Chapter = 11

Heat

HEAT:

The energy which is transferred from one body to the other due to the differences in temperature is called heat. The transfer of heat continues till the bodies come in thermal equilibrium. The S.I unit of heat is joule (J).

INTERNAL ENERGY:

The sum of all the microscopic kinetic and potential energies of all the molecules in a body is known as its internal energy.

TEMPERATURE:

The measure of the degree of hotness or coldness of a body is called its temperature. Temperature determines the direction of flow of heat when two bodies at different temperatures are brought in thermal contact with each other. Temperature depends upon average translational kinetic energy of the molecules of the substances. The S.I unit of temperature is Kelvin.

EFFECT OF TEMPERATURE:

An increase or decrease in temperature of a body may change its.

1. Dimensions (i.e length, volume and area)
2. Colour
3. resistance
4. Pressure
5. Physical state (i.e solid, liquid or gas)

THERMOMETER:

Thermometer is an instrument which is used to note the temperature of a body. There are many types of thermometer of the commonly used thermometer. It consists of a capillary of uniform bore having a bulb at this bottom is filled with mercury. The tube is with equidistance lines so that the temperature of a body can be noted.

SCALE OF TEMPERATURE:

There are three scales of temperature.

1. Celsius or centigrade scale
2. Fahrenheit scale and
3. Kelvin scale

1. Celsius:

In this scale the freezing point of water is 0 ^{o}C and the boiling point of water is 100 ^{o}C. The internal between the freezing and the boiling point of water is divided in to 100 equidistance points. Each part is called a centigrade.

2. Fahrenheit scale:

In this scale the freezing point of water is 32 ^{o}F and the boiling point of water is 212 ^{o}F. The interval between the freezing and the boiling point of water is divided into 180 equidistance part. Each part is called Fahrenheit.

3. Kelvin scale:

In this scale the freezing point of water is 273K and the boiling point of water is 373K. The interval between the freezing and the boiling point of water is divided into 100 equal parts. Each part is called a Kelvin.

Relation between centigrade and Kelvin scale:

Centigrade and Kelvin scales are related with each other by formula.

$$Tc + 273 = T_K$$

$$Tc = T_K - 273$$

Relation between Centigrade and Fahrenheit scale:

Centigrade and Fahrenheit scales are related with each other by formula.

$$\frac{C - 0}{100} = \frac{F - 32}{180}$$

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

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

Relation between Kelvin and Fahrenheit scale:

Kelvin and Fahrenheit scales are related with each other by formula.

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

$$\frac{K - 273}{5} = \frac{F - 32}{9}$$

THERMAL EXPANSION:

Generally bodies expand on heating and contract on cooling. They may expand in length, volume and area. The change in size on heating is called thermal expansion.

LINEAR EXPANSION:

If by heating a body its length increases then such an expansion is known a linear expansion.

EXPLANATION:

Consider a uniform metallic rod of length l at temperature T_1K if the rod is heated to temperature T_2K its length becomes L_2 then.

Increase in length of the rod = $L_2 - L_1 = \Delta L$

Rise in temperature of the rod = $T_2 - T_1 = \Delta T$

It is experimentally found that the change in length ΔL is directly proportional to the original length L_1 of the rod and change in temperature ΔT.

$$\text{i.e } \Delta L \propto L_1 \Delta T$$

or

$$\Delta L = \propto L_1 \Delta T \quad \text{-------------}\rightarrow \quad \text{(i)}$$

where α is a constant of proportionally and is called coefficient of linear expansion. By putting the value of L in eq^n (i) we get.

$$L_2 - L_1 = \alpha L_1 \Delta T$$

$$L_2 = L_1 + L \alpha \Delta T$$

$$L_2 = L_1 \{1 + \alpha \Delta T\}$$

$$L_2 = L_1 \{1 + \alpha (T_2 - T_1)\}$$

COEFFICIENT OF LINEAR EXPANSION:

The change in length per unit length per Kelvin change is temperature is called coefficient of linear expansion. (OR) The fractional change in length per unit change in temperature of a metallic rod is called coefficient of linear expansion It depends upon the nature of material of the rod. Its S.I unit is K^{-1}.

SUPERFICIAL EXPANSION:

If by heating a body its area increases then such an expansion is called superficial expansion.

COEFFICIENT OF SUPERFICIAL EXPANSION:

The change in area per unit area per Kelvin change temperature is called coefficient of superficial expansion. (OR) The fractional change in area per unit change in temperature of a plate is called coefficient of superficial expansion Its S.I unit is K^{-1}. Its depend upon the nature of material of the substance. The coefficient of superficial expansion is twice the coefficient of linear expansion.

VOLUME EXPANSION:

If by heating a body volume increases then such an expansion is known as volume expansion.

EXPLANATION: Consider a body having volume V_1 at temperature T_1K. If the body is heated to a temperature T_2K and its volume becomes V_2 then increase in volume of the body $= V_2 - V_1 = \Delta V$. Rise in temperature of the body $= T_2 - T_1 = \Delta T$.

It is experimentally found that the change in volume ΔV is directly proportional to the original volume and rise in temperature ΔT.

$$\text{i.e } \Delta V \propto V_1 T$$
$$\Delta V = \beta V_1 T$$

Where β is a constant of proportionally and is called coefficient of volume expansion.

COEFFICIENT OF VOLUME EXPANSION:

The change in volume per unit volume per Kelvin rise in temperature is called coefficient of volume expansion. (OR) The fractional change in volume per unit change in temperature of a substance is called coefficient of volume expansion It depends upon the nature of material of the rod .Its unit is K^{-1}. Its value depends upon the nature of material of the body.

RELATION BETWEEN α AND β:

Consider an object in the shape of a rectangular box of dimensions l_1, w_1 and h_1. its initial volume at some temperature is given by.

$$V_1 = l_1 h_1 w_1$$

If the temperature of the object is raised through ΔT then it's each side increases. The final volume $V_2 = V_1 + \Delta V$ is given by.

$$V_2 = V_1 + \Delta V = l_2\, w_2\, h_2$$
$$\text{Where, } l_2 = l_1\,(1 + \alpha\,\Delta T),\ w_2 = w_1\,(1 + \alpha\,\Delta T),\ h_2 = h_1\,(1 + \alpha\,\Delta T)$$
$$\text{Therefore, } V_2 = V_1 + \Delta V = \{l_1\,(1 + \alpha\Delta T)\}\ \{h_1\,(1 + \alpha\Delta T)\}\ \{w_1\,(1 + \alpha\Delta T)\}$$
$$= l_1\, h_1\, w_1\,(1 + \alpha\,\Delta T)^3 = V_1[\,(1)^3 + 3(1)^2\,(\propto \Delta T) + 3(1)\,(\propto\Delta T)^2 + (\propto\Delta T)^3\}$$
$$= V_1\,\{1 + 3\alpha\Delta T + 3\alpha^2(\Delta T)^2 + \alpha^3\,(\Delta T)^3\}$$

Since α is very small there fore we can neglect the terms containing higher powers of α. thus

$$V_1 + \Delta V = V_1\,\{1 + 3\alpha\Delta T\} = V_1 + 3\propto V_1\,\Delta T$$
$$V_2 = 3\alpha V_1\,\Delta T \text{ ----------------i}$$
$$\text{Also } V_2 = \beta V_1\,\Delta T \text{ ---------------ii}$$

Comparing eq^n(i) and (ii)

$$\beta V_1\,\Delta T = 3\alpha V_1 \Delta T$$
$$\boldsymbol{\beta = 3\alpha}$$

Thus the coefficient of cubical expansion is three times the coefficient of linear expansion.

BIMETALLIC THERMOSTAT:

Thermostat is commonly used for maintaining required temperature.

Construction:

It consists of two dissimilar metal strips whose coefficients of linear expansion are different. The strips are joined very well.

Working:

It works as an electric contact breaker in an electrical heating circuit. When the desired temperature of the body is reached the strip bends and the circuit is broken. Thus the current steps flowing falls the strip contracts and the connection is restored.

BIMETALLIC THERMOMETER:

A bimetallic strip can be used to make a thermometer. In this case the bimetallic strip often is in the form of a coil. Its one end is fixed and the other end is attached to a pointer as shown in the figure. This kind of thermometer is usually used for ordinary air thermometer oven thermometer and in automobile for automatic choke.

BOYLE'S LAW:

According to this law "the volume V of a given mass of a gas is inversely proportional to its pressure P provided that the absolute temperature remains constant".

$$V \propto \frac{1}{P}$$

$$V = (\text{constant})\ \frac{1}{P}$$

$$PV = \text{constant}$$

Thus Boyle's law can also be stated as the product of pressure and volume of a given mass of a gas is constant provided that the temperature remained constant.

If a graph is plotted between volume and pressure of the gas then it will be a hyperbola as shown in the figure.

The product PV depends upon many factors including mass m by increasing the mass PV increases thus.

$$PV \propto m$$

$$PV = (\text{constant}) \times m$$

$$\frac{PV}{m} = Constant$$

If P_1, V_1 and m_1 be the initial pressure, volume and mass of a gas and they change to P_2, V_2 and m_2 respectively then.

$$\frac{P_1V_1}{m_1} = \frac{P_2V_2}{m_2}$$

Boyle's is not valid for high pressure.

CHARLES LAW:

According to this law "the volume V of a given mass of a gas is directly proportional to its absolute temperature T provided that applied external pressure remains constant.

$$\text{i.e} \quad V \propto T$$

$$V = \text{constant} \times T$$

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

If a graph is plotted between temperature and volume of the gas then it will be a straight line as shown in the figure. Form the graph it is found that at 0^oC the gas still possesses a volume V_1. When the lower and lower temperature axis as shown by the dotted line it intersects the temperature axis at a temperature of -273^oC is called the absolute zero of the temperature Charles is not valid for law temperature.

GENERAL GAS EQUATION:

Consider m mass of a gas in a cylinder having pressure P_1 volume V_1 and absolute temperature T_1. If the pressure of the gas is changed from P_1 to P_2 by keeping temperature constant then volume will also change form V_1 to V_2 as shown in figure 2. thus by Boyle's law.

$$P_1V_1 = P_2V_2$$

$$\frac{V_1}{V_2} = \frac{P_2}{P_1} \quad \text{----------------(1)}$$

Now if the temperature of the gas is changed from T_1 to T_2 by keeping the pressure constant volume will also change from V_1 to V_2. Thus, by Charles law.

$$\frac{V_1}{V_2} = \frac{T_1}{T_2} \quad \text{---------------(2)}$$

By equations 1 and 2

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

Thus we can write

$$PV = \text{constant} \times T$$
$$PV \propto T$$

The product PV also depends upon mass m of the gas.

Thus $PV \propto mT$

$$PV = (\text{constant})\, mT$$

$$\frac{PV}{mT} = Constant \text{ -------------------(3)}$$

The constant in equation (3) can be calculated if all the quantities in L.H.S of the equation are known. But the value of the constant is different for different system of units, samples of gases because the mass and hence the number of molecules changes. Thus it is convenient to express the amount of gas in a given volume in terms of number of moles.

A mole of any substance is that mass of the substance that contains a specific number of molecules called Avogadro's number N_A.

$N_A = 6.02\ 10^{23}$ molecule / moles

The number of moles n of a substance is related to its mass m through the equation.

$$n = \frac{mass\ of\ gas}{molar\ mass} = \frac{m}{M}$$

$$m = n \times M$$

Putting the value of m in equation (3).

$$\frac{PV}{(n \times M)T} = Constant$$

$$\frac{PV}{(n)T} = (Constant) \times M$$

$$\frac{PV}{nT} = R$$

$$PV = nRT$$

The universal gas constant R does not depends on the mass of gas in the sample.

$R = 8.314$ J/mole. K $= 8.314 \times 10^7$ erg/mole. K.

FUNDAMENTAL ASSUMPTION OF KINETIC THEORY OF GASES:

1. A gas consists of particles called molecules. Depending on the gas each molecule with consist of an atom or a group of atoms. All molecule of a gas in a stable state are considered identical.

2. Any finite volume of a gas consists of very large number of these molecules. At standard conditions there are 3×10^{25} molecules in a cubic meter.

3. The molecules are separated by distance large as compared to their own dimensions. The diameter of a molecule considered as a sphere is about 3×10^{-10}m.

4. The molecule move in all directions and with various speeds making elastic collisions with one another and with the walls of the container. The walls of the container can be considered perfectly smooth.
5. Molecules exert no force on one another except during collision. Therefore in between collisions with other molecule or with the walls of a container they move freely in straight lines.
6. Newtonian mechanics is applicable to the motion of molecules.

PRESSURE OF A GAS:

Explanation:

Consider N number of molecules an ideal gas in a cubic vessel whose walls are perfectly elastic. Length of a side of cube is ℓ, therefore area of a wall is ℓ^2 and volume of cube or is ℓ^3.Consider a molecule of mass m moving with velocity v. this velocity can be resolve into three components v_x, v_y and v_z. After colliding with wall A. the molecule rebounds in such a way that its velocity vx become vy and vz remain unchanged momentum of molecules before collision along x axis is mv_x and after collision is "$-mv_x$" change of momentum along axis = $-mv_x-(mv_x) = -2mv_x$.

Rate of change of momentum along x axis = $\frac{-2mv_x}{t}$

Where t = time of a round tip

$$t = \frac{distance}{Speed} = \frac{2l}{v_x}$$

Rate of change momentum along x-axis = $\frac{-2mv_x}{\frac{2l}{v_x}} = -\frac{mv_x^2}{l}$

But rate of change of momentum= Force

Force on molecule = $-\frac{mv_x^2}{l}$

Thus, Force on the wall = $\frac{mv_x^2}{l}$

(It is a reaction force)

The force exerted by all the molecules=

$$F= \frac{mv_{1x}^2}{l} + \frac{mv_{2x}^2}{l} + \frac{mv_{3x}^2}{l} + ------ + \frac{mv_{Nx}^2}{l}$$

Where $v_{1x}, v_{2x}, v_{3x}, -----, v_{Nx}$, are the X-components of velocities of the 1st , 2nd, 3rd ---, Nth molecule respectively

$$F=\frac{m}{l}\,[v_{1x}^2 + v_{2x}^2 + v_{3x}^2 + ------- + v_{Nx}^2]$$

Multiply and divide R.H.S. by N i.e. number of molecules in n moles.

$$F= \frac{mN}{l}\left[\frac{\{v_{1x}^2+v_{2x}^2+v_{3x}^2+------+v_{Nx}^2\}}{N}\right]$$

$$F = \frac{mN\,\overline{v_x^2}}{l}$$

Pressure: "P"

Now pressure is the force applied per unit area therefore,

$$P = \frac{F}{A}$$

$$P = \frac{\frac{mN\,\overline{v_x^2}}{l}}{l^2}$$

$$P = \frac{mN}{l^3}\,\overline{v_x^2}$$

Here,

$$\frac{mN}{l^3} = \frac{mass\ of\ the\ gas}{Volume\ of\ cubic\ container} = density\ of\ the\ gas = \rho$$

$P = \rho\,\overline{v_x^2}$ ______________________________(i)

Since the velocity 'v' of the molecule was resolved into three components

$$\overline{v^2} = \overline{v_x^2} + \overline{v_y^2} + \overline{v_z^2}$$

Suppose, $\overline{v_y^2} = \overline{v_z^2} = \overline{v_x^2}$

$$\overline{v^2} = \overline{v_x^2} + \overline{v_x^2} + \overline{v_x^2}$$

$$\overline{v^2} = 3\overline{v_x^2}$$

$$\overline{v_x^2} = \frac{1}{3}\,\overline{v^2}$$

Thus equation (i) becomes

$$P = \frac{1}{3}\rho\,\overline{v^2}$$

Boltzmann's constant:

The universal gas constant per molecule is called "Boltzmann's constant" it is denoted by "K" and is given. $K = \frac{R}{N_A}$, Its value is 1.38x 10^{-23} joules/molecule. K.

Root mean Square Speed:

The square root of $\overline{v^2}$ is called root mean square speed it is denoted by V_{rms} and $V_{rms} = \sqrt{\overline{v^2}}$

Average translational K.E. of a gas molecule is equal to $\frac{3}{2}$ KT.

Average translational K.E. of a gas molecule is directly proportional to the absolute temperature of a gas

To prove $\frac{1}{2}\,m\overline{v^2} \propto T$

Proof:

The pressure of an ideal gas is given by

$$P = \frac{1}{3}\rho v^{\overline{2}} \text{ --------------(i)}$$

Where $v^{\overline{2}}$ = Average square velocity

ρ = Density of the gas = $m \times n_V = \frac{mN}{V} = \frac{mn\,N_A}{V}$

Here m= Mass of a molecule

n_V= Number of molecules per unit volume

By general gas law, PV = nRT

$$P = \frac{nRT}{V}$$

Where R= General or Universal gas constant

n = Number of moles

Now, Eq^n⇒(i) $\frac{nRT}{V} = \frac{1}{3}\,\frac{mn\,N_A}{V}\,v^{\overline{2}}$

$$mv^{\overline{2}} = 3 \times \frac{R}{N_A} \times T$$

Since, Boltzmznn Constznt K=$\frac{R}{N_A}$ therefore,

$$mv^{\overline{2}} = 3KT$$

Dividing both the sides by 2,

$$\frac{1}{2}\,mv^{\overline{2}} = \left(\frac{3}{2}K\right) \times T$$

$$\text{Here, } \frac{3}{2}K = \text{constant}$$

$$\frac{1}{2}\,mv^{\overline{2}} \propto T$$

The pressure of an ideal gas is given by

$$P = \frac{1}{3}\rho v^{\overline{2}} \text{ --------------(i)}$$

Where $v^{\overline{2}}$ = Average square velocity

ρ = Density of the gas = $m \times n_V = \frac{mN}{V}$

Here m= Mass of a molecule

n_V= Number of molecules per unit volume

Therefore, Eq$^n \overset{(i)}{\Rightarrow}$ $P = \frac{1}{3}\frac{mN}{V}v^{\overline{2}}$

$$PV = \frac{1}{3}N(m\overline{v^2})\text{------------(ii)}$$

According to equation of kinetic interpretation of absolute temperature,

$$\frac{1}{2}\,m\overline{v^2} = \frac{3}{2}KT$$

$$m\overline{v^2} = 3KT$$

Therefore, $Eq^n \overset{(ii)}{\Rightarrow} PV = \frac{1}{3}N(3KT)$

$$PV=NKT \text{ ----------------(iii)}$$

Boyle’s law on the basis of K.M.T

In R.H.S. of eq^n(iii)
N=Total number of molecules= Constant in Boyle’s Law
K= Boltzmann’s Constant
T= Absolute temperature = Constant in Boyle’s Law

Hence, $PV = \text{Constant}$

This proves Boyle’s Law

Charle’s Law on the basis of K.M.T of gases:

Now from Eq^n(iii)

$$\frac{V}{T} = \frac{NK}{P}\text{------------(iv)}$$

In R.H.S. of eq^n(iv)
N=Total number of molecules= Constant in Charles Law
K= Boltzmann’s Constant
P= Pressure of the gas = Constant in Charles Law

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

This proves Charles law.

Specific Heat:

It is the amount of heat required to raise the temperature of unit mass of a substance through unit degree. The amount of heat “ΔQ” supplied to a substance is directly proportional to it mass “m” and change of temperature “ ΔT” i.e.

$$\Delta Q \propto m\,\Delta T$$

$$\Delta Q = c\, m\Delta T$$

Where “C” is a constant and is called “specific heat” its value depends upon the nature of material of the substance its S.I. unit is J/Kg.K.

HEAT CAPACITY:

It is the amount of heat required to raise the temperature of any mass of a substance (body) through unit degree centigrade.
It is given by formula

$$\text{Heat capacity} = \frac{Heat\ Supplied}{Change\ in\ temperature} = \frac{\Delta Q}{\Delta T}$$

Law of heat exchange:

According to this law “heat lost by that body is equal to the heat gained by cold bodies” i.e.

Heat lost = Heat gained

This law is used to determine the specific heat capacity

MOLAR SPECIFIC HEAT: It is the amount of heat required to raise the temperature of one mole of a substance through 1 K.

The amount of heat “ΔQ” supplied directly depend upon the number of moles “n” and change of temperature “ΔT” i.e.

$$\Delta Q \propto n\Delta T$$
$$\Delta Q = C\, n\, \Delta T$$

Where “C” is a constant and is called “molar specific heat” it is the product of molar mass “M” and specific heat capacity “c” of substance i.e.

$$C = Mc$$

Its S.I unit is J/mole. K

MOLAR SPECIFIC HEAT OF GASES:

A gas can be heated by two different ways it can be heated at constant volume and at constant pressure that’s why a gas has two molar specific heats,

1) Molar specific heat at constant volume and
2) Molar specific heat at constant pressure

Molar Specific heat at constant volume “Cv”:

It is the amount of heat required to raise the temperature of 1 mole of a gas through 1K at constant volume.

$$\Delta Q_V = C_V\, n\, \Delta T$$

Molar specific heat at constant pressure “Cp”:

It is the amount of heat required to raise the temperature of 1 mole of a gas through 1 K at constant pressure.

$$\Delta Q_P = C_P\, n\, \Delta T$$

THERMODYNAMICS:

Thermodynamics is the study of the laws governing the concession of heat energy into mechanical energy and vice versa and the methods employed for such transformations.

THE FIRST LAW OF THERMODYNAMICS:

“During any thermodynamic change in a system when heat energy is converted into mechanical energy or vice versa the total amount of energy remains constant”. (OR)

According to this law “the change in internal energy of a system in any process is equal to the net heat flow into the system minus the total work done by this system”.

EXPLANATION:

Consider a system consisting of a gas in a cylinder which is provided with a frictionless piston if ΔQ is the amount of heat supplied to the system and as a consequence of this it performs “ΔW” amount of work then the remaining energy ΔQ – ΔW is retain by the system due to which internal energy of the system changes from to ΔU. If the above process is repeated it is found that the change in internal energy $U_f - U_i$ does not depend upon the path adopted it only depends upon the initial and final states thus we can write,

$$\Delta Q - \Delta W = U_f - U_i$$
$$\Delta Q - \Delta W = \Delta U \quad \text{----------------(i)}$$
$$\Delta Q = \Delta U + \Delta W$$

This equation is called equation of first law of thermodynamics.

Special Cases:

1) If the system is isolated (i.e. which does no external work and there is no flow of heat) then $\Delta Q = O$, $\Delta W=O$ thus eq 1 becomes $U_f - U_i = O$ or $\Delta U=O$

It means that the internal energy of the system remain constant.

2) If the system is carried through a cyclic process (a process which starts and ends upto the same rate) then the change in internal energy is zero i.e. $\Delta U = 0$ thus eq(i) becomes

$$\Delta Q - \Delta W = O$$

$$\Delta Q = \Delta W$$

It means that the work done by the system is equal to the heat supplied to the system.

APPLICATIONS OF THE FIRST LAW OF THERMODYNAMICS

(i)ISOBARIC PROCESS:

It is that process in which pressure of the system remains constant.

EXPLANATION:

Consider a thermodynamic system at initial state where external pressure, volume and absolute temperature of a gas in a cylinder are P, V_1 and T_1. When ΔQ_p amount of heat is supplied to the system at constant external pressure the absolute temperature of the gas increases from T_1 to T_2 and volume increases from V_1 to V_2.

CONDITION FOR THE PROCESS:

The work done by the gas in moving the piston of area “A” to a small distance “Δy” is given by,

$$\Delta W = F\,\Delta y$$

By the definition of pressure

$$P = \frac{F}{A}$$

$$F = PA$$

Thus,

$$\Delta W = PA\,\Delta y$$

But $A\,\Delta y = \Delta V = V_2 - V_1 =$ change in volume

$$\Delta W = P\Delta V$$

APPLICATION OF EQUATION OF FIRST LAW:

$$\Delta Q = \Delta U + \Delta W$$

$$\Delta Q_P = \Delta U + P\Delta V$$

This equation is called equation of first law in isobaric process.

PV-DIAGRAM:

If a graph is plotted between the volume and pressure of the gas then it will be a horizontal line. The area under the line above the axis of volume is PΔV.

2. ISOCHORIC PROCESS: It is that process in which volume of the gas remains constant

EXPLANATION:

Consider a thermodynamic system at initial state where external pressure, volume and absolute temperature of a gas in a cylinder are P_1, V and T_1. When ΔQ_v amount of heat is supplied to the system and external pressure is increased from P_1 to P_2 to maintain volume at V the absolute temperature of the gas increases from T_1 to T_2.

CONDITION FOR THE PROCESS:

Since the volume of the gas remains constant in this process therefore, work done will be zero. i.e. **ΔW=0.**

APPLICATION OF EQUATION OF FIRST LAW:

$$\Delta O = \Delta U + \Delta W$$

$$\Delta Q_V = \Delta U + 0$$
$$\Delta Q_V = \Delta U$$

This equation is called equation of first law in isochoric process.

CONCLUSION:

According to above equation "In isochoric process the amount of heat is supplied to the system is completely converted into the increase in internal energy of the system".

PV-DIAGRAM:

If a graph is plotted between the volume and pressure of the gas then it will be a vertical line and the area under the line above the axis of volume is zero.

3. ISOTHERMAL PROCESS:

It is that process in which absolute temperature of the working substance remains constant.

EXPLANATION:

Consider a thermodynamic system at initial state where external pressure, volume and absolute temperature of a gas in a cylinder are P_1, V_1 and T. When the cylinder is placed on a heat reservoir at temperature T and external pressure is decreased from P_1 to P_2 then the volume of working substance increases from V_1 to V_2 and due to the amount of heat ΔQ is supplied by the heat reservoir the absolute temperature remains at T.

CONDITION FOR THE PROCESS:

Since the absolute temperature of the gas remains constant in this process therefore, change in internal energy of system is equal to zero. i.e. $\Delta U=0$.

APPLICATION OF EQUATION OF FIRST LAW:

$$\Delta Q = \Delta U + \Delta W$$
$$\Delta Q = 0 + \Delta W$$
$$\Delta Q = \Delta W$$

This equation is called equation of first law in isothermal expansion process.

CONCLUSION:

According to above equation "In isothermal expansion process the amount of heat is supplied to the system is completely converted into the work done by the system".

PV-DIAGRAM:

If a graph is plotted between the volume and pressure of the gas then it will be a curve called ISOTHERM CURVE and the area under the curve above the axis of volume is maximum work done. For isothermal process it is found that **PV**= constant.

(4)-ADIABATIC PROCESS: It is that process in which no heat can flow into or out of the system.

OR

It is the process in which entropy of the system remains constant.

EXPLANATION:

Consider a thermodynamic system at initial state where external pressure, volume and absolute temperature of a gas in a cylinder are P_1, V_1 and T_1 respectively. When the cylinder is placed on a heat insulator and external pressure is decreased from P_1 to P_2 then the volume of working substance increases from V_1 to V_2 and the absolute temperature of the working substance decreases from T_1 to T_2.

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CONDITION FOR THE PROCESS:

Since no amount of heat is supplied or expelled by the system in this process therefore, $\Delta Q=0$.

APPLICATION OF EQUATION OF FIRST LAW:

$$\Delta Q = \Delta U + \Delta W$$
$$0 = \Delta U + \Delta W$$
$$-\Delta U = \Delta W$$

This equation is called equation of first law in adiabatic expansion process.

CONCLUSION:

According to above equation "In adiabatic expansion process the amount of decrease in internal energy of the system is completely converted into the work done by the system".

PV-DIAGRAM:

If a graph is plotted between the volume and pressure of the gas then it will be a curve called ADIABATIC CURVE and the area under the curve above the axis of volume is work done. For adiabatic process it is found that PV^{γ} = constant where $\gamma = \frac{C_P}{C_V} = \frac{\textit{Molar specific heat at constant pressure}}{\textit{Molar specific heat at constant volume}}$

DERIVATION OF $C_p - C_v = R$:

Consider "n" moles of an ideal gas showing two isotherm curves at initial absolute temperature T_1 and final absolute temperature T_2. Consider point A when initial volume, pressure and temperature of the gas are V_1, P_1 and T_1 respectively. When ΔQ_p amount of heat is supplied to the system at constant external pressure P_1 then the absolute temperature of the gas increases from volume of the gas from T_1 to T_2 and the volume of the gas increases from V_1 to V_2 i.e. point B of the graph. In this case, according to equation of first law in isobaric process,

$$\Delta Q_P = \Delta U_{A\text{-}B} + P_1 \Delta V$$

Since, $\Delta Q_P = nC_p \Delta T$

Therefore, $nC_p \Delta T = \Delta U_{A\text{-}B} + P_1 \Delta V$ ------------------(i)

Now consider the graph from point A to C for isochoric process where the coordinates of point C are (V_1,P_2,T_2). As we know, the equation of first law in isochoric process is,

$$\Delta Q_V = \Delta U_{A\text{-}C}$$

And, $\Delta Q_V = nC_V \Delta T$

Therefore, $\Delta U_{A\text{-}C} = nC_V \Delta T$

For the same temperature change, $\Delta U_{A\text{-}B} = \Delta U_{A\text{-}C} = nC_V \Delta T$

Thus eq^n(i) becomes,

$$nC_p \Delta T = nC_V \Delta T + P_1 \Delta V$$

$$nC_p \Delta T - nC_V \Delta T = P_1 \Delta V$$

$n \Delta T (C_p - C_V) = P_1 \Delta V$ ------------------(ii)

By general gas equation, $PV = nRT$

For initial state in isobari process, $P_1 V_1 = nRT_1$ --------------------(iii)

For initial state in isobari process, $P_1 V_2 = nRT_2$ --------------------(iv)

Subtracting eq^n (iii) from eq^n (iv)

$$P_1 V_2 - P_1 V_1 = nRT_2 - nRT_1$$

$$P_1 (V_2 - V_1) = nR(T_2 - T_1)$$

$$P_1 \Delta V = nR \Delta T$$

Thus eq^n (ii) becomes

$$n \Delta T (C_p - C_V) = nR \Delta T$$

$$Cp\text{-}Cv=R$$

HEAT ENGINE:

It is a device which convert heat energy into mechanical energy the essentials of a heat engine are (a) Hot body (b) Working substance (3) Cold body

There are two types of heat engine

(1) Internal combustion engine (2) External combustion engine

INTERNAL COMBUSTION ENGINE:

it is that engine in which fuel burns inside the engine e.g. petrol or diesel engine this engine consists of (i) Hot body (combustion chamber) and (ii) Cold body (atmosphere) fuel burns inside the combustion chamber a part of heat produced (burnt fuel) is used in moving the piston while remaining energy goes to atmosphere

EXTERNAL COMBUSTION ENGINE:

It is that engine in which fuel burs outside the engine e.g. steam engine this engine consist of (1) Hot body (steam boiler or furnace) and (ii) Cold Body (condenser or atmosphere) fuel burns inside the furnace where water is converted into steam in steam boiler a part of heat steam is used in moving the piston while remaining goes to the cold body

THE SECOND LAW OF THERMODYNAICS

KELVING STATEMENT: According to this statement "It is impossible to derive a continuous supply of work (energy) by cooling a body to a temperature lower than that of the coldest of its surrounding"
OR "It is impossible to construct an engine operating in a cycle (continuously) which does nothing other than to take heat from hot body and perform an equivalent amount of work without having a cold body to which a part of heat is transferred"

CLAUSIUS STATEMENT:

According to this statement "It is impossible to cause heat to flow from cold body to a hot body without the expenditure of external energy"

KELVINS AND CLAUSIUS STATEMENTS ARE EQUIVALENT:

We can prove that both Kelvin and Clausius statements are equivalent by showing that if either of these statements is supposed to be false the other must be false also. We suppose that Kelvin statement is false then we could have a perfect heat engine which takes heat from a source and converts it completely into work without having a cold body if we connect this perfect heat engine to an ordinary refrigerator we take heat from the hot body and convert it completely to work this work can be used to operate the refrigerator which conveys heat from the cold body to the hot body the net result is a transfer of heat from a cold body to hot body without false Clausius statement is also false

THE CARNOT ENGINE:

The cannot engine is an ideal engine which consists of (i) a hot body of infinite thermal capacity at temperature T_1 (ii) a large cold body at temperature T_2 (iii) a perfect heat insulator and (iv) a cylinder fitted with a piston enclosed by working substance the cylinder has a heat conducting base and non-conducting walls and piston

CARNOT CYCLE: The working substance is carried through the following cycle of operations known as the Carnot cycle it consist of four processes.

Process-1:

Consider a Carnot engine at initial state where external pressure, volume and absolute temperature are P_1, V_1 and T_1 respectively. When the cylinder is placed on a heat reservoir at temperature T_1 and external pressure is decreased from P_1 to P_2 then the volume of working substance increases from V_1 to V_2 and due to the amount of heat Q_1 is absorbed by the engine the temperature of working substance remains at T_1. This expansion is known as isothermal expansion

HEAT ABSORBED = INPUT = Q_1

Process-2:

In this process the cylinder is placed on an insulator and the external pressure is decreased from P_2 to P_3 then the volume of working substance increases from V_2 to V_3 since no heat can enter or leave the system therefore this explanation is known as adiabatic expansion in this process temperature of the gas decreases from T_1 to T_2.
This expansion is known as adiabatic expansion

Process-3:
In this process the cylinder is placed on a cold body (heat reservoir at low temperature "T_2") and the gas is compressed when external pressure is increased from P_3 to P_4 then the volume of working substance decreases from V_3 to V_4 and due to the amount of heat Q_2 is expelled by the engine the temperature of working substance remains at T_2. This compression is known as isothermal compression

HEAT EXPELLED = Q_2

OUTPUT = $Q_1 - Q_2$

Process-4: In this process the cylinder is placed on the insulator and the gas is compressed by increasing external pressure from P_4 to P_1 then the volume of working substance increases from V_4 to V_1 and absolute temperature of the working substance increases from T_2 to T_1. Since no heat can enter or leave the system therefore this compression is known as adiabatic compression.

If a graph is plotted between volume and pressure of the gas for the above process a loop is obtained which is known as cannot cycle as shown in figure 6

EFFICIENCY OF CARNOT ENGINE:

Efficiency is the ratio between output and input energies of an engine i.e.

Efficiency = $\eta = \frac{OUTPUT}{INPUT}$

Energy supplied to a system is called "input" in the Carnot cycle input = Q_1

Work done by the system is called "output" in the above processes output = $\Delta W = Q_1 - Q_2$

Therefore,

$$\eta = \frac{Q_1 - Q_2}{Q_1}$$

$$\eta = 1 - \frac{Q_2}{Q_1}$$

$$\eta_{\%} = \left[1 - \frac{Q_2}{Q_1} \right] \times 100 \quad \text{-------------(i)}$$

The heat transferred to or from a Carnot engine is directly proportional to the absolute temperature of hot and cold reservoirs. It has been found that,

$$\frac{Q_2}{Q_1} = \frac{T_2}{T_1}$$

Eq^n (i) becomes

$$\eta_{\%} = \left[1 - \frac{T_2}{T_1} \right] \times 100 \quad \text{-------------(ii)}$$

Efficiency is less than 100:

Efficiency of an engine even Carnot engine cannot be 100/ because it does not completely convert heat into work a part of heat is always rejected to the cold reservoir

ENTROPY:

Entropy is the measure of molecular disorder and in any process the entropy increases or remains constant that is the disorder increases or remains constant.

EXPLANATION:

Consider a large number of molecules of a gas confined in an insulated cylinder fixed with a removable partition. To start with all the molecules are confined in volume $V_1 = V$. If the partition is removed the molecules now occupy the whole volume 2V and are less localized then they were before the partition was removed. The degree of localization is measure of disorder. As the system increases in volume the disorder increases and we say that the entropy increases.

Consider equal number of black and white balls contained in a box. The black occupy me half of the box white the white balls occupy me half of the box. We would say that the balls are placed in order. As we shake the box this order of the block and white balls is distributed. As the box is shaken more the order is distributed move. Thus disorder increases and the original arrangement cannot be restored no matter how we shake the box. This situation can be described by saying that the entropy of the system has increased. The natural phenomenon are taking place in such a way that the entropy of the universe is increasing. If Q be the heat transferred to a system is increasing then change in entropy = $\Delta S = \frac{\Delta Q}{T}$

Its unit in system international is J/K.

ENTROPY AND THE SECOND LAW OF THERMODYNAMICS:

The considerations about the entropy lead to define the second law of thermodynamics as follows.

"When an isolated system undergoes a change the disorder in the system increases".

The second law of thermodynamics can also define as.

"When an isolated system undergoes a physical change the entropy of the system either remains constant or it increases".