THERMAL EXPANSIVITY

When heated, most solids and liquids expand. They also contract when cooled. Expansion means an increase in the size or volume of an object.

According to the kinetic molecular theory, when an object is heated the molecules acquire more kinetic energy which enables them to overcome their intermolecular forces. Therefore the vibrations of the molecules increase and their displacements about their mean positions increase. As a result of this, the average distance between the molecules of the substance becomes larger leading to an increase in size of the substance. This increase in the dimension of the heated object depends on the strength of the intermolecular forces. If these forces are strong, the expansion will be small and vice versa.

The intermolecular forces are stronger in solids than in liquids and weaker in gases. Thus, when heat is applied, gases expand more than liquids, and liquids expand more than solids.

Each particular substance has intermolecular forces peculiar to it. Therefore the addition of heat causes different expansions in different expansions in different substances.

Expansion in Solids

Solids expand when heated and contract when cooled. This can be demonstrated using the ball and ring experiment.

The apparatus consists of a metal ring through a metal ball just fits. To perform

- Bring the metal ball out of the ring. Heat the ball strongly over a hot flame for several minutes.
- Place the hot ball over the ring and that it no longer fits into the ring.
- Allow the hot ball to cool sufficiently for several minutes and put it over the ring again.

Notice that the ball now passes through the ring.

- The metal ball had increased in size when heated and decreased in size when cooled.

We have linear, area and cubic expansions in solid.

Linear Expansivity: Different solids expand by different amounts when heated over the same temperature range. Copper for example expands more than steel when both are heated through the same rise in temperature. This is because they have different coefficient of linear expansion or linear expansivity. The formula is given as:

$$\alpha = \frac{l_2 - l_1}{l_1(\theta_2 - \theta_1)} = \frac{e}{l_1\theta}$$

where α= linear expansivitiy

l_1 = length of metal at θ_1

l_2 = length of metal at θ_2

$\theta = \ temperature\ rise\ and\ is\ equal\ to\ \theta_2\ - \theta_1$

e = expansion and is equal to $l_2 - l_1$.

Below are some metals and their linear expansivity:

Substance	Linear expansivity (K^{-1})
Platinum	0.000009
Iron	0.0000120
Copper	0.0000170
Brass	0.0000180
Aluminium	0.0000230
Lead	0.0000290
Zinc	0.0000300
Invar (alloy)	0.0000010
Glass	0.0000085
Silica	0.0000004

Area and Volume Expansivity: When a solid is heated, it expands in all dimensions – length, breadth, and height. Hence, there is an increase in the area as well as in the volume of solid. The increase in area when a body is heated is known as

area or superficial expansion. Similarly, the increase in volume when a body is heated is known as cubic or volume expansion.

Formulae for area and cubic expansivitiy are given as:

$$\beta = \frac{A_2 - A_1}{A_1 \theta}$$

where β = area expansivitiy

A_1 = area of metal at θ_1

A_2 = area of metal at θ_2

$$\theta = \theta_2 - \theta_1$$

$$\gamma = \frac{V_2 - V_1}{V_1 \theta}$$

where γ = volume expansivitiy

V_1 = volume of metal at θ_1

V_2 = volume of metal at θ_2

$$\theta = \theta_2 - \theta_1$$

The Relationship between Linear Expansivity (α), Area Expansivity (β), and Cubic Expansivity (γ)

Consider a sheet of a metal of length l_1 and breadth b_1. Let the length and breadth be l_2 and b_2 after the sheet has been heated through a rise in temperature, θ.

Initial area of sheet = $A_1 = l_1.b_1$

Final area of sheet = $A_2 = l_2.b_2$

$$l_2 = l_1(1 + \alpha\theta) \quad and \quad b_2 = b_1(1 + \alpha\theta)$$

Remember that $A_2 = A_1 + A_1\beta\theta$

Hence $A_2 = l_2.b_2 = l_1(1 + \alpha\theta) \times b_1(1 + \alpha\theta)$

$$A_2 = l_1\, b_1\, (1 + 2\alpha\theta + \alpha^2\, \theta^2)$$

$$\alpha^2 \approx 0\ (negligible) thus\ \alpha^2\, \theta^2 \approx 0$$

$$A_2 = A_1(1 + 2\,\alpha\beta)$$

$$A_2 = A_1\,(1 + 2\,\alpha\,\beta)$$

$$A_2 = A_1\,(1 + \beta\,\theta);\ thus\ \beta = 2\,\alpha$$

Hence, the area expansivity β is approximately twice the linear expansivity α.

Similarly using the same kind of calculation, we can show that the cubic expansivity (γ) is thrice the linear expansivity (γ).

$$\gamma = 3\alpha$$

Expansion in Liquids

Like solids, liquids expand on heating and contract on cooling. Because liquids are always held in a container, the expansion of liquid is often complicated by the expansion of the containers.

We can experiment the expansion of liquids through the following steps:

- Colour some water by putting into it a few crystals of copper sulphate.
- Fill a flask with coloured water and cover the flask with a rubber bung with a hole.

- Push a narrow tube through the hole of the rubber bung until some liquid rises in the tube.
- Ensure that there are no air bubbles under the bung and that the flask is completely filled with the coloured water.
- Warm the liquid gently with a bursen burner and observe the level of the coloured liquid in the narrow tube.
- Remove the heat and observe the movement of the liquid level in the tube.

You will observe that the liquid level initially falls slightly and then rises slowly and steadily as more heat is applied. The reason for this is because on the application of heat, the glass first expands faster than the liquid, hence the fall of the liquid level. As more heat is applied, the expansion of the liquid increases more than that of the glass and the liquid rises in the narrow tube. On removal of heat the

liquid contracts and the level of liquid in the tube is seen to fall.

Also, equal volumes of different liquids expand by different amounts when heated through the same temperature range.

Real and Apparent Expansivity: Because the expansion of liquids is complicated by the expansion of their containers, it is necessary to distinguish between the real and the apparent cubic expansivity of a liquid.

Real expansion = apparent expansion + expansion of the container

Real (or absolute) cubic expansivity (γ_γ) of a liquid is the increase in volume per unit volume per degree rise in temperature.

Apparent cubic expansivity (γ_a) of a liquid is the increase in volume per unit volume per degree rise in temperature when the liquid is heated in an expansible vessel.