Thus critical angle is the angle of incidence in optically dense medium when angle of refraction in optically less dense medium is 90^0.

Critical angle, c of a medium of index, n is obtained from $\sin c = \frac{1}{n}$

e.g. for glass of $n = 1.5$, $\sin c = \frac{1}{1.5}$ $\Rightarrow c = 41.8^0$

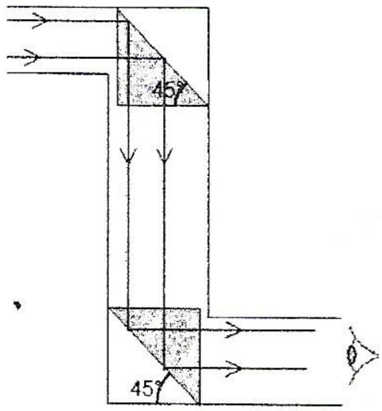
If the angle of incidence is greater than the critical angle, the reflected ray becomes bright. At this point all the light is totally internally reflected. (*Fig. c*)

Thus total internal reflection occurs when

- light travels from an optically dense medium to optically less dense medium.
- angle of incidence in optically dense medium is greater than its critical angle.

Applications of total internal reflection

1. *reflection by prisms in periscopes*



This simple periscope consists of triangular glass prisms at opposite ends of a tube with the longest surfaces parallel to each other and inclined at an angle of 45° to the axis of the tube.

How it works

Parallel rays from a distant object enter normally in the periscope. They are incident on the longest side at an angle of 45° which is greater than critical angle of glass. The rays are totally internally reflected on two prisms and a bright image is observed.

In periscopes prisms are preferred to plane mirrors because

- mirrors absorb some of the incident light and produce fainter images whereas all the incident light is reflected when total internal reflection occurs in prisms.

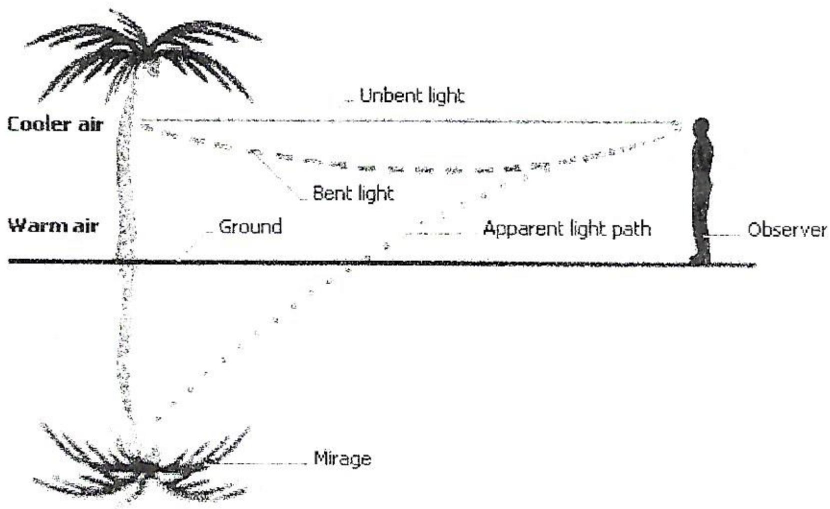
- mirrors form multiple images which are non-existent in prisms
- silvering in plane mirrors wears off with time while no silvering is required in prisms.

2. *Mirages*: mirages are created when light is refracted as it travels through air layers with differing densities due to changes in their temperatures.

On a hot day, air near earth surface is heated and becomes optically less dense than air above. Light from the sky is gradually refracted as it passes from warm to cold air layers. At a point when critical angle of denser air layers is exceeded, all the light is reflected upwards into denser layers.

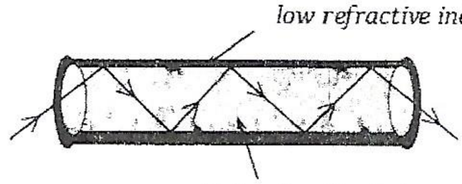
To the observer, the ray seems to point into the ground and a pool of water is seen in the road away from him.

In hot deserts, people may see an inverted image of a tree in a pool of water below the actual tree.



3. Fibre-optics: this is a branch of optics dealing with the transmission of light signals through hair-thin strands of high – quality glass coated with glass of lower refractive index.

   When light signals enter a solid glass obliquely [at an angle that is not a right angle], they are totally internally reflected at the boundary of the tube. After a number of successive total reflections, light emerge from the other end to the receiver (which accepts the transmitted light signal and converts it to an electrical signal).



Uses of fiber-optics

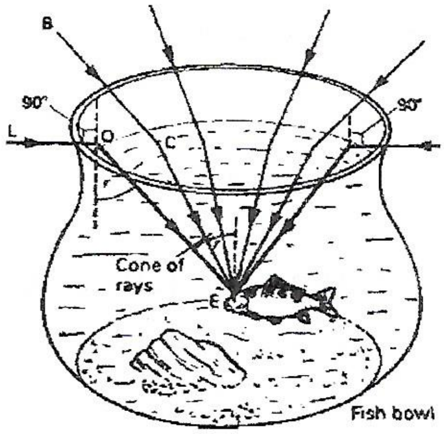
- In communications, they offer vastly increased bandwidths, allowing tremendous amounts of information to be carried quickly from place to place.

They allow signals to travel for long distances without repeaters, which are needed in older type of communication to compensate for reductions in signal strength.

- Medically, glass fibers are used to transmit images of parts of human body that are otherwise difficult to illuminate.
- Fibers have also been developed to carry high-power laser beams for cutting and drilling.

4. Fish-eye view

Rays incident on air-water boundary are refracted as in the figure. At a point when the angle of incidence is 90^0 angle of refraction r is 49^0.



$n_1 \sin i_1 = n_2 \sin r_2$ *where* $n_1 = 1 \quad i_1 = 90^0$

$n_2 = 1.33 \quad$ *and* $r_2 = r\,?$

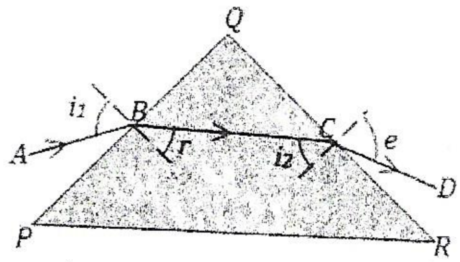
$\Rightarrow \sin 90^0 = 1.33 \sin r \quad \Rightarrow r = 48.75^0 \approx 49^0$

Angle of refraction is 49^0 *(this is critical angle of water)*

Thus rays in the cone of angle 98^0 fall into the fish's eye.

Refraction by triangular prisms

If light falls on one surface, PQ of a prism, it is refracted along BC and the emergent ray CD is no longer parallel to the incident ray AB.



i_1 is the angle of incidence on face PQ,

i_2 is the angle of incidence on face QR,

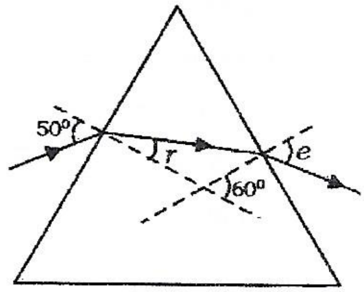
r and e are angle of refraction at faces PQ and QR respectively.

e is also called angle of emergence.

At each point of incidence, $\boxed{n_1 \sin i_1 = n_2 \sin r_2}$

Example

1. The diagram in the figure below shows a ray of yellow light incident at an angle of 50^0 on one side of an equilateral triangular glass prism of refractive index 1.52. Calculate the angles marked r and e



Solution: Using $n_1 \sin i_1 = n_2 \sin r_2$

For air – glass; $n_1 = 1, i_1 = 50^0, r = ?$

$\Rightarrow 1 \sin 50^0 = 1.52 \sin r \quad r = 30.3^0$

Let angle of incidence on second face be i_2

$r + i_2 = 60^0$ *(sum of two interior angles)*

$30.3^0 + i_2 = 60^0 \quad \Rightarrow i_2 = 29.7^0$

For glass – air, $n_1 = 1.52,\ i_2 = 29.7^0,\ r = e = ?, n_2 = 1$

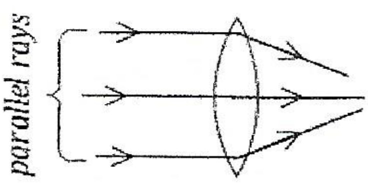
$\Rightarrow 1.52 \sin 29.7^0 = \sin e \quad \Rightarrow e = 48.9^0$

LENSES AND OPTICAL INSTRUMENTS

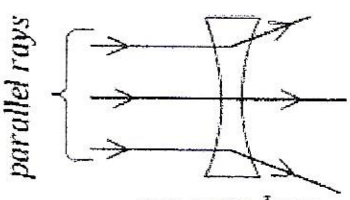
A lens is a transparent substance usually made of glass, with two refracting surfaces. Lenses are used in spectacles, cameras microscopes, telescopes, eyes.

A lens is regarded as a combination of many triangular prisms each refracting light toward its base. Rays incident at the centre of the lens pass through undeviated since prisms at the centre have no refracting angles.

There are two types of lenses – convex (converging) and concave (diverging) lens

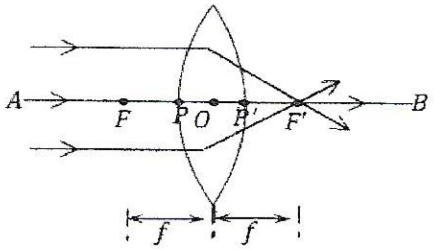


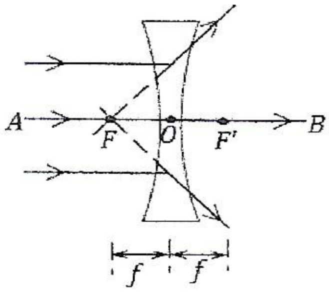
convex lens (converging)



concave lens (diverging)

Terms used





1. *Optical centre,* O is the centre of the lens between the poles of the curved surfaces.
2. The *principal axis* (AB) is a line through the optical centre joining the centres of the curved surfaces of the lenses.
3. *Principal focus* F is a point on the principal axis to which rays parallel to the axis converge at or diverge from after refraction through convex lens and concave lens respectively.
4. *Focal length f* is the distance between the focal point and the optical centre of a lens.

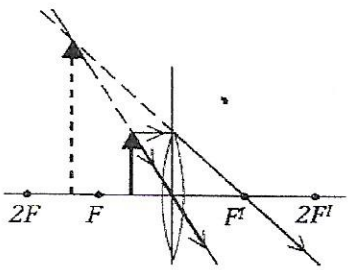
Construction of ray diagrams

(a) For a converging (convex) lens

Key rays:

1. Rays parallel and close to the principal axis converge at focal point, F. (vice versa)
2. Rays through optical centre are not deviated

(i) Object placed between optical centre and focal point



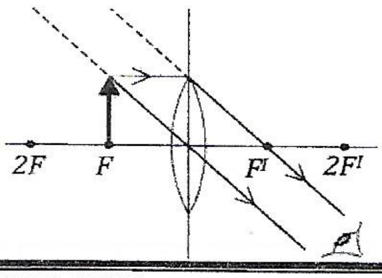
Nature: image formed is

- *Magnified*
- *Erect*
- *Virtual*
- *On same side as the object*

A convex lens in this way acts as a magnifying glass

A magnifying glass is a large convex lens commonly used to examine small objects. The lens bends incoming light so that an enlarged, virtual image of the object appears beyond it. The image is called virtual because it is only perceived by the viewer's brain, and cannot be produced on a screen.

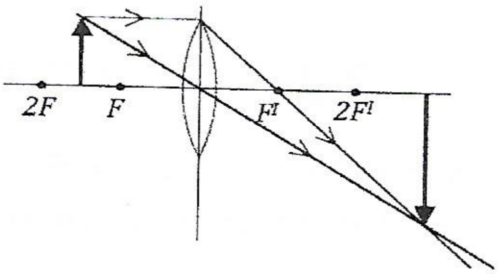
(ii) Object placed at focal point



Nature: image formed is

- *Magnified*
- *Erect*
- *Virtual*

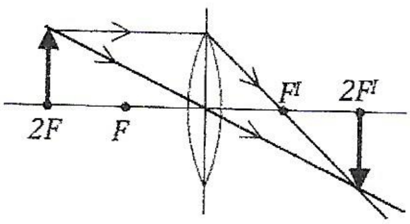
(iii) Object placed between 2F and focal point, F



Nature: image formed is

- *Magnified*
- *inverted*
- *real*
- *at 2F'*

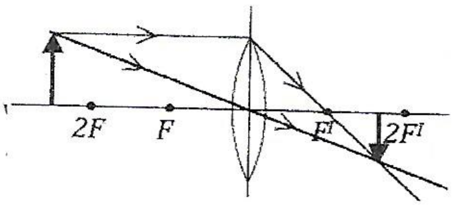
(iv) Object placed at 2F



Nature: image formed is

- *of same size as the object*
- *inverted*
- *real*
- *formed at 2F'*

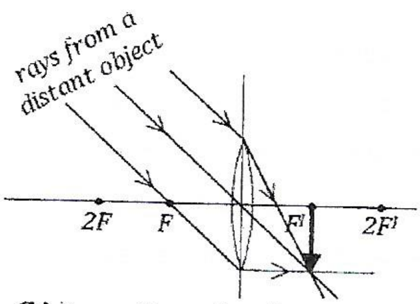
(v) Object placed beyond 2F



Nature: image formed is

- *diminished*
- *inverted*
- *real*
- *between F' and 2F'*

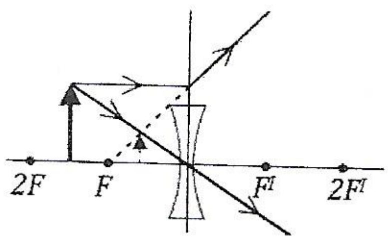
(vi) Object at infinity



Nature: image formed is

- *diminished*
- *inverted*
- *real*
- *at F'*

(b) For a diverging (concave) lens



Nature: image formed is

- *diminished*
- *erect*
- *virtual*
- *between F and optical centre*

Generally, images formed by a diverging lens are always *virtual, erect, diminished* and *formed between optical centre and the focal point,* for all positions of the object.

Magnification of the image by a lens $m = \frac{v}{u} = \frac{h_I}{h_o}$

u is the object distance of height/size h_o

v is the image distance of height h_I

Note: u and v are measured from the optical centre of a lens

Power of a lens: is the reciprocal of its focal length in metres $P = \frac{1}{f}$. f is the focal length of a lens.

S.I units of power of a lens are *diopters* (D).

f is "positive" for a convex lens and "negative" for concave lens.

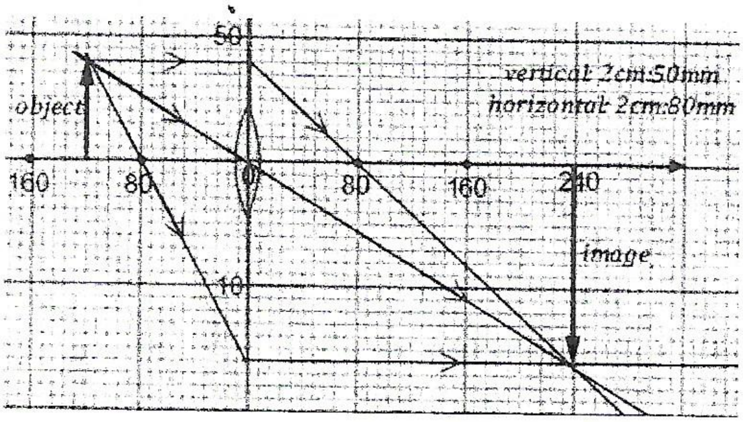
Examples

1. An object is 40 mm high and 120 mm from the centre of the convex lens of focal length 80 mm.

   Find the

   (i) image distance and its height.

   (ii) power of the lens.



From the graph;

Image distance is $240\ mm$

Height of image

$= 16 \times 5 = 80\ mm$

(ii) $f = 80mm = \frac{80}{1000}$

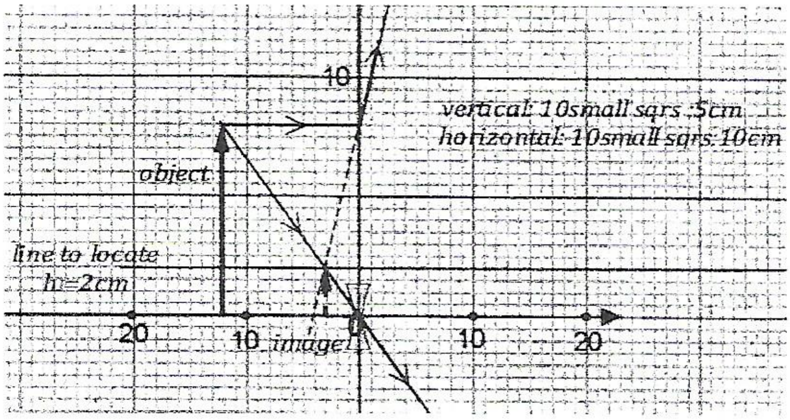
$= 0.0\,8m$

Thus power $P = \frac{1}{f} = \frac{1}{0.08} = 12.5D$

2. An object 8 cm high is placed perpendicularly on the principal axis 12 cm away from a diverging lens. If the height of the image formed is 2 cm, with the aid of a ray diagram, find the

   (i) image distance and

(ii) focal length of the lens.



Location of image:

Draw a horizontal line at $h_I = 2\ cm$

Draw a ray through the optical centre.

Where these intersect, is the where the head of the image is supposed to be.

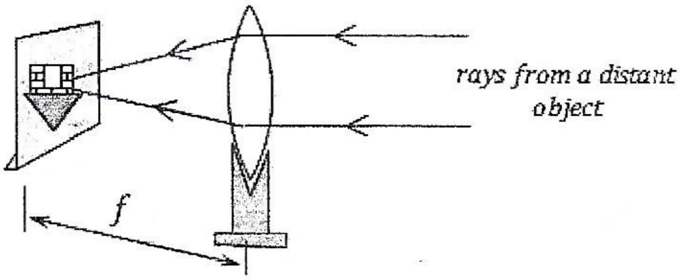
The other ray parallel to the axis passes through this point after refraction. This ray meets the axis at the focal point of the lens. Thus image distance 3cm and the focal length is 4cm

Questions

1. A convex lens forms a real image twice the size of an object, 15 cm from the lens. The focal length of the lens is 10 cm. find the position of the image from the lens.
2. A lens 20 cm from an object produces a virtual image $\frac{2}{3}$ the size of the object. Find the position of the image, the kind of the lens used and its focal length
3. A screen is placed 80 cm from the object. A lens is used to produce an image with magnification 3 on the screen.
   What is the
   (i) distance between the object and the lens,
   (ii) focal length of the lens?

Determination of focal length of a converging lens

1. *Focusing a distant object*



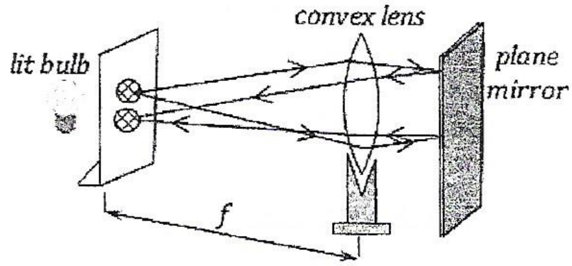
A lens and a screen are arranged as in the figure.

A lens is moved to and fro until a clearly focused image is obtained.

The distance f between the screen and the lens is measured and recorded.

This distance give estimated focal length of the lens.

2. *Plane mirror method*



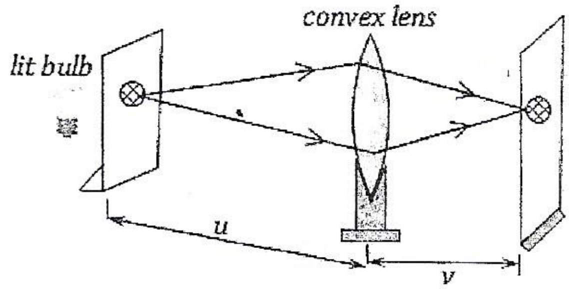
A plane mirror is placed behind a convex lens and an illuminated object in front of the lens.

The lens is moved to and fro until a sharp image is formed alongside the object.

The distance f between the screen and the lens is measured and recorded.

At different positions of the lens, various values of f are obtained and the average value gives focal length of the lens.

3. *Measurement of u and v*



The apparatus is arranged as in the figure.

A lens is placed at a known distance u from the wire gauze.

The screen is moved to and fro until a clearly focused image is observed.

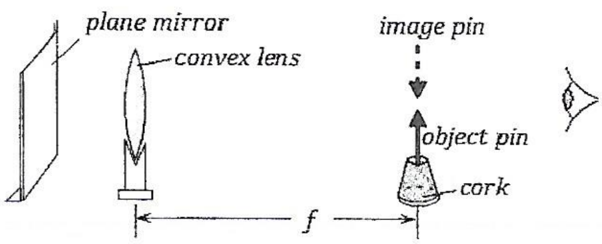
The distance v between the lens and the screen is measured and recorded.

Experiment is repeated for different values of u and values of uv and $(u + v)$ obtained.

A graph of uv against $(u + v)$ is plotted and its slope obtained.

This slope gives focal length f of the lens.

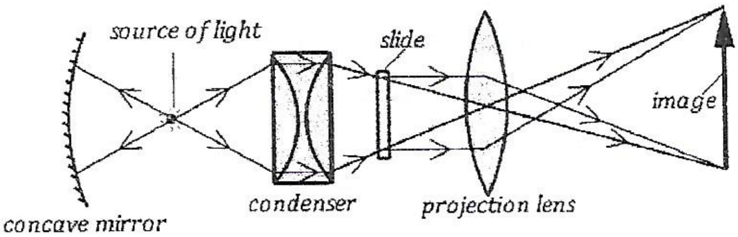
4. *No parallax method*



- A plane mirror is placed behind the convex lens and a corked pin in front with the tip of the pin in line with the centre of the lens
- The pin is moved to and fro until it coincides with its image as seen through the lens.
- The distance, f between the pin and the lens is measured and recorded
- More than two values of f are obtained and the average value gives focal length of the lens.

Application of lenses

(a) Slide projector



The slide is illuminated by a powerful source of light which is placed at the centre of curvature of the concave mirror.

The mirror reflects back the light which would be wasted.

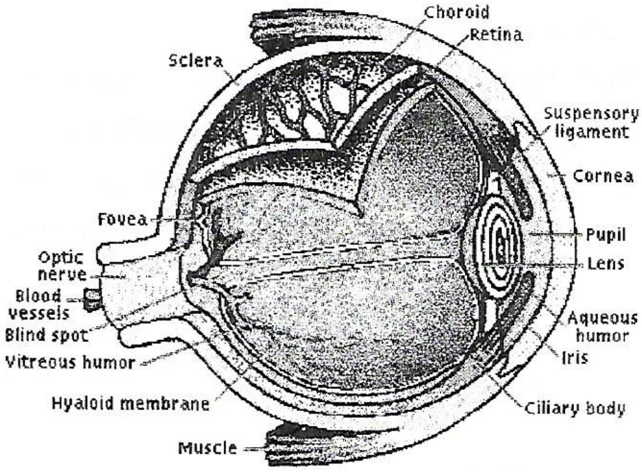
The condenser (combination of Plano – convex lenses) collects and concentrates light onto the slide.

A heater filter inside the condenser (*not shown*) helps to absorb any heat from the source which would melt the slide.

A projection lens moved to and fro forms a sharp, real, erect and magnified image on the screen.

Note: distance from the slide to the lens should be greater than the focal length of the lens so as to form a real image.

(b) The eye



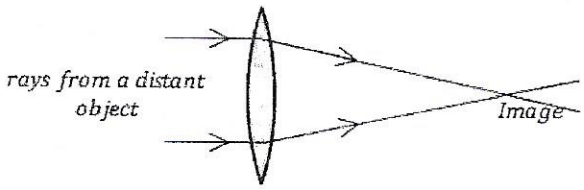
The eye lens is elastic and focuses light entering the eye forming a real, inverted and diminished image on the retina.

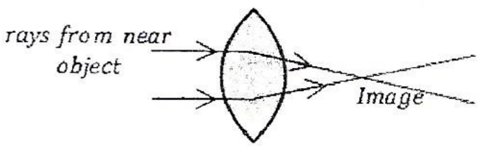
Iris controls size of the pupil by making it narrow in bright light and wide in dim light, by reflex action.

The pupil allows light to pass through.

Ciliary muscle controls the shape of the lens

A normal eye in focusing a distant object, the ciliary muscle makes its lens thinner with a longer focal length. Lens is made thicker with a short focal length to focus nearby objects.

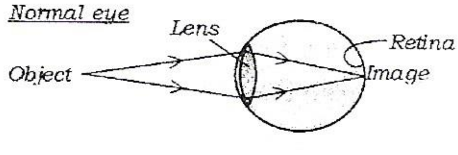




An image is formed on the retina and impulses are sent to the brain for interpretation. The image lasts on the retina for about a $\frac{1}{10}^{th}$ of a second after the object has disappeared. This means that the brain retains an impression of the image on the retina for about a $\frac{1}{10}^{th}$ of a second. This is termed as *persistence vision.*

Accommodation is the ability of the lens for a normal eye to focus the images of objects at different distances, on the retina.

Defects of the eye

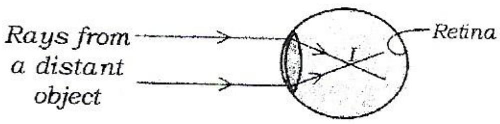


A normal eye forms an inverted, real and diminished image on the retina.

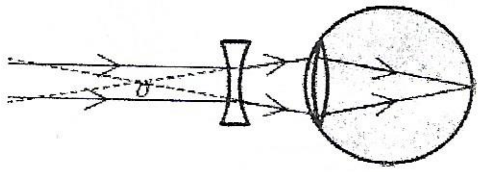
The defects of the eye are *short sightedness (myopia)* and *long sightedness (hyperopia)*

1. ***Short sightedness:*** a person with this defect sees near objects clearly and distant objects appear blurred.

   Rays from distant objects come to focus before reaching the retina. This is caused by eyeball being too long hence shorter focal length of the lens.



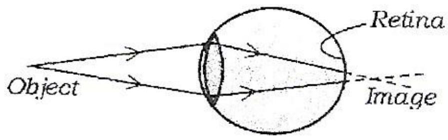
   It is corrected by wearing spectacles containing a diverging lens.



Diverging lens causes rays to diverge as though coming from O

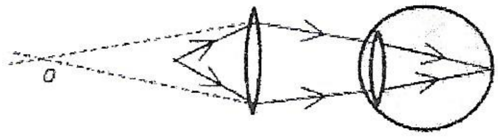
2. ***Long sightedness:*** a person with this defect sees distant objects clearly but not near ones.

   Rays from near objects are focused behind the retina. This is caused by eyeball being too short hence long focal length.



   This is corrected by wearing spectacles containing converging lens.

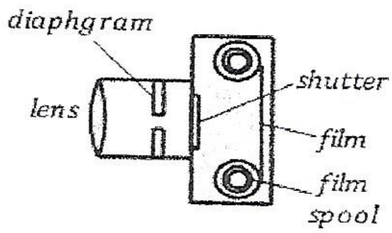
   Converging lens reduces divergence of rays so that they appear to come from O



(c) *The lens camera*

This is a light – tight box in which a convex lens at the front forms a real, inverted image on the photo – sensitive (film) at the back.

Its inside is painted black in order to absorb any stray light that would blur the image.



The diaphragm regulates the size of the aperture thus controlling the amount of light from the lens.

The shutter controls amount of light entering the camera by the length of time it is opened.

(b) *The eye*

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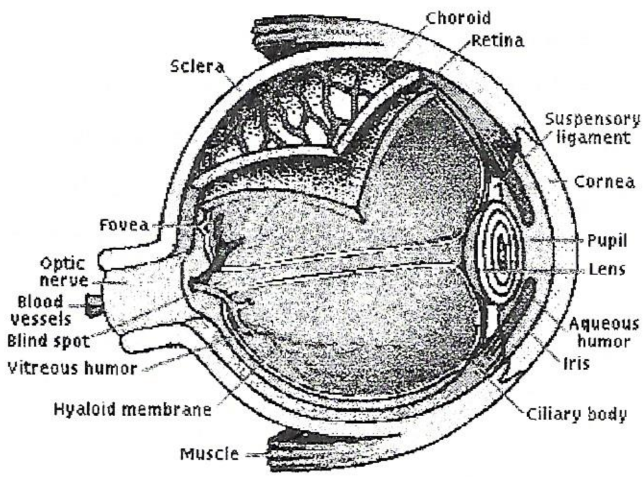
The pupil allows light to pass through.



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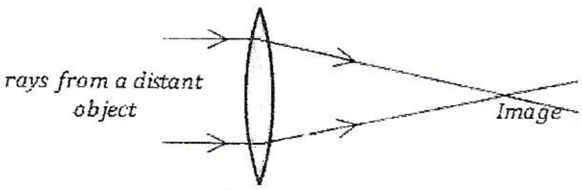

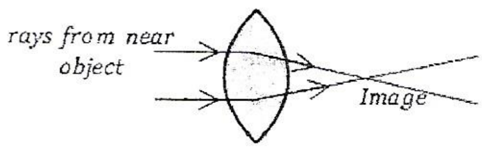

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Defects of the eye

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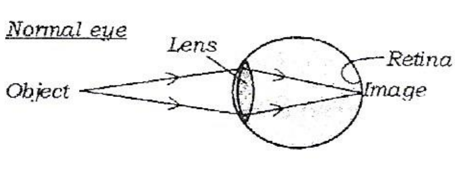


The defects of the eye are *short sightedness (myopia)* and *long sightedness (hyperopia)*

Comparisons of the eye and the lens camera

(a) Similarities

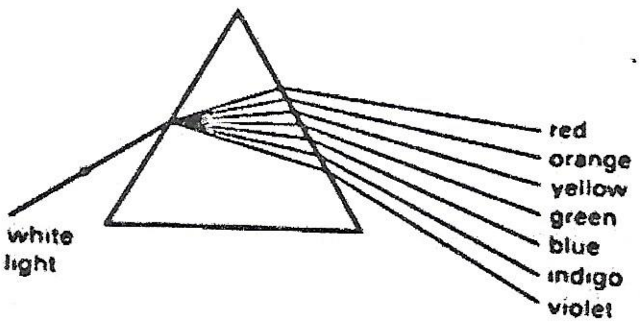
1. The camera is painted black inside and the eye is impregnated with a black pigment called choroid.
2. Both have systems regulating the amount of light entering them – diaphragm for a camera and iris for the eye.
3. Both have light sensitive parts – film for a camera and retina for the eye.
4. Both have lenses for focusing light from external objects.

(b) Differences

1. Image distance in an eye is fixed whereas it is variable in a camera.
2. Eye lens has a variable focal length whereas for a camera it is fixed.
3. Lens in a camera is artificial whereas an eye is a biological organ.
4. Aperture is changed mechanically in a camera whereas in an eye it is altered involuntarily by reflex action.
5. Only a lens refracts light in a camera whereas vitreous humor, aqueous humor and the lens do refract light.

THE SPECTRUM

When white light is passed through a glass prism a band of coloured patches showing colors of rainbow is formed on the screen. This band is called *spectrum*. Its constituent colors are *red, orange, yellow, green, blue, indigo and violet (ROYGBIV)*



The separation of white light by glass prism into its constituent colors is called *dispersion.*

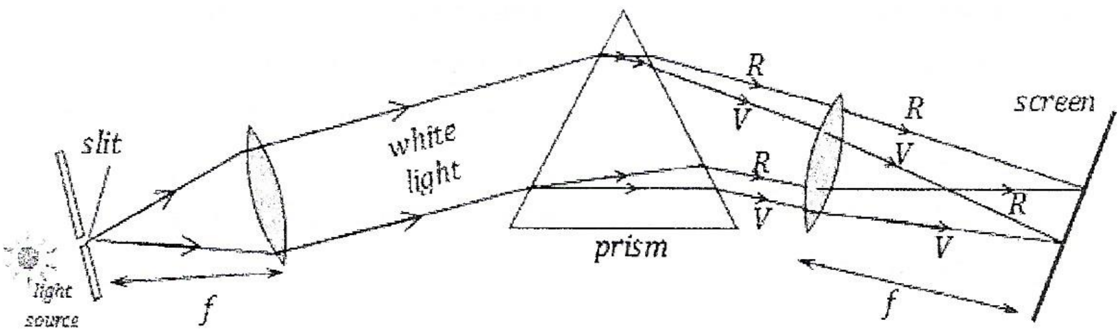
How does dispersion occur? *White light constitutes of different colors of different refractive indices with glass. When it is incident on glass different colours are refracted to* *different extents. Red colour which has least refractive index than violet is least deviated, hence dispersion.*

Alternatively: *White light constitutes of different colors of different refractive indices with glass. When it is incident on glass different colours are refracted to different extents. Red light with longer wavelength is refracted least while violet with shorter wavelength is refracted most, hence dispersion.*

Note: The spectrum formed is impure since different colours overlap on the screen.

Production of a pure spectrum

A pure spectrum is the one in which colours do not overlap on the screen.



This can be obtained by by using a narrow beam of white light through a slit placed at the focal point of the first lens so that a parallel beam of white-light is incident to the prism.

Separate parallel beams of different colours are brought in focus in the plane of second lens.

MIXING OF COLOURS

(a) by addition

(i) *Primary colours*: these are colours of light which can not be made by mixing any other colours of light.

Examples primary colours are *red, blue* and *green*(RBG)

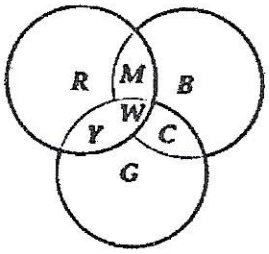
(ii) *secondary colours*: These are colours of light which are made by adding two primary colours. These are *yellow, magenta* (reddish purple) and *cyan* (greenish purple).

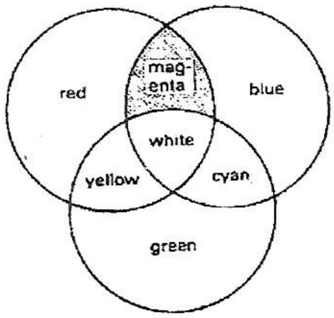
i.e. $red + green = yellow\ (RGY)$, $red + blue = magenta(RBM)$ and $blue + green = cyan(BGC)$

(i) <u>complementary colours</u>: these are pairs of colours which when mixed together form a white light. A combination of one primary cplour and one secondary colourgives a complementary colour.

$Red + cyan = white(RCW)$, $Green + magenta = white(GMW)$

$Blue + yellow = white(BYW)$

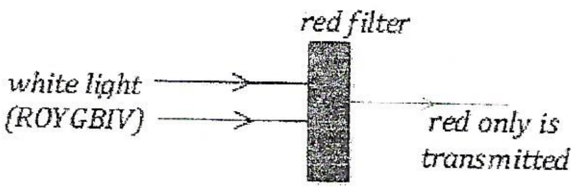




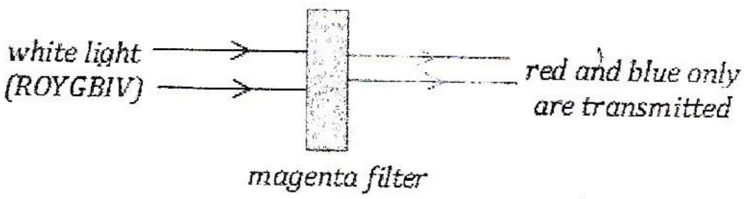
(b) <u>by subtraction (absorption)</u>

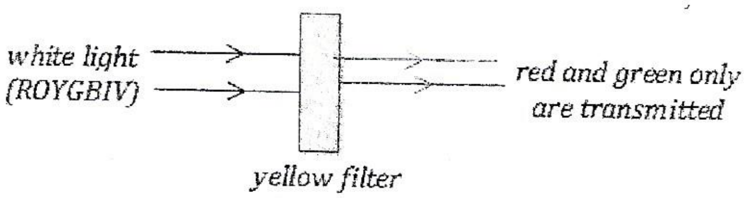
When light falls on any object, it is either reflected, absorbed or transmitted. The colour of an object is determined by the colours of light which it reflects i.e. it absorbs all other colours which fall on it and transmits only its own colour. Such a behavior is shown by a colour filter.

<u>Case 1</u>: when white light falls on a primary colour filter all the other colours are absorbed and only the colour of the filter is transmitted.

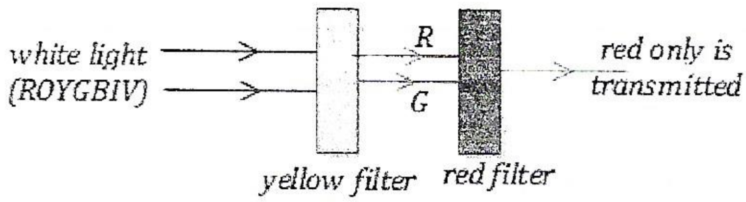


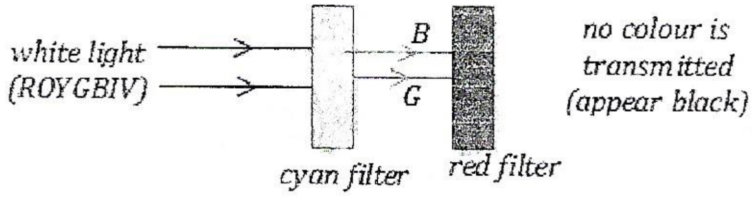
<u>Case 2</u>: when white light falls on a secondary colour filter only the colours forming the filter are transmitted and the other colours are absorbed.





Case 3: a primary colour filter placed after a secondary colour filter





The colour of an object in white light

An object appears red because it absorbs all other colours of light and reflects red. A black object absorbs all other colours and reflects none.

The colour of an object depends on the

- colour of incident light
- colour it reflects

Colour of object	*Colour of incident light*	*Colours absorbed*	*Colours reflected (appearance of object)*
Blue	White	ROYGBIV	Blue
Blue	Blue	None	Blue
Blue	Red	Red	None (black)
Red	Blue and green	Blue and green	None (black)
Red	Red	None	Red

ELECTROMAGNETIC WAVES (E/M)

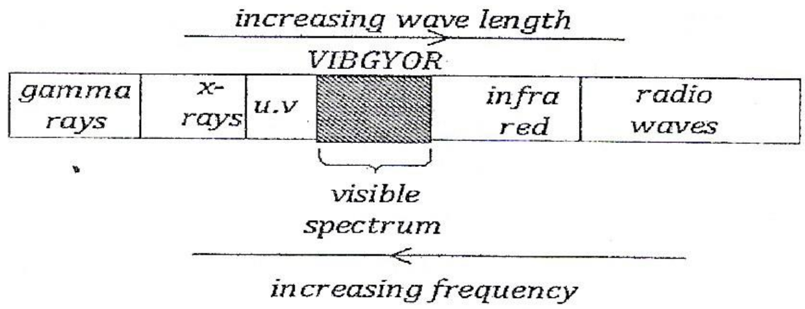
These are waves produced by both electric and magnetic vibrations of very high frequencies.

<u>Properties of e/m waves</u>

- They travel at the speed of light
- They do not need a medium for their transmission
- They are transverse in nature
- They can be emitted and absorbed by matter
- They undergo reflection, refraction, diffraction and interference
- They can be polarized
- They have energy.

<u>Electromagnetic spectrum</u>

This is a band of electromagnetic radiations in the sequence of their wavelength or frequency.



<u>Uses of electromagnetic waves</u>

1. Radio waves are used in radar systems and in communication satellites
2. I.R radiations emitted from hot bodies are used in
   (i) remote controls
   (ii) treatment of muscular complaints.
   (iii) taking photographs especially in fog or smoke
   (iv) shooting targets in total visual darkness.
   (v) green houses to keep plants warm

   [I.R can be detected by our bodies because of their heating effects]
3. U.V are used in

(i) sterilizing surgical instruments.

(ii) the detection of forged documents, finger prints

(iii) the study of molecular structure.

[U.V cause suntan and produce vitamins in the skin though an overdose is harmful.]

4. X – rays are used in
   (i) hospitals to kill cancer cells
   (ii) industries to detect faults, cracks, flaws and holes in metal products
   (iii) the study of crystal structure.

5. Gamma rays are used in
   (i) hardening rubber solution and lubricating oil when exposed to it.
   (ii) the study of nuclear structure.

Examples

1. A radio wave is transmitted at a frequency of 150MHz. Calculate its wavelength.
   $V = 3.0 \times 10^8\ ms^{-1}, f = 150\text{MHz} = 150 \times 10^6 Hz$

   From $V = \lambda f, \Rightarrow 3.0 = 10f \Rightarrow \lambda = \frac{3.0\times10^8}{150\times10^6} = 2m$
2. Explain why the sky appears red during sunset and sunrise.
   The wavelength of red colour is greater than that of any other colour. During the sunrise and sunset, red light travels through greater thickness of earth's atmosphere and is seen most than any other colour.
3. Name the electromagnetic radiation which
   (i) cause sensation of heat *(I.R)*
   (ii) passes through thin sheets of lead *(Gamma rays)*
   (iii) is used in satellite communication *(Radio waves)*
   (iv) is used for remote controls of a television receiver *(I.R)*

SENIOR 3: TERM 3

STATIC ELECTRICITY (ELECTROSTATICS)

This is the study of charges at rest.

Evidence of static electricity

1. When a pen or plastic comb or rubber balloon is rubbed in dry hair and brought nearby small pieces of papers the papers get attracted.
2. Rubber band rubbed with duster will attract dust particles
3. Crackling is heard when a nylon shirt is removed from the body and sometimes sparks are seen in the dark.
4. Mirrors and windows attract dust when wiped with dry duster.

All these observations are as a result of electrification.

Bodies showing this attracting property are said to have an electric charge which is acquired by friction. These charges are usually at rest and are referred to as stationary or static charges.

The charges acquired are either positive or negative.

S.I units of quantity of charge are coulombs (C).

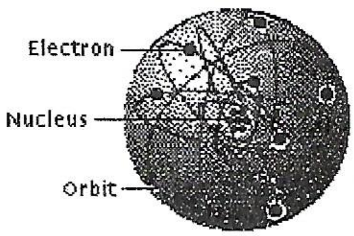
Law of electrostatics: **'like charges repel, unlike charges attract each other'**

Structure of an atom

An atom consists of

- central nucleus which contains neutrons and protons. These are called nucleons. The protons are positively charged and the neutrons have no charge.
- electrons revolving round the nucleus in certain allowed orbitals/shells

  The number of protons is always equal to the number of electrons and the atom is electrically neutral.



Theory of charging by friction

When two bodies are rubbed together, heat energy is developed between them. This energy weakens the electrostatic forces between electrons and the nucleus.

As a result loosely held negative charges (less massive than positive charges) transfer from one body to the other. A body with excess electrons is said to be negatively charged and the one that has lost electrons becomes positively charged.

Note:

1. Excess of negative charges on one body is equal to excess of positive charges on the other body.
2. Nature of charges acquired depends on the rubbing material

Material	What happens when rubbed?
Polythene Ebonite Metals Silk Wool/flannel Glass Fur	Materials above acquire negative charges when rubbed with materials below. - Ebonite rubbed with fur [ebonite gains electrons from fur] - Glass rod rubbed with silk [silk gains electrons from glass] - Polythene rod rubbed with cotton wool [polythene gains electrons from cotton] - Cellulose acetate rod rubbed with cotton wool [cotton gains electrons from cellulose]

PEMS WenGa Fa

E.g. *a plastic comb (made of polythene) run through your hair causes electrons jump from your hair to the comb. This gives the comb a negative electric charge and hair a positive electric charge.*

Conductors and insulators

Conductors: All metals are good conductors of electricity because they contain free electrons which wander along and around the conductor. Conductors easily gain charge and easily lose it.

Examples of good conductors of electricity include; metals, human body, fresh/wet wood, earth, moisture.

Insulators are bad conductors of electricity because their electrons are firmly bound to their atoms. Charges that are produced on top of the surfaces of insulators remain static.

Examples of insulators include; glass, rubber, silk, cork, dry air, plastic, dry wood.

Potential difference

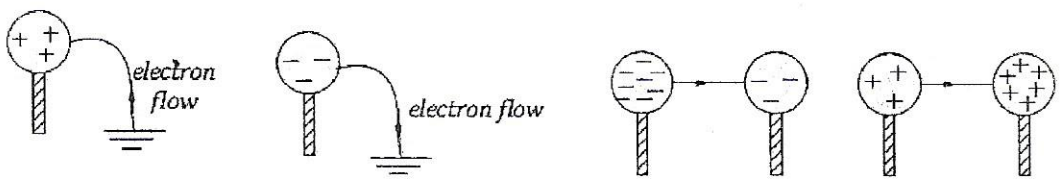
When a negatively charged body is connected to a positively charged body by a conductor, electrons flow to a positively charged body.

Bodies with different concentrations of the electrons are said to be at different potentials i.e a negatively charged body has excess electrons and is at low potential and a positively charged body has few electrons and is a high potential.

When two bodies are connected, electrons flow from a body of low potential to a body of high potential.

Note: The earth is conventionally taken to have zero potential.

The figures below show the directions of the electrons when two bodies are connected.



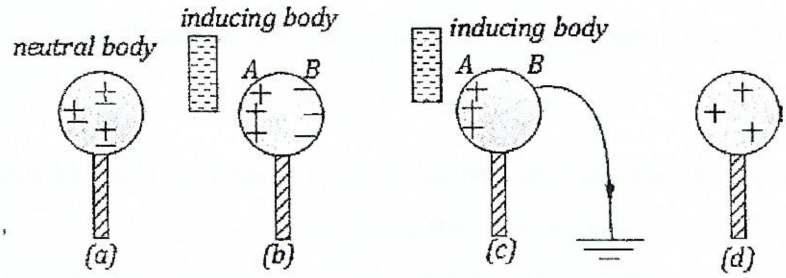
Charging by induction

An induced charge is the one acquired by another body without any contact with a charging/inducing body. This process involves attraction and repulsion of the electrons to and from different parts of bodies.

Charging one body by induction

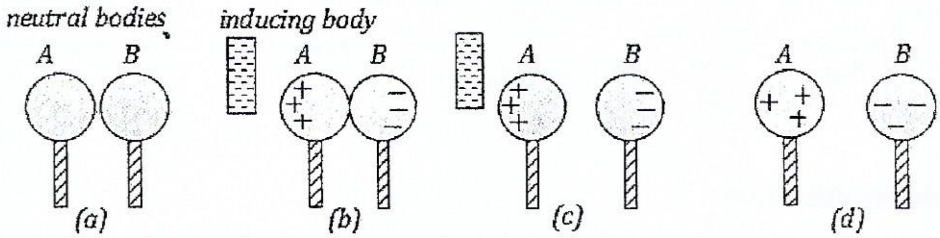
- A negatively charged rod is brought near a neutral conductor placed on an insulator.
- Negative charges are induced to the remote side B and positive charges to side A of the conductor (fig b).

- In the presence of the inducing rod, electrons flow to earth when a bare wire is touched on end B (fig c).
- Inducing rod and wire are removed at the same time and the positive charges distribute themselves. The body becomes positively charged (fig d).

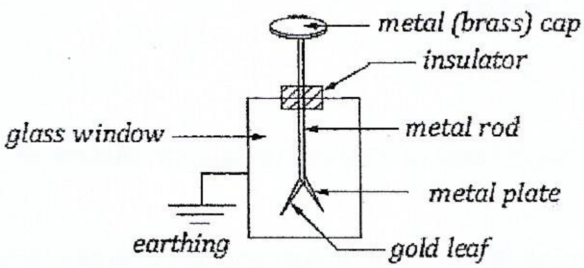


Charging two bodies by induction

- A negatively charged rod is brought near two neutral conductors A and B in contact placed on insulators.
- Negative charges are induced to the remote side of B and positive charges on side of A nearby the inducing body (fig b).
- In the presence of the inducing rod, conductors are separated (fig c).
- Inducing rod is removed and charges distribute themselves in both bodies. The body acquire equal and opposite charges (fig d).



The gold leaf electroscope (G.L.E)



It is a device that is used to;

- detect the presence of electric charges

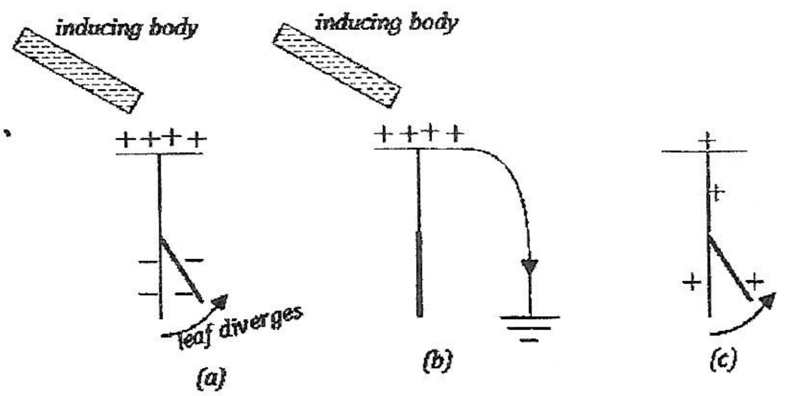
- test for the sign/nature of charge on a body
- detect the strength of charge on the body
- test for insulating and conducting properties of a material

Charging a GLE by induction

- A negatively charged body is brought near the cap of a neutral GLE.
- The leaf is observed to diverge indicating that a charge has been acquired (fig a).

Explanation: a negatively charged body repels negative charges on the cap of a GLE to the metal plate and the leaf. This therefore leaves the cap positively charged and the repulsion between like charges on the plate and leaf cause the leaf to diverge.

- The cap is earthed by use of a wire still in the presence of the inducing body. Negative charges on the leaf and metal plate escape/flow to earth and as a result the leaf collapses (fig b).
- Earthing and the inducing body are removed at the same time. This allows positive charges redistribute evenly. Hence a GLE becomes positively charged (fig c).



Summary table

Object brought near cap of GLE	Effect on a neutral GLE	Effect on a positively charged GLE	Effect on a negatively charged GLE
Neutral conductor	Nothing happens	Leaf collapses slowly	Leaf collapses slowly
Positive rod	Leaf diverges	Leaf diverges further	Leaf collapses easily
Negative rod	Leaf diverges	Leaf collapses quickly	Leaf diverges further

Note:

- Repulsion is the only sure test of a charge

- If the inducing body is removed, the leaf collapses showing that the charge acquired on the electroscope is temporary.

Questions:

1. Explain briefly how a G.L.E is used to test for a negative charge on a body.
   - *A body of unknown charge is brought near the cap of a negatively charged GLE.*
   - *A further divergence of the leaf observed, shows that the body is negatively charged.*
2. Explain briefly how a G.L.E is used to distinguish between a conductor or an insulator.
   - *A material under test is brought nearby the cap of a negatively charged GLE.*
   - *If a leaf is observed to fall rapidly, a body is a good conductor.*
   - *If a leaf is observed to fall slowly, a body is a bad conductor*
   - *If a leaf does not fall at all , a body is an insulator*

Application of electric charges

1. Spraying paint on cars: A car is earthed and paint drops from a spray gun are given positive charges which are uniformly attracted by the car.
2. Electrostatic precipitators are used in eliminating atmospheric pollution from the exhausts of industrial devices such as steam boilers and cement kilns.
3. Electrostatic induction is used in photocopying machines.

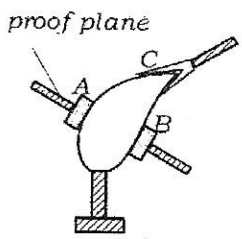
Discharging a conductor

This is done by

- placing it in contact with another conductor of equal and opposite charge
- earthing by touching it with bare hands
- holding it near a flame of fire
- holding it with wet substances

Charge distribution on a conductor

Proof planes, A, B and C one at a time, are placed in contact with the surface of the conductor at different parts and then transferred to a neutral GLE.



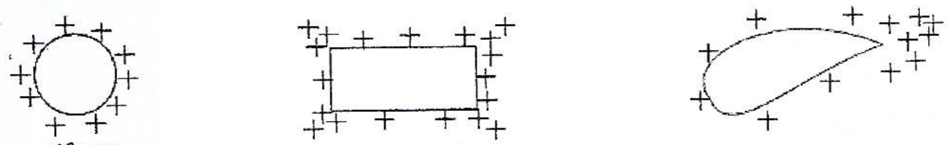
The divergence of the leaf which gives the measure of the amount of charge acquired, is observed.

Great divergence is observed for a proof plane, C, from a pointed/sharp end of a conductor.

This therefore shows that concentration of charge is greatest on pointed parts of a conductor.

Definition: ***Charge density is the quantity of charge on a given area on a body's surface.***

Charge distribution on conductors



uniform spherical body *rectangular body* *pear shaped body*

Action at a point

At sharp points surface charge density is greatest and an intense electric field arises around them. The high electric field intensity breaks down the insulation of air sending a stream of charged molecules. Similar charges are repelled away creating an electric wind and opposite charges are attracted towards the sharp point leading to apparent loss of charge near the point.

Lightning conductor

Clouds moving through air become electrically charged due to friction.

A lightning is a large spark discharge between the charged clouds and the earth which is at a zero potential.

Charges between clouds or between a cloud and the ground produce atmospheric electrical discharges or lightning. The flow of electricity from one discharge point to another also produces a sound wave heard as thunder.

Action of a lightning conductor

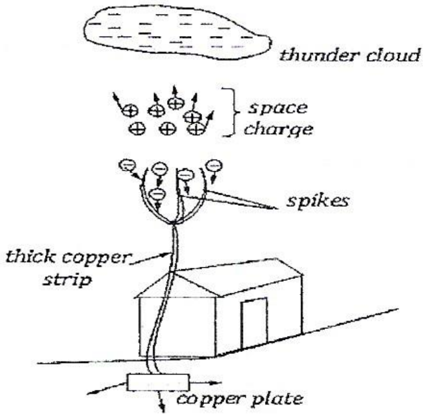
When a negatively charged thunder cloud passes overhead a building, it induces positive charges on the spikes and the negative charges on the copper plate where they are dissipated to earth.

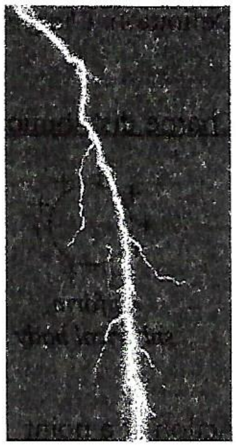
Point action occurs at the spikes. Negative ions are attracted to the spikes and then discharged to earth.

At the same time, positive ions are repelled upwards forming space charge which neutralizes the negative charge on the cloud.

A lightning conductor thus accepts any discharge and conducts it harmlessly to earth.

In absence of a lightning conductor, negative charges violently discharge to the highest point of a building setting it on fire.





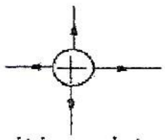
Electric fields

An electric field is a region round a charged body where the forces of attraction or repulsion are experienced.

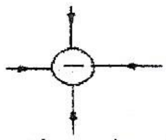
Electric fields are represented by lines of force/field lines, which give directions of force at that point.

Note:

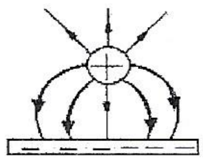
- Field lines point towards a negative charge and point away from a positive charge
- No field lines ever cross each other.



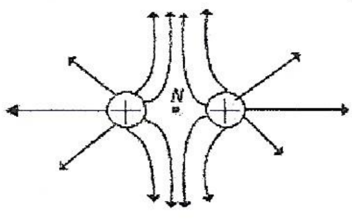
positive point charge



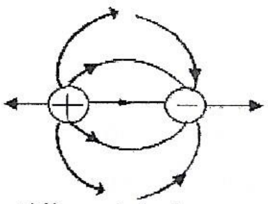
negative point charge



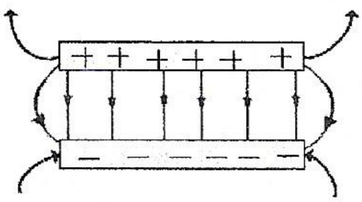
positive point charge near negative plate



like point charges



unlike point charges



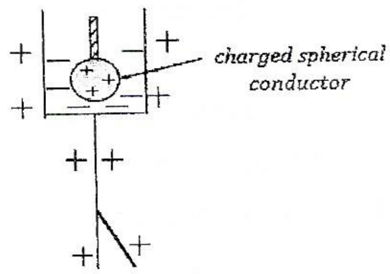
opposite charged plates

A neutral point is *a point in the electric field where the resultant force is zero.*

Faraday's ice – pail experiment

A positively charged sphere is lowered into a metal can without touching its sides.

Negative charges are induced inside the can and positive charges are induced outside the can and the leaf. The leaf diverges due to repulsion of charges on the leaf and plate.



Note:

If the charged conductor touches the sides of the can, the leaf does not fall even after the conductor is removed.

Reason: the charge on the metal sphere is neutralized by the induced charge inside the can leaving an equal charge outside the can.

Questions

1. (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.

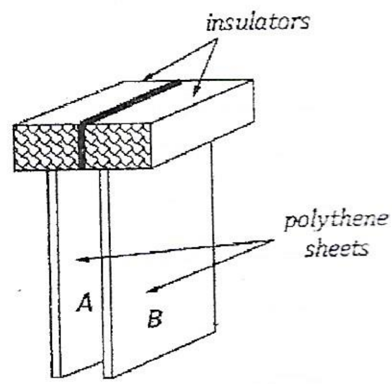
   (c) Draw the electric field pattern for
   (i) An insulated negative charge
   (ii) Two oppositely charged parallel plates at a small distance apart

   (d) Explain why it is not advisable to touch the copper strip of a lightning conductor when it is raining.

2. (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 in the figure below

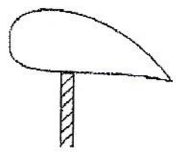
(i) Describe and explain what happens

(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 a rainstorm.

3. (a) What happens to an insulator when it is rubbed by another insulator of different material?

(b) The figure below shows a conductor supported on an insulator. The conductor is given some charge. Show how the charge is distributed on the conductor.



(c) Sketch the electric field pattern due to two unlike charges P and Q below

QUANTITY OF HEAT

Heat is a form of energy that flows from one point of a conductor to another due to temperature difference between the points.

The quantity/amount (Q) of heat is measured in joules (J).

HEAT CAPACITY (C)

This is the quantity of heat required to raise temperature of a substance by one degree celcius or one kelvin. Its S.I units are JK^{-1}

Heat capacity is calculated from $C = \frac{Q}{\Delta\theta}$ where $\Delta\theta$ is the temperature change

Specific heat capacity (c): this is the quantity of heat required to raise temperature of one kilogram mass of substance by one degree celcius or one kelvin.

Its S.I units are $Jkg^{-1}K^{-1}$

$c = \frac{Q}{m\Delta\theta} \Rightarrow Q = mc\Delta\theta \Rightarrow mc = \frac{Q}{\Delta\theta}$ is called heat capacity

Thus heat capacity $C = mc$

The table below shows approximate specific heat capacities of some materials

Material	Specific heat capacity ($Jkg^{-1}K^{-1}$)
Aluminium	900
Brass	380
Copper	400
Glass	670
Water	4200
Iron	460
Ice	2100

Because of its high specific heat capacity, water is a most suitable liquid used in car radiators to cool the engine. Less amount of water is needed to draw much of the heat energy from the engine as compared to other liquids.

Water has a specific heat capacity of $4200\,Jkg^{-1}K^{-1}$. What does the statement mean?

It means that one kilogram mass of water requires 4200 Joules of heat energy to raise its temperature by one kelvin.

Calculations

1. Calculate the quantity of heat required to raise the temperature of a metal block with a heat capacity of $460\,JK^{-1}$ from 15°C to 45°C

   Solution

   Heat capacity, $460\,JK^{-1}$ *Temperature change* $\Delta\theta = 45 - 15 = 30°C$

   Quantity of heat $Q = C\Delta\theta = 460 \times 30 = 13800\,J$

2. A piece of copper of mass 60g and specific heat capacity $390\,JK^{-1}kg^{-1}$ cools from 90°C to 40°C. Find the quantity of heat given out.

   Solution: Quantity of heat $Q = mc\Delta\theta = \frac{60}{1000} \times 390 \times (90 - 40) = 1170\,J$

3. Calculate the amount of heat received by 5kg of copper of specific heat capacity $400\,Jkg^{-1}K^{-1}$ if its temperature rises from 15°C to 25°C.

   $Q = mc\Delta\theta \Rightarrow Q = 5 \times 400 \times (25 - 15) = 20{,}000J$

4. $570\,J$ of heat are required to cool a piece of zinc of specific heat capacity $380\,JK^{-1}kg^{-1}$ from 60°C to 20°C . What is the mass of zinc?

Solution: Quantity of heat $Q = mc\Delta\theta$

$570 = m \times 380 \times (60 - 20) \Rightarrow m = 0.0375\ kg$

Questions

1. Calculate the heat given out when 50g of iron cools from 45°C to 15°C. (Specific heat capacity of iron is $460 J\ kg^{-1}K^{-1}$).
2. Calculate the specific heat capacity of gold if $108\ J$ of heat raise the temperature of 9g of the metal from 0°C to 100°C.

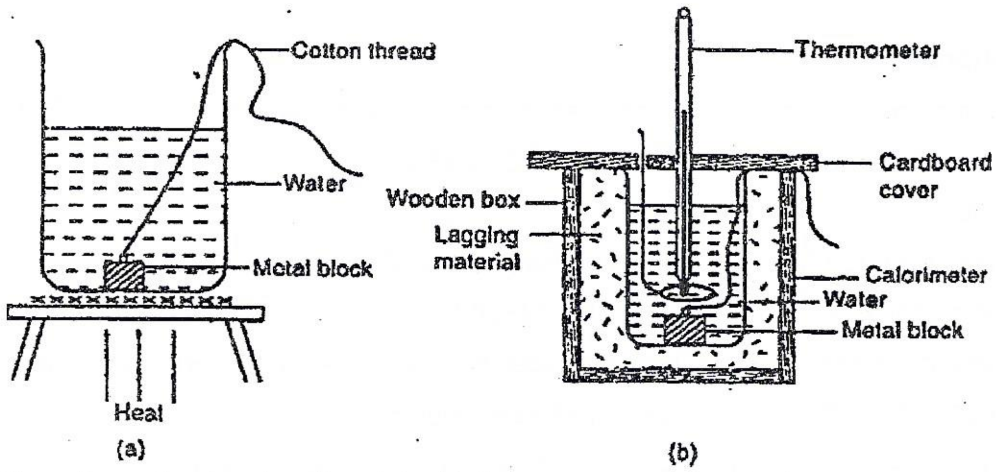
Note: in calorimetry heat loss is minimized by

(i) lagging

(ii) smoothening surfaces of the object

Determination of specific heat capacity of a solid by the method of mixtures

- A metal block of known mass m is heated in boiling water at a temperature θ_3
- It is transferred to a copper calorimeter of mass m_c containing water of mass m_w at a temperature θ_1



- The mixture is stirred well and the highest temperature θ_2 is obtained.
- Specific heat capacity, C is obtained from $mC(\theta_3 - \theta_2) = m_w C_w \Delta\theta + m_c C_c \Delta\theta$

  where $\Delta\theta = \theta_2 - \theta_1$

This method is also used to determine s.h.c of a liquid. In this case, a heated metal of known s.h.c and mass is dropped into a liquid whose s.h.c is required.

Examples

1. The temperature of 500g of a certain metal is raised to 100°C. It is then placed in 200g of water at 15°C. If the final steady temperature rises to 21°C, calculate the specific heat capacity of the metal. [specific heat capacity of water is $4200\,Jkg^{-1}K^{-1}$]

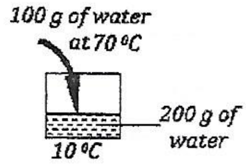
   Solution: $\begin{matrix} heat\ lost\ by\ hot\ metal \\ from\ 100°C\ to\ 21°C \end{matrix} = \begin{matrix} heat\ gained\ by\ water \\ from\ 15°C\ to\ 21°C \end{matrix}$

   $\Rightarrow \frac{500}{1000} \times c \times (100 - 21) = \frac{200}{1000} \times 4200 \times (21 - 15)$

   $\Rightarrow$ *Specific heat capacity of metal* $c = 127.6 Jkg^{-1}K^{-1}$

2. What is the final temperature of the mixture if 100g of water at 70°C is added to 200g of water at 10°C and the mixture is well mixed? (Neglect heat absorbed by container)

   Solution: Let the final temperature of the mixture be θ

   $\begin{matrix} heat\ lost\ by\ hot\ water \\ from\ 70°C\ to\ \theta \end{matrix} = \begin{matrix} heat\ gained\ by\ cold\ water \\ from\ 10°C\ to\ \theta \end{matrix}$

   $\Rightarrow \frac{100}{1000} \times 4200 \times (70 - \theta) = \frac{200}{1000} \times 4200 \times (\theta - 10)$

   $\Rightarrow Final\ temperature\ of\ mixture\ \ \theta = 30°C$

3. The temperature of a piece of copper of mass 250g is raised to 100°C and it is then transferred to a well-lagged aluminium can of mass 10g containing 120g of methylated spirit at 10°C. Calculate the final temperature after the spirit has been well stirred. [specific heat capacity of Aluminium, methylated spirit and copper is $900\,Jkg^{-1}K^{-1}$, $2400\,Jkg^{-1}K^{-1}$ and $4000\,Jkg^{-1}K^{-1}$]

   Solution: Let the final temperature of the mixture be θ

   $\begin{matrix} heat\ lost\ by\ hot\ copper \\ from\ 100°C\ to\ \theta \end{matrix} = \begin{matrix} heat\ gained\ by\ spirit\ and\ Al\ can \\ from\ 10°C\ to\ \theta \end{matrix}$

   $\Rightarrow \frac{250}{1000} \times 400 \times (100 - \theta) = \frac{10}{1000} \times 900 \times (\theta - 10) + \frac{120}{1000} \times 2400 \times (\theta - 10)$

   $\Rightarrow Final\ temperature\ of\ spirit\ \theta = 32.7°C$

Questions

1. A piece of copper of mass 0.12kg was heated by a Bunsen flame for some time. It is quickly dropped into 0.6kg of water at 23°C. The final temperature of water was 37°C. Calculate the temperature of the Bunsen flame.

2. 2kg of lead at 100°C are dropped into a vessel containing 0.3kg of water at 10°C and rapidly stirred. The final temperature attained by the vessel and its contents is 16°C. If the s.h.c of lead is $130\ Jkg^{-1}K^{-1}$, calculate the s.h.c of the vessel.
3. A lady wanted to have a warm bath at 40°C. She had 5kg of water in a basin at 85°C. What mass of cold water at 25°C must she have added to the hot water to obtain her choice of bath? Neglect heat losses and take specific heat capacity of water to be $4200\ Jkg^{-1}K^{-1}$.
4. A bath contains 100kg of water at 60°C. Hot and cold taps are then turned on to deliver 20kg per minute each at temperatures of 70°C and 10°C respectively. How long will it be before the temperature in the bath has dropped to 45°C?
5. The temperature of a brass cylinder of mass 100g was raised to 100°C and transferred to a thin aluminium can of negligible heat capacity containing 150g of paraffin at 11°C.

   If the final steady temperature after stirring was 20°C, calculate the specific heat capacity of paraffin.

   (Neglect heat losses and assume specific heat capacity of brass is $380Jkg^{-1}K^{-1}$)
6. 0.2 kg of iron at 100°C is dropped into 0.09 kg of water at 26°C inside a calorimeter of mass 0.15kg and specific heat capacity $800\ Jkg^{-1}K^{-1}$. Find the final temperature of the water. (Specific heat capacity of iron is $460\ Jkg^{-1}K^{-1}$and that of water $4200\ Jkg^{-1}K^{-1}$)

LATENT HEAT

Latent heat is defined as *the quantity of heat required to change a substance from one state to another state at constant temperature.*

Specific latent heat of fusion: is the quantity of heat required to change one kilogram mass of a solid to liquid state or liquid to solid state at constant temperature.

Its S.I units are Jkg^{-1}. $l = \frac{Q}{m}$ or $Q = ml$

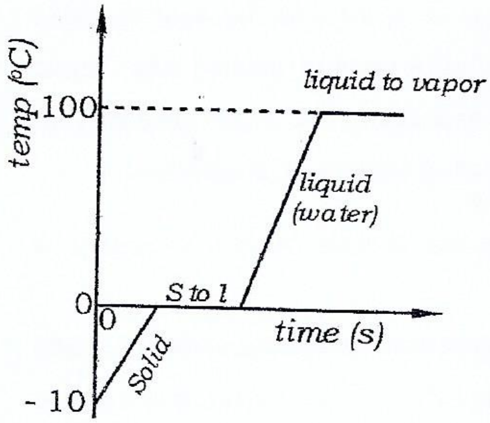
The constant temperature is called melting/freezing point.

Specific latent heat of vaporization: is the quantity of heat required to change one kilogram mass of a liquid to vapour state or vapour to liquid state at constant temperature. Its S.I units are Jkg^{-1}. $l = \frac{Q}{m}$ or $Q = ml$

The constant temperature is called boiling point.

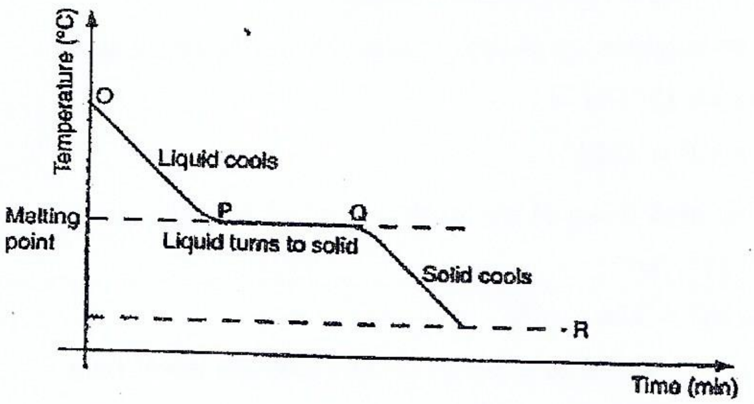
Specific latent heat of steam is $2{,}260{,}000 Jkg^{-1}$ this means that 2,260,000 Joules of heat energy are required to convert 1kg of water at its boiling point to steam at the same temperature.

Heating graph of ice



When ice at about $-10°C$ is heated, heat energy absorbed is used to increase vibrations of ice molecules hence increase in temperature up to 0°C. [$Q=mc\theta$]
On further heating, latent heat energy given to ice at 0°C is used to change ice solid to water [$Q=ml$]. After all the ice has melted, heat energy given to water is used in raising its temperature [$Q=mc\theta$]. Further heating causes the water reach it boiling point where there is no further increase in temperature [$Q=ml$].

Cooling graph of Naphthalene liquid



During cooling, heat energy is lost; kinetic energy of liquid molecules reduces thus temperature of liquid falls from point O to P. From P to Q, liquid changes to solid at constant temperature after which the temperature falls further to room temperature R.

<u>Explanation of latent heat of fusion kinetic theory</u>

Solid molecules vibrate about their mean positions and are held by stronger intermolecular forces. As heat is supplied to the solid its internal energy increases and a point is reached when the attraction forces between molecules can no longer hold them. The molecules will have a greater freedom to move as liquid molecules. The work necessary to overcome the intermolecular forces of the solid is called *latent heat of fusion.*

Explanation of latent heat of vaporization using kinetic theory

Molecules in liquids are held by weak intermolecular force and the heat supplied only increases the potential energy of the molecules. A point is reached when liquid molecules move around independently as gas molecules. The work necessary to overcome the gravitational forces at this point is called *latent heat of vaporization.*

Question: explain briefly why temperature does not change when a substance is melting.

During melting, part of heat supplied does work against attractive forces of the molecules instead of increasing their kinetic energy. Hence heat supplied does not result in a rise in temperature of the substance.

Calculations

The formulae and the assumption below are used in heat calculations

a) $Q = ml$ if there is a change in state of a body

b) $Q = mc\Delta\theta$ if there is a change in a body's temperature

c) $heat\ lost = heat\ gained$ this is conservation of energy

1. How much heat is required to vaporize 2g of boiling water? [specific latent heat of vaporization of water is $2.26 \times 10^6\ Jkg^{-1}$]

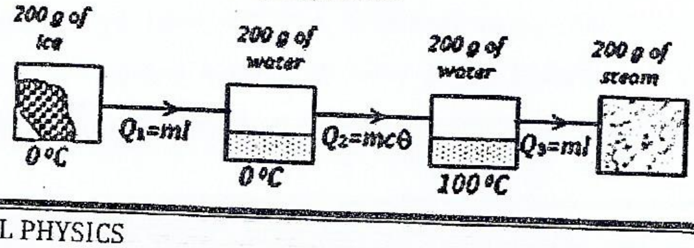
   $Q = ml \Rightarrow Q = \frac{2}{1000} \times 2.26 \times 10^6 = 4520J$

2. How much heat is required to melt 0.1kg of ice at 0°C to water? [specific latent heat of fusion of ice is $3.36 \times 10^5\ Jkg^{-1}$]

   $Q = ml \Rightarrow Q = 0.1 \times 3.36 \times 10^5 = 3.36 \times 10^4 J$

3. How much heat is required to change 200g of ice to steam? [specific latent heat of vaporization of water is $2.3 \times 10^6\ Jkg^{-1}$, specific latent heat of fusion of ice is $3.4 \times 10^5\ Jkg^{-1}$, specific heat capacity of water is $4200\ Jkg^{-1}K^{-1}$]

Stages involved



Heat energy required = Heat energy absorbed by ice in melting + heat energy absorbed by melted ice + heat energy in vaporizing water

Heat required $Q = Q_1 + Q_2 + Q_3$

$$= \frac{200}{1000} \times 3.4 \times 10^5 + \frac{200}{1000} \times 4200 \times 100 + \frac{200}{1000} \times 2.3 \times 10^6 = 61{,}200 J$$

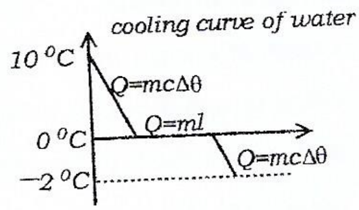
4. A copper can of mass 0.2 kg contains 200 g of water at 10°C. The can and its contents are placed in a refrigerator. Calculate the quantity of heat given out if the temperature of the can and its contents falls to −2 °C.

   [Specific latent heat of fusion of ice is 340,000 Jkg^{-1}, specific heat capacity of water is 4200 $Jkg^{-1}K^{-1}$, specific heat capacity of copper is 400 $Jkg^{-1}K^{-1}$]

Heat energy lost =

$$\underset{10°C \rightarrow -2\,°C}{\text{Heat energy lost by can}} + \underset{10°C \rightarrow 0\,°C}{\text{heat lost by water}}$$

$$+ \underset{\text{in forming ice at } 0°C}{\text{latent heat energy lost}} + \underset{0°C \rightarrow -2\,°C}{\text{heat energy lost by ice}}$$



Heat energy lost

$$Q = 0.2 \times 400 \times 12 + \frac{200}{1000} \times 4200 \times 10 + \frac{200}{1000} \times 340{,}000 + \frac{200}{1000} \times 4200 \times 2 = 78160\ J$$

5. A refrigerator extracts 0.7 kW of heat. How long will it take to convert 500g of water at 20°C into ice? [specific heat capacity of water is 4200 $Jkg^{-1}K^{-1}$ and specific latent heat of fusion of ice is $3.36 \times 10^5\ Jkg^{-1}$]

   Solution: Energy lost by the water in forming ice

   $Q = Power \times t = mc(20 - 0) + ml$

   $\Rightarrow 0.7 \times 1000\, t = \frac{500}{1000} \times 4200(20 - 0) + \frac{500}{1000} \times 3.36 \times 10^5$

   $\Rightarrow t = 300\ s$ *It will take 300 s*

<u>Questions</u>

Where necessary, use: Specific latent heat of fusion of ice is $3.36 \times 10^5 Jkg^{-1}$, Specific heat capacity of water is $4.2 \times 10^3 Jkg^{-1}K^{-1}$, Specific latent heat of vaporization of water is $2.26 \times 10^6\ Jkg^{-1}$, Specific heat capacity of ice is 2100 $Jkg^{-1}K^{-1}$ and Specific heat capacity of copper is 400 $Jkg^{-1}K^{-1}$

1. 2 kg of ice in a beaker at −10°C is heated until it becomes steam at 100°C
   (i) Represent diagrammatically the various stages the ice goes through until it becomes steam.
   (ii) Calculate the amount heat supplied.

capacity of water is $4200\,Jkg^{-1}K^{-1}$ and specific latent heat of vaporization of water is $2{,}260{,}000\,Jkg^{-1}$]

Solution: $heat\ capacity\ of\ copper = m_c c_c = 60Jkg^{-1}$

$$\begin{matrix} Heat\ lost\ by\ steam \\ in\ condensing \end{matrix} + \begin{matrix} heat\ given\ by\ condensed \\ water \\ (100°C \to 50°C) \end{matrix} = \begin{matrix} heat\ gained\ by \\ water + calorimeter \\ (20°C \to 50°C) \end{matrix}$$

$ml + mc_w(100 - \theta_2) = (m_1c_w + m_cc_c)(\theta_1 - \theta_2)$

$\Rightarrow\ m \times 2{,}260{,}000 + m \times 4200(100 - 50) = (0.5 \times 4200 + 60)(50 - 20)$

$\Rightarrow m = 2.84 \times 10^{-3}kg \qquad \therefore Mass\ of\ steam\ condensed = 2.84 \times 10^{-3}kg$

2. A calorimeter of mass 20 g and specific heat capacity 800 $Jkg^{-1}K^{-1}$ contains 500 g of water at 30°C. Dry steam is passed into the water until the temperature of the calorimeter and water reaches 70°C. If the specific latent heat of vaporization of water is 2,260,000 Jkg^{-1}, calculate the mass of steam condensed.

$$\begin{matrix} Heat\ lost\ by\ steam \\ in\ condensing \end{matrix} + \begin{matrix} heat\ given\ by\ condensed \\ water \\ (100°C \to 70°C) \end{matrix} = \begin{matrix} heat\ gained\ by \\ water + calorimeter \\ (30°C \to 70°C) \end{matrix}$$

$ml + mc_w(100 - \theta_2) = (m_1c_w + m_cc_c)(\theta_1 - \theta_2)$

$\Rightarrow\ m \times 2{,}260{,}000 + m \times 4200(100 - 70) = (0.5 \times 4200 + 0.02 \times 800)(70 - 30)$

$\Rightarrow m = 0.035\ kg \qquad \therefore Mass\ of\ steam\ condensed = 0.035\ kg$

<u>Question</u>

Dry steam is passed into a well lagged copper can of mass 250g containing 400g of water and 50g of ice at 0 °C. The mixture is well stirred and the steam supply cut off when the temperature of the can and its contents reaches 20°C. Neglecting heat losses, find the mass of steam condensed.

[Specific latent heat of fusion of ice is $3.36 \times 10^5 Jkg^{-1}$, Specific heat capacity of water is $4.2 \times 10^3 Jkg^{-1}K^{-1}$, Specific latent heat of vaporization of water is $2.26 \times 10^6\ Jkg^{-1}$, and Specific heat capacity of copper is $400\,Jkg^{-1}K^{-1}$]

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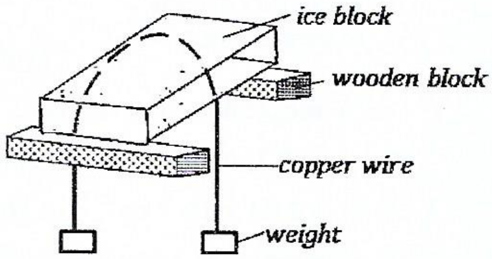
Factors affecting melting

1. Pressure: The application of pressure on a substance that expands on solidification lowers its melting point.

   Experiment

- A block of ice is placed on two pieces of wood
- A thin copper wire carrying weights is hung over ice block
- After some time, wire cuts through leaving ice as a solid block



Explanation: A thin copper wire exerts great pressure on ice block when weights are hung on it. This pressure lowers the melting point of ice in contact and water flows above the wire. This water refreezes and in the process it loses heat to copper wire causing further melting of ice beneath.

2. Impurities: When impurities are added to a substance its melting point decreases. An antifreeze material is added to water in car radiators to stop water from freezing when temperatures fall below 0°C

EVAPORATION AND BOILING

Evaporation

Evaporation is defined *as the escape of most energetic surface liquid molecules against gravitational forces and other forces from bulk molecules.*

Factors affecting evaporation

1. Temperature: increase in temperature increases rate of evaporation since more molecules in the liquid are moving fast enough to escape from the surface.
2. Humidity (amount of vapour in the atmosphere): the higher the humidity the lower the rate of evaporation
3. Nature of liquids: liquids of low boiling points evaporate easily eg ethanol (78.5°C) evaporates faster than water (100°C)
4. Surface area: the greater the surface area exposed the greater the rate of evaporation. Water in a basin evaporates faster than water in a jug.

5. Wind: wind blows off surface vapour molecules away from the surface thus stopping them from returning to the liquid and making it easier for more liquid molecules to break free. In greater winds the rate of evaporation is great
6. Pressure: atmospheric pressure prevents the escape of liquid molecules thus the higher the pressure the lower the rate of evaporation.

Effects of evaporation

(i) Some methylated spirit spilt on the back of your hand, the hand feels cold.

Explanation: *methylated spirit has very low boiling point and so evaporates easily. When spilt on our hand, the latent heat extracted from the hand is sufficient to vaporize it. Consequently, the hand feels cold.*

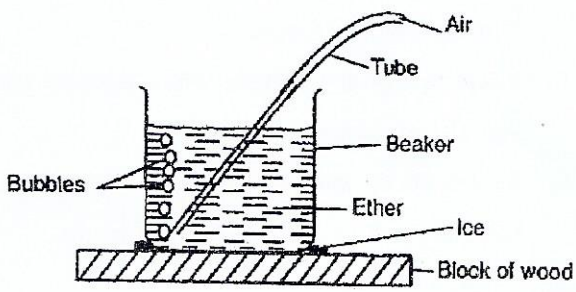
(ii) When air is bubbled through ether in a test tube, frost forms on the outside surface of the tube.

Explanation: *Ether has low boiling point and evaporates easily. Bubbling increases the rate of evaporation of ether.*

The evaporating ether draws latent heat of vaporization from the liquid ether, the test tube and the surrounding space. The tube therefore cools and the frost forms around it.

(iii) A beaker containing ether is placed in a pool of water poured on the table and a current of air blown into ether.

Explanation: *Ether has a low boiling point and evaporates easily. Blown air increases the rate of evaporation of ether. The evaporating ether draws latent heat of vaporization from liquid ether, the beaker and the surrounding water. The beaker therefore cools and the water freezes.*



Questions

1. Explain evaporation using kinetic theory

Liquid molecules are in a state of continuous random motion with varying kinetic energy. When a liquid is heated, molecules gain energy and rise to the surface of the liquid.

A molecule which acquires sufficient energy to overcome the attractive forces from the neighbouring molecules in the liquid escapes hence evaporation.

2. Explain how evaporation causes cooling

   Liquid molecules are held by weak intermolecular forces which are broken when temperature changes. During evaporation a liquid loses surface molecules with high kinetic energy. This lowers the average kinetic energy of the remaining molecules resulting into temperature fall hence cooling.

3. Explain why if you stand in the wind in a wet swimming suit, you feel much colder than if your suit is dry.

   Latent heat from your body causes the water in the suit to vaporize.

   The wind increases rate of evaporation of water from your skin and the body loses more latent heat and then feels cold.

Boiling

Boiling is the process by which a liquid changes to a vapour when vapour pressure is equal to atmospheric pressure.

Differences between evaporation and boiling

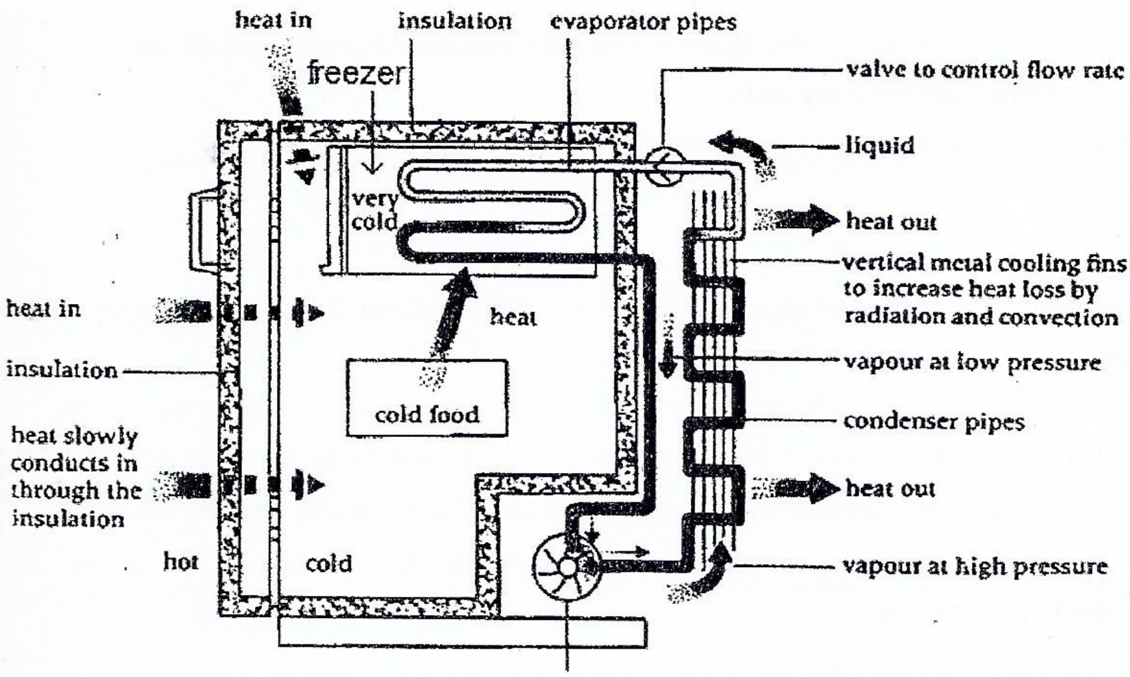
1. Evaporation takes place on the surface of the liquid while boiling takes place throughout the liquid.
2. Evaporation is invisible while boiling is visible. i.e formation of bubbles can be visualised during boiling.
3. Evaporation occurs at any temperature while boiling occurs at a fixed temperature called the boiling point.

Applications of latent heat

1. We use electric fans on sweating and the cooling effect is produced by rapid evaporation
2. Water kept in pots is cooler. Pots are porous and water seeps (to pass or escape through an opening very slowly and in small quantities) through the pores with the

loss of latent heat from the internal energy inside the pot. Consequently, water in the pot cools.

3. The refrigeration: Refrigeration is a process of lowering the temperature for the purpose of chilling foods or preserving certain substances.



The volatile liquid (which has a low boiling point) in the freezer evaporates taking latent heat from the items in the refrigerator hence causing cooling. The pump removes the vapour lowering the vapour pressure causing more evaporation and forces it into the heat exchanger. The fins dissipated heat quickly to the surrounding hence the vapour liquefies. The liquid returns to the freezer and the cycle is repeated.

$$\begin{matrix} evaporation \\ of\ liquid \end{matrix} \rightarrow \begin{matrix} cooling \\ of\ items \end{matrix} \rightarrow compression\ of\ vapour \rightarrow condesation$$

The rate of vaporization and consequent degree of cooling is controlled by a thermostat switch which switches the pump motor on and off at intervals.

Change of volume on solidification

When water freezes to form ice, expansion occurs and the ice takes up a bigger volume than the water.

For this reason

- water pipes may burst during very cold weather
- a bottle placed in the freezing chamber should not be filled with water, to allow a room for expansion.

Most substances such as paraffin however contract when they solidify.

VAPOURS

A vapour is the gaseous state of a liquid. It is produced when a liquid evaporates or boils.

In a closed vessel containing a liquid and its vapour, the vapour molecules collide with the walls and rebound from it exerting a pressure on it called vapour pressure.

A state of dynamic equilibrium is reached when the rate at which molecules leave the surface of the liquid is equal to the rate at which they re-enter the liquid. The vapour is said to be saturated.

Saturated vapour pressure (s.v.p) is defined *as the pressure of a vapour which is in dynamic equilibrium with its own liquid.*

What happens when a liquid is heated?

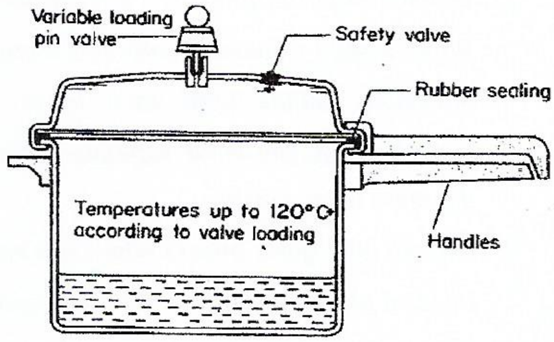
If a liquid is heated its temperature rises and its s.v.p increases. Eventually, when the s.v.p is equal to atmospheric pressure, the liquid boils.

Boiling point of a liquid is defined as *the constant temperature at which its saturated vapour pressure becomes equal to the external atmospheric pressure.*

Further heating causes all the liquid to vaporize and the vapor becomes unsaturated. *Unsaturated vapor pressure is the pressure in which a vapour is not in contact with its own liquid.*

Effect of pressure on boiling point

A liquid boils when its saturated vapour pressure (s.v.p) is equal to atmospheric pressure.



(i) When water is heated in a closed container, surface pressure on water rises. Its s.v.p increases to a new level and water boils at a temperature above its usual boiling point and time of cooking reduces.

Thus boiling point increases when pressure increases on a liquid surface.

A pressure cooker works on this principle.

(ii) Reducing the external pressure by pouring cold water on a closed vessel containing boiling water reduces the s.v.p. The liquid then boils at this reduced pressure. Thus boiling point of a liquid decreases when the external pressure reduces. *(Demonstrate it)*

Question

Explain what may happen when one is to cook food from very high altitude.

At high altitudes, air is less dense hence low atmospheric pressure. The surface water pressure is thus reduced. A lower s.v.p is reached at a lower temperature so the water boils at a reduced boiling point.

Effect of impurities on boiling point

Impurities such as salt when added to a liquid, increases its boiling point and this reduces time of cooking.

EXPANSION OF SOLIDS AND LIQUIDS

Effect of heat on matter

When matter is heated it expands and cools when it contracts.

- Length increases when solids are heated.
- Volume increases when solids, liquids and gases are heated.
- Density decreases for all states of matter when heated.

Expansion of solids and liquids

This is the increase in size of objects when they are heated.

Questions:

1. Explain what happens to a solid when heated.

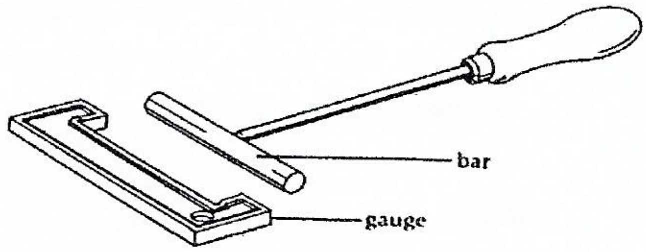
   When a solid is heated molecules vibrate with larger amplitude about fixed positions. Molecules collide with each other with large forces which push them apart consequently, the solid expands. Volume of the solid then increases leading to a decrease in its density.

2. Explain why glass breaks when hot water is poured in it.

   Inside a glass, molecules get heated and expand even when the outside part gets warm. This leads to difference in forces between the inside and outside molecules hence the glass breaks.

Demonstrating expansion of a solid

1. The metal bar shown is made such that it will just fit into the gap in the gauge when both the bar and the gauge are cold.

   The bar is heated and is tested if it may fit again.

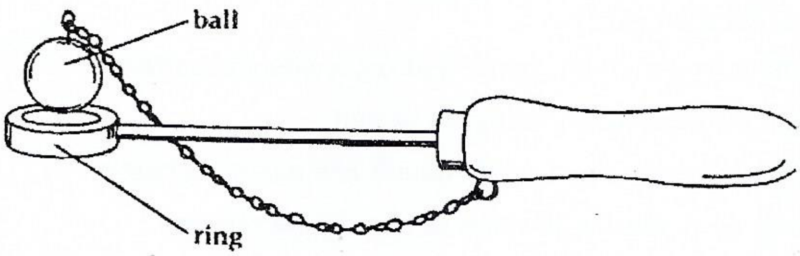
   Observation: the bar does not fit. The rise in temperature of the bar leads to increase in length.

2. A spherical metal ball is made to pass through the ring when both the ring and metal ball are cold.

   The ball is then heated and tested if it passes through the ring again.

   Observation: The metal ball does not pass through the ring.

   Thus when the metal ball is heated its diameter increases in all directions hence expansion.



Uses of expansion and contraction

1. Railway tracks are designed with gaps in between them to allow room for expansion.
2. Pipelines which carry liquids and gases over long distances must have flexible expansion joints built in them at regular intervals.
3. Expansion and contraction is used in riveting to get a tight joint. A hot rivet is pushed through a hole in the two plates to be joined. Then the end of a hot rivet is hammered to form another head. As the rivet cools it contracts and pulls the two plates together more tightly.

Linear Expansivity

This is a measure of tendency of a particular material to expand when heated.

Linear expansivity of a substance depends on the

(i) length of the substance.

(ii) rise in temperature.

Linear expansivity is the fraction increase in length of a material for each degree rise in temperature.

Linear expansivity α is obtained from $\alpha = \frac{\Delta l}{l\Delta\theta}$ $\Rightarrow \Delta l = \alpha l \Delta\theta$

Δl is the change in length, $\Delta\theta$ is the rise in temperature and l is the original length.

S.I units of linear expansivity are per kelvin (K^{-1}).

Example: Linear expansivity of iron is $12 \times 10^{-6}\ K^{-1}$. *This means that 1 metre of iron expands by* 12×10^{-6} *m when its temperature rises by 1kelvin.*

The table below shows linear expansivity of some materials

Material	Linear expansivity (K^{-1})
Glass	9×10^{-6}
Concrete	12×10^{-6}
Iron	12×10^{-6}
Brass	19×10^{-6}
Aluminium	26×10^{-6}
Nylon	100×10^{-6}

Brass has a higher expansivity than iron thus it expands more than iron when heated by the same amount.

Calculations

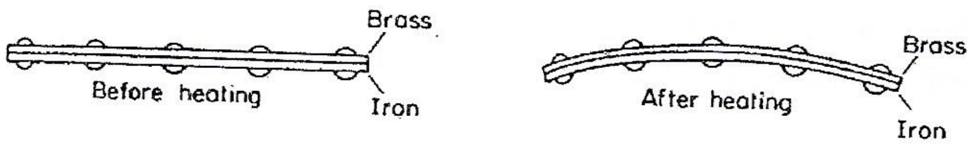
1. Calculate the linear expansion of a concrete bridge of span 100 m when the temperature rises by 20°C. (Linear expansivity of concrete is $1.2 \times 10^{-5}\ K^{-1}$)

   $l = 100\ m,\ \Delta\theta = 20°C,\ \alpha = 1.2 \times 10^{-5}\ K^{-1}$

   $Using\ \Delta l = \alpha l \Delta\theta, \quad \Rightarrow \Delta l = 1.2 \times 10^{-5} \times 100 \times 20 = 0.024\ m$

   Concrete will expand by $0.024\ m$

The bimetallic strip: A bimetallic strip is made of two strips of different metals, same length and cross-sectional area, are joined together e.g. iron and brass.



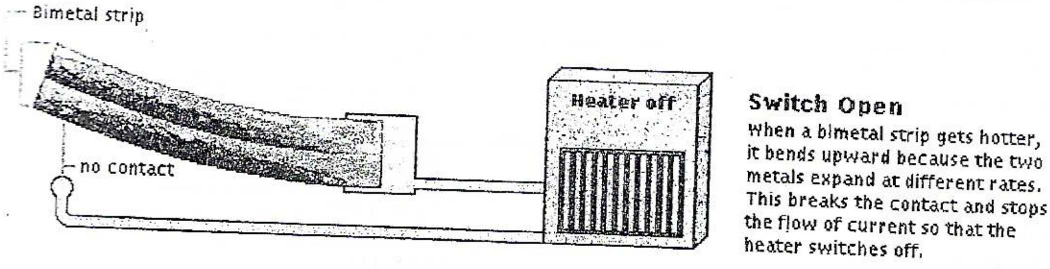
When the metals are heated, they expand differently causing them to bend towards the metal with lower expansion rate.
Since brass expands more than iron, the two will bend with brass on the outside.

Applications of linear expansivity

Bimetallic strips are applied in

i) thermostats

A thermostat is a device that automatically regulates the temperature of a system by maintaining it constant or varying it over a specific range.
Thermostats are applied in heating systems of hot-water storage tanks, electric irons

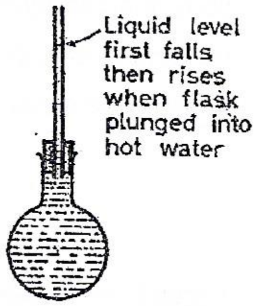


and in the radiator of an automobile engine that is water-cooled.

ii) automatic flashing unit for direction indicators on vehicles

iii) fire alarms

Demonstrating expansion of liquids



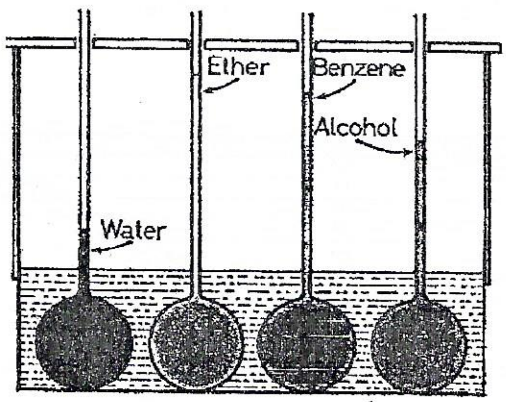
A glass flask is filled with coloured water. A stopper with long glass tube is fitted so that there is no air in the flask and water rises a short way up the tube.

When the flask is heated, water level drops first and then rises after heating.

Explanation: *The drop is due to expansion of glass flask which increases in volume. This creates space inside and hence a drop in water level to occupy the created space. Once heat reaches the liquid, it expands rapidly up and water level increases.*

Rapid increase in water level shows that liquids expand much more in volume than solids.

Different liquids have different thermal expansions.

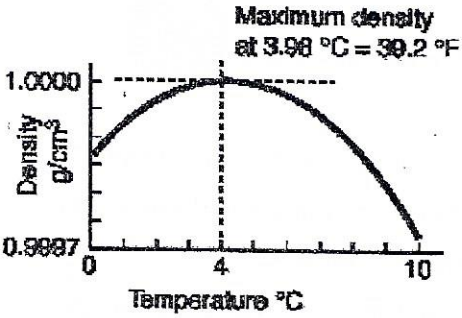


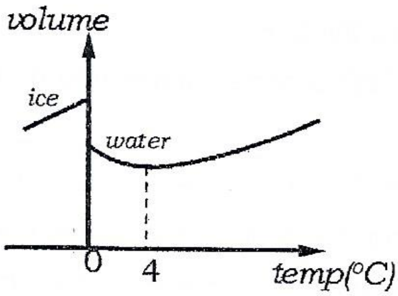
Several large glass bulbs of the same size with glass stems are filled to a short distance above the bulb with various liquids. The bulbs are immersed in a metal trough containing cold water and left until they have reached a steady temperature. A little extra liquid is then added in case the levels are not the same anymore. The bath is heated and well stirred to ensure uniform temperature. When the bulbs and their contents have acquired the new temperature of the bath, it will be seen that the liquid levels have risen by different amounts. Thus, for a given rise in temperature equal volumes of different liquids show different expansions in volume.

The unusual expansion of water

Most liquids contract steadily as they cool and contract further on freezing.

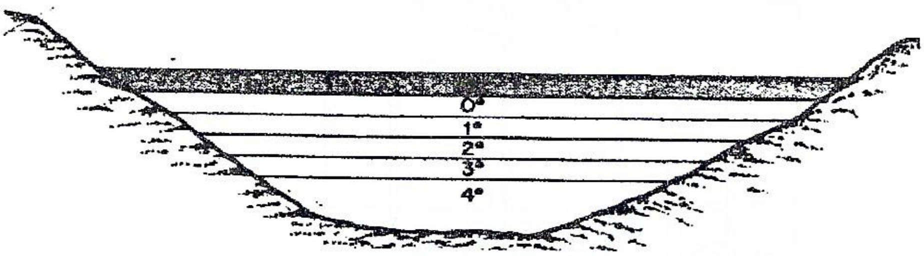
Heating ice increases its temperatures up to 0°C when it melts. This melting is accompanied by a contraction in volume between 0°C and 4°C. Hence water has its maximum density and minimum volume at 4°C. Beyond 4°C water expands and density decreases. This behavior is described as anomalous (irregular).





Biological importance of the anomalous expansion of water

It helps preserve aquatic life during very cold weather.



When a lake cools, denser water at 4°C sinks and less dense water at lower temperatures remain above. If further cooling occurs, water at the top freezes and a layer of ice is formed. Ice being a bad conductor of heat, it slows down further loss of heat from water below and fish can survive in the layers below where unfrozen water still exists.

MECHANICAL PROPERTIES OF MATTER

Materials commonly used for construction of buildings, bridges, dams and roads are metals, plastics, glasses, concrete that are first tested whether they withstand the conditions of the finished structure.

Some of the tested mechanical properties are; elasticity, strength, brittleness, ductility e.t.c.

Terms used.

1. *Tensile forces:* These are the forces that increase or tend to increase the length or shape of a material when they are applied. When this happens, the material is said to be under tension.
2. *Compressional forces:* These are the forces that decrease or tend to decrease the length or shape of a material when they are applied.
3. *Shear force:* A shear force is a force necessary to fracture a material in a direction to the force applied and section of the material shears over its neighbor as shown below

4. *Strength:* This is the ability of a material to withstand the applied forces before breaking. The force may be tensile compression or shear. The strength of the material depends on;
   - nature of the substance e.g. force needed to break steel is greater than force needed to break wood of the same size.
   - diameter of the material. The bigger the diameter the greater the force needed to break it than a material of a small diameter.
5. *Stiffness:* This is the ability of a material to withstand shock forces or ability to resist bending, change in size or shape.
6. *Elasticity:* This is the ability of a material to regain its original size, length and shape after the applied force is removed.
7. *Ductility:* This is the ability of a material to be hammered, pressed, bent, rolled, and stretched into useful forms. Most metals such as copper, aluminum and iron are ductile.

8. *Brittleness:* This is the ability of a material to break easily just after the elastic limit is exceeded. Brittle materials are glass rod, piece of chalk, biscuits and concrete. *These substances crack easily under tension and are weakened by surface scratches.*
9. *Elastic deformation:* This is when the material regains its shape or length when the applied force is removed.
10. *Plastic deformation:* This is when the material does not regain its shape or length when the applied force is removed.

If a force F acts on a wire of length l and cross-sectional area A so that the wire extends by e, then

- tensile stress is the force acting normally on a unit area; $stress = \frac{F}{A}$
  Its units are Nm^{-2}
- tensile strain is the extension caused per original length; $strain = \frac{e}{l}$
  It has no units since it is a ratio of two lengths

Calculations

1. A wire 10 cm long is subjected to a force of 2 N. If its cross-sectional area is $5cm^2$and extension caused is 0.2 cm, calculate tensile stress and strain.
   Solution; $F = 2N,\ A = 5 \times 10^{-4}m^2,\ e = 0.2 \times 10^{-2}\ m$
   $stress = \frac{F}{A} = \frac{2}{5\times10^{-4}} = 4000Nm^{-2},\ strain = \frac{e}{l} = \frac{0.2}{10} = 0.02$
2. A spring of natural length 5cm extends by 2 mm when a force of 1.8 N acts on it. Calculate the extension and strain when a force of 10 N is applied to the spring.
   $Using \frac{F_1}{e_1} = \frac{F_2}{e_2} \Rightarrow \frac{1.8}{2} = \frac{10}{e_2} \Rightarrow e_2 = 11.1\ mm = 1.11\ cm$
   Extension caused is $1.11\ cm$ $\quad Strain = \frac{extension}{original\ length} = \frac{1.11\ cm}{5\ cm} = 0.222$

Practice questions

1. A force of 500N acts at the end of the wire 2m long and cross-sectional radius 2mm. If the force causes an extension of 3cm, calculate
   ii. tensile stress
   iii. tensile strain

   Solution

   (i) $Area\ A = \pi r^2 = 3.14 \times \left(\frac{2}{1000}\right)^2 = 1.256 \times 10^{-5}m^2$

$$Tensile\ stress = \frac{F}{A} = \frac{500}{1.256\times10^{-5}} = 3.981\times10^{7}Nm^{-2}$$

(ii) $Tensile\ strain = \frac{e}{l} = \frac{3}{100} \div 2 = 0.015$

2. A force of 35N is applied to a wire of length 3m and diameter 12mm. Find the tensile stress and strain of the wire if it extends by 38%.

Solution; Radius $r = \frac{12}{2} = 6mm = 6\times10^{-3}m$

Area $A = \pi r^2 = 3.14\times(6\times10^{-3})^2 = 1.13\times10^{-6}m^2$

$stress = \frac{F}{A} = \frac{35}{1.13\times10^{-6}} = 3.097\times10^{7}Nm^{-2}$

Extension caused $e = \frac{38}{100}\times 3 = 1.14m$

$strain = \frac{e}{l} = \frac{1.14}{3} = 0.38$

Concrete

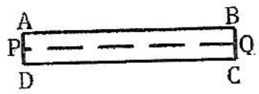
This is a mixture of sand, water, gravel and cement in appropriate proportions. Concrete is used to provide strong materials for construction of buildings, bridges, roads and slabs. The amount of cement in concrete determines the strength.

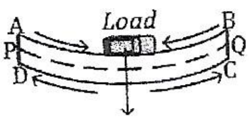
Reinforcement of concrete

This is the act of strengthening concrete to be used for construction. This is done by using

- wire nets especially in making slabs
- iron / steel bars which are corrugated or twisted for fine grip of concrete
- fibers like sisal or wood strands. This is normally used for portioning purposes where high strength is needed.
- iron / steel which have hooks on them.

Bending of beams





When a beam ABQCD is loaded,

- AB tends to shorten in length and is said to be in a state of compression
- CD tends to increase in length and is said to be in a state of tension

- PQ is neither under tension nor compression and is called neutral plane.

I-shaped steel beams are used in large structures because they have materials removed from their neutral plane and so they

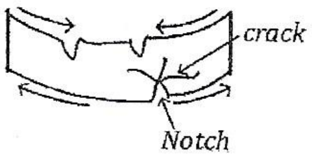
- weigh less
- withstand compressional and tensional forces

Hollow beams too have the same advantages. Hollow beams such as culverts withstand compressional forces as these forces are uniformly distributed along their rings.

Notch effect

A notch is a scratch or crack made a material.

A notch on a brittle material spreads rapidly when under tension than under compression.



The notch effect is minimized by

- rounding the notch. The stress is evenly distributed around a circular notch hence reducing the breaking effect.
- placing a notch under compression

Structures

These consist of girders – beams/rods jointed together to support structures by being under tension or compression.

Girders under tension are called ***ties*** and girders under compression are called ***struts***.

Structures include bridges, rafters, water tank stands.

<u>Identification of a tie from a strut</u>