity moved with time for a body falling freely under gravity.
- **Projectile:** This is the body moving under the influence of gravity.
- **Trajectory:** This is the path followed by a projectile.
- **Time of flight:** This is the time the particle spends in motion.
- **Inertia:** This is the tendency of a body to remain at rest or keep moving with uniform motion.
- **Momentum:** This is the product of mass and its velocity.
- **Elastic collision:** This is the type of collision where the colliding bodies separate after collision and both momentum and kinetic energy are conserved.
- **Inelastic collision:** This is the type of collision where the colliding bodies stick together after collision and momentum is conserved but kinetic energy is not conserved.
- **Impulse:** This is the product of force and the time for which it acts on the body.
- **Recoil velocity:** This is the velocity with which a body moves backwards when an explosion occurs.
- **A Machine:** This is a device that enables the force applied at one point to overcome another force placed at some other point.
- **Load:** This is the force a machine must overcome.
- **Effort:** This is the force applied to a machine to overcome the load.
- **Mechanical advantage:** This is the ratio of load to effort.
- **Velocity ratio:** This is the ratio of distance moved by the effort to distance moved by the load.
- **Efficiency:** This is the ratio of useful work done by the machine to work put into a machine expressed as a percentage.
- **A lever:** This is a type of machine with a rigid body capable of turning about a fixed point.
- **First class levers:** These are type of levers where the pivot is between the load and the effort.
- **Second class levers:** These are type of levers where the load is between the pivot and the effort.
- **Third class levers:** These are type of levers where the effort is between the load and the pivot.
- **Pulley:** This is a wheel with a grooved rim.
- **Single fixed pulley:** This is a simple pulley system with a rope passing around the groove of a fixed wheel.

- **Single movable pulley:** This is a simple pulley system with a rope passing around the groove of a movable wheel.
- **Block and tackle pulley:** This is a pulley system where two or more pulleys are combined to form a machine of larger velocity ratio and higher mechanical advantage.
- **An inclined plane:** This is a slope that allows a load to be raised more gradually using a smaller effort.
- **Wheel and axle:** This is a machine with a common axis of rotation.
- **Gears:** This is the type of machine with gears rigidly fixed to the axis and are turned with the axis.
- **Screw:** This is the type of machine used for holding bodies together.
- **Pitch:** This is the distance between two successive threads of the screw.
- **Moment:** This is the turning effect of the force about the fixed point.
- **Moment of a force:** This is the product of force and its perpendicular distance of the line of action of the force from the pivot.
- **Couple:** This refers to two equal and opposite parallel forces whose lines of action do not meet.
- **Centre of gravity:** This is the point of application of the resultant force due to the earth's attraction on it.
- **Equilibrium:** This is when the resultant force on the body is equal to zero and the body does not move.
- **Neutral Equilibrium:** This is when a body is slightly displaced its Centre of gravity does not change position relative to the ground.
- **Stable equilibrium:** This is when a body is slightly displaced its Centre of gravity is raised and the body returns to its original position.
- **Un-Stable equilibrium:** This is when a body is slightly displaced its Centre of gravity is lowered and the body does not return to its original position.
- **Terminal velocity:** This is the constant velocity attained by a body falling vertically in a fluid.
- **Streamline flow:** This is a flow of liquid where successive particles passing any point travel in the same direction and parallel to one another.
- **Turbulent flow:** This is a flow of liquid where successive particles passing any point travel in different directions and is not parallel to one another.

LIGHT DEFINITIONS:

- **Light:** This is a form of energy which is responsible for the sense of sight.
- **Luminous bodies:** These are bodies which produce their own light.
- **Nonluminous bodies:** These are bodies which don't produce their own light.
- **Incandescent bodies:** These are bodies which give off light when hot.
- **Fluorescent bodies:** These are bodies that produce light without being hot.
- **Phosphorescent bodies:** These are bodies that absorb the incident energy falling on them and emit this energy in form of light.
- **Transparent medium:** This is the type of medium which allows almost all the light to pass through it and objects are seen clearly.

- **Translucent medium:** This is the type of medium which allows some of the light to pass through it and objects are not seen clearly.
- **Opaque medium:** This is the type of medium which does not allow any light to pass through it and objects are not seen at all.
- **A ray of light:** This is the direction or the path along which light travels.
- **A beam:** This is a collection of light rays.
- **Parallel beam:** This is the collection of light rays which do not meet or intersect.
- **Convergent beam:** This is the collection of light rays originating from different directions but meeting at one point.
- **Divergent beam:** This is the collection of light rays originating from one point but travel in different directions.
- **Rectilinear propagation of light:** This is the process by which light travels in a straight line when produced from its source.
- **Shadow:** This is an area or space where light cannot reach.
- **Umbra:** This is the region of the shadow where no light reaches at all.
- **Penumbra:** This is the region of the shadow where some light reaches.
- **Eclipse:** This occurs when the sun, the moon and the earth appear in a straight line.
- **Solar eclipse:** This occurs when the moon is between the sun and the earth.
- **Lunar eclipse:** This occurs when the earth is between the moon and the sun.
- **Annular eclipse:** This occurs when the sun is far away from the earth and the moon is between the sun and the earth.
- **Magnification:** This is the ratio of size of the image to size of the object.
- **Reflection of light:** This is the bouncing off of light from the reflecting surface.
- **Regular (Specular) reflection:** This is the type of reflection when a parallel beam incident on a smooth surface is reflected as a parallel beam.
- **Irregular (Diffuse) reflection:** This is the type of reflection when a parallel beam incident on a rough surface is scattered in different directions.
- **Incident ray:** This is the ray of light from the source falling onto the reflecting or refracting surface.
- **Reflected ray:** This is the ray of light which bounces off from the reflecting surface.
- **Refracted ray:** This is the path along which light travels in another medium after changing direction.
- **The normal:** This is the line perpendicular to the reflecting surface or given media.
- **Angle of incidence:** This is the angle between the incident ray and the normal at the point of incidence.
- **Angle of reflection:** This is the angle between the reflected ray and the normal at the point of incidence
- **Angle of refraction:** This is the angle between the refracted ray and the normal at the point of incidence.

- **Glancing angle:** This is the angle between the incident ray and the reflecting surface at the point of incidence.
- **Angle of deviation:** This is the angle between the original direction of the ray and the reflected ray at the point of incidence.
- **Deviation:** This is the change of direction of the ray on striking the reflecting or refracting surface.
- **Centre of curvature of the mirror:** This is the center of the sphere of which the mirror forms apart.
- **Radius of curvature of the mirror:** This is the distance between the center of curvature and the pole of the mirror.
- **Pole of the mirror:** This is center point of the mirror.
- **Aperture of the mirror:** This is the width of the mirror.
- **Principal axis of the mirror:** This is the line joining the center of curvature to the pole of the mirror through its principal focus.
- **Principal focus of the mirror:** This is the point on the principal axis to which rays parallel and close to the principal axis converge and appear to diverge after reflection from the mirror.
- **Principal focus of a converging mirror:** This is the point on the principal axis to which rays parallel and close to the principal axis converge after reflection from the mirror.
- **Principal focus of a diverging mirror:** This is the point on the principal axis to which rays parallel and close to the principal axis appear to diverge after reflection from the mirror.
- **Focal length of the mirror:** This is the distance between the principal focus and the pole of the mirror.
- **Virtual image:** This is the image formed by apparent intersection of rays.
- **Real image:** This is the image formed by actual intersection of rays.
- **Refraction:** This is the bending of light ray as it moves from one medium to another medium of different optical densities.
- **Refractive index:** This is the ratio of sine of angle of incidence to sine of angle of refraction for light moving from air to any other given medium.
- **Total internal reflection:** This is a phenomenon which occurs when light is moving from a denser medium to a dense medium and the angle of incidence is greater than the critical angle.
- **Critical angle:** This is the angle of incidence in a denser medium for which its angle of refraction in a dense medium is ninety degrees.
- **Lens:** This is a spherical surface of transparent material.
- **Principal axis of the lens:** This is the line joining the principal focus to the optical center of the lens.
- **Optical center of the lens:** This is the center point between the poles of the lens.
- **Poles of the lens:** These are center points of the surfaces of the lens.
- **Principal focus of the lens:** This is the point on the principal axis to which rays parallel and close to the principal axis converge and appear to diverge after refraction from the lens.

- **Principal focus of a converging lens:** This is the point on the principal axis to which rays parallel and close to the principal axis converge after refraction from the lens.
- **Principal focus of a diverging lens:** This is the point on the principal axis to which rays parallel and close to the principal axis appear to diverge after refraction from the lens.
- **Focal length of the lens:** This is the distance between the principal focus and the optical center of the lens.
- **Power of the lens:** This is the reciprocal of its focal length in meters.
- **Optical instruments:** These are instruments that change the visual angle.
- **Visual angle:** This is the angle subtended by an object at the eye.
- **Accommodation:** This is changing of the focal length of the eye lens to focus the image of an object.
- **Short sight (Myopia):** This is a defect of the eye whereby a person cannot see far objects clearly but can only see nearby objects clearly.
- **Long sight (Hypermetropia):** This is the defect of the eye whereby a person cannot see nearby objects clearly but can see far objects clearly.
- **Astigmatism:** This is the defect in the eye or in a lens caused by a deviation in a spherical curvature that results in distorted images as light rays are prevented from meeting a common focus.
- **Dispersion:** This is the splitting of white light into its constituent colours by the prism.
- **Spectrum:** This is the band of colours of white light formed on the screen after passing through the prism.
- **Pure spectrum:** This is the spectrum formed by the prism when the colours do not overlap each other.
- **Rain bow:** This is a phenomenon that is caused by reflection, refraction and dispersion of light in water droplets resulting in a spectrum of light appearing in the sky.
- **Primary colours:** These are colours that cannot be obtained by mixing any other colours.
- **Secondary colours:** These are colours that can be obtained by mixing two primary colours.
- **Complementary colours:** These are colours when added together a white colour is produced.
- **Filter:** This is a transparent material which absorbs other colurs but allows its own colour to pass through it.

WAVES DEFINITIONS:

- **A wave:** This is a disturbance in the medium which transfers energy from one point to another without causing any permanent displacement of medium itself.
- **Oscillations:** This is a to and fro movement.
- **Frequency:** This is the number of oscillations made per second.
- **Period:** This is the time taken to complete one oscillation.
- **Hertz:** This is the frequency of one oscillation made in one second.
- **Amplitude:** This is the maximum displacement from undisturbed position of the wave.
- **Crest:** This is the point of maximum displacement from undisturbed position of the wave.
- **Trough:** This is the point of minimum displacement from undisturbed position of the wave.
- **Wave length:** This is the distance between two successive crests or troughs.

- **Wave form:** This is the shape of the wave.
- **Phase:** This is the time of the wave in comparison with another wave.
- **Mechanical wave motion:** This is a mechanism by which energy is transferred from one point to another through a material medium.
- **Electromagnetic waves:** These are waves made up of electric and magnetic vibrations of high frequency.
- **Radio waves:** These are waves produced when electrons are accelerated in an aerial.
- **Infrared radiations:** These are radiations that cause the body temperature to rise due to heat energy.
- **Ultraviolet light:** This is a radiation which causes certain metal surfaces to emit electrons and photosynthesis in green plants.
- **Progressive waves:** These are waves which carry energy away from the source of the wave.
- **Transverse wave:** This is a wave where the direction of travel of the particles is perpendicular to the direction of travel of the wave.
- **Longitudinal wave:** This is a wave in which the direction of travel of the particles is the same as the direction of travel of the wave.
- **Compression:** These are regions in which the oscillating particles are close together.
- **Rarefaction:** These are regions in which the oscillating particles are far apart.
- **Stationary wave:** This is the wave formed when two progressive waves of the same speed, frequency and wavelength moving in opposite direction meet.
- **Antinodes:** These are points on a stationary wave which are vibrating with maximum displacement.
- **Nodes:** These are points on a stationary wave which are permanently at rest.
- **Wave front:** This is the surface of the wave form on which every particle transmitting the wave is at the same distance from the source of the wave and in the same state of disturbance.
- **Reflection of the waves:** This is the bouncing off of the waves when they meet a barrier.
- **Refraction of waves:** This is the change of direction or speed of the waves when they move from one medium to another of different optical densities.
- **Diffraction of waves:** This is the spreading of the waves of the same speed, frequency and wavelength around a corner or barrier.
- **Interference:** This is the effect which occurs when two waves of the same speed, frequency and wavelength moving in the same direction meet.
- **Constructive interference:** This is the type of interference which occurs when a crest of one wave meets a crest of another wave.
- **Destructive interference:** This is the type of interference which occurs when a crest of one wave meets a trough of another wave.
- **Sound:** This is a form of energy produced when particles of the medium are set into vibrations.
- **Echo:** This is the reflected sound.
- **Reverberation:** This is the prolonged sound.

- **Ultrasonic sound:** This is the sound of very high frequency which cannot be detected by the human ear.
- **Musical sounds:** These are sounds with uniform and regular vibrations.
- **Music:** This is the sound with uniform and regular frequency.
- **Noise:** This is the sounds produced by sources vibrating at irregular frequency.
- **Pitch of sound:** This is the sharpness or mildness of the musical note.
- **Loudness of sound:** This is the sensation of the musical note in the mind of an individual.
- **Quality of sound:** This is the property that distinguishes a musical from another of the same pitch and loudness.
- **Intensity:** This is the rate of flow of energy per unit area perpendicular to the direction of sound.
- **Fundamental note:** This is the lowest musical note produced by any musical instrument.
- **Fundamental frequency:** This is the lowest predominat frequency note produced by any musical instrument on which other notes are derived from.
- **Harmonics:** These are integral multiples of the fundamental frequency.
- **Overtones:** These are higher frequency musical notes produced that are integral multiples of the fundamental frequency.
- **Resonance:** This occurs when a body is set into vibrations with its own natural frequency as a result of vibrations received from another body vibrating with the same frequency.

HEAT DEFINITIONS:

- **Heat:** This is the form of energy which flows from one point to another due to temperature difference.
- **Temperature:** This is the average kinetic energy of the molecules in the body.
- **Thermometric property:** This is a physical property which changes continuously and linearly with change in temperature.
- **Fixed point:** This is temperature at which a physical change is expected to occur.
- **Lower fixed point:** This is the temperature of ice-water mixture.
- **Upper fixed point:** This is the temperature at which steam and water exist in equilibrium.
- **Scale of temperature:** This is the scale used to measure the degree of hotness or coldness.
- **Heat transfer:** This is the transition of heat from a hot region to a cold region.
- **Conduction:** This is the transfer of heat through matter from a region of high temperature to a region of low temperature without the movement of matter as a whole.
- **Convection:** This is the transfer of heat through fluids from a region of high temperature to a region of low temperature b with the movement of the fluid as a whole.
- **Radiation:** This is the transfer of heat from one place at high temperature to another of low temperature by means electromagnetic waves.
- **Green house effect:** This is used in providing appropriate conditions for plants in cold regions.
- **Sea breeze:** This is cool air which blows from the sea to inland during day time.
- **Land breeze:** This is warm air which blows from inland to the sea at night.
- **Thermal expansion:** This is the increase in size of matter in all directions when matter in heated.

- **Anomalous expansion of water:** This is an abnormal property of water where by water expands instead of contracting when the temperature rises from 0^oC to 4^oC and becomes less dense.
- **Bimetallic strip:** This is formed when two metals of different expansivity are riveted together.
- **Heat capacity:** This is the heat required to raise the temperature of a body by one kelvin.
- **Specific heat capacity:** This is the heat required to raise the temperature of one kilogram mass of a body by one kelvin.
- **Calorimetry:** This is the method used in measurement of heat flow.
- **Latent heat:** This is the heat required to change the state of a substance without change in temperature.
- **Latent heat of fusion:** This is the heat required to change the state of a substance from solid to liquid without change in temperature.
- **Latent heat of vaporization:** This is the heat required to change the state of a substance from liquid to vapour without change in temperature.
- **Specific latent heat:** This is the heat required to change the state of one kilogram mass of substance without change in temperature.
- **Specific latent heat of fusion:** This is the heat required to change the state of one kilogram mass substance from solid to liquid at constant temperature.
- **Specific latent heat of vaporization:** This is the heat required to change the state of one kilogram mass substance from liquid to vapour without change in temperature.
- **Gas:** This is the state of a substance above its critical temperature.
- **Ideal gas:** This is a gas whose intermolecular forces of attraction or repulsion are negligible.
- **Real gas:** This is a gas whose intermolecular forces attraction or repulsion are not negligible.
- **Absolute zero temperature:** This is the temperature at which the molecules of the gas have minimum kinetic energy.
- **Triple point of water:** This is the temperature at which pure water, pure melting ice and saturated vapour exist in equilibrium.
- **Vapour:** This is the mass of liquid drops in air.
- **Saturated vapour:** This is the vapour which is in dynamic equilibrium with its own liquid.
- **Unsaturated vapour:** This is the vapour which is not in dynamic equilibrium with its own liquid.
- **Saturated vapour pressure:** This is the pressure exerted by the vapour which is in dynamic equilibrium with its own liquid.
- **Unsaturated vapour pressure:** This is the pressure exerted by the vapour which is not in dynamic equilibrium with its own liquid.
- **Evaporation:** This is the escape of molecules of the liquid from its surface.
- **Boiling:** This is the process which occurs when the saturated vapour pressure is equal to external pressure.
- **Boiling point:** This the temperature at which the saturated vapour pressure is equal to external pressure.
- **Freezing:** This is the process that occurs when a substance changes from liquid state to liquid state at constant temperature.

- **Freezing point:** This is the temperature at which a substance changes from liquid state to solid state.
- **Melting:** This is a process which occurs when a substance changes from solid state to liquid state at constant temperature.
- **Melting point:** This is the temperature at which a substance changes from solid state to liquid state.
- **Dew point:** This is the temperature at which air is saturated with water vapour.

ELECTRICITY DEFINITIONS:

- **Electrostatic electricity:** This is the study of electric charges at rest.
- **Current electricity:** This is the study of electric charges in motion.
- **A conductor:** This is a substance in which electrons are free to move and conducts heat and electricity easily.
- **An insulator:** This is a substance in which electrons are not free to move and does not conduct heat and electricity easily.
- **Electrostatic induction:** This is the method of charging a conductor using the charged body without touching it.
- **Lightening:** This occurs when two oppositely charged clouds meet.
- **Electric field:** This is an area around a charge where an electric force can experienced.
- **Electric flux:** This is the number of electric field lines.
- **Electric field line:** This is the line drawn such that its direction at any point is the direction of electric field line at that point.
- **Neutral point:** This is an area with no electric field lines.
- **Electric cell:** This is a device which is capable of driving an electric charge around the circuit in form of current.
- **An electrolyte:** This is a substance when in solution or molten form conducts electricity.
- **Primary cells:** These are cells which cannot be renewed when exhausted.
- **Secondary cells:** These are cells which can be renewed when exhausted.
- **Polarization:** This is the accumulation of hydrogen bubbles around the copper plate.
- **Local action:** This is when the zinc plate is eaten away due to impurities.
- **Amalgamation:** This is coating zinc with mercury.
- **Zinc amalgam:** This is zinc coated with mercury.
- **Charge:** This is the quantity of electricity that passes any section of a conductor.
- **Charge density:** This is the charge per unit area.
- **A coulomb:** This is the quantity of electricity that passes any section of a conductor in one second when a current of one ampere is flowing through the conductor.
- **Corona discharge (Charge leakage):** This is the electrical discharge brought about by ionization of air surrouding a charged conductor.
- **Current:** This is the rate of flow of charge.
- **Ampere:** This is a constant current which when flowing in two long straight pallel conductors placed one metre apart in a vacuum produces a force of 2×10^{-7}N per metre length between them.

- **Resistance:** This is the opposition to the flow of current with in a conductor.
- **An ohm:** This is the resistance of a conductor in which a current of one ampere flows when a potential difference of one volt is applied across its ends.
- **Potential difference (p.d):** this is the work done to move one coulomb of charge from one to another.
- **A volt:** This is the potential difference between two points when one joule of work is done to move one coulomb of charge from one point to another.
- **Electromotive force (emf):** This is the work done to move one coulomb of charge from one point to another in a circuit in which a cell is connected.
- **Internal resistance of a cell:** This is the opposition to the flow of current with in the cell.
- **Electrical energy:** This is the work done on an electrically charged particle by an electric field.
- **Electrical power:** This is the rate of change of electrical energy.
- **Kilowatt hour:** This is the rate of working of one thousand watts for one hour.
- **Filament:** This is a small coil tungsten wire which becomes white hot when current flows through it.
- **Fluorescent tube:** This is a gas discharge lamp that uses electricity to excite mercury vapour.
- **Switch:** This is a device used for connecting and disconnecting the current.
- **Fuse:** This is a device which cuts off current if too much of it flows.
- **Short circuit:** This occurs when the positive terminal is connected to the negative terminal.

MODERN DEFINITIONS:

- **An atom:** This is the smallest particle of an element that can take part in a chemical reaction.
- **Atomic number:** This is the number of protons in the nucleus of an atom.
- **Atomic mass:** This is the number of protons and neutrons in the nucleus of an atom.
- **Isotopes:** These are atoms of the same element with the same atomic number but different mass numbers and number of neutrons.
- **Isotopy:** This is the existence of an element in more than one form.
- **Radioactivity:** This is the spontaneous disintegration of unstable nucleus to form a stable nucleus with emission of radiations.
- **Alpha particle:** This is a high speed helium nucleus.
- **Beta particle:** This is a high speed electron emitted from the nucleus of radioactive atom.
- **Gamma ray:** This is a high energy electromagnetic radiation of very short wavelength emitted from the nucleus of radioactive atom.
- **Radioactive decay:** This is a spontaneous break down of radioactive nuclide with emission of radiations.
- **Transmutation:** This is the change of an element into another element.
- **Background radiations:** These are ionizing radiations from a variety of natural sources, artificial sources and are always present in the environment.
- **Nuclear fusion:** This is the process by which two light nuclei combine to form a heavy nucleus with a release of energy.

- **Nuclear fission:** This is the process by which a heavy nucleus splits into two light nuclei with release of energy.
- **Activity:** This is the number disintegrations per second.
- **Half-life:** This is the time taken by a radioactive substance to decay to a half its original value.
- **Thermionic Emission:** This is a process by which electrons are emitted from the metal surface by application of heat energy.
- **Photoelectric Emission:** This is a process by which electrons are emitted from the metal surface when exposed to radiation of given frequency.
- **Diode:** This is an electrical device that conducts electricity in only one direction.
- **Rectifier:** This is an electrical device that converts alternating current to direct current.
- **Half wave rectifier:** This is an electronic circuit in which one half-cycle of incoming alternating current changes to direct current output.
- **Full wave rectifier:** This is an electronic circuit in which both half-cycles of incoming alternating current change to direct current output.
- **Rectification:** This is a process of changing alternating current to direct current by use of a diode.
- **Half wave rectification:** This is a process by which one half-cycle of incoming alternating current is converted to direct current output.
- **Full wave rectification:** This is a process by which both half-cycles of incoming alternating current are converted to direct current output.
- **Cathode rays:** These are streams of electrons moving at a very high speed.
- **Cathode ray oscilloscope:** This is a device used to study current and voltage wave forms.
- **Time base:** This is a special circuit that generates potential difference which rises steadily to a maximum value and falls rapidly to zero.
- **X-Rays:** These are short wavelength electromagnetic waves produced when cathode rays are stopped by a heavy metal.
- **Soft X-Rays:** These are x-rays produced when a low potential difference is used.
- **Hard X-Rays:** These are x-rays produced when a high potential difference is used.

MAGNETISM DEFINITIONS:

- **A magnet:** This is a piece of metal that attracts other metals.
- **Ferro magnetic substances:** These are substances which are strongly attracted by a magnet.
- **Diamagnetic materials:** These are magnetic materials that are slightly repelled by a magnetic field.
- **Paramagnetic materials:** These are materials that are slightly attracted by a magnetic field and the material does not retain the magnetic properties when the external field is removed.
- **Non-Ferro magnetic substances:** These are substances which are not attracted by a magnet at all.
- **A pole of magnet:** This is an area on a magnet where the magnetic force is strongest.
- **Magnetic field:** This is the area around a magnet where the magnetic force is experienced.

- **Magnetic field line:** This is the path a magnetic pole follows if it is placed in a magnetic field.
- **Magnetic flux:** This is the number of magnetic field lines.
- **Magnetism:** This is the force exerted by the magnetic field.
- **Magnetic shielding (screening):** This is protecting a delicate instrument from the magnetic fields using a soft iron ring.
- **Magnetic saturation:** This is the point where a magnetic substance cannot be magnetized any more.
- **Neutral point:** This is an area where the resultant magnetic force is zero.
- **Geographic meridian:** This is the vertical plane which passes through the earth's geographic poles.
- **Magnetic meridian:** This is the vertical plane in which a freely suspended magnetic needle sets itself.
- **Angle of declination:** This is the angle between the geographic meridian and the magnetic meridian.
- **Angle of dip:** This is the angle between the horizontal and the magnetic axis of a freely suspended magnet in the magnetic meridian.
- **Soft magnetic materials:** These are magnetic materials which are easily magnetized but do not retain their magnetism.
- **Hard magnetic materials:** These are magnetic materials which are difficult to magnetize and retain their magnetism for a long time.
- **Magnetization:** This is a process by which randomly arranged molecular magnets of a ferromagnetic substance are made to point in one direction.
- **Induced magnetism:** This is the process of magnetizing a magnetic material temporarily by induction.
- **Demagnetization:** This is a process by which randomly arranged molecular magnets of a magnet are made to point in different directions.
- **Electro magnet:** This is the magnet produced when an electric current flows in a solenoid with soft iron core.
- **Eddy currents:** These are currents induced when the magnetic flux linking the coil changes.
- **Current sensitivity:** This is the deflection per unit current.
- **Voltage sensitivity:** This is the deflection per unit voltage.
- **Electromagnetic induction:** This is the process by which an electric current is induced in coil due to the change in magnetic flux linking the coil.
- **Moving coil galvanometer:** This is a device used to detect small currents and potential differences.
- **Self-induction:** This is a process by which an emf is induced due the change of current in the coil itself.
- **Mutual induction:** This is the process by which emf is induced in coil due to change of current in the nearby coil.
- **A generator:** This is a device that converts mechanical energy into electrical energy.

- **An electric motor:** This is a device that converts electrical energy into mechanical energy.
- **Ac transformer:** This is a device used to increase or decrease an alternating voltage.
- **Step up transformer:** This is the type of transformer in which the number of turns in the secondary coil is greater than the number of turns in the primary coil.
- **Step down transformer:** This is the type of transformer in which the number of turns in the secondary coil is less than the number of turns in the primary coil.
- **A multiplier:** This is a resistor of very high resistance.
- **A shunt:** This is a resistor of very low resistance.

SCIENTIFIC LAWS:

- **Laws of friction:**
  - Frictional force is independent of the area of contact but depends on the nature of the surface.
  - Frictional force always opposes relative motion.
  - Frictional force is independent of the relative velocity of the two surfaces in motion.
  - Frictional force is directly proportional to the normal reaction.
- **The principle of conservation of energy:** It states that energy is neither created nor destroyed but changes from one form to another.
- **The principle of transmission of pressure in fluids (Pascal's principle):** It states that pressure applied at any point of an enclosed fluid is transmitted equally throughout the whole fluid.
- **Hooke's law:** It states that the force applied to elastic material is directly proportional to the extension provided elastic limit is not exceeded.
- **Kinetic theory of matter:** It states that matter is made up of tiny particles which are in constant random motion and possess energy.
- **Newton's laws of motion:**
  - Everybody continues in its state of rest or uniform motion in a straight line unless acted upon by external force.
  - The rate of change of momentum is directly proportional to the force applied and takes place in the direction of force.
  - For every action there is always an equal but opposite reaction.
- **The principle of conservation of linear momentum:** It states when two or more bodies collide, their total linear momentum remains constant provided no external force is acting.
- **The principle of moments:** It states that when body is in equilibrium the sum of clockwise moments is equal to the sum of anticlockwise moments about the same point.
- **Archimedes' principle:** It states that when a body is wholly or partially immersed in a fluid it experiences an up-thrust equal to the weight of the fluid displaced.
- **The law of floatation:** It states that a floating body displaces its own weight of the fluid on which it floats.
- **Laws of reflection of light:**
  - Angle of incidence is always equal to angle of reflection.
  - The incident ray, reflected ray and the normal at point of incidence all lie in the same plane.
- **Laws of refraction of light:**
  - The incident ray, refracted ray and the normal at point of incidence all lie in the same plane.
  - The ratio of sine of angle of incidence to sine of angle of refraction is a constant for a ray of light moving from air to any other medium of different optical density.
- **Snell's law:** It states that the ratio of sine of angle of incidence to sine of angle of refraction is a constant for a ray of light moving from air to any other medium of different optical density.
- **The law of reversibility of light:** It states that light will follow exactly the same path if its direction of travel is reversed.

- **Laws of reflection of wave:**
  - Angle of incidence of the wave is always equal to angle of reflection of the wave.
  - The incident wave, reflected wave and the normal at point of incidence all lie in the same plane.
- **Boyle's law:** It states that the volume of the fixed mass of a gas is inversely proportional to its pressure provided temperature is kept constant.
- **Charles' law:** It states that the volume of a fixed mass of gas is directly proportional to its absolute temperature provided pressure is kept constant.
- **Pressure law:** It states that pressure of a fixed mass of a gas at constant volume is directly proportional to its absolute temperature.
- **The law of charges:** It states that like charges repel and unlike charges attract each other.
- **The law of conservation of charge:** Tt states that charge can neither be created nor destroyed but it is transferred from one body to another.
- **Ohm's law:** It states that current flowing through a conductor is directly proportional to the potential difference across its ends provided temperature and other physical factors are kept constant.
- **The law of magnetism:** It states that like poles repel and unlike poles attract each other
- **Domain theory of magnetism:** It states that all magnetic materials are composed of dipoles which are divided into regions and point in different directions.
- **Right hand grip rule:** It states that if the wire carrying current is grasped in the right hand with the thumb pointing in the direction of current then the other fingers will point in the direction of field.
- **Maxwell's cork screw rule:** It states that if the right hand is used to screw a cork screw along the wire carrying current and in the direction of current then the direction of rotation of the screw gives the direction of the field.
- **Fleming's left hand rule:** It states that if the left hand is held with the thumb and the first two fingers mutually at right angles with the first finger pointing in the direction of the field, the second finger in the direction of current then the thumb will point in the direction force
- **Fleming's right hand rule:** It states that if the right hand is held with the thumb and the first two fingers mutually at right angles with the thumb pointing in the direction motion, the first finger in the direction of field then the second finger will point in the direction current.
- **Faraday's law:** It states that the induced emf in coil is directly proportional to the rate of change of the magnetic flux linked with the coil.
- **Lenz's law:** It states that the induced emf flows in a direction so as to oppose the effect causing it.