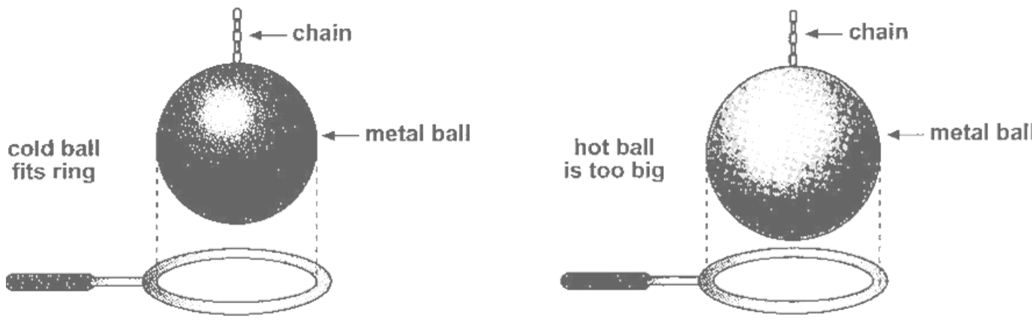
TOPIC: HEAT
SUBTOPIC: EXPANSION OF SOLIDS, LIQUIDS AND GASES.

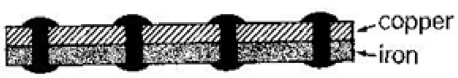
- Demonstrate and explain expansion of solids and liquids.
- Identify and describe applications of expansion and their consequences.
- Sate the anomalous expansion of water and state its importance.

EXPANSION OF SOLIDS.
Expansion is an increase in size of a substance. When heated, most substance increase in size in all directions.

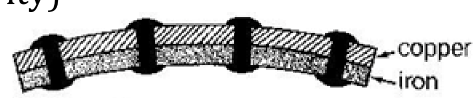
Expansion of solids can be illustrated using a metal ball with a ring as shown below.



The metal ball passes through the ring when it is cold, but when heated, the ball doesn't pass through the ring any more, showing that it has expanded. It passes through the hole again when it cools, meaning that the metal contracts when it loses heat.
Different metals expand at different rates when equally heated, this can be shown using a metal strip made of two metals such as copper and iron bounded tightly together (bi-metallic strip). When the bimetallic strip is heated, the copper expands more than iron and the strip bends as shown. (The two metals forming the bimetallic strip must be of equal length and thickness but of different linear expansivity)



(a) Before heating

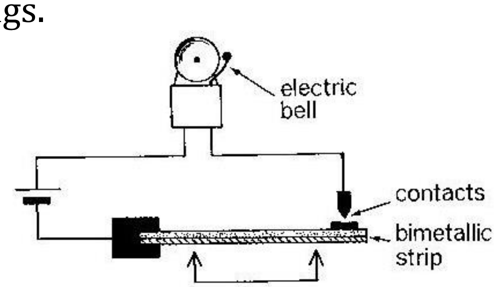


(b) After heating

NOTE:
The metal that that expands most describes a longer curvature than that which expands the least. (i.e. copper expands more than iron)

USES OF A METALLIC STRIP (APPLICATION OF EXPANSION OF SOLIDS)

(a) **Fire alarm**
Heat from the source makes the bimetallic strip bend and completes the electric circuit and the bell rings.

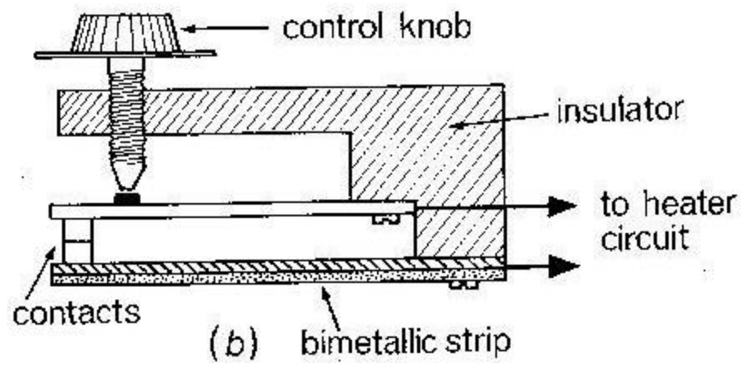


(a)

(b) **Thermostat**

This is a device that makes temperature of an electrical appliance or room to remain constant.

The thermostat shown below uses a bimetallic strip in the heating circuit of a flat iron.

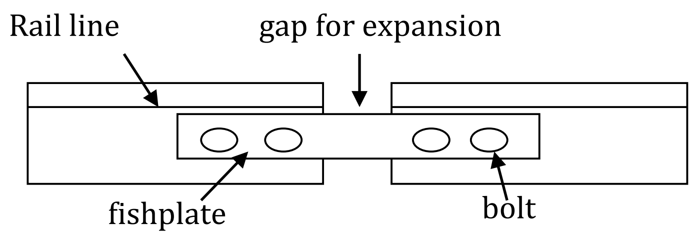


When flat iron reaches, the required temperature;
The strip bends and breaks the circuit at the contact, hence switching off the heater.
The strip makes contact again after cooling a little and the heater is on again.
A nearly steady temperature results. If the control knob screwed further, the strip has to bend more in order to break the circuit and this leads into a higher temperature.

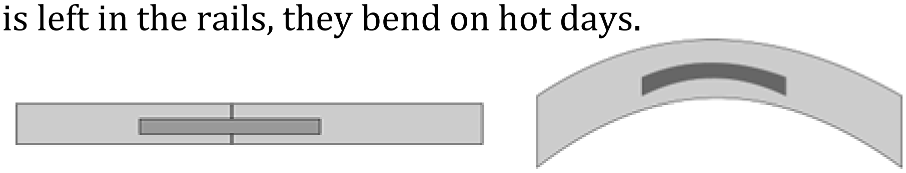
DISADVANTAGES OF EXPANSION

Expansion can cause a number of problems:

- Contraction of railway lines, bridges, oil pipes and putting up electrical transmission wires. Therefore, allowance must be made for expansion.
- **Railway lines are** constructed with gaps left in between consecutive rails such that on hot days, when the rails expand; they have enough room for expansion.

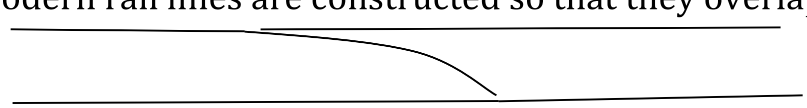


If no gap is left in the rails, they bend on hot days.



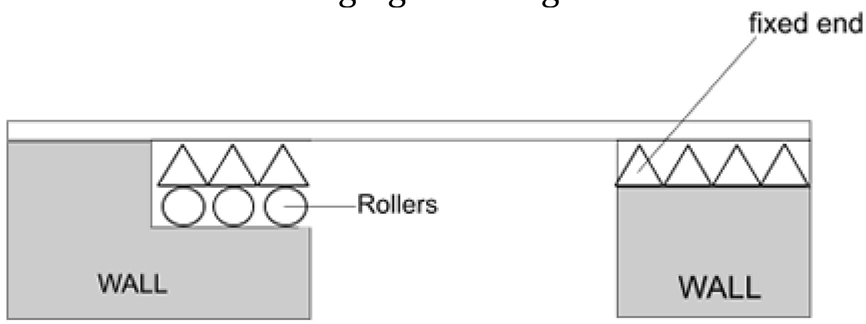
Cold days　　hot days

Modern rail lines are constructed so that they overlap as shown below.

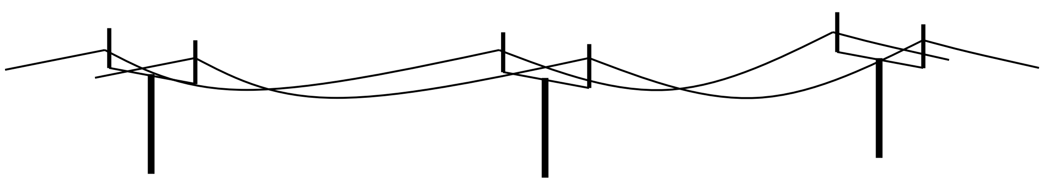


During expansion, the rails simply slide along each other.

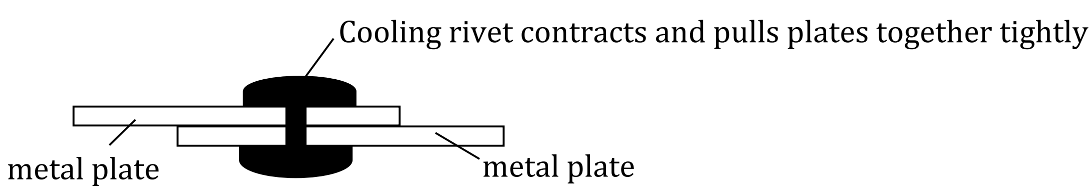
- **Steam pipes and telephone wires:**
  Steam pipes are built to have flexible expansion joints in them to allow room for expansion.
- **Steel bridges**
  These are constructed in such a way that one end is rested on rollers and the other end is normally fixed. This is to ensure that the structure can contract and expand freely at various temperatures without damaging the bridge.



- **Transmission cables**
  Wires or cables in transmission or telephone cables are normally not pulled tightly during installation but are loosely held or have loops at various intervals over long distances in order to allow room for expansion and contraction during extreme weather conditions.



- **Rivets:**
  They are tight joints obtained by riveting two metals together. A hot rivet is pushed through a hole in the two plates to be joined together, then hammered and left to cool. It contracts and pulls the two metals together.



LINEAR EXPANSIVITY:

Different solids have different rates of expansion. This difference can be distinguished by their linear expansivities.

Definition:

The linear expansivity of a substance is the fraction of the original length by which a rod of the substance expands per Kelvin rise in temperature.

Linear expansivity of a substance depends on:

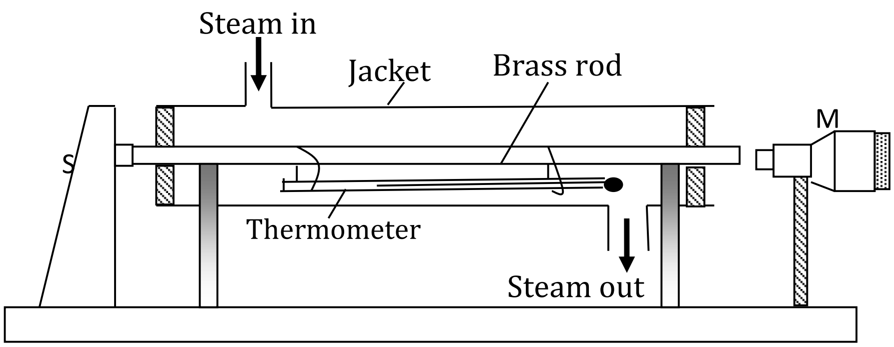
1. The length of the substance.

2. The rise/change in temperature.
3. The nature of the material.

Linear expansivity, α is given by the equation:

$$\alpha = \frac{change\ in\ length}{original\ length \times change\ in\ temperature} = \frac{\Delta l}{l_o \times \Delta\theta}$$

AN EXPERIMENT TO MEASURE THE LINEAR EXPANSIVITY OF A METAL:



- The original length of the brass rod is measured using a metre rule.
- The rod is fitted inside a steam jacket and also the thermometer is fitted in its socket.
- The micrometer screw gauge is screwed up so that there is no gap at either end of the rod and the reading of the micrometer scale, l_1 is taken.
- The initial temperature of the rod, θ_1 is noted.
- The micrometer screw gauge is unscrewed to leave room for expansion of the rod and steam is passes through the jacket for a few minutes.
- The micrometer screw gauge is screwed up again and a second reading of the micrometer scale, l_2 is taken.
- The final temperature of the rod, θ_2 is noted.

The following calculations are then carried:
- Change in the length of the rod, $\Delta l = l_2 - l_1$.
- Change in the temperature, $\Delta\theta = \theta_2 - \theta_1$.

Linear expansivity is given by the calculation,

$$\alpha = \frac{\Delta l}{l_1 \times \Delta\theta} = \frac{l_2 - l_1}{l_1 \times \Delta\theta}$$

S.I unit of Linear expansivity:

The S.I unit of linear expansivity $\alpha, = per\ kelvin\ or\ per\ degree\ Celcius\ (C\ or\ {}^{o}C^{-1})$

From the definition of linear expansivity,

$linear\ expansion = linear\ expansivity \times original\ length \times temperature\ rise.$

i.e. $\Delta l = \alpha l_1 \Delta\theta$ OR $l_2 - l_1 = \alpha \times l_1 \times (\theta_2 - \theta_1)$.

Also

$New\ length = original\ length + extension$

$$\therefore \quad l_2 = l_1 + l_1\alpha\Delta\theta \qquad OR \qquad l_2 = l_1(1 + \alpha\Delta\theta)$$

Examples:

1. A steel bridge is 2.5 m long. If the linear expansivity of steel is $1.1 \times 10^{-5} K^{-1}$, how much will it expand when temperature rises by 5^oC? Give your answer in cm.

$$linear\ expansion = linear\ expansivity \times original\ length \times temperature\ rise.$$

$$\Delta l = \alpha l_1\ \Delta\theta$$

$$\Delta l = (1.1 \times 10^{-5} \times 2.5 \times 5\ )100\ cm$$

$$\therefore\ \Delta l = 1.135 \times 10^{-2}\ \ cm$$

2. In an experiment to measure linear expansivity of a metal, a rod of this metal 800 mm long is found to expand 1.36 mm when heated from 15 ^oC to 100 ^oC.
Find the value of linear expansivity.

$$linear\ expansivity, \alpha = \Delta l/(l_1 \times \Delta\theta)\ \ .$$

$$\alpha = \frac{1.36}{800 \times (100 - 15)}$$

$$= \frac{1.36}{800 \times 85}$$

$$= \ \ 2.0 \times 10^{-5}\ K^{-1}$$

3. A metal rod has a length of 100 cm at 200^0C. At what temperature will its length be 99.4 cm if the linear expansivity of the material of the rod is 0.00002 K^{-1}.

$$linear\ expansion = linear\ expansivity \times original\ length \times temperature\ rise.$$

$$\therefore\ \ \Delta l = \alpha l_1 \Delta\theta$$

$$\therefore\ \ 99.4 - 100 = 0.00002 \times 100(\theta - 200)$$

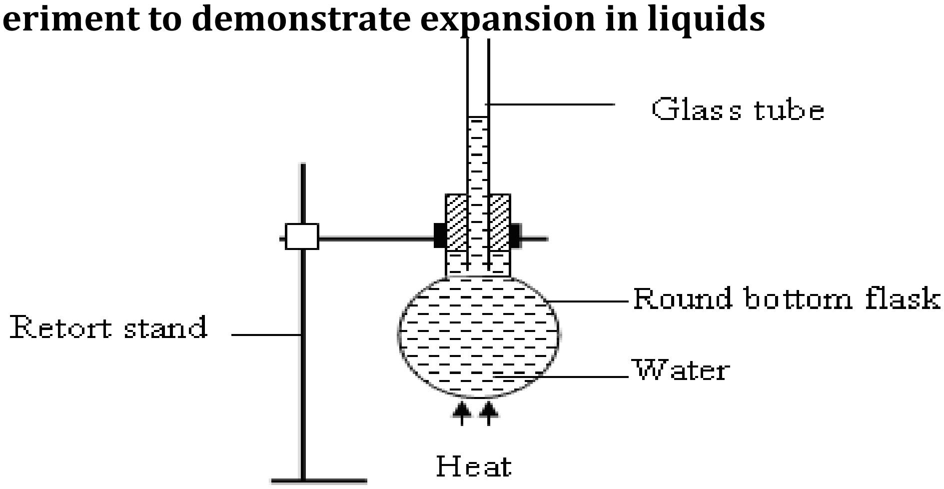
$$\therefore\ \ \frac{-0.6}{0.002} + 200 = \ \theta$$

$$\therefore\ \theta = \ -100^oC.$$

EXPANSION IN FLUIDS

When liquids or gases (fluids) get hot, they expand just as solids do, but their expansion is greater than that of solids for the same amount of heat. Since liquids do not have fixed length or surface area, but always take up the shape of the vessel, it's their volume changes that are considered when they are heated.

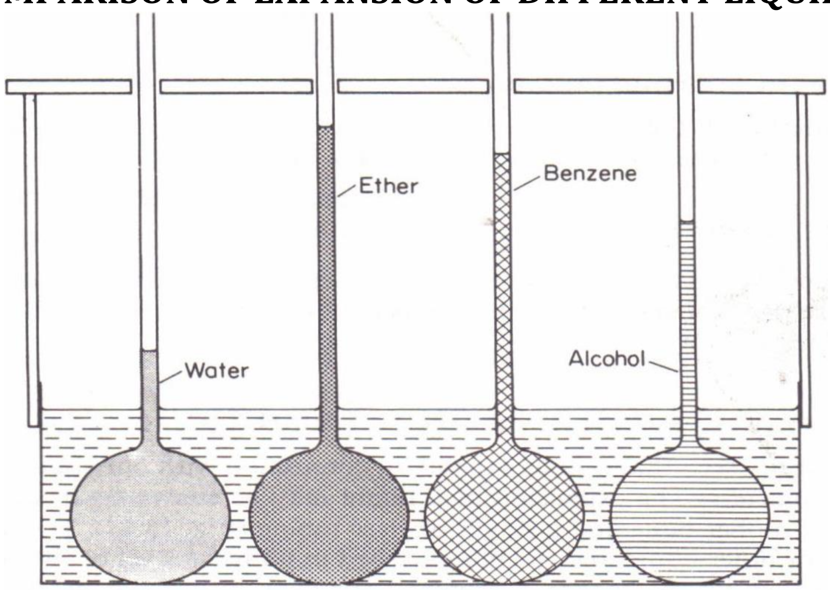
Experiment to demonstrate expansion in liquids



Procedure
The flask is completely filled with colored water.
The narrow tube is passed through the hole of the cork and the cork is fixed tightly into the flask.
The first level of water in the narrow tube is observed.
The bottom of the flask is heated.
The new level of water in the capillary tube is observed.
Observation:
The water level in the narrow tube first falls before it starts to rise.
Conclusion:
The eventual rise in water level confirms that liquids expand when heated.

The initial fall in the water level can be explained by the fact that the glass (container) gets heated first and it expands before the heat is passed on to the water inside. The glass therefore expands and increases in volume before the water resulting in the water level falling.
Eventually, the water starts expanding when the heat reaches it and its level starts to rise.

COMPARISON OF EXPANSION OF DIFFERENT LIQUIDS:



- Four identical glass bulbs are filled with different liquids to the same level as shown in the diagram.
- The glass bulbs are immersed in hot water the contained in a water bath which is maintained at the same temperature by stirring.

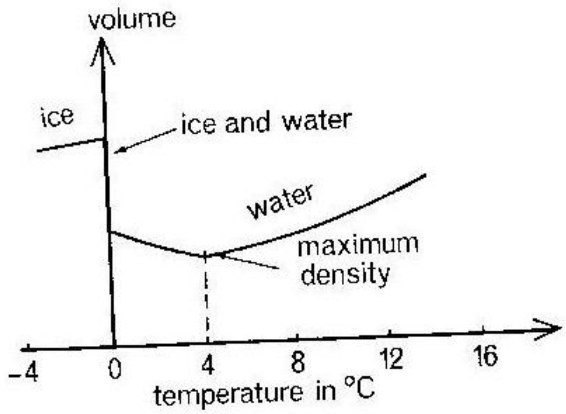
Observation shows that the liquid levels first drop before they start rising to different levels.
Since the liquids are subjected to the same temperature, yet they rise to different levels, confirms that different liquids expand differently for the same temperature change.

Application of expansion property of liquids
This property is used in thermometer; the liquids used include alcohol and mercury.

ANOMALOUS EXPANSION OF WATER

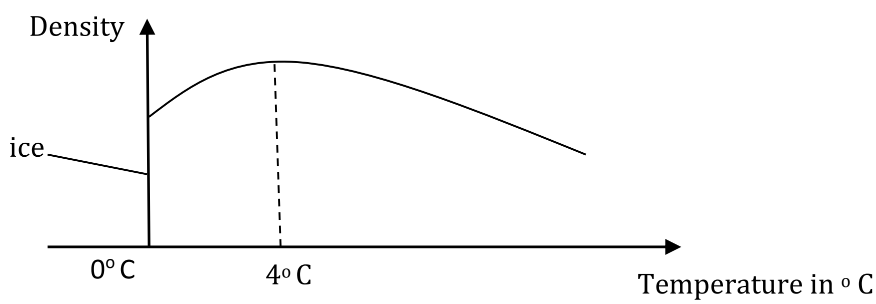
- Liquids expand when heated but water behaves differently over the temperature range of $0^oC - 4^0C$.
- When water is heated from 0^oC to 4^oC, it contracts instead of expanding.
- This situation is referred to as the ***abnormal (anomalous) expansion of water***.

The volume – temperature graph below represents the variation of the volume of the water with temperature change.



- The volume of water is minimum at 4^0C
- Therefore, the density of water is maximum at 4^oC
- Beyond 4^oC, the volume of water increases i.e. expands with increase in temperature.

Variation of density of water with temperature:

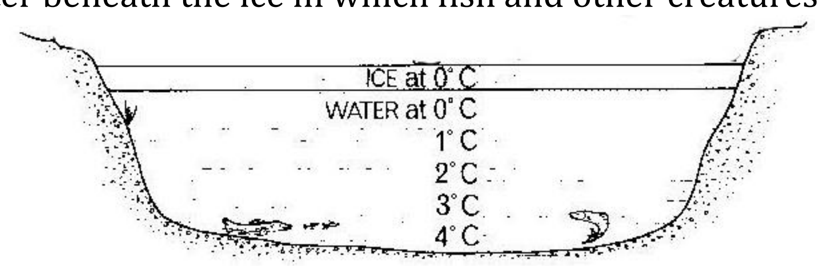


Application of anomalous behaviour of water.

It is used to preserve aquatic life during cold weather.

As the temperature of the pond or lake falls the water contracts, it becomes denser and sinks. It is replaced by the colder and denser water from the top of the water body and a circulation is thus set up until all the water reaches its maximum density at 4 ^{0}C if further cooling occurs any water below 4^0C will stay at the top due to its lighter density thus ice forms and stays at the top of water.

The lower layer of water at 4^0C can only lose heat by conduction. So in deep water there will be always water beneath the ice in which fish and other creatures can live.



Disadvantages of anomalous behavior of water.

- it can cause water pipes to bust due to formation of ice inside the pipe.
- it prevents water being used as a thermometric liquid.

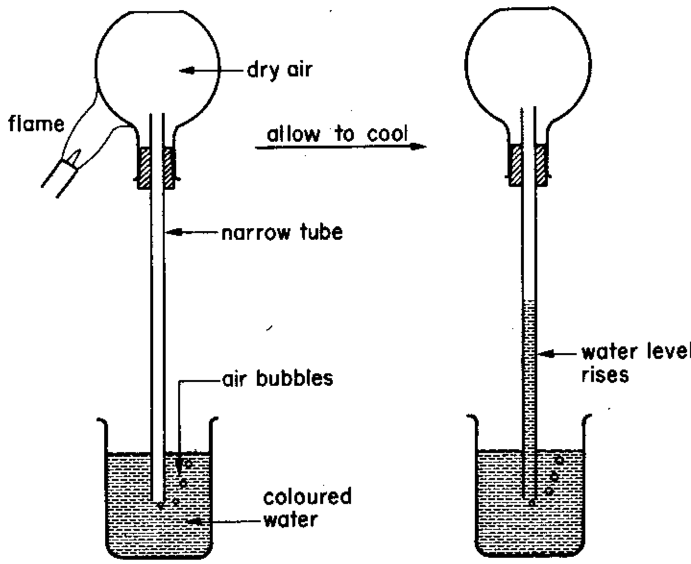
NOTE:

- Anomalous expansion of water causes weathering of rocks due to its expansion and contraction.

EXPANSION OF GASES:

A gas expands when heated almost 10,000 times more than solids. This is due to the fact that cohesive forces that exist between their molecules are extremely weak.

EXPERIMENT TO DEMONSTRATE EXPANSION IN GASES



- Coloured water is poured in a beaker.
- A flat bottomed flask is obtained and is tightly closed with a rubber cork with narrow tube fixed through it.
- The flask is slightly heated.
- Air bubbles will be seen coming out from the other end of the tube.
- This shows that air expands when heated.
- In the second set up, when the surface of heat is removed and the flask is allowed to cool by pouring cold water, the level of water will rise. This shows that air contacts when cooled.

Application of expansion of air.

Hot air balloon

Expansion of air is used in hot air balloons. When air in the balloon is heated, it expands and becomes less dense and as a result the balloon rises up.

THE END.