3.2 Effects of Heat

Thermal expansions

It is common observation that most substances (solids, liquids and gases) expand on being heated and contract and being cooled.

Illustrative examples

1) You may have observed that sometimes sealed bottles with metallic lids are so tightly screwed that one has to put the lid in hot water for some time to open the lid this would allow the metallic cover to expand their by making it loose to unscrew it easily.
2) The expansion joints being provided on railway tracks and on concrete highways.
3) In metal pipes carrying an oil or another liquid over long distances, loops are generally provided at regular intervals this is to avoid strain that could otherwise develop in the pipe due to changes in the temperature.
4) In the case of gases, a balloon partially inflated in a cool room may expand to full size when placed in warm water. On the other hand a fully inflated balloon when immersed in cold water would starts shrinking due to contraction of the air inside.

Activity

Blacksmiths make use of the effect of expansion on heating when they are required to fix a metallic ring on the rim of wooden wheel of a bullock cart for these they make the metallic ring a little smaller in diameter than that of the wheel. The ring expands on heating and fits on the wheel. Then it is allowed to contract by pouring water over it which can thus fit over the wheel tightly.

Thermal expansions in solids

We know that solids have definite shape so there are three types of thermal expansions in solids

- Linear expansion (change in length)
- Superficial expansion (change in area)
- Cubical expansion (change in volume)

To give a quantitative meaning to the expansion of solid we introduce a concept of coefficient of linear expansion of the material, superficial expansion of the material, coefficient of volume expansion of the material

Coefficient of linear expansion of the material

It is the ratio between the increases in length to the initial length of a material of solid when its temperature is increased by 1^0C.

OR

It is the fractional change in the length per degree rise in temperature.

$$L_2 = L_1 [1 + \alpha (T_2 - T_1)]$$

Where α is a constant for a given material and is called the coefficient of the linear expansion of the material .

$$\alpha = \frac{L_2 - L_1}{L_1(T_2 - T_1)}$$

$/ ^0 C$

Values of coefficient of linear expansion for some materials

Solid	Coefficient of linear expansion, α ($10^{-5}\ {}^0C^{-1}$)
Aluminum	2.5
Brass	1.8
Iron	1.2
Copper	1.7
Silver	1.9
Gold	1.4
Glass	0.3
Lead	0.31

Similarly Coefficient of superficial expansion is defined as fractional change in the area per degree rise in temperature.

$$A_2=A_1\ [\ 1 + \beta\ (T_2 - T_1\ )]$$

$$\beta = \frac{A_2 - A_1}{A_1(T_2 - T_1)}\ {}^0C^{-1}$$

Coefficient of cubical expansion is defined as fractional change in the volume per degree rise in temperature.

$$V_2=V_1\ [\ 1 + \gamma\ (T_2 - T_1\ )]$$

$$\gamma = \frac{V_2 - V_1}{V_1(T_2 - T_1)}\ {}^0C^{-1}$$

Note: -

$$\alpha : \beta : \gamma = 1 : 2 : 3$$
$$\beta = 2\alpha$$
$$\gamma = 3\alpha$$

Practical applications of thermal expansions of metals is in bimetallic strips , theses are commonly used as thermo switches in automatic electric heaters , toasters , iron box and refrigerators .

Thermal expansions of liquids

In the case of the liquids accurate measurement of the expansion with rise in temperature is made difficult because of the simultaneous expansion of liquid and the vessel containing it. It is observed that most liquids and gases, like solids, expand by an amount, which is proportional to the rise in temperature and the original volume.

$$V_2=V_1\ [1 + \gamma\ (T_2 - T_1)]$$

$V_1 \rightarrow$ Volume of given mass of liquid or gas at temperature T_1.

$V_2 \rightarrow$ Is the Volume when it is heated to temperature T_2.

$\gamma \rightarrow$ Coefficient of volume expansion

Coefficient of volume expansion of some solids and liquids

Solid	γ **(10^{-5} $^oC^{-1}$)**	**Liquid**	γ **(10^{-5} $^oC^{-1}$)**
Iron	3.55	Mercury	18.2
Lead	0.84	Water	20.7
Paraffin	58.8	Petroleum	89.9
Glass	2.53	Alcohol	122

Thermal expansions of gases :-

When gases are heated pressure and volume change, gases have large thermal expansion because of large intermolecular distance between the molecules of the gas .

There are two types of expansions of gases

1) The coefficient of volume expansion of gas
2) Coefficient of Pressure expansion of gas

The coefficient of volume expansion of gas: - (α)

The coefficient of volume expansion of a given mass of gas at constant pressure is defined as the ratio of increase in volume per degree rise in temperature to its original volume at 0^oC.

$$\alpha = \frac{V_t - V_0}{V_0 t}$$

Coefficient of Pressure expansion of gas : - (β)

The coefficient of pressure expansion of a given mass of gas at constant volume is defined as the ratio of increase in Pressure per degree rise in temperature to its original pressure at 0^oC.

$$\beta = \frac{P_t - P_0}{P_0 t}$$

NOTE: - The value of α & β is found to be same for all gases and is very nearly equal to $\frac{1}{273}$.

Gas laws: -

Boyle's Law: The pressure of a given mass of gas is inversely proportional to its volume then the temperature is kept constant

i.e **PV = constant**

Charles's Law : The volume of the given mass of gas at constant pressure varies directly as its absolute temperature .

i.e −

Gay-Lussac's Law : Pressure of the given mass of gas at constant volume varies directly as its absolute temperature.

i.e −

Ideal gas OR Perfect gas:-

A gas which obeys Boyle's law and Charles's law at all temperatures and pressures is called a perfect gas .

PERFECT GAS EQUATION

PV = RT

Where R is the universal gas constant

For n moles of a gas the gas equation is **PV = n RT**

Isothermal process

Pressure P and Volume V change at **constant temperature T** then the process is called isothermal process

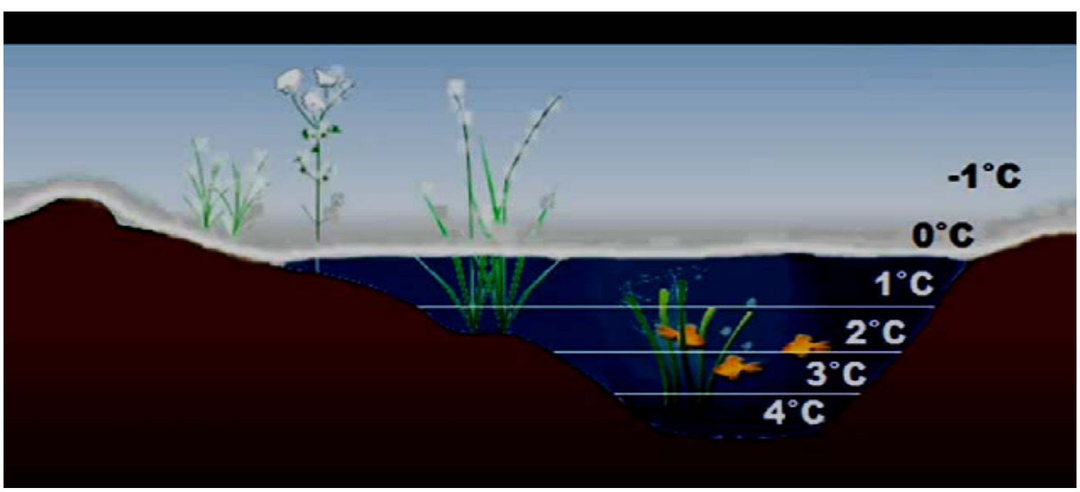
Ex: Slow expansion or compression of a gas

Adiabatic process

It is the physical change that takes place under perfect thermal isolation, that is heat neither be allowed to enter the system nor leave the system.

Ex: Sudden expansion or compression of a gas

Anomalous expansion of water



For most of nature's substances it usually is the case that when you cooled them, they contract and occupy less space, substances like mercury, ammonia and gold all contract consistently when you cool them, but **water is exceptional** for at a certain point when cooled, it fills expands.

It becomes densest at 4^0C then it starts expanding even when it starts to freeze. This can cause some nasty things, like bursting frozen pipes or the damage done to living cells which we call frostbite.

<u>Questions</u>

1) Can a wire be expanded without heating it?
2) When a vessel full of liquid is suddenly heated, in the beginning the level of the liquid falls down why?
3) Why a solid floating in a liquid fully immersed sinks to the bottom when the temperature of the system increases?
4) Two spheres are, one hollow and other the solid are made of the same material and are of the same size they are heated to same temperature. Do they have equal expansion or not?
5) Will the density of the liquid change when its temperature changes?
6) Are they linear and areal coefficient expansions of liquids?
7) Which is lighter dry air or humid air?
8) What does the area of P-V diagram give?

Answers

1) yes
2) Because of the vessel expansion first
3) Density of the liquid decreases
4) No
5) Yes
6) No
7) Humid air
8) Work done