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Class 11
Physics

Chapter 8

Handwritten Notes

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Chapter #08
Heat & Thermodynamics

Temperature:-
Average Kinetic energy per molecule of a substance is called temperature. It is also related to degree of hatness and coldness of body.
→ It is represented by "T". Its SI unit is Kelvin (K).
→ Greater the average K.E per molecule of a substance, greater is the Temperature of substance.

Heat:-
Amount of energy that is transferred from one location to another because of temperature differences b/w these locations is called heat or heat energy.
→ It is represented by "Q" or ΔQ. It's SI unit is Joule "J".

Thermal equilibrium:
Two or more than two objects are said to be in thermal equilibrium if they all are at the same temperature.

→ When two or more then two objects are in thermal equilibrium, There is no net transfer of heat b/w these objects.
→ Thermodynamical properties of one object are not affected by other object.

Examples:-
All objects in classroom are in thermal equilibrium.

Internal Energy (U/ΔU):-

The sum of all forms of energies of atoms or molecules (translational K.E, rotational K.E) vibrational K.E, and Potential K.E) of a substance is called internal energy.

Explanation:-

- It is represented by "U" or "ΔU" and its SI unit is Joule J.
- In case of Ideal gass, internal energy of ideal gases is just the sum of translational K.E of atoms of ideal gas because. There is no attraction b/w the atoms of ideal gas.
- According to the K.E of gases, the average translational K.E of atoms or molecules of an ideal gas is given by

$$\langle K.E \rangle = \frac{3}{2} KT$$

where "K" is Boltzman's constant "T" is the temperature of ideal gas is Kelvin

→ when temp of a gas increases, average K.E of its atoms or molecules also increases resulting in the increase in internal energy of gas.

→ It means that the internal energy of an object is directly proportional to its temp.

→ Internal energy of an object increased by heating it or doing mechanical work on it.

Sign Convention:

Suppose internal energy initial is U at temp "T_1" and final internal energy is "U_2" at temperature "T_2". Then change in internal energy is given by $\Delta U = U_2 - U_1$

→ If temperature of a system increases then its "$\Delta U > 0$" and its internal energy also increases.

→ If temperature of a system decreases then its "$\Delta U < 0$" and its internal energy also decreases.

→ If temperature of a system remains unchanged then its $\Delta U = 0$ and its internal energy remains unchanged.

→ Internal energy of a system is the state function and depends only on the initial and final state of functions but not on the path followed while going from initial state to final state.

Gas Laws:-

Boyle's Law:

The volume of fixed mass (amount) of gas at constant temperature is inversely proportional to the pressure of gas. This statement is called Boyle's Law.

→ It related to the volume of a given mass of gas with pressure of gas.

Mathematically:-

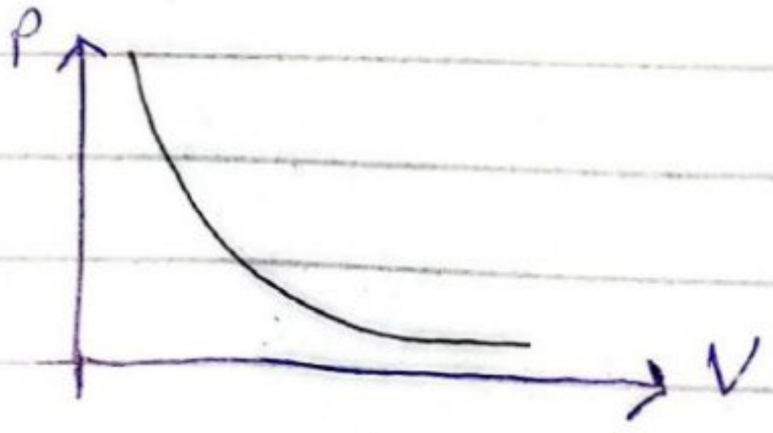
$$\text{Volume of gas} \propto \frac{1}{\text{Pressure of gas.}}$$

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

$$V = \frac{\text{Constant}}{P}$$

$$PV = \text{Constant}$$

$$P_1V_1 = P_2V_2 = \text{Constant}$$



Charle's Law:-

The volume of a fixed mass (amount) of gas at constant pressure is directly proportional to the absolute temperature of gas.

→ It is related to the volume of a given mass of agas to temperature of gas.

Mathematically:-

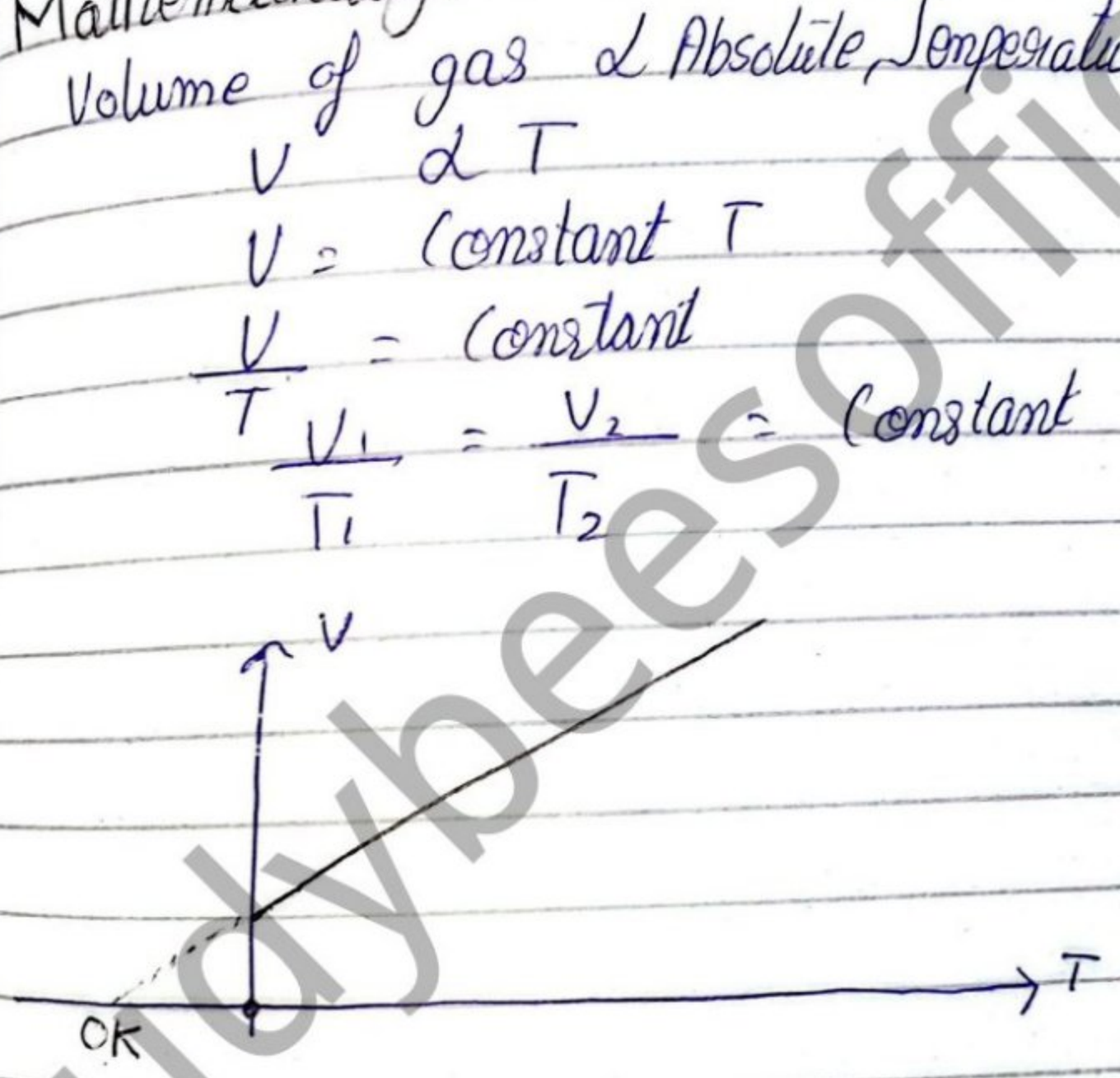
Volume of gas ∝ Absolute Temperature

$$V \propto T$$

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

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

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} = \text{Constant}$$



The hypothetical temperature at which have volume of a gas becomes zero is called absolute zero or Zero Kelvin.

Gay Lussac's Law:-

The pressure of ~~gas~~ given amount of gas at constant volume is directly proportional to the absolute temperature of gas. This statement is called Gay-Lussac's Law.

→ It relates the pressure and temperature of a given mass of gas at constant volume.

Mathematically:-

Pressure of gas ∝ Absolute temp of gas.

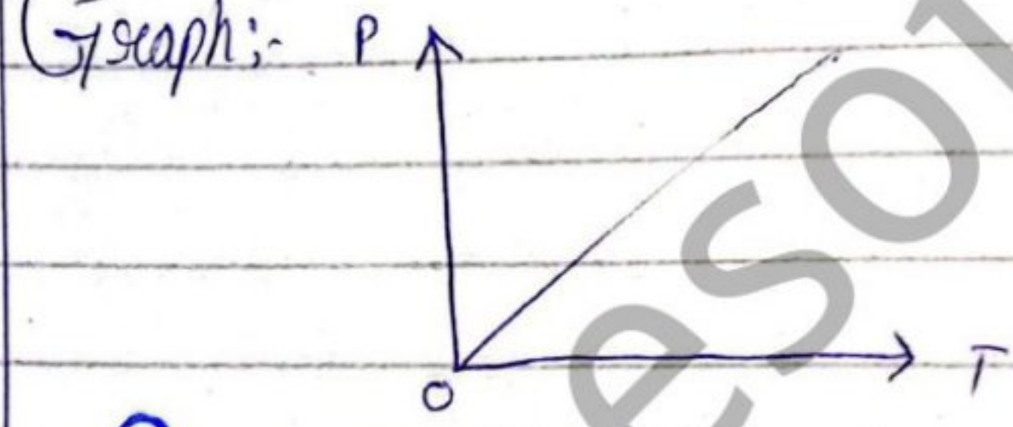
$P \propto T$

P = Constant T

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

$\frac{P_1}{T_1} = \frac{P_2}{T_2}$ = Constant.

Graph:-



Ideal Gas Equation:-

The mathematical relationship b/w the volume, pressure, absolute temperature and amount of a gas (number of moles of an ideal gas) is called ideal gas equation.

Mathematically:-

According to Boyle's Law, Charle's Law and Avagadro's Law.

$V \propto \frac{1}{P}$ ... ①

$V \propto T$ ... ②

$V \propto n$ ... ③

Combining all these we get.

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

$$V = \frac{\text{Constant } nT}{P}$$

$$V = \frac{RnT}{P} \quad \ldots a$$

Where, "R" is the constant of proportionality called ideal gas constant.
Its value is given as $R = 8.314\ J \cdot mol^{-1} \cdot K^{-1}$
Therefore.

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

$$PV = nRT$$

Here;
P = Pressure of gas.
V = Volume of gas.
n = number of moles of gas.
T = Absolute temperature of gas.
R = Ideal gas constant.

Boltzman Constant (K_B):-

Defination:

The ratio of universal gas constant (R) and avagadro number (N_A) is called Boltzman's constant.

It is represented by K_B.

It's value is $K_B = 1.38 \times 10^{-3} J K^{-1}$

Mathematically:-

By defination, we have.

$$\text{Boltzman's Constant} = \frac{\text{Universal gas Constant}}{\text{Avagadro number.}}$$

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

and corresponding numerical value is given by:

$$K_B = \frac{8.314\ J.mol^{-1}.K^{-1}}{6.02 \times 10^{23}\ mol^{-1}}$$

$$K_B = \frac{8.314\ J.K^{-1}}{6.02 \times 10^{23}}$$

$$K_B = 1.38 \times 10^{-23} J K^{-1}$$

General Gas Eq in term of Bolzman's Constant:

According to general gas equation,

$$PV = nRT$$

$$PV = \left(\frac{N}{N_A}\right) RT \quad \because n = \frac{N}{N_A}$$

$$PV = N\left(\frac{R}{N_A}\right)T$$

$$PV = N K_B T$$

This is general gas equation in terms of Boltzman's constant.

Kinetic Theory of gases:-

Kinetic theory of gases suggests that the properties of gases such as temperature, pressure and volume, etc are due to the random motion of atoms or molecules of gases.

Postulates Assumption:-

Kinetic Theory of gases is based on the following postulates / assumption.

→ Atoms / molecules of an ideal gas don't have any forces of attraction b/w them. They interact with each other only through elastic collision.

→ All collisions b/w atoms of ideal gases and b/w walls of container are perfectly elastic.

→ Atoms / molecules of ideal gas are in random motion and they apply pressure on walls of container upon collision

→ Atoms molecules of gas may change their directions at any point during motion upon collision.
→ A finite number of gas consists of very large atoms / molecules of ideal gas.

Condition for ideal gas to behave as ideal gas:

According to the general eqn of gas.

$$PV = nRT$$

$$PV = \left(\frac{m}{M}\right) RT$$

$$PM = \left(\frac{m}{V}\right) RT \qquad \left[n = \frac{m}{M}\right]$$

$$PM = \rho RT$$

$$\rho = \frac{PM}{RT} \star$$

Where;
R = Universal gas constant = $8.314\ J mol^{-1} K^{-1}$
M = Molar mass of given gas = constant.

$$\rho = \frac{PM}{RT} = \left(\frac{M}{R}\right) \frac{P}{T}$$

ρ = constant $\frac{P}{T}$.

$\rho \propto \frac{P}{T}$.

→ At low temp- pressure and high temperature, density of gas is small i.e;- molecules of gases are "far apart", there is almost no attractive forces b/w atoms / molecules of real gas and real gas behave like as ideal gas.

→ At high pressure and low Temperature, density of gases is large keeping atoms of gases closer and there are strong forces of attraction b/w atoms or molecules Gases don't behave as ideal gas.

Example 8.1

Calculate the average translational K.E of molecules in a gas at room temp.

Given data:-

$T = 25°C = 25 + 273 = 298K$

To find:-

$\langle K.E \rangle = ?$

Calculation:-

We know that.

$$\langle K.E \rangle = \frac{3}{2} K_B T$$

$$= \frac{3}{2} \times 1.38 \times 10^{-23} \times 298$$

$$\langle K.E \rangle = 6.17 \times 10^{-21} J.$$

Assignment 8.1

Estimate the total no of air molecules (including molecules of oxygen, N, water vapour and other constituents) in a room of capacity 200 m^3 at a temperature of 27°C and 1 atm pressure:

Given data:

$V = 20\ m^3$, $T = 300K$, $P = 101300\ Pa$.

To find:

$N = ?$

Calculations:

We know that

$PV = NK_BT$

$N = \frac{PV}{K_BT}$

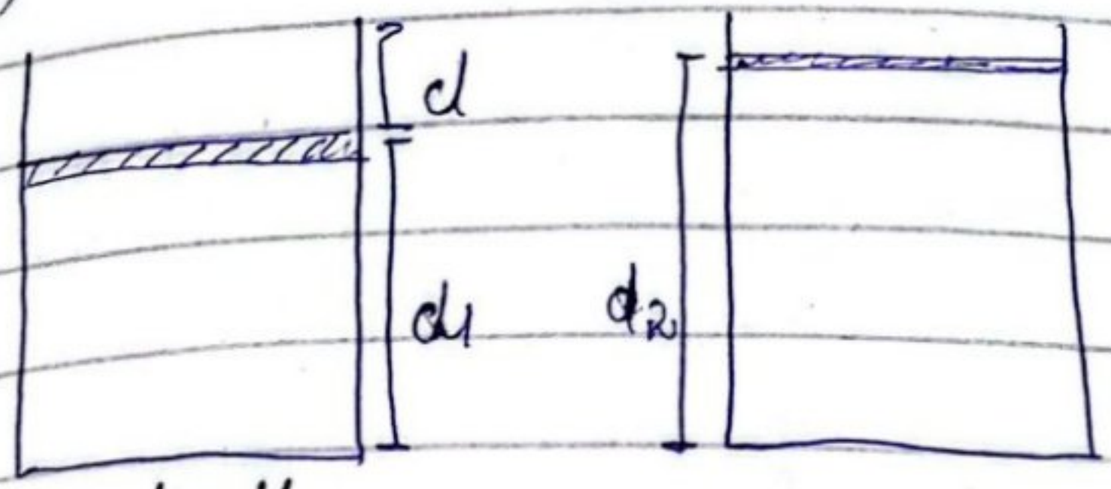
$N = \frac{101300 \times 20}{1.38 \times 10^{-23} \times 300}$

$N = 4.9 \times 10^{26}$ molecules.

Show that work done during a thermodynamical process is $P\Delta V$.

Consider a cylinder filled with gas at pressure "P" and Volume "V." with a frictionless piston on it. Now, gas is allowed to expand and it displaces the piston through displacement "d" during work on it.

Diagram:-



Mathematically:-

By definition of work.

$$W = \vec{F} \cdot \vec{d}$$

$$W = Fd\cos\theta \qquad \because \theta = 0°$$

$$W = Fd\cos 0°$$

$$W = Fd \qquad \because P = \frac{F}{A}$$

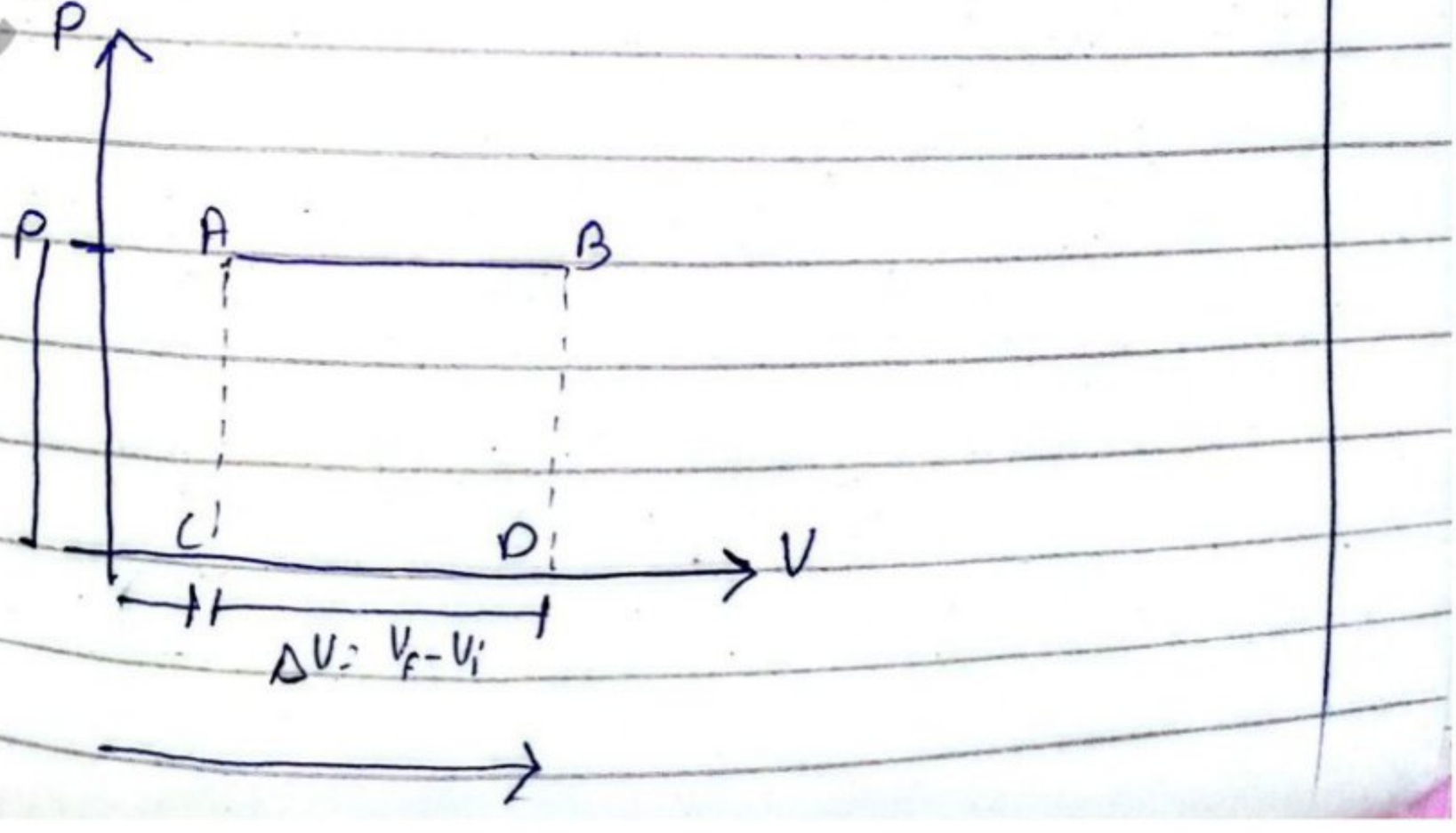
$$W = PAd$$

$$W = P(Ad)$$

$$W = P\Delta V$$

This is the work done during any thermodynamical process and depends only on change in volume of system.

Graphical Method to find work:-



Area under PV graph is given by.
Area = AC × AB.
= P × (Vf - Vi)
= PΔV = Work done.
Work done = Area Under PV-graph = PΔV.

Types of work.-

There are three types of work done during thermodynamical process.

1- Positive Work :-
When gas expands then $V_f > V_i$ and $\Delta V = (V_f - V_i) > 0$ and work done is also positive. This is positive work done or work done by the system i.e; $W = +P\Delta V$
$W = +P(V_f - V_i)$

2- Negative work / done on the system / gas :-
When gas contracts then $V_f < V_i$ and $\Delta V = (V_f - V_i) < 0$ and work is also -ve. This is -ve work done or work done on the system by surrounding i.e;
$W = -P\Delta V$
$W = -P(V_f - V_i)$

3- Zero work / No work ;-
When gas neither contracts nor expands then $V_f = V_i$ and $\Delta V = V_f - V_i = 0$, then no

work is done by or on the system or gas.

$$W = P\Delta V$$
$$W = P(0)$$
$$W = 0.$$

Example 8.2

A 2kg of argon gas is heated to a temp of 30°C. If the gas is contained in a cylinder of radius 1m and height 2m, what is the pressure of the gas.

Given data:

$m = 2000g$, $T = 303K$, $r = 1m$, $h = 2m$.

To find:

$P =$?

Calculation:

We know that.

$$PV = nRT$$
$$P = \frac{nRT}{V} = \frac{nRT}{Ah} = \frac{nRT}{\pi r^2 h}.$$
$$P = \frac{nRT}{\pi r^2 h} \quad \ldots (1)$$
$$n = \frac{m}{M} = \frac{2000}{40} = 50\ mol$$

$n = 50\ mol$, put in eq(i)

$$P = \frac{50 \times 8.314 \times 303}{3.14 \times (1)^2 \times 2} = 200442Pa \text{ (Ans.)}$$

Assignment 8.2:

A sample of gas is compressed to $\frac{1}{3}$ of its initial volume at constant pressure of $2.25 \times 10^5 \, Nm^{-2}$. During the compression, 200J of work is done on the gas. Determine the final volume of the gas.

Given data:

$W = -200J$, $V_F = \frac{V_i}{3}$, $P = 2.25 \times 10^5 \, Nm^{-2}$

To find:

$V_F = ?$

Calculation:

we know that

$$W = P\Delta V$$

$$W = P(V_F - V_i)$$

$$-200 = 2.25 \times 10^5 (V_F - 3V_F)$$

$$-200 = 2.25 \times 10^5 (-2V_F)$$

$$V_F = \frac{200}{4.50 \times 10^5}$$

$$V_F = 4.4 \times 10^{-4} \, m^3 \quad \text{Ans.}$$

First Law of Thermodynamics:

Definition:-

When heat (ΔQ) is added to a system, it is utilized to increase the ~~initial~~ internal energy of system plus work done by system on surroundings. This statement is called First Law of Thermodynamics.

First Law of thermodynamics is nothing but law of conservation of energy.

Mathematically:-

Mathematically, First Law of thermodynamics can be written as,

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

where,

ΔQ = Heat entered into the system.
W = Work done by system on surrounding
ΔU = Change in internal energy.

Sign Convention:-

→ ΔQ is taken as positive when heat enters into the system.
→ ΔQ is taken as -ve when heat leaves the system.
→ "W" is taken as -ve when work is done on the system i.e;- Gas contracts.
→ "W" is taken as +ve when work is done by the system i.e;- Gas expands.
→ "ΔU" is taken as +ve when temp of system increases.
→ "ΔV" is taken as -ve when temp of system decreases.

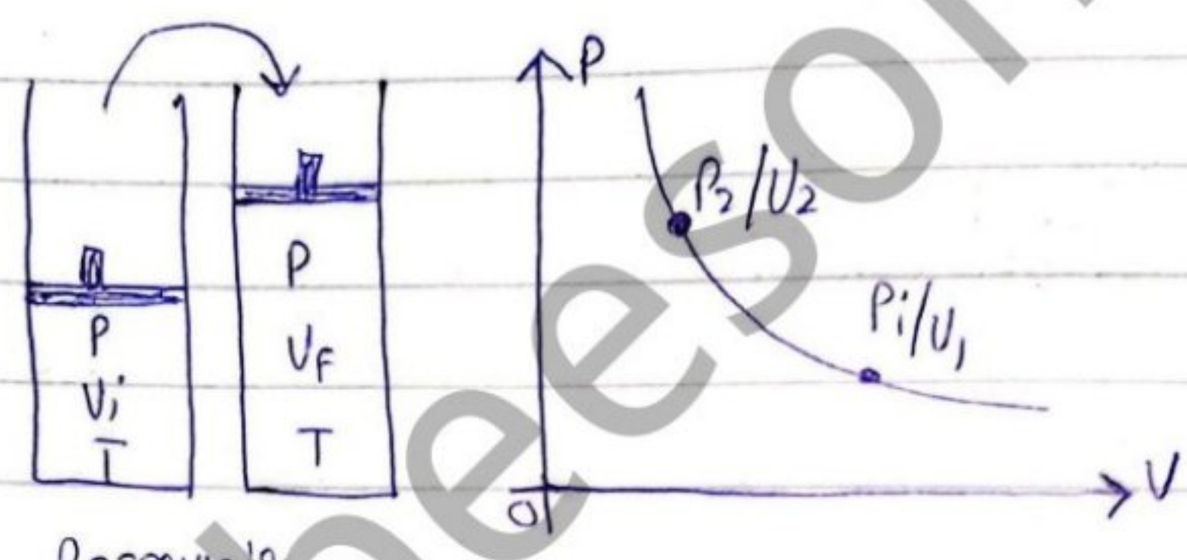
Applications of First Law of Thermodynamics

1- Isothermal process:-

Definition:

A Thermodynamical process in which temp of system remains unchanged / constant throughout the process is called isothermal process.

Diagram;-



Mathematically;-

According to the first law of thermodynamics

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

Since, process is isothermal. Therefore there is no change in internal energy of system i.e;-

T= constant, $\Delta U = 0$, Δ

Therefore;

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

$$\Delta Q = W + 0$$

$$\Delta Q = W$$

Heat given to the system is completely used up by the system in doing work by system.

Isothermal expansion:-

During this process, gas absorbs heat from reservoir and utilizes it in during work on the surrounding i.e;

$$\Delta Q = \Delta W$$

Isothermal compression:-

During this process work is done on the system by external agent and equal amount of heat leaves the system i.e;

$$-\Delta Q = -W$$

e.g;-

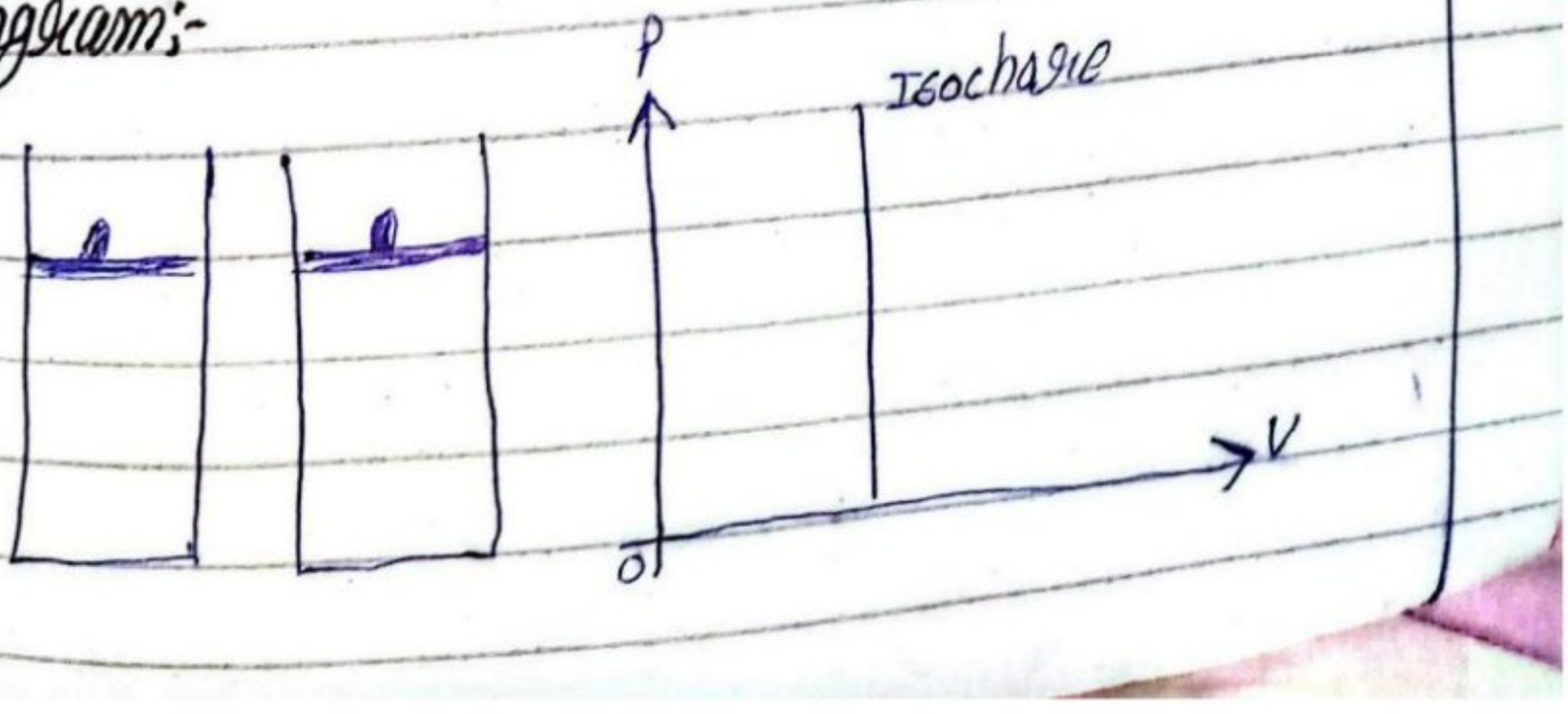
melting of ice cube is an example of first law of thermodynamics.

2 Isochoric Process:-

Definition:

A Thermodynamic process in volume of system remains constant is called isochoric process.

Diagram:-



Mathematically:
According to first law of Thermodynamics.

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

But V = Constant, $\Delta V = 0$, $W = 0$.
Therefore,

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

But V = constant, $\Delta V = 0$, $W = 0$.
Therefore;

$$\Delta Q = W + \Delta U.$$
$$\Delta Q = 0 + \Delta U.$$
$$\Delta Q = \Delta U.$$
$$+\Delta Q = +\Delta U$$
$$\text{OR} \quad -\Delta Q = -\Delta U.$$

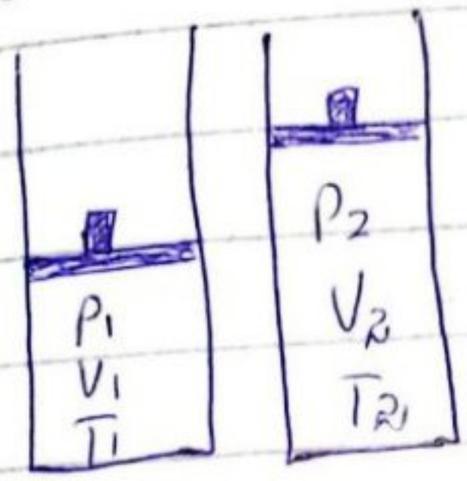
It means that, amount of heat entering or leaving the system is equal to the increase or decrease in internal energy of system during isochoric process.
Example:-
Cooking of food in cooker.

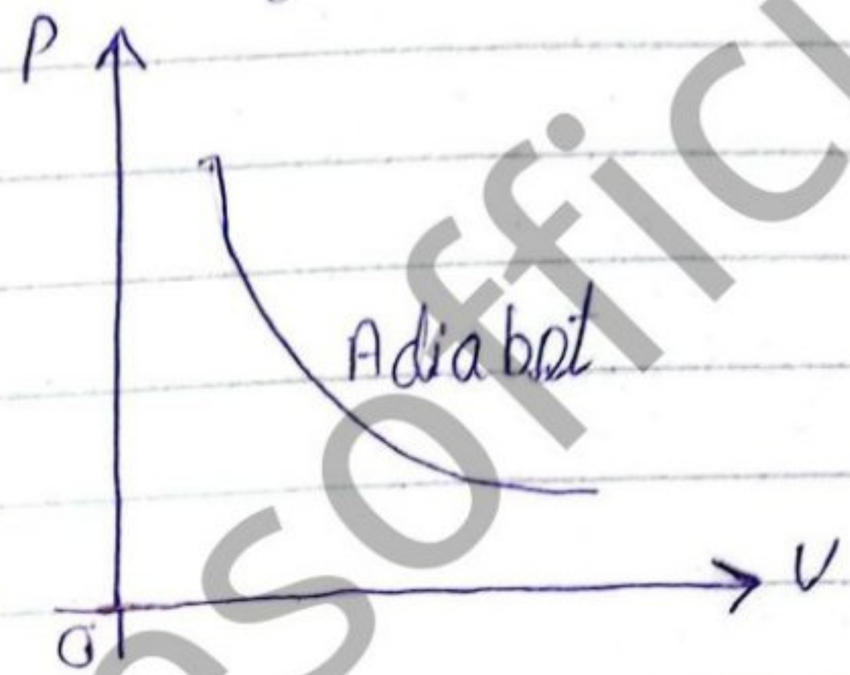
3 Adiabatic Process:-

Diagram:-

A Thermodynamic process in which no heat enters or leave the system is called adiabatic process. During this process, heat of system remains unchanged.

Diagram:-





Mathematically:-

According to first law of Thermodynamics

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

But process is adiabatic. Therefore, $\Delta Q = 0$.

So,

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

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

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

Adiabatic compression:-

During this process, work is done on the system i.e: gas is compressed and this work done increases the internal energy of the system causing temp to increase.

$W + \Delta U = 0$.

$\Delta U = 0 - W$

$\Delta U = -W$

$-W = \Delta U$.

Adiabatic expansion:-

During this process, work is done on the system ~~i.e; Gas~~ on the expanse of its internal energy i.e:- Gas expands and this work decrease the internal energy of system causing cooling.

$$W + \Delta U = 0$$

$$W = 0 - \Delta U$$

$$W = -\Delta U$$

During this process poisson's relation holds.

$$PV^{\delta} = \text{Constant}$$

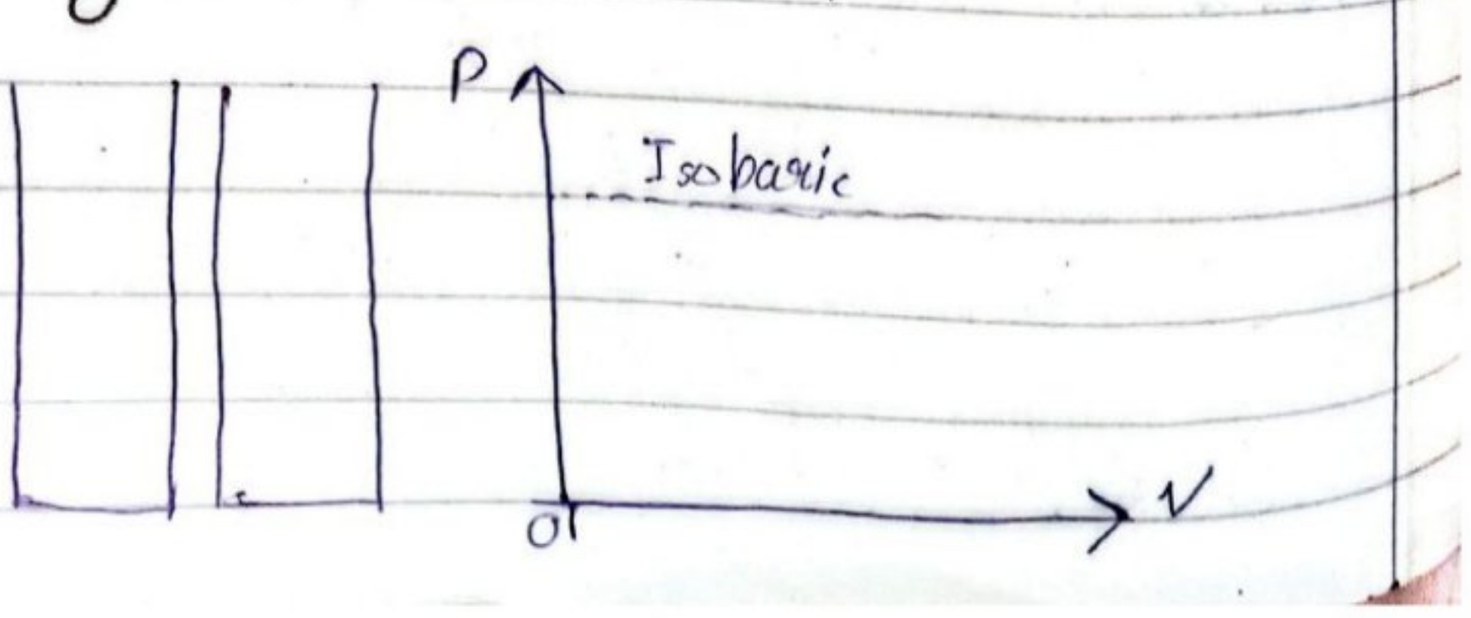
$$P_1 V_1^{\delta} = P_2 V_2^{\delta}$$

4 Isobaric process

Definition:-

A Thermodynamic process during which pressure of system remains constant is called isobaric process.

Diagram:



Mathematically:-

According to first law of Thermodynamics

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

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

Amount of heat supplied to the system is used in doing work by the system and to increase internal energy of system.

Molar specific heat capacity (C):-

Amount of heat required to increase temperature of one mole of gas through one celsius or one Kelvin is called molar specific heat capacity.

Types of Molar specific heat capacity:-

There are two types of molar specific heat capacity:-

→ Molar specific heat capacity at constant pressure (C_p).

→ Molar specific heat capacity at constant volume (C_v)

Define Cp:-

Amount of heat required to raise the temperature of one mole of gas through 1K or 1°C at constant pressure.

Define Cv:-

Amount of heat required to raise the temp of one mole of gas through 1K or 1°C at constant volume.

Define γ :-

The ratio of "Cp" and "Cv" is called gama. It is a dimensionless constant.

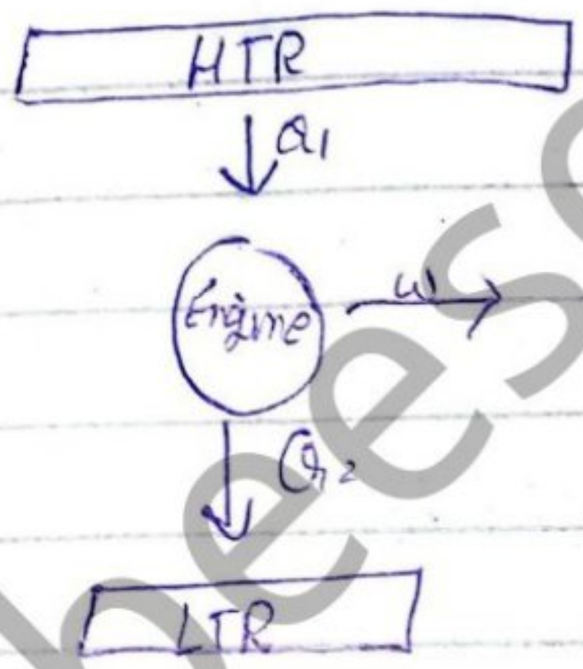
$$\gamma = \frac{C_p}{C_v}$$

Heat engine:-

Definition:
A Device which converts heat energy into mechanical work is called heat engine.

Construction:-
A heat engine consists of three major Parts:-
1- Hot reservoir / Heat Source.
2- Cold reservoir / Sink
3- Working Substance.

Diagram:-



Adiabatic Hot reservoir:-
A reservoir that is at higher temperature and contain huge amount of energy / heat and supplies to the heat engine. When it provides heat to heat engine, its temperature does not fall.

Cold reservoir:
A reservoir that is at relatively lower temperature and its function is to absorb the heat rejected by the engine. When it absorbs heat, its temperature does not change (increase)

Working Substance:-

A substance that absorbs heat from hot reservoir and converts it into mechanical work is called working substance. It may be a gas, steam or any substance.

Mathematically:-

According to first law of Thermodynamics.

$$Q_1 = W + Q_2$$

$$W + Q_2 = Q_1$$

$$W = Q_1 - Q_2$$

Examples:-

Examples of heat engine include. petrole engine, diesel engine and steam engine.

Reversible process:-

A process which can be traced in exactly reverse order without producing any change in the surrounding is called reversible process.

Example:-

Example of a reversible process is the conversion of water into ice and ice into water.

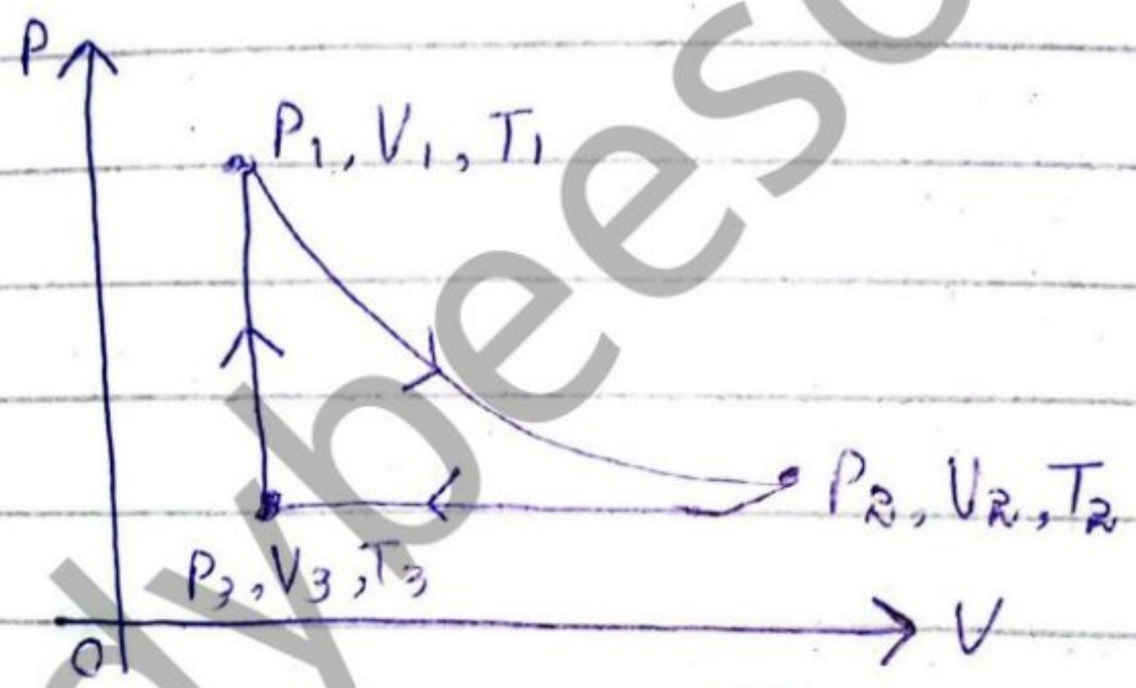
Irreversible process:-

A process which cannot be traced in exactly reverse order without producing any change in the surrounding is called reversible process.

Examples:
All sudden process that involve less of energy through friction such as explosions are irreversible process.

Cyclic process:-

A series of events that brings the system back to its initial state with the same pressure, volume and temperature is called cyclic process.
All heat engines work in cyclic process.



Second Law of Thermodynamics:-

Lord Kelvin Statement:-

It is impossible to construct a heat engine operating in a cycle which absorbs heat from a hot reservoir and converts it completely into useful work without rejecting any heat to sink.

Rudolf Calsius statement :-

It is impossible to cause heat to flow from cold body to hot body without any expenditure of external work on it.

Refrigerator:-

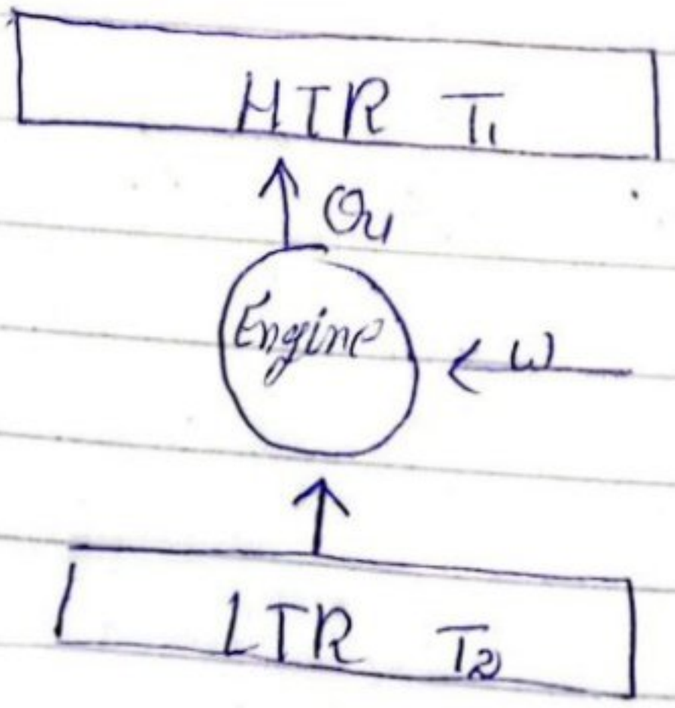
Definition:-

A device which is used to extract / absorb heat from cold body and expel it into hot body on the expanse of external work is called refrigerator. It is also called reverse heat engine or heat pump because it moves heat against its natural flow.

Construction:

It consists of a high temperature reservoir, low temperature reservoir, slow source of external work, working substance (refrigerent) and compressor.

Diagram:



Working :-
Working substance (refrigerent) absorbs heat from the cold body and expels it into the hot reservoir on the expanse of external work.

Co-efficient of performance / energy ratio (α) :-
It is ratio of heat extracted / removed from the body by refrigerator to work required to do so. It tells us how effectively heat is being removed from body.

$$\alpha = \frac{\text{Heat removed from object}}{\text{Work require to remove heat}}$$

$$\alpha = \frac{Q_2}{W} = \frac{Q_2}{Q_1 - Q_2}$$

In terms of temperature, it can be written as.

$$\alpha = \frac{Q_2}{W} = \frac{Q_2}{Q_1 - Q_2} = \frac{T_2}{T_1 - T_2}$$

Co-efficient of performance of heating (β) :-
If the ratio of heat delivered to the HTR to the work required to do so,

$$\beta = \frac{\text{Heat delivered to HTR}}{\text{work required to deliver that heat.}}$$

$$\beta = \frac{Q_1}{W} = \frac{Q_1}{Q_1 - Q_2} = \frac{T_1}{T_1 - T_2}$$

Or Explain the increase in temp increases the disorder of the system?

Entropy:-

Entropy is the measure of the molecular disorder, or randomness of a system.

"A Thermodynamic quantity representing the unavailability of a system's thermal energy for conversion into Mechanical work is called entropy".

- Entropy is state variable of thermodynamically system.
- It was introduced by Rudolph claudius in 1856.
- This gives quantitative basis on mechanical formula for Second Law of Thermodynamics.
- If ΔQ is the amount of heat absorbed by the system at Temp 'T'.

Then change in entropy (ΔS) state variable of the system is,

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

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

Just like internal energy and P.E, it is change in entropy which is more imp than its absolute value.

Sign convention:

→ Positive change in Entropy ($\Delta S > 0$). Entropy increases when heat is added to a system.

→ Negative change in Entropy ($\Delta S < 0$). Entropy decreases when heat is removed from a system.

→ SI unit is JK^{-1}

→ Dimension of entropy is $ML^2T^{-2}K^{-1}$

→ Key Concept :-

- When temperature increases particle K.E and disorder increases. So entropy increases.
- This shows that systems become more disordered as they gain heat.

—

Q. Explain energy is degraded during all natural processes?

Ans **Degradation of energy during Natural processes:-**

Energy is degraded in all natural processes because heat flows from a hot reservoir to a cold reservoir, and in doing so, the total entropy of the system increases.

Let:-

- T_1 = temperature of hot reservoir.
- T_2 = temperature of cold reservoir ($T_1 > T_2$)
- Q_2 = heat transferred.

Entropy changes:

- Hot reservoir: $\Delta S = -\frac{Q}{T_1}$ (entropy decreases)
- Cold reservoir $\Delta S = \frac{Q}{T_2}$ (entropy increases)

Net entropy change:-

$$\Delta S_{net} = \frac{Q}{T_2} - \frac{Q}{T_1} > 0$$

Since the net entropy is +ve, energy becomes less available to do work, meaning it is degraded.

→ According to second Law of Thermo-dynamics, in all natural processes, total entropy always increases, showing that energy is degraded as systems move towards greater disorder.

Q Explain the increase in entropy means degradation of energy?
OR.
Identify that system tends to become less orderly over time?

Entropy as Unavailability of Mechanical Work (i.e; Degradation of energy):

- Energy degradation refers to the process where energy is transformed from a more useful form to a less useful form, often as waste heat.
- In nature only those processes are more likely to occur where the entropy of the system increases or remains constant.
- For all reversible processes, entropy of the systems remains constant.
- Entropy increases for irreversible process.
- Every time entropy increases the opportunity to convert some heat into work is lost.
- An increase in entropy means the degradation of energy
- In a car engine, fuel burning burning produces work, but heat available for work and causing entropy change.

Heat Death of Universe:-

When the entropy of the universe will reach at maximum value, every thing will be at same temperature. All physical, chemical and biological process will have ceased and there will be no way to convert heat into useful work and this state of affairs is referred heat death of universe.

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