UNIT = 8

THERMODYNAMICS

5

Thermodynamics: The branch of science which deal with study of heat, temp. and pressure etc. is called thermodynamics.

* Some terms related with thermodynamics:

i) **System:** The thing which is under study or consideration is known as system.

2) **Surrounding:** The part of universe except system is known as surrounding.

3) **Thermodynamic Wall:** A thing which seprate system and surrounding is known as thermodynamic wall.

There are 2-types of thermodynamic wall

(i) **Conducting / Diathermic Wall:** The walls through which heat can flow from system to surrounding and from surrounding to system are called Diathermic wall. Ex- Walls of a Kettle.

ii) **Adiabatic / insulating wall:** The walls through which heat cannot flow from system to surrounding and from surrounding to system are called Adiabatic wall. Ex- Walls of a tea thermus.

*4) **Thermodynamic Variable:** The parameters whose value changes during any process are known as Thermodynamic Variable. For ex: Volume (V), Pressure (P), Temp. (T)

*5) **Thermodynamics process:** If value of any thermodynamic variable changes, a thermo-dynamic process is said to occur.

There are 4-type of thermo-dynamic process.

i) **Iso-thermal process:** The thermodynamic process in which temp. of system remains constant is called isothermal process.

2) **Adibatic process** - The thermodynamic process in which heat energy of system remains constant such that flow of heat from system to surrounding and vice-versa does not take place, is called adiabetic process.

iii) **Isobaric:** The thermodynamic process in which pressure of system remains constant is called iso-baric process.

iv) **Isovolumic (Isochoric):** The thermodynamic process in which vol^m of system remains constant is called Isovolumic / Isochoric process. It is also known as Isometric process.

* Isothermal process –

Conditions for isothermal :

1) For isothermal process, walls of system must be diathermic (conducting) so that heat flow b/w system and surrounding takes place
2) The process must be slow, so that system get enough time to exchange heat with surrounding

* Equation of isothermal process –

Acc. to ideal gas eqⁿ

$PV = RT$

as temp. is constant

$\boxed{PV = \text{constant}}$

Let P_1 and P_2 be the initial and final pressure V_1 and V_2 be the volᵐ respect...

Then for isothermal process

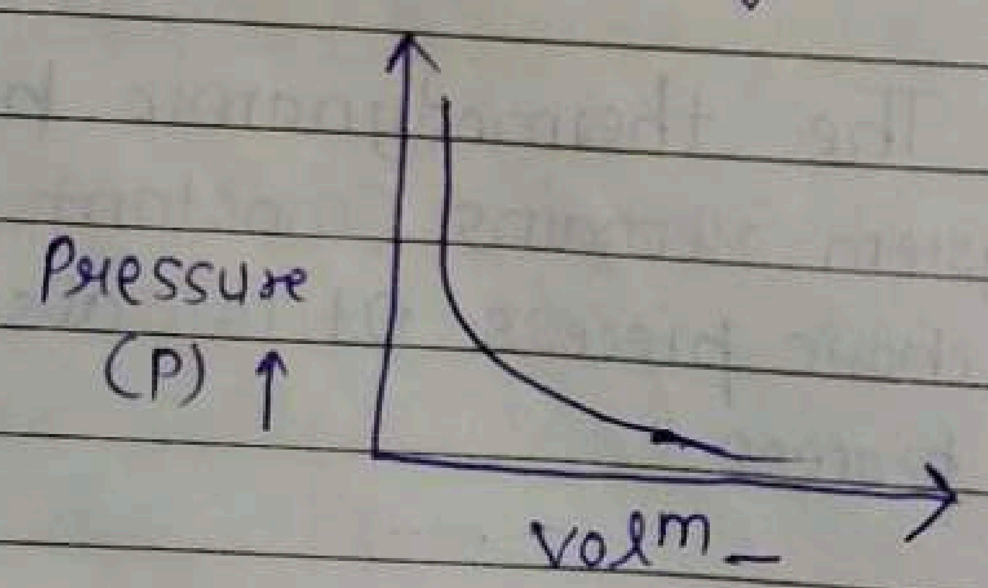
$$\boxed{P_1V_1 = P_2V_2 = \text{constant}}$$

* Indigcator diagram:

It is a graph b/w pressure and volᵐ for a gas.

As, $PV = \text{constant}$

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



* Slope of indicator diagram :

$$\text{Slope} = \frac{dP}{dV}$$

using eqⁿ of isothermal process

$PV = \text{constant}$

Differentiating both side

$$P.dV + V.dP = 0$$

$$\boxed{\frac{dP}{dV} = -\frac{P}{V}}$$

So, slope of indicator diagram is $\left(-\frac{P}{V}\right)$

* Work done by isothermal process:

let 'dx' be the small displacement so, 'dw' be the small work done

$$dw = F.dx \quad \text{—— (i)}$$

let 'P' be the pressure exerted and 'A' be the area

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

$$F = P.A \quad , \quad dw = P.A.dx$$

$$dw = P.dV \quad [A.dx = dV]$$

For total workdone integrating both side

$$W = \int dw = \int_{V_1}^{V_2} P.dV \quad \text{— (ii)}$$

using ideal gas eqⁿ

$$PV = RT$$

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

put this value in eqⁿ (ii)

$$W = \int_{V_1}^{V_2} \frac{RT}{V} . dV$$

$$W = RT \int_{V_1}^{V_2} \frac{1}{V} . dV$$

$$W = RT \left[\log_e V \right]_{V_1}^{V_2} \rightarrow W = RT \left[\log_e V_2 - \log_e V_1 \right]$$

$$W = RT \quad \left[\log_e m - \log_e n = \log_e \frac{m}{n} \right]$$

$$W = RT \log_e \frac{V_2}{V_1}$$

$$W = 2.303\, RT \log_{10} \frac{V_2}{V_1}$$

as, $P_1 V_1 = P_2 V_2$

$$\frac{V_2}{V_1} = \frac{P_1}{P_2}$$

So, $$\boxed{W = 2.303\, RT \log_{10} \frac{P_1}{P_2}}$$

*** Adiabatic process:**

 # Condition for adiabatic process

i) For adiabatic process walls of system must be adiabatic (insulating) so, that no transfer of heat take place.

2) The process must be sudden process

*** Equation of Adiabatic process;**

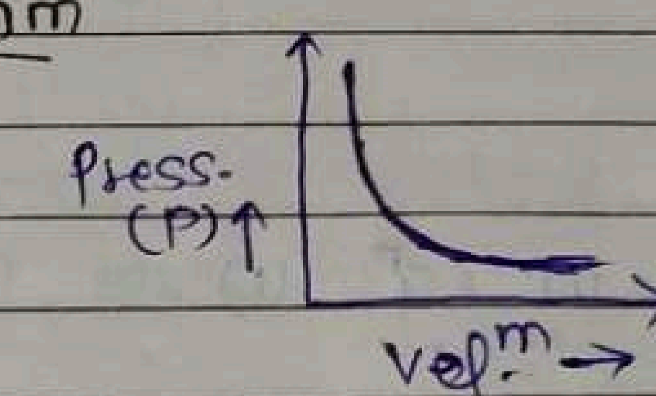
$$PV^\gamma = \text{constant}$$

Where 'γ' is called specific heat constant

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

or, $$\boxed{P_1 V_1^\gamma = P_2 V_2^\gamma = \text{constant} = K}$$

*** Indicator diagram**



*** Slope of indicator diagram:-**

$$\text{Slope} = \frac{dP}{dV}$$

as an eqn of adiabatic process is

$$PV^\gamma = \text{constant}$$

Differentiating both side

$$P.\gamma.V^{\gamma-1}.dV + V^\gamma.dP = 0$$

$$P.\gamma.V^{\gamma-1}.dV = -V^\gamma.dP$$

$$\frac{dP}{dV} = \frac{-P.\gamma.V^{\gamma-1}}{V^\gamma}$$

$$\frac{dP}{dV} = \gamma.P.V^{\gamma-1}.V^{-\gamma}$$

$$\frac{dP}{dV} = -\gamma.P.V^{\gamma-1-\gamma}$$

$$\frac{dP}{dV} = -\gamma.PV^{-1}$$

$$\boxed{\frac{dP}{dV} = -\frac{\gamma.P}{V}}$$

* Workdone in Adiabatic process:

let dx be the small displacement for which 'dW' be the small workdone.

$$dW = F \cdot dx \quad \text{--- (i)}$$

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

$\Rightarrow F = P \cdot A$

Put this value in eqⁿ (i)

$$dW = P \cdot A \cdot dx$$

$$dW = P \cdot dV \quad [A \cdot dx = dV]$$

using eqⁿ of adiabatic process

$$PV^{\gamma} = K$$

$$P = \frac{K}{V^{\gamma}}$$

So, $dW = \frac{K}{V^{\gamma}} \cdot dV$

For total workdone integrate both side

$$W = \int dW = \int_{V_1}^{V_2} \frac{K}{V^{\gamma}} \cdot dV$$

$$W = K \int_{V_1}^{V_2} V^{-\gamma} \cdot dV$$

$$W = K \left[\frac{V^{1-\gamma}}{1-\gamma} \right]_{V_1}^{V_2}$$

$$W = \frac{K}{1-\gamma} \left[V_2^{1-\gamma} - V_1^{1-\gamma} \right]$$

as, $P_1 V_1^{\gamma} = P_2 V_2^{\gamma} = K$

$$W = \frac{1}{1-\gamma} \left[K V_2^{1-\gamma} - K V_1^{1-\gamma} \right]$$

$$W = \frac{1}{1-\gamma} \left[P_2 V_2^{\gamma} \cdot V_2^{1-\gamma} - P_1 V_1^{\gamma} \cdot V_1^{1-\gamma} \right]$$

$$W = \frac{1}{1-\gamma} \left[P_2 V_2 - P_1 V_1 \right]$$

Using ideal gas eqⁿ

$$PV = RT$$

$$P_1 V_1 = RT_1$$

or, $P_2 V_2 = RT_2$

$$W = \frac{1}{1-\gamma} \left[RT_2 - RT_1 \right]$$

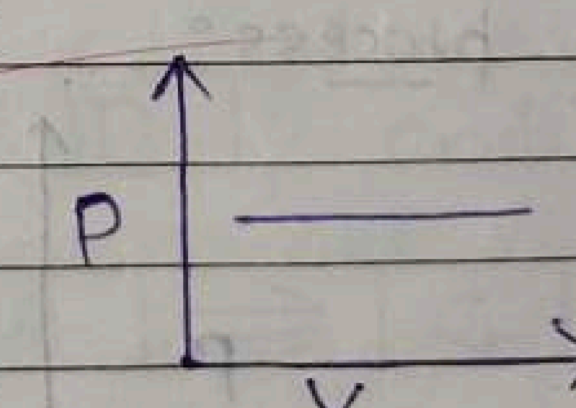
$$\boxed{W = \frac{R}{1-\gamma} \left[T_2 - T_1 \right]}$$

* Isobaric process:

The thermodynamic process in which pressure of system remains constant is called isobaric process.

$$P = \text{constant}$$

* Indicator diagram:



* Workdone:

$$dW = P \cdot dV$$

Total workdone, $W = \int dW = \int_{V_1}^{V_2} P \cdot dV$

$\therefore W = P(V_2 - V_1)$ → Area of indicator diagram

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

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

When output = Input
$\eta = 1$ (max.)

* In terms of temp...

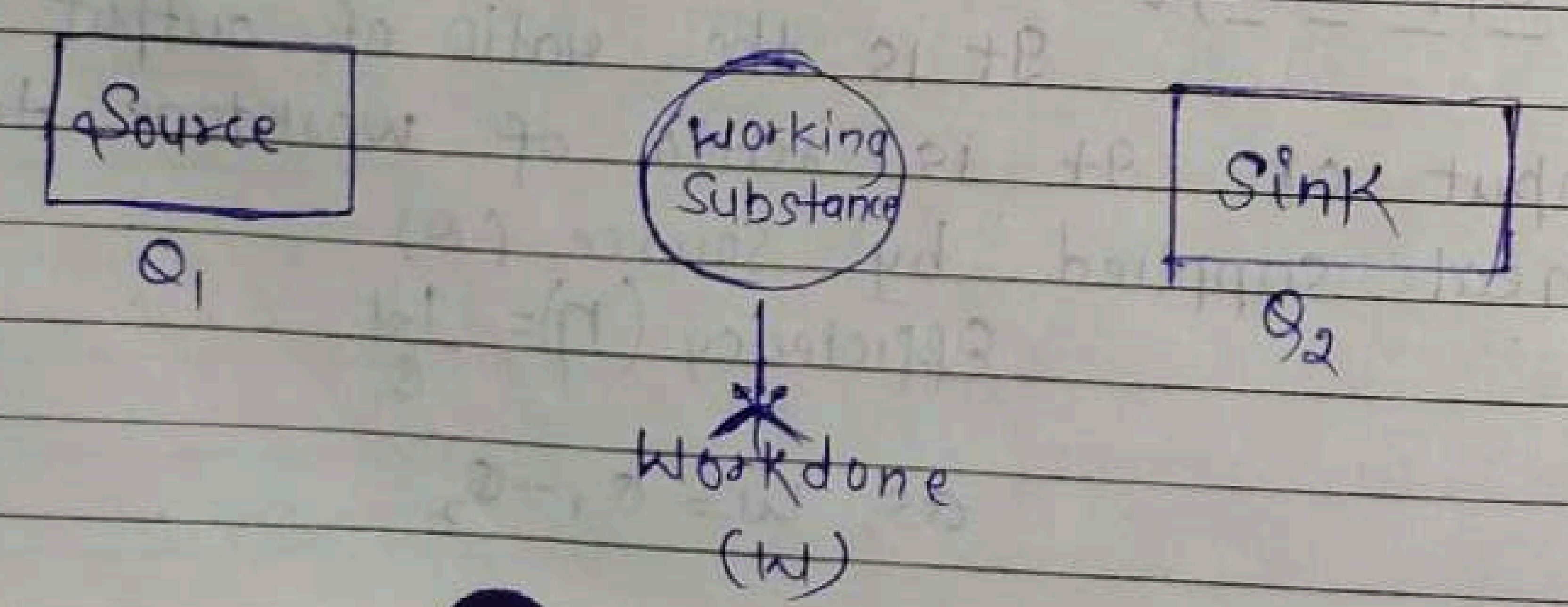
$\frac{Q_2}{Q_1} = \frac{T_2}{T_1}$

Then,

$\boxed{\eta = 1 - \frac{T_2}{T_1}}$

*Types of heat engine: There are two types of heat engine — External and Internal heat engine
In external heat engine the combustion chamber is seprate. For ex: Railway engine.
In internal heat engine cambustion chamber is in it. Ex- Bike, car.

* Refrigerator: (Heat pump)
It is a device which is used for cooling things.



Construction: A refrigerator consist of three main parts-
1) Source- Source is at high temp. (T_1). Let Q_1 be the heat rejected to the source.

2) Working Substance. It includes gas mixture. Usually refrigerator use dicholoro diflluromethane (CCl_2F_2). Working Sub. do workdone to take out heat from sink.

3) Sink: Sink is at low temp. (T_2). The working substance will take out heat Q_2 from the sink.

* Working: Working substance will absorb heat Q_2 from sink and reject heat Q_1 to the source. During it's working, refrigerator follow cyclic process.

Net change in heat energy
$dQ = Q_1 - Q_2$
or for cyclic process:-
$dU = 0$
Acc. to 1st law of thermodynamics
$dQ = dU + dW$
$dQ = 0 + dW$
$dQ = dW$
as, 'W' be the workdone
So, $\boxed{W = Q_1 - Q_2}$

Efficiency: let 'β' be the efficiency of refrigerator It is equal to the ratio of heat energy of sink (Q_2) to the workdone (W)

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

(a) **Kelvin's statement:** It is immpossible to obtain workdone from a body by cooling it below its surrounding temprature.

(b) **Clausius Statement:** It is immpossible for a machine to transfer heat from lower temp. to higher temp. without any external help.

(c) **Plank's statement:** It is immpossible to construct a heat engine which would convert whole heat from source into workdone. OR

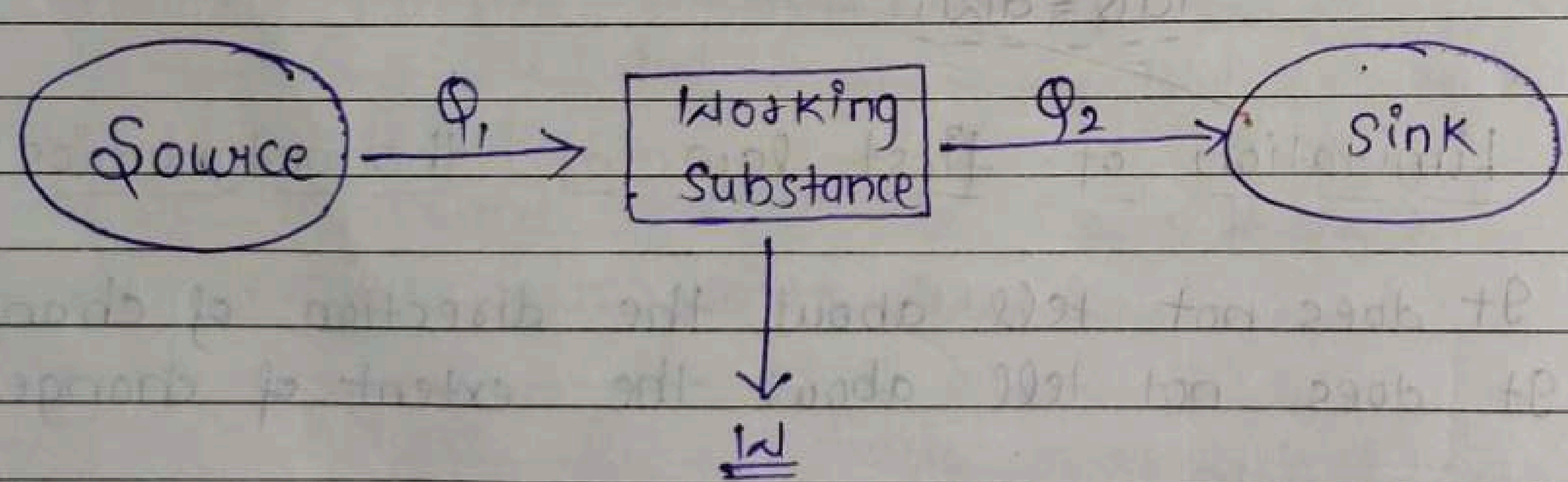
It is immpossible to construct a heat engine with 100% efficiency.

* Heat Engine:

It is a device which does work done using heat engine energy or

It is an engine which uses heat energy to do mechanical work done. Ex - Petrol engine, diesal engine, steam engine.

Diagram:



Construction: A heat engine consist of 3 main parts-
1) Source, Working Substance, Sink

1) **Source:** Function of source is to supply heat to the system. Source is kept at higher temp. (T_1) Q_1 be the heat supplied by the source.

2) **Working Substance:** Working substance include fuel and air mixture. Working substance takes heat from source and does workdone.

3) **Sink:** Sink is kept at low temp. (T_2). The waste heat is escaped to the sink. Let Q_2 be the heat escaped to the sink.

Working: Let Q_1 be the heat supplied by the source. Some work is done in expansion or compression then let the heat occupied to the sink

Then change in heat energy

$$dQ = Q_1 - Q_2$$

using 1st law of the thermodynamics

$$dQ = dU + dW$$

$$Q_1 - Q_2 = 0 + dW$$

$$\boxed{Q_1 - Q_2 = dW}$$

* Efficiency:

It is the ratio of output to the input or It is ratio of workdone to the heat supplied by source (Q)

$$\text{Efficiency } (\eta) = \frac{W}{Q_1}$$

as, $W = Q_1 - Q_2$

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$d\theta = dU + dW$

Where $d\theta$ = change in heat energy
dU = change in internal energy.
dW = Small workdone.

→ Sign Convention:

i) If heat is given to system then $d\theta$ will be +ve.
ii) If heat is evolved from system $d\theta$ will be -ve.
iii) If temp. increases, Internal energy increases So, dU will be +ve.
iv) If temp. decreases then internal energy decreases So, dU will be -ve.
v) If work is done by system then dW be +ve.
vi) If work is done on the system then dW will be -ve.

* Application of first law of thermodynamics:

(a) During isothermal process: In isothermal process, temp. is constant. Then internal energy does not change.

$dU = 0$

From 1st law of thermodynamics

$dQ = dU + dW$

$\boxed{dQ = dW}$

So, In isothermal process the heat energy totally convert into work done.

(b) Isochoric process: In Isochoric process Volm is constant as,

$dW = P.dv$
here $dv = 0$
$dW = 0$

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Using 1st law of thermodynamics

$dQ = dU + dW$

$\boxed{dQ = dU}$

So, heat energy completely convert into change in internal energy.

(c) During Adiabatic process: In adiabatic process heat transfer does not take place So, $d\theta = 0$

From 1st law of thermodynamics

$d\theta = dU + dW$

$0 = dU + dW$

$\boxed{dU = -dW}$

So, some work will be done in changing internal energy.

(d) During cyclic process- In cyclic process system returns to the initial state So, $U_{initial} = U_{final}$

$\Rightarrow dU = 0$

From 1st law of thermodynamics

$dQ = dU + dW$

$dQ = 0 + dW$

$\boxed{dQ = dW}$

* Limitation of first law of thermodynamics:

i) It does not tell about the direction of change
2) It does not tell about the extent of change.

* 2nd law of thermodynamics:

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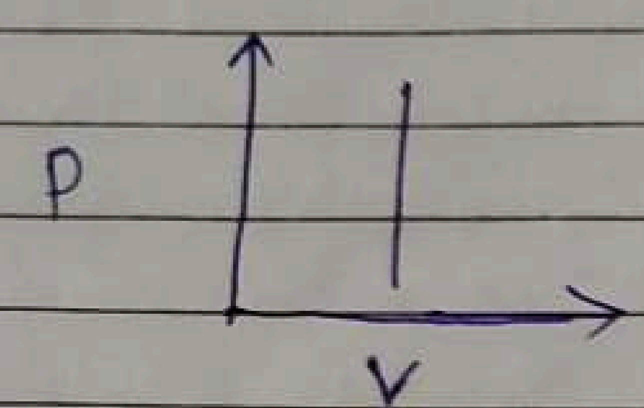
*** Isochoric process:** The thermodynamic process in which volume of system remains constant.

$V = \text{constant}$

*** Indicator diagram:**



*** Workdone –**

$dW = P \cdot dV$

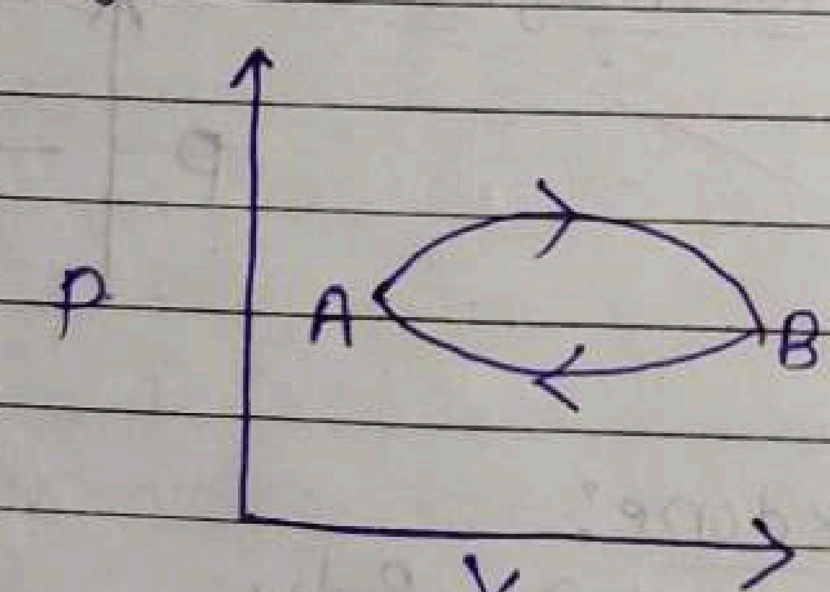
as, $dV = 0$

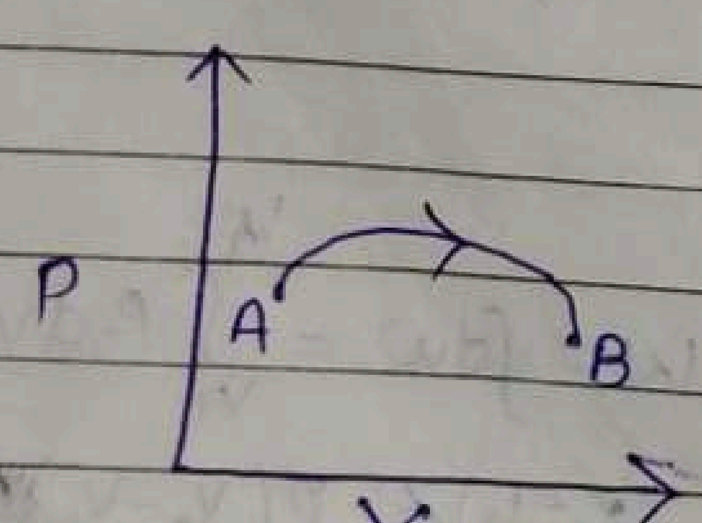
Then, total workdone $= \boxed{W = 0}$

*** Cyclic process:** A cyclic process is that process after which system returns to initial state.

*** Non-Cyclic process:** It is that process after which system does not return to initial state.

*** Graph for cyclic process:**





(non-cyclic graph)

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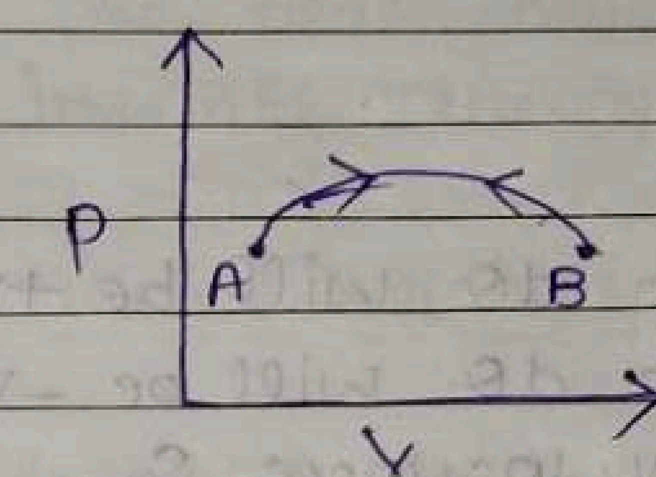
*** Reversible process:** A Reversible process is that process in which system returns to initial state following excatly the same path.



*** Internal energy of a gas:** Internal energy of a gas is the energy possessed by a molecule of a gas. It is denoted by 'U'. It is equal to the sum of K.E and P.E. K.E of a gas is a function of temprature and P.E of a gas is a function of Vol^m.

*** Zeroth law of Thermodynamics:** Acc. to this law if a body 'A' is in thermal equilibrium with a body 'B' and body 'B' is in thermal equilibrium with body 'C' then body 'A' will also be in thermal equilibrium with body 'C'.

If $\boxed{A} \rightleftharpoons \boxed{B}$ and $\boxed{B} \rightleftharpoons \boxed{C}$

then, $\boxed{A} \rightleftharpoons \boxed{C}$

*** 1st law of thermodynamics:** Acc. to this law the change given to the heat of system will be equal to change in internal energy and workdone

Mathematical expression –

In terms of temp...

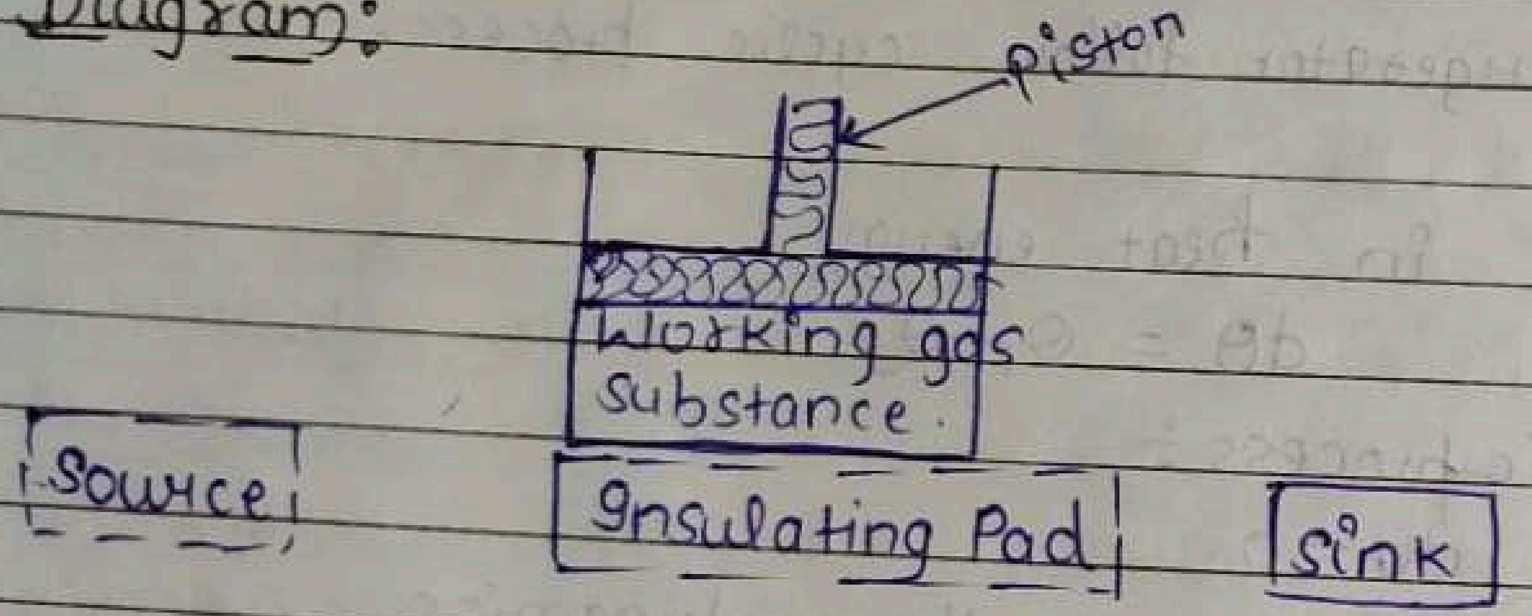
$$\frac{Q_2}{Q_1} = \frac{T_2}{T_1}$$

$$\therefore \boxed{\beta = \frac{T_2}{T_1 - T_2}}$$

* Carnot Heat Engine :

A carnot heat engine is a heat engine with max. efficiency. It is based on carnot cycle. It has four stages.
1) Isothermal expansion 2) Adiabatic expansion 3) Isothermal compression 4) Adiabatic Compression

* Diagram:



* Construction:

A carnot heat engine consist of four main parts.

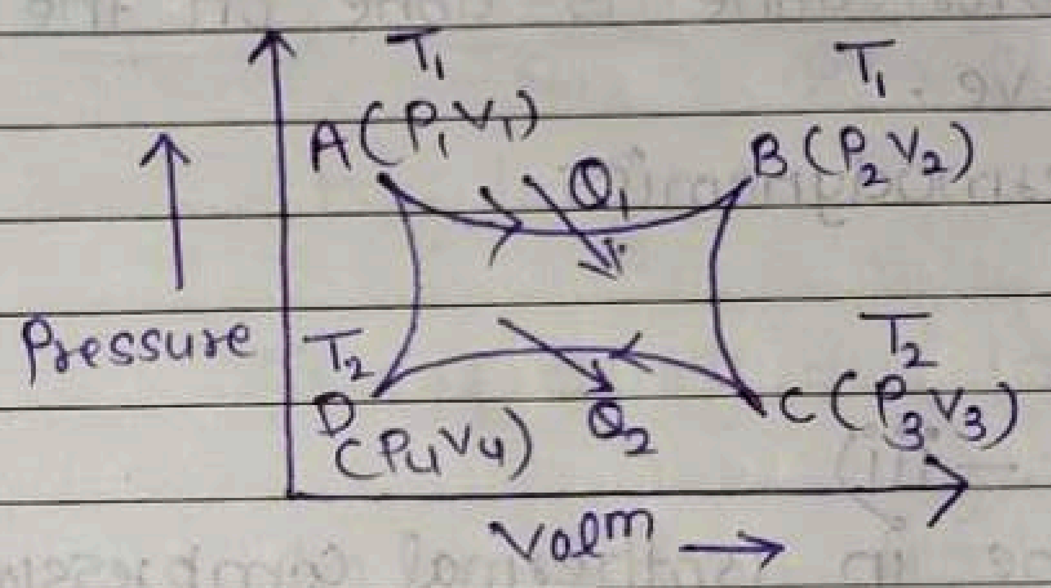
i) Source: It is used to supply heat to the system. Source is kept at high temp. (T_1). Q_1 be the heat supplied by the source.

) Working Substance: Gas is taken in a piston as a working subst. The base of piston is conducting. All other sides of piston is made insulating.

Working substance takes heat Q_1 from source and does workdone (W)

iii) Sink: Sink is kept at low temprature (T_2). Q_2 be the heat escaped from sink.

iv) Insulating Pad: Insulating Pad will act like adiabatic wall and stop heat flow.



Working: Working of Carnot heat engine is based on carnot cycle which completes a cycle following 4 Phases.

i) Isothermal expansion — During isothermal expansion Temp. (T_1) remain constant. Pressure and Volm changes. As temp. is constant so, change in internal energy is also zero. i.e. $dU = 0$

using 1st law of thermodynamics

$$dQ = dU + dW$$
$$dQ = 0 + dW$$
$$dQ = dW$$
$$\boxed{Q_1 = W_1} \quad -\text{ i)}$$

Where W_1 be the Workdone for isothermal expansion.

ii) Adiabatic expansion- W_2 be the workdone in adiabatic expansion. (P_2V_2) and (P_3,V_3) be the corresponding values for pressure and vol^m.

$$W_2 = \frac{R}{1-\gamma}(T_2-T_1) \quad - ii)$$

iii) Isothermal compression: As we move from point $C(P_3V_3)$ to point $D(P_4V_4)$ then isothermal compression takes place.

During compression is workdone is done on the system so, it will be -ve.

Using 1st law of thermodynamics

$$dQ = dV + dW$$
$$dQ = 0 + dW$$
$$\boxed{Q_2 = -W_3} \quad - iii)$$

where W_3 is workdone in isothermal compression

iv) Adiabatic compression:

W_4 be the workdone for adiabatic compression from point $D(P_4,V_4)$ to point $A(P_1V_1)$

$$-W_4 = \frac{R}{1-\gamma}(T_2-T_1) \quad - iv)$$

let 'W' be the total 'workdone' during carnot cycle.

Then, $W = W_1 + W_2 + W_3 + W_4$

Using eq^n 1), 2), 3) & 4)

$$W = Q_1 + \cancel{\frac{R}{1-\gamma}(T_2-T_1)} = Q_2 - \cancel{\frac{R}{1-\gamma}(T_2-T_1)}$$

$\boxed{W = Q_1 - Q_2}$ So, workdone is equal to change in heat energy.

*Efficiency: Let 'η' be the efficiency of heat energy. It is equal to ratio of workdone to the supplied heat by source (Q_1)

$$\eta = \frac{W}{Q_1}$$

as, $W = Q_1 - Q_2$

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

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

$$\%\ \text{efficiency} = \left(1 - \frac{Q_2}{Q_1}\right) \times 100$$

In terms of temp...

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

* A refrigerator works b/w $-10°C$ and $17°C$ find its coff. of performance.

Sol^n $\beta = \frac{T_2}{T_1 - T_2}$

$T_1 = 17 + 273 = 290\,K$

$T_2 = -10 + 273 = 263\,K$

$\beta = \frac{263}{+27} \Rightarrow 9.74$

* Find the efficiency of carnot engine working b/w steam point and ice point

Sol^n $T_1 = 100°C$

$T_2 = 0°C$

$$\left(1 - \frac{273}{373}\right) \times 100$$

$\eta = 1 - \frac{273}{373}$

$\Rightarrow \left(\frac{373-273}{373}\right)\times 100 = \frac{100\times 100}{373} = \frac{10,000}{373} = 26.81\%$

* A carnot engine takes 4200J of heat from a source at 427°C and exhaust it to sink at 27°C.

i) What is the efficiency of heat.
2) Find the heat exhausted to sink. Q_2
3) Find work done by system.

Soln $\eta = \left(1 - \frac{T_2}{T_1}\right)$

$\frac{\cancel{700}}{\cancel{1000}-3}$ $\frac{700-300}{700} \Rightarrow \frac{400}{\cancel{700}}\times \cancel{100}$

$\rightarrow \frac{400}{7} = 57.1$

ii) $\frac{Q_2}{Q_1} = \frac{T_2}{T_1} \Rightarrow \frac{T_2}{T_1}\times Q_1$

$= \frac{300\times \cancel{4200}^{6}}{\cancel{700}} = 1800J$

iii) $Q_1 - Q_2 = 4200 - 1800 \Rightarrow 2400J$

Good
Yadav 19/10/23

Unit-9
Kinetic Theory of Gases

* **Ideal gas/Perfect gas**:- An ideal gas is that gas which obeys gas laws and ideal gas equation.
$PV = nRT$

* **Characteristics of Ideal gas**:

1) The size of molecules of Ideal gas is taken zero
2) The molecules of Ideal gas are very far apart from each other so that force b/w them becomes negligible

At low pressure and high temp. some real gases becomes ideal gas.

Postulates
* **Assumptions of kinetic theory of gases**:

1) A gas has a very large no. of identical molecules which are elastic sphere.
2) The molecule of gas are in continuous random motion
3) The size of gas molecules are very small and gas molecules are very far apart. So, the size of gas molecules is negligible as compared to distance b/w them.
4) They do not exert force on each other except collision
5) The collision of molecules with each other and with container walls are elastic collision.
6) The molecular density of gas is assumed to be uniform.
7) A molecule moves along a straight line b/w any two successive collision.
8) The collisions are instantaneous such that the time of contact during collision is negligible.