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Chapter 1

Basic Concepts

"Thermodynamics" is a Branch of a science which deals with the study of energy interaction and its impact on the properties of system.

or

It is the Branch of a science which deals with the study of 3 E's that is :- (a) Equilibrium
(b) Energy
(c) Entropy

or

It is the Branch of a science which deals with the conversion of Disorganised form of energy into organised form.

SYSTEM :→ Anything under consideration.

or

It is a control region in space over which our attention is focused.

SURROUNDING :→ Anything external to the system.

BOUNDARY :→ which separates system from surrounding.

NOTE :→ (1) Boundary may be real or imaginary.

(2) Real Boundary are represented by continuous line or curve whereas imaginary Boundary are represented by dotted lines or curve.

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③ Boundary may be fixed or movable.

④ It should be consider of nearly zero thickness.

UNIVERSE :→ System + surrounding

* **TYPES OF SYSTEM** :→ ① Open system :→ It is a system in which both mass interaction and energy interaction takes place b/w system and surrounding

Example :→
- Boiler
- Turbine
- Condenser
- Pump
- Compressor
- nozzle
- diffuser
- evaporator.
- piston-cylinder arrangement with valves

② CLOSED system :→ in which only energy interaction takes place between system and surrounding.

Ex :→ • piston - cylinder arrangement without valves.

③ Isolated System :→ in which neither mass interaction nor energy interaction takes place b/w system and surrounding.

Ex :→ • Thermo flask
• Universe

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* Microscopic Approach v/s Macroscopic :→

In the case of microscopic approach, single individual particle is under consideration. It is also known as statistical approach. whereas in the case of macroscopic approach, the time average behaviour of the molecules are under consideration and this approach is also known as classical approach.

NOTE :→ In our thermodynamics, we are ~~consid~~ generally dealing with macroscopic approach.

* CONTINUUM Approach :→ In this approach, we are considering our matter as continuous.

NOTE :→ (a) In case of Rarefied Gases theory, the concept of continuum is not valid.

* THERMODYNAMIC PROPERTY :→ It represents the characteristics of the system.

Types of Property :→ (1) Intensive property or Intrinsic property :→ These properties are independent of mass.

For Example :- P, T, conductivity (K), (α) coefficient of thermal expansion, specific heat, Ratio of two extensive property like density, specific energy (energy / mass) etc.

(2) Extensive Property or Extrinsic Property :→ These are dependent on mass.

For example :- V, ~~old~~ all forms of energy like kinetic energy, enthalpy, internal energy, heat capacity, entropy.

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* **THERMODYNAMIC EQUILIBRIUM** :→ A system is said (5) to be thermodynamic equilibrium if they are in thermal equilibrium, mechanical equilibrium and chemical equilibrium.

Thermal equilibrium is equality of tempr., mechanical equilibrium means equality of forces and pressure & chemical equilibrium means equality of chemical potential.

* **PURE SUBSTANCE** :→ It is a substance of constant chemical composition throughout its volume of mixture irrespective of phase.

Examples :- (1) ice

(2) water

(3) steam

(4) ice (S) + liquid (L) H_2O

(5) Liq (L) H_2O + steam (V)

(6) ice (S) + H_2O (L) + steam (V)

(7) Gases air

NOTE :→ (a) atmospheric air is not a pure substance because the % of water vapour content varies from place to place as we have see that at some places, there is a high humidity and at some places, there is a low humidity.

* **THERMODYNAMIC STATE** :→ It represent the condition of the system.

Path :→ It is obtained by joining 2 equilibrium states.

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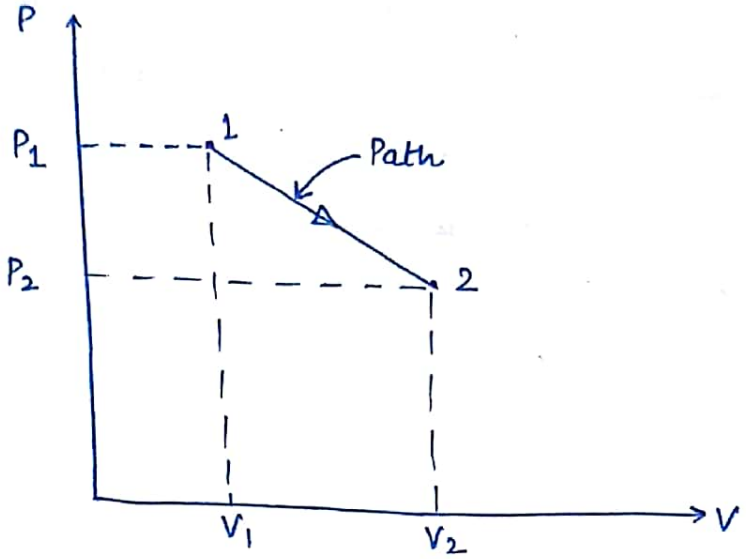
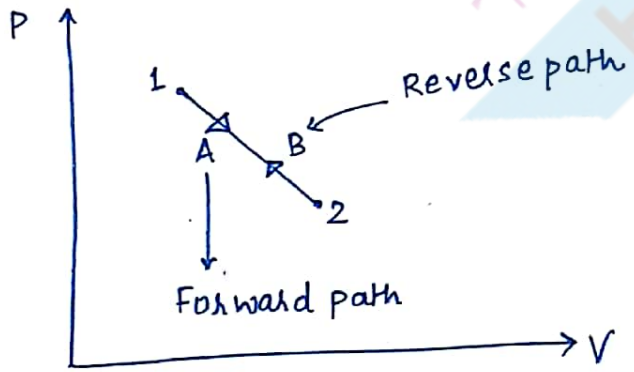


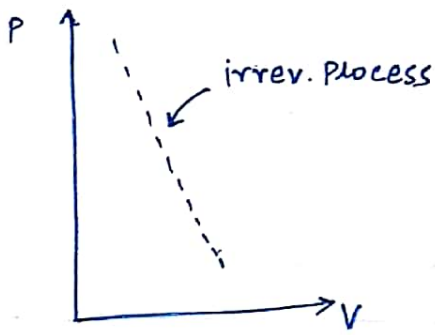
* REVERSIBLE PROCESS & IRREVERSIBLE PROCESS :→

A process is said to be reversible in which system returns to its original state without leaving any effect on the surrounding. Reversible process is possible to achieve practically.

NOTE :→ (a) for the reversible process, both forward path and reversed path has to be same.

(b) Reversible process are represented by continuous line or curve. whereas irreversible process are represented by dotted lines or curves





* METHODS which makes the process irreversible :→

(1) Friction.

(2) Free expansion.

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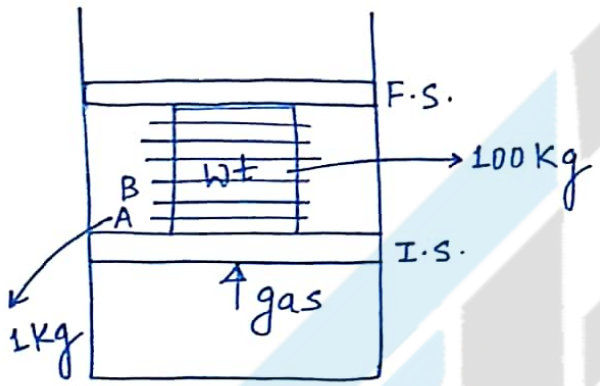
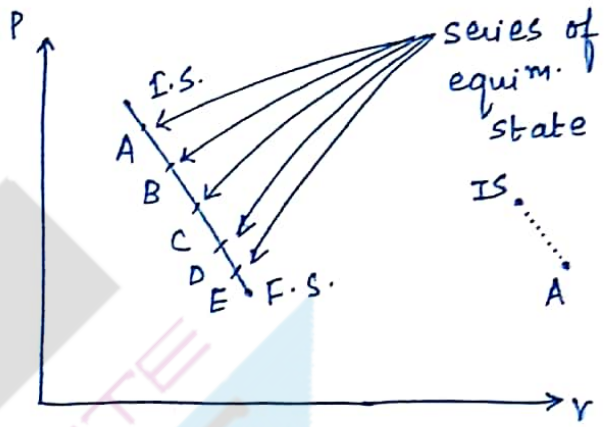
③ Mixing of fluids.

④ Heat transfer through a finite temperature difference.

* **QUASI-STATIC PROCESS** :→ Infinite slowness is a characteristic of the quasi-static process over or it is a process by joining (almost) a series of equilibrium states.

NOTE :→ Quasi-static without friction is a reversible process.

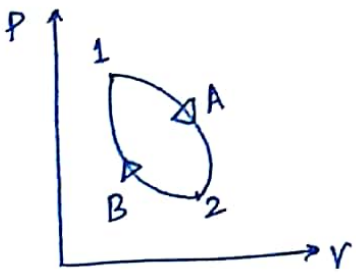




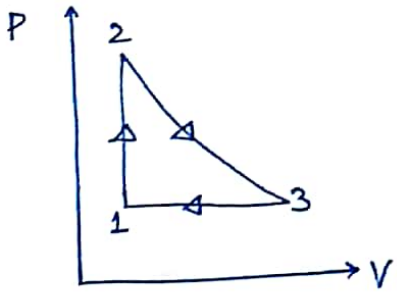
* **CYCLIC PROCESS** :→ A process is said to be cyclic in which initial state and final state are same.

NOTE :→ Minimum no. of process required to make a cycle are

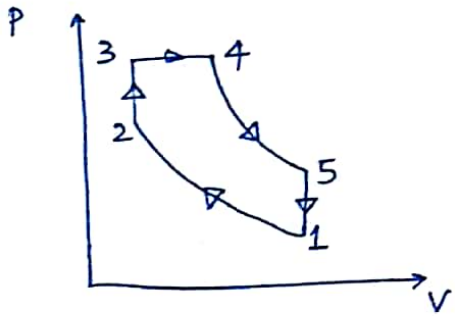
2.



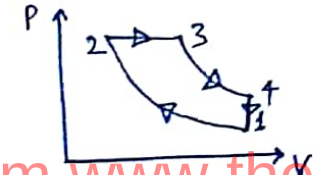
2 Process cyclic



3process cyclic



5 Process cyclic



4process cyclic

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* IDEAL GAS EQUATION :→

Any gas behaves as an ideal gas under low pressure and high temperature and the expression of ideal gas equation is

$$PV = mRT$$

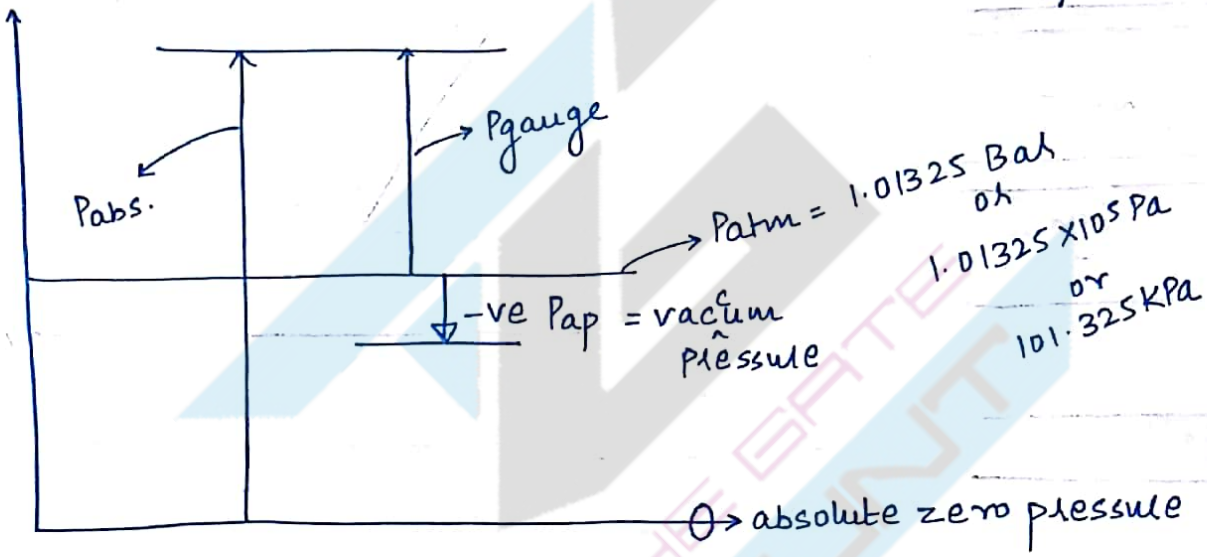
where P is absolute pressure.

V is volume

m is mass

R is characteristics gas constant

T is absolute temperature in (K).



$$\left[P_{ABS.} = P_{atm} + P_{gp} \right]$$

Now, the other form of equation is

$$PV = n\bar{R}T$$

$$n = \text{no. of moles} = \frac{\text{mass } (m)}{\text{Mol. wt. } (M)}$$

$$\therefore \quad PV = \text{mass} \left(\frac{\bar{R}}{\text{Mol. wt}} \right) T$$

$$PV = mRT$$

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so, $R = \frac{\bar{R}}{Mol.wt}$

$\bar{R} = 8.314\ KJ/K\,mole\,K$

NOTE :- (a) $t \rightarrow {}^\circ C$

(b) $T \rightarrow K$

(c) $0^\circ C \rightarrow 273.15\,K$

(d) $(TP)_{Temp\ H_2O} \longrightarrow$ 273.16 K or 0.01°C

(e) $(TP)_{Pressure\ H_2O} \longrightarrow$ 4.587 mm Hg

$P = \rho g h$

$P = 13.6 \times 1000 \times 9.81 \times 4.587 \times 10^{-3}$

$= 611.97\ N/m^2$

or

$0.611\ KPa\ (N/m^2 \times 10^3)$

Unit Conversion

$\frac{kg}{m^3} \times \frac{m}{sec^2} \times m$

$\frac{1\,kg}{m\text{-}sec^2}$

$F = m \times a$

$N = kg \times \frac{m}{s^2}$

$\frac{N}{m} = \frac{kg}{s^2}$

* **THERMOMETRIC PROPERTY** :- The variable which helps us to calculate the value of temperature is known as thermometric property.

Ex :- (1) In case of constant volume gas thermometer, pressure will plays the role of T.P..

(a) $V = C$

$PV = mRT$

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

$T = F(P)$

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② In case of constant pressure gas thermometer, Volume will ~~placed~~ plays the role of thermometric property.

$$P = C$$

$$PV = mRT$$

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

$$\boxed{T = F(V)}$$

③ In case of electrical resistance thermometer, $\boxed{\text{resistance}}$ will plays the role of thermometric property.

④ In case of thermocouple, $\boxed{EMF/\Delta V}$ plays the role of T.P.

⑤ In case of ordinary thermometer, ⓐ $\boxed{\text{length}}$

ⓑ $\boxed{\text{Volume}} \rightarrow \frac{V_2}{V_1} = \frac{A \times L_2}{A \times L_1}$

$\boxed{2/9/2016}$

* $\boxed{\text{TEMPERATURE MEASUREMENT SCALE}}$:→

* $\boxed{\text{Case I :→ Method used before 1954}}$

In this method, two reference points are taken into consideratio that is ice point and steam point.

$$t = ax + b$$

$$t_{ice} = 0°C \longrightarrow x = x_i \longrightarrow 0 = ax_i + b \Rightarrow \boxed{b = -ax_i}$$

$$t_{steam} = 100°C \longrightarrow x = x_s \longrightarrow 100 = ax_s + b$$

$$100 = ax_s - ax_i$$

$$a(x_s - x_i) = 100$$

$$\boxed{a = \frac{100}{x_s - x_i}}$$

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$$t = ax + b$$

$$t = \frac{100x}{x_s - x_i} - \frac{100\, x_i}{x_s - x_i}$$

$$\boxed{t = \frac{100(x - x_i)}{x_s - x_i}}$$

*** Case 2 :→ Method used after 1954**

In this method a single fixed reference point is taken into consideration that is triple point.

For Example :- In case of constant volm. gas thermometer.

$$PV = mRT$$

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

$$T \propto P$$

$$\boxed{T = KP} \quad (1)$$

At Triple Point, $T = T_{TP}$

$P = P_{TP}$

$$\therefore T_{TP} = K P_{TP}$$

$$K = \frac{T_{TP}}{P_{TP}}$$

$$\therefore T = \left(\frac{T_{TP}}{P_{TP}}\right) P$$

$$T = T_{TP}\left(\frac{P}{P_{TP}}\right)$$

$$\boxed{T = 273.16\left(\frac{P}{P_{TP}}\right)}$$

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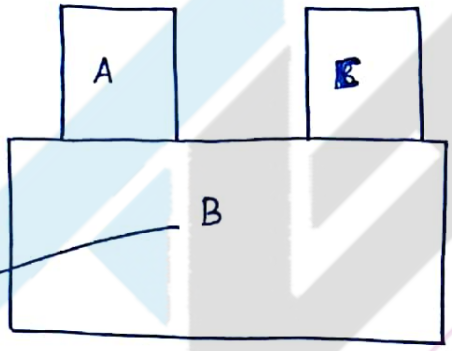
* ZEROTH LAW OF THERMODYNAMICS :→

It was given by R.H. FOWLER.

Statement :→ Acc. to Z.L.O.T., if body A is in thermal equilibrium with body B and Body B is in thermal equilibrium with body C separately, then body A and C will be in thermal equilibrium with each other.

The role played by the common body is of thermometer.

NOTE :→ Zeroth law of thermodynamics provides the concept of thermal equilibrium.



$T_A = T_B$ —— (1)

$T_B = T_C$ —— (2)

By (1) & (2) :→

$\therefore \boxed{T_A = T_C}$

Role played by common body is thermometer

* IDEAL GAS THERMOMETER :→ (IGT)

It is a thermometer which is independent of the material of construction.

* GIBB'S PHASE RULE :→

$$P + F = C + 2$$

P → phase, F → DOF, C → component

* **DOF** → It is the minimum (intensive or extensive variables.) no. of independent variables are required to locate or fix the state of any system ~~or in~~.

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✓ **Case I** :→ Single phase, single component system.

Example :→ Ice

$$P + F = C + 2$$

$$1 + F = 1 + 2$$

$$\boxed{F = 2}$$

✓ **Case II** :→ Two phase, single component system.

Example :→ Ice + water

$$P + F = C + 2$$

$$2 + F = 1 + 2$$

$$\boxed{F = 1}$$

✓ **Case III** :→ Three phase, single component system.

Example :→ Ice + water + steam

$$P + F = C + 2$$

$$3 + F = 1 + 2$$

$$\boxed{F = 0}$$

It is a unique reference point having 0 DOF known as Triple Point.

NOTE :→ $\boxed{1\,K = \frac{1}{273.16}\ (\text{TP Temp}^{r.}\ \text{of } H_2O)}$

* **POINT FUNCTION & PATH FUNCTION** :→

P.F → Point fn. are the variables whose values does not depend on the path followed by the system.

Example → • Pressure
• Volume

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Path functions :→ are the variables whose value depends on the past history of the system.

For example :→ heat and work.

* **Exact Differential** :→ The cyclic integral of the variable is equal to 0.

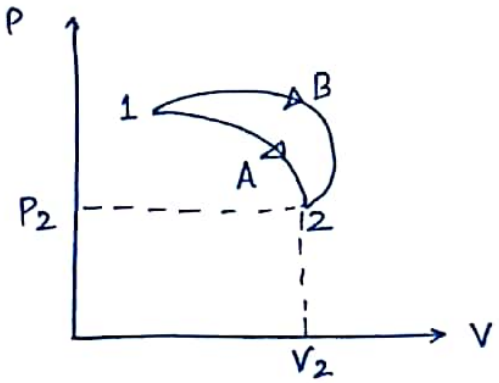
For example :→ P, V

* **Inexact Differential** :→ The cyclic integral of the variable is not equal to 0.

For example :→ heat & work.

NOTE :→ ① All properties are point function and exact differential.

② Heat and work are path function and inexact differential.



P_1 ✓
V_1 ✓
T_1 ✓

W_{1-A-2}

W_{1-B-2}

Q_{1-A-2}

Q_{1-B-2}

P_{1-2}
V_{1-2}

W_1
Q_1

W_{1-2}
Q_{1-2}

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(23) IES 10 marks

$t_A = l + m t_B + n t_B^2$

$t_A = t_B = 0°C \longrightarrow 0 = l + 0 + 0 \Rightarrow \boxed{l = 0}$

$t_A = t_B = 100°C \longrightarrow 100 = m \times 100 + n \times (100)^2 = 0 \rightarrow \boxed{m + 100n = 1}$

$t_A = 51°C$, $t_B = 50°C$ $\longrightarrow 51 = m \times 50 + 2500n \rightarrow 50m + 2500n = 51$

$50m + 5000n = 50$

$-2500n = +1$

$$\boxed{n = \frac{-1}{2500}}$$

$m + 100 \times \frac{-1}{2500} = 1$

$m - \frac{1}{25} = 1$

$m = 1 + 1/25$

$m = 26/25$

$t_A = \frac{26}{25} t_B - \frac{1}{2500} t_B^2$

$t_B = 25°C$

$t_A = \frac{26}{25} \times 25 - \frac{1}{2500} \times 25 \times 25$

$t_A = 25.75°C$ ✓

Both the thermometers are correct because the temperature scales are arbitrary or dependent on the material of construction.

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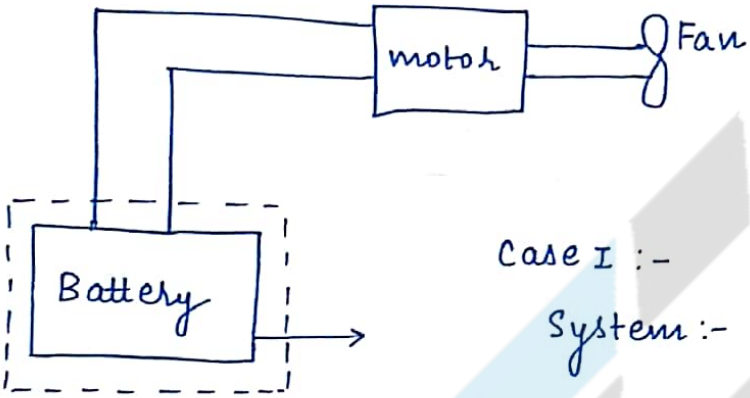
Chapter 2

Energy Interaction

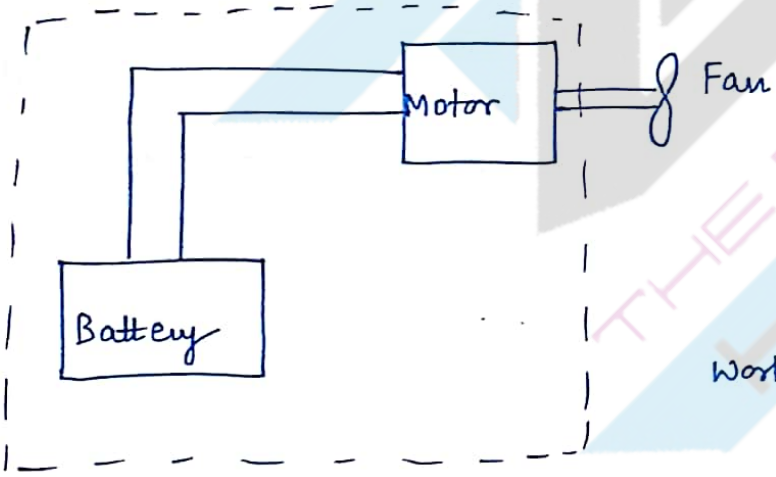
WORK :→ Work is said to be done by the system with the sole effect on things external to the system gets reduced to the raising of weight. (The weight may not be actually raised).



Work ✓

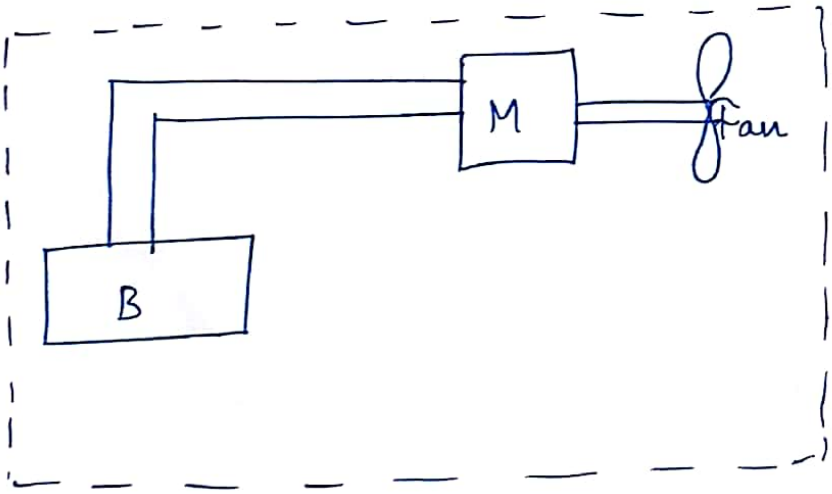
Case I :-

System :- Battery



Case 2 :- System :→ B+M

Work ✓



Case 3 :- system → B+M+F

work ✗

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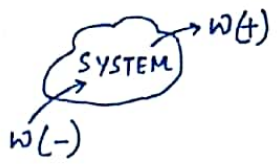
* Sign Convention :-



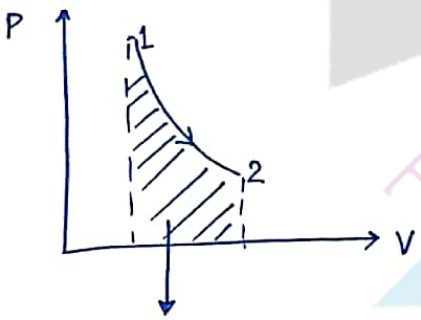
1. W.D. on the system → -ve
2. W.D. by the system → +ve

* TYPES OF WORK :-

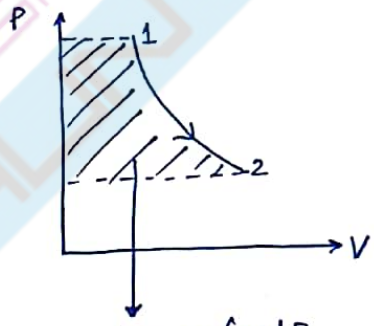
1. **Closed System work or Non-flow work** :- To obtain the closed system work, the area under P-V should be projected on volume axis. and the Mathematically expression for closed system work is $\boxed{\int P dv.}$

2. **Open System work or steady (flow) work** :- To obtain the open system work, area under P-V should be projected on pressure axis and the mathematical expression is

$$\boxed{-\int V dP}$$



$W_{CLOSED} = \int P dV$



$W_O = -\int V dP$

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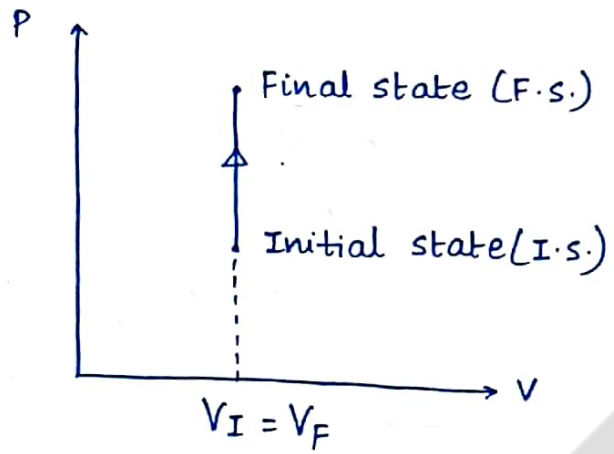
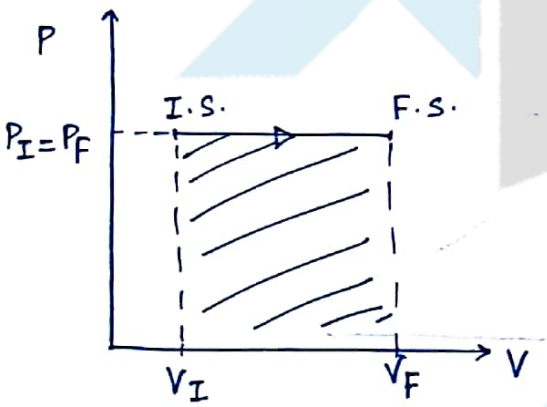
* EXPRESSION OF CLOSED SYSTEM WORK FOR DIFFERENT PROCESS :→

① Constant Volume Process (V = C) or Isochoric process or Isometric Process :→



$\boxed{\text{Zero work}}$

② Constant Pressure Process (P = C) or Iso-baric process or Isopiestic process :→



$$W = \int P\,dV$$

$$= P\int dV$$

$$= PV\Big|_{V_I}^{V_F} = P(V_F - V_I)$$

$$\boxed{W = P(V_F - V_I)}$$

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③ CONSTant Temperature Process (T = C) or isothermal Process or hyperbolic Process :→

$$T = C$$

$$PV = mRT$$

$$PV = C$$

$$\boxed{P = \frac{C}{V}}$$

$$W = \int P\,dV$$

$$W = \int \frac{C}{V}\,dV$$

$$W = C\int_{V_I}^{V_F} \frac{dV}{V}$$

$$W = C \ln V \Big|_{V_I}^{V_F}$$

$$W = C\left[\ln V_F - \ln V_I\right]$$

OBJ

$$\boxed{W = C \ln \frac{V_F}{V_I} \quad \text{or} \quad C \ln \frac{P_I}{P_F}}$$

and

$$\boxed{C = P_I V_I = P_F V_F = mRT_I = mRT_F}$$

$$\frac{V_F}{V_I} = \frac{P_I}{P_F}$$

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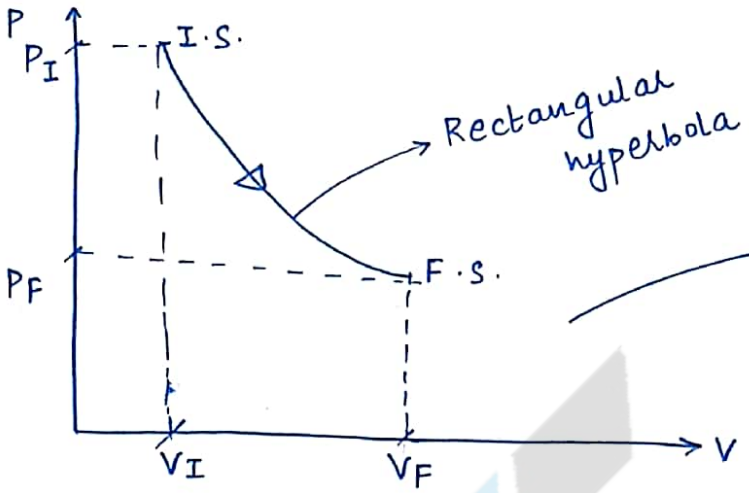
During isothermal expansion as the volume increases by using the expression of closed system for isothermal process, we got "+ve" sign that is workdone by the system.



$V_F > V_I$

$\frac{V_F}{V_I} > 1$

hence

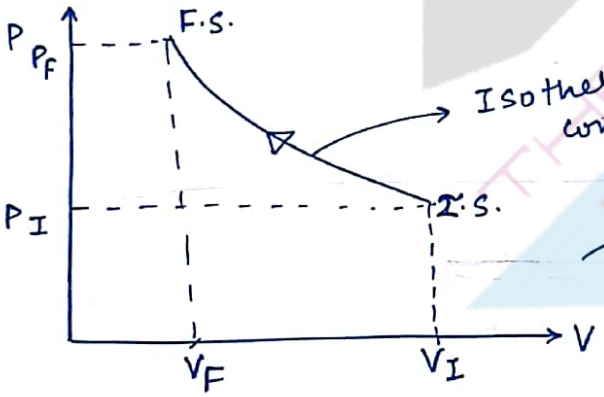
$W = C \ln \frac{V_F}{V_I}$

$\boxed{W = +ve}$

$PV = C$

$P \propto 1/V$

During isothermal compression



$V_F < V_I$

$\frac{V_F}{V_I} < 1$

hence

$W = C \ln \frac{V_F}{V_I}$

$\boxed{W = -ve}$

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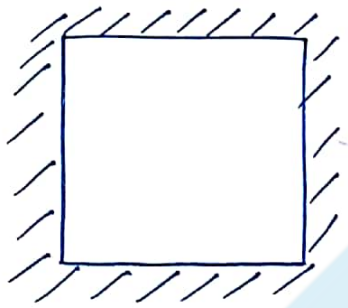
④ Adiabatic Process :→

It is a process in which there is no heat interaction between system and surrounding.

For example :→ insulated vessel.

It will follows a law $\boxed{P * V^{\gamma} = C}$ where γ is the adiabatic index. This is defined as the ratio of specific heat at constant pressure (C_p) to the specific heat at constant volume (C_v).



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

$$\gamma = C_p / C_v$$

For air →

$$\left.\begin{aligned} C_p &= 1.005 \\ C_v &= 0.718 \end{aligned}\right] \text{KJ/Kg K}$$

$$R = C_p - C_v = 0.287 \text{ KJ/Kg K}$$

$$\boxed{\gamma = \frac{C_p}{C_v} = 1.4}$$

Note → ✓ $PV^{\gamma} = C = P_I V_I^{\gamma} = P_F V_F^{\gamma}$

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

$$W = \int P\,dV$$

$$W = \int \frac{C}{V^{\gamma}}\,dV$$

$$W = C \int \frac{dV}{V^{\gamma}}$$

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$$W = C \int_{V_I}^{V_F} V^{-\gamma} dV$$

$$W = C \left[\frac{V^{-\gamma+1}}{1-\gamma} \right]_{V_I}^{V_F}$$

$$W = \frac{C}{1-\gamma} \left[V_F^{1-\gamma} - V_I^{1-\gamma} \right]$$

$$W = \frac{1}{1-\gamma} \left[C V_F^{1-\gamma} - C V_I^{1-\gamma} \right]$$

$$W = \frac{1}{1-\gamma} \left[P_F V_F^{\gamma} V_F^{1-\gamma} - P_I V_I^{\gamma} V_I^{1-\gamma} \right]$$

$$W = \frac{1}{1-\gamma} \left[P_F V_F - P_I V_I \right]$$

OBJ

$$\boxed{W = \frac{P_I V_I - P_F V_F}{\gamma - 1} \quad \text{or} \quad \frac{mR(T_I - T_F)}{\gamma - 1}}$$

⑤ **Polytropic Process** :→ It is exactly similar to adiabatic process except the heat ~~trav~~ interaction is not equal to 0. It will follows a law $\boxed{PV^n = C}$ where n is polytropic index

$$PV^n = C$$

$$1 < n < \gamma$$

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OBJ

$$\boxed{W = \frac{P_I V_I - P_F V_F}{n-1} \quad \text{or} \quad \frac{mR(T_I - T_F)}{n-1}}$$

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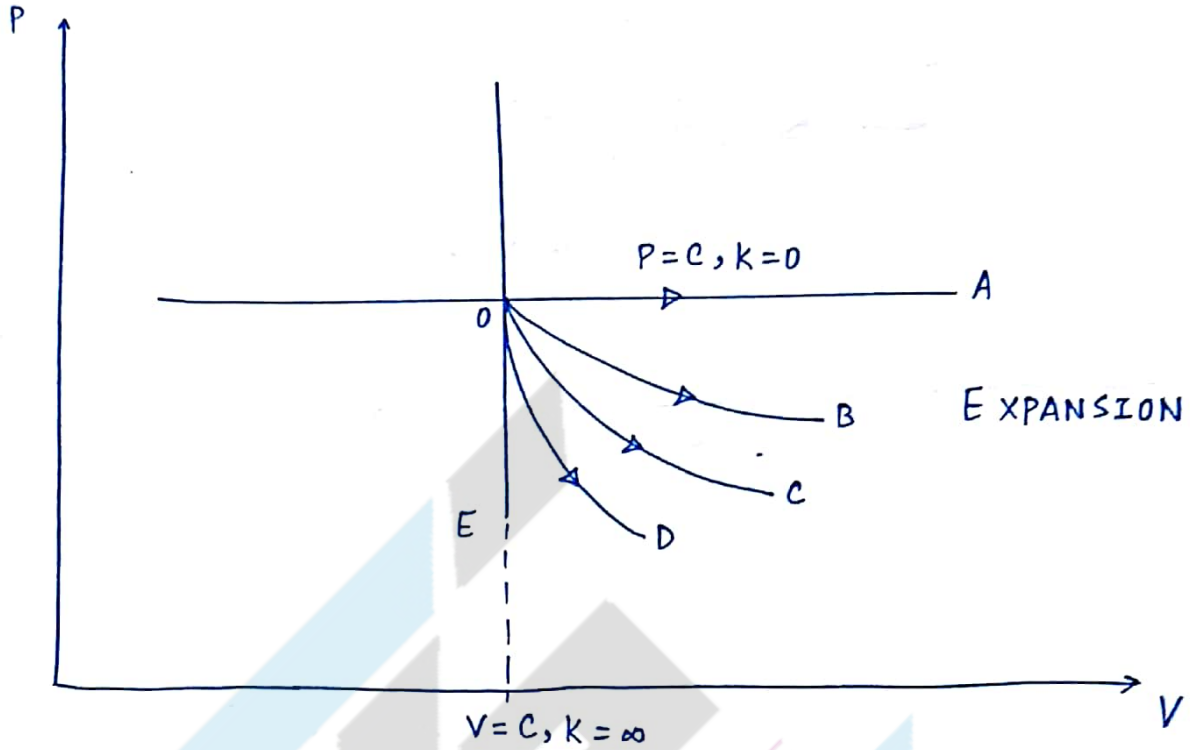
* Representation of all the above processes on the same p-v curve :→



$PV^K = C$

$K=1 \rightarrow PV = C \rightarrow$ isothermal Process

$K=n \rightarrow PV^n = C \rightarrow$ Polytropic Process

$K=\gamma \rightarrow PV^\gamma = C \rightarrow$ Adiabatic Process.

$PV^\gamma = C$

Diff:-

$dP\,V^K + KV^{K-1}\,dV\,P = 0$

$dP\,V^K = -KPV^{K-1}\,dV$

$dP/dV = \dfrac{-KPV^{K-1}}{V^K} = -KPV^{-1}$

OBJ $\boxed{\dfrac{dP}{dV} = K\left(\dfrac{-P}{V}\right)}$ → if $dP = 0 \rightarrow K = 0$ → if $dV = 0 \rightarrow K = \infty$

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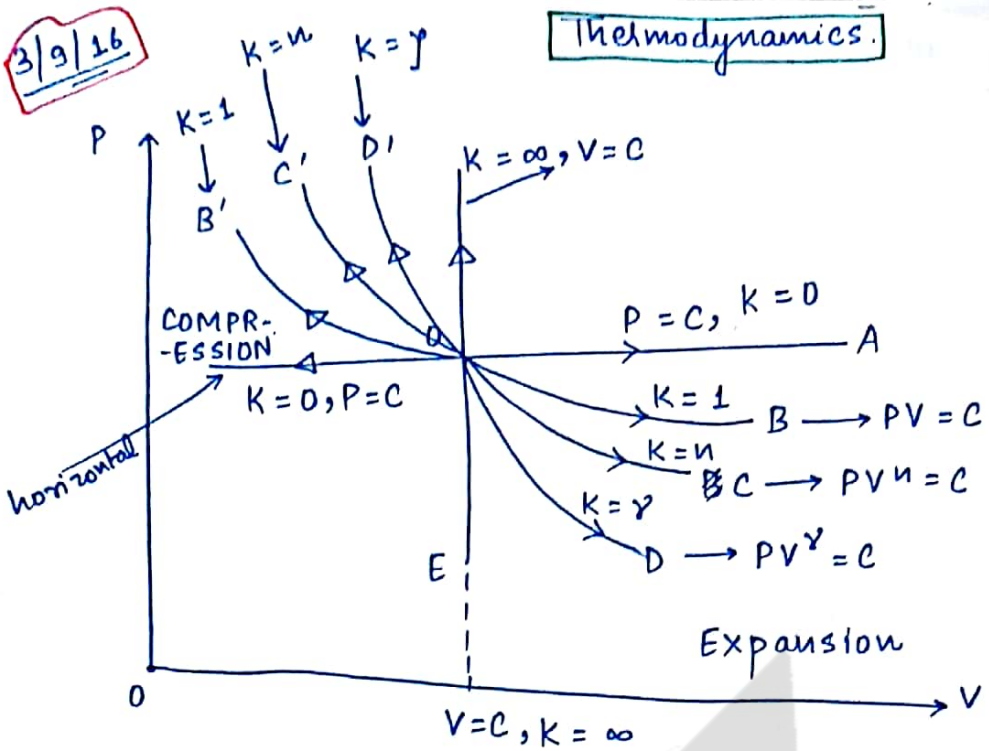
Thermodynamics.

$\gamma > n > 1$



$$\left(\frac{dP}{dV}\right) = K\left(\frac{-P}{V}\right)$$

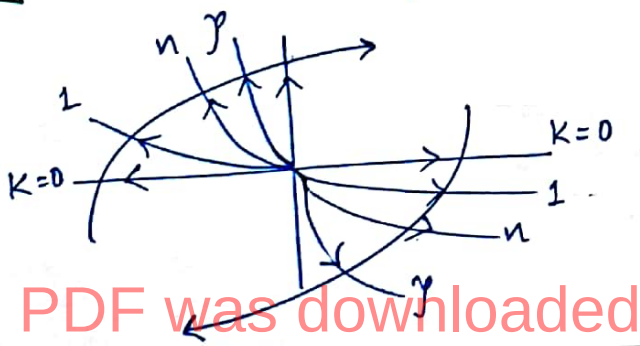
isothermal process $\rightarrow K = 1 \Rightarrow \left(\frac{dP}{dV}\right)_{T=C} = -\frac{P}{V}$

Polytropic process $\rightarrow K = n \Rightarrow \left(\frac{dP}{dV}\right)_{PV^n=C} = n\left(\frac{-P}{V}\right)$

Adiabatic Process $\rightarrow K = \gamma \rightarrow \left(\frac{dP}{dV}\right)_{PV^\gamma=C} = \gamma\left(\frac{-P}{V}\right) = \gamma\left(\frac{dP}{dV}\right)_T$

NOTE :→ The slope of adiabatic process is γ times the slope of isothermal process.

NOTE :→ The value of index is increasing in clockwise direction.



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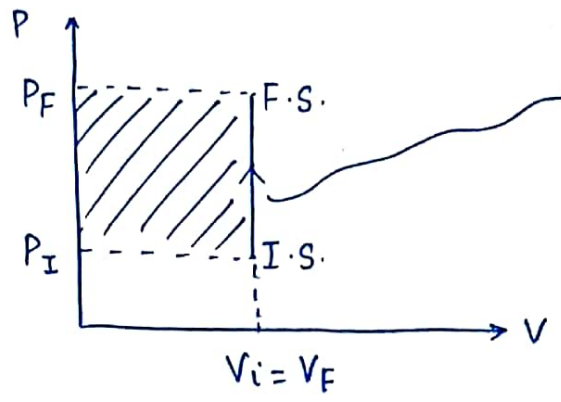
* Expression of open system work for different process:

① Constant Volume (V = c) Process.



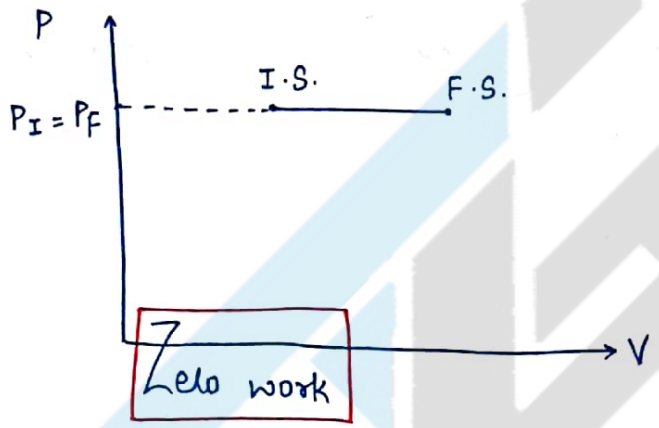
$$W = -\int V\,dP = -V\int dP = -VP\Big|_{P_I}^{P_F}$$

$$W = -V(P_F - P_I)$$

OBJ

$$\boxed{W = V(P_I - P_F)}$$

② Constant Pressure Process (P = c)



③ Constant Temperature Process (T = c)

$$PV = mRT$$

$$PV = c$$

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

$$W = -\int V\,dP$$

$$W = -\int \frac{c}{P}\,dP$$

$$W = -c\int \frac{dP}{P}$$

$$W = -c\ln P\Big|_{P_I}^{P_F}$$

$$W = -c\left[\ln P_F - \ln P_I\right]$$

$$W = -c\ln\frac{P_F}{P_I}$$

OBJ

$$\boxed{W = c\ln\frac{P_I}{P_F} \quad \text{or} \quad c\ln\frac{V_F}{V_I}}$$

$$\boxed{c = P_I V_I = P_F V_F = mRT_I = mRT_F}$$

$$\boxed{\frac{P_I}{P_F} = \frac{V_F}{V_I}}$$

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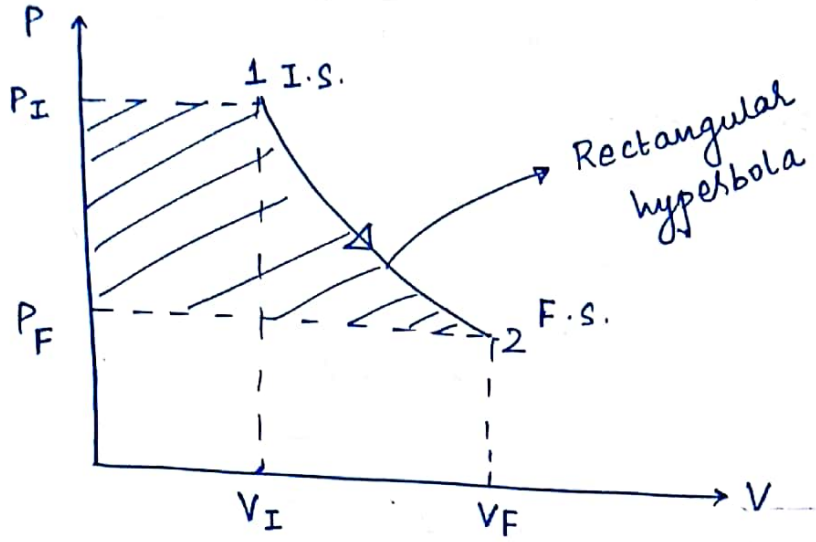


NOTE :→ ① In the case of isothermal Expansion as the volume increases that is expansion of the working fluid takes place by using the expression of open system work for isothermal process. so we got +ve sign of work.

Above diagram
↓
Isothermal expansion

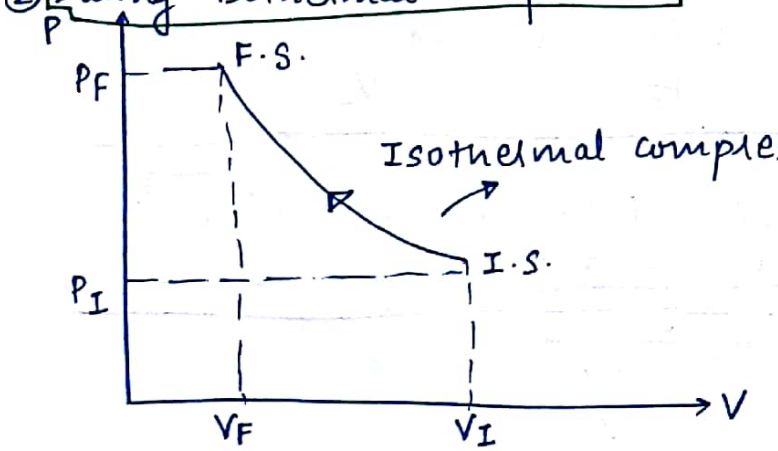
$V_F > V_I$

$$\frac{V_F}{V_I} > 1$$

$$\boxed{W = C \ln \frac{V_F}{V_I}}$$

(thats why we introduce - sign in derivation).

② During isothermal compression :→



$V_F < V_I$

$$\frac{V_F}{V_I} < 1$$

$$\boxed{W = C \ln \frac{V_F}{V_I}}$$

$$\boxed{W = -ve}$$

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③ In the case of isothermal process, the expression of closed system work and open system work are same.

$$PV = mRT$$

$$T = C$$

$$PV = C$$

Differentiate both sides

$$PdV + VdP = 0$$

$$\int PdV = \int -VdP = -\int VdP$$

$$\boxed{W_{CLOSED} = W_{OPEN}}$$

*Imp

④ **ADIABATIC PROCESS ($PV^{\gamma} = C$)**

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

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

$$V = \left(\frac{C}{P}\right)^{1/\gamma}$$

$$W = -\int VdP$$

$$W = -\int \frac{C^{1/\gamma}}{P^{1/\gamma}} dP$$

$$W = -C^{1/\gamma} \int \frac{dP}{P^{1/\gamma}}$$

$$W = -C^{1/\gamma} \int_{P_I}^{P_F} P^{-1/\gamma} dP$$

$$W = -C^{1/\gamma} \left[\frac{P^{1-1/\gamma}}{1-1/\gamma}\right]_{P_I}^{P_F}$$

$$W = \frac{-C^{1/\gamma}}{\left(\frac{\gamma-1}{\gamma}\right)} \left[P_F^{1-1/\gamma} - P_I^{1-1/\gamma}\right]$$

$$W = \left(\frac{\gamma}{\gamma-1}\right) \left[-C^{1/\gamma} P_F^{1-1/\gamma} + C^{1/\gamma} P_I^{1-1/\gamma}\right]$$

$$W = \left(\frac{\gamma}{\gamma-1}\right) \left[-(P_F V_F^{\gamma})^{1/\gamma} P_F^{1-1/\gamma} + (P_I V_I^{\gamma})^{1/\gamma} P_I^{1-1/\gamma}\right]$$

$$W = \left(\frac{\gamma}{\gamma-1}\right) \left[-P_F^{1/\gamma} V_F P_F^{1-1/\gamma} + P_I^{1/\gamma} V_I P_I^{1-1/\gamma}\right]$$

$$W = \gamma \underbrace{\left[\frac{-P_F V_F + P_I V_I}{\gamma - 1}\right]}$$

Obj

$$\boxed{W_{OPEN} = \gamma W_{CLOSED}}$$

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⑤ **POLYTROPIC PROCESS ($PV^n = C$)** :→

$$W_{OPEN} = n \cdot W_{CLOSED}$$

$$= n\left(\frac{P_I V_I - P_F V_F}{n-1}\right)$$

or

$$= n\left[\frac{(mRT_I - mRT_F)}{n-1}\right]$$

* HEAT

It is a form of energy interaction due to temperature

Expression for heat is → $dQ = mC\Delta T$

where C is specific heat

ΔT is the temperature difference either in °C or K.

* **SPECIFIC HEAT** :→ It is the amount of heat which is required to raise the temperature of unit mass by unit tempr. difference.

units → • KJ/KgK

$$C = \frac{dQ}{m\Delta T}$$

(1) (1)

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NOTE :→ (1) In the case of solids and liquids, there is a single value of specific heat whereas in the case of gases, it depends on the process.

$$\left.\begin{aligned} C_{H_2O} &= 4.187 \\ C_p &= 1.005 \\ C_v &= 0.718 \end{aligned}\right] KJ/Kg$$

(2) The value of adiabatic specific heat is zero and isothermal specific heat is ∞

$$dQ = mC\Delta T$$

$$C = \frac{dQ}{m\Delta T}$$

$C_{adiabatic} = 0$

$\downarrow$

$dQ = 0$

$C_{isothermal} = \infty$

$\downarrow$

$\Delta T = 0$

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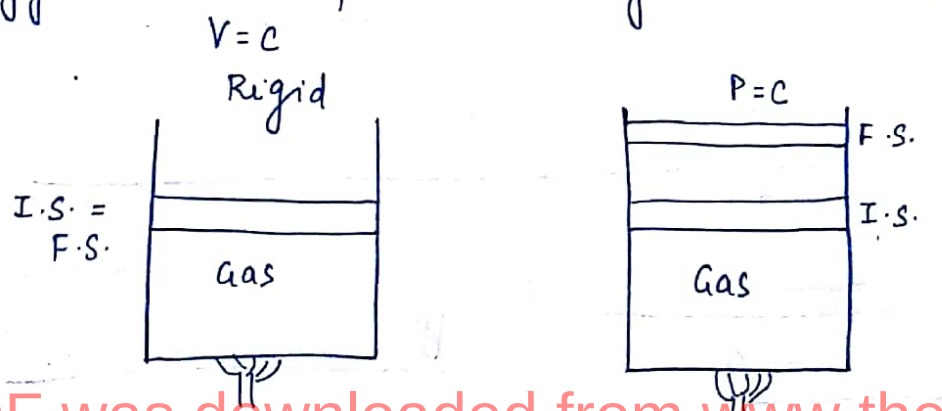
Q.> Why the value of C_p is always greater than C_v ?

Ans> In the case of constant volume process, complete heat is utilized to increase the internal energy of the gaseous molecule whereas in the case of constant Pressure process some part of the heat is utilised to increase the internal energy and some part in doing some external work.



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* SIGN CONVENTION :→

① Heat supplied to the system

$$Q_{supplied} = +ve$$

② Heat Rejected from the system

$$Q_{Rejected} = -ve$$

* TYPES OF HEAT :→

① **Sensible heat** → It is a form of energy interaction by the virtue of temperature difference.

② **Latent heat** → It is the amount of heat required to cause the phase change.

$$\text{Sensible heat} = mC\Delta T$$

$$\text{Latent heat} = m(LH)_{S/V/F}$$

$-10°C$ ice $\xrightarrow{SH}$ $0°C$ ice $\xrightarrow{LH}$ $0°C$ H_2O $\xrightarrow{SH}$ $100°C$ H_2O $\xrightarrow{LH}$ $100°C$ H_2O vapour $\xrightarrow{SH}$ $150°C$ superheated steam

* Ist LAW OF THERMODYNAMICS :→

OR

LAW OF CONSERVATION OF ENERGY :→

OR

JOULES LAW :→ OR **QUANTITATIVE LAW :→**

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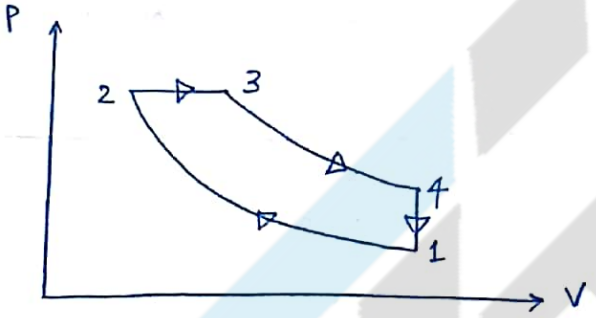
Statement :→ "Energy can neither be created nor be destroyed rather it converts from one form of energy to another form"

OR

"for a Closed System undergoing a cyclic process, the net heat interaction is equal to net work interaction when they are expressed in their own units"

$$\boxed{\oint \delta Q = \oint \delta W} \quad \text{—— (1)}$$



$$Q_{1-2} + Q_{2-3} + Q_{3-4} + Q_{4-1} = W_{1-2} + W_{2-3} + W_{3-4} + W_{4-1}$$

The equation no. (1) is applicable for both reversible process and irreversible process.

Q.> What is the problem with eqn. 1 ?

Ans.> The equation no. 1 is applicable only for a cycle or not applicable for a single process (like 1 ⟶ 2)

* **CONSEQUENCES OF FIRST LAW OF THERMODYNAMICS :→**

"[N.P.]"

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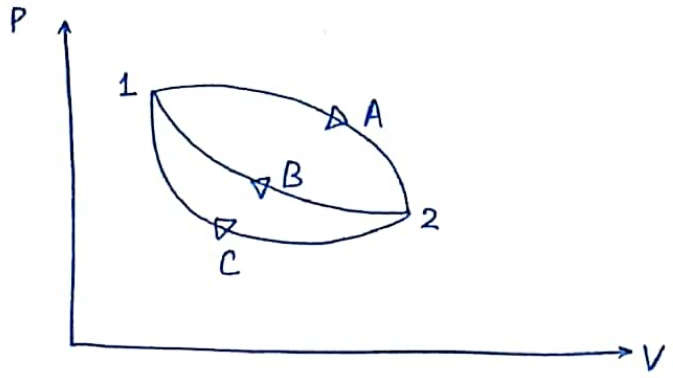
① **Heat transfer is a path function**



$1-A-2-B-1 :\rightarrow \quad Q_{1-A-2} + Q_{2-B-1} = W_{1-A-2} + W_{2-B-1}$ —— (A)

$1-A-2-C-1 :\rightarrow \quad Q_{1-A-2} + Q_{2-C-1} = W_{1-A-2} + W_{2-C-1}$ —— (B)

$-\qquad -\qquad -\qquad -$

$$Q_{2-B-1} - Q_{2-C-1} = W_{2-B-1} - W_{2-C-1} \quad \text{—— (C)}$$

$$W_{2-B-1} - W_{2-C-1} \neq 0$$

$$Q_{2-B-1} - Q_{2-C-1} \neq 0$$

$$\boxed{Q_{2-B-1} \neq Q_{2-C-1}}$$

.....hence, heat transfer is a path function, proved —.....

② **Energy is a PROPERTY**

using above equ. no (C)

$$Q_{2-B-1} - Q_{2-C-1} = W_{2-B-1} - W_{2-C-1} \quad \text{—— (C)}$$

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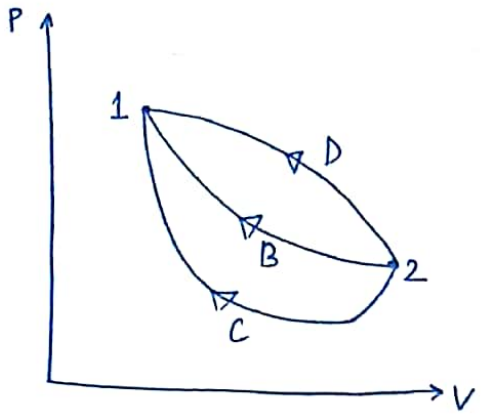


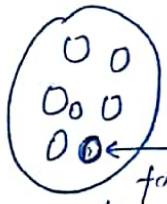
$$Q_{2-B-1} - W_{2-B-1} = Q_{2-C-1} - W_{2-C-1}$$
$$= Q_{2-D-1} - W_{2-D-1}$$

$$\delta Q - \delta W = dE \quad (\because \text{Point fn} \rightarrow \text{exact diff.})$$

$$\boxed{\delta Q = dE + \delta W} \quad (2)$$

$$\boxed{\delta Q = dE + \delta W}$$

$$dE = d(\underbrace{\cancel{KE}^{\,0} + \cancel{PE}^{\,0}}_{\text{macroscopic form}} + \underbrace{U}_{\text{microscopic form}})$$

$U \rightarrow$ 

$$\boxed{dE = dU}$$

$$\boxed{\delta Q = dU + \delta W} \quad (3)$$ (Assumption :- Neglect KE, PE)

* **Condition for Applying PdV work** :→

1. It should cross the Boundary.
2. It should be a closed system.
3. It should be a reversible process.

$$\boxed{\delta Q = dU + PdV} \quad (4)$$

The eqn. (4) is applicable for a reversible process and closed system.

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③ **Energy of a isolated system is CONSTANT**

$$\delta Q = dE + \delta W$$

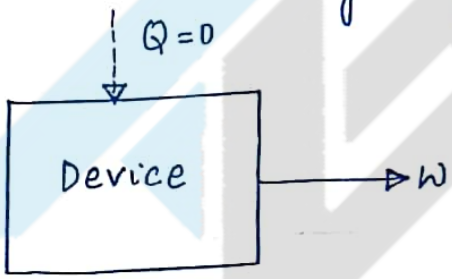
$$\boxed{dE = 0} \rightarrow \text{change in energy}$$

$$E_F - E_I = 0$$

$$\boxed{E_F = E_I} \rightarrow \text{energy constant.}$$

④ **PMM-1** :→ Perpetual motion machine of 1st kind is impossible because it violates 1st law of thermodynamics.

It is impossible to construct a device which produces work continuously without consuming any other form of energy.



$$\boxed{\oint \delta Q = \oint \delta W}$$

* **EXPRESSION OF HEAT FOR DIFFERENT PROCESSES** :→

① **Constant Volume Process (V = c)** :→

$$dQ = dU + PdV$$

$$V = c$$

$$dV = 0$$

$$\boxed{dQ = dU} \quad (1)$$

$$\boxed{dQ = mC_v\Delta T} \quad (2)$$

Compare eqn. (1) & (2)

$$\boxed{\text{imp} \quad dU = mC_v\Delta T}$$

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① The expression $\boxed{dU = mC_v\Delta T}$ is applicable for all processes because it contains all point functions.

② Internal Energy is a function of temperature only for ideal gas.

* **ENTHALPY** :→ It represents the total heat content of the system and the mathematical expression for the enthalpy is Imp

$$\boxed{H = U + PV}$$

Unit → Joule → NM
ML^2T^{-2}

* **Specific Enthalpy** :→ It is a summation of specific internal energy and flow work.

$$h = \frac{H}{m} = \frac{U}{m} + P\left(\frac{V}{m}\right)$$

$$\boxed{h = u + Pv}$$

flow work

* **Flow Work** :→ It is the amount of work which is require to displace a infinitely small fluid element into or out of the control volume is known as Flow work.

NOTE :→ ⓐ Control Volume is also known as Open system and the Boundary of Control Volume is known as Control surface.

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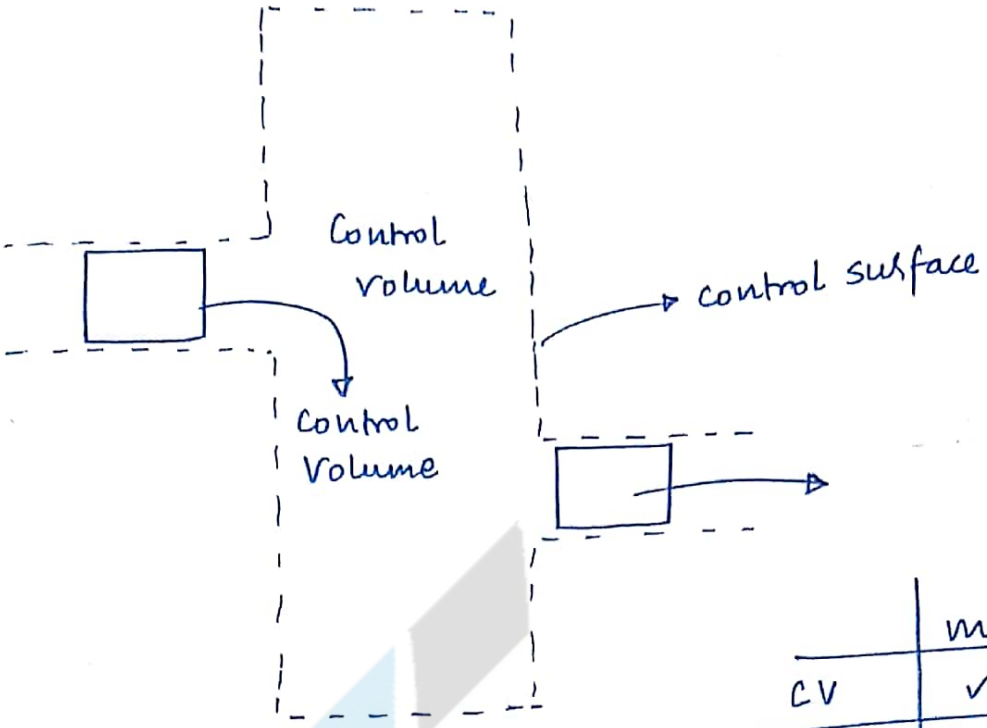
(b) Control mass is also known as close system.



	mI	EI
CV	✓	✓
CM	✗	✗

(a) **Constant Pressure Process (P = c)**

$P = C$

$đQ = dU + PdV$

$P = C$

$đQ = dU + d(PV)$

$đQ = d(U + PV)$

$$\boxed{đQ = dH} \quad (1)$$

$$\boxed{dQ = mC_p\Delta T} \quad (2)$$

on comp. (1) & (2) eqn :→

$$\boxed{dH = mC_p\Delta T}$$

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Note :→ ① Enthalpy is a function of temperature only for ideal gas

② The expression for $\boxed{dH = mC_p\Delta T}$ is applicable for all processes because it contains all properties and all properties are point function.

③ **ISOTHERMAL PROCESS (T = C)** :→

$T = C$

$dQ = \cancel{dU}^{\,0} + PdV$

$T = C$

$dT = 0$

$mC_v dT = 0$

$dU = 0$

OBJ

$$\boxed{dQ = dW = C\ln\frac{V_F}{V_I} \text{ or } C\ln\frac{P_I}{P_F}}$$

$$\boxed{C = P_I V_I = P_F V_F = mRT_I = mRT_F}$$

④ **Adiabatic Process ($PV^\gamma = c$)** :→ It is a process in which there is no heat interaction between system and surrounding.

Example :- Insulated Tank.

Q.> Prove that there is no heat interaction in adiabatic process?

Sol.> $PV^\gamma = C$

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* **Relationship between C_p, C_v, R and γ :→**

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

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

$$R = C_p - C_v$$

$$R = \gamma C_v - C_v$$

$$R = (\gamma - 1) C_v$$

$$C_v (\gamma - 1) = R$$

OBJ

$$C_v = \frac{R}{\gamma - 1}$$

$$C_p = \frac{R\gamma}{\gamma - 1}$$

Previous Qn Proof :→

$$dQ = dU + PdV$$

$$dQ = mC_v dT + \frac{P_I V_I - P_F V_F}{\gamma - 1}$$

$$dQ = mC_v (T_F - T_I) + \frac{P_I V_I - P_F V_F}{\gamma - 1}$$

$$PV = mRT$$

$$\neq mC_v T$$

$$dQ = m\frac{R}{\gamma - 1}(T_F - T_I) + \frac{P_I V_I - P_F V_F}{\gamma - 1}$$

$$= \frac{P_F V_F - P_I V_I}{\gamma - 1} + \frac{P_I V_I - P_F V_F}{\gamma - 1}$$

$$= \text{Zero}(0)$$

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Q.> Prove that $\boxed{PV^{\gamma} = C}$ for a reversible adiabatic process?

(41)

Sol

$$\cancel{dU = mC_v dT}$$
$$\cancel{dH = mC_p dT}$$

$$dQ = dU + PdV$$

$$dQ = mC_v dT + PdV$$

Rev. Adiabatic :→ $dQ = 0$

$$mC_v dT + PdV = 0$$

$$\boxed{mC_v dT = -PdV} \quad (1)$$

$$H = U + PV$$

Diff :-

$$dH = dU + PdV + VdP$$

$$dQ = dU + PdV$$

$$dH = dQ + VdP$$

imp

$$\boxed{dQ = dH - VdP}$$

Rev. adiabatic :- $dQ = 0$

$$dH - VdP = 0$$

$$dH = VdP$$

$$\boxed{mC_p dT = VdP} \quad (2)$$

$$(2)/(1) \quad \frac{\cancel{m}C_p \cancel{dT}}{\cancel{m}C_v \cancel{dT}} = \frac{-VdP}{PdV}$$

$$\frac{C_p}{C_v} = \gamma = -\left(\frac{V}{dV}\right)\left(\frac{dP}{P}\right)$$

$$\frac{C_p}{C_v} = \gamma = -\left(\frac{V}{dV}\right)\left(\frac{dP}{P}\right)$$

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

$$\int \frac{dP}{P} + \gamma \int \frac{dV}{V} = \int 0$$

$$\ln P + (\ln V)\gamma = \ln C$$

$$\ln P + \gamma \ln V = \ln C$$

$$\ln P + \ln V^{\gamma} = \ln C$$

$$\ln PV^{\gamma} = \ln C$$

$$\boxed{PV^{\gamma} = C}$$

... — HP. — ...

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Q. Prove that $\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\gamma-1/\gamma} = \left(\frac{V_1}{V_2}\right)^{\gamma-1}$

$$\frac{T_F}{T_I} = \left(\frac{P_F}{P_I}\right)^{\frac{\gamma-1}{\gamma}} = \left(\frac{V_I}{V_F}\right)^{\gamma-1}$$

for reversible adiabatic process executed by this gas ?

Sol

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

$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$

using $PV^{\gamma} = C$

$PV = mRT$

or

using $PV = mRT$

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

$PV^{\gamma} = C$

$\left(\frac{T}{V}\right) V^{\gamma} = C$

$TV^{\gamma-1} = C$

$T_I V_I^{\gamma-1} = T_F V_F^{\gamma-1}$

$$\boxed{\frac{T_F}{T_I} = \left(\frac{V_I}{V_F}\right)^{\gamma-1}} \quad \text{—— (1)}$$

$PV = mRT$

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

$PV^{\gamma} = C$

$P\left(T/P\right)^{\gamma} = C$

$P^{1-\gamma} T^{\gamma} = C$

$P_F^{1-\gamma} T_F^{\gamma} = P_I^{1-\gamma} T_I^{\gamma}$

$\left(\frac{T_F}{T_I}\right)^{\gamma} = \left(\frac{P_I}{P_F}\right)^{1-\gamma}$

$$\boxed{\frac{T_F}{T_I} = \left(\frac{P_F}{P_I}\right)^{\frac{\gamma-1}{\gamma}}} \quad \text{—— (2)}$$

from (1) & (2) & compr.

.... —hence, proved— ....

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5 POLYTROPIC PROCESS :→

γ
n
P_I
V_I
P_F
V_F

$$dQ = dU + PdV$$

$$dQ = mC_v dT + \frac{P_I V_I - P_F V_F}{n-1}$$

$$= m\frac{R}{\gamma-1} dT + \frac{P_I V_I - P_F V_F}{n-1}$$

$$= m\frac{R}{\gamma-1}(T_F - T_I) + \frac{P_I V_I - P_F V_F}{n-1}$$

$$= \frac{P_F V_F - P_I V_I}{\gamma-1} + \frac{P_I V_I - P_F V_F}{n-1}$$

$$dQ = \frac{P_I V_I - P_F V_F}{n-1} - \frac{P_I V_I - P_F V_F}{\gamma - 1}$$

$$= (P_I V_I - P_F V_F)\left[\frac{1}{n-1} - \frac{1}{\gamma-1}\right]$$

$$= (P_I V_I - P_F V_F)\left[\frac{\gamma - \cancel{1} - n + \cancel{1}}{(n-1)(\gamma-1)}\right]$$

$$= \left[\left(\frac{P_I V_I - P_F V_F}{n-1}\right)\right]\frac{(\gamma-n)}{(\gamma-1)}$$

OBJ

$$\boxed{dQ = \left(\frac{\gamma-n}{\gamma-1}\right) W_{CLOSED}}$$

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* Polytropic Specific Heat :-

$$dQ = \left(\frac{\gamma - n}{\gamma - 1}\right) W_{CLOSED}$$

$$dQ = \left(\frac{\gamma - n}{\gamma - 1}\right)\left(\frac{P_I V_I - P_F V_F}{n-1}\right)$$

$$dQ = \left(\frac{\gamma - n}{\gamma - 1}\right) \frac{mR(T_I - T_F)}{n-1}$$

$$dQ = m\left[\frac{(\gamma - n)}{(\gamma - 1)} \times \frac{R}{n-1}\right](T_I - T_F)$$

m C ΔT

$$= m\left[\left(\frac{n-\gamma}{\gamma-1} \times \frac{R}{n-1}\right)\right](T_F - T_I)$$

$$\boxed{C_{pv^n = c} = \frac{C_v(n-\gamma)}{n-1}}$$

Imp $\boxed{\gamma > n > 1}$ -ve

$pv^n = c$

R

γ $\frac{C_p}{C_v} = \gamma$

n

$C_p - C_v = R$

$dQ = du + P\,dV$

$mC_v dT$

NOTE :- The value of polytropic specific heat is -ve if the value of $\gamma > n > 1$.

Q.> Prove Meyer's Equation :- $C_p - C_v = R$.

$C_p = \frac{dQ}{m\Delta T}$

$C_v = \frac{dQ}{}$

Proof :- $H = U + PV$

diff :-

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$Cp - Cv = R$

$dQ = mCv\,dT + PdV$

PdV

$$dH = dU + d(PV)$$

$$dH = dU + d(mRT)$$

$$\cancel{m}Cp\,\cancel{dT} = \cancel{m}Cv\,\cancel{dT} + \cancel{m}R\,\cancel{dT}$$

$$Cp = Cv + R$$

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

—Hence, proved—....

* Important Points regarding heat and work :→

✓ **Similarities** :→ (a) Both are path function.

(b) Both are inexact differential.

(c) Both are Boundary phenomenon.

(d) Both are energy in Transit or Transient phenomenon.

✓ **Differences** :→ (a) All the forms of energy interaction are work interaction except energy interaction due to tempr. difference.

(b) Area under P-V provides work interaction and area under T-S provides heat interaction.

NOTE :- (1) All the work producing devices are shown in clockwise direction on P-V and T-S diagram.

Ex :- Carnot Cycle ; otto cycle ; rankine cycle ; etc.

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(2) all the work absorbing devices are shown in anticlockwise direction on P-V and T-S.

For Example :- Reversed Carnot Cycle, Reversed Brayton Cycle

IES
2013
10 Marks

Q.> A spherical Balloon of 1m dia. contains a gas at 150 KPa. The gas inside the Balloon is filled under the pressure reaches for 50 KPa. during the process of heating, the pressure of the gas inside the Balloon is proportional to the cube of the diam. of Balloon. Find the workdone by the gas inside the Balloon?

Sol.> Sphere

$D_1 = 1m$

$P_1 = 150 KPa$

$P_2 = 450 KPa$

$P \propto D^3$

$\boxed{W = ?}$

$V = \frac{4}{3}\pi R^3 = \frac{\pi D^3}{6}$

$dV = \frac{\pi}{6} \times 3D^2 \times \delta D$

$\boxed{dV = \frac{\pi D^2}{2} \delta D}$

$P \propto D^3$

$\boxed{P = KD^3}$

$W = \int P dV$

$W = \int_{D_1}^{D_2} KD^3 \times \frac{\pi D^2}{2} \delta D$

$W = \int_{D_1}^{D_2} \left(\frac{K\pi}{2}\right) D^5 \delta D$

$W = \frac{K\pi}{2} \int_{D_1}^{D_2} D^5 \delta D$

$W = \frac{K\pi}{2} \left[\frac{D^6}{6}\right]_{D_1}^{D_2}$

$W = \frac{K\pi}{12} [D_2^6 - D_1^6]$

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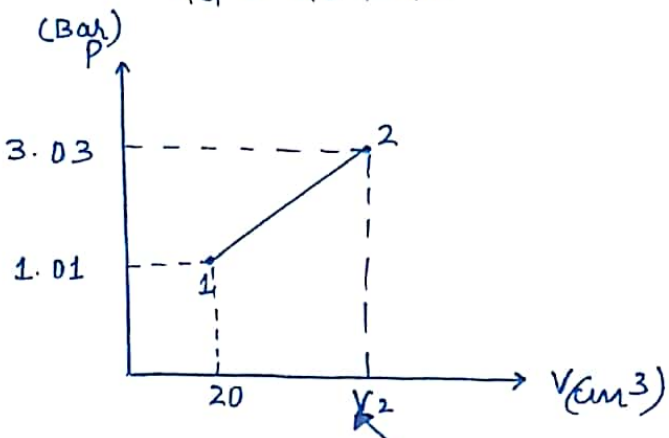
$dQ = dU + dW$



$\Rightarrow V_2 - V_1 = A_p x$

$\Rightarrow V_2 - 20\times10^{-6} = 4\times10^{-4} x$ —— (1)

$\hookrightarrow \boxed{V_2 = 23.23\,cm^3}$

$P_{sp} = \frac{F}{A_p} = \frac{kx}{A_p}$

$P_{sp} = \frac{104x}{4\times10^{-4}}$ —— (2) $\frac{N/m}{m^2}$

$\frac{N}{m^2}$

$x = 8.08\times10^{-3} m$

$P_2 = P_{Atm} + P_{sp}$

$3.03 = P_{Atm} + P_{sp}$ —— (3)

$P_1 = P_{Atm} = 1.01$ Bar

$\hookrightarrow P_{sp} = 2.02$ Bar

$W = \frac{1}{2}(1.01 + 3.03)\times10^5 * (23.23 - 20)\times10^{-6}$

$= 0.656$ Joule

$dU = mC_v(T_2 - T_1)$

$dU = m\frac{R}{\gamma-1}(T_2 - T_1)$

$= \frac{P_2V_2 - P_1V_1}{\gamma-1}$

$\Rightarrow 12.58$ Joule

$dQ = 12.58 + 0.656$

$= 13.25$ Joule

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* STEADY FLOW ENERGY EQUATION (SFEE) :→

Steady flow means when the properties does not varies with respect to time. that is mass flow rate at the entry and exit of control volume is same.

Let us assume h is a specific enthalpy

KE is a specific kinetic energy

$PE \longrightarrow$ specific potential energy

$u \longrightarrow$ specific Internal energy

$Pv \rightarrow$ flow work

$C \rightarrow$ velocity

$z \rightarrow$ Datum head

$\dot{m} \rightarrow$ mass flow rate

$\dot{Q} \rightarrow$ rate of heat transfer

$\dot{W} \rightarrow$ rate of work transfer

Subscript ① & ② represents the Inlet & outlet section properties

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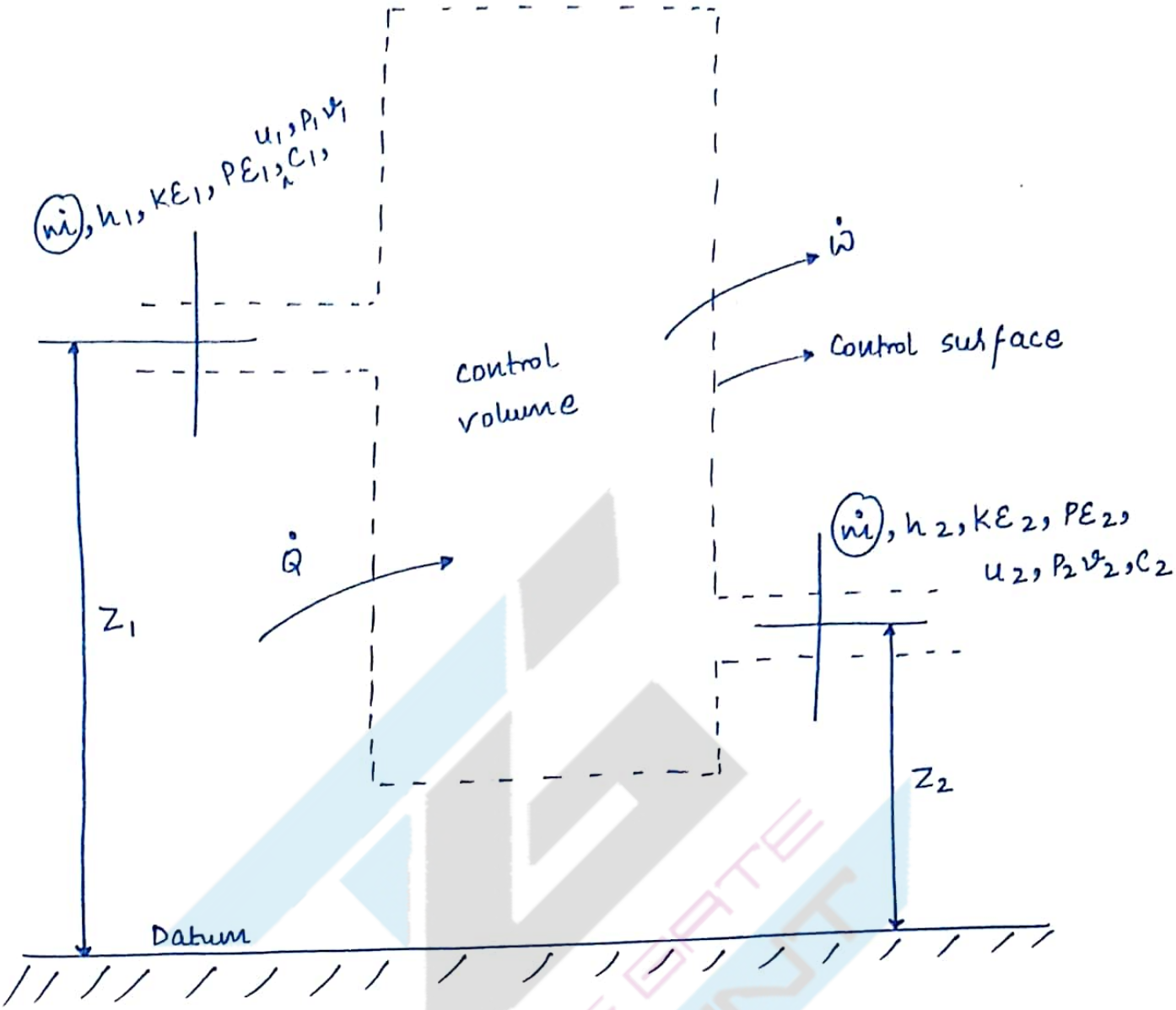

Apply Energy Conservation,

$$\underbrace{u_1 + P_1 v_1}_{h_1} + KE_1 + PE_1 + Q = \underbrace{u_2 + P_2 v_2}_{h_2} + KE_2 + PE_2 + W$$

$$h_1 + KE_1 + PE_1 + Q = h_2 + KE_2 + PE_2 + W$$

$$C_pT_1 + \frac{1}{2000} C_1^2 + \frac{gZ_1}{1000} + Q = C_pT_2 + \frac{1}{2000} C_2^2 + \frac{gZ_2}{1000} + W$$

$\frac{KJ}{kg\,K}$

$KE = \frac{1}{2} mC^2$

$J = kg \times m^2/sec^2$

$kg \times m^2/sec^2 = J/kg$

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$\frac{J}{kg} \times \frac{kg}{sec} \rightarrow \dot{m}$

$$\dot{m}\left[C_p T_1 + \frac{1}{2000} C_1^2 + \frac{g z_1}{1000}\right] + \dot{Q}$$

$$= \dot{m}\left[C_p T_2 + \frac{1}{2000} C_2^2 + \frac{g z_2}{1000}\right] + \dot{W}$$

kW ← $\dot{H}$ ans

* **SPECIAL CASES** :→

① **Nozzle** :→ It is a device of variable passage use to increase the kinetic energy at the expanse of pressure energy.

Assumptions :- ⓐ Neglecting potential energy changes ($\Delta PE = 0$).

ⓑ assume to be well insulated ($Q = 0$) → adiabatic

ⓒ No work interaction ($W = 0$).

Imp ⓓ Neglecting inlet kinetic energy ($V_2 >>>>>> V_1$)

Using steady Flow energy eqn :-

$$h_1 + \cancel{KE_1}^{0} + \cancel{PE_1} + \cancel{Q} = h_2 + KE_2 + \cancel{PE_2} + \cancel{W}$$

$$h_1 = h_2 + KE_2$$

$$h_1 = h_2 + \frac{1}{2000} C_2^2$$

$$\frac{C_2^2}{2000} = h_1 - h_2$$

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$$C_2 = \sqrt{2000(h_1 - h_2)} \quad (h \rightarrow kJ/kg)$$

Imp

$$\boxed{C_2 = 44.72\sqrt{h_1 - h_2}} \quad \rightarrow \text{if } h = \frac{kJ}{kg}$$

② **DIFFUSER** :→ It is a device of variable passage used to decrease the velocity.

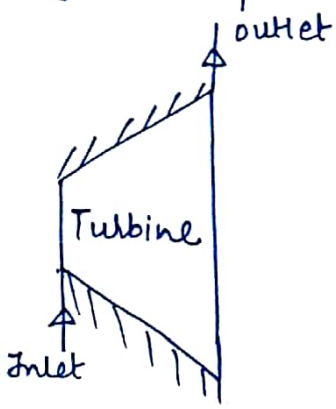
③ **TURBINE** :→ It is a work producing device in which energy is transferred from working fluid to the rotor. In turbine, expansion of the working fluid takes place. that is work is done by the system.

Assumptions :→ ⓐ Neglecting Kinetic energy changes ($\Delta KE = 0$)

ⓑ Neglecting Potential —"— ($\Delta PE = 0$)

ⓒ Well insulated ($Q = 0$)

Using steady flow energy eqn :→



$$h_1 + \cancel{KE_1} + \cancel{PE_1} + \cancel{Q} = h_2 + \cancel{KE_2} + \cancel{PE_2} + W$$

$$h_1 = h_2 + W$$

OBJ

$$\boxed{W_T = h_1 - h_2}$$

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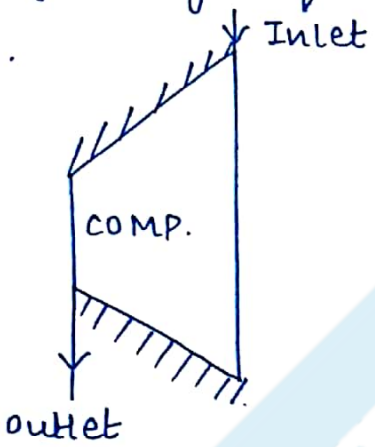
④ **COMPRESSOR & PUMP** :→ Both are work absorbing device in which energy is transferred from rotor to working fluid. Compressor is generally used to handle the gaseous phase of the working fluid and used to increase both (pressure and temperature of the working fluid). Whereas pump is used to handle generally liquid phase and used to increase the pressure.



OBJ

$$\boxed{W_{P/C} = h_2 - h_1}$$

⑤ **BOILER / EVAPORATOR** :→ These are the type of heat exchanger in which heat is absorbed by the working fluid at constant pressure.

Assumption :- ⓐ Neglecting KE changes ($\Delta KE = 0$)

ⓑ Neglecting PE changes ($\Delta PE = 0$)

ⓒ No work interaction ($W = 0$)

$$h_1 + \cancel{KE_1} + \cancel{PE_1} + \cancel{Q} = h_2 + \cancel{KE_2} + \cancel{PE_2} + \cancel{W}$$

$$h_1 + Q = h_2$$

Objective

$$\boxed{Q_{B/E} = h_2 - h_1}$$

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⑥ **CONDENSER** :→ heat rejected by the working fluid (77) at constant pressure.

OBJ

$$\boxed{Q_{CON.} = h_1 - h_2}$$

⑦ **THROTTLING** :→ It is flow through a restricted passage or partially opened valve or porous plug or constricted passage is known as throttling

Assumptions :→ ⓐ Neglecting Kinetic energy changes. ($\Delta KE = 0$)

ⓑ Neglecting Potential energy changes. ($\Delta PE = 0$)

ⓒ Well insulated ($Q = 0$)

ⓓ No work interaction ($W = 0$)

using stead flow energy eqn.,

$$h_1 + \cancel{KE_1} + \cancel{PE_1} + \cancel{Q} = h_2 + \cancel{KE_2} + \cancel{PE_2} + \cancel{W}$$

$$\boxed{h_1 = h_2}$$

NOTE :→ ⓐ Throttling is also known as constant enthalpy process or isenthalpic process.

ⓑ Throttling is a irreversible adiabatic process.

ⓒ Throttling always results a decrease in pressure that is expansion

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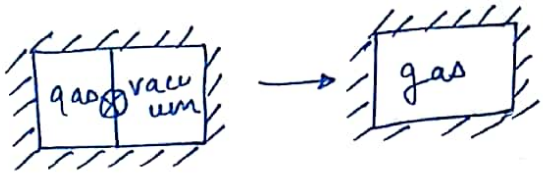
* FREE EXPANSION :→ or unrestrained Expansion :→

Expansion against vaccuum is known as free expansion. It is a case of irreversible process and in the case of free expansion

$$đQ = dE + đW$$

$dQ = 0$
$dW = 0$
$dE = 0$
$dU = 0$



It is also known as unrestrained Expansion.

Q Air at a tempr. of 15°C passes through a heat exchanger at a velocity of 30m/sec where the tempr. is raised to 800°C. It then enters the turbine with the same velocity of 30 m/sec and expands until the tempr. falls to 650°C. on leaving the turbine air is taken at a velocity of 60m/sec to a nozzle where it expands until the temperature has fallen to 500°C. If the air flow rate 2kg/sec, then calculate:-

(a) Rate of heat transfer to the air in the heat exchanger.

(b) Power output from the turbine assuming no heat losses in the turbine.

(c) Velocity at exit from the nozzle assuming no heat loss in nozzle.

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$$dU = 238.32 - 1.01 \times 105(2400 - 2000) \times 10^{-6}$$ 87

$$= 198.2\,J$$

T3
Gate
4 marks

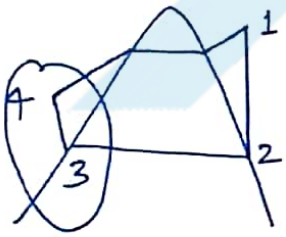
$$h_1 + KE_1 + PE_1 + Q = h_2 + KE_2 + PE_2 + W$$

$$h_1 + \frac{1}{2000}c_1^2 + \frac{gz_1}{1000} + \cancel{Q} = h_2 + \frac{1}{2000}c_2^2 + \frac{gz_2}{1000} + W$$

$$W = _____\ KJ/kg \times 20\ kg/sec$$

$$W = 12157\ KW$$

$$\rho = 1000\ kg/m^3$$



$$\rho = \frac{m}{vol}$$

$$v = \frac{vol}{m}$$

$$v\,dP$$

$$\frac{1}{\rho}(dP) \Rightarrow \frac{3000 - 70}{1000} = \underline{\underline{2.930}}$$

$$h_1 + KE_1 + PE_1 + Q = h_2 + KE_2 + PE_2 + W$$

$$3200 + \frac{1}{2000}(160)^2 + \frac{2.2}{1000} = 2600 + \frac{1}{2}(100)^2$$

$$12.15 \times 10^6\ J/sec$$

$$\rho_1 = 1000\ kg/m^3$$

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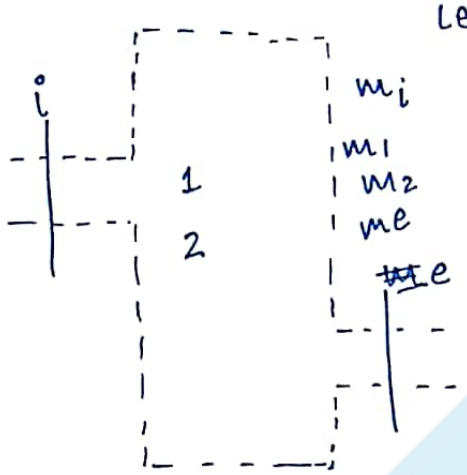
* UNSTEADY FLOW ENERGY EQUATION (USFEE) :→

Unsteady Flow means the properties varies with respect to time that is mass at the entry of control volume and at the exit of control volume are different. Unsteady state problems are solved by using 2 conservation principles. that is mass conservation and energy conservation.



Let us assume m_i → mass at the entry of control volume.

m_e → mass at the exit of control volume.

m_1 → initial mass inside the control volume.

m_2 → final mass inside the control volume.

① Apply mass conservation :→

$$\boxed{\left(\frac{dm}{dt}\right)_{CONSERV} = \dot{m}_i - \dot{m}_e} \quad (1)$$

$$\dot{m}_i - \dot{m}_e = \dot{m}_{cons}$$

② Apply energy conservation :→

$$\boxed{\left(\frac{dE}{dt}\right)_{CONSERV} = \frac{d}{dt}\left(m_i h_i + KE_i + PE_i + Q\right) - \frac{d}{dt}\left(m_e h_e + KE_e + PE_e + W\right)} \quad (2)$$

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Assumptions :→ (a) neglecting kinetic energy changes.

(b) neglecting potential energy changes.

$$\left(\frac{dE}{dt}\right)_{CONS} = \frac{d}{dt}\left(m_i h_i + \cancel{KE_i} + \cancel{PE_i} + Q\right) - \frac{d}{dt}\left(m_e h_e + \cancel{KE_e} + \cancel{PE_e} + W\right)$$

$$\frac{dE}{dt} = \frac{d}{dt}\left(\cancel{KE} + \cancel{PE} + U\right) = \frac{dU}{dt}$$

$$\boxed{\frac{dU}{dt} = \frac{d}{dt}\left(m_i h_i + Q\right) - \frac{d}{dt}\left(m_e h_e + W\right)} \quad (3)$$

(c) Neglecting the variation of enthalpy at inlet and outlet with respect to time :→

$$\frac{dU}{dt} = \frac{d}{dt}\left(m_i h_i + Q\right) - \frac{d}{dt}\left(m_e h_e + W\right)$$

$$= \frac{d}{dt}\left(m_i h_i\right) + \frac{dQ}{dt} - \frac{d}{dt}\left(m_e h_e\right) - \frac{dW}{dt}$$

$$\frac{dU}{dt} = \cancel{m_i \frac{dh_i}{dt}} + h_i \frac{dm_i}{dt} + \frac{dQ}{dt} - \cancel{m_e \frac{dh_e}{dt}} - h_e \frac{dm_e}{dt} - \frac{dW}{dt}$$

$$= \dot{m}_i h_i + \dot{Q} - \dot{m}_e h_e - \dot{W}$$

$$\boxed{\frac{dU}{dt} = \left[\left(m_i h_i\right) + \dot{Q}\right] - \left(\dot{m}_e h_e + \dot{W}\right)} \quad (4)$$

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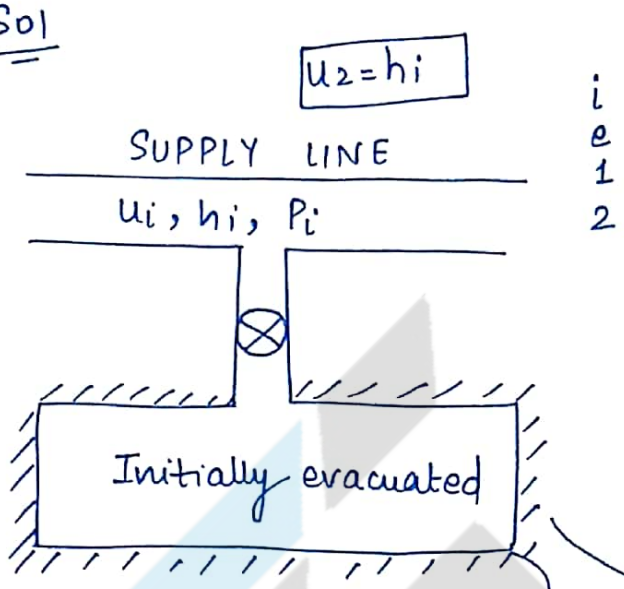
* APPLICATION OF USFEE :-

① Charging ~~and~~ / discharging of a tank.

② Bottle filling process.

WB
CH#3
Q32
IES 15 marks
2 Times

Sol



i
e
1
2

u_i, h_i
$dQ = 0$

$$\frac{dm}{dt} = \dot{m}_i - \cancel{\dot{m}_e} \quad \text{—(1)}$$

$$\boxed{\frac{dm}{dt} = m_i} \quad \text{—(3)}$$

$$\frac{dE}{dt} = \frac{d}{dt}(m_i h_i + \cancel{KE_i} + \cancel{PE_i} + \cancel{Q}) \rightarrow \boxed{\frac{dU}{dt} = \frac{d}{dt}(m_i h_i)} \quad \text{—(4)}$$

$$\frac{d}{dt}(m_e h_e + \cancel{KE_e} + \cancel{PE_e} + \cancel{W}) \quad \text{—(2)}$$

Assume :-

① $\Delta KE = 0$

② $\Delta PE = 0$

③ $\frac{dh_i}{dt} = 0$

④ $\frac{dh_e}{dt} = 0$

⑤ $Q = 0$

⑥ $W = 0$

⑦ $m_e = 0$

⑧ $m_1 = 0$

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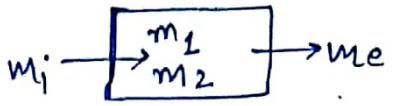
eqn. (4) $\frac{dU}{dt} = \cancel{m_i \frac{dh_i}{dt}}^{0} + h_i \frac{dm_i}{dt}$

$$\frac{dU}{dt} = \dot{m}_i h_i$$

use equation no. (3) :-

$$\frac{dU}{dt} = \left(\frac{dm}{dt}\right) h_i$$

$$\dot{U}_2 - \dot{U}_1 = (\dot{m}_2 - \dot{m}_1) h_i$$



$m_i - m_e \neq 0$

$$u = \frac{\dot{U}}{\dot{m}} \Rightarrow \boxed{\dot{U} = \dot{m} u}$$

$$\dot{m}_2 u_2 - \cancel{\dot{m}_1 u_1}^{0} = (\dot{m}_2 - \cancel{\dot{m}_1}^{0}) h_i$$

$$\cancel{\dot{m}_2} u_2 = \cancel{\dot{m}_2} h_i$$

$$\boxed{u_2 = h_i}$$

NOTE :- If the working fluid is ideal gas, then the final temperature inside the cylinder/tank is γ times the temperature of supply line.

$$u_2 = h_i$$

$$C_v T_2 = C_p T_i$$

$$T_2 = \frac{C_p}{C_v} T_i$$

Imp $\boxed{T_2 = \gamma T_i}$

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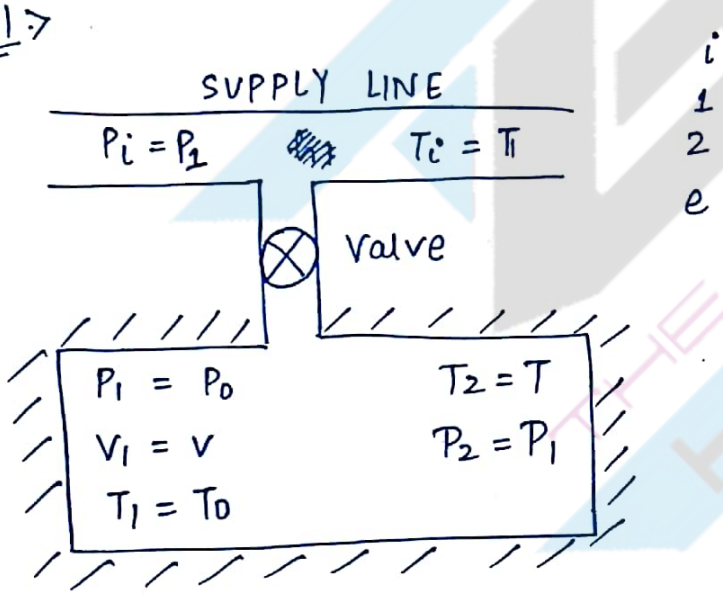
Q> An insulated pressure cylinder of volume V contains air at a pressure P_0 and temperature T_0. It is to be filled with from compressed air line maintained at a constant Pressure P_1 and tempr. T_1, then show that the tempr. of the air in the cylinder after it has been charged to the pressure of air line is given by

V
P_0
T_0
P_1
T_1

$$\boxed{T = \frac{\gamma T_1}{1 + \frac{P_0}{P_1}\left(\frac{\gamma T_1}{T_0} - 1\right)}}$$

Sol>

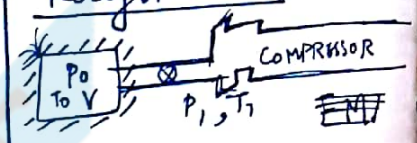


$$m_2 u_2 - m_1 u_1 = (m_2 - m_1) h_i$$

$$PV = mRT$$

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

Rough work



$$T_{\text{AIR in cyl}} = \frac{\gamma T_1}{1 + \frac{P_0}{P_1}\left(\frac{\gamma T_1}{T_0} - 1\right)}$$

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II ND LAW OF THERMODYNAMICS :-

OR

QUALITATIVE LAW :-

OR **LAW OF DEGRADATION OF ENERGY** :-

OR **DIRECTIONAL LAW** :-

Ist law of thermodynamics simply says that Total Energy is conserved. It does not provide any information regarding the direction of possible energy conversion. It is the second law of thermodynamics which provides the feasibility or direction of possible energy conversion through the concept of Entropy. and second law of thermodynamics defines the concept of energy on quality basis. Therefore, it is the IInd law of thermodynamics which is applied first in the numericals to find out the direction and then apply Ist law of Thermodynamics.

NOTE :- ① Heat is a low grade energy and work is a high grade energy.

② Complete conversion of low grade Energy into high grade is not possible. But the complete conversion of high grade energy into low grade is possible.

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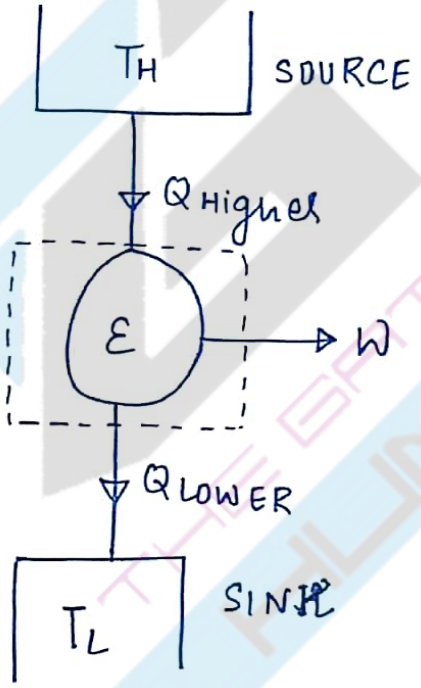
* THERMAL ENERGY RESERVOIR :-

It is a reservoir of infinite heat capacity.

✓ **SOURCE** :- It is a supplier of Heat Energy without affecting its temperature.

✓ **SINK** :- absorber of Heat Energy without any change in its temperature.



* **Kelvin Planck's statement** → It is impossible to construct a device which operate in a cycle produces work continuously while interacting with single thermal Reservoir.

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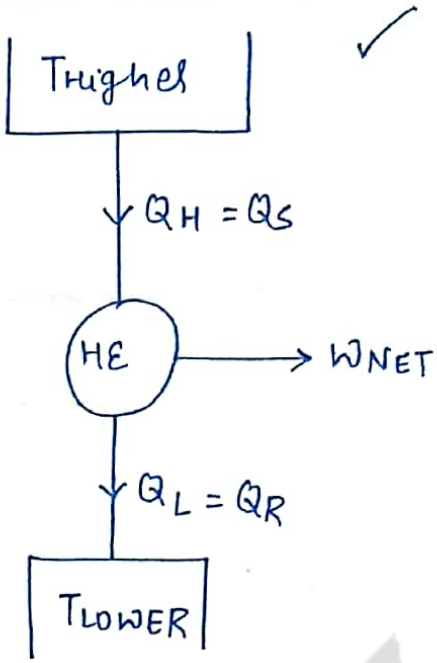

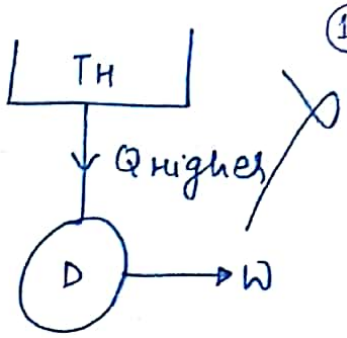

$$\boxed{\eta = \frac{O/P}{I/P} = \frac{W_{NET}}{Q_S} = \frac{Q_{NET}}{Q_S} = \frac{Q_S - Q_R}{Q_S} = 1 - \frac{Q_R}{Q_S} = 1 - \frac{Q_L}{Q_H}}$$

Thermodynamic Temp. scale or kelvin Temp. scale :- $Q \propto T$

$$\frac{Q_L}{Q_H} = \frac{T_L}{T_H} \Rightarrow \text{Imp} \quad \therefore \boxed{\eta = 1 - \frac{T_L}{T_H}}$$

* **Clausius statement** :- It is impossible to construct a device which operate in a cycle transfer heat from low temp. Reservoir to High Temp. Reservoir without consuming any other form of energy (work input = 0)

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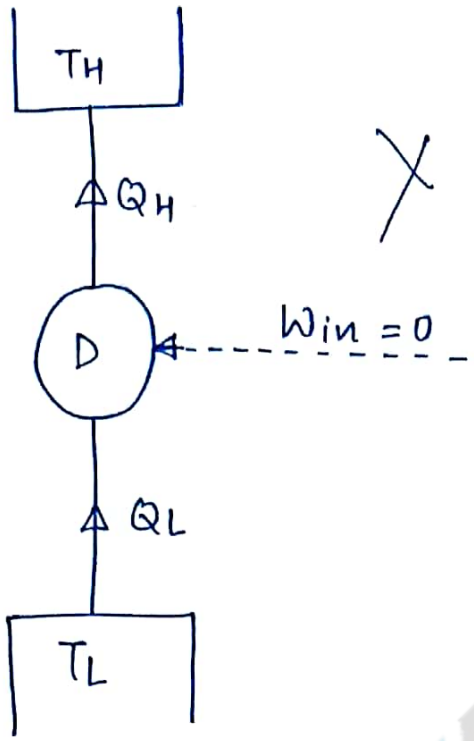

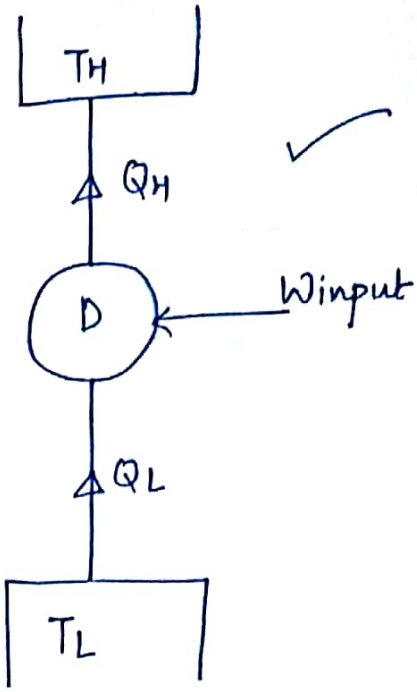

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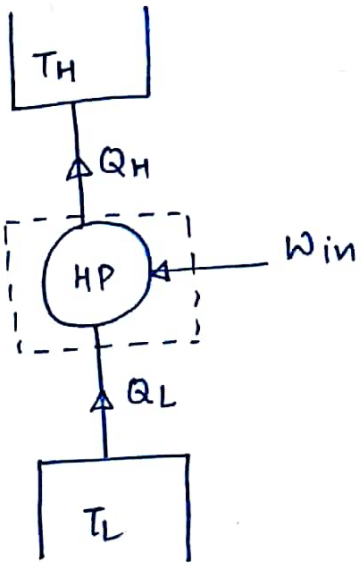
COP (Coefficient of Performance) :-

OR

EPR (Energy Performance Ratio) :- It is defined as the ratio of the desired effect to the work input.



$$COP_{HP} = \frac{DE}{W_{in}} = \frac{Q_H}{W_{in}}$$

$$Q_L + W_{in} = Q_H$$

$$W_{in} = Q_H - Q_L$$

$$COP_{HP} = \frac{Q_H}{Q_H - Q_L}$$

OBJ

$$\boxed{COP_{HP} = \frac{T_H}{T_H - T_L}}$$

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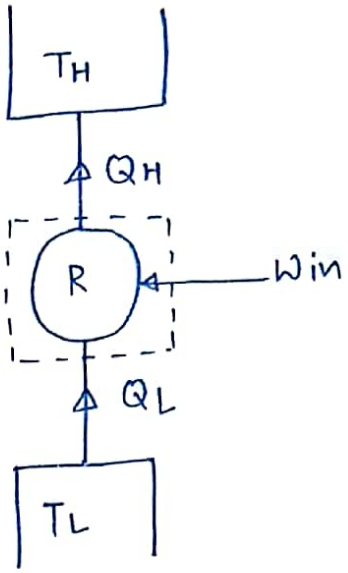


$$COP_R = \frac{DE}{W_{in}} = \frac{Q_L}{W_{in}} = \frac{Q_L}{Q_H - Q_L}$$

$$= \frac{T_L}{T_H - T_L}$$

OBJ

$$\boxed{COP_R = \frac{T_L}{T_H - T_L}}$$

NOTE :- (a) Kelvin - Planck's statement provides the concept of work producing devices that is heat Engine and Clausius statement provides the concept of work absorbing devices that is Heat pump and Refrigerator.

* **Relationship between COP of Heat Pump and COP of Refrigeration** :-

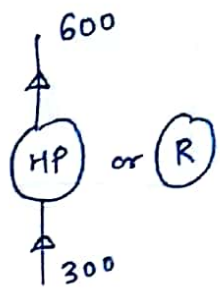
$$1 + COP_R = \frac{T_L}{T_H - T_L} + 1$$

$$= \frac{\cancel{T_L} + T_H - \cancel{T_L}}{T_H - T_L}$$

$$1 + COP_R = \frac{T_H}{T_H - T_L} = COP_{HP}$$

OBJ

$$\boxed{(COP)_{HP} = 1 + COP_R}$$



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The above expression is applicable between the same temperature limits.

Q If the η of the reversible Heat Engine ~~operating b/w~~ is 30% then determine the COP of reversible heat pump.

$\cancel{\frac{30\% \eta}{100}}$

(a) 0.33

(b) 1.33

(c) 2.33

(d) 3.33

Sol

$$\eta = 1 - \frac{T_L}{T_H}$$

$$0.3 = 1 - \frac{T_L}{T_H}$$

$$\frac{T_L}{T_H} = 0.7$$

$$COP_{HP} = \frac{T_H}{T_H - T_L} = \frac{1}{1 - \frac{T_L}{T_H}} = \frac{1}{1-0.7} = \frac{1}{0.3} = \frac{10}{3}$$

$$= 3.33$$

OR

OBJ

$$\boxed{COP_{HP} = 1 + COP_R = \frac{1}{\eta_{HE}}}$$

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The above expression is applicable between the same temperature limits.

NOTE :- ① Both heat pump and Refrigerator are known as Reversed Heat Engine.

* **CLAUSIUS INEQUALITY** :- According to this, the cyclic integral of factor $\frac{dQ}{T}$ should be less than or equal to zero i.e.

$$\oint \frac{dQ}{T} \leq 0$$

$\oint \frac{dQ}{T} < 0 \longrightarrow$ irreversible Device

$\oint \frac{dQ}{T} = 0 \longrightarrow$ Reversible Device

$\oint \frac{dQ}{T} > 0 \longrightarrow$ Impossible Device

* **ENTROPY (S)** :→ It is a measurement of degree of disorderness or randomness associated with the molecules.

* **ENTROPY CHANGE in the system** :→

The entropy change of the system is the summation of entropy change due to internal irreversibility and entropy change due to external interaction.

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$$ds = (ds)_{IIR} + (ds)_{EI}$$

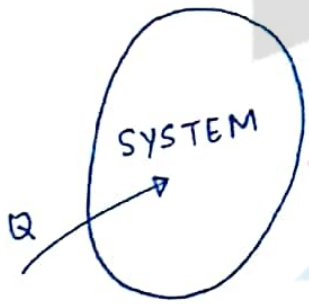
$$\boxed{ds = S_{gen} + \frac{dQ}{T}}$$

Case A :- If the system is reversible that is the value of entropy generation is equal to zero, then the entropy change of the system is given by

$$\boxed{(ds)_{IIR} = 0}$$

$$\boxed{ds = \frac{dQ}{T}}$$

Case I :- If Heat is supplied to the system, then the entropy change of the system is having positive value.



$$\boxed{dQ > 0}$$

$$\boxed{\frac{dQ}{T} > 0}$$

$$\boxed{ds > 0}$$

Case II :- If Heat is rejected from the system, then the entropy change of the system is having <u>negative value</u>.

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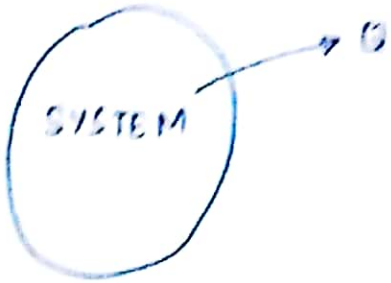
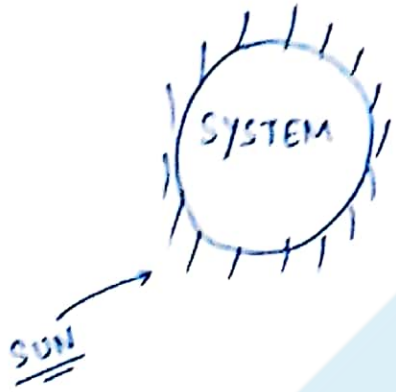


$$dQ < 0$$

$$\frac{dQ}{T} < 0$$

Imp $\boxed{ds < 0}$

Case III :- If the system is well insulated, then the entropy change of the system is equal to zero.



$$dQ = 0$$

$$\frac{dQ}{T} = 0$$

$$\boxed{ds = 0}$$

NOTE :- (a) If the system is reversible and adiabatic, then it has to be isentropic.

(b) Entropy change of the system may be +ve value, zero value or negative value but the entropy change of the universe can never have negative value.

Case B :- If the system is irreversible then the entropy change is given by

$$ds = (ds)_{IIR} + (ds)_{EI}$$

$$ds = S_{gen} + \frac{dQ}{T}$$

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Case I :- If the system is adiabatic :-

$$dQ = 0$$

$$\therefore \boxed{ds = S_{gen}}$$

NOTE :- The value of entropy generation is always positive

Case II :- The increase in internal irreversibility is compensated by decrease in external interaction, then the value of entropy change is equal to zero that is isentropic.

$$\boxed{ds = \uparrow (ds)_{IIR} + \downarrow \left(\frac{dQ}{T}\right)_{EI}}$$

* **ENTROPY PRINCIPLE** :- According to this principle, the entropy change of the universe can never have negative value.

$$\boxed{(ds)_{universe} \geq 0}$$

$$\boxed{\left[(ds)_{system} + (ds)_{surrounding}\right] \geq 0}$$

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$(ds)_{universe} > 0 \longrightarrow$ irreversible

$(ds)_{universe} = 0 \longrightarrow$ rev. process

$(ds)_{universe} < 0 \longrightarrow$ impossible.

* T-ds Equation :-

$$dQ = dU + PdV$$

Rev. process :- $\frac{ds}{\cancel{dt}} = \frac{dQ}{T}$

$$dQ = Tds$$

Imp

$$\boxed{Tds = dU + PdV} \quad (1)$$

$$H = U + PV$$

$$dH = dU + PdV + VdP$$

$$dQ = dU + PdV$$

$$dH = dQ + VdP$$

$$dQ = dH - VdP$$

Rev. process :- $dQ = Tds$

Imp

$$\boxed{Tds = dH - VdP} \quad (2)$$

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The eqn. ① and ② are applicable for Both reversible process as well as irreversible process because it contains all point functions.

* INTEGRAL FORM of Tds :-

$$Tds = du + PdV$$

$$ds = \frac{du}{T} + \frac{P}{T} dV$$

$$du = C_v dT \qquad \Big| \qquad PV = RT, \quad \frac{P}{T} = \frac{R}{V}$$

$$\int_{S_I}^{S_F} ds = C_v \int_{T_I}^{T_F} \frac{dT}{T} + R \int_{V_I}^{V_F} \frac{dV}{V}$$

$$S_F - S_I = C_v \ln T \Big|_{T_I}^{T_F} + R \ln V \Big|_{V_I}^{V_F}$$

$$= C_v [\ln T_F - \ln T_I] + R [\ln V_F - \ln V_I]$$

$$\boxed{S_F - S_I = C_v \ln \frac{T_F}{T_I} + R \ln \frac{V_F}{V_I}} \quad (1)$$

$$Tds = dh - vdP$$

$$ds = \frac{dh}{T} - \frac{v}{T} dP$$

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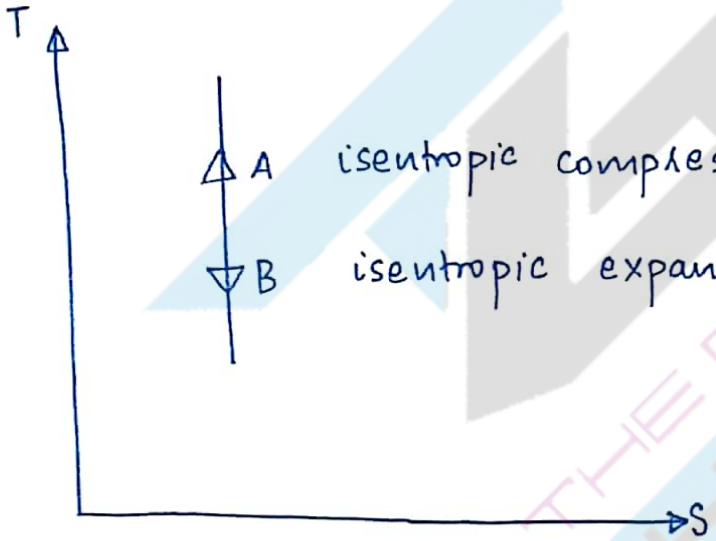
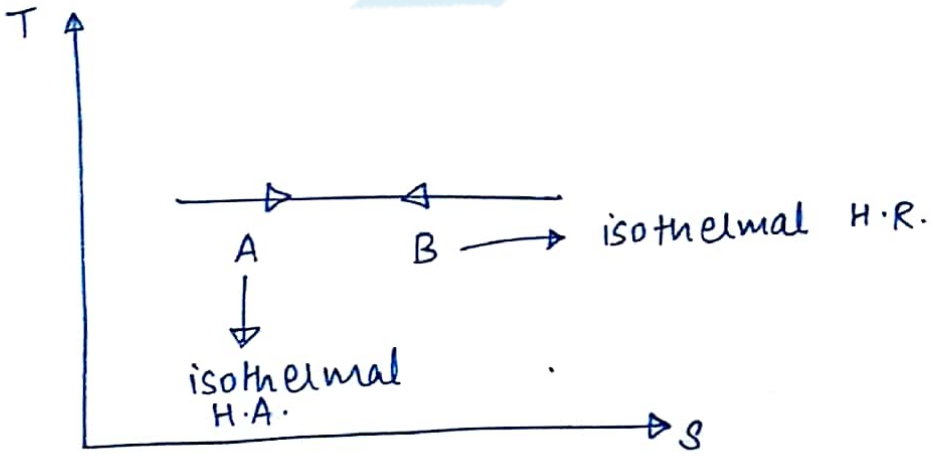
$$dh = C_p\, dT \qquad \Big| \qquad PV = RT, \quad \frac{V}{T} = \frac{R}{P}$$

$$\int ds = C_p \int \frac{dT}{T} - R \int \frac{dP}{P}$$

$$\boxed{S_F - S_I = C_p \ln \frac{T_F}{T_I} - R \ln \frac{P_F}{P_I}} \quad (2)$$

* **Representation of constant Pressure and constant volume line on T-S curve :-**





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$$Tds = dU + PdV$$

$$V = C$$

$$dV = 0$$

$$Tds = du$$

$$Tds = C_v dT$$

OBJ

$$\boxed{\left(\frac{dT}{ds}\right)_v = \frac{T}{C_v}}$$

$$Tds = dh - vdP$$

$$P = C$$

$$dP = 0$$

$$Tds = dh$$

$$Tds = C_p dT$$

OBJ

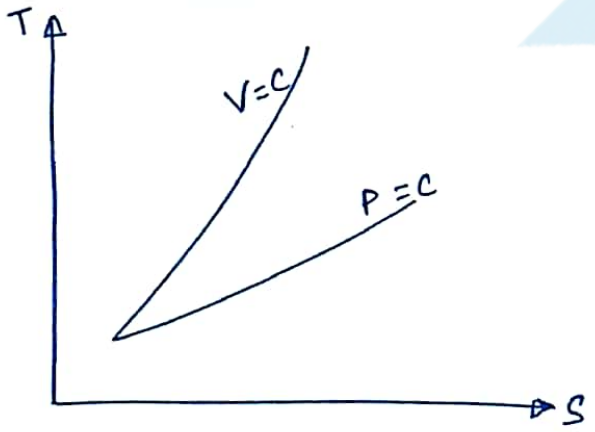
$$\boxed{\left(\frac{dT}{ds}\right)_P = \left(\frac{T}{C_P}\right)}$$

$$C_p > C_v$$

$$\frac{1}{C_P} < \frac{1}{C_v}$$

$$\frac{T}{C_P} < \frac{T}{C_v}$$

$$\boxed{\left(\frac{dT}{ds}\right)_P < \left(\frac{dT}{C_v}\right)_v}$$



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NOTE :- (a) The slope of constant volume line on T-S curve is always greater than the slope of constant pressure line on T-S curve.

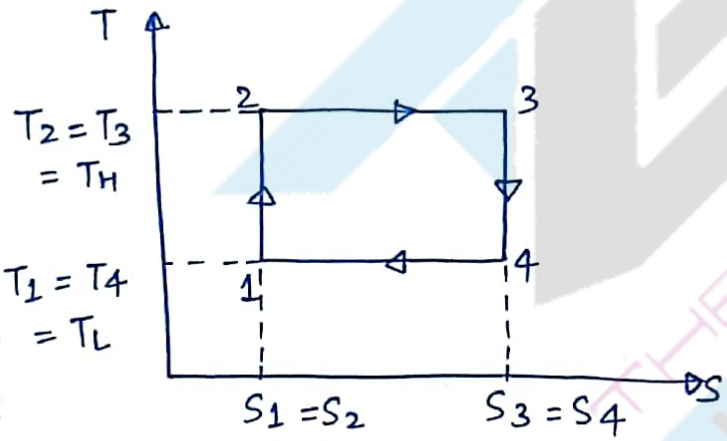
* CARNOT CYCLE :-

Process 1-2 → isentropic compression

Process 2-3 → constant tempr. Heat addition

Process 3-4 → isentropic expansion

Process 4-1 → constant T / isothermal Heat Rejection



$$ds = (ds)_{IIR} + \frac{dQ}{T}$$

$$(ds)_{IIR} = 0$$

$$ds = \frac{dQ}{T}$$

$$dQ = TdS$$

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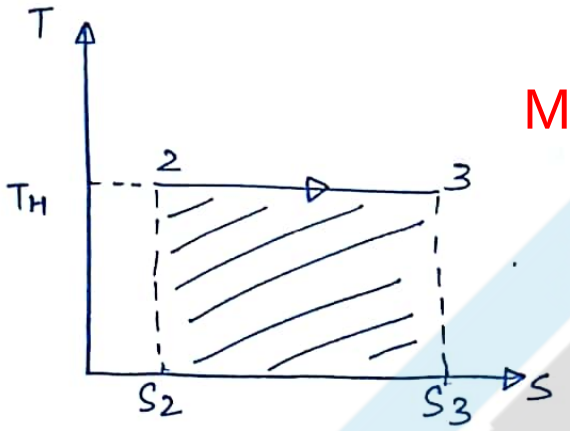
$$\boxed{\eta = \frac{O/P}{I/P} = \frac{W_{NET}}{Q_S} = \frac{Q_{NET}}{Q_S}} \quad \text{—— (1)}$$

$$Q_{NET} = \cancel{Q_{1-2}}^{\,0} + Q_{2-3} + \cancel{Q_{3-4}}^{\,0} + Q_{4-1}$$

$$\boxed{Q_{NET} = Q_{2-3} + Q_{4-1}} \quad \text{—— (2)}$$



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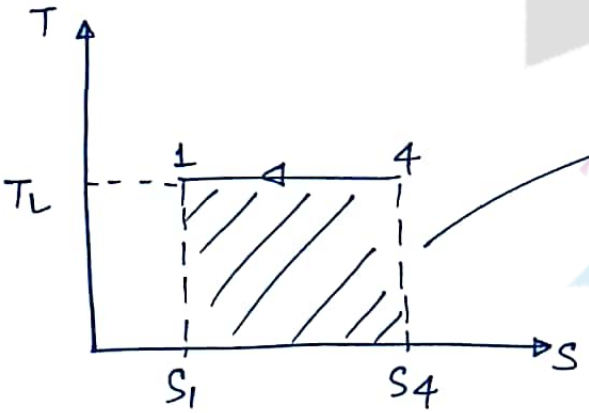
$$\boxed{dQ_S = T(S_F - S_I) = T_H(S_3 - S_2)} \quad \text{—— (3)}$$



$$dQ = T(S_F - S_I)$$

$$= T_L(S_1 - S_4)$$

$$= -T_L(S_4 - S_1)$$

$$\boxed{Q_R = -T_L(S_3 - S_2)} \quad \text{—— (4)}$$

use (3) & (4) in equ. (2) :-

$$Q_{NET} = T_H(S_3 - S_2) - T_L(S_3 - S_2)$$

$$Q_{NET} = (T_H - T_L)(S_3 - S_2).$$

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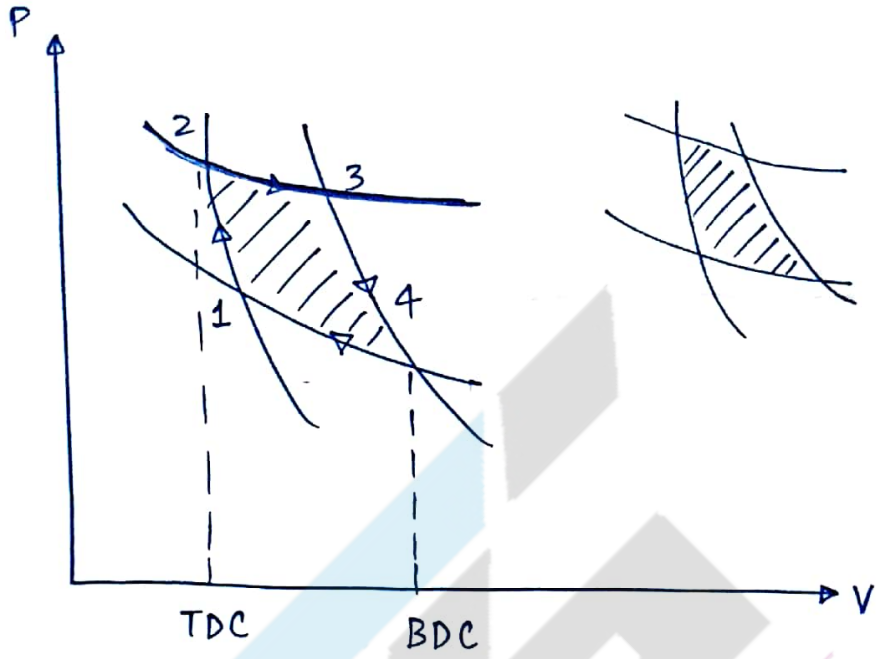
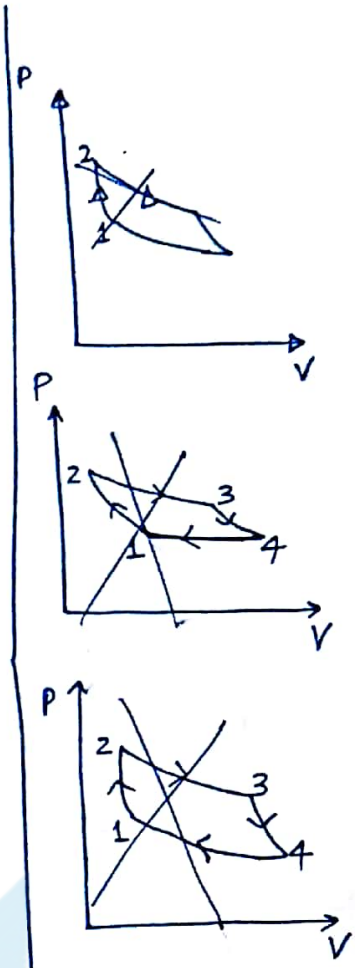
$$\eta = \frac{T_H - T_L}{T_H}$$

OBJ

$$\boxed{\eta = 1 - \frac{T_L}{T_H}}$$





* **DRAWBACKS** :- ① all the processes are reversible which is impossible to achieve practically.

② To achieve the isothermal condition, the process has to be extremely slow. whereas to achieve the adiabatic condition, the process has to be extremely fast.

③ The area under the P-V curve is having very narrow reason and moreover the swept volume is very large.

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NOTE :- ① The efficiency of the reversible Engine is always greater than irreversible engine.

② The maximum possible efficiency of the reversible engine is given by carnot.

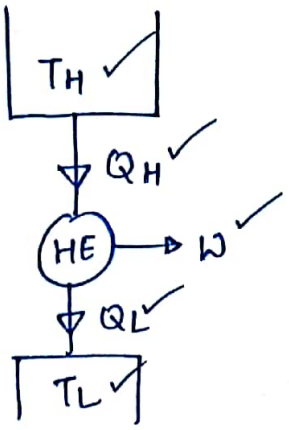
③ The expression of carnot efficiency is

$$\boxed{\eta = 1 - \frac{T_L}{T_H}}$$

④ Carnot efficiency is a function of only temperature.

⑤ If there are "n" no. of reversible engines operating between same temperature limits with different working fluids then the value of maximum possible η or ideal efficiency or carnot efficiency is having same value.

⑥ Carnot η is independent of working fluid.



$$\eta_C = 1 - \frac{T_L}{T_H} = 50\%$$

$$\eta_A = \frac{W_{NET}}{Q_S} = 40\%$$

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The η of the engine is

(a) 40% $\longrightarrow$ η_{engine}

(b) 50% $\longrightarrow$ η_{max} or η_{ideal}

The above engine is :-

① Rev./IDEAL $\longrightarrow$ $\oint \frac{dQ}{T} = 0$, $(ds)_{universe} = 0$, $\eta_{carnot} = \eta_{actual}$

② irrev./Possible $\longrightarrow$ $\oint \frac{dQ}{T} < 0$, $(ds)_{universe} > 0$, $\eta_{carnot} > \eta_{actual}$

③ Impossible $\longrightarrow$ $\oint \frac{dQ}{T} > 0$, $(ds)_{universe} < 0$, $\eta_{carnot} < \eta_{actual}$

IAS
20 marks
Q> Prove that following for the ideal gas :-

$$\boxed{ds = C_p \frac{dv}{v} + C_v \frac{dP}{P}}$$

using this result, show that for an ideal gas undergoing an isentropic change of state with constant specific heat is

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

Sol

[N.P.]

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Proof :- $Tds = du + Pdv$

$$ds = \frac{du}{T} + \frac{P}{T}dv$$

$du = C_v dT$

$PV = RT$

$$\frac{P}{T} = \frac{R}{V}$$

$$ds = C_v\frac{dT}{T} + R\frac{dv}{v}$$

$$ds = C_v\frac{dT}{T} + (C_p - C_v)\frac{dv}{v}$$

$$ds = C_v\frac{dT}{T} + C_p\frac{dv}{v} - C_v\frac{dv}{v}$$

$$ds = C_p\frac{dv}{v} + C_v\frac{dT}{T} - C_v\frac{dv}{v}$$

$$ds = C_p\frac{dv}{v} + C_v\left(\frac{dT}{T} - \frac{dv}{v}\right) \quad \text{--- (1)}$$

$PV = mRT$

Diff :-

$$\frac{Pdv + vdP}{PV} = \frac{mRdT}{PV}$$

$$\frac{\cancel{P}dv}{\cancel{P}v} + \frac{\cancel{v}dP}{P\cancel{v}} = \frac{\cancel{mR}dT}{\cancel{mR}T}$$

$$\frac{dv}{v} + \frac{dP}{P} = \frac{dT}{T}$$

$$\cancel{ds = C_p\frac{dv}{v} + C_v\frac{dP}{P}}$$

$\cancel{PV = mRT}$

$\cancel{Tds = du + Pdv}$

$\cancel{Tds = du - vdP}$

$\cancel{du + P}$

$$\cancel{S_F - S_I = C_v \ln\frac{T_F}{T_I} + R\ln\frac{V_F}{V_I}}$$

$$\cancel{Tds = du + Pdv}$$

$$\cancel{\frac{PV}{mR}ds = mC_p dT + Pdv}$$

$$\cancel{ds = \frac{mC_p dT mR}{PV} + \frac{Pdv\, mR}{PV}}$$

$\cancel{dv}$

$\cancel{Tds = du - vdP}$

$\cancel{Tds = mC_p dT - vdP}$

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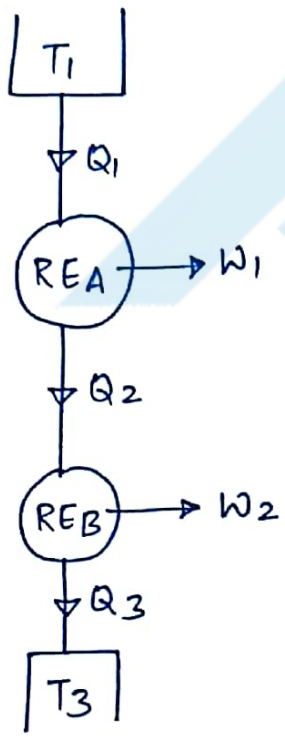
$$\frac{Q_1}{T_1} = \frac{Q_3}{T_3}$$

$$Q_3 = 120 KJ$$

NOTE :- Q> There are 2 Reversible heat engines operating in series. The Heat rejected by engine A directly to the engine B then find out the expression of intermediate temperature when :- (a) Both engines are equally efficient (GM). Geometric Mean.

(b) Both engine produce equal amount of work (Arithmetic Mean - AM).



① $\eta_1 = \eta_2$

$$1 - \frac{T_2}{T_1} = 1 - \frac{T_3}{T_2}$$

$$\frac{T_2}{T_1} = \frac{T_3}{T_2}$$

$$T_2^2 = T_1 T_3$$

Imp

$$\boxed{T_2 = \sqrt{T_1 T_3}}$$

② $W_1 = W_2$

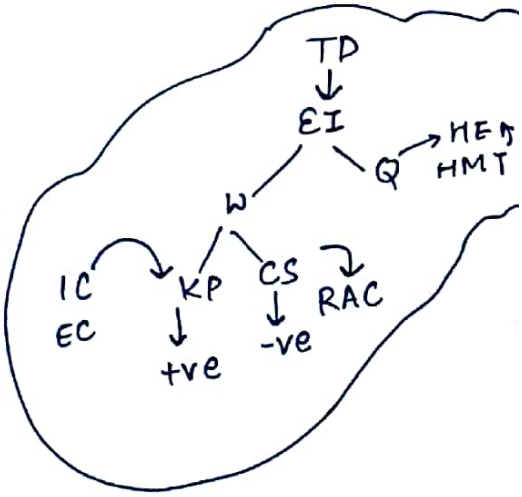
$$Q_{1-2} = Q_{2-3}$$

$$2Q_2 = Q_1 + Q_3$$

$$Q_2 = \frac{Q_1 + Q_3}{2}$$

AM

$$\boxed{T_2 = \frac{T_1 + T_3}{2}}$$



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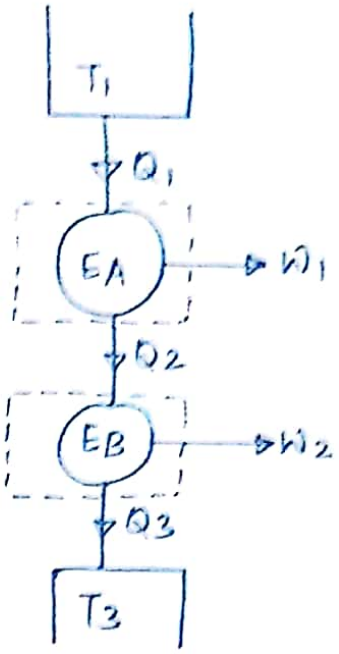
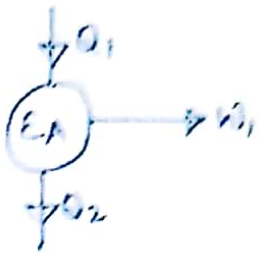
Q. Derive the expression for combined η of the plant





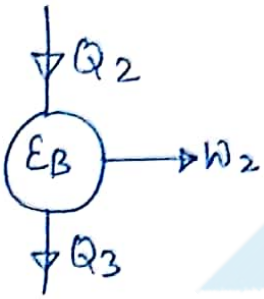
$$\eta_1 = \frac{O/P}{I/P} = \frac{W_1}{Q_1}$$

$$\boxed{W_1 = \eta_1 Q_1} \quad (1)$$

$$Q_1 = W_1 + Q_2$$

$$Q_2 = Q_1 - W_1$$

$$\boxed{Q_2 = Q_1 - \eta_1 Q_1}$$



$$\eta_2 = \frac{O/P}{I/P} = \frac{W_2}{Q_2}$$

$$\boxed{W_2 = \eta_2 Q_2} \quad (2)$$

$$\eta_{cc} = \frac{O/P}{I/P} = \frac{W_1 + W_2}{Q_1}$$

$$\eta_{cc} = \frac{\eta_1 Q_1 + \eta_2 Q_2}{Q_1}$$

$$= \underline{\eta_1 + \eta_2 \left(\frac{Q_2}{Q_1}\right)}$$

$$= \eta_1 + \eta_2 \left[\frac{Q_1 - \eta_1 Q_1}{Q_1}\right] = \boxed{\eta_1 + \eta_2 - \eta_1 \eta_2}$$

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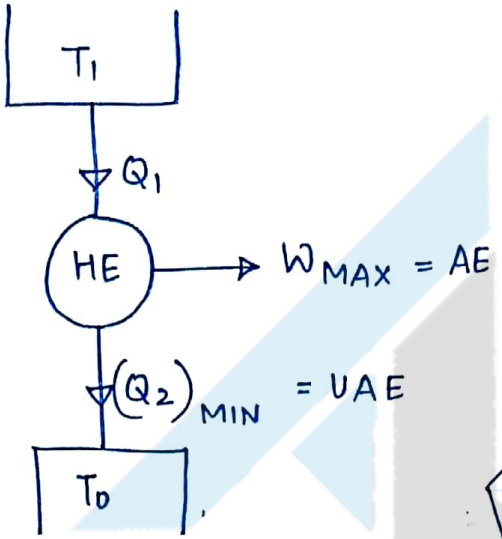
AVAILABLE ENERGY & UNAVAILABLE ENERGY (AE & UAE) :-

* **Available Energy (AE) or EXERGY** :→ It is the maximum amount of work that can be extracted from a certain heat input in a cycle. ~~Unavailable energy~~

* **Unavailable Energy**: It is the minm. amount of heat that has been rejected to the sink.



$$Q_1 = W + Q_2$$

$$W_{MAX} = Q_1 - (Q_2)_{MIN}$$

Carnot Engine

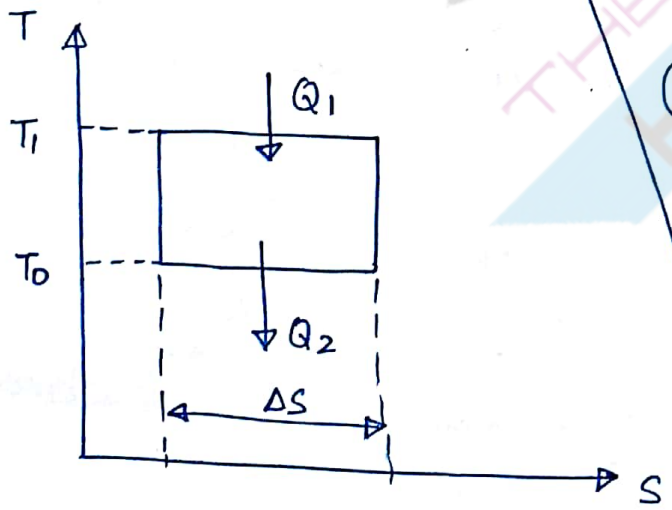
$$\eta = 1 - \frac{T_L}{T_H}$$

(a) T_L = constant, $T_H \uparrow$

$$\rightarrow \uparrow \eta = \left(1 - \frac{T_L}{T_H \uparrow} \downarrow\right)$$

(b) T_H = constant, $T_L \downarrow \rightarrow \uparrow \eta =$

$$\left(1 - \frac{T_L \downarrow}{T_H} \downarrow\right)$$



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$$\eta = 1 - \frac{T_L}{T_H} = 1 - \frac{T_0}{T_1} = \frac{W_{max}}{Q_S}$$

$$1 - \frac{T_0}{T_1} = \frac{W_{max}}{Q_1}$$

$Q_1 = T_1 \Delta S$

$$\boxed{\frac{Q_1}{T_1} = \Delta S}$$

$$W_{max} = Q_1\left(1 - \frac{T_0}{T_1}\right)$$

$$W_{max} = Q_1 - T_0\left(\frac{Q_1}{T_1}\right)$$

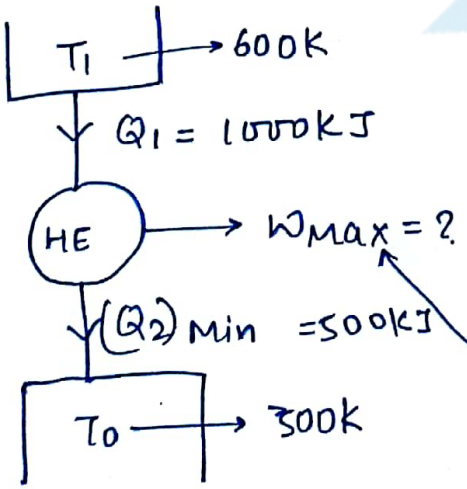
$$W_{max} = Q_1 - T_0 \Delta S$$

$$AE = Q_S - VAE$$

$$\boxed{VAE = T_0 \Delta S}$$

Q.> 1000 KJ of heat is supplied to the Reversible heat Engine from a source maintained at 327°C. and the sink Temp^r. is 27°C then find out the available energy and unavailable energy?

Sol

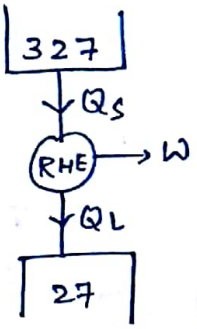


$$\eta = 1 - \frac{300}{600}$$

$$= 1 - \frac{1}{2}$$

$$\frac{1}{2} = \frac{W_{max}}{1000}$$

$$W_{max} = 500 \text{ KJ}$$



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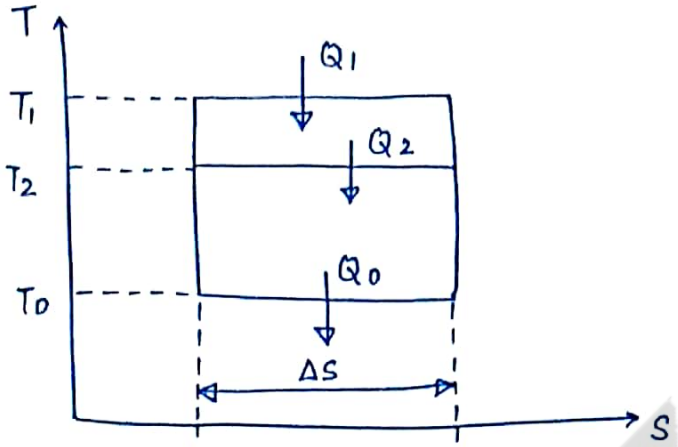
* ~~LAWS~~ LOSS OF AVAILABLE ENERGY when same Heat is transferred through a finite temperature difference :-



$$\eta = \frac{O/P}{I/P} = \frac{W_{NET}}{Q_S} = \frac{Q_{NET}}{Q_S} = \frac{Q_S - Q_R}{Q_S} = 1 - \frac{Q_R}{Q_S}$$

actual

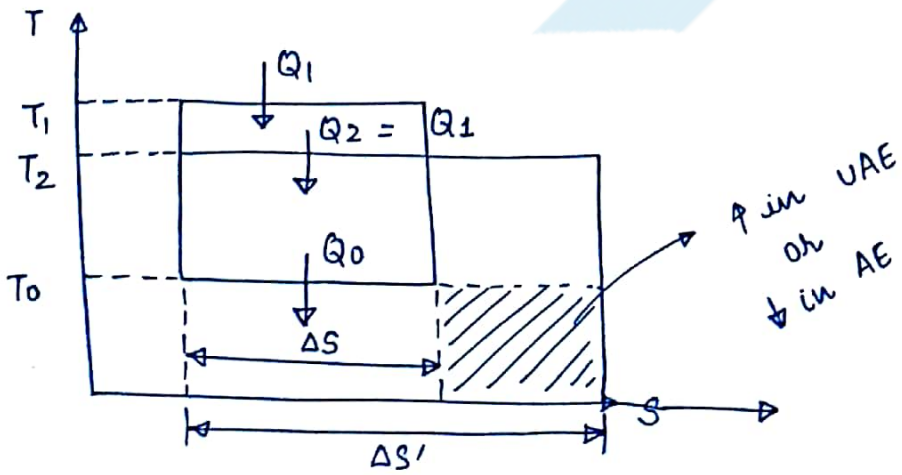
(i) Q_R = const.] $Q_S \uparrow$ $\longrightarrow \uparrow\eta = \left(1 - \frac{Q_R}{Q_S \uparrow} \downarrow\right)$

$Q_1 = T_1 \Delta S$
$Q_2 = T_2 \Delta S$] $\rightarrow$ $\boxed{Q_R = Q_0 = T_0 \Delta S}$

$T_1 > T_2$

$T_1 \Delta S > T_2 \Delta S$

$Q_1 > Q_2$



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$$\eta = \frac{O/P}{I/P} = \frac{W_{NET}}{Q_S} = \frac{Q_{Net}}{Q_S} = \frac{Q_S - Q_R}{Q_S} = 1 - \frac{Q_R}{Q_S}$$

(ii) $Q_S = \text{const.}$

$Q_R \uparrow$ $\Rightarrow \downarrow \eta = \left(1 - \frac{Q_R \uparrow}{Q_S}\right)\uparrow$

$Q = \uparrow T \, \Delta S \downarrow$

$Q_1 = T_1 (\Delta S)$

$Q_2 = T_2 (\Delta S')$

$T_1 > T_2$

$\Delta S < \Delta S'$

$Q_1 = Q_2$

$Q_R = Q_0$ → Q_1 at T_1, Q_2 at T_2

$Q_0 = T_0 \Delta S$ (Q_1 at T_1)

$Q_0 = T_0 \Delta S'$ (Q_1 at T_2)

$\Delta S' > \Delta S$

$T_0 \Delta S' > T_0 \Delta S$

$(Q_R)_{Q_1 \text{ at } T_2} > (Q_R)_{Q_1 \text{ at } T_1}$

$(\eta)_{Q_1 \text{ at } T_2} < (\eta)_{Q_1 \text{ at } T_1}$

$\left(\frac{(A\varepsilon)}{\cancel{Q_1}}\right)_{Q_1 \text{ at } T_2} < \left(\frac{A\varepsilon}{\cancel{Q_1}}\right)_{Q_1 \text{ at } T_1}$

$(A\varepsilon)_{Q_1 \text{ at } T_2} < (A\varepsilon)_{Q_1 \text{ at } T_1}$

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$\uparrow$ in UAE $= T_0 (\Delta S' - \Delta S)$ —— ①

$$Q_1 = T_1 \Delta S \longrightarrow \Delta S = \frac{Q_1}{T_1}$$

$$Q_1 = T_2 \Delta S' \longrightarrow \Delta S' = \frac{Q_1}{T_2}$$ —— ②

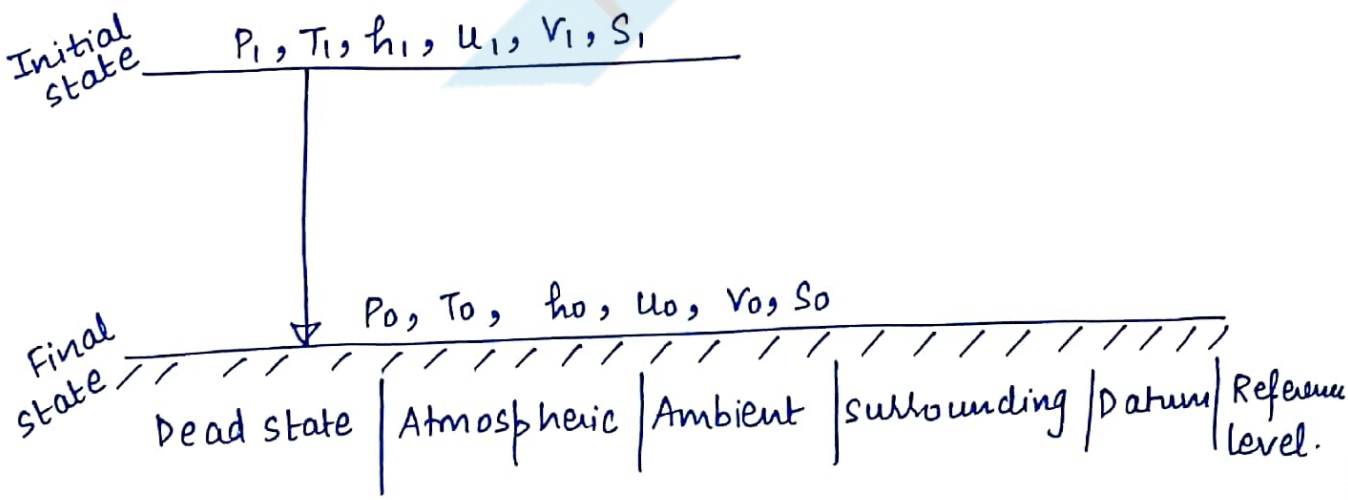
use ② in eqn. ① :- increase in UAE $\uparrow = T_0 \left[\frac{Q_1}{T_2} - \frac{Q_1}{T_1}\right]$

OBJ Imp

$$\boxed{\uparrow \text{ in UAE} = \frac{T_0 Q_1 (T_1 - T_2)}{T_1 T_2}}$$

More the temperature difference, more will be the loss of available Energy, therefore same heat is having more importance at higher temperature incomparison to the lower temperature.

* **AVAILABILITY** :→ It is a maximum useful work which can be extracted in a process in which system comes into equilibrium with the dead state.



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(1.) Closed system :→

$$Tds = du + PdV$$

$$Tds = du + (U.W.)_{c.s.}$$

$$(U.W.)_{cs} = Tds - du$$

useful work

$$= T_0 (S_F - S_I) - (U_F - U_I)$$

$$= T_0 (S_0 - S_1) - (u_0 - u_1)$$

$$(U.W.)_{c.s.} = (u_1 - u_0) - T_0 (S_1 - S_0)$$

Maximum useful work $(M.U.W.)_{cs}$.

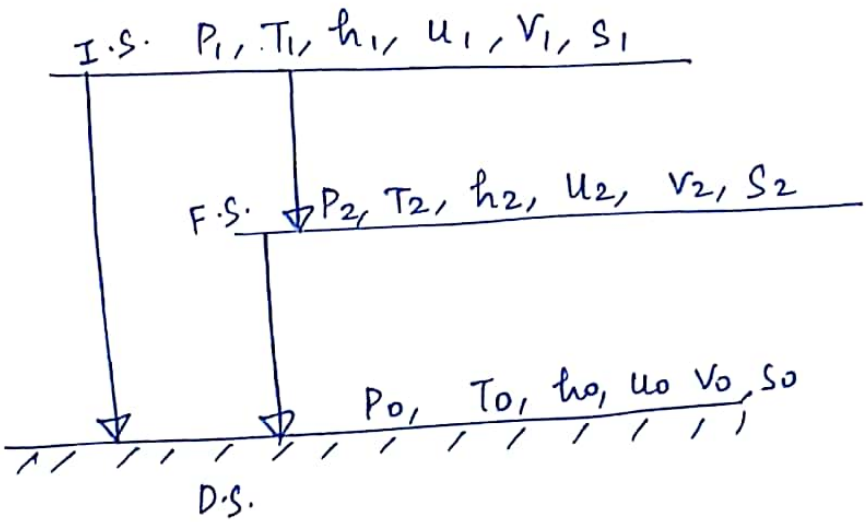
$$(M.U.W.)_{cs} = \left[(u_1 - u_0) - T_0(S_1 - S_0)\right] - P_0\, dV$$

$$= (u_1 - u_0) - T_0(S_1 - S_0) - P_0(V_F - V_I)$$

$$= (u_1 - u_0) - T_0(S_1 - S_0) - P_0(V_0 - V_1)$$

OBJ

$$\boxed{(M.U.W.)_{c.s.} = (u_1 - u_0) - T_0(S_1 - S_0) + P_0(V_1 - V_0)}$$



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$$\boxed{(U.W.)_{CS.} = (u_1 - u_2) - T_0(s_1 - s_2)}$$

1-0 :- $(u_1 - u_0) - T_0(s_1 - s_0)$

2-0 :- $(u_2 - u_0) - T_0(s_2 - s_0)$

(1-2) :- $(u_1 - u_2) - T_0(s_1 - s_2)$

Imp

$$(U.W.)_{C.S.} = (U_I - U_F) - T_0(S_I - S_F)$$

$$(M.U.W)_{C.S.} = (U_I - U_F) - T_0(S_I - S_F) + P_0(V_I - V_F)$$

② OPEN SYSTEM :→

$$(U.W.)_{O.S.} = (h_I - h_F) - T_0(S_I - S_F)$$

$$(M.U.W.)_{O.S.} = (h_I - h_F) - T_0(S_I - S_F)$$

NOTE :- The expression of useful work and maxm. useful work is same for open system.

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* **IRREVERSIBILITY** :→ It is defined as the difference of maximum work and actual work.

Theorem :→ Gouy's Stodala Theorem :-

IES 2008

$$\dot{I} \propto (\dot{ds})_{universe}$$

$$\boxed{\dot{I} = T_0 (\dot{ds})_{universe}}$$

According to this theorem, Rate of irreversibility is directly proportional to rate of entropy generation.

* **GIBBS FUNCTION** :→

OBJ

$$\boxed{G = H - TS}$$

change in Gibbs function (dG) :-

$$dG = dH - TdS - SdT$$

$$TdS = dH - VdP$$

$$dH - TdS = VdP$$

OBJ

$$\boxed{dG = VdP - SdT}$$

* **Gibbs Helmholtz Function** :- OBJ $\boxed{F = U - TS}$

change in Gibbs Helmholtz function :-

$$dF = dU - TdS - SdT$$

$$TdS = du + PdV$$

$$dU - TdS = -PdV$$

OBJ

$$\boxed{dF = -PdV - SdT}$$

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* **PMM-2 (Perpeptual Motion machine of IInd kind)** :→ Bike + Petrol without silencer

PMM-2 is impossible because it voilates second law of thermodynamics that is complete conversion of low grade energy into high grade is not possible.

* **PMM-3 (Perpeptual Motion machine of IIIrd kind)**:→

It is impossible to contstruct a device which runs completely in the absence of friction.

* **IIIRD LAW OF THERMODYNAMICS**:→ It is impossible to achieve absolute 0 temperature in a finite no. of process.

✓ **(NERNST SIMON STATEMENT)**:- The entropy of a pure crystalline substance is zero at absolute zero temperature.

* **COMPRESSIBILIY FACTOR (Z)**:- This factor represents the deviation of real gas from the behaviour of ideal Gas. The mathematical representation of compressibility factor is

$$\boxed{Z = \frac{PV}{RT}}$$

The value of Z is 1 for ideal

$\left.\begin{matrix} <1 \\ >1 \end{matrix}\right\}$ Real gas

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WB Pg-27

(32) 6 times repeat without data change

$Q = 1000 KJ$

$T_1 = 600K$

$T_2 = 400K$

$T_0 = 300K$

$$\frac{Q_1 T_0 (T_1 - T_2)}{T_1 T_2} = \frac{1000 \times 300 (600-400)}{600 \times 400}$$

$= 250 KJ$

(33) $h_1 = 400$

$h_2 = 100$

$S_1 = 1.1$

$S_2 = 0.7$

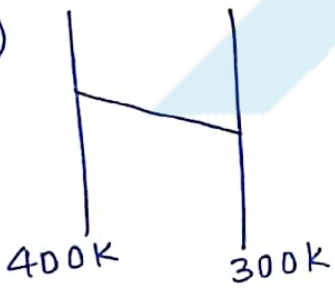
$T_0 = 300K$

$(h_1 - h_2) = -T_0 (S_1 - S_2)$

$300 - 300 \times 0.4$

$1800 KJ/Kg$

(34)



$T_0 ds$

$$\left(\frac{-1000}{400} + \frac{1000}{300} \right) \times 298$$

248.33 watt

Q35 VVIMP IAS 15 marks

ambient temperature

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Q

$T_i = 200°C = 473K$

$T_F = 25°C = 298K$

25°C → $T_0 = 298\,K$

sphere

$\rho = 2700$

$C = 0.9$

$D = 0.1m$

$$I = T_0\left[(ds)_{sphere} + (ds)_{surr.}\right]$$

$$= T_0\left[mc\ln\frac{T_F}{T_I} + \frac{dQ}{T}\right]$$

$$= 298\left[m \times 0.9 \times \ln\frac{298}{473} + \frac{dQ}{298}\right]$$

$$\cancel{kg} \times \frac{kJ}{\cancel{kg}\,K} = 47.2\,kJ$$

$\rho = \frac{m}{vol}$ → $4/3\pi r^3$

$m = \rho \times vol$

$m = 2700 \times \frac{4}{3}\pi\left(\frac{0.1}{2}\right)^3$

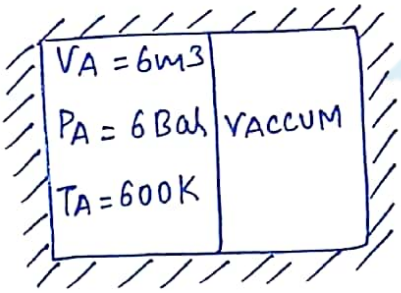
$m = 1.418\,kg$

$dQ = mC\Delta T$

$= 1.418 \times 0.9 \times (200 - 25)$

$= 222$

IES
15 marks
37



$V_T = 10\,m^3$

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$$I = T_0 \left[(ds)_{system} + \cancel{(ds)_{SURR.}}^{\to 0} \right]$$

$$dQ = 0$$

$$(ds)_{SUR} = 0$$

$$I = T_0 (ds)_{system}$$

$$Tds = \cancel{du} + PdV$$

$$ds = \frac{P}{T} dV$$

$$\frac{\cancel{K} \times \frac{KJ}{Kg\cancel{K}} \times Kg}{\frac{KJ}{\cancel{Kg}} \cancel{Kg}}$$

$$ds = R \int \frac{dV}{V}$$

$$ds = R \ln \frac{V_F}{V_I}$$

$$I = m T_0 R \ln \frac{V_F}{V_I}$$

$$= \frac{P_A V_A}{\cancel{R} T_A} (T_0 \cancel{R}) \ln \frac{V_F}{V_I}$$

$$= \frac{6 \times 100 \times 6}{600} \times 300 \ln \frac{10}{6}$$

$$= 919.2 \, KJ$$

38

IES

15 marks

$P_1 = 9$ Bar

$T_1 = 400K$

$P_2 = 1.5$ Bar

$T_2 = 300K$

$P_0 = 1$ Bar

$T_0 = 288$ K

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$$(U.W)_{CLOSED} = (u_1 - u_2) - T_0(s_1 - s_2)$$

$$= C_v(T_1 - T_2) - T_0(s_1 - s_2)$$

$$= 0.718(400-300) - 288(s_1 - s_2) \quad \text{--- (1)}$$

$$= 136 \text{ kJ/kg}$$

$$ds = C_p \ln\frac{T_2}{T_1} - R\ln\frac{P_2}{P_1}$$

$$= 1.005 \ln\frac{300}{400} - 0.287 \ln\frac{1.5}{9}$$

$$s_2 - s_1 = 0.225 \text{ kJ/kg K}$$

$$s_1 - s_2 = -0.225 \text{ kJ/kg K}$$

$$(MUW) = 136 + P_0(V_1 - V_2) \qquad \left[\begin{array}{l} PV = RT \\ V = \frac{RT}{P} \end{array}\right]$$

$$= 136 + P_0\left[\frac{RT_1}{P_1} - \frac{RT_2}{P_2}\right]$$

$$= 136 + 1\left[\frac{0.287 \times 400}{9} - \frac{0.287 \times 300}{1.5}\right]$$

$$= 91.9 \text{ kJ/kg}$$

T4 / IES / 10 marks

NOTE :- Availability Function :-
or
Flow Availability

Change in availability Function represents the max^m. useful work :- (1) Closed system :-

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OBJ $\boxed{Q_{c.s.} = u + P_0V - T_0S}$

(1)

$$(M.U.W.)_{c.s.} = (u_1 - u_2) - T_0(S_1 - S_2) + P_0(V_1 - V_2)$$

$$= u_1 - u_2 - T_0S_1 + T_0S_2 + P_0V_1 - P_0V_2$$

$$= (u_1 - T_0S_1 + P_0V_1) - u_2 + T_0S_2 - P_0V_2$$

$$= (u_1 + P_0V_1 - T_0S_1) - (u_2 + P_0V_2 - T_0S_2)$$

$$\boxed{(M.U.W.)_{cs} = \phi_1 - \phi_2}$$

(2) Open system (o.s.) OBJ $\boxed{Q_{o.s.} = h - T_0S}$

$$(M.U.W.)_{o.s.} = (h_1 - h_2) - T_0(S_1 - S_2)$$

$$= h_1 - h_2 - T_0S_1 + T_0S_2$$

$$= (h_1 - T_0S_1) - (h_2 - T_0S_2)$$

$$\boxed{(M.U.W.)_{o.s.} = \phi_1 - \phi_2}$$

T4

$h_1 = 4142$

$h_2 = 2500$

$\phi_1 = 1850$

$\phi = 140$

KJ/kg

$T_0 = 300\ K$

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① $h_1 + \cancel{KE_1} + \cancel{PE_1} + \cancel{Q} = h_2 + \cancel{KE_2} + \cancel{PE_2} + W$

$$h_1 = h_2 + W$$

$$W_A = h_1 - h_2$$

$$W_A = 4142 - 2500 = 1642 \text{ KJ/kg}$$

② $(MUW)_{O.S.} = \phi_1 - \phi_2 = 1850 - 140 = 1710 \text{ KJ/kg}$

③ $M.U.W. = (h_1 - h_2) - T_0(S_1 - S_2)$

$$1710 = 1642 - 300(S_1 - S_2)$$

$$S_1 - S_2 = -0.226$$

$$S_2 - S_1 = 0.226 \frac{KJ}{kg\,K}$$

T6
IES
20 marks

$P_1 = 100 \text{ KPa}$

$T_1 = 300 K$

$V_1 = 0.002 m^3$

$V_2 = 0.003 m^3$

$P_2 = 125 \text{ KPa}$

$$C_p \ln \frac{V_2}{V_1} + C_v \ln \frac{P_2}{P_1}$$

$$\Rightarrow \underline{0.567}$$

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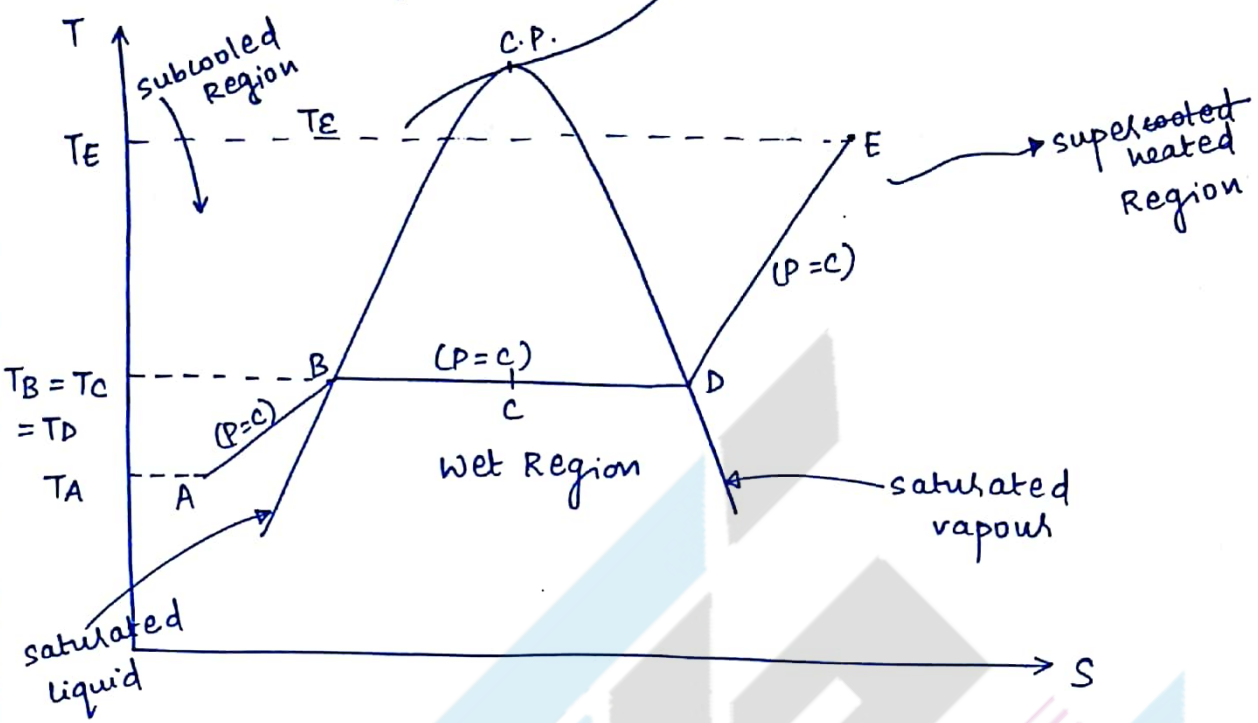
NEW CHAPTER :→ PURE SUBSTANCE (PS)

Representation of constant pressure line on T-S curve :-



at C.P. $\Rightarrow (CT)_{H_2O} = 374°C$

$\Rightarrow (CP)_{H_2O} = 221.2$ Bar

Degree of superheating $= T_E - T_D$

—"— —"— subcooling or undercooling $= T_B - T_A$

*Superheating :→ It is the process of increasing the temp^r. at constant pressure above saturated vapour.

* ~~Dryness f~~ Subcooling :→ It is the process of decreasing the temperature at constant pressure below saturated liquid.

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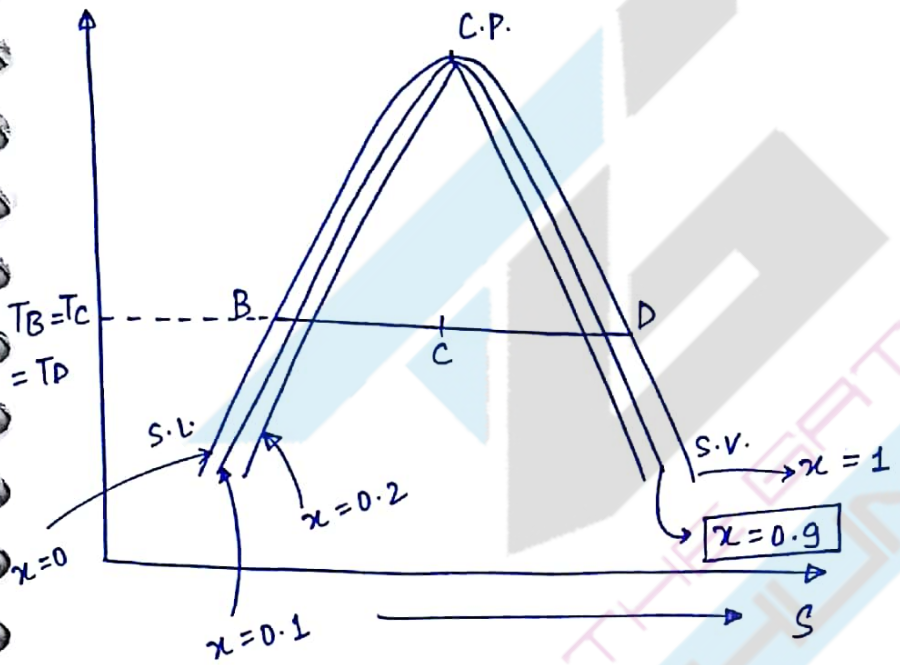
* Wet Region :- It is a mixture of liquid and vapour.

* C.P. (Critical Point) :- It is a point above which liquid will directly flash off into vapours.

NOTE :- The value of latent heat of vapourisation at critical point is 0.

* DRYNESS FRACTION OR QUALITY :→ (x)



$x = 0.20$ → 20% V, 80% L

$$x = \frac{m_v}{m_v + m_L}$$

x_B (sat. liquid) ⇒ $m_v = 0$

$x_B = 0$

x_D (sat. vapour) ⇒ $m_L = 0$

$x_D = 1$

$$0 \le x \le 1$$

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It is defined as the ratio of mass of vapour to the total mass of mixture. The value of dryness fraction is 0 for saturated liquid and the value of dryness fraction is 1 for saturated vapour.

NOTE :→ (1)

DO NOT APPLY $PV = mRT$ in WET REGION

(2) h_F s_F h_g s_g v_F u_F v_g u_g

F → saturated liquid

g → saturated vapour

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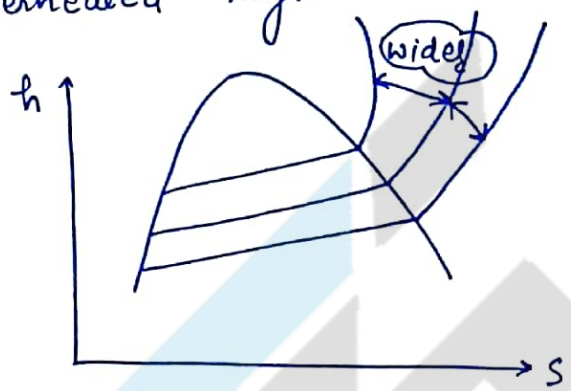
③ The Reference state for the steam table is

$$\left.\begin{array}{l} u = 0 \\ s = 0 \end{array}\right] \text{ at } 0.01^\circ C \text{ (Triple point of water)}$$

④ MOLLIER'S :→ It is a plot on h-s. The slope of constant pressure line on h-s curve is equal to absolute temperature. and the constant pressure line are of diverging nature in the superheated region.



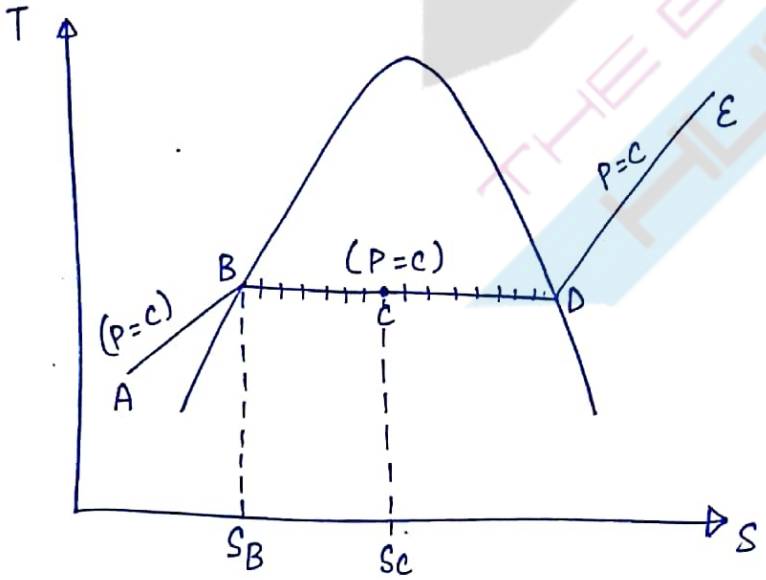
$$Tds = dh - vdP$$

$$P = C$$

$$Tds = dh$$

$$\boxed{\left(\frac{dh}{ds}\right)_P = T}$$

* The expression of enthalpy and entropy for the various states :-



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① h_B (sat. liquid) $= h_F$

② h_D (sat. vapour) $= h_g$

③ h_C (Wet Region) $= h_B + x h_{fg}$

$= h_F + x(h_g - h_F)$

④ $h_E = h_D + (C_p)_{vapour}(T_E - T_D) \longrightarrow \because (h_D < h_E)$

or

h_g

⑤ $h_A = h_B - (C_p)_{liq}(T_B - T_A) \longrightarrow (\because h_A < h_B)$

or

h_F

① $S_B = S_F$

② $S_D = S_g$

③ $S_C = S_B + x S_{fg}$

$= S_F + x(S_g - S_F)$

$= S_F + x\left(\frac{h_{fg}}{T}\right)$

④ $S_E = S_D + (C_p)_{vapour} \ln\left(\frac{T_E}{T_D}\right)$

or

S_g

⑤ $S_A = S_B - (C_p)_{liq} \ln\left(\frac{T_B}{T_A}\right)$

or

S_F

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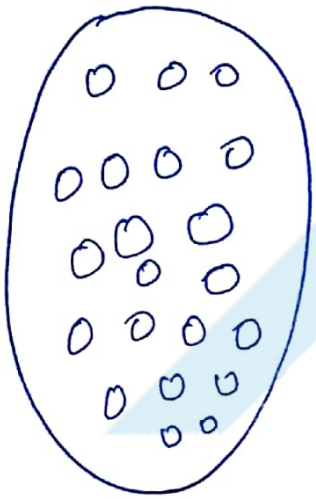
* MIXTURE OF GASES :→

✓ Vanderwaal's Equation :-

$$\left(P + \frac{a}{V^2}\right)(V-b) = RT$$

$\frac{a}{V^2}$ = Force of cohesion

b = co-volume = $\frac{V_c}{3}$ → critical volume.



$$(C_p)_{mix} = \frac{m_1 C_{p_1} + m_2 C_{p_2} + \text{-------}}{m_1 + m_2 + \text{----------}}$$

$$(C_v)_{mix} = \frac{m_1 C_{v_1} + m_2 C_{v_2} + \text{------}}{m_1 + m_2 + \text{----------}}$$

$$(h)_{mix} = \frac{m_1 h_1 + m_2 h_2 + \text{-------}}{m_1 + m_2 + \text{-------}}$$

$$(u)_{mix} = \frac{m_1 u_1 + m_2 u_2 + \text{----------}}{m_1 + m_2 + \text{-------}}$$

$$(R)_{mix} = \frac{m_1 R_1 + m_2 R_2 + \text{--------}}{m_1 + m_2 + \text{--------}}$$

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* Dalton's law of partial pressure :-

$$\boxed{P = p_1 + p_2 + \text{------}}$$

$x_1 \rightarrow$ mole fraction

x_2

$$\boxed{x_1 = \frac{n_1}{n_1 + n_2}}$$

$$\boxed{x_2 = \frac{n_2}{n_1 + n_2}}$$

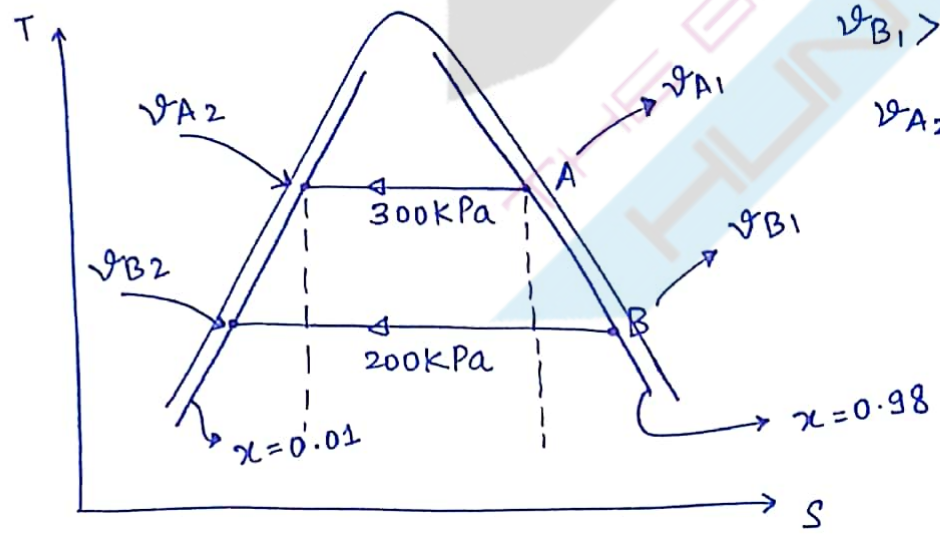
$\frac{x_1}{P}$ $\boxed{p_1 = x_1 P}$

CH # 6
Workbook
Q1 Imp
VV

$v_g >>> v_F$

$v_{B1} > v_{A1}$

$v_{A2} > v_{B2}$



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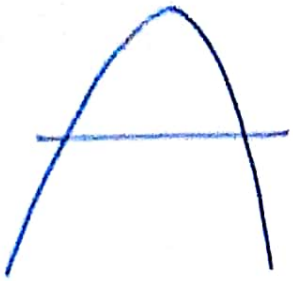
(2)



$$x = \frac{m_V}{m_V + m_L}$$

$$v = \frac{vol}{m}$$

$$m = \frac{vol}{v}$$

$$= \frac{\frac{(V)_V}{v_g} \cancel{8V_L}}{\frac{(vol)_V}{v_g} \cancel{8V_L} + \frac{(vol)_L}{v_F}}$$

$$= \frac{8/v_g}{8/v_g + 1/v_F}$$

= (A)

(3) $U_A = U_B$

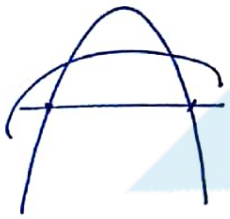
$$u = \frac{U}{m}$$

$$U = mu$$

$$\frac{u_g}{u_F}$$

$$\frac{2583.6}{761.7}$$

(C)



(4) $Q = v_F + x\, v_{Fg}$

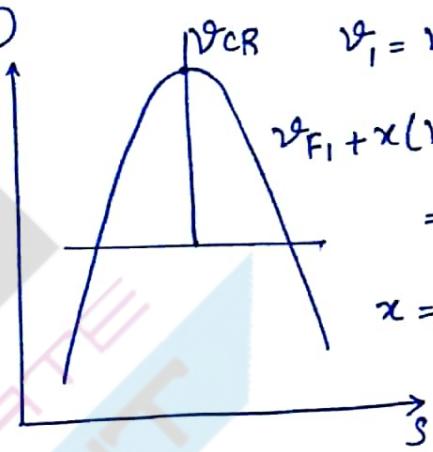
$$= v_F + x(v_g - v_F)$$

$$= v_F + x v_g - x v_F$$

$$= x v_g + (1-x) v_F$$

(A)

(5)



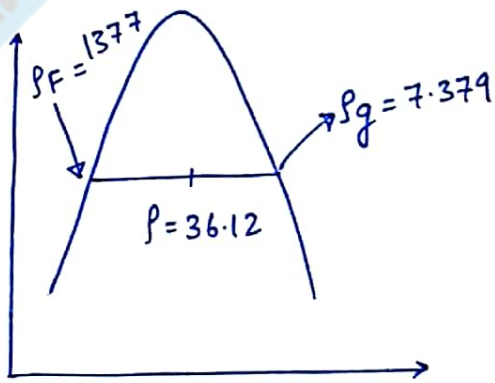
$v_1 = v_{CR}$

$v_{F_1} + x(v_{g_1} - v_{F_1}) = v_{CR}$

$x = 0.10$

(6) C

(7)



$$\rho = \frac{mass}{volume}$$

$$v = \frac{vol_m}{m}$$

$$v = v_F + x(v_g - v_F)$$

$$1/\rho = 1/\rho_F + x(1/\rho_g - 1/\rho_F)$$

$x = 0.2$ (B)

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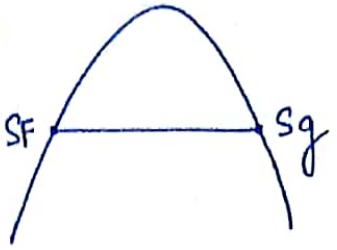
(9)



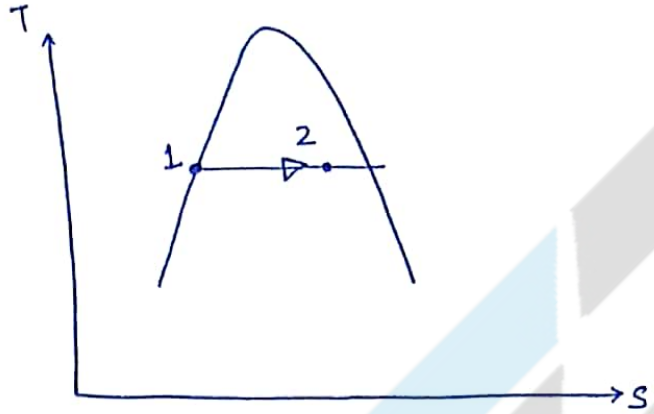
$$S_g = S_F + \cancel{x}^{1}\left[\frac{h_g - h_F}{T}\right]$$

$$= S_F + \frac{(h_g - h_F)}{273 + 99.63}$$

$$= 7.362$$

(11) (A)

(12)



$$Tds = dh - \cancel{vdp}$$

$$dQ = dh$$

$$dQ = h_2 - h_1$$

$$= (\cancel{h_F} + x h_{Fg}) - \cancel{h_F}$$

$$dQ = x(h_g - h_F)$$

$$m_v = ?$$

$$KJ\ \frac{10}{2} = x(2778.1 - 762.8)\frac{KJ}{Kg}$$

$$x = 2.48 \times 10^{-3}$$

$$x = \frac{m_v}{m_v + m_l}$$

$$2.48 \times 10^{-3} = \frac{m_v}{2}$$

$$m_v = 4.96 \times 10^{-3}\ kg$$

$$= 4.96\ gm$$

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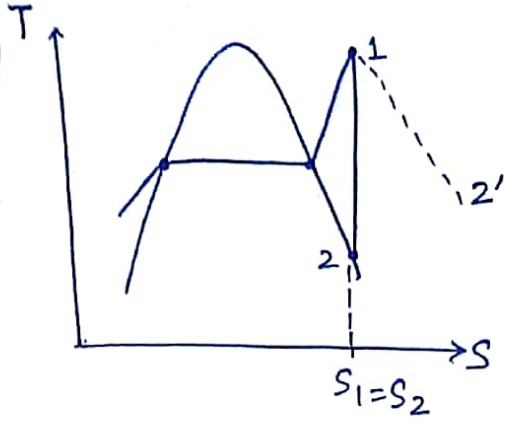
(13) b

(14)



(15) Rigid → V=C

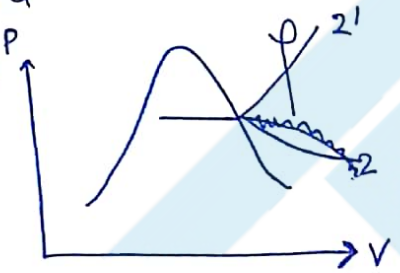
$Tds = du + \cancel{Pdv}$

(c) $dQ = du$

(16) b

(17) d

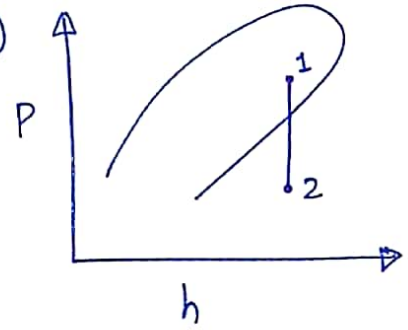
(19)



(c)

(20) c

(21)



(D)

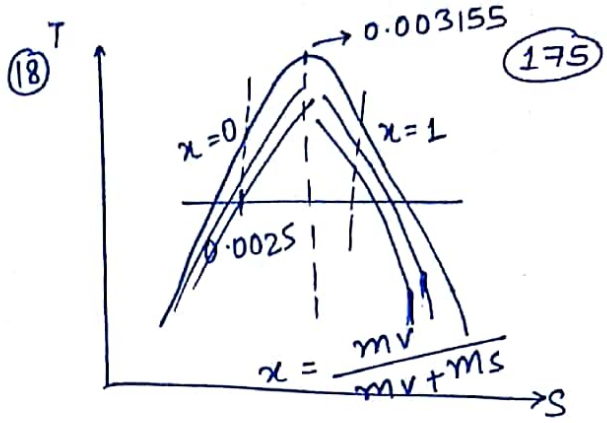
(26) $P = a/v^2$

$\frac{F}{A} = \frac{a}{v^2}$

$\frac{kg \times m/sec^2}{m^2} = \frac{a}{(m^3/kg)^2}$

$a = m^5/kg\text{-}s^2$

(18)



175

$x \downarrow \rightarrow$ VAP $\downarrow$

Liq $\uparrow$

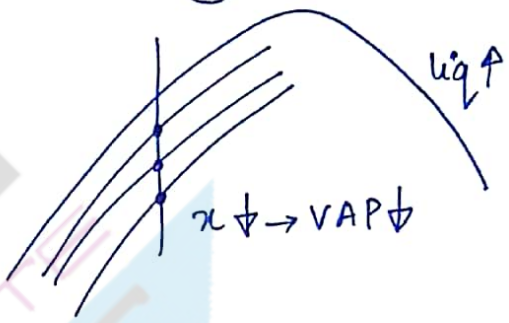
$V = 0.025$

$m = 10$ kg

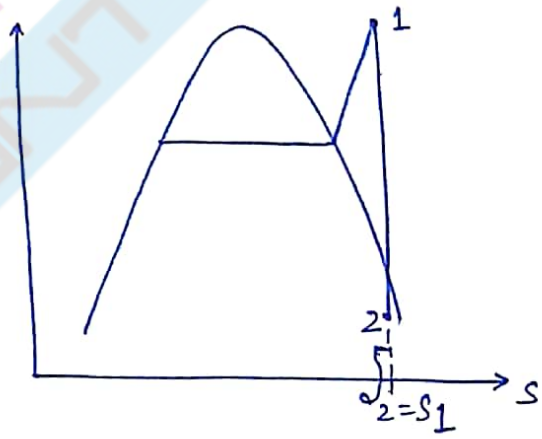
$v = \frac{vol}{m}$

$v = 0.0025$

(A)



(22)



$S_1 = S_2$

$S_1 = S_{F_2} + x(S_{g_2} - S_{F_2})$

$x = 90\%$

(23) A ✓ R ✓ (A)

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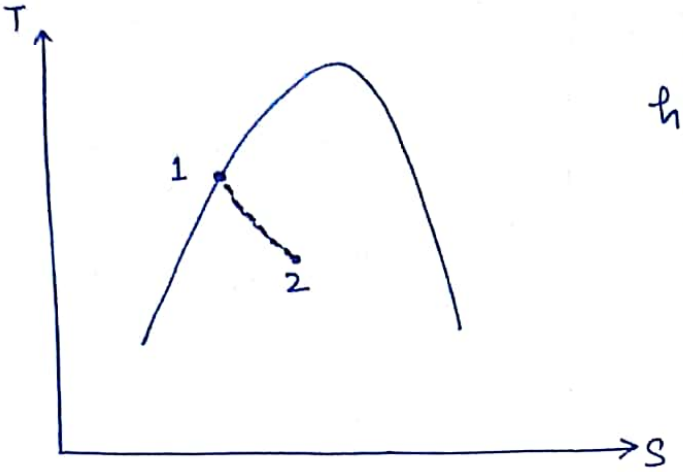
(27)



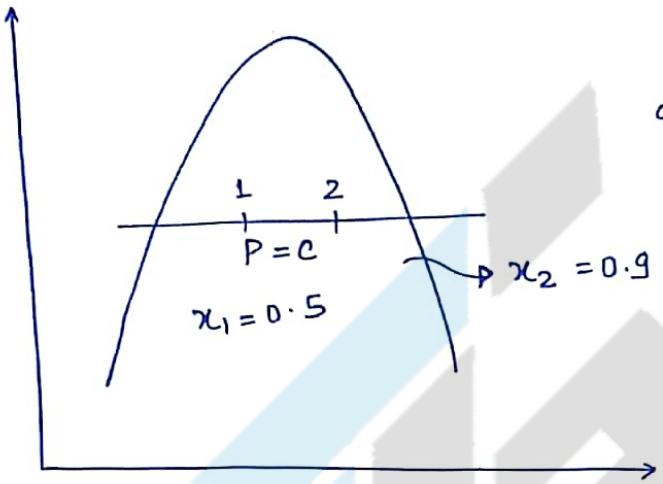
$$h_1 = h_2$$

$$h_{F_1} = h_{F_2} + x(h_{g_2} - h_{F_2})$$

$$1000 = 800 + x(2800 - 800)$$

$$x = 0.1$$

(28)



$$dQ = h_2 - h_1$$

$$dQ = (\cancel{h_F} + x_2 h_{Fg}) - (\cancel{h_F} + x_1 h_{Fg})$$

$$dQ = (x_2 - x_1)(h_g - h_F) \times 2$$

$$dQ = 1761$$

(29)

$$\frac{m_1R_1 + m_2R_2 + m_3R_3}{m_1 + m_2 + m_3}$$

$$\frac{0.60 \times \frac{8.314}{28} + 0.30 \times \frac{8.314}{32} + 0.10 \times \frac{8.314}{44}}{0.6 + 0.3 + 0.1}$$

274.99

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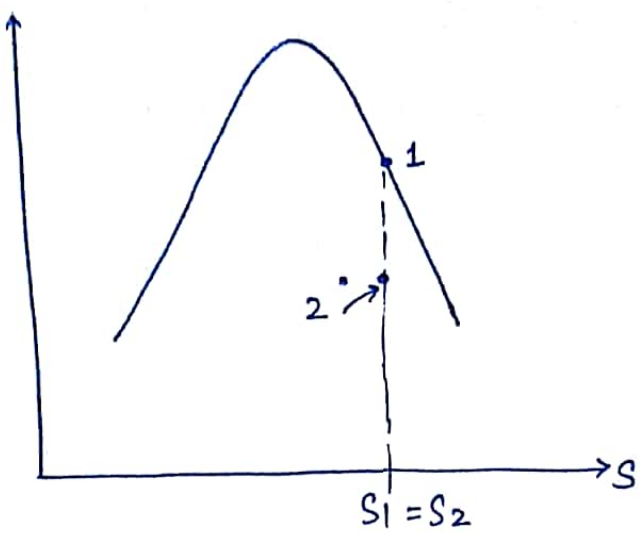
30



$P = \dot{m}[h_1 - h_2]$

$= \dot{m}[h_{g_1} - (h_{F_2} + x(h_{g_2} - h_{F_2}))]$

$= 1282\,kW$

$S_1 = S_2$

$S_{g_1} = S_{F_2} + x(S_{g_2} - S_{F_2})$

$x = 0.829$

24/25 Gate 4 marks

1	2	3	4	5	6	7	8
		u_F	S_F	h_F	S_g	u_g	h_g

$h / u / S$

$\downarrow \quad \downarrow \quad \downarrow$

$\frac{KJ}{Kg} \quad \frac{KJ}{Kg} \quad \frac{KJ}{Kg\,K}$

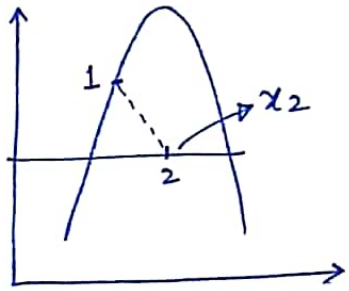
(a) $h > u > S$

(b) $g > F$

(d) $h_F = u_F + P v$ → 0.000

$g \quad g \quad g$

$v_g >>> v_F$



$h_{F_1} = h_{F_2} + x(h_{g_2} - h_{F_2})$

$x = 0.212$

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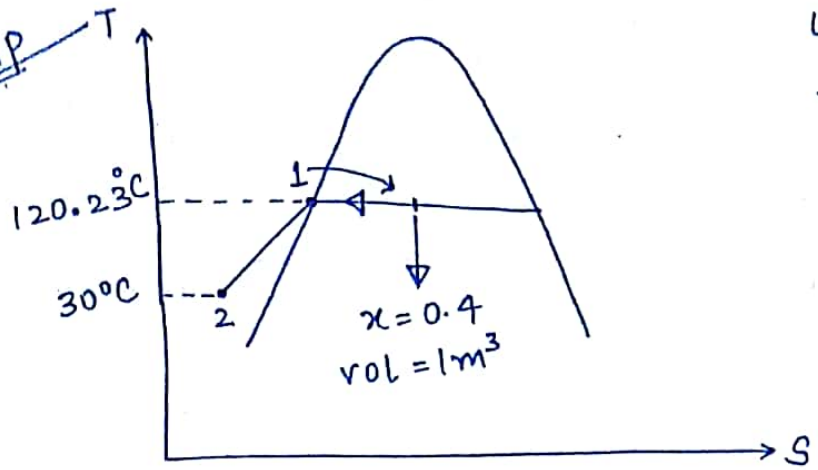
(8) Vimp



$u_2 = h_2 = 125.77$

$Tds = dh - \cancel{vdp}$

$dQ = dh$

$dQ = h_1 - h_2$

$= [h_F + x(h_g - h_F)] - h_2$

$= 1260 \frac{KJ}{kg} \times m$

$= 3550 KJ$

$v = \frac{Vol}{m}$

$m = \frac{Vol}{v}$

$m = \frac{1}{v_{F_1} + x(v_{g_1} - v_{F_1})}$

$\boxed{m = 2.81 kg}$

(10) C

$Tds = du$

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Theorem 1 :- $dz = M dx + N dy$

$$\left(\frac{\partial M}{\partial y}\right)_x = \left(\frac{\partial N}{\partial x}\right)_y$$

Theorem 2 :- $F = \phi(x, y, z)$

$$\left(\frac{\partial x}{\partial y}\right)_F \left(\frac{\partial y}{\partial z}\right)_F \left(\frac{\partial z}{\partial x}\right)_F = +1$$

Theorem 3 :- $PV = mRT$

$T = F(P, V)$

$$\left(\frac{\partial T}{\partial P}\right)_V \left(\frac{\partial P}{\partial V}\right)_T \left(\frac{\partial V}{\partial T}\right)_P = -1$$

* Maxwell Equation :-

$Tds = du + Pdv$

$du = Tds - Pdv$

$dz = M dx + N dy$

$M \longrightarrow T$

$X \longrightarrow S$

$N \longrightarrow -P$

$Y \rightarrow V$

$$\left(\frac{\partial M}{\partial Y}\right)_X = \left(\frac{\partial N}{\partial X}\right)_Y$$

$$\boxed{\left(\frac{\partial T}{\partial V}\right)_S = -\left(\frac{\partial P}{\partial S}\right)_V} \quad (1)$$

Now, $Tds = dh - vdP$

$dh = Tds + vdP$

$dz = M dx + N dy$

$$\left(\frac{\partial M}{\partial Y}\right)_X = \left(\frac{\partial N}{\partial X}\right)_Y$$

$$\boxed{\left(\frac{\partial T}{\partial P}\right)_S = \left(\frac{\partial V}{\partial S}\right)_P} \quad (2)$$

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$$G = H - TS$$

$$dG = dH - TdS - SdT$$

$$TdS = dH - VdP$$

$$-TdS + dH = VdP$$

$$dG = VdP - SdT$$

$$dz = Mdx + Ndy$$

$$\left(\frac{\partial M}{\partial y}\right)_x = \left(\frac{\partial N}{\partial x}\right)_y$$

$$\boxed{\left(\frac{\partial V}{\partial T}\right)_P = -\left(\frac{\partial S}{\partial P}\right)_T} \quad (3)$$

Now, $F = U - TS$

$$dF = dU - TdS - SdT$$

$$TdS = dU + PdV$$

$$dU - TdS = -PdV$$

$$dF = -PdV - SdT$$

$$dz = Mdx + Ndy$$

$$\left(\frac{\partial M}{\partial y}\right)_x = \left(\frac{\partial N}{\partial x}\right)_y$$

$$\boxed{\left(\frac{\partial P}{\partial T}\right)_V = \left(\frac{\partial S}{\partial V}\right)_T} \quad (4)$$

Thermal Power Station in Village

T	P
V	S

$$\boxed{\left(\frac{\partial T}{\partial V}\right)_S = -\left(\frac{\partial P}{\partial S}\right)_V}$$

T	V
P	S

$$\boxed{\left(\frac{\partial T}{\partial P}\right)_S = \left(\frac{\partial V}{\partial S}\right)_P}$$

P	S
T	V

$$\boxed{\left(\frac{\partial P}{\partial T}\right)_V = \left(\frac{\partial S}{\partial V}\right)_T}$$

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V	S
T	P

$$\boxed{\left(\frac{\partial V}{\partial T}\right)_P = -\left(\frac{\partial S}{\partial P}\right)_T}$$

*Ist Tds Equation :→

$Tds = du + PdV$

$ds = \frac{du}{T} + \frac{P}{T}dV$

$du = C_v dT$ | $PV = RT$

$\frac{P}{T} = \frac{R}{V}$

$\therefore ds = C_v \frac{dT}{T} + R\frac{dV}{V}$

$S = F(T, V)$

use Partial Differential :-

$ds = \left(\frac{\partial S}{\partial T}\right)_V dT + \left(\frac{\partial S}{\partial V}\right)_T dV$

Multiply Both sides with T :-

$Tds = T\left(\frac{\partial S}{\partial T}\right)_V dT + T\left(\frac{\partial S}{\partial V}\right)_T dV$ — (A)

$Tds = du + PdV$

$V = C$

$Tds = du$

$Tds = C_v dT$

$$\boxed{T\left(\frac{ds}{dT}\right)_V = C_v}$$ — (B)

use eqn. no. 4 :-

$F = U - TS$

$\left(\frac{\partial S}{\partial V}\right)_T = \left(\frac{\partial P}{\partial T}\right)_V$ — (C)

use (B) & (C) in eqn. no. (A) :-

$$\boxed{Tds = C_v dT + T\left(\frac{\partial P}{\partial T}\right)_V dV}$$ — (5)

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* IInd Tds Eqn :-

$$Tds = dh - vdP$$

$$ds = \frac{dh}{T} - \frac{v}{T}dP$$

$$dh = C_p dT \quad \Big| \quad PV = RT, \quad \frac{V}{T} = \frac{R}{P}$$

$$\therefore ds = C_p \frac{dT}{T} - R\frac{dP}{P}$$

$$S = F(T, P)$$

use partial Diff:-

$$ds = \left(\frac{\partial s}{\partial T}\right)_P dT + \left(\frac{\partial s}{\partial P}\right)_T dP$$

Multiply both sides with T :-

$$Tds = T\left(\frac{\partial s}{\partial T}\right)_P dT + T\left(\frac{\partial s}{\partial P}\right)_T dP \quad \text{—— (A)}$$

$$Tds = dh - vdP$$

$$P = C$$

$$Tds = dh$$

$$Tds = C_p dT$$

$$\boxed{T\left(\frac{ds}{dT}\right) = C_p} \quad \text{—— (B)}$$

use Eqn. No. 3 :-

$$\left(\frac{\partial s}{\partial P}\right)_T = -\left(\frac{\partial V}{\partial T}\right)_P \quad \text{—— (C)}$$

use (B) & (C) in eqn. no (A) :-

$$\boxed{Tds = C_p dT - T\left(\frac{\partial V}{\partial T}\right)_P dP} \quad \text{—— (6)}$$

* Volume Expansivity (β) :-

$$\boxed{\beta = \frac{1}{V}\left(\frac{\partial V}{\partial T}\right)_P} \quad \text{—— (7)}$$

* Isothermal Compressibility (K_T) :-

Compressibility is defined as Reciprocal of Bulk modulus.

Bulk modulus is —"— —"— the ratio of direct stress to the volumetric strain.

$$\text{comp.} = \frac{1}{B.M.}$$

$$B.M. = \frac{-dP}{(\partial V/V)} = -V\left(\frac{dP}{dV}\right)$$

Isothermal

$$\text{comp.} = \frac{1}{B.M.} = \frac{-1}{V(dP/dV)}$$

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$$= -\frac{1}{V}\left(\frac{dV}{dP}\right)_T$$

$$\boxed{K_T = -\frac{1}{V}\left(\frac{dV}{dP}\right)_T} \quad \text{—— (8)}$$

Q> Prove that

vvimp $$\boxed{C_p - C_v = \frac{TV\beta^2}{K_T}}$$

Proof :- Comparing equ. No. (5) and (6),

$$C_v dT + T\left(\frac{\partial P}{\partial V}\right)_V dV = C_p dT - T\left(\frac{\partial V}{\partial T}\right)_P dP$$

$$C_p dT - C_v dT = T\left(\frac{\partial P}{\partial T}\right)_V dV + T\left(\frac{\partial V}{\partial T}\right)_P dP$$

$$(C_p - C_v)\, dT = T\left(\frac{\partial P}{\partial T}\right)_V dV + T\left(\frac{\partial V}{\partial T}\right)_P dP$$

$$dT = \frac{T}{C_p - C_v}\left(\frac{\partial P}{\partial T}\right)_V dV + \frac{T}{C_p - C_v}\left(\frac{\partial V}{\partial T}\right)_P dP \quad \text{—— (A)}$$

$T = F(P, V)$

use Partial diff. :-

$$dT = \left(\frac{\partial T}{\partial P}\right)_V dP + \left(\frac{\partial T}{\partial V}\right)_P dV \quad \text{—— (B)}$$

Compare coff of dV (A) and (B) :-

$$\frac{T}{C_p - C_v}\left(\frac{\partial P}{\partial T}\right)_V = \left(\frac{\partial T}{\partial V}\right)_P$$

$$C_p - C_v = T\left(\frac{\partial P}{\partial T}\right)_V\left(\frac{\partial V}{\partial T}\right)_P \quad \text{—— (C)}$$

$T = F(P, V)$

$$\left(\frac{\partial T}{\partial P}\right)_V\left(\frac{\partial P}{\partial V}\right)_T\left(\frac{\partial V}{\partial T}\right)_P = -1 \quad \text{—— (D)}$$

~~use (D) in C~~

$$\boxed{\left(\frac{\partial P}{\partial T}\right)_V = -\left(\frac{\partial P}{\partial V}\right)_T\left(\frac{\partial V}{\partial T}\right)_P}$$

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~~use Eq. No. (7) :-~~

$$\cancel{\beta = \frac{1}{V}\left(\frac{dV}{dT}\right)_P}$$

$$\cancel{\boxed{\left(\frac{dV}{dT}\right)_P = \beta V}} \quad \cancel{(8)}$$

~~use~~

use (D) in (C)

$$C_P - C_V = T\left[-\left(\frac{\partial P}{\partial V}\right)_T \left(\frac{\partial V}{\partial T}\right)_P\right]\left(\frac{\partial V}{\partial T}\right)_P$$

$$\boxed{C_P - C_V = -T\left(\frac{\partial P}{\partial V}\right)_T \left(\frac{\partial V}{\partial T}\right)_P^2} \quad (9)$$

NOTE :- Prove that the value of C_P is always greater than C_V.

The slope of constant temperature on P-V curve is always negative, therefore by using Eqn. no. 9, we can say that $C_P > C_V$

$$PV = C$$

$$P \propto 1/V$$

$$\left(\frac{\partial P}{\partial V}\right)_T = -ve$$

$$C_P - C_V = -[+ve \times -ve \times +ve]$$

$$C_P - C_V > 0$$

$$C_P > C_V$$

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use Eqn. no. (7) :-

$$\beta = \frac{1}{V}\left(\frac{dV}{dT}\right)_P$$

$$\boxed{\left(\frac{dV}{dT}\right)_P = \beta V} \quad \text{(E)}$$

use Eqn. no. (8) :-

$$K_T = \frac{-1}{V}\left(\frac{dV}{dP}\right)_T$$

$$\boxed{\left(\frac{dV}{dP}\right)_T = -K_T V} \quad \text{(F)}$$

use eqn. no. (E) & (F) in eqn (9) :-

$$\boxed{C_P - C_V = -T\left(\frac{\partial P}{\partial V}\right)_T\left(\frac{\partial V}{\partial T}\right)_P^2} \longrightarrow \boxed{C_P - C_V = \frac{TV\beta^2}{K_T}} \quad (10)$$

* JOULE THOMSON COEFFICIENT OR JOULE KELVIN EQUATION :-

$$\boxed{\mu_J = \left(\frac{dT}{dP}\right)_h}$$

$$Tds = dh - v.dP$$

$$dh = Tds + vdP$$

use eqn NO (6) :-

$$dh = \left[C_P dT - T\left(\frac{\partial V}{\partial T}\right)_P dP\right] + vdP$$

$$dh = C_P dT + \left[V - T\left(\frac{\partial V}{\partial T}\right)_P\right] dP \quad \text{(A)}$$

$$dh = 0$$

$$C_P dT + \left[V - T\left(\partial V/\partial T\right)_P\right] dP = 0$$

$$C_P dT = -\left[V - T\left(\partial V/\partial T\right)_P\right] dP$$

$$C_P dT = \left[T\left(\frac{\partial V}{\partial T}\right)_P - V\right] dP$$

$$\boxed{\mu_J = \left(\frac{dT}{dP}\right)_h = \frac{1}{C_P}\left[T\left(\frac{\partial V}{\partial T}\right)_P - V\right]} \quad (11)$$

NOTE :- The value of Joule thomson coefficient is zero for ideal gas.

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$PV = RT$

Diff :-

$$PdV + \cancel{VdP} = RdT + \cancel{TdR}$$

$$PdV = RdT$$

$$\left(\frac{dV}{dT}\right)_P = \frac{R}{P}$$

$$T\left(\frac{dV}{dT}\right)_P = \frac{TR}{P}$$

$$\boxed{T\left(\frac{dV}{dT}\right)_P = V} \quad \text{— (B)}$$

use (B) in EQ (11) :-

$$\boxed{\mu_J = \left(\frac{dT}{dP}\right)_h = \frac{1}{C_P}\left[T\left(\frac{\partial V}{\partial T}\right)_P - V\right]}$$

$$\boxed{\mu_J = 0}$$

Q> Prove that enthalpy is a function of temperature only for Ideal gas :-

Ans

Using EQ (A) {(Refer Joule thomson coefficient)}

$$dh = C_P dT + \left[V - T\left(\frac{\partial V}{\partial T}\right)_P\right] dP \quad \text{— (A)}$$

use (B) in (A) :- $\left(T\left(\frac{dV}{dT}\right)_P = V \text{ — B} \right)$

$$\boxed{dh = C_P dT}$$

..... H. P. .....

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Q Prove that internal Energy is a function of Tempr. only for an ideal gas.

Proof:- $Tds = du + Pdv$

$du = Tds - Pdv$

use EQ No. 5 :-

$$du = \left[C_v dT + T\left(\frac{\partial P}{\partial T}\right)_v dv\right] - P\,dv$$

$$du = C_v dT + \left[T\left(\frac{\partial P}{\partial T}\right)_v - P\right] dv$$

$PV = RT$

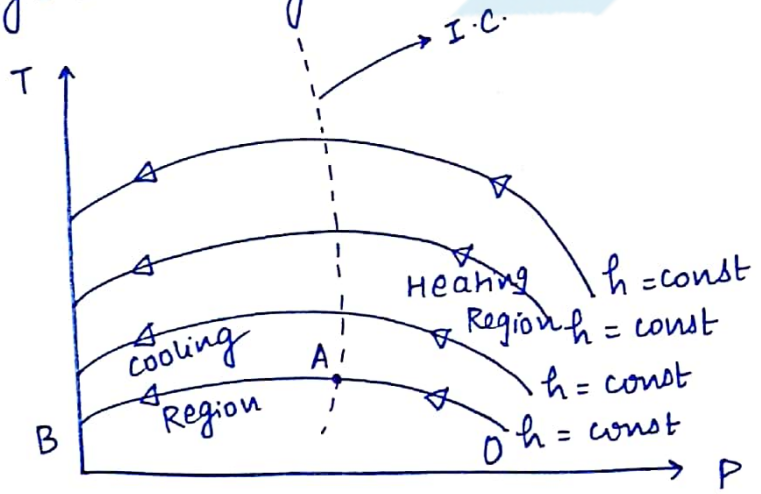
$VdP = RdT$

$$T\left(\frac{dP}{dT}\right)_v = \frac{RT}{V} = P$$

$$\boxed{du = C_v dT}$$

H.P.

* **INVERSION CURVE** :- It is obtained by joining the peaks of different isenthalpic curve on T-P plot. outside the inversion curve, the Region is known as heating Region and having -ve slope whereas inside the inversion curve, the region is known as cooling region & having +ve slope



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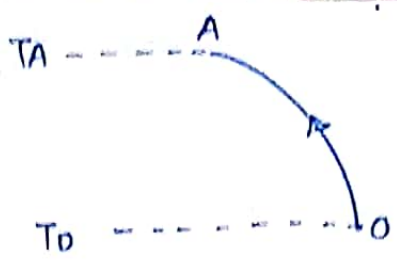
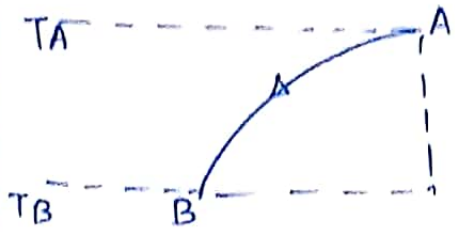


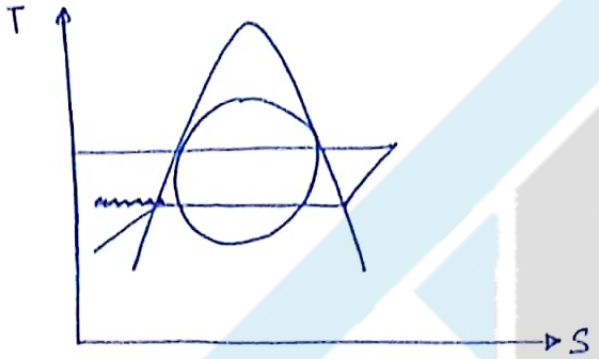
$$\frac{dT}{dP} = \frac{+ve}{-ve} = -ve$$



$$\frac{dT}{dP} = \frac{-ve}{-ve} = +ve$$

* CLAPEYRON CLAUSIUS EQ^n :- (C.C.)

In the case of wet region the pressure and temperature are independent of volume.



Use EQ 4 :- $F = U - TS$

$$\left(\frac{\partial P}{\partial T}\right)_V = \left(\frac{\partial S}{\partial V}\right)_T = \frac{\left(\frac{dQ}{T}\right)}{dV}$$

$$= \frac{dQ}{T\,dV} = \frac{m h_{fg}}{T\,dV} = \frac{h_{fg}}{T\,dv}$$

$$= \frac{h_{fg}}{T v_{fg}}$$

$$\boxed{\left(\frac{dP}{dT}\right)_V = \frac{(h_g - h_f)}{T(v_g - v_f)}} \quad \text{—— (12)}$$

$v_g >>>> v_f$

$$\therefore \left(\frac{dP}{dT}\right)_V = \frac{LH}{T v_g} \quad \text{—— (A)}$$

$PV = mRT$

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$$P\left(\frac{v}{m}\right) = RT$$

$$Pv = RT$$

$$v = \frac{RT}{P} \quad \text{— (B)}$$

use (B) in (A) :-

$$\left(\frac{dP}{dT}\right)_v = \frac{LH}{T \times \frac{RT}{P}}$$

$$\boxed{\left(\frac{dP}{dT}\right)_v = \frac{P(LH)}{RT^2}} \quad \text{— (13)}$$

WB CH#7

(1) $\frac{dP}{dT} = 17.69$

$h_{fg} = ?$

$T = 20°C$

$v_f = \checkmark$

$v_g = \checkmark$

$$\frac{dP}{dT} = \frac{h_{fg}}{Tv_{fg}}$$

$h_{fg} = 181.5$ (d)

(2) A/D]

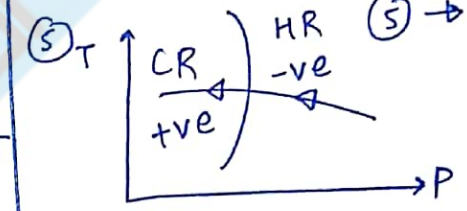
(4) $G = H - TS$

(B) $F = U - TS$

$G - F = H - U$

$= T - T$

$= T$

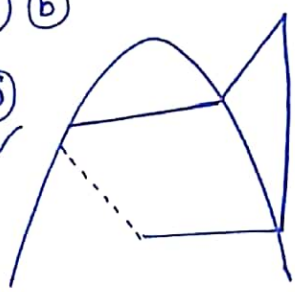
(5) 

(5) → C

(8) (a)

(15) (b)

(16) (a)



(9) $\left(\frac{\partial s}{\partial v}\right)_T = \left(\frac{\partial P}{\partial T}\right)_v = \frac{R}{V}$

$PV = RT$ (b)

$vdP = RdT$

(10) (c)

(11) → $-n_1R_1\log x_1 - n_2R_2\log x_2$

(12) $Tds = du + Pdv$ (c)

$du = Tds - Pdv$

$Tds = dh - vdP$

$dh = Tds + vdP$

(13) A $\left(\frac{dv}{dT}\right)_s$ → 4 (D)

(14)

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(18) $C_p - C_v = R$

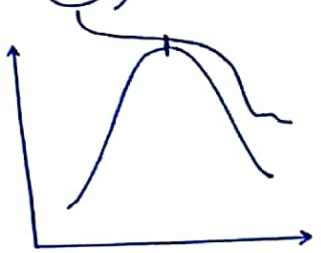
Q3 | Q6 | Q7

(19) A ✓ R ✓] (A)

Q3.7 | Q20 $Mdx + Ndy$ ← check

(d)

(21) $\left(P + \frac{a}{V^2}\right)(V - b) = RT$



P_c, T_c, V_c

$\frac{\partial P}{\partial V} = 0$

$\frac{\partial^2 P}{\partial V^2} = 0$

$\frac{\partial^3 P}{\partial V^3} < 0$

(22) $\frac{dP}{dT} = \frac{h_{fg}}{T(v_g - v_f)}$

$h_{fg} = 1851$

(3) $T_1 = 76°C \rightarrow P_1 = 101\ KPa$

$L_H = 195$

$R = 0.055$

$P_2 = 202\ KPa$

$T_2 = ?$

$\frac{dP}{dT} = \frac{P(L_H)}{RT^2}$

$\int_{P_1}^{P_2} \frac{dP}{P} = \frac{L_H}{R}\int_{T_1}^{T_2} \frac{dT}{T^2}$

$T^{-2} \rightarrow \frac{T^{-2+1}}{-2+1} \rightarrow \frac{T^{-1}}{-1} \rightarrow \left.\frac{-1}{T}\right|_{T_1}^{T_2} \rightarrow T_2 = 374K$

$\ln \frac{P_2}{P_1} = \frac{L_H}{R}\left[\frac{-1}{T_2} + \frac{1}{T_1}\right]$

$273 + 76$

~~$76°C = T_1$; $P_1 = 101\ KPa$~~

~~$L_v = 195\ KJ/Kg$~~

~~$R = 0.055\ KJ/Kg\,K$~~

~~$P_2 = 202\ KPa$, $T_2 = ?$~~

~~$\frac{mR}{V_1} = \frac{P_1}{T_1}$~~

~~$\frac{1(287)}{V_1} = \frac{101}{76°C}$~~

$76°C$ 1000

$101\ KPa$

$L_v = 195$ 7000 +3000 +1000 11000 +1000 12000

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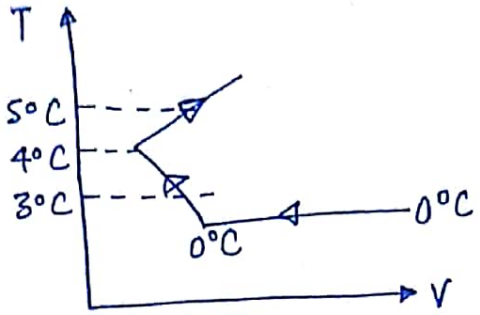
6.



$$\left(\frac{\partial s}{\partial P}\right)_T = -\left(\frac{\partial v}{\partial T}\right)_P$$

3° to $4^\circ C \rightarrow -\left[\frac{-ve}{+ve}\right] \rightarrow +ve$

4° to $5^\circ C \rightarrow -\left[\frac{+ve}{+ve}\right] \rightarrow -ve$

(D)

7. $\ln P_{sat} = A - \frac{B}{T_{sat}}$

$$\frac{1}{P_{sat}} \frac{dP}{dT} = +\frac{B}{T_{sat}^2}$$

$$\frac{dP}{dT} = \frac{h_{fg}}{T v_{fg}}$$

$T^{-1} \Rightarrow -1\, T^{-2} \Rightarrow \frac{-1}{T^2}$

$$\frac{dP}{dT} = \frac{B P_{sat}}{T_{sat}^2} = \frac{h_{fg}}{T v_{fg}}$$

(b)

$$h_{fg} = \frac{B P_{sat} v_{fg}}{T_{sat}}$$

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