Thermal properties of matter

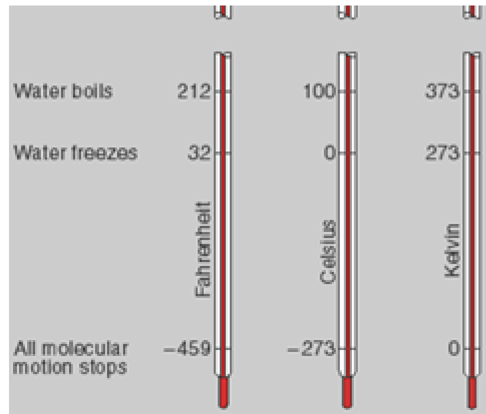
Heat: - Heat is a form of energy transferred between two (or more) systems or a system and its surroundings by virtue of temperature difference.

**Conventionally, the heat energy Q supplied to a body is taken to be positive (+Q) and the heat energy given out of a body is taken to be negative (-Q).

S.I unit of heat = Joule(J) ; C.G.S unit = Calorie. [1 Calorie= 4.2 Joule]

Temperature: - It is a measure of hotness or coldness of a body.

Thermometer: a device which is used to measure the temperature of a body is known as thermometer.Commonly used thermometer scales are: (i) Celsius scale (^{0}C) (ii) Kelvin scale (K) (iii) Fahrenheit scale (^{0}F)



(i).Conversion from Kelvin to ^{0}C.

$$t^0\,C = (273+t)K$$

(ii).Conversion from ^{0}C to Fahrenheit:-

$$^0C = \frac{5}{9}(F - 32)$$

(ii).Conversion from Fahrenheit to ^{0}C:-

$$F = \frac{9}{5}C + 32$$

Relation between different scales:-

$$\frac{C}{100} = \frac{F-32}{180} = \frac{K-273}{5}$$

Conversion of temperature from one scale to another.

$$\frac{\text{temp on one scale} - \text{lower fixed point}}{\text{upper fixed point} - \text{lower fixed point}} = \frac{\text{temp on another scale} - \text{lower fixed point}}{\text{upper fixed point} - \text{lower fixed point}}$$

$$\text{i.e } \frac{C-0}{100} = \frac{F-32}{180} = \frac{K-273.15}{100}$$

* 0 K is called absolute zero.

e.g: 1. Temperature of the human body is 98.4^{0}F.find the corresponding temperatures on the Celsius scale and Kelvin scale. (Ans: 36.9^{0}C = 309.9K)

Thermal Expansion:-

1.Expansion of solid:-

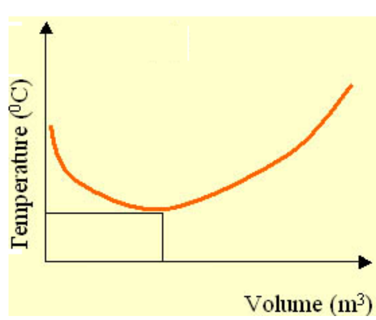
The change in temperature of a body may change its length, area or volume. The fractional change in dimension [ratio of change in dimension to original dimension = $\frac{\Delta l}{l}$] is proportional to change in temperature (ΔT). $\rightarrow \frac{\Delta l}{l} \;\alpha\; \Delta T \rightarrow \frac{\Delta l}{l\,\Delta T}$ = constant.

There are three types of thermal expansion.

Types of thermal expansion	Linear expansion	Area expansion	Volume expansion
The dimension that changes	length	Area	Volume
Coefficient of	$\alpha = \frac{\Delta l}{l\,\Delta T}$	$\beta = \frac{\Delta A}{A\Delta T}$	$\gamma = \frac{\Delta V}{V\,\Delta T}$
Relation		$\beta = 2\alpha$	$\gamma = 3\alpha$

2. Expansion of liquids:-

A liquid has volume expansion only. It requires a container to hold the liquid. When a liquid is heated, the container also expands.



*Anomalous expansion of water: - Generally volume of liquid increases with temperature .When water is heated, its volume starts to decrease from 0 ^{0}C and reaches minimum at 4^{0}C. Hence density of water is maximum at 4^{0}C.

Consequences of anomalous expansion of water:-

In cold countries, during winter the atmospheric temperature reduces. When it reaches 4^{0}C, the water will have maximum density and sinks to bottom. With further cooling, the top layer becomes ice. Since ice is a bad conductor of heat, the lower layer remains at 4^{0}C.thus aquatic animals are saved.

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Heat Capacity: - It is the quantity of heat required to raise the temperature of the body through 1K.

Unit: J/K

Dimension = $[M L^2 T^{-2}K^{-1}]$

Specific heat capacity:- It is the quantity of heat required to raise the temperature of unit mass of the substance through 1K.

Unit: $Jkg^{-1}K^{-1}$

Dimension = $[L^2 T^{-2}K^{-1}]$

Molar specific heat capacity [C]:-

It is the quantity of heat required to raise the temperature of 1 mole of substance through one Kelvin.

Unit: $J\ mol^{-1}K^{-1}$

Relation between quantity of heat & raise of temperature:-

The quantity of heat supplied to a body of mass 'm' and specific heat 'c' to raise the temperature through θ^0 C is given by : $Q = mC\theta$.

Specific heat of gases:-

Specific heat capacity at constant volume [C_V]:-

It is the amount of heat required to raise the temperature of unit mass of the gas through one Kelvin keeping its volume constant.

Molar Specific heat capacity at constant volume [C_V]:-

It is the amount of heat required to raise the temperature of 1 mole of the gas through one Kelvin keeping its volume constant.

Specific heat capacity at constant pressure [C_P]:-

It is the amount of heat required to raise the temperature of unit mass of the gas through one Kelvin keeping its pressure constant.

Molar Specific heat capacity at constant pressure [C_P]:-

It is the amount of heat required to raise the temperature of 1 mole of the gas through one Kelvin keeping its volume constant.

1. Why C_P is greater than C_V ?

Ans: When one mole of a gas heated at constant volume, the heat supplied is utilized only to increase the internal energy (temperature) of the gas. When it is heated at constant pressure, the heat supplied is used not only for increasing the internal energy but also for doing external work during expansion. Hence $C_P > C_V$.

Mayer's relation:-

$$C_P - C_V = R$$

Ratio of specific heats

$$\frac{C_P}{C_V} = \gamma$$

1. Find the ratio of specific heats for different gases.

(a). Monoatomic:-

No.of degrees of freedom = 3

Energy per degree of freedom = ½ kT

Energy associated with a molecule = 3 x ½ kT

Energy associated with one mole = $\frac{3}{2}$ kT x N = $\frac{3}{2}$ RT

$$C_V = \frac{dE}{dT} = \frac{3}{2}R$$

$$C_P - C_V = R \rightarrow \quad C_P = C_V + R = \frac{3}{2}R + R = \frac{5}{2}R$$

$$\text{Also } \gamma = \frac{C_P}{C_V} = \frac{\frac{5}{2}R}{\frac{3}{2}R} = 1.67$$

(b). (a). Diatomic:-

No.of degrees of freedom = 5

Energy per degree of freedom = ½ kT

Energy associated with a molecule = 5 x ½ kT

Energy associated with one mole = $\frac{5}{2}$ kT x N = $\frac{5}{2}$ RT

$$C_V = \frac{dE}{dT} = \frac{5}{2}R$$

$$C_P - C_V = R \rightarrow \quad C_P = C_V + R = \frac{5}{2}R + R = \frac{7}{2}R$$

$$\text{Also } \gamma = \frac{C_P}{C_V} = \frac{\frac{7}{2}R}{\frac{5}{2}R} = 1.4$$

(b). (a). Triatomic:-

No.of degrees of freedom = 6

Energy per degree of freedom = ½ kT

Energy associated with a molecule = 6 x ½ kT

Energy associated with one mole = $\frac{6}{2}$ kT x N = 3 RT

$$C_V = \frac{dE}{dT} = 3\,R$$

$$C_P - C_V = R \rightarrow \quad C_P = C_V + R = 3\,R + R = 4\,R$$

$$\text{Also } \gamma = \frac{C_P}{C_V} = \frac{4R}{3\,R} = 1.33.$$

- If 'n' is the number of degrees of freedom then, $\gamma = (1 + \frac{2}{n})$

<u>Change of state:-</u>

<u>Specific latent heat of fusion of a solid (L):-</u>

It is the quantity of heat required to convert unit mass of the solid at its melting point into liquid at the same temperature.

Unit: J/kg

<u>Specific latent heat of vaporization of a liquid:</u>

It is the quantity of heat required to convert unit mass of liquid at its boiling point into vapour at the same temperature.

<u>Quantity of heat:-</u>

Quantity of heat required to convert a substance of mass 'm' and specific latent heat L from one state to other state is Q= mL.

<u>Heat transfer:-</u>

Different modes of heat transfer are (1).Conduction, (2).Convection & (3).Radiation.

<u>Conduction: -</u> It is the mode of heat transfer from a hot region to cold region without any bodily movement of the molecule of the intervening medium.

<u>Temperature gradient:-</u> It is the rate of change of temperature with distance.

$$\frac{d\theta}{dx} = \frac{(\theta_1 - \theta_2)}{d}$$ where θ_1, θ_2 – temp. of two sections & d- distance between two sections.

<u>Coefficient of thermal conductivity:-</u>

When a substance attains a steady state, the quantity of heat conducted normally through any section is directly proportional to

(i).area of cross section A $\rightarrow Q \,\alpha\, A$

(ii).temperature gradient $\rightarrow Q \,\alpha\, \frac{(\theta_1 - \theta_2)}{d}$

& (iii).Time during which heat is conducted $\rightarrow Q \,\alpha\, t$

i.e., $Q \,\alpha\, A \frac{(\theta_1 - \theta_2)}{d} t = \lambda A \frac{(\theta_1 - \theta_2)}{d} t$; λ-coefficient of thermal conductivity.

If A=1, $\frac{(\theta_1 - \theta_2)}{d} = 1$ & t=1 then $Q = \lambda$

Coefficient of thermal conductivity (λ) of a substance is defined as the quantity of hear conducted normally per second through unit area of the substance per unit temperature gradient when the substance attains steady state.

$$\text{Unit : } \lambda = \frac{Q\,d}{A(\theta_1 - \theta_2)\,t} = \frac{J\,m}{m^2\,Ks} = J\,m^{-1}\,K^{-1}\,s^{-1}$$

<u>Convection:-</u>

It is the mode of heat transfer from a hot to a cold region with actual bodily movement of the particles of the intervening medium.

Application:-

1. Land breeze, sea breeze and trade winds
2. Used in ventilations.

Radiation:-

It is the mode of transfer of heat from hot region to cold region without the help of an intervening medium.

Characteristics of thermal radiation:-

1. They are electromagnetic waves travelling with a speed of $3x10^8$ m/s in vacuum.
2. Thermal radiation lies in the infrared region.
3. They can be reflected or refracted like light.
4. They exhibit interference and diffraction.
5. They exert pressure on bodies on which they fall.

Black body and black body radiation:-

A perfectly black body is that which absorbs completely the radiations of all wave lengths incident on it. A perfect black body is a good absorber of radiant energy.

When a perfect blackbody is heated to a suitable high temperature, it emits radiation of all wavelengths in a particular region of the electromagnetic spectrum. The radiation emitted by perfect black body is called black body radiation.

Define emissive power and absorptive power:-

Emissive power: - emissive power of the surface of a body for a given wavelength λ at a given temperature is defined as the amount of energy emitted per second per unit area of the surface.

Absorptive power:- absorptive power of the surface of a body for a given wavelength λ is the ratio of the quantity of heat absorbed by it to the quantity of heat incident on it.

Wien's displacement law:-

It states that the wavelength (λ_m) of radiation corresponding to the maximum energy emitted by a block body is inversely proportional to the absolute temperature(T) of the black body.

$$\lambda_m \; \alpha \; \frac{1}{T} \quad \rightarrow \lambda_m T = b \quad [b=0.002898 \text{ mK} \text{ –wien's constant}]$$

Stefan's law:-

It states that the total radiant energy emitted per second from unit area of the surface of a blackbody is directly proportional to fourth power of its absolute temperature.

$$E \alpha \, T^4 \quad \rightarrow \quad E = \sigma \, T^4 \quad [\sigma\text{-Stefan's constant} = 5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}]$$

Newtons law of cooling:-

The law states that the rate of loss of heat of the body is directly proportional to the difference of temperature of the body and the surroundings.

$$\frac{-dQ}{dt} \; \alpha \; T_2 - T_1$$

If a body of mass 'm' and specific heat capacity 'c' cools from θ_1 to θ_2 in a time 't' second in a surrounding at θ^0C . According to Newtons law ,

$$\frac{mc(\theta_1 - \theta_2)}{t} \; \alpha \; \left[\frac{(\theta_1 + \theta_2)}{2} - \theta_0\right]$$