UNIT-7

HEAT AND THERMODYNAMICS

HEAT -:

- It is a form of thermal energy that gives us sensation of hotness and coldness of a body.

TEMPERATURE -:

- It is a measurement of degree of hotness and coldness of a body.

❖ ***Heat energy always flows from a body at high temperature to a body at low temperature.***

HEAT	TEMPERATURE
1. It is a form of thermal energy that gives us sensation of hotness and coldness of a body.	1. It is a measurement of degree of hotness and coldness of a body.
2. It is a derived physical quantity.	2. It is a fundamental physical quantity.
3. M.K.S unit – kilocalorie (kcal)	3. M.K.S unit – degree centigrade (℃)
4. C.G.S unit – calorie (cal)	4. C.G.S unit – degree centigrade (℃)
5. F.P.S unit – BTU (British Thermal Unit)	5. F.P.S unit – degree Fahrenheit (℉)
6. S.I. unit – joule (J)	6. S.I. unit – kelvin (K)
7. Dimension – $[M^1L^2T^{-2}]$	7. Dimension – $[K^1]$

SCALES OF TEMPERATURE –:

CELSIUS OR CENTIGRADE SCALE (℃) – It is a scale of temperature having lower fixed point (LFP) at 0 (melting point of ice) and upper fixed point (UFP) at 100 (boiling point of water).

- The scale is equally divided into 100 divisions.

FAHRENHEIT SCALE (℉) – It is a scale of temperature having lower fixed point (LFP) at 32 (melting point of ice) and upper fixed point (UFP) at 212 (boiling point of water).

- The scale is equally divided into 180 divisions.

KELVIN OR ABSOLUTE SCALE (K) – It is a scale of temperature having lower fixed point (LFP) at 273 (melting point of ice) and upper fixed point (UFP) at 373 (boiling point of water).

- The scale is equally divided into 100 divisions.

REAUMER SCALE (°R) – It is a scale of temperature having lower fixed point (LFP) at 0 (melting point of ice) and upper fixed point (UFP) at 80 (boiling point of water).

- The scale is equally divided into 80 divisions.

TEMPERATURE CONVERSION FORMULA –:

$$\frac{Temperature\ on\ one\ scale - LFP}{UFP - LFP} = \frac{Temperature\ on\ another\ scale - LFP}{UFP - LFP}$$

$$\frac{C}{100} = \frac{F-32}{180} = \frac{K-273}{100} = \frac{R}{80}$$

SPECIFIC HEAT CAPACITY -:

Let H quantity of heat energy is supplied to a body of mass m to change its temperature through ΔT.

The quantity of heat energy required is directly proportional to mass of the substance for constant change in temperature ΔT

$$H \;\alpha\; m$$

The quantity of heat energy required is directly proportional to the change in temperature for constant mass of the substance.

$$H \;\alpha\; \Delta T$$

Combing the above two expressions we get

$$H \;\alpha\; m(\Delta T)$$
$$H = ms(\Delta T)$$

Where s is the constant of proportionality is known as specific heat capacity of the substance.

So

$$S = \frac{H}{m\Delta T}$$

If m = 1 unit and $\Delta T = 1°C$, n $s = H$

- **So specific heat capacity of a substance is defined as the amount of heat energy required to raise the temperature of unit mass of the substance through 1°C.**
- S.I. unit – J/kg $°K$
- M.K.S unit – kcal/kg °C
- Dimension – $[M^0L^2T^{-2}K^{-1}]$

In case of a gas there are 2 types of specific heat capacities.

1) **SPECIFIC HEAT CAPACITY AT CONSTANT VOLUME (c_V)** – It is defined as the amount of heat energy required to raise the temperature of 1g of gas through 1°C keeping its volume constant.

- For 1 mole of gas it is called molar specific heat at constant volume (C_V).

$$C_v = Mc_v \qquad where\ M\ is\ molcular\ weight\ of\ gas$$

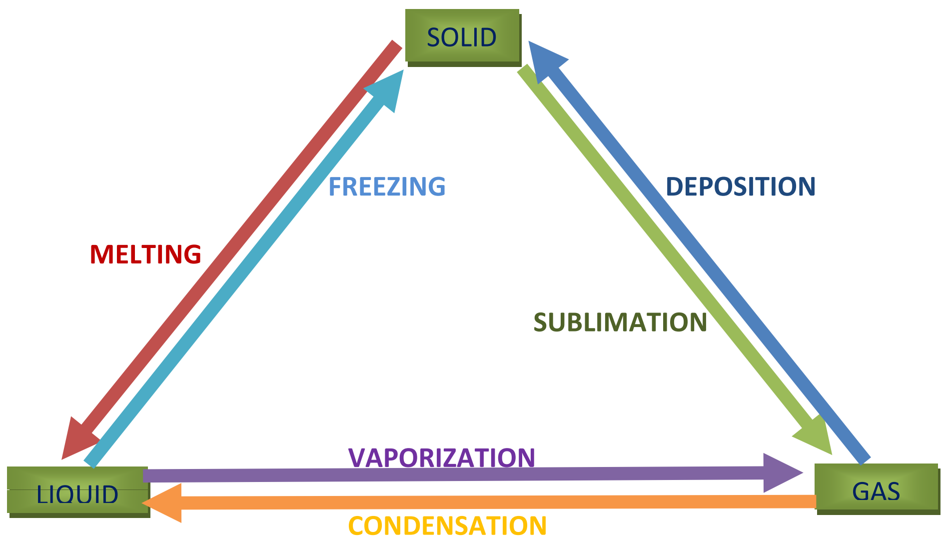
2) **SPECIFIC HEAT CAPACITY AT CONSTANT PRESSURE (c_p) –** It is defined as the amount of heat energy required to raise the temperature of 1g of gas through 1℃ keeping its pressure constant.

- For 1 mole of gas it is called molar specific heat at constant pressure (Cp).

$$C_p = Mc_p \qquad where\ M\ is\ molcular\ weight\ of\ gas$$

CHANGE OF STATE -:

- Change of state is the physical change of matter.
- It is a reversible process and it does not involve of any change of the chemical properties of matter.
- Change of state occurs when the matter absorbs or loses heat energy.



- **MELTING -:** The process in which solid is converted into liquid is known as melting.
  - The temperature at which the state of a matter changes from solid to liquid is called its melting point.
  - The melting point (MP) of ice (solid state of water) is at 0℃ or 32℉.
- **FREEZING -:** The process in which liquid is converted into solid is known as freezing.
  - The temperature at which the state of a matter changes from liquid to solid is called its freezing point.
  - The freezing point of water is at 0℃ or 32℉.
- **VAPORIZATION -:** The process in which liquid boils and is converted into gas is known as vaporization.
  - The temperature at which liquid starts to boil is called its boiling point.
  - The boiling point (BP) of water is at 100℃ or 212℉.
- **CONDENSATION -:** The process in which the state of matter changes from gas to liquid is known as condensation.
  - It is the reversible process of vaporization.

EVAPORATION -: The process in which liquid is converted into gas without boiling is known as evaporation.

SUBLIMATION -: The process in which solid is directly converted into gas without undergoing the liquid state is known as sublimation.

DEPOSITION -: The process in which gas is directly converted into solid is known as deposition.

LATENT HEAT -:

- It is defined as amount of heat energy in hidden form which is supplied or extracted to change the state of the matter without changing its temperature.
- If m mass of the substance undergoes a change of state by absorbing H quantity of heat energy at constant temperature T, then latent heat of the substance is given by

$$L = \frac{H}{m}$$

- S.I. unit – J/kg
- M.K.S unit – kcal/kg
- Dimension – $[M^0L^2T^{-2}]$

It is of two types.

1) **LATENT HEAT OF FUSION (L_f) -:** *It is defined as the quantity of heat energy supplied per unit mass of the substance at its melting point to change the state of the substance from solid to liquid without changing its temperature.*
2) **LATENT HEAT OF VAPORIZATION (L_v) -:** *It is defined as the quantity of heat energy supplied per unit mass of the substance at its boiling point to change the state of the substance from liquid to gas without changing its temperature.*

THERMAL EXPANSION -:

The expansion of the body on heating is called thermal expansion.

THERMAL EXPANSION ALONG 1-D – LINEAR EXPANSION -:

- Consider a one dimensional body whose length is much greater than as compared to its diameter.
- Let its length is L_0 at 0°C. On heating the body it expands. Now L_t be the new length of the one dimensional body at t°C.
- So the change in length = $L_t - L_0$
- This change in length depends upon two factors.

1) It depends upon the original length of the body at 0°C .

i.e. $L_t - L_0 \propto L_0$

2) It depends upon the rise in temperature of the body.

i.e. $L_t - L_0 \propto t$

- Combining the above two expressions we get

$$L_t - L_0 \propto L_0 t$$

$$\Rightarrow L_t - L_0 = \alpha L_0 t$$

[*where α is the constant of proportionality and is called as the coefficient of linear expansion.*]

$$\Rightarrow L_t = L_0 + \alpha L_0 t$$

$$\Rightarrow \boldsymbol{L_t = L_0(1 + \alpha t)}$$

OR

$$\boldsymbol{\alpha = \frac{L_t - L_0}{L_0 t}}$$

- If $L_0 = 1\ unit$ and $t = 1$°C, then

$$\boldsymbol{\alpha = L_t - L_0}$$

- **So coefficient of linear expansion of a substance is defined as the change in length per unit length of the body at 0°C per degree centigrade rise of temperature.**

THERMAL EXPANSION ALONG 2-D – SUPERFICIAL EXPANSION -:

- Consider a two dimensional body having some length & breadth but negligible thickness.
- Let its area is A_0 at 0°C. On heating the body it expands. Now A_t be the new area of the two dimensional body at t°C.
- So the change in area = $A_t - A_0$
- This change in area depends upon two factors.

1) It depends upon the original area of the body at 0°C .

i.e. $A_t - A_0 \propto A_0$

2) It depends upon the rise in temperature of the body.

i.e. $A_t - A_0 \propto t$

- Combining the above two expressions we get

$$A_t - A_0 \propto A_0 t$$

$$\Rightarrow A_t - A_0 = \beta A_0 t$$

[*where β is the constant of proportionality and is called as the coefficient of superficial expansion.*]

$$\Rightarrow A_t = A_0 + \beta A_0 t$$

$$\Rightarrow \boldsymbol{A_t = A_0(1 + \beta\, t)}$$

OR

$$\boldsymbol{\beta = \frac{A_t - A_0}{A_0 t}}$$

- If $A_0 = 1\, unit$ and $t = 1°C$, then

$$\boldsymbol{\beta = A_t - A_0}$$

- **So coefficient of superficial expansion of a substance is defined as the change in area per unit area of the body at 0°C per degree centigrade rise of temperature.**

THERMAL EXPANSION ALONG 3-D – CUBICAL EXPANSION -:

- Consider a three dimensional body having some length & breadth and thickness.
- Let its volume is V_0 at 0°C. On heating the body it expands. Now V_t be the new volume of the three dimensional body at t°C.
- So the change in volume = $V_t - V_0$
- This change in volume depends upon two factors.

1) It depends upon the original volume of the body at 0°C .
   i.e. $V_t - V_0 \propto V_0$
2) It depends upon the rise in temperature of the body.
   i.e. $V_t - V_0 \propto t$

- Combining the above two expressions we get

$$V_t - V_0 \propto V_0 t$$

$$\Rightarrow V_t - V_0 = \gamma\, V_0 t$$

$[where\ \gamma\ is\ the\ constant\ of\ proportionality\ and\ is\ called\ as\ the\ coefficient\ of\ cubical\ expansion.]$

$$\Rightarrow V_t = V_0 + \gamma\, V_0 t$$

$$\Rightarrow \boldsymbol{V_t = V_0(1 + \gamma\, t)}$$

OR

$$\boldsymbol{\gamma = \frac{V_t - V_0}{V_0 t}}$$

- If $V_0 = 1\, unit$ and $t = 1°C$, then

$$\boldsymbol{\gamma = V_t - V_0}$$

- **So coefficient of cubical expansion of a substance is defined as the change in volume per unit volume of the body at 0°C per degree centigrade rise of temperature.**

RELATION AMONG EXPANSION COEFFICIENTS -:

1) RELATION BETWEEN α AND β -:

- Consider a two dimensional body having some length & breadth.
- Let l_0, b_0 & A_0 be the length, breadth & area of the two dimensional body at 0°C. On heating the body through t°C, it expands.
- Now, l_t, b_t & A_t be the length, breadth & area of the two dimensional body at t°C.

$$A_t = l_t b_t$$

- We know that

$$l_t = l_0(1 + \alpha t)$$

$$b_t = b_0(1 + \alpha t)$$

&

$$A_t = A_0(1 + \beta t)$$

$$\Longrightarrow \quad l_t b_t = l_0 b_0(1 + \beta t)$$

$$\Longrightarrow \quad l_0(1 + \alpha t) b_0(1 + \alpha t) = l_0 b_0(1 + \beta t)$$

$$\Longrightarrow \quad (1 + \alpha t)^{2} = (1 + \beta t)$$

$$\Longrightarrow \quad 1 + 2\alpha t + \alpha t^2 = 1 + \beta t$$

$$\Longrightarrow \quad 2\alpha t + \alpha t^2 = \beta t$$

$[\boldsymbol{since\ \alpha\ is\ a\ very\ small\ quantity, so\ we\ can\ neglect\ the\ terms\ higher\ order\ in\ \alpha.}]$

$$\Longrightarrow 2\alpha t = \beta t$$

$$\Longrightarrow 2\alpha = \beta$$

$$\Longrightarrow \boldsymbol{\alpha = \frac{\beta}{2}}$$

This is the relation between α and β.

2) RELATION BETWEEN α AND γ -:

- Consider a three dimensional body having some length, breadth & height.
- Let l_0, b_0, h_0 & V_0 be the length, breadth, height & volume of the three dimensional body at 0°C. On heating the body through t°C, it expands.
- Now, l_t, b_t, h_t & V_t be the length, breadth, height & volume of the three dimensional body at t°C.

$$V_t = l_t b_t h_t$$

- We know that

$$l_t = l_0(1 + \alpha t)$$

$$b_t = b_0(1 + \alpha t)$$

$$h_t = h_0(1 + \alpha t)$$

& $$V_t = V_0(1+\gamma t)$$
$$\Rightarrow \quad l_t b_t h_t = l_0 b_0 h_0 (1+\gamma t)$$
$$\Rightarrow \quad l_0(1+\alpha t) b_0 (1+\alpha t) h_0 (1+\alpha t) = l_0 b_0 h_0 (1+\gamma t)$$
$$\Rightarrow \quad (1+\alpha t)^{\mathbf{3}} = (1+\gamma t)$$
$$\Rightarrow \quad 1 + 3\alpha t + 3\alpha^2 t^2 + \alpha^3 t^3 = 1 + \gamma t$$
$$\Rightarrow \quad 3\alpha t + 3\alpha^2 t^2 + \alpha^3 t^3 = \gamma t$$
$[\boldsymbol{since\ \alpha\ is\ a\ very\ small\ quantity, so\ we\ can\ neglect\ the\ terms\ higher\ order\ in\ \alpha.}]$
$$\Rightarrow 3\alpha t = \gamma t$$
$$\Rightarrow 3\alpha = \gamma$$
$$\boldsymbol{\Rightarrow \alpha = \frac{\gamma}{3}}$$
This is the relation between α and γ.

MECHANICAL EQUIVALENT OF HEAT -:

- Dr. James Prescott Joule, after conducting a series of experiments concluded that there is an equivalence between work & heat.

$$WORK \rightleftharpoons HEAT$$

- According to him "whenever heat is converted into work or work into heat, the quantity of energy disappearing in one form is equivalent to the quantity of energy appearing in other".
- Let W amount of workdone results in the production of H quantity of heat.

Then $$W \propto H$$
$$W = JH$$
$[where\ J\ is\ the\ constant\ of\ proportionality\ and\ is\ known\ as\ Joule's\ mechanical\ equivalent\ of\ heat.]$

$$\boldsymbol{J = \frac{W}{H}}$$

If $H = 1cal$, then $J = W$

- ***So Joule's mechanical equivalent of heat is defined as the amount of work done required to produce unit calorie of heat.***

$$J = 4.2\ joule/calorie$$

- It is a dimensionless physical quantity.

FIRST LAW OF THERMODYNAMICS -:

STATEMENT -: *"If some quantity of heat energy supplied to a system is capable of doing some work, then the quantity of heat energy absorbed by the system is equal to the sum of increase in internal energy and external workdone by the system."*

EXPLANATION -:

- Consider 1 mole of an ideal gas in a cylindrical barrel having insulating walls but conducting bottom. The gas is maintained at a pressure P, temperature T and it has a volume V.
- Let U_1 is the initial internal energy of the system. H quantity of heat energy is supplied to the system through the bottom.
- At the beginning, total energy of the system = $U_1 + H$
- After absorbing H quantity of heat, the piston moves upward and there is an increase in volume of the gas.
- So W be the amount of workdone by the system after absorbing H quantity of heat.
- U_2 be the final internal energy of the system.
- At the end, the total energy of the system = $U_2 + W$
- According to Energy conservation law,

$$U_1 + H = U_2 + W$$

$$H = (U_2 - U_1) + W$$

$$H = (U_2 - U_1) + W$$

- *If an infinitesimal amount of heat energy (dH) is supplied to a system and is absorbed by the system, then the corresponding change in internal energy (dU) and workdone (dW) are also very small.*
- According to First law of thermodynamics

$$\boldsymbol{dH = dU + dW}$$

- This the mathematical form of First law of thermodynamics.