UNIT - 2

HEAT AND THERMODYNAMICS

2.1. Thermal Expansion

Concept of Heat

A body is made up of a large number of particles called molecules. The heat or thermal energy of a body is due to the KE of its molecules: So, heat is the energy that is transferred from one body to another due to temperature difference between the two bodies. Unit of heat is Joule or calorie.

Concept of Temperature

Heat and temperature are closely related to each other but the two quantities are different. The temperature of a body is its degree of hotness or coldness. Its SI unit is Kelvin. Flow of heat depends on the temperature of two bodies. It flows from a body of higher temperature to a body at lower temperature.

Zeroth Law of Thermodynamics

Its two systems are thermal equilibrium with the third one, and then both of them also have the same temperature and thermal equilibrium with each other.

Thermal Expansion of Solid

Most solids expand when heated and contract when cooled. When the temperature of a solid is increased, its atoms and molecules vibrate with greater amplitude; as a result, a solid expands on heating. The expansion in length is called linear expansion. The expansion in length and breadth, i.e. area is called superficial expansion while the expansion in three dimensions, i.e. in length, breadth and thickness of an object is called cubical expansion.

Coefficient of Linear Expansion

Suppose the initial length of rod of some material is / at temperature T_1. When temperature is at $T_2 = T_1 + \Delta T$, the length will increase to $/_1 + \Delta l = l_2$. Then, the increase in length is directly proportional to the original length.

i.e. $\Delta l \propto l_1$………………….(i)

The increase in length is directly proportional to the rise in temperature.

i.e. $\Delta l \propto \Delta T$………………….(ii)

From (i) and (i),

$$\Delta l \; \alpha \; l \, . \, \Delta T$$

$$\Delta l = \alpha \, l. \, \Delta T$$

Where α is coe. of linear expansion and defined as the fractional change in length per degree change in temperature.

Superficial Expansion

Suppose the surface area of a plate is A_1 at some initial temperature T_1. Then at temperature $T_1 + \Delta T$, the surface area will increase to $A_1 + \Delta A$.

Here, increase in area is directly proportional to the original area and the rise in temperature.

i.e. $\Delta A \; \alpha \; \Delta T$…………..(i)

$\Delta A \; \alpha \; A_1$………(ii)

$\Delta A = \beta A_1 \Delta T$

Where, β is called the coefficient of superficial expansion.

Cubical Expansion

Suppose the volume of solid is V at some initial temperature T_1. At temperature $T_1 + \Delta T$, the volume will increase to $V_1 + \Delta V$. Experimentally, increase in volume is directly proportional to the original volume and rise in temperature.

i.e. $\Delta V \; \alpha \; V_1$...... (i)

$\Delta V \; \alpha \; \Delta T$……….. (ii)

Therefore, $\Delta V \; \alpha \; \Delta T \, V_1$

$\Delta V = \gamma \, \Delta T \, V_1$

Where, γ is a proportionality constant and is called the coefficient of cubical expansion.

Relation Between coe. of Expansion

Relation between α and β

We have, for linear expansion;

$\Delta L = \alpha \, \Delta T \, l_1$

or, $l_2 - l_1 = \alpha \, \Delta T \, l_1$

or, $l_2 = l_1 + \alpha \, \Delta T \, l_1$

$l_2 = l_1 (1 + \alpha \, \Delta T)$

or, $l_2^2 = l_1^{\,2} (1 + \alpha \, \Delta T)^2$

$A_2 = A_1 (1 + 2 \, \alpha \, \Delta T + \alpha^2 \Delta T^2)$

Since, the value of α is small. So, the term $\alpha^2\Delta T^2$ may be neglected.

Therefore, $A_2 = A_1 (1+ 2\alpha \Delta T)$...........(i)

For superficial expansion;

$\Delta A = \beta \Delta T A_1$

$A_2 - A_1 = \beta \Delta T A_1$

$A_2 = A_1 + \beta \Delta T A_1$

$A_2 = A_1(1+ \beta \Delta T)$...............(ii)

Hence, $\beta = 2\alpha$

Relation between α and γ

We have, for linear expansion;

$l_2 = l_1 (1+ \alpha \Delta T)$

$l_2^3 = l_1^3(1+ \alpha \Delta T)^3$

$= l_1^3(1+ 3\alpha \Delta T + 3\alpha^2\Delta T^2 + \alpha^3\Delta T^3)$

or, $V_2 = V_1 (1+ 3\alpha \Delta T + 3\alpha^2\Delta T^2 + \alpha^3\Delta T^3)$...........(iii)

Similarly, from cubical expansion;

$V_2 = V_1(1+\gamma\Delta T)$

From (iii) and (iv)

$1+ 3\alpha \Delta T + 3\alpha^2\Delta T^2 + \alpha^3\Delta T^3 = 1+\gamma\Delta T$

Neglecting higher power of α for its small value;

$1 + 3\alpha \Delta T = 1+\gamma\Delta T$

or, $3\alpha = \gamma$

Thermal expansion of liquid

Like solid, liquid also expands on heating, since the liquids do not have a fixed shape, hence, we take only volume expansion in case of liquids.

Coefficient of real expansion

It is defined as the real increase in volume of the liquids per unit original volume per ^{0}C rise in temperature. It is denoted by γ_r.

$$\gamma_r = \frac{Real\ increase\ in\ volume}{Original\ volume\ x\ rise\ in\ temperature}$$

Coefficient Apparent Expansion

It is defined as the apparent increase in volume of the liquid per unit original volume per °C rise in temperature. It is denoted by for γ_a.

$\gamma_a = \frac{Apparent\ increase\ in\ volume}{Original\ volume\ x\ rise\ in\ temperature}$

Latent Heat

The amount of heat required to change the unit mass of a substance completely from one state to another at constant temperature is called latent heat of the substance. If mass m of a substance requires heat Q to change completely from one state to another at constant temperature, then;

Latent heat (L) = $\frac{Q}{m}$

2.2 Calorimetry

Calorimetry is an experimental technique for the quantitative measurement of heat exchange. To make such measurements, a calorimeter is used. Figure shows a simple calorimeter.

One important use of the calorimeter is to determine the sp. heat of a substance. Specific heat capacity (S) from using the calorimeter is given by;

S = $\frac{(m1S1 + m2S2)(\theta 2 - \theta 1)}{M(\theta 3 - \theta 2)}$

Where, m_1 = mass of calorimeter and stirrer

m_2 = mass of water

S_2 = sp. heat capacity of calorimeter

S_1 = sp. heat capacity of liquid

M = mass of solid (ice)

θ_1 = initial temperature of water and calorimeter

θ_2 = final temperature of mixture

θ_3 = initial temperature of solid (ice)

2.3 Some Gasses and Thermodynamics Laws

Boyle's law

Boyle's law states that, at constant temperature, the volume of a given mass of a gas is inversely proportional to its pressure.

i.e. V $\alpha \frac{1}{P}$

or, pV = constant

Thus for a given mass of a gas, if pressure changes from P_1 to P_2 and the corresponding volume changes from V_1 toV_2 at constant temperature, then according to Boyle's law;

$P_1V_1 = P_2V_2$

Charle's law

Charle's law states that, at constant pressure, the volume of the given mass of a gas is directly proportional to its absolute temperature.

i.e. V α T at cost. p

$\frac{V}{T}$ = constant

or, $\frac{V1}{T1} = \frac{V2}{T2}$

2.4 Law of Thermodynamics

First Law of Thermodynamics

The branch of physics which deals with the relationship between heat and work is called thermodynamics.

Hence, the study of heat and its transformation to mechanical energy is called thermodynamics.

When the law of conservation of energy is applied to thermal systems, we call it the first law of thermodynamics. First law of thermodynamics states that, "whenever heat is added to a system, it transforms to an equal amount of some other forms of energy"

It means when a certain quantity of heat is supplied to a system, a part of the heat may be used in doing external work on expansion and the rest of the heat is used in increasing the internal energy of the system.

If dQ be the heat supplied to a system, the amount of external work done be d'W and the increase in internal energy of the molecules be dU. Then from the first law of thermodynamics;

$$dQ = dU + dw$$

Thermodynamic processes

The following are the important thermodynamic process:

i) Isothermal process:

If the temperature of a system does not change during a process, the process is called isothermal. Hence, a thermodynamic process which takes place at constant temperature is called an isothermal process. We know that pressure P and volume V of a mole of an ideal gas are related by the equation;

$$Pv = RT............(i)$$

Where, T is the absolute temperature of the gas and R is the universal gas constant. In an isothermal process, temperature (T) is constant. So, equation (i) becomes,

Pv = constant…………..(ii)

Equation (ii) is called the equation of the isothermal process for an ideal gas.

Work done during isothermal process

Suppose an ideal gas is allowed to expand very slowly from V_1 to V_2 at constant temperature, then the work done by the gas in expanding from one state of volume V_1 to state of volume V_2 is given by;

$W = \int_{V1}^{V2} PdV$………..(i)

For an ideal gas,

$PV = nRT$

or, $P = \frac{nRT}{V}$ ……………(ii)

Hence, from equation (i) and (ii);

$W = \int_{V1}^{V2} \frac{nRT}{V} dV = RT \int_{V1}^{V2} \frac{dV}{V}$

$W = nRT.\log_e(V_2/V_1)$.............(iii)

Equation (iii) gives the expression for work done during isothermal expansion for n moles of an ideal gas.

ii) Adiabatic process

If no heat enters or leaves the system during the process, the process is called adiabatic i.e. P, V and T change in the process. Adiabatic process for an ideal gas is not described in terms of PV = nRT alone because all three state variables (P, V and T) change during the process. The equation for adiabatic process relating pressure and volume of the gas is;

$PV\gamma$= constant………(i)

or, $P_1V_1\gamma = P_2V_2\gamma$…….(ii)

Work done during an adiabatic process

Suppose the gas expands adiabatically from the initial volume V_1 to the final volume V_2. Then the work done by the gas is,

$W = \int_{V1}^{V2} PdV$………(i)

During an adiabatic process,

$PV\gamma = k$ (constant)

or, $P = K/V\gamma$

Hence, from (i),

$$W = \int_{V1}^{V2} KV^{-}\gamma dV = K \int_{V1}^{V2} V^{-}\gamma dV = K\left[\frac{V^{-\gamma+1}}{-\gamma+1}\right]$$

$$= \frac{1}{\gamma-1}[P_1V_1 - P_2V_2]................(ii)$$

If the temperature of the initial state T_1 and final state T_2, then, $P_1V_1 = nRT$, and $P_2V_2 = nRT$.

Hence, equation (ii) becomes;

$$W = \frac{1}{\gamma-1}[nRT_1 - nRT_2]$$

$$= \frac{nR}{\gamma-1}[T_1 - T_2].........(iii)$$

Equation (ili) gives the expression for work done during adiabatic expansion.

Second Law of Thermodynamics

According to Kelvin, the second law of thermodynamics can be stated as follows;

"It is impossible to get a continuous supply of work from a body by cooling it to a temperature lower than that of its surrounding0”.

Efficiency of heat engine

It is defined as the ratio of the external work obtained by the system to the energy absorbed. It is denoted by η.

i.e. $\eta = \frac{work\ output}{energy\ input}$

Entropy

Entropy is a measure of the disorder of a system. So, if the physical system is allowed to distribute freely, it always does in a manner of disorder i.e., entropy increases.

Suppose if we have a box with partition dividing into two parts, fill with gas on one side of partition and evacuated in other part as shown in figure (a). With all the molecules of gas in one side are highly ordered situation. However, if the partition is removed, the gas molecules will distribute themselves throughout the box as shown in figure (b). They move in random directions and being in less ordered situation. Hence the entropy of two gases has increased because the amount of disorder has inversed