Chapter =11

Heat

Heat:

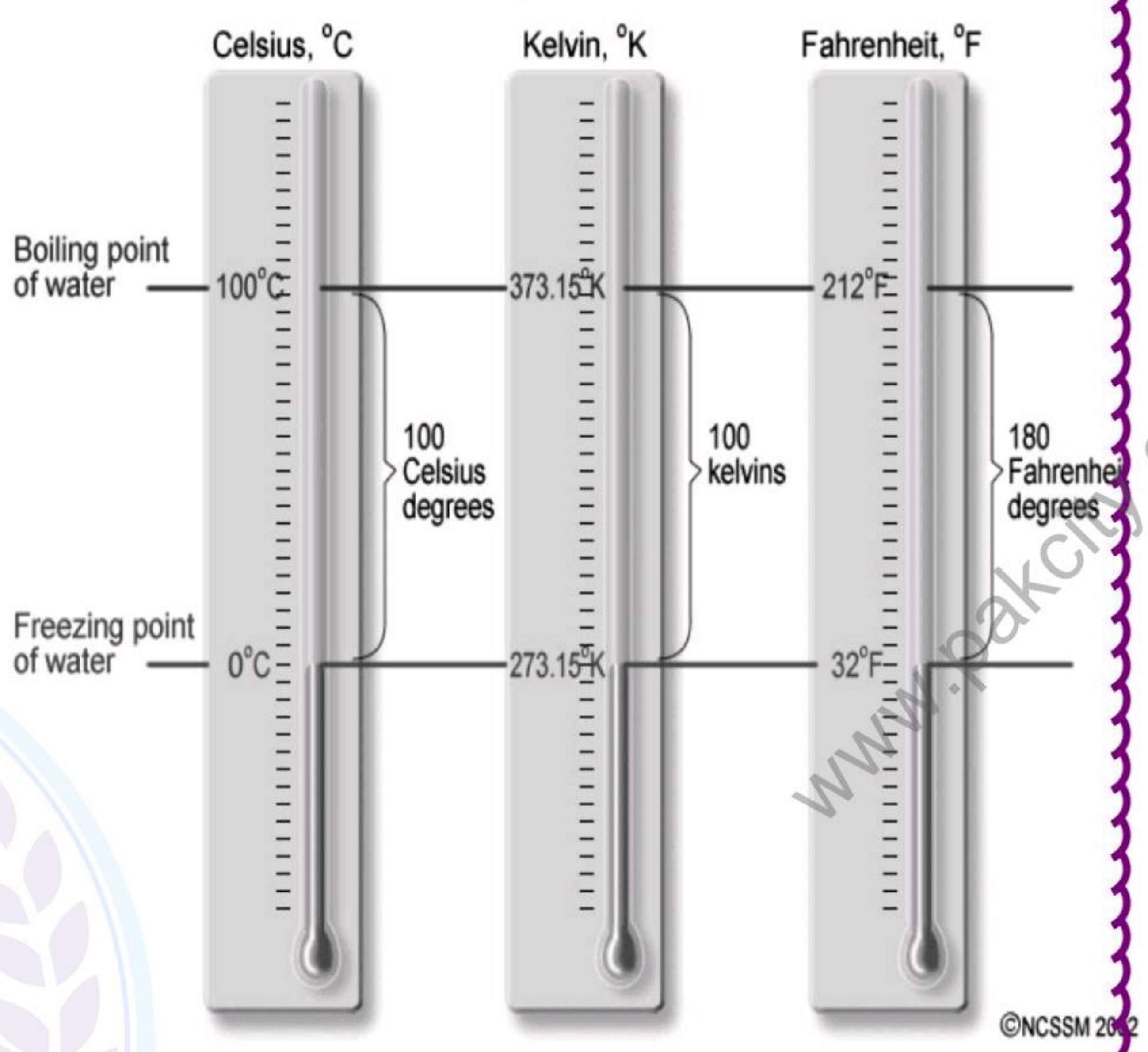
The energy that flows due the temperature difference between two bodies is called heat.

Temperature:

Temperature is a physical quantity which is directly proportional to the average translational kinetic energy of molecules of a body or system.

Different Temperature Scales:

Three different temperature scales are developed for the determination of temperature of the Body.



These are:

1) Celsius scale
2) Fahrenheit Scale
3) Kelvin scale

Celsius Scale:

On Celsius scale the freezing point of water is selected to be 0^oC, boiling point of water is selected to be 100^oC, and the region between them is divided into 100 equal segments representing 1^oC.

Fahrenheit Scale:

On Fahrenheit scale, the freezing point of water is selected to be 32^oF, and boiling point of water is selected to be 212^oF and the region between them is divided into 180 equal segments representing 1^oF.

Relationship between Celsius and Fahrenheit scale:

Mathematical relation between Celsius and Fahrenheit scale is given by following relation.

$$T_C = \frac{5}{9}(T_F - 32)$$

$$T_F = \frac{9}{5}(T_C) + 32$$

Here T_C and T_F represent the temperature in Celsius and Fahrenheit, respectively.

Kelvin scale:

On Kelvin scale the freezing point of water is selected to be 273K and boiling point of water is selected to be 373K and the region between them is divided into 100 equal segments representing 1K. Segment on Kelvin scale is equal to the segment on Celsius scale.

Unit of temperature:

The SI unit of temperature is Kelvin and it is defined as

The $\frac{1}{273.15}$ of thermodynamic temperature of triple point of water is called 1 Kelvin.

Law of Heat Exchange:

Heat lost by the hotter body is equal to the amount of heat gain by the colder body.

$$\text{Heat lost} = \text{Heat gain}$$

Thermometric Properties:

Property of a substance, which changes uniformly with the change in temperature, is called Thermometric property.

For Example:

Volume of gases, electrical resistance of a material or electrical conductivity of a semiconductor material etc.

Thermal Expansion:

Change in physical dimension of a body (e-g length, Area or volume) with the change in temperature is called Thermal expansion.

Explanation:

According to classical physics, molecules of substances are in continuous vibratory motion about their mean position with certain amplitude. When a material is heated its molecule absorb energy, which causes an increase in amplitude of the vibrating molecules that is way the gap between them is increased and results in their change in dimension (e-g Length, Area and Volume).

Type of Thermal Expansion:

There are following type of thermal expansion:

- Linear Expansion.
- Volumetric Expansion.
- Areal Expansion

Linear Expansion:

The phenomenon in which length of an object Changes due to change in its temperature is called *Linear Expansion.*

OR

The phenomenon in which length of an object changes on heating is called ***Linear Expansion.***

Mathematical Expression:

Experimentally it is found that change in length is directly proportional to the original length L_o and change in temperature ΔT.

$$\Delta L \propto L_o$$

$$\Delta L \propto \Delta T$$

$$\boxed{\Delta L = \alpha L_o \Delta T} \text{ --------- (1)}$$

Where α is constant of proportionality and termed as coefficient of linear expansion it may be defined as:

"Fractional change in length per unit change in temperature."

OR

"Change in length per unit original length per unit temperature."

$$\boxed{\alpha = \frac{\Delta L}{L_o \Delta T}}$$

Numerical value of $\boldsymbol{\alpha}$ depends upon material and temperature range.

If L_f is the final length then change in length can be expressed as

$$\Delta L = L_f - L_o$$

Equation (1) becomes

$$L_f - L_o = \alpha L_o \Delta T$$

$$L_f = L_o + \alpha L_o \Delta T$$

$$L_f = L_o(1 + \alpha \Delta T)$$

Replacing ΔT by the difference between final temperature "T_f"and initial temperature "T_i "we get:

$$\boldsymbol{L_f = L_o\{1 + \alpha(T_f - T_i)\}}$$

Above expression gives the relation among final length, original length and change in temperature.

Volumetric Expansion:

The phenomenon in which Volume of an object Changes due to change in its temperature is called *Volumetric Expansion.*

OR

The phenomenon in which volume of an object changes on heating is called *Volumetric Expansion.*

Mathematical Expression:

Experimentally it is found that change in volume is directly proportional to the original volume V_o and change in temperature ΔT.

$$\Delta V \propto V_o$$

$$\Delta V \propto \Delta T$$

$$\boldsymbol{\Delta V = \beta V_o \Delta T} \text{ --------- (1)}$$

Where β is constant of proportionality and termed as coefficient of volumetric expansion it may be defined as

"Fractional change in volume per unit change in temperature."

OR

"Change in volume per unit original volume per unit temperature."

$$\boldsymbol{\beta = \frac{\Delta V}{V_o \Delta T}}$$

Numerical value of βstrictly depends upon temperature and material.

If V_f is the final volume then change in volume can be expressed as

$$\boldsymbol{\Delta V = V_f - V_o}$$

Equation (1) becomes

$$V_f - V_o = \beta V_o \Delta T$$

$$V_f = V_o + \beta V_o \Delta T$$

$$\boldsymbol{V_f = V_o(1 + \beta\Delta T)}$$

Replacing ΔT by the difference between final temperature "T_f" and initial temperature "T_i" we get

$$\boxed{\boldsymbol{V_f = V_o\{1 + \beta(T_f - T_i)\}}}$$

Above expression gives the relation among final volume, original volume and change in temperature.

Relation between Coefficient of linear and volumetric expression:

Consider a box of dimensions l, w, and h. Its volume at some temperature T_o is V_o. If the temperature changes to T_f and its volume changes to $V_0+\Delta V$. Where each dimension changes according to relation

$$\boldsymbol{L_f = L_o(1 + \alpha\Delta T)}$$

New dimensions will be

$$\boldsymbol{l_f = l(1 + \alpha\Delta T)}$$

$$\boldsymbol{w_f = w(1 + \alpha\Delta T)}$$

$$\boldsymbol{h_f = h(1 + \alpha\Delta T)}$$

If V_f is final volume, then

$$V_o + \Delta V = V_f$$

But

$$V_f = l_f w_f h_f$$

$$V_f = l(1 + \alpha\Delta T)w(1 + \alpha\Delta T)\,h(1 + \alpha\Delta T)$$

$$V_f = lwh(1 + \alpha\Delta T)^3$$

$$V_f = V_o(1 + \alpha\Delta T)^3$$

Using the mathematical relation

$$(a + b)^3 = a^3 + b^3 + 3a^2b + 3ab^2$$

Equation (1) will become

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

As α is very small in magnitude neglecting its higher powers we get

$$V_f = V_o(1 + 3\alpha\Delta T) \text{ ----------- (2)}$$

Now, equation for volumetric expansion may be written as

$$V_f = V_o(1 + \beta\Delta T) \text{ ------------- (3)}$$

Comparing equation (1) and (2) we get

$$\boxed{\beta = 3\alpha}$$

Hence, coefficient of linear expansion is thrice the coefficient of volumetric expansion.

Bimetallic Thermostat:

It is a temperature sensitive device, which works on the principle of thermal expansion.

Construction:

It is made by joining two strips of metals with different coefficient of linear expansion

Working principle:

As the temperature of the strip increases, the two metals expand by different amounts and the strip bends. The change in shape can make or break an electrical connection. As shown in figure.

Bimetallic Thermostat

Kinetic Molecular Theory:

In 19^{th} century Scientist give assumption on which they define an ideal gas. According to these assumptions an ideal gas is a gas which follows following assumptions:

- A gas consists of small hard spherical balls called molecules of that gas.
- There is no molecular force of attraction between two molecules of a gas.
- The collision between two molecules or with the surface container of a gas is perfectly elastic.
- The pressure of a gas is directly proportional to the number of collision of molecules with the surface of container.
- The temperature of a gas is directly proportional to average kinetic energy of the molecules of gas.
- The laws of mechanics are applicable on the molecules of gas.

- Molecules move in a straight line until they collide with another molecule or with the walls of container.
- The separation between two molecules is very large as compare to the size of the molecule.
- At S.T.P $1m^3$ of an ideal gas container contain 3×10^{25} molecules.

Gas Laws:

Physical laws that relate pressure, volume mass and temperature of a gas are called gas laws.

Boyles law:

In 1660 Robert Boyles Studied the relation between the pressure and the volume of a gas and conclude an empirical law Known as Boyles Law.

Statement:

According to Boyles Law

"Volume of a given mass of a gas is inversely proportional to its pressure keeping the temperature of gas constant."

Mathematically

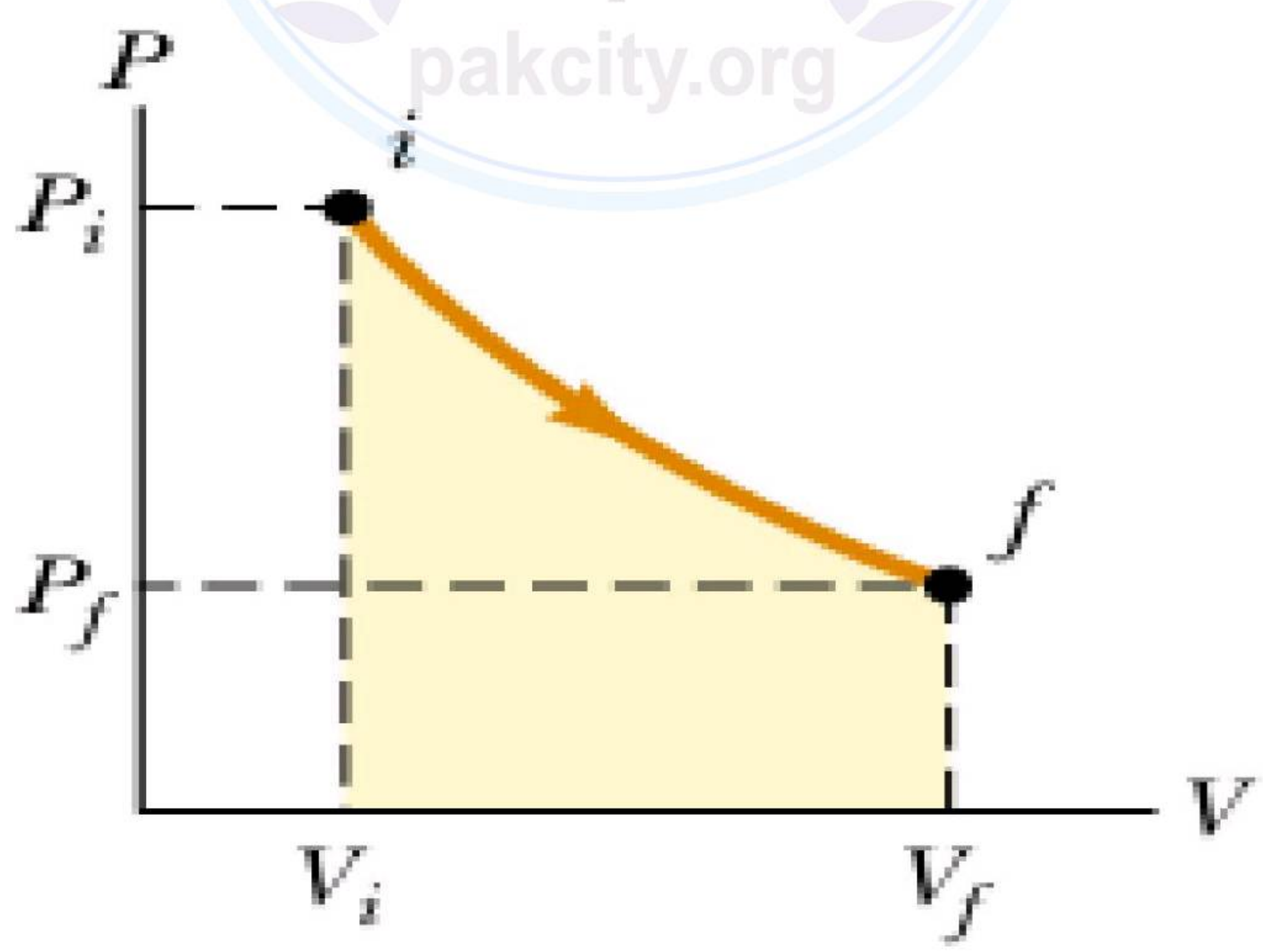
$$V \propto \frac{1}{P}$$

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

$$PV = constant$$

Graphical Representation:

Pressure versus Volume graph of Boyle's law is given below. From graph it is clear that the relation between pressure and volume is hyperbolic. If P_1 and V_1 are pressure and volume at point "*i*" and P_2 and V_2 are pressure and volume at point "*f*" than according to Boyle's law:



$$P_1V_1 = (Constant)$$

$$P_2V_2 = (Constant)$$

Or

$$P_1V_1 = P_2V_2$$

Above equation is called sate form of Boyle's law.

Charles Law:

In 1787 Jacques Charles studied the relation between the volume and temperature at constant pressure.

Statement:

"Volume of given mass of a gas is directly proportional to the absolute temperature keeping the pressure of gas constant."

Mathematically

$$V \propto T$$

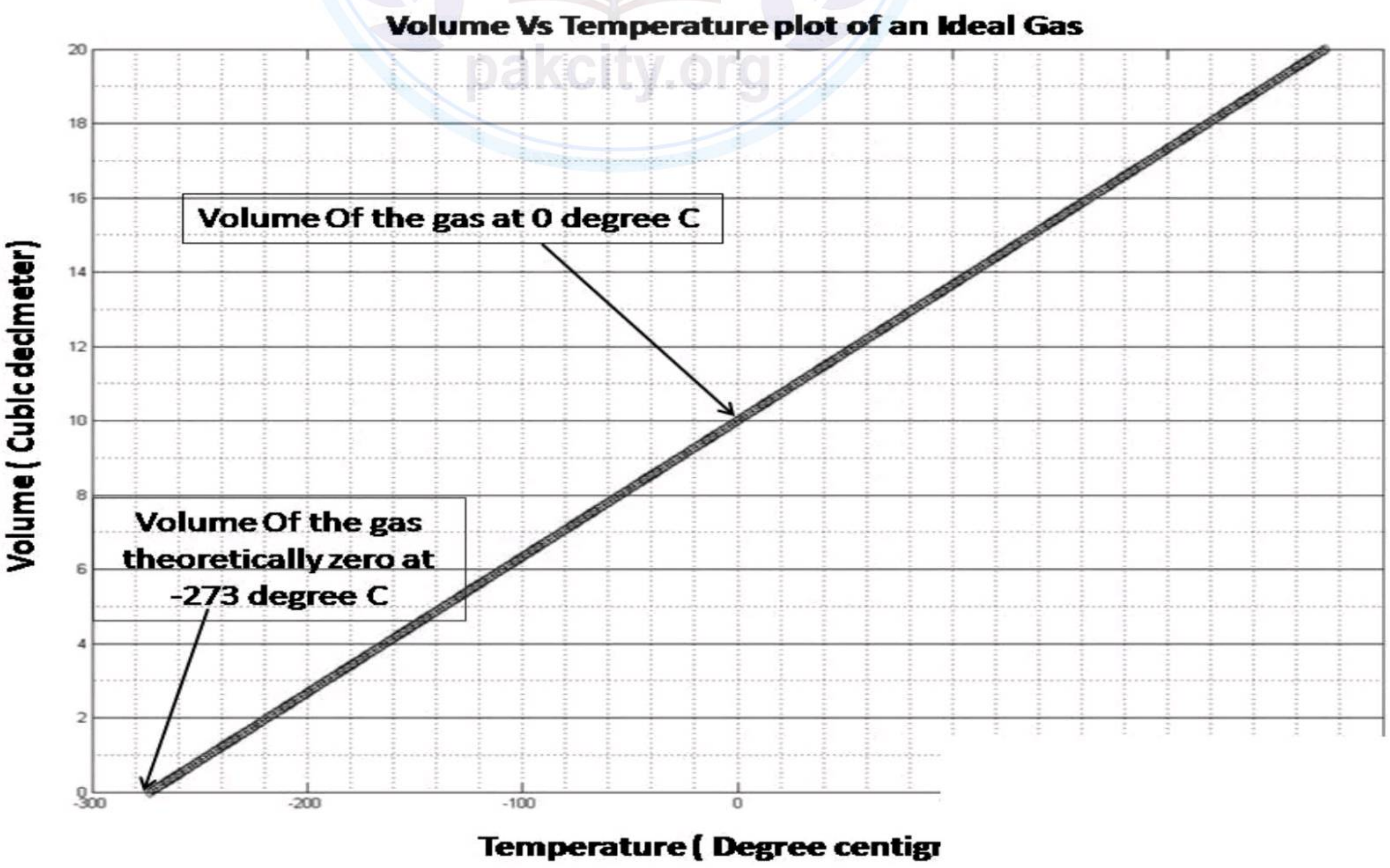
$$V = (Constant)T$$

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

Graphical Representation:

Volume versus Temperature graph of Charles's law is given below

From graph it can be seen that volume of an ideal gas at constant pressure is linearly related with the temperature and Volume is mathematically (or theoretically) Zero at -273 ^{o} C. this point is called Absolute zero.



Absolute zero can be defined as:

"It is the temperature, at which Volume of an ideal gas is theoretically Zero."

Hence Charles law is not applicable at Zero Kelvin because:

- At zero Kelvin nothing can exist in gaseous state and Charles law is only applicable on gases.
- According to law of conservation of energy volume of an any material cannot be zero at any temperature.

General Gas Law:

Consider the gas Laws

According to Boyle's Law:
"Volume of a given mass of a gas is inversely proportional to its pressure keeping the temperature of gas constant."

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

Or

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

According to Charles Law:
"Volume of given mass of a gas is directly proportional to the absolute temperature keeping the pressure of gas constant."

$$V \propto T$$

According to Avogadro Law

"Volume of given mass of a gas is directly proportional to the number of moles keeping the pressure and temperature of gas constant."

$$V \propto n$$

Combine all laws given above we get

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

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

$$\boxed{PV = nRT}$$

Where R is called general Gas Constant and it has numerical value of 8.313 $Jmol^{-1} K^{-1}$.

$$R = \frac{PV}{nT} - - - - - - - - -(1)$$

Now if P_1, V_1, T_1 and P_2, V_2, T_2 are pressure, volume and temperature at two different instant then equation (1) becomes

$$R = \frac{P_1 V_1}{n T_1} - - - - - - - - - -(2)$$

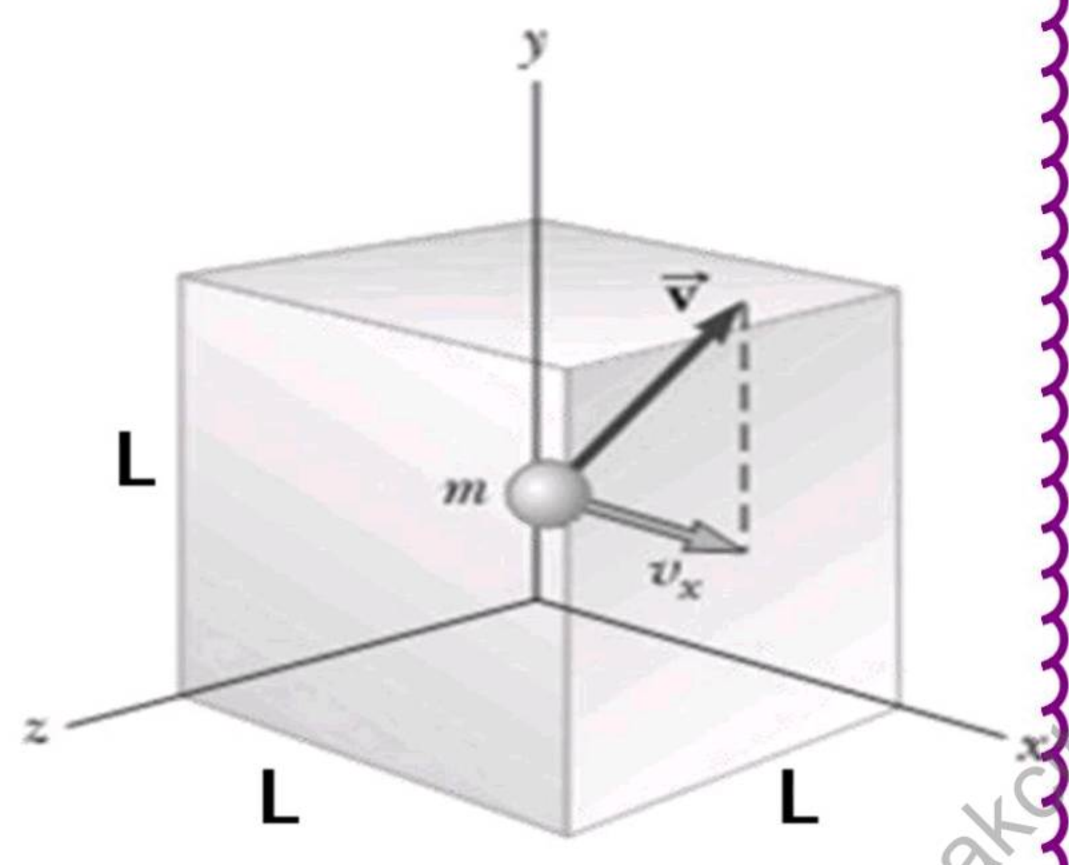
$$R = \frac{P_2 V_2}{n T_2} - - - - - - - - - -(3)$$

Combining above equations we get

$$\frac{P_1 V_1}{n T_1} = \frac{P_2 V_2}{n T_2}$$

$$\boxed{\frac{\boldsymbol{P_1 V_1}}{\boldsymbol{T_1}} = \frac{\boldsymbol{P_2 V_2}}{\boldsymbol{T_2}}}$$

Pressure of an Ideal Gas (Pressure Equation):



Consider a cubical container of dimensions equal to "L" containing N number of molecules of an ideal gas. Each is having mass "m". Let one of the n molecules is moving along X-**direction** with velocity $\boldsymbol{v_x}$ and after striking the wall of the container it bounces back in opposite direction.

Change in the momentum of the molecule can be written as

Initial momentum: $p_i = m v_{1x}$

Final momentum: $p_f = -m v_{1x}$

Change in momentum = Final momentum - Initial momentum

$$\Delta p = p_f - p_i$$

$$\Delta p = -m v_{1x} - m v_{1x}$$

$$\Delta p = -2 m v_{1x}$$

Time taken during the complete trip can be find out as

$$S = Vt$$

Here

S=2L
V=v_x
t=Δt

$$2L = v_{1x} \Delta t$$

$$\Delta t = \frac{2L}{v_{1x}}$$

Force responsible for the change in momentum can be written as

$$F = \frac{\Delta p}{\Delta t}$$

$$F_x = \frac{-2mv_{1x}}{2L/v_{1x}}$$

$$F_x = -m\frac{v_{1x}^2}{L}$$

This is the force exerted by the wall on the molecule. According to the third law of motion, the force exerted by the molecule on the wall is equal and opposite.

$$F_x = m\frac{v_{1x}^2}{L}$$

Similarly, the forces due to "N" molecules can be written as

$$F_x = \frac{m}{L}(v_{1x}^2 + v_{2x}^2 + v_{3x}^2 + \cdots + v_{Nx}^2)$$

Since pressure is defined as force per unit area

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

$$P_x = \frac{m}{L}(v_{1x}^2 + v_{2x}^2 + v_{3x}^2 + \cdots + v_{Nx}^2) \times \frac{1}{L^2}$$

$$P_x = \frac{m}{L^3}(v_{1x}^2 + v_{2x}^2 + v_{3x}^2 + \cdots + v_{Nx}^2)$$

Multiply by N/N

$$P_x = N\frac{m}{L^3}\frac{(v_{1x}^2 + v_{2x}^2 + v_{3x}^2 + \cdots + v_{Nx}^2)}{N}$$

Now since Nm is equal mass of the gas enclose and L^3 is the volume of container hence density of the gas "***ρ"** can be written as:*

$$\rho = \frac{Nm}{L^3}$$

Similarly, square mean of the velocities can be written as

$$\overline{V_x^2} = \frac{(v_{1x}^2 + v_{2x}^2 + v_{3x}^2 + \cdots + v_{Nx}^2)}{N}$$

Now pressure can be written as

$$P_x = \rho \overline{V_x^2}$$

Using pascal principle $P_x = P_y = P_z = P$

$$P = \rho \overline{V_x^2} \text{------------------------------- (1)}$$

For molecule having all three components of velocity

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

For $\overline{v_x^2} = \overline{v_y^2} = \overline{v_z^2}$

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

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

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

Putting in equation (1) we get

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

Above equation is called Pressure equation or an ideal gas.

Kinetic Energy of Molecules of an Ideal Gas:

Consider the pressure equation for ideal gas

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

Since

$$\rho = \frac{Nm}{V}$$

$$P = \frac{1}{3}\frac{Nm}{V}\overline{v^2}$$

$$PV = \frac{1}{3}Nm\overline{v^2}$$

Using General Gas law **PV=nRT**

$$nRT = \frac{1}{3}\,Nm\overline{v^2} ----(1)$$

Number of moles can be expressed in terms of number of molecules (N) and Avogadro number (N_A) as:

$$n = \frac{N}{N_A}$$

Equation (1) becomes

$$\frac{N}{N_A}RT = \frac{1}{3}Nm\overline{v^2}$$

$$\frac{R}{N_A}T = \frac{1}{3}m\overline{v^2} - - - - (2)$$

Here

$$\frac{R}{N_A} = K_B$$

Where K_B is called Boltzmann Constant

Equation (2) becomes

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

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

Dividing both sides with 2 we get

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

Since $K.E = \frac{1}{2}mv^2$

$$\boxed{\boldsymbol{K.E = \frac{3}{2}K_BT}}$$

Above equation represent the kinetic energy of molecules of an ideal gas. From above equation it is clear that Kinetic energy of molecule is dependent only on temperature of the gas.
Hence

$$\boldsymbol{K.E \propto T}$$

Derivation of Gas Laws from Pressure equation:

Boyles Law:

Consider the pressure equation for ideal gas

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

Since

$$\rho = \frac{Nm}{V}$$

$$P = \frac{1}{3}\frac{Nm}{V}\overline{v^2}$$

$$PV = \frac{1}{3}Nm\overline{v^2} - - - - - (1)$$

Now from relation for kinetic energy of molecule of an ideal gas

$$K.E = \frac{3}{2}K_BT$$

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

Separating velocity

$$\overline{v^2} = \frac{3K_BT}{m}$$

Putting above in equation (1) we get

$$PV = \frac{1}{3}Nm\frac{3K_BT}{m}$$

$$PV = (NK_BT)$$

Hence

$$PV = constant$$

Or

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

Hence volume of an ideal gas is found to be inversely proportional to its pressure keeping other factors constant which is according to Boyles Law.

Charles Law:

Consider the pressure equation for ideal gas

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

Since

$$\rho = \frac{Nm}{V}$$

$$P = \frac{1}{3}\frac{Nm}{V}\overline{v^2}$$

$$V = \frac{1}{3P}N\,m\overline{v^2} - - - - - (1)$$

Now

$$K.E = \frac{3}{2}K_BT$$

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

Separating velocity

$$\overline{v^2} = \frac{3K_BT}{m}$$

Putting above in equation (1)

$$V = \frac{1}{3P}Nm\frac{3K_BT}{m}$$

$$V = \left(\frac{NK_B}{P}\right)T$$

Hence

$$V = (constant)T$$

Or

$$\boldsymbol{V \propto T}$$

Hence volume of an ideal gas is found to be directly proportional to the absolute temperature which is according to Charles Law.

Root Mean Square Velocity of Molecule of an Ideal Gas(v_{rms}):

Consider the relation for kinetic energy of an ideal gas

$$K.E = \frac{3}{2}K_BT$$

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

Separating velocity

$$\overline{v^2} = \frac{3K_BT}{m}$$

Taking Squaring on both side

$$\boldsymbol{v_{rms} = \sqrt{\frac{3K_BT}{m}}}$$

Heat Capacity:

Amount of heat required to raise the temperature of a body by ***1K***is called Heat capacity of the body.

Mathematically heat capacity (***C***) can be expressed as

$$\boldsymbol{C = \frac{\Delta Q}{\Delta T}}$$

Specific Heat Capacity:

Amount of heat required to raise the temperature of ***1 Kg*** of a material by ***1K***is called Specific Heat Capacity.

Mathematically Specific heat capacity (***c***) can be expressed as

$$\boldsymbol{c = \frac{\Delta Q}{m\Delta T}}$$

The unit of specific heat capacity is Joules per Kilogram per Degree Kelvin $\boldsymbol{J.Kg^{-1}K^{-1}}$

Molar Specific Heat:

Amount of heat required to raise the temperature of ***1 mole*** of substance by ***1K***is called Molar Specific Heat.

Mathematically:

Consider relation for specific Heat of a substance

$$c = \frac{\Delta Q}{m\Delta T} - - - - - - -(1)$$

Number of moles (n) can be defined as the ratio of mass of the substance (m) and its molecular mass (M);

$$n = \frac{m}{M}$$

$$m = nM$$

Putting in equation (1) we get

$$c = \frac{\Delta Q}{nM\Delta T}$$

$$(M)(c) = \frac{\Delta Q}{n\Delta T}$$

$$\boldsymbol{M_C = \frac{\Delta Q}{n\Delta T}}$$

Here M_C is called molar specific heat of the substance and its unit is $\boldsymbol{J.mol^{-1}K^{-1}}$.

DETERMINATION OF SPECIFIC HEAT CAPACITY:

Heat capacity of the material can be determined by method of mixture.

PRINCIPLE:

"Heat loss by hot bodies is equivalent to heat gain by cold bodies."

METHOD:

In this method, hot substance is mixed with cold substance because of which hot body will lose heat, which is gain, by cold body, which result in rise in temperature of cold body. The specific heat capacity of unknown material can be determined by using liquid & calorimeter of known masses, specific heat & temperature using following relation.

$$c_b = \frac{(m_w c_w + m_c c_c)(T_f - T_i)}{(T_b - T_f)m_b}$$

Where,

- C_b is the specific heat capacity of material of bob (unknown).
- m_b is mass of bob.
- C_c is the specific heat capacity of material of Calorimeter.
- m_c is mass of calorimeter.
- C_w is the specific heat capacity of water.
- m_w is mass of water.
- T_i is the initial temperature of water.
- T_f is the final temperature of water after placing heated bob.
- T_b is the temperature of heated bob.

Molar specific heats of an ideal gas:

Molar specific heat of an ideal gas be defined in two ways
I-e

1. At Constant Volume.
2. At Constant Pressure.

Molar Specific Heat at Constant Volume:

Amount of heat required to raise the temperature of a gas by 1K in such a way that gas is not allowed to expand (At constant volume) is called *Molar Specific Heat at Constant Volume* and it is represented by $\mathbf{C_V}$.

Molar Specific Heat at Constant Pressure:

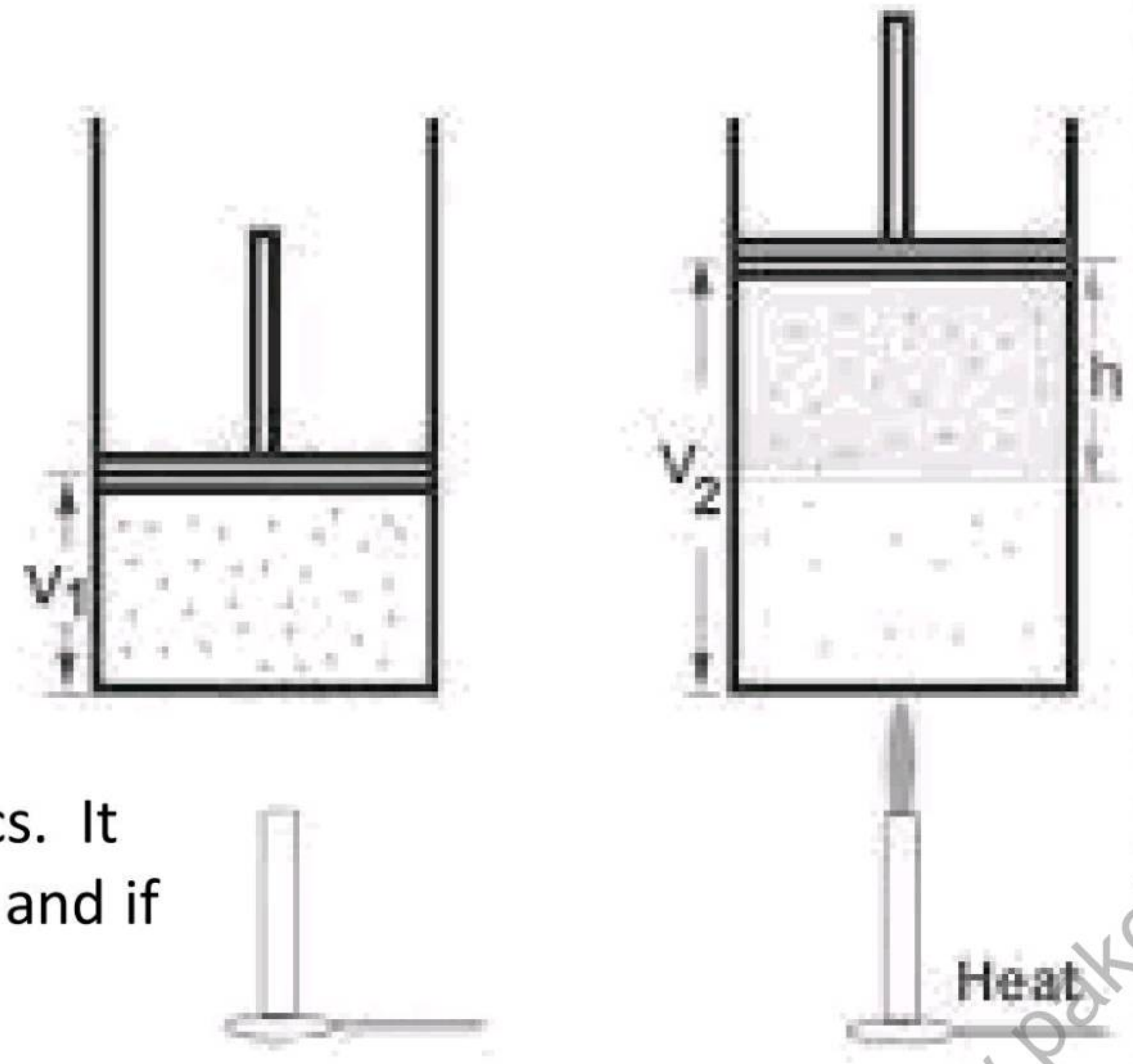
Amount of heat required to raise the temperature of a gas by 1K in such a way that gas is allowed to expand (At constant pressure) is called *Molar Specific Heat at Constant pressure* and it is represented by $\mathbf{C_P}$.

Thermodynamics:

"The Branch of thermal physics which deals with the study of interconversion Heat energy and other form of energies is called Thermodynamics."

Work Done in Thermodynamics:

Consider a thermodynamic system such as a gas in a cylinder fitted with a movable piston. When the gas is heated the gas in container is allowed to expand and results in increase in height of the piston (h) (due to increase in volume) to Work done by the system can be written as



$$\Delta W = F.d \, --(1)$$

Since

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

Or $$F = PA$$

Equation (1) becomes

$$\Delta W = PAh$$

Since $Ah = \Delta V$(change in volume)

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

Above equation, represent work done in thermodynamics. It shows that if volume is increased, the work will be positive and if volume is decreased, the work will be negative.

First Law of Thermodynamics:

Statement:

"The net heat flow into the system is equal to the sum of total work done and change in internal energy."

Mathematical Expression:

Let ΔQ is the amount of heat energy absorbed or extract out from the system and due to that work is done represented by $\Delta W$and internal energy is changed by amount ΔU. Then accordingto; first law of thermodynamics:

$$\boldsymbol{\Delta Q = \Delta U + \Delta W}$$

Sign convention:

- Heat absorbed +ve.
- Heat ejected or lost –ve.
- Work done by the system +ve.
- Work done on the system –ve.
- Final internal energy is greater change in internal energy will be +ve.
- Final internal energy is lesser change in internal energy will be -ve.

Application of First Law of Thermodynamics:

Using first Law of thermodynamics 4 thermodynamic processes can be define

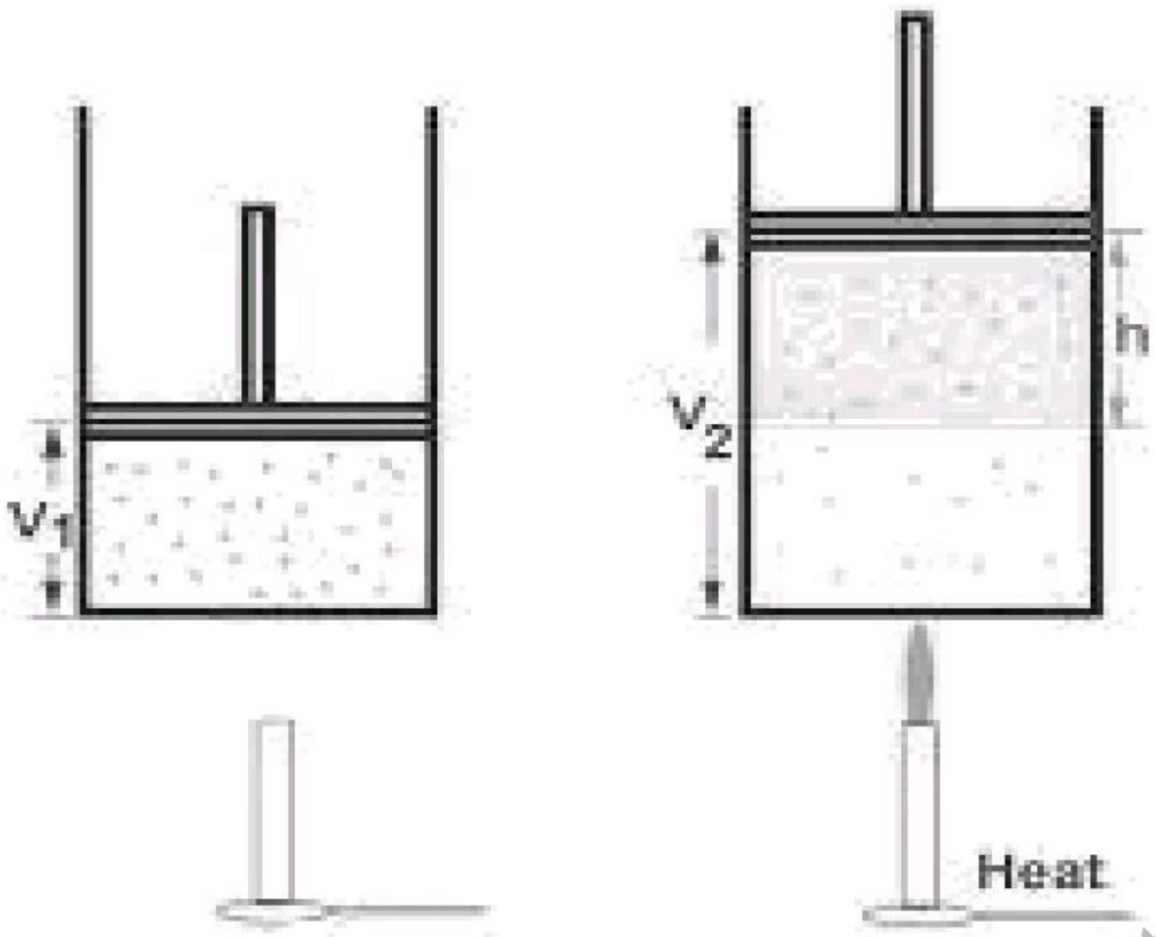
- Isobaric process.
- Isochoric process.
- Isothermal process.
- Adiabatic process

Isobaric Process:

Such a thermodynamic process in which pressure of the gas enclosed remain same throughout the process is called Isobaric process.

Explanation:

Consider a thermodynamic system such as a gas in a cylinder fitted with a movable piston. When the gas is heated the gas in container is allowed to expand and results in increase in height of the piston (h) (due to increase in volume) to Work done by the system can be written as



$$\Delta W = F.d --(1)$$

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

Or

$$F = PA$$

Equation (1) becomes

$\Delta W = PAh$

Since $Ah = \Delta V$ (change in volume)

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

Now according to first law of thermodynamics

$$\Delta \boldsymbol{Q} = \Delta \boldsymbol{U} + \Delta \boldsymbol{W}$$

Putting value of Work in above equation we get

$$\boxed{\Delta \boldsymbol{Q} = \Delta \boldsymbol{U} + \boldsymbol{P}\Delta \boldsymbol{V}}$$

Above equation represent Isobaric process. So, in isobaric process heat supplied to the system is used partially to change the internal energy and partially to do work.

Graph of Isobaric process:

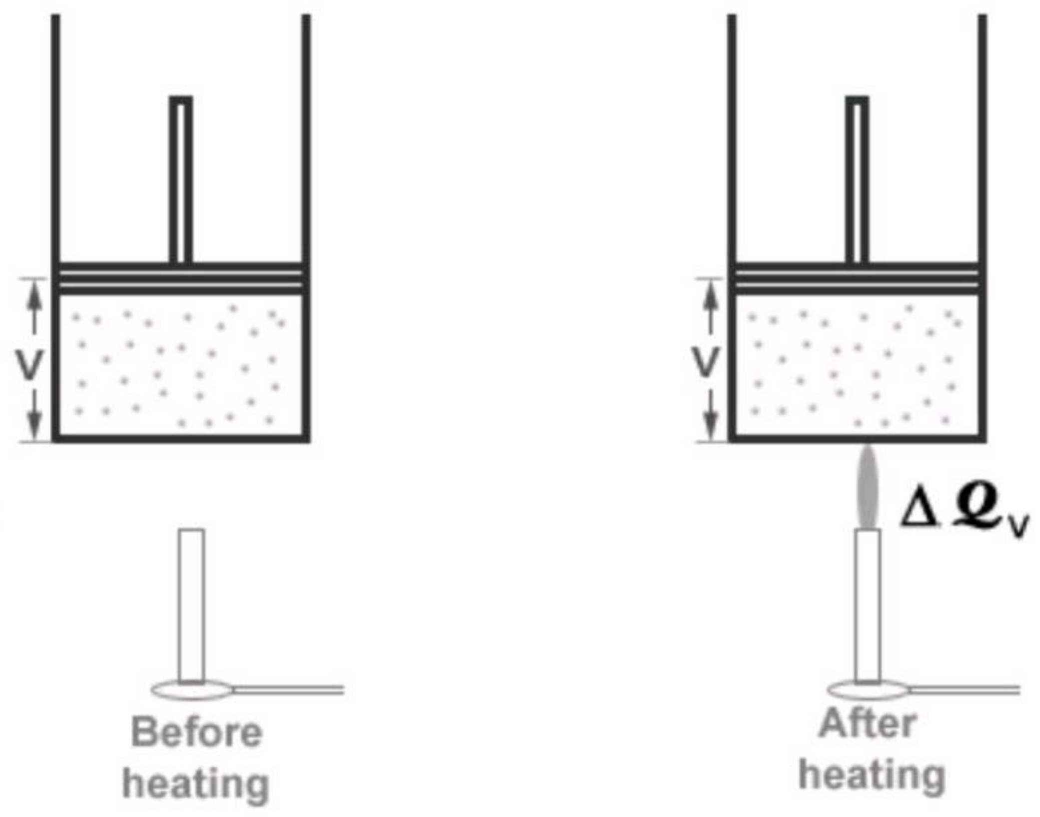
Graph of an isobaric process is a straight line parallel to x-axis.

Isochoric Process:

Such a thermodynamic process in which the Volume the gas enclosed remains same throughout the process is called isochoric process.

Explanation:

Consider a thermodynamic system such as a gas in a cylinder fitted with a fixed piston. Hence when the gas is heated it is not allowed to expand and no work is done.



Now according to first law of thermodynamics

$$\Delta \boldsymbol{Q} = \Delta \boldsymbol{U} + \Delta \boldsymbol{W}$$

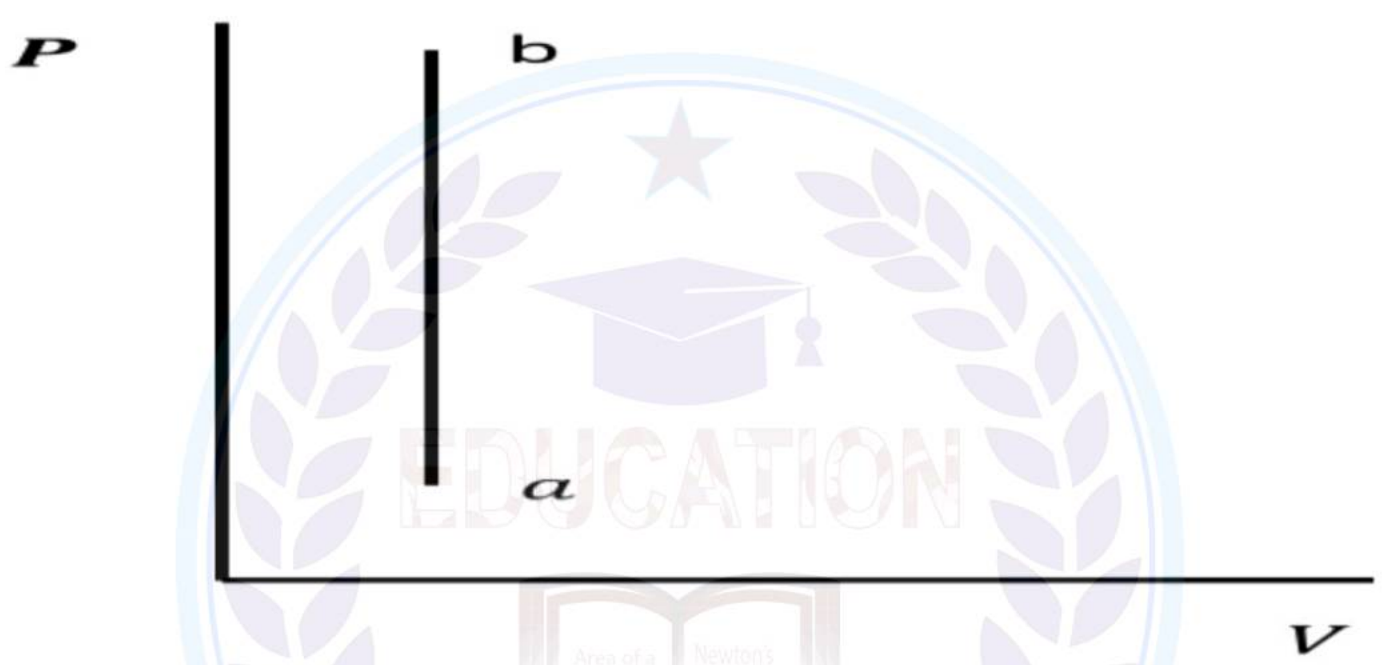
Since work done is zero. Hence,

$$\boxed{\Delta \boldsymbol{Q} = \Delta \boldsymbol{U}}$$

Above equation represent Isochoric process. So, in isochoric process heat supplied to the system is used completely to change the internal energy.

Graph of Isochoric process:

Graph of an isobaric process is a straight line parallel to y-axis.

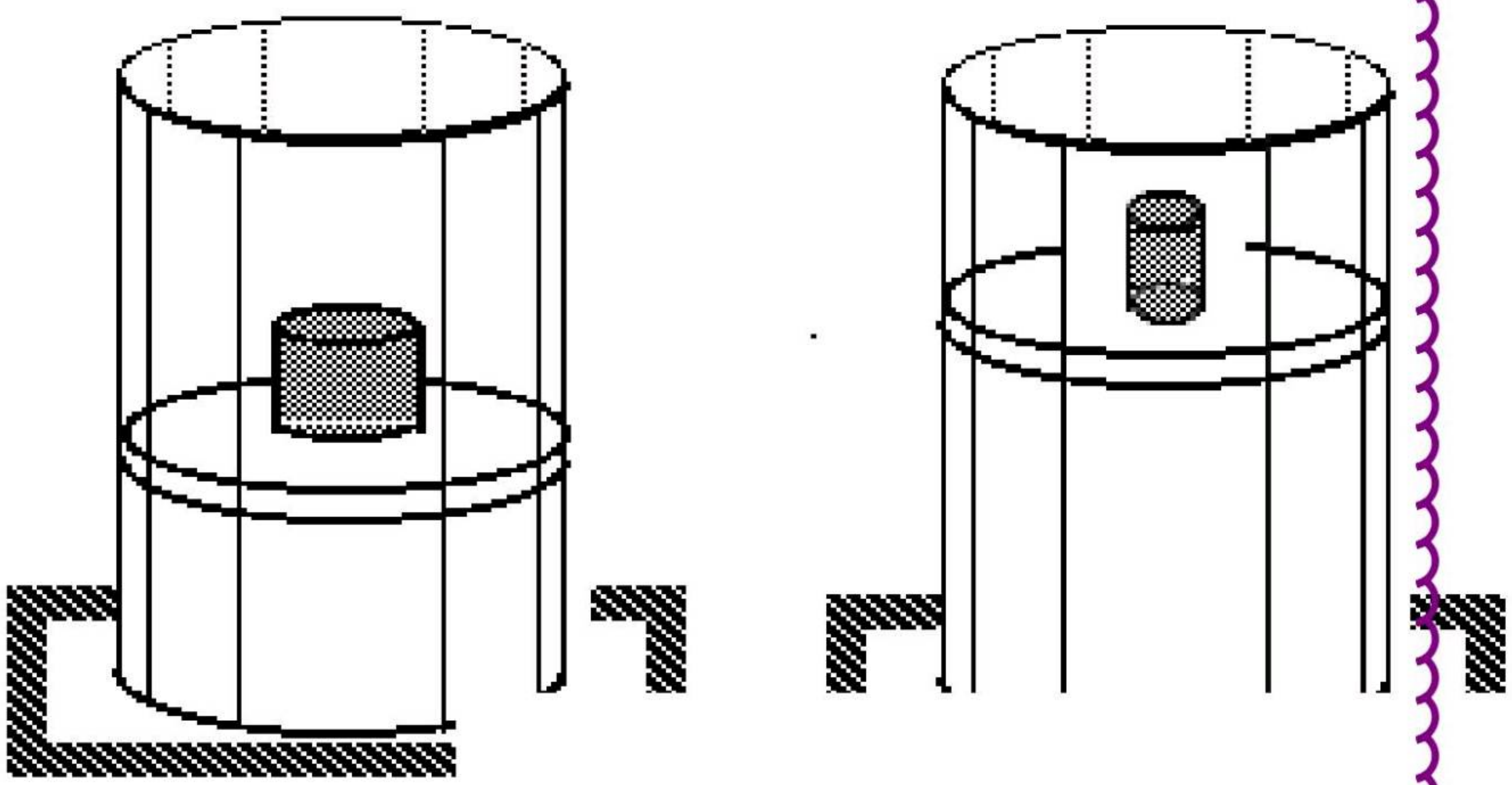


Isothermal Process:

Such a thermodynamic process in which the temperature of the gas enclosed remains same throughout the process is called isothermal process.

Explanation:

Consider a thermodynamic system, have some weights placed on it to provide the required external pressure, the base of the system is perfectly heat conducting and walls are perfectly none conducting. If the weights on the piston are decreased the external pressure become less than the internal pressure and gas expands and temperature start to decrease but since the base is perfectly conducting it will absorb



more heat energy and temperature will remain same (or remains at a constant value).
Now according to first law of thermodynamics

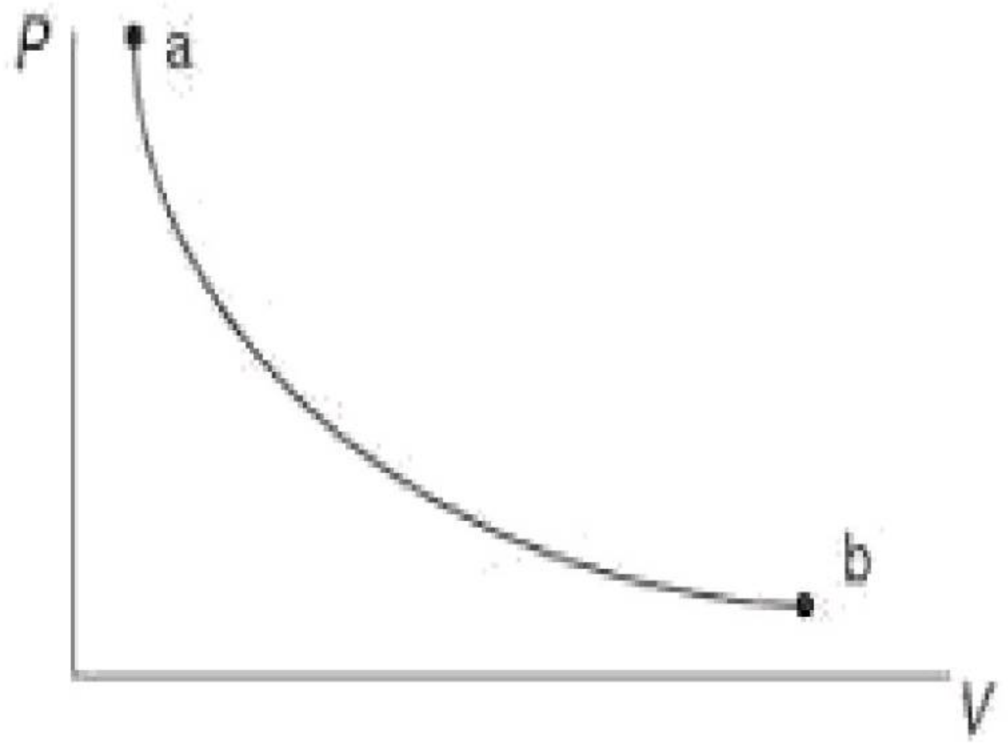
$$\Delta Q = \Delta U + \Delta W$$

Since temperature remains constant, therefore, there will be no change in internal energy. Hence, above equation will become

$$\boxed{\Delta Q = \Delta W}$$

Hence for an isothermal process all the heat energy absorbed is utilized in doing work with no change in internal energy.

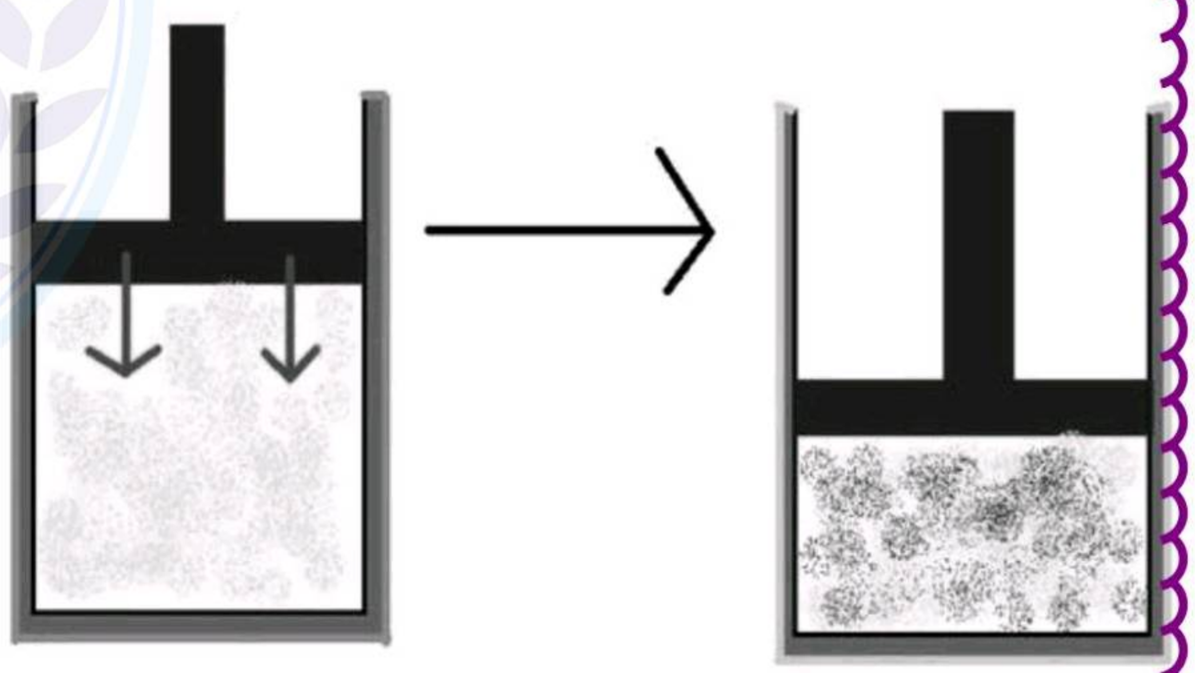
Graph of Isothermal process:
Graph of an isobaric process is a Hyperbola.



Adiabatic Process:

Such a thermodynamic process in which no heat flows in or out of the system is called adiabatic process.

Explanation:
Consider a thermodynamic system such as a gas in a cylinder fitted with a movable piston. The walls and base of the container are perfectly insulated from its surrounding and no heat flow in or out of the system.
If the piston is pressed and the gas is allowed to compress than the internal energy of the gas is increased but no heat will flow in or out of the system.



Now according to first law of thermodynamics

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

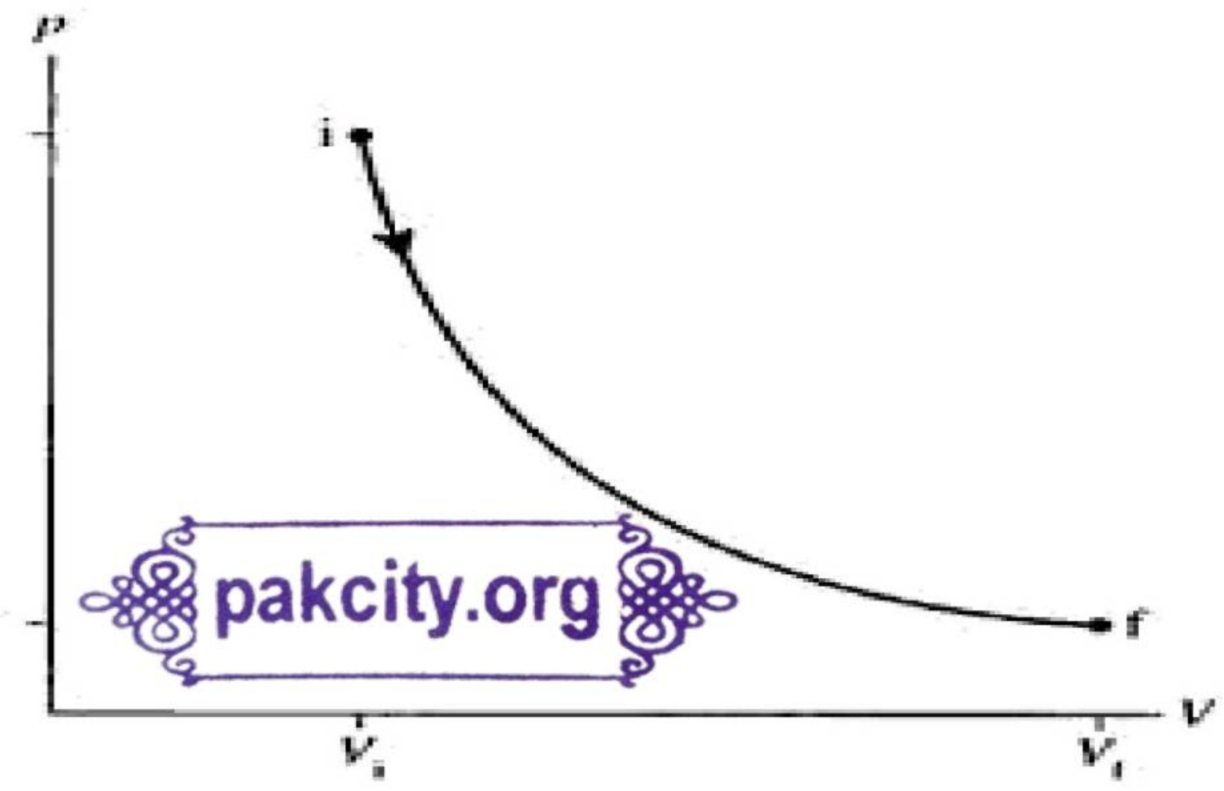
Since no Heat in flown

$$\boxed{\Delta U = -\Delta W}$$

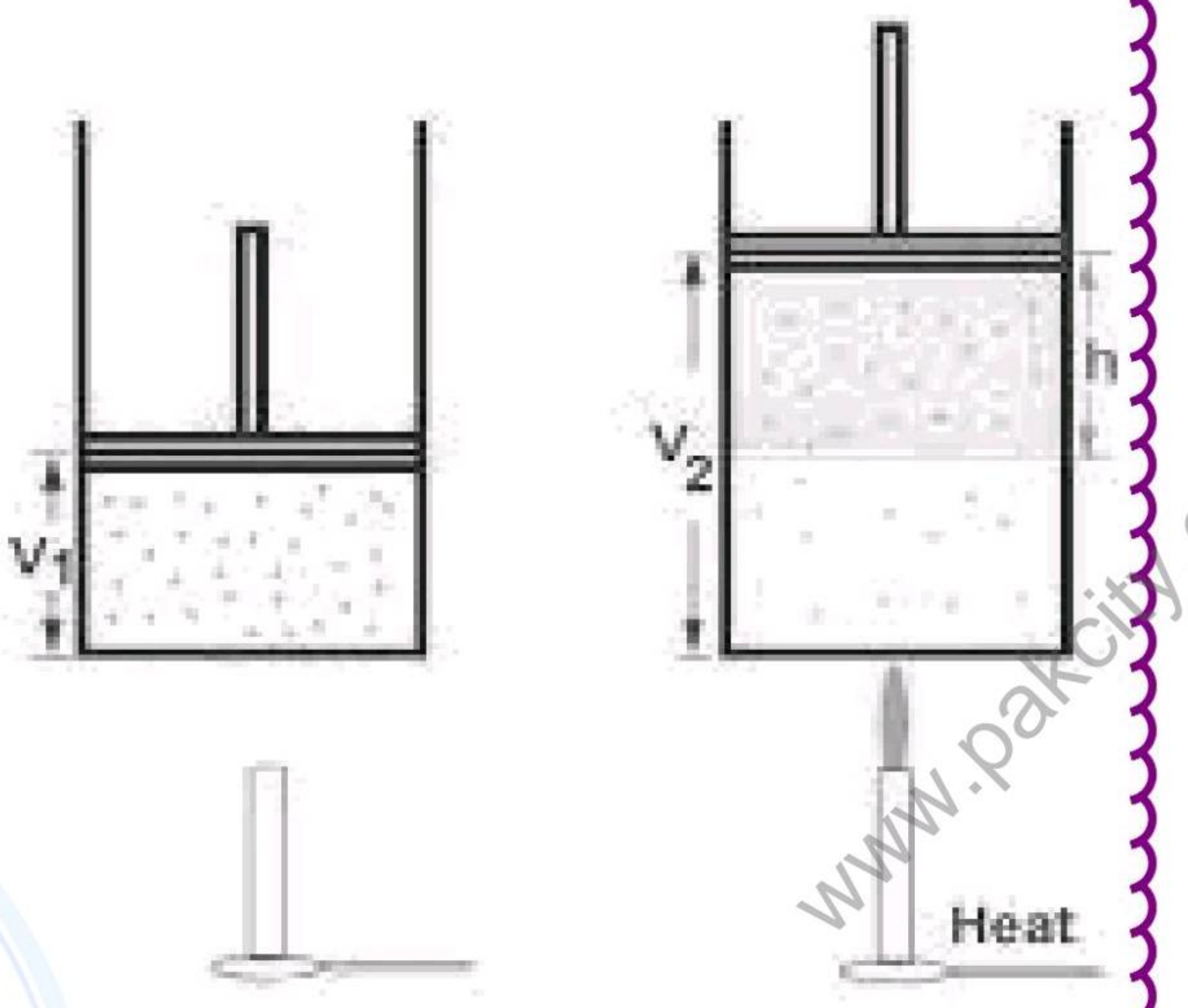
So, in Adiabatic process no heat is flow or out of the system and Change in internal energy is Equal to the negative of the Work done.

Graph of Adiabatic process:

Graph of an adiabatic process is a Hyperbola.



Relation between Specific Heat at Constant Pressure and Specific Heat at Constant Volume:



Consider a gas in a container if we heat the gas so that gas is allowed to expand and pressure of the gas remain constant all the heat energy will be used to increase the internal energy of the gas and to do work than according to first law of thermodynamics.

$$\Delta \boldsymbol{Q} = \Delta \boldsymbol{U} + \Delta \boldsymbol{W}$$

Since

Above equation will become

$$\Delta Q_P = \Delta U + P\Delta V ------(1)$$

Using general gas law

$$PV = nRT$$

Hence

$$P\Delta V = nR\Delta T$$

Putting in Equation (1) we get

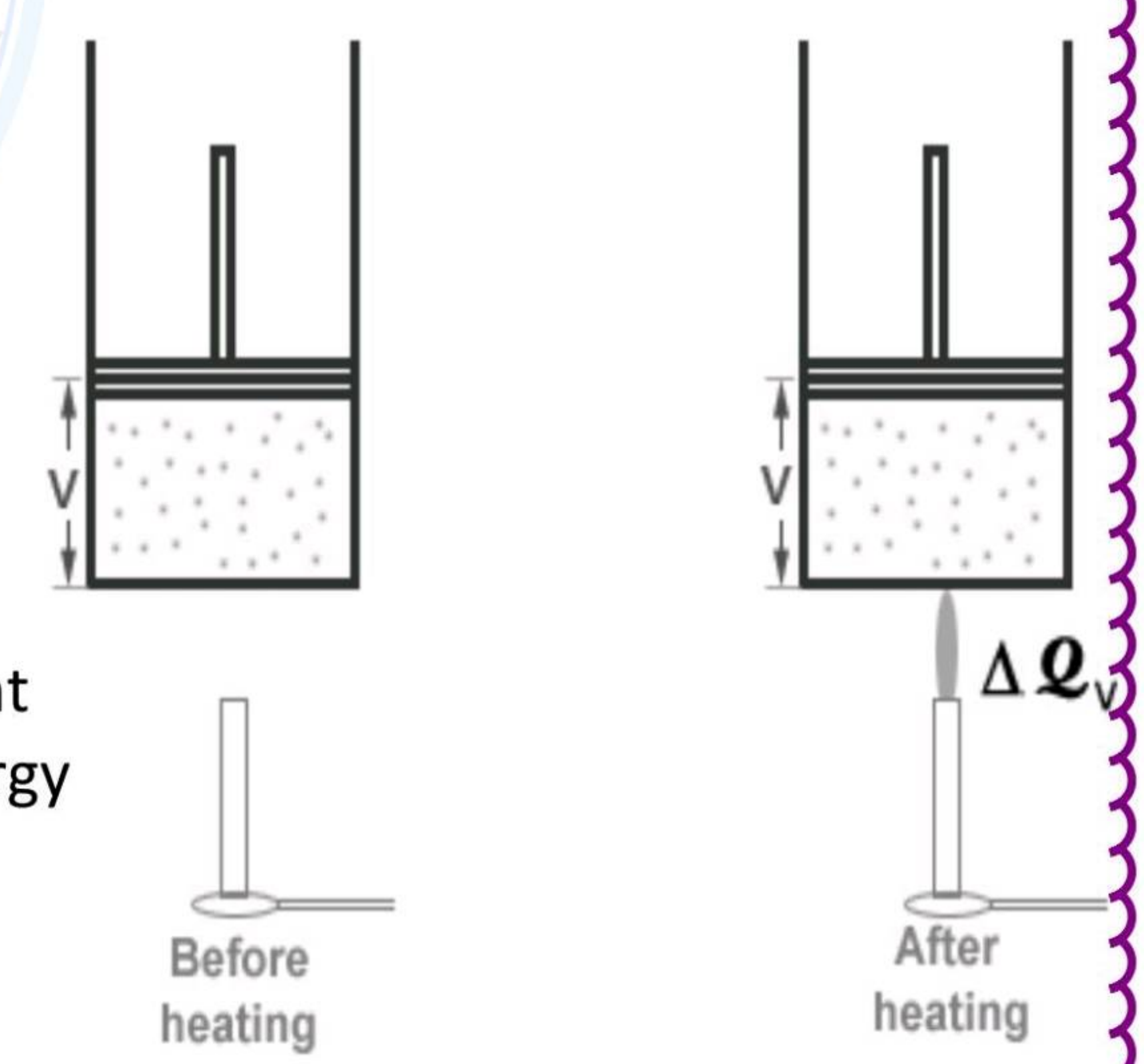
$$\Delta Q_P = \Delta U + nR\Delta T$$

Since

$$\Delta Q_P = nc_P\Delta T$$

Above equation will become

$$nc_P\Delta T = \Delta U + nR\Delta T \text{-- (a)}$$



Consider a gas in a container if we heat the gas so that gas is not allowed to expand so that volume of the gas remain constant and all the heat energy will be used to increase the internal energy of the gas than according to first law of thermodynamics.

$$\Delta \boldsymbol{Q} = \Delta \boldsymbol{U} + \Delta \boldsymbol{W}$$

Since work done is Zero

$$\Delta \boldsymbol{Q}_v = \Delta \boldsymbol{U}$$

Since

$$\Delta Q_v = nc_v\Delta T$$

Above equation will become

$$\Delta U = nc_v\Delta T \text{-------- (b)}$$

Putting equation (a) in equation (b) we get

$$nc_P\Delta T = nc_v\Delta T + nR\Delta T$$

Or

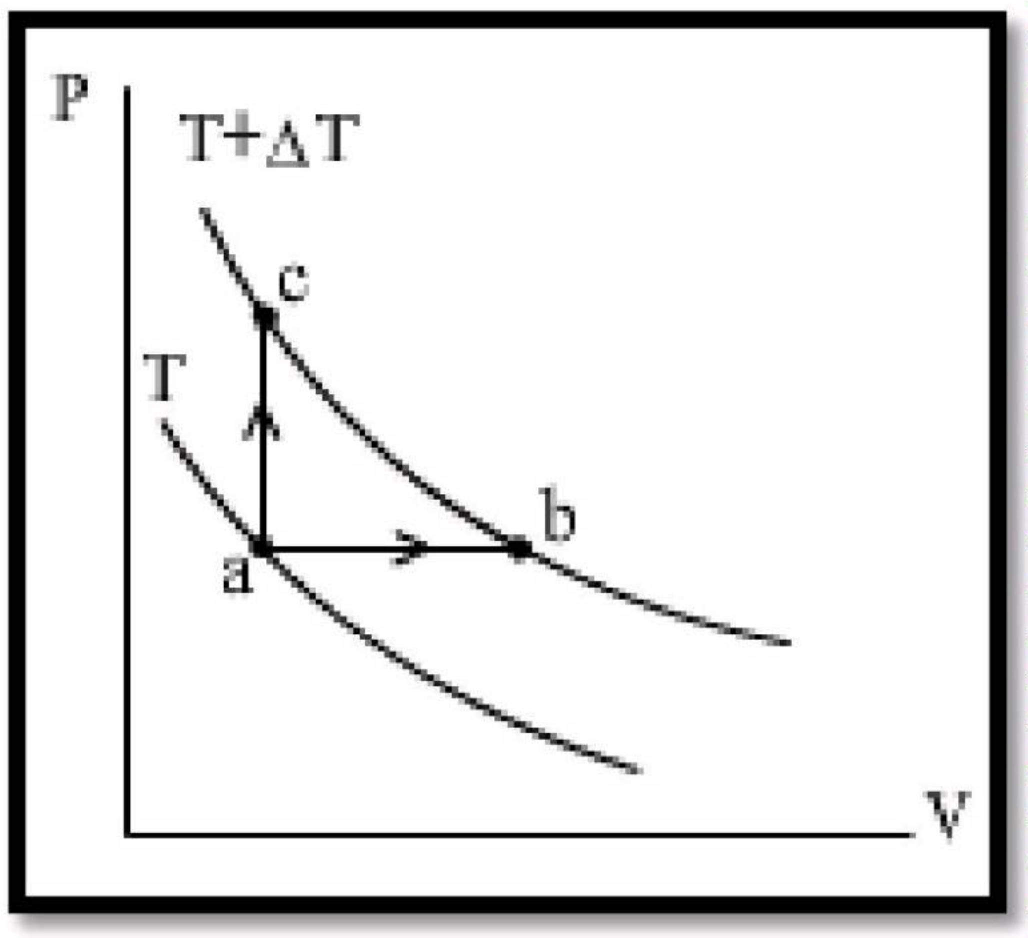
$$nc_P\Delta T = n\Delta T(c_v + R)$$

Or

$$c_P = c_v + R$$

Or

$$\boxed{c_P - c_v = R}$$



Hence the difference of Specific Heat at Constant Pressure and Specific Heat at Constant Volume is equal to the general gas constant. Above equation also shows that the specific heat capacity of any ideal gas at constant pressure is always greater that specific heat capacity of the same gas at constant volume. I-e

$$\boxed{c_p > c_v}$$

Heat Engine:

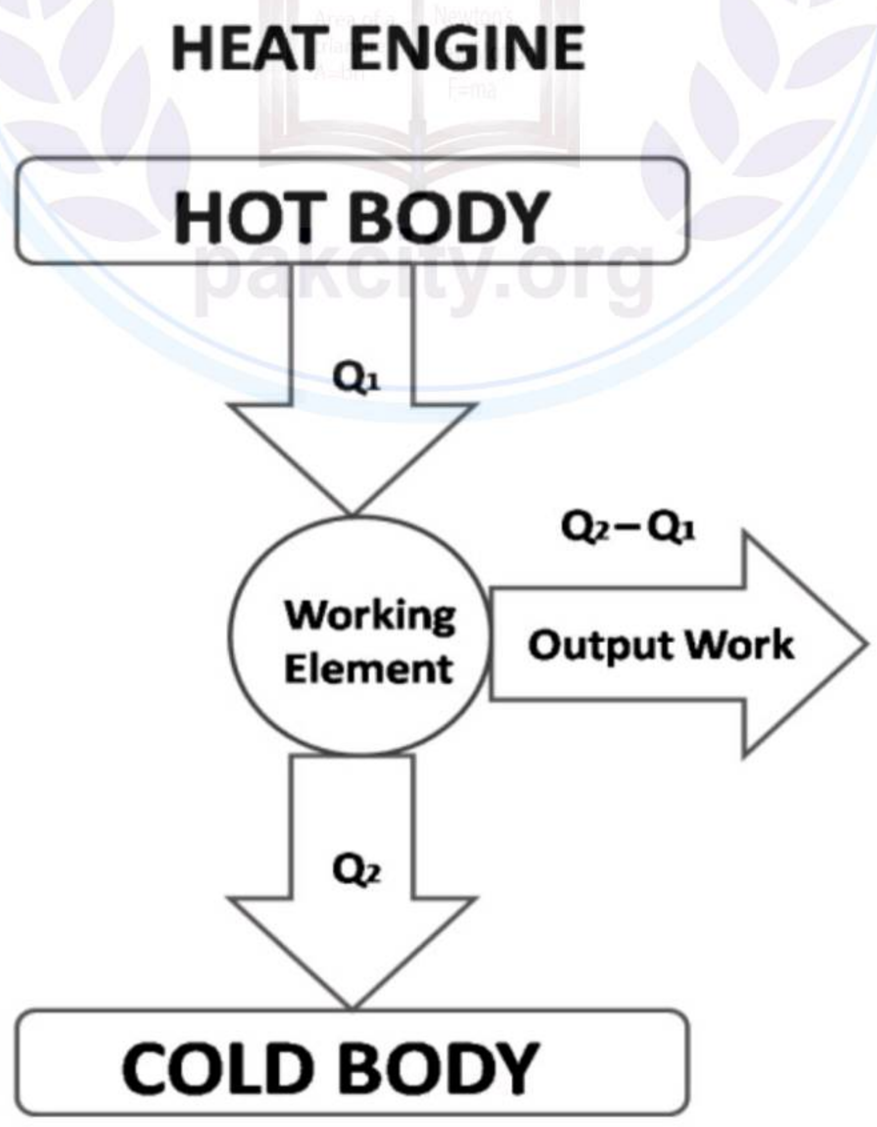
The device, that convert heat energy into mechanical energy is called Heat engine.

Essentials of Heat Engine:

Essential of heat engines are:

- Furnace or hot body.
- Working substance.
- Condenser or Cold body.

Heat flow Diagram of Heat Engine:



Refrigerator:

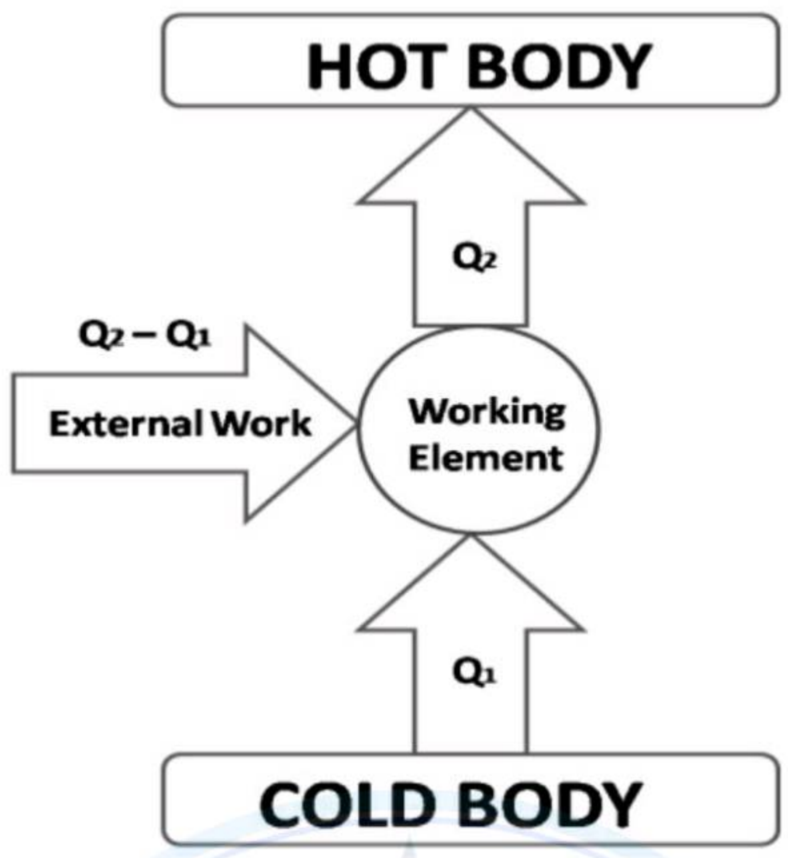
The device that makes heat to flow from cold body to hot body is called Refrigerator.

Essential of Refrigerator:

- Condenser or cold body.
- Working substance.
- Furnace or hot body.

Heat flow Diagram of Refrigerator:

REFRIGERATOR



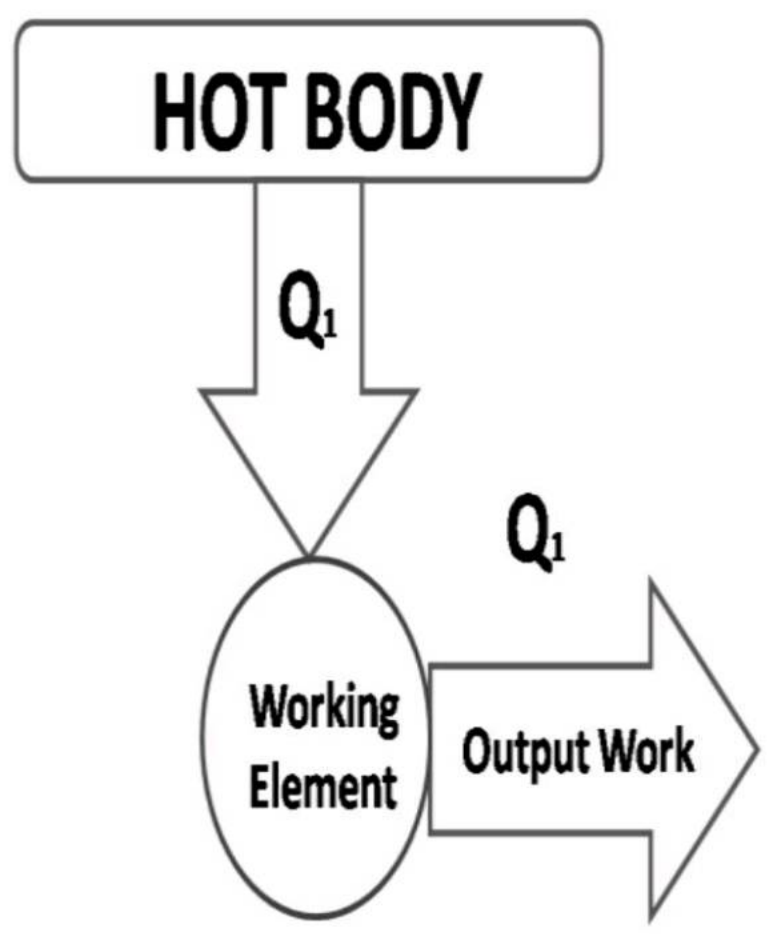
The Second Law of Thermodynamics:

Two statements can state the Second law of thermodynamics.

Kelvin Statement:

"We cannot construct a heat engine which does nothing but convert heat energy into mechanical energy."

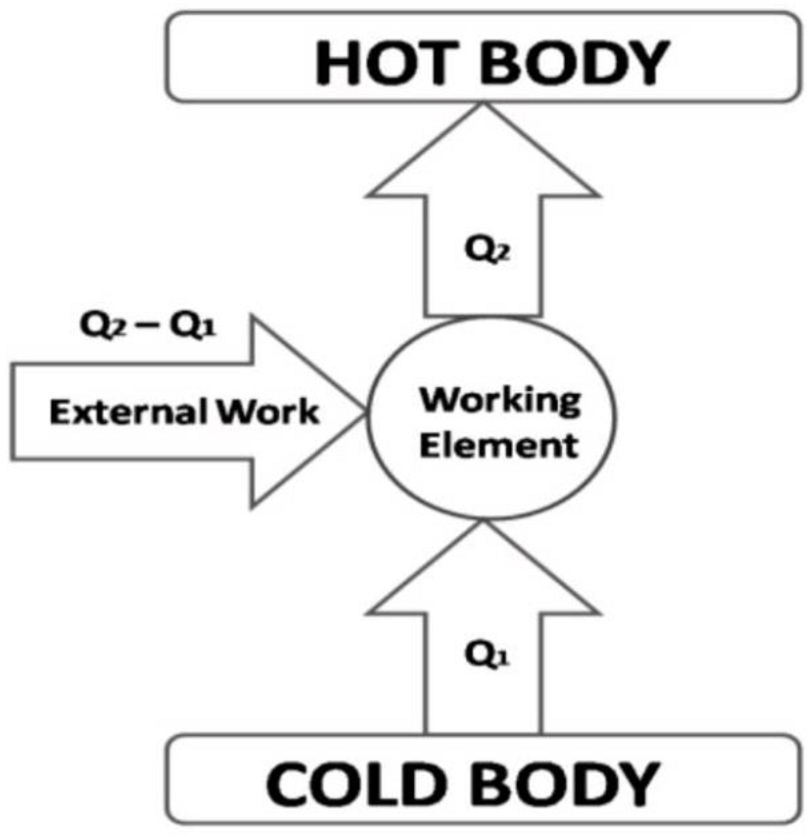
IDEAL HEAT ENGINE



***Clausius Statement*:**

"We cannot make heat to flow from cold body to hot body without expenditure of external work."

REFRIGERATOR



Equivalency of Kelvin and Clausius Statements:

In order to prove the equivalency of Kelvin and Clausius statements let us suppose that the Kelvin stamen is wrong. I-e

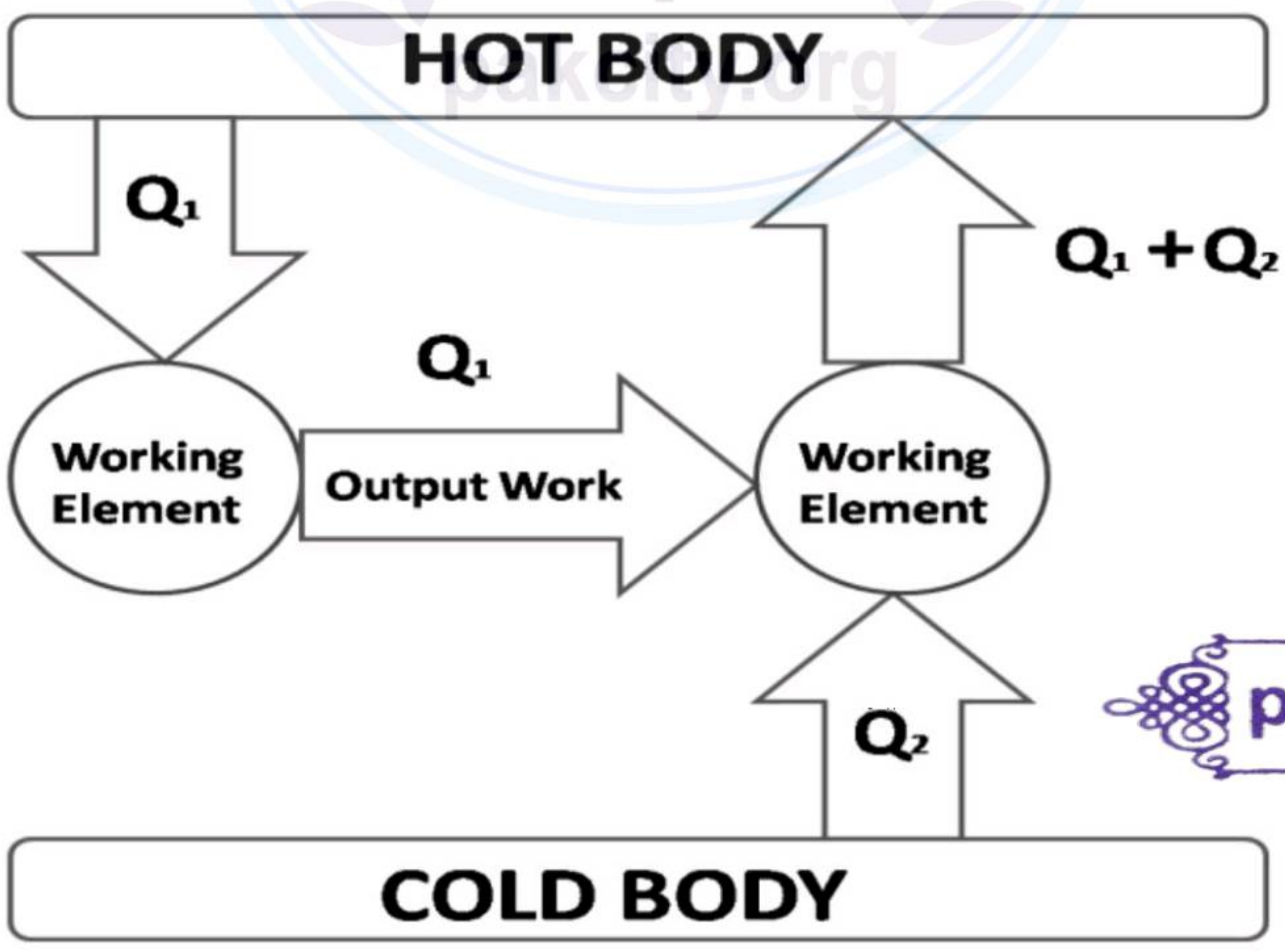
"We can construct a heat engine that can convert Heat energy completely into mechanical energy"

Now consider a refrigerator that makes heat to flow from cold body to hot body but some external work is required for that refrigerator to work.

If we connect the perfect heat engine with the refrigerator that we can use the work output buy the ideal heat engine to run refrigerator. And so, we have a refrigerator that make heat to flow form cold body to hot body without expenditure of work which is false according to Clausius statement.

So, we conclude that if one Statement is wrong other automatically become wrong.

Hence, both Kelvin and Clausius statements are equivalent.



Carnot Engine:

Introduction:

Carnot engine is an ideal heat engine which converts heat energy into mechanical energy. It is an imaginary heat engine free from friction & heat losses due to radiations or conduction.

Construction:

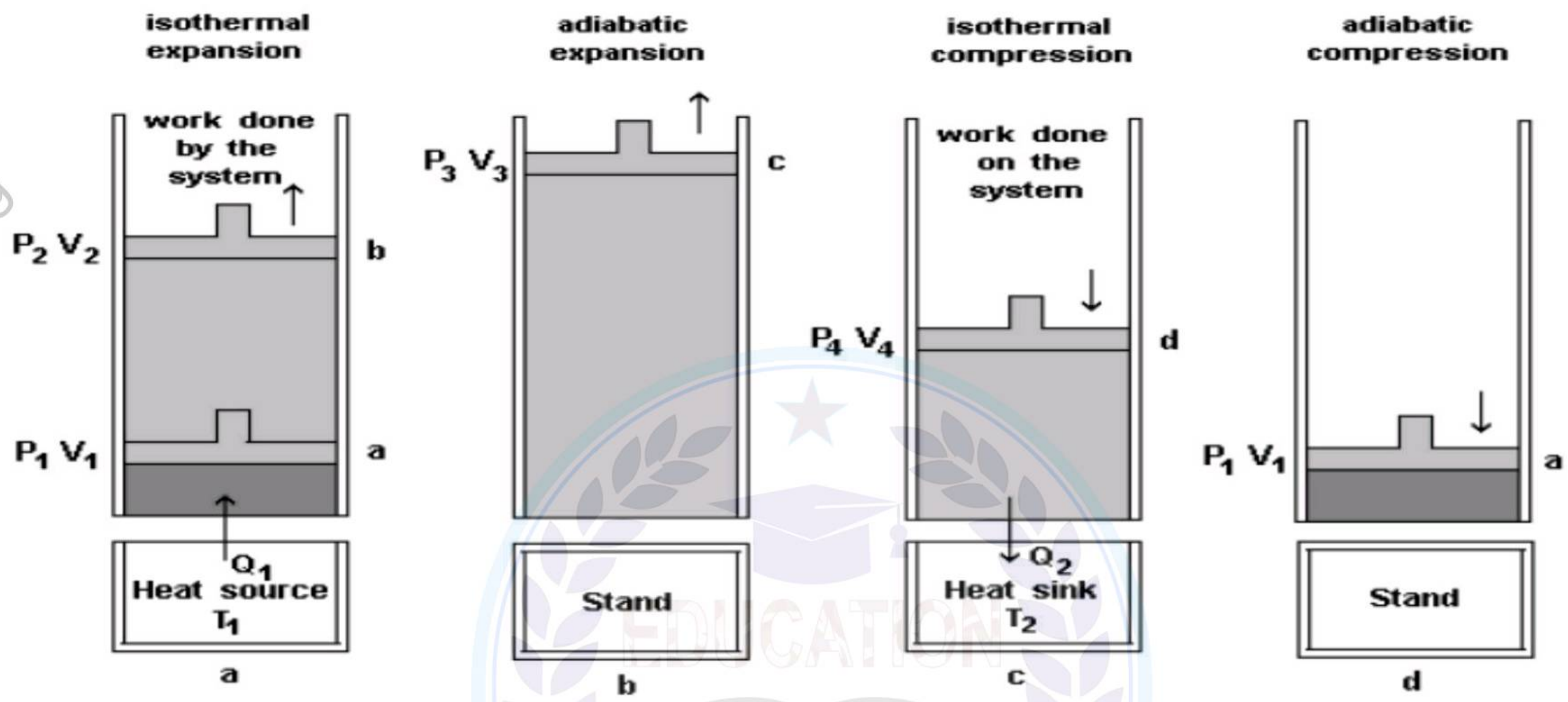
It consists of an ideal gas cylinder having conducting base, non-conducting walls and non-conducting movable frictionless piston.

Carnot Cycle:

A Carnot engine converts heat energy into mechanical energy using a cyclic process consisting of two isothermal and two adiabatic reversible processes called Carnot Cycle.

Working:

Working of Carnot engine consist of steps as follows



Step#1: (Isothermal Expansion).

Gas in cylinder is initially at pressure P_1, volume V_1 and temperature T_1. The cylinder is than placed at a heat reservoir and absorbs heat energy(Q_1)and gas can expand isothermally, and physical variables changes to **P_2, V_2, T_1**.

Step#2: (Adiabatic Expansion).

The cylinder is than placed at an insulator and external work is done and gas can expand adiabatically, and physical variables changes to **P_3, V_3, T_2**.

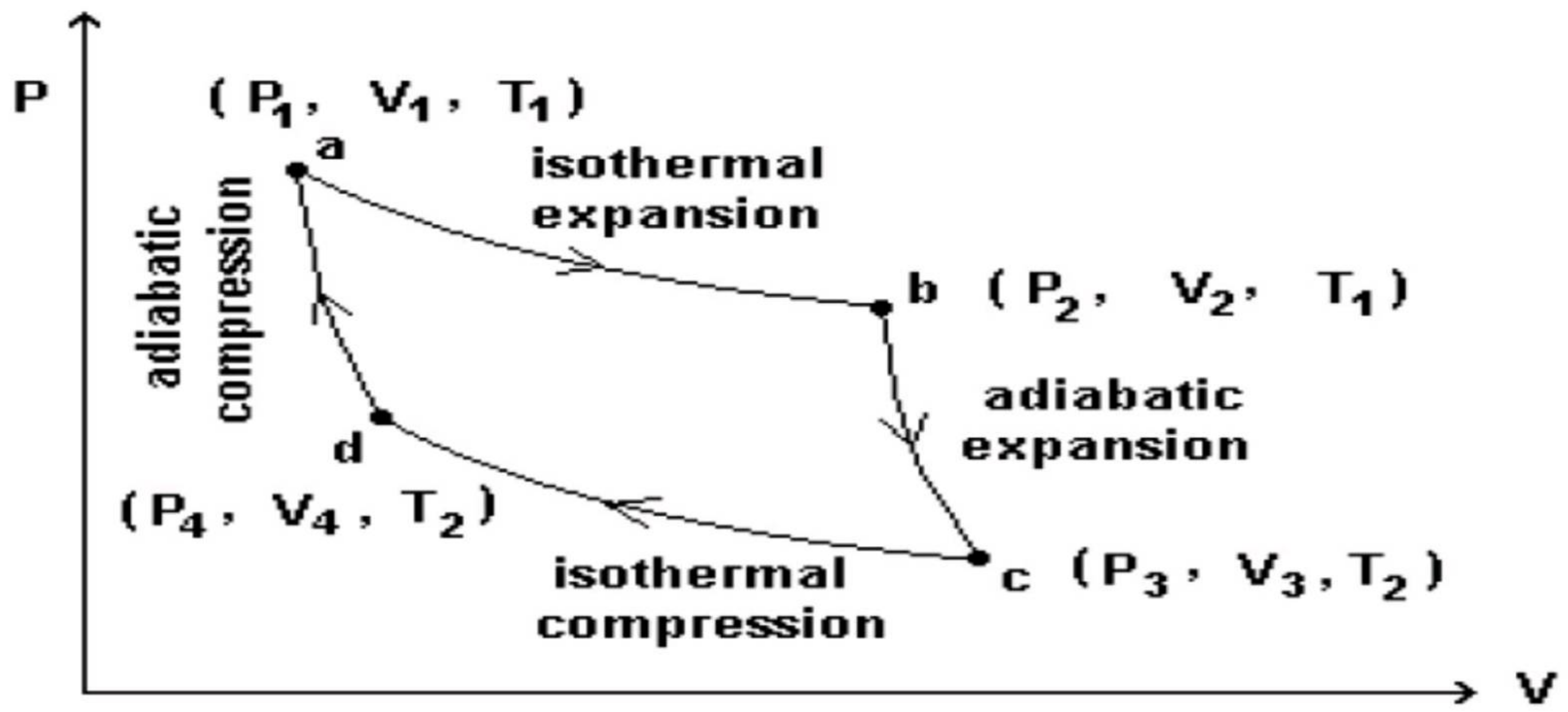
Step#3: (Isothermal Compression).

The cylinder is than placed at a cold reservoir and eject heat energy(Q_2) and gas is allowed to compress isothermally and physical variables changes to **P_4, V_4, T_2**.

Step#4: (Adiabatic Compression).

The cylinder is than placed at an insulator and external work is done and gas can compress adiabatically, and physical variables changes to P_1, V_1, T_1.

Graphical Representation of Carnot Cycle:



Carnot cycle

Efficiency of Carnot Engine:

Since throughout the Carnot Cycle net change in internal energy is zero there for firth law of thermodynamics will be written as

$$\Delta Q = \Delta W$$

$$\Delta Q = Q_1 - Q_2$$

Efficiency of the Carnot engine can be written as

$$\eta = \frac{Output}{Input} \times 100$$

$$\eta = \frac{\Delta W}{Q_1} \times 100$$

$$\eta = \frac{Q_1 - Q_2}{Q_1} \times 100$$

$$\boxed{\eta = \left(1 - \frac{Q_2}{Q_1}\right) \times 100}$$

Since heat supplied by and absorbed by hot and cold reservoir are function of their temperature there for above expression can be written as

$$\boxed{\eta = \left(1 - \frac{T_2}{T_1}\right) \times 100}$$

It is obvious from above expression that efficiency of Carnot engine cannot be 100% because it is possible if and only if the temperature of cold reservoir is 0K which impossible to reach (according to 3rd law of thermodynamics).

Entropy:

The measure of molecular disorder of a system during a process is called Entropy.

Explanation:

Consider ***N*** molecules of gas confine in a container of volume ***V*** if we supply the heat energy to the system then the Volume of the gas increases and arrangement of molecules is disturbed now if we place the container on a cold reservoir the heat is lost by the system and the volume of the gas become ***V*** again but probability of all molecule to be the same position as they are initially is zero. That is why we conclude that

"Entropy of the system during an isothermal process increases or remains constant."

Now Second law of thermodynamics can be stated in terms of entropy as

"**When an isolated system undergoes change entropy of the system Either increases or remains same.**"

If heat is supplied to a system at constant temperature than change in entropy can be written as

$$\Delta S = \frac{\Delta Q}{T}$$

Unit: The S.I unit of entropy is JK^{-1}.

CHAPTER-11 **NUMERICALS from PAST PAPER**

1. A Carnot engine whose low temperature reservoir is 200K has efficiency 50%. It is desired to increase this to 75% by how many degrees must the temperature of low reservoir be decreased if the temperature of high temperature reservoir remains constant.
2. A 200g piece of metal is heated at 150°C and then drop into an aluminum calorimeter of mass 500g containing 500g water initially at 25°C. Find the final equilibrium temperature of the system if the specific heat of metal is 128.1 J/kg.K, aluminum is 907 J/kg.K and water is 4200 J/kg.K.
3. A heat engine performing 400J work in each cycle has an efficiency of 25%. How much Heat is absorbed and rejected in each cycle.

4. A scientist store 22g gas in tank at pressure 1200 atm overnight the tank develops slight leakage and the pressure drops to 950 atm calculate the mass of gas escaped.
5. In an isobaric process 2000J heat energy is supplied to a gas in a cylinder at constant pressure of 1.01×10^5 N/m^2. The piston of area of cross-section $2 \times 10^2 m^2$ moves through 40cm. Calculates increase in internal energy of system.
6. A steel bar is 10m in length is at -2.5°C what will be the change in length when it is heated to 25°C. **($\beta = 3.31 \times 10^{-8}$ K^{-1})**
7. A Carnot engine performs 2000J of work & rejects 4000J of heat to sink. If temperature difference between source and sink is 85°C. Find the temperature of source and sink.
8. Calculate the density of hydrogen gas, considering it to be ideal gas when root mean square velocity of hydrogen molecules is 1850m/s at 0°C and at 1 atm pressure.
9. Heat engine perform work at rate of 500KW. The efficiency of the engine is 30%. Calculate loss of heat per hour.
10. Find the change in volume of brass sphere 0.6m diameter. When it is heated from 30 °C to 100°C. **($\alpha = 19 \times 10^{-6}$ K^{-1})**
11. A Celsius thermometer in laboratory reads the surrounding is 30°C. What is the temperature in Fahrenheit & absolute scale?
12. The brass ring of 20 cm diameter is to mount on a metal rod of 20.02cm diameter at 20°C. To what temperature should ring be heated. **($\alpha = 19 \times 10^{-6}$ K^{-1})**
13. A 100g copper block is heated in boiling water for 10 minutes and then it is dropped into 150g water at 30°C in 200g calorimeter. If the temperature of water is raised to 33.6°C. Determine specific heat of calorimeter. **(C_{copper} = 386J/Kg.K)**
14. The low temperature reservoir of Carnot engine is at -3°C and has an efficiency of 40%. It is desired to increase the efficiency by 50%. By how many degrees should the temperature of hot reservoir be increased?
15. An air storage tank whose volume is 112 L contains 2Kg air at pressure of 15atm. How much air would have to force to enter tank so that pressure becomes 18 atm. assuming no change in temperature.
16. 1200J of heat energy is supplied to the system at constant pressure. The internal energy of system increased by 750J and volume by $4.5m^3$. Find work done against the piston & the pressure on the piston.
17. Find the root mean square velocity of hydrogen molecule at 100°C take the mass of hydrogen molecule 3.32×10^{-27} Kg. and $K = 1.38 \times 10^{-23}$ J/K.
18. A Carnot engine performs 1000J of work & rejects 4000J of heat to sink. If temperature difference between source and sink is 75°C. Find the efficiency & the temperature of source.
19. A cylinder of diameter 1.00cm at 30°C is to be slid into hole in a steel plate. The hole has a diameter 0.99970cm at 30°C. To what temperature must the plate be heated?

20. If 1 mole of monatomic gas is heated at constant pressure from -30°C to 20°C. Find the change in internal energy and the work done during the process.
    (Cv = 12.5J/K.mol & Cp = 20.8 J/K.mol)
21. An ideal heat engine operates in a cycle between temperature 227°C and 127°C. it absorbs 600 joules of heat find work done per cycle and efficiency
22. Find the volume occupied by gram mole of a gas at 10 °C and 1 atm pressure.
23. A glass is filled to mark 60 $cm^3$with Hg at 20°C. If flask contents are heated to 40°C how much Hg will above the mark. (αglass = $9x10^{-6}$/K
    β_{Hg} = $182x10^3$/K)
24. 540 cal of heat is required to vaporize water at 100°C. Determine the entropy change involved to vaporized 5g water (1cal = 4.2J)
25. The meter bar of steel is measured at 0°C & -2.5°C. what will be difference in their length at 30°C (α = $11x10^{-5}$ K^{-1})