

BASIC CONCEPTS :-

Thermodynamics :- It is the science of energy transfer and its effects on properties of system.

The main aim of thermodynamics

study is to convert disorganised form of energy (heat) into organised form of energy (work) in an efficient manner.

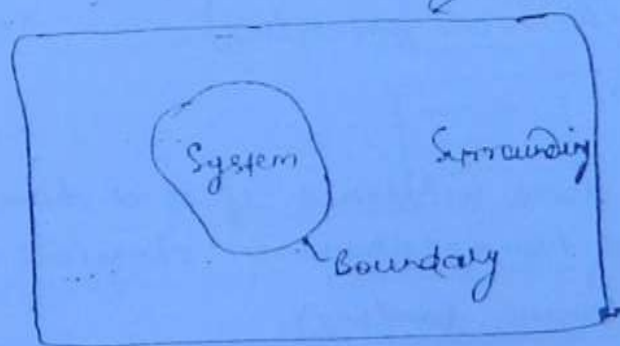
System :- It is a region in space upon which the study is focussed or concentrated.

Surroundings :- Anything external to the system is known as surroundings.

Boundary :- The separation between systems and surroundings is known as boundary.

Boundary can be either "rigid or movable" and boundary can be "real or imaginary."

Note :- Universe = System + Surrounding



** TYPES OF SYSTEM :

Types of System	Mass Transfer	Energy Transfer	Examples
Closed	X	✓	Piston cylinders without valves.
Open	✓	✓	Turbine, Comp., Pump, etc.
Isolated	X	X	Universe, Hot coffee in a well insulated flask.

* Microscopic and Macroscopic approach of Thermodynamics :-

In microscopic approach, the behaviour of individual molecules is taken into consideration. This approach is also known as statistical thermodynamics, and this approach is useful at low densities (higher altitudes).

$$\rho = \frac{m}{V} \quad \left. \begin{array}{l} \text{No. of molecules} \\ \text{---} \end{array} \right\}$$

In macroscopic approach, the behaviour of individual molecules is not taken into consideration but the average behaviour of molecules is taken into consideration. This approach is also known as classical thermodynamics.

In our course we follow Classical Thermodynamics. 6

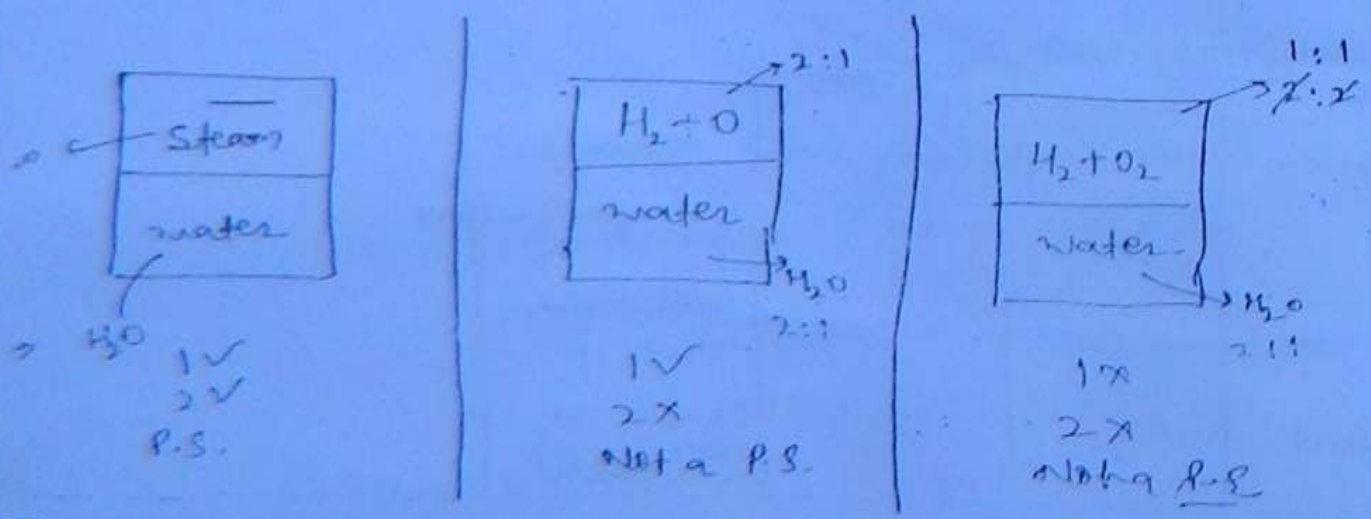
* Thermodynamic Equilibrium :-

A system is said to be in thermodynamic equilibrium, if it is in thermal equilibrium (equality of temperature), mechanical equilibrium (equality of forces or pressure) and chemical equilibrium (equality of chemical potential).

* Pure Substances :-

A substance is said to be a pure substance if it is homogeneous in chemical composition and homogeneous in chemical aggregation.

* (Aggregation means bonding).



* PROPERTIES OF A SYSTEM! - (Important).

Properties are characteristics of system. Examples Pressure, temp^o, volume, density, mass, etc. Properties are of two types:-

① Intensive (or intrinsic)

② Extensive (or extrinsic)

Intensive properties are independent of size or mass.

Examples - Pressure, temperature, density, thermal conductivity, viscosity, etc.

Extensive properties depend on size or mass of the system.

Examples - volumes, all forms of energy, etc.

Note:- Ratio of two extensive properties is an intensive property.

m
V
P
T

$m/2$	$m/2$
$V/2$	$V/2$
P	P
T	T

⑦

$$f = \frac{m \rightarrow E}{V \rightarrow E}$$

$m = 10 \text{ kg}$
$V = 10 \text{ m}^3$

$$f = m/V = 1$$

$m = 5$	$m = 5$
$V = 5$	$V = 5$

$$f = m/V = 1$$

Note:- Specific properties are extensive properties per unit mass and these ~~specific~~ properties are intensive properties.

Specific properties are intensive properties.

Example:-
 specific volume (v)
 specific enthalpy (h)
 specific internal energy (u)
 specific entropy (s).

Important points with respect to properties:-

- ① Properties are point functions or state functions.
- ② Properties are independent of past history.
- ③ Properties are exact differentials.

⑧

State of a system:-

The condition of a system is known as state of a system. The condition of a system is specified by means of its properties. As long as the properties are fixed, the condition is also fixed.

Process:- A change of state is known as a process.

GIBB'S PHASE RULE:-

According to Gibb's phase rule:-

$$P + F = C + 2$$

where,

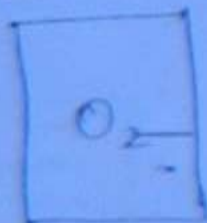
P = No. of Phases

F = Degree of freedom

or
Minimum no. of independent ^{intensive} variables required.

C = No. of components.

Expt-1



$$P = 1$$

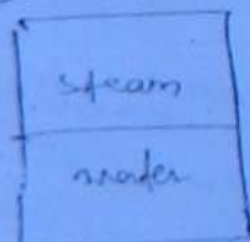
$$C = 1$$

$$P + F = C + 2$$

$$1 + F = 1 + 2$$

$$\therefore F = 2$$

Expt-2



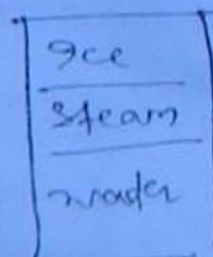
$$P = 2$$

$$C = 1$$

$$P + F = C + 2$$

$$F = 1$$

Expt-3



$$P = 3$$

$$C = 1$$

$$P + F = C + 2$$

$$F = 0$$

→* THERMODYNAMIC CYCLES:-

A system is said to have undergone a cycle if the initial and final points are same. Minimum number of processes required for a cycle are 2.

Note:- for a cycle the change in property is equal to zero. because property depend on point and for a cycle initial and final points are same.

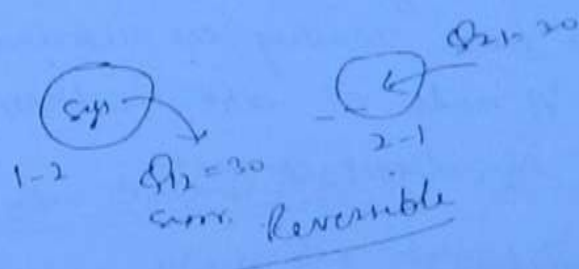
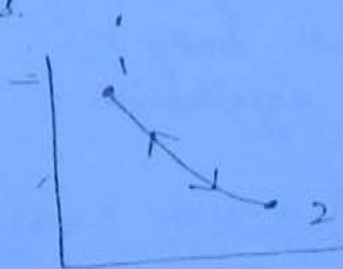
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→* REVERSIBLE AND IRREVERSIBLE PROCESSES:-

A process is said to be a reversible process, if when reversed in direction follows the same path as that of the forward-path without leaving any effect on system and surroundings.

A process which is not a reversible process is an irreversible process.

Friction is one of the reasons which makes a process irreversible. Reversible process is the most efficient process.

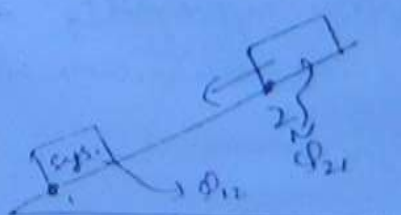


System Surroundings

$$Q_{12} = -30 \quad Q_{12} = +30$$

$$Q_{21} = +30 \quad Q_{21} = -30$$

$$0 \qquad 0$$



Signature

⇒ * QUASI-STATIC PROCESS :-

(almost) (rest)

A process is said to be quasi-static process, if it is carried out in a very slow manner with small gradient. Frictionless quasi-static process is a reversible process.

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⇒ * ZEROth LAW OF THERMODYNAMICS (Concept of Temperature)

statement :-

When a body 'A' is in thermal equilibrium with body 'B' and body 'B' is in thermal equilibrium with body 'C' separately, then 'A' and 'C' are in thermal equilibrium.

In zeroth law of thermodynamics 'one' body acts as thermometer. Let us assume that body 'B' is thermometer. Let us immerse thermometer 'B' in body 'A'. When the thermal equilibrium is reached, body 'B' records some temperature. Now, place the body 'B' (thermometer) in body 'C'. If the thermometer records same reading as recorded with body 'A', then we can say that 'A' and 'C' are in thermal equilibrium without bringing them in direct contact.

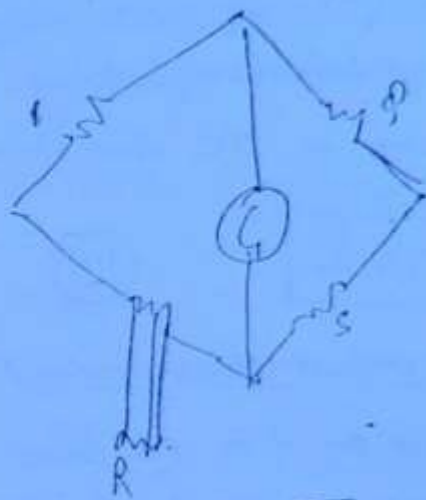
* Principle of Thermometers :-

In finding temperature, first the property which varies with temperature is found and this property is known as thermometric property and with the help of thermometric property, the unknown tempⁿ 'T' can be found.

⇒ * Types of thermometers :-

① Resistance Thermometer (Thermistor) :-

These thermometers are based on Wheatstone bridge principle. In these thermometers, resistance plays the role of thermometric property.



$$R_1 = R_2$$

$$R = \frac{R_3}{S}$$

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$$R = R_0(1 + \alpha t + \beta t^2)$$

- ② Thermocouple: Thermocouples are based on Seebeck effect. According to this Seebeck effect, when two dissimilar metals are joined to form two separate junctions and if these junctions are maintained at different temp^s emf (voltage) is generated as this ~~temp~~ emf is proportional to the temperature difference.

- ③ Constant Volume Gas ~~thermometer~~ thermometer: In constant volume gas thermometer, pressure plays the role of thermometric property.

- ④ Constant Pressure Gas thermometer:-

Volume plays the role

of thermometric property.

✓ Type of thermometer

Thermometric Property

- 1) Thermistor →
- 2) Thermocouple →
- 3) Constant Vol^m Gas thermometer →
- 4) Constant Pressure " " →

Temperature Scale:-

Temperature scales are arbitrary.

In Celsius scale, ice point is taken as 0°C and steam point is taken as 100°C .

$$K = ^{\circ}\text{C} + 273.15$$

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Method used before 1954 for temperature measurement :-

This method is based on two reference temperatures i.e. ice point (0°C) and steam point (100°C):

$$t = ap + b$$

$$t_i = a p_i + b$$

$$t_s = a p_s + b$$

$$100 = a p_s + b$$

$$0 = a p_i + b$$

$$100 = a(p_s - p_i)$$

$$\therefore a = \frac{100}{(p_s - p_i)}$$

And

$$0 = a p_i + b$$

$$\text{or } b = -a p_i$$

$$= -\frac{100}{(p_s - p_i)} \times p_i$$

$$\therefore t = \frac{100}{(p_s - p_i)} p - \frac{100 \cdot p_i}{(p_s - p_i)}$$

$$\therefore t = \frac{100}{(p_s - p_i)} \cdot (p - p_i)$$

By knowing the unknown property " p ", the temperature ' t ' can be found.

* Method used after 1954 for temperature measurement :-
It is based on single fixed temperature i.e. triple point of water.

$$PV = nRT$$

$$\text{let } v = c.$$

$$P \propto T$$

$$P = cT.$$

$$c = P/T$$

At triple point,

$$c = \frac{P_{tr}}{T_{tr}}$$

$$\therefore P = \frac{P_{tr}}{T_{tr}} \times T.$$

$$T = \frac{P}{P_{tr}} \cdot T_{tr}$$

$$T = 273.15 \left(\frac{P}{P_{tr}} \right)$$

The triple point of water is assigned a value of 0.01°C (273.15).

Note:- Ideal gas thermometers are independent of material of construction. \therefore All ideal gas behave same.

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At triple point,

$$T = 0.01^\circ\text{C}$$

$$K = 0.01 + 273.15$$

$$K = \underline{\underline{273.16 K.}}$$

PROBLEM

Q.3 The reading t_A and t_B of 2°C thermometers 'A' & 'B' agree at ice point (0°C) and steam point (100°C) and are related by the equation, $t_A = l + m t_B + n t_B^2$. Between these temp where l , m and n are constants when both are immersed in oil 'A' reads 51°C and 'B' reads 50°C . Determine the reading on 'A', when 'B' reads 25°C . And discuss the question which thermometer is correct?

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

$$t_A = 0^\circ\text{C} = t_B$$

$$0 = l + m(0) + n(0)$$

$$\Rightarrow \boxed{l = 0}$$

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

$$t_A = 100^\circ\text{C} = t_B$$

$$100 = m(100) + n(100)^2$$

$$1 = m + 100n \quad \text{--- (1)}$$

$$t_A = 51^\circ\text{C}, \quad t_B = 50^\circ\text{C}$$

$$51 = 0 + m(50) + n(50)^2$$

$$\Rightarrow 51 = 50m + 2500n \quad \text{--- (2)}$$

from (1) & (2)

$$m = 1.04$$

$$n = -4 \times 10^{-4}$$

$$t_A = 0 + 1.04 t_B - 4 \times 10^{-4} t_B^2 \quad \text{--- (3)}$$

$$\text{At } t_B = 25^\circ\text{C}$$
$$t_A = 1.04(25) - 4 \times 10^{-4}(25)^2$$

$$\boxed{t_A = 25.75^\circ\text{C}}$$

Though the end temperatures are same, it does not necessarily mean the intermediate point temperatures are also same.

① Assertion (A) - If alcohol and mercury thermometers read exactly at ice point and steam point, these two thermometers will also give same reading exactly at 50°C .

Reasoning (R) - Temperature scales are arbitrary.

Ans: Assertion is wrong and Reasoning is independently correct.

② Which of the following are intensive properties?

1. Kinetic Energy
2. Thermal conductivity
3. ~~Volume~~ Pressure
4. Volume.

Ans: (b) (2 and 3)

③ Match the following Question:-

List I
(Type of thermometer)

List II
(Thermometric Property)

A) Mercury in Glass

1) Pressure

B) Thermocouple

2) Resistance

C) Thermistor

3) Volume or length

4) Constant Vol^m Gas Thermometer

4) Emf

Ans: 3-4-2-1

④ The thermometric property x varies with tempⁿ T according to the relation $x = at + b$, where t is in $^{\circ}\text{C}$ and x is in cm. If a and b are constants. At ice point (0°C) and steam point (100°C), the values of x are 5 cm and 20 cm respectively. When this thermometer is brought in contact with heated body, the value of x is recorded as 15 cm. Then the tempⁿ of heated body is?

Soln:

$$0 = 25a + b \Rightarrow b = -25a \quad \text{--- (1)}$$

$$100 = 400a + b$$

$$\Rightarrow 100 = 400a - 25a \Rightarrow a = 100/375 = 0.27$$

$$\therefore b = -25 \times 0.27 = -6.75$$

$$t = 0.27(15)^2 + -6.75$$

$$a = 0.26$$

$$b = -6.66$$

$$\Rightarrow \boxed{t = 54^\circ\text{C}} \approx \boxed{53.3^\circ\text{C}} \dots$$

1.4.1

Q.5 In a new temperature scale, $^\circ\text{P}$, the boiling and freezing points of water are 100°P and 300°P respectively. Find the reading corresponding to 0°C on Celsius scale.

Ans let us assume a linear relation between $^\circ\text{C}$ and $^\circ\text{P}$ scale.

let it be,

$$^\circ\text{P} = a \times ^\circ\text{C} + b.$$

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Now

$$300 = a \times (0) + b$$

$$\Rightarrow \boxed{b = 300}$$

Again

$$100 = a \times 100 + 300$$

$$\Rightarrow \boxed{a = -2}$$

$$\therefore ^\circ\text{P} = -2 \times ^\circ\text{C} + 300 =$$

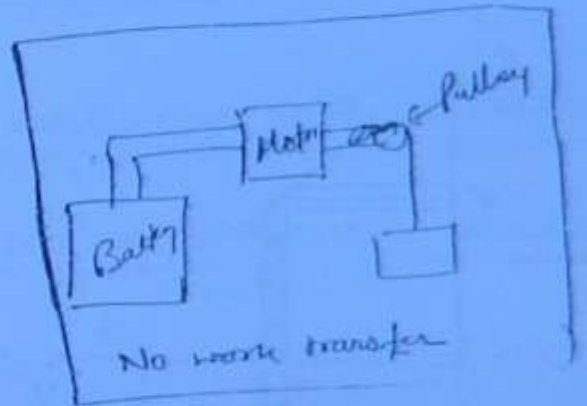
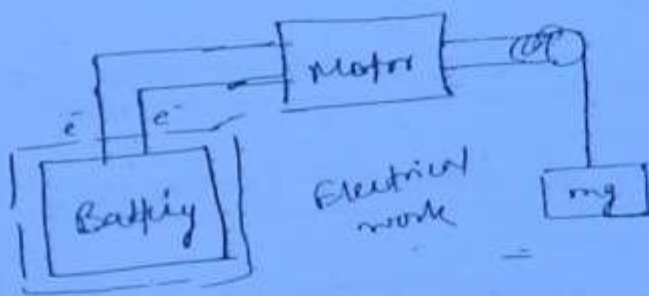
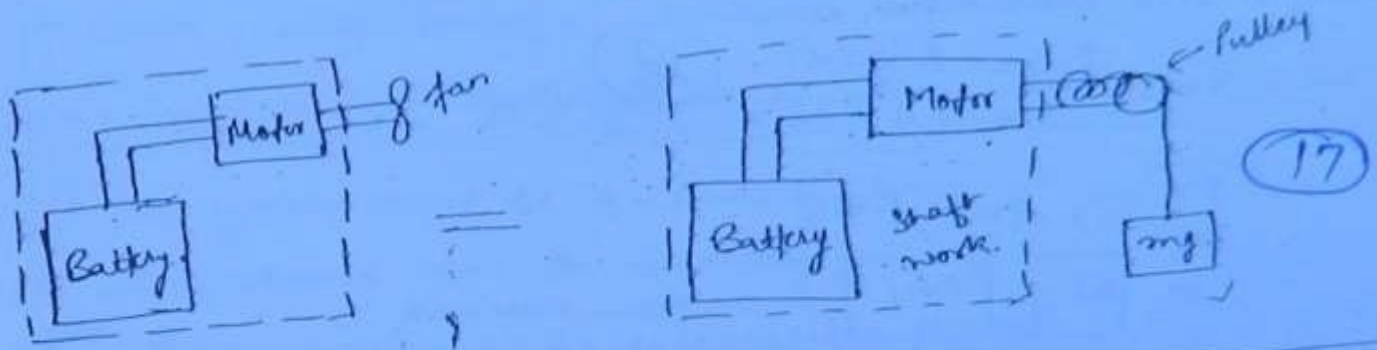
$$\text{let } 0 = -2 \times ^\circ\text{C} + 300.$$

$$\therefore \boxed{^\circ\text{C} = 150}$$

CHAPTER-2 :-

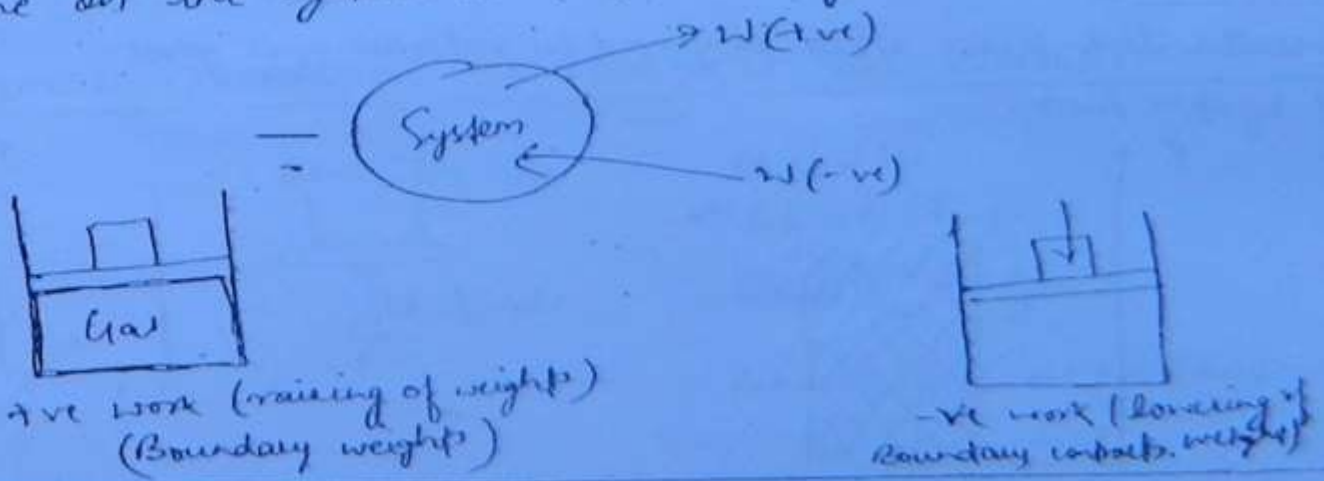
ENERGY INTERACTIONS (WORK & HEAT)

⇒ * Thermodynamic work :- Work is said to be done by the system if the sole 'effect on things' external to the system can be equated to raising of weights (weights may not be actually raised but the effect can be equated to raising of weights).

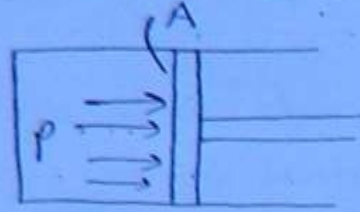


⇒ * Conventions of work transfer

Work done by the system is taken as positive and work done on the system is taken as negative.



→ * Generalised Equation for Non-flow work or closed system work!-



$$P = F/A$$

$$F = PA$$

$$W = F \times x$$

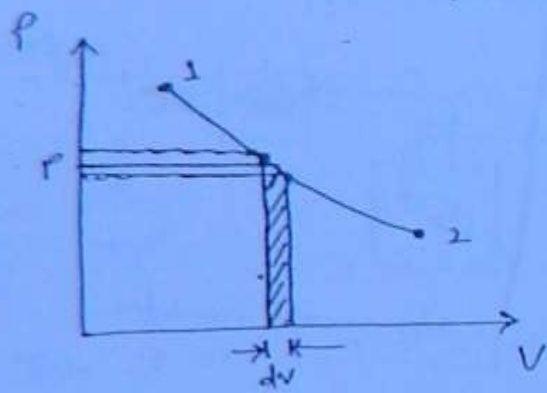
$$dW = F \times dx$$

$$= \underbrace{P \cdot A}_{(18)} \times dx$$

$$\therefore dW = P \cdot dV$$

$$\text{or } \boxed{W = \int P dV}$$

→ Non-flow work / (Closed system work).



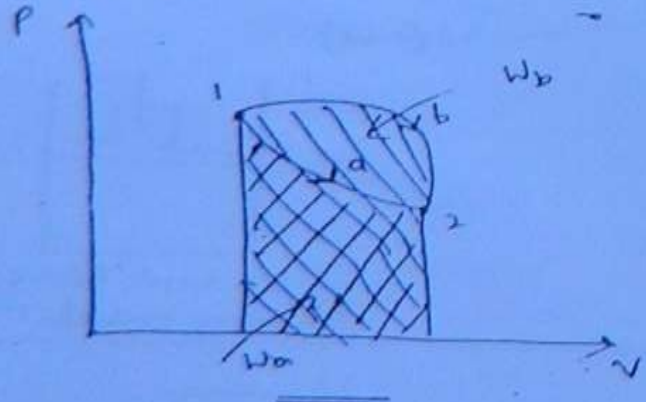
$$\text{Area} = P \cdot dx$$

Also, work = P dx.

$$\therefore \boxed{\text{Area} = \text{Work}}$$

(very important sentence)

→ Area under the curve when projected on volume axis gives closed system work.



$$W_a \neq W_b$$

→ Though the end points for 'a' and 'b' are same, work transfer is not same because areas are different. Therefore, work transfer depends on path followed by the process and hence work transfer is a path function and it is not a property and it is inexact differentials (dW or δW).

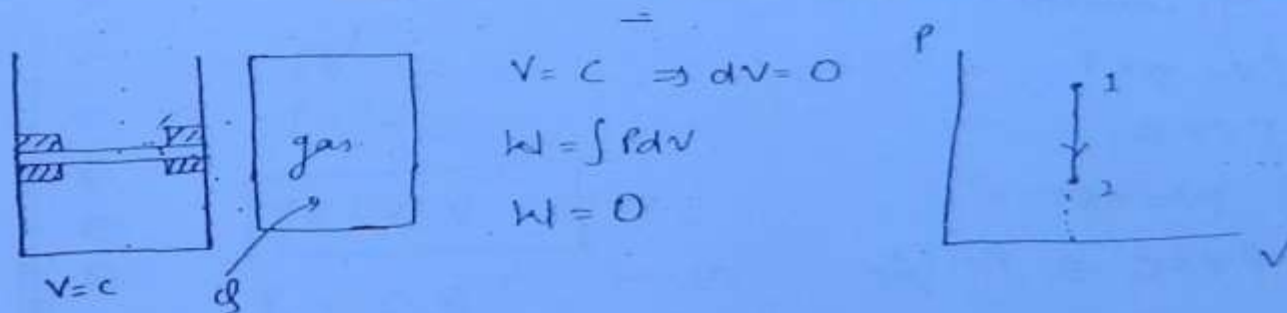
⇒* There is no work transfer when the system is in equilibrium state. Work transfer is always associated with a process.

⇒* Conditions for Applying the Equation $W = \int P dV$: →

- ① The system must be a closed system. (19)
- ② Work should cross the boundary.
- ③ The process must be a reversible process.

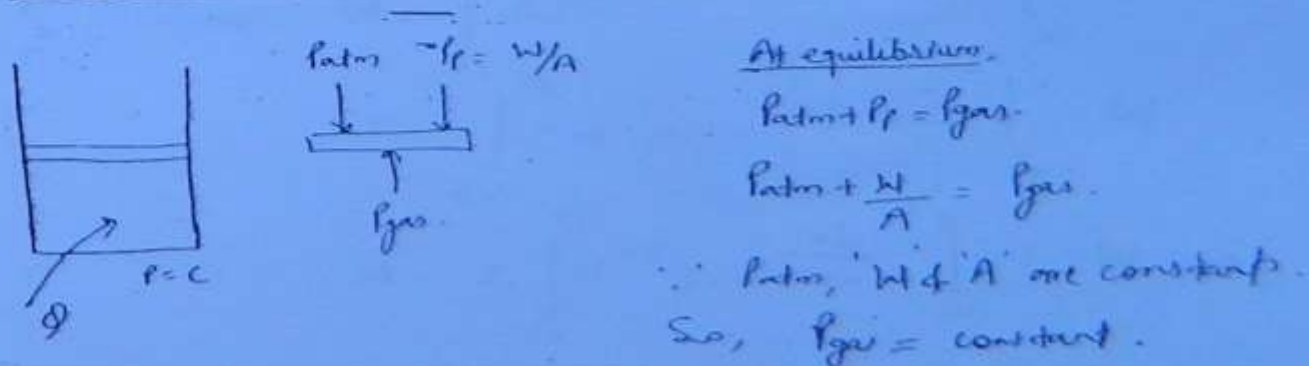
⇒* NON-FLOW OR CLOSED SYSTEM WORK FOR VARIOUS PROCESSES

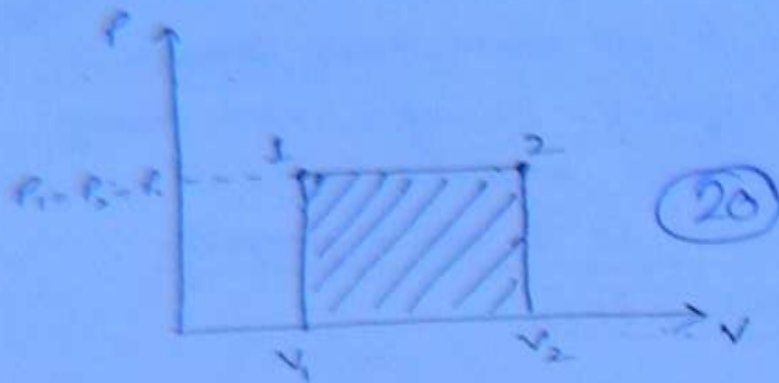
① CONSTANT VOLUME OR ISOCHORIC OR ISOMETRIC PROCESS:



Constant volume closed system work = 0.

② CONSTANT PRESSURE OR ISOBARIC OR ISOPIESTIC PROCESS:





W = Area.

$$W = P(V_2 - V_1)$$

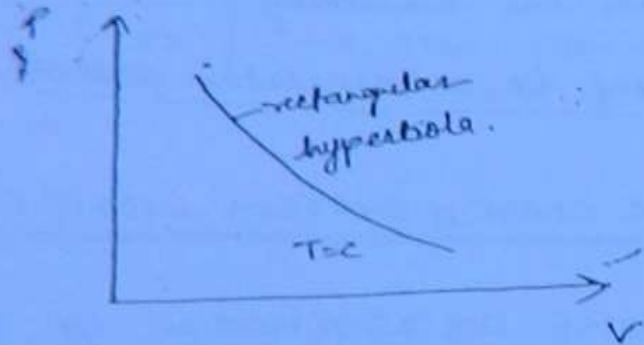
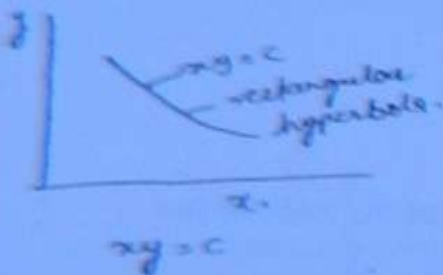
$$W = \int_{V_1}^{V_2} P \cdot dV.$$

$$W = P \int_{V_1}^{V_2} dV.$$

$$W = P(V_2 - V_1)$$



3) CONSTANT TEMPERATURE OR ISOTHERMAL PROCESS:-



T = constant.

$$PV = nRT$$

$$PV = C.$$

$$\therefore PV = nRT = C.$$

$$PV = C \Rightarrow P = \frac{C}{V}.$$

$$P_1 V_1 = P_2 V_2 = C.$$

Now,

$$W = \int_{V_1}^{V_2} P \cdot dV$$

$$W = \int_{V_1}^{V_2} \frac{C}{V} \cdot dV$$

$$\text{or, } W = C \int_{V_1}^{V_2} \frac{dV}{V}$$

$$W = C [\ln v_2 - \ln v_1]$$

$$\text{or, } W = C \ln \left(\frac{v_2}{v_1} \right)$$

$$\therefore \boxed{W = P_1 v_1 \ln \left(\frac{v_2}{v_1} \right)}$$

$$\boxed{W = mRT \ln \left(\frac{v_2}{v_1} \right)}$$

So,

An adiabatic process can never be an isolated process

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((Isothermal curves for an ideal gas are rectangular hyperbola on P-V diagram.))

(4) ADIABATIC PROCESS :- A process is said to be adiabatic process in which there is no heat transfer from the system or to the system.

For adiabatic process;

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

where, γ = adiabatic index and it is greater than 1 ($\gamma > 1$).

$$Pv^\gamma = C$$

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

$$\boxed{P = C \cdot v^{-\gamma}}$$

$$P_1 = C \cdot v_1^{-\gamma} \quad \text{--- (1)}$$

$$P_2 = C \cdot v_2^{-\gamma} \quad \text{--- (2)}$$

Now

$$W = \int_{v_1}^{v_2} P \, dv$$

$$W = \int_{v_1}^{v_2} C \cdot v^{-\gamma} \, dv$$

$$W = C \int_{v_1}^{v_2} v^{-\gamma} \, dv$$

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

$$W = \frac{C}{-\gamma+1} \left[V_2^{-\gamma+1} - V_1^{-\gamma+1} \right] \quad (22)$$

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

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

$$\Rightarrow W = \frac{P_1 V_1 - P_2 V_2}{\gamma - 1}$$

$$\therefore \boxed{W = \frac{(P_1 V_1 - P_2 V_2)}{(\gamma - 1)}}$$

⑤ POLYTROPIC PROCESS :-

A process is said to be a polytropic process, if pressure & volume follows the relation $PV^n = C$, where, 'n' is known as polytropic index.

Generally,

$$\boxed{n > 1 \text{ and } n < \gamma}$$

In polytropic process, there is both heat transfer and work transfer but in adiabatic process, there is only work transfer.

Polytropic work,

$$\boxed{W = \frac{(P_1 V_1 - P_2 V_2)}{(n - 1)}}$$

Any process can be represented as $PV^k = C$. $N^k = C$

* for constant pressure process,

$$P = C$$

$$PV^k = C$$

$$k = 0$$

$$PV^0 = C$$

$$P \cdot 1 = C$$

$$\boxed{P = C}$$

(23)

* for thermal constant process,

$$T = C$$

$$PV = mRT$$

$$PV = C$$

$$PV^1 = C$$

$$\boxed{k = 1}$$

* for constant volume process,

$$V = C$$

$$PV^k = C$$

$$(PV^k)^{1/k} = C^{1/k}$$

$$P^{1/k} \cdot V = C^{1/k} \text{ (constant new)}$$

when, $k = \infty$

$$P^0 \cdot V = C$$

$$\therefore \boxed{V = C}$$

* for adiabatic process,

$$PV^\gamma = C$$

$$\boxed{k = \infty}$$

* for polytropic process,

$$PV^n = C$$

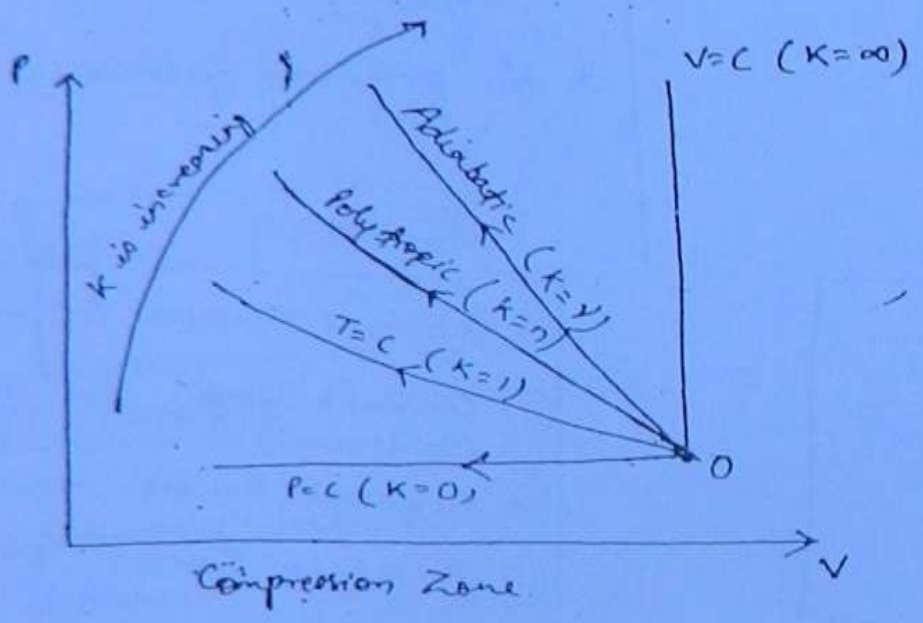
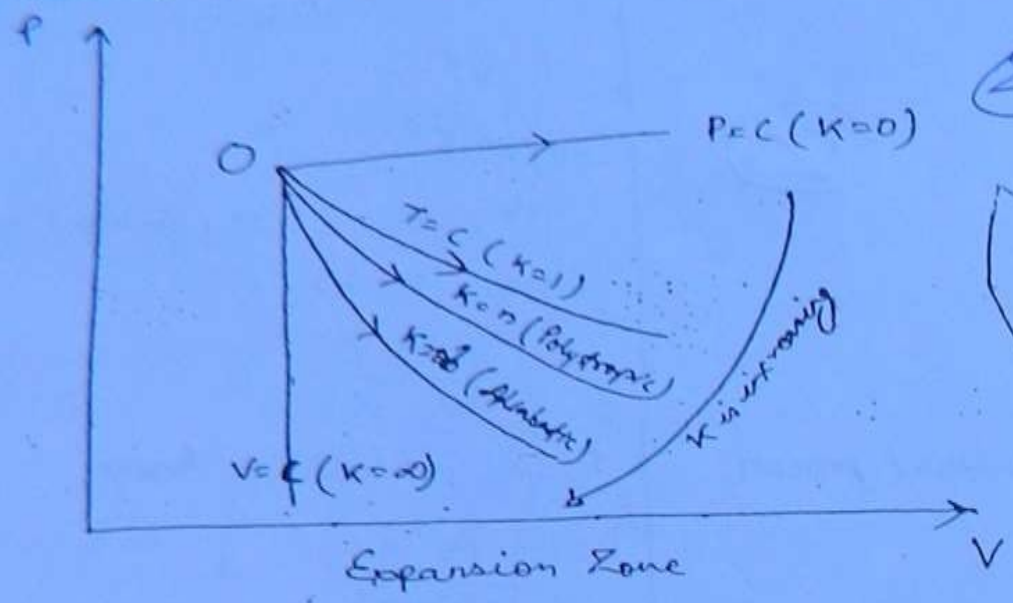
$$\boxed{k = n}$$

- | |
|------------------------------------|
| $P = C \rightarrow k = 0$ |
| $V = C \rightarrow k = \infty$ |
| $T = C \rightarrow k = 1$ |
| Adiabatic $\rightarrow k = \gamma$ |
| Polytropic $\rightarrow k = n$ |

- | |
|---|
| ① Constant pressure, $P = C, \rightarrow k = 0$ |
| ② Constant Temp ^r , $T = C, \rightarrow k = 1$
(isothermal) |
| ③ Polytropic process, $k = n$ |
| ④ Adiabatic process $k = \gamma$ |
| ⑤ Constant volume, $V = C \rightarrow k = \infty$ |

$$PV^k = C$$

⇒ * Representation of Various process on P-V diagram:-

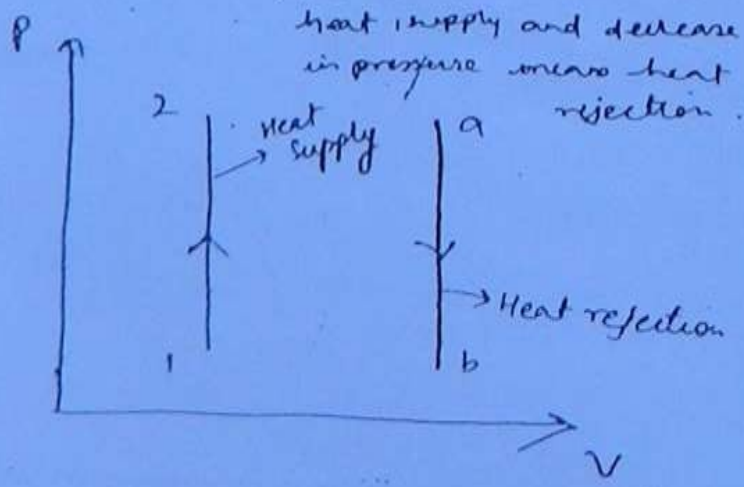


⇒ * Ideal Gas Equations for Various Processes:-

① Constant Volume Process:-

$V = C$
 $P \propto T$
 $P \propto T$
 $\frac{P_2}{P_1} = \frac{T_2}{T_1}$

Increase in pressure means heat supply and decrease in pressure means heat rejection.



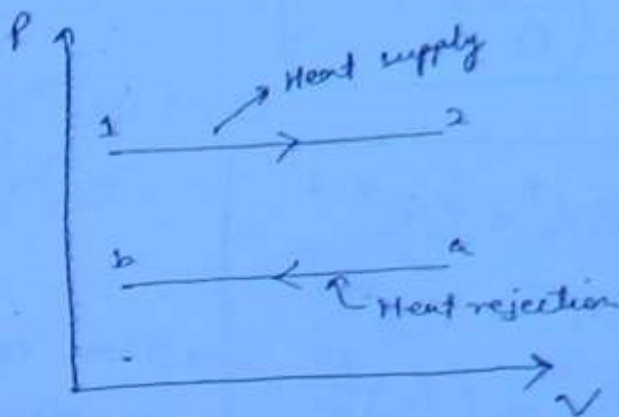
② Constant Pressure Process :-

$$P = \text{constant}$$

$$PV = mRT$$

$$V \propto T$$

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



③ Isothermal Process :-

$$T = \text{constant}$$

$$PV = mRT$$

$$PV = C$$

$$P_1 V_1 = P_2 V_2$$

(25)

④ Adiabatic Process :-

$$PV^\gamma = C$$

$$PV = mRT$$

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

$$\frac{mRT}{V} \cdot V^\gamma = C$$

$$\text{or, } T \cdot V^{\gamma-1} = \frac{C}{RT} = C$$

$$\text{or, } T \cdot V^{\gamma-1} = \text{const.}$$

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

$$T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1} \quad \text{--- (2)}$$

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

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

(26)

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

$$T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1}$$

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

These equations are valid for an ideal gas undergoing adiabatic process.

⑤ Polytropic process :-

$$P_1 V_1^n = P_2 V_2^n$$

$$T_1 V_1^{n-1} = T_2 V_2^{n-1}$$

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

These equations are valid for an ideal gas undergoing adiabatic polytropic process.

* SLOPE OF ISOTHERMAL CURVES ON P-V DIAGRAM :-

$T = \text{constant}$

$$PV = nRT$$

$$PV = C$$

$$Pdv + vdp = 0$$

$$Pd\bar{v} = -v d\bar{p}$$

$$\frac{d\bar{p}}{d\bar{v}} = -\frac{\bar{p}}{\bar{v}}$$

Slope of isothermal curves on P-V diagram = $-\frac{P}{V}$

⇒ * SLOPE OF ADIABATIC CURVES ON P-V DIAGRAM :-

$$PV^\gamma = C$$

$$P[\gamma \cdot V^{\gamma-1} \cdot dV] + V^\gamma [dP] = 0$$

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

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

(27)

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

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

∴ Slope of adiabatic curves = γ (Slope of isothermal curves)

$$\frac{\text{Slope of adiabatic}}{\text{Slope of isothermal}} = \gamma$$

$$\because \gamma > 1$$

$$\therefore \frac{\text{Slope of adiabatic}}{\text{Slope of isothermal}} > 1$$

Hence,

Slope of adiabatic curves > Slope of isothermal curves

CONVENTIONAL PROBLEM

Q. A system undergoes three processes as shown in figure.

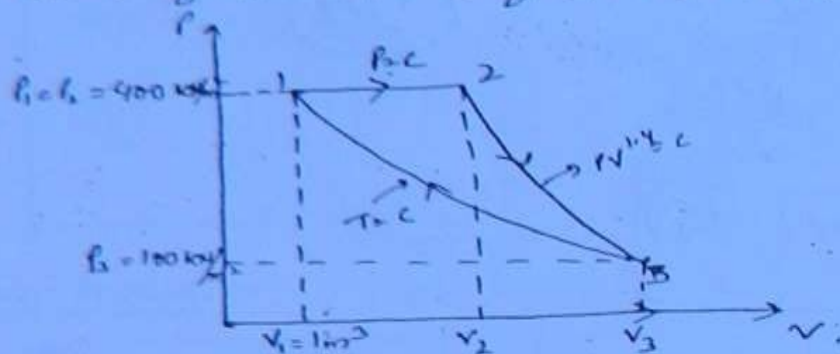
1-2 → Isobaric process

2-3 → Adiabatic process with $\gamma = 1.4$

3-1 → Isothermal process with $PV = C$.

(28)

Find the value of V_2 and also find net work transfer.



(Process 3-1)

$$T = C$$

$$\text{Also } PV = C$$

$$P_3 V_3 = P_1 V_1$$

$$\Rightarrow 100 \times V_3 = 400 \times 1$$

$$\therefore \underline{V_3 = 4 \text{ m}^3}$$

Again

(Process 2-3)

$$PV^{1.4} = C$$

$$P_2 V_2^{1.4} = P_3 V_3^{1.4}$$

$$\Rightarrow 400 \times V_2^{1.4} = 100 \times (4)^{1.4}$$

$$\Rightarrow \boxed{V_2 = 1.486 \text{ m}^3} \quad \text{(Ans)}$$

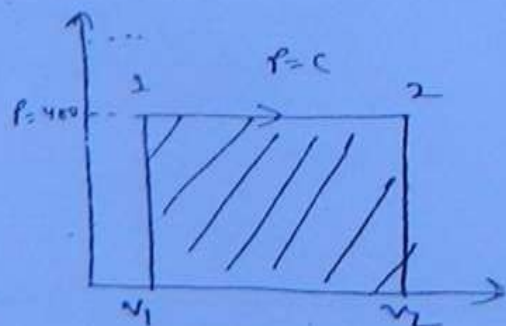
Now

$$W_{\text{net}} = W_{12} + W_{23} + W_{31}$$

$$W_{12} = P(V_2 - V_1)$$

$$= 400(1.486 - 1) \frac{\text{N}}{\text{m}^2} \times \text{m}^3$$

$$\therefore \underline{W_{12} = 194.4 \text{ kJ}}$$



$$W_{23} = \frac{P_2 V_2 - P_3 V_3}{\gamma - 1}$$

$$\Rightarrow W_{23} = \frac{400 \times 1.486 - 100 \times 4}{1.4 - 1}$$

$$\Rightarrow \boxed{W_{23} = 486 \text{ kJ}}$$

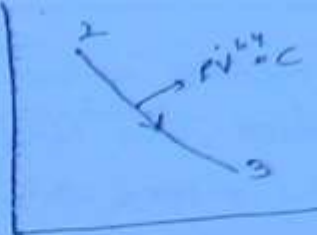
$$W_{31} = P_3 V_3 \ln \frac{V_1}{V_3}$$

$$= 100 \times 4 \ln \left(\frac{1}{4} \right)$$

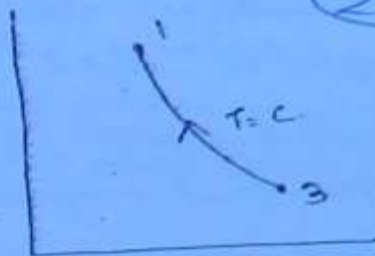
$$\boxed{W_{31} = -554.5 \text{ kJ}}$$

$$W_{\text{net}} = 194.4 + 486 + (-554.5)$$

$$\therefore \boxed{W_{\text{net}} = 125.8 \text{ kJ}}$$



(28)



$$W = P_i V_i \ln \frac{V_f}{V_i}$$

Note:- Net work in a cycle is equal to area of the closed region. All clockwise cycles on P-V diagram are work producing or power producing cycles. All anti-clockwise cycles are power absorbing or work absorbing cycles.

Q:- An imaginary engine receives heat and performs work on a slowly moving piston at such a rate that the cycle of operation of 1 kg of working fluid can be represented as a circle of 10 cm diameter on P-V diagram, in which 1 cm = 300 kPa and 1 cm = 0.1 m³/kg. Then, find the net work during the cycle.

$$1 \text{ cm} = 300 \text{ kPa}$$

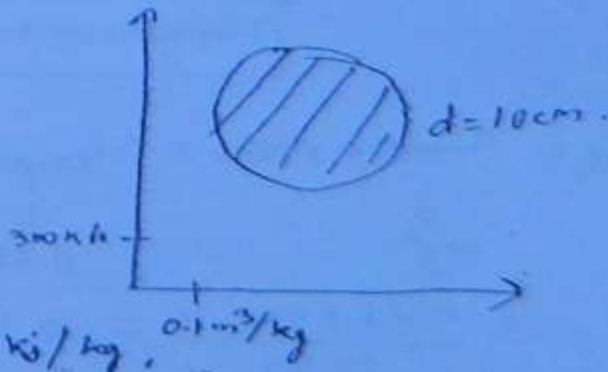
$$1 \text{ cm} = 0.1 \text{ m}^3/\text{kg}$$

$$1 \text{ cm}^2 = 300 \times 0.1 = 30 \text{ kJ/kg}$$

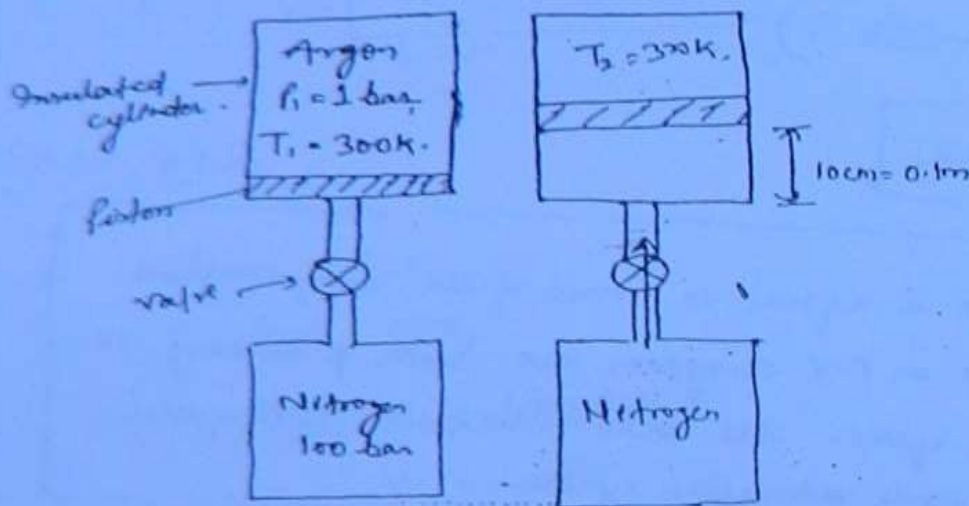
$$W_{\text{net}} = \text{Area} = \frac{\pi}{4} d^2$$

$$= \frac{\pi}{4} (10)^2 = 78.54 \text{ cm}^2$$

$$\therefore W_{\text{net}} = (78.54 \times 30) = 2356.2 \text{ kJ/kg}$$



Q An insulated vertical cylinder contains 0.1 kg of Argon gas. With the help of a frictionless non-conducting piston as shown in figure. The mass of the piston is 5 kg and it initially rests on the bottom of the cylinder. The cylinder is connected to nitrogen tank at 100 bar to a pipeline fitted with the valve. The valve is opened and nitrogen slowly enters the cylinder. During this process, the piston is lifted to a height of 10 cm by nitrogen gas. The initial pressure and temperature of argon are 300 k and 1 bar. The final temperature of argon gas is 320 K. For argon gas $k = 0.208 \text{ kJ/kg K}$ and $\gamma = 1.67$.



$$W_{\text{argon}} = \frac{P_1 V_1 - P_2 V_2}{\gamma - 1} = \frac{m_1 R_1 T_1 - m_2 R_2 T_2}{\gamma - 1} \quad (\because m \& R \text{ are constant})$$

$$\therefore W_{\text{argon}} = \frac{mR(T_1 - T_2)}{\gamma - 1}$$

$$= \frac{0.1 \times 0.208 (300 - 320)}{1.67 - 1}$$

$$\therefore \boxed{W_{\text{argon}} = -0.621 \text{ kJ}}$$

$$W_{N_2} = W_{\text{raising piston}} + W_{\text{compressing Argon}}$$

$$\downarrow \qquad \qquad \qquad \downarrow$$

$$\text{mgh} \qquad \qquad \qquad 0.621 \text{ kJ}$$

$$= \frac{5 \times 9.81 \times 0.1}{1000} = 4.905 \times 10^{-3} \text{ KJ}$$

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

∴ Net work done by Nitrogen.

$$W_{N_2} = 4.905 \times 10^{-3} \text{ kJ} + 0.621 \text{ kJ}$$

$$W_{N_2} = 0.626 \text{ kJ} \quad (\text{Ans})$$

$$V_s = A \times L$$

V_s = swept vol.

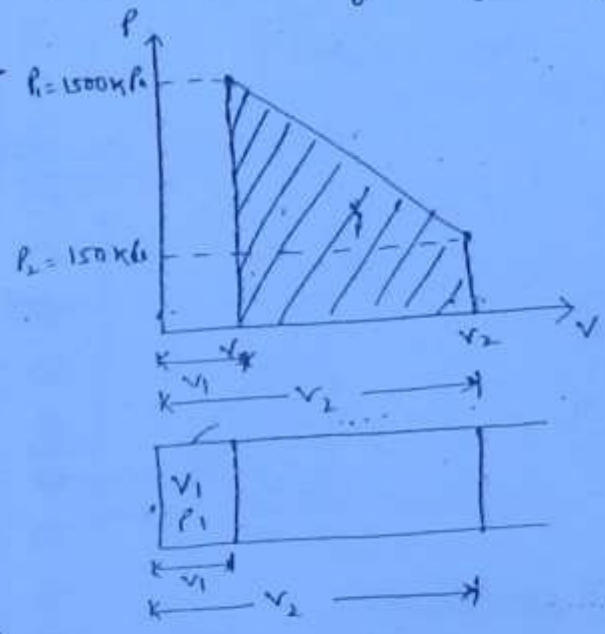
L = stroke length

A = Area of piston.

Q1.
Important

An engine cylinder has a piston area of 0.12 m^2 and contains a gas at a pressure of 1.5 MPa . The gas expands according to a process which is represented by a straight line on P - V diagram. The final pressure is 0.15 MPa . Calculate the work done by the gas if the stroke length is 0.3 m .

Soln.



Work = Area under curve

$$= \frac{1}{2} (1500 + 150) \times (V_2 - V_1)$$

But, $V_2 - V_1 = V_s = AL$

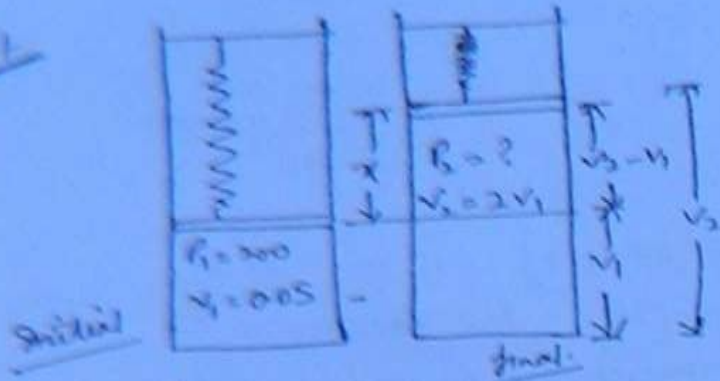
$$= \frac{1}{2} \times 1650 \times (0.12 \times 0.3)$$

$$W = 29.7 \text{ kJ} \quad (\text{Ans})$$

Q1.
Imp

A piston cylinder device contains 0.05 m^3 of a gas initially at 200 kPa . At this state a linear spring which has spring constant of 150 kN/m is just touching the piston but exerting no force on it. ^{Now} Heat is transferred to the gas causing the piston to rise and to compress the spring until the volume inside the cylinder doubles. If the cross-sectional area of the piston is 0.25 m^2 , find :-

- ① Final pressure inside the cylinder.
- ② Work done by the gas.



$$V_2 - V_1 = A \times x$$

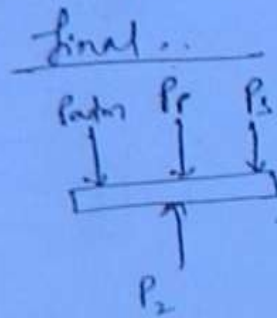
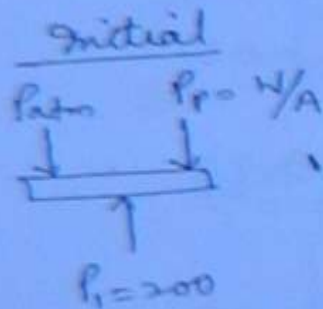
$$\Rightarrow 2V_1 - V_1 = 0.25 \times x$$

$$\Rightarrow 0.05 = 0.25x$$

$$\therefore \boxed{x = 0.2 \text{ m}}$$

(12)

Now free body diagrams.



At equilibrium

$$p_1m + W/A = 200 \quad \text{--- (1)}$$

At equilibrium

$$p_1m + p_1 + p_2 = p_2 \quad \text{--- (2)}$$

But from eqⁿ (1), $p_1m + p_1 = 200$

$$\therefore 200 + p_2 = p_2 \quad \text{--- (3)}$$

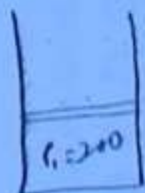
Now

$$p_2 = \frac{F_2}{A} = \frac{K \cdot x}{A}$$

$$\therefore p_2 = \frac{150 \times 0.2}{0.25} = 120 \text{ kN/m}^2 \text{ or kPa}$$

$$\therefore \boxed{P_2 = 200 + 120 = 320 \text{ kPa}} \quad \text{--- (Ans)}$$

Work done by gas = work done in raising piston + work done in compressing spring.



(33)

$$W_{\text{piston}} = P(V_2 - V_1)$$

$$200(2V_1 - V_1)$$

$$= 200 \times (0.05) \Rightarrow W_{\text{piston}} = 10 \text{ kJ}$$

$$W_{\text{Total}} = 10 + 3 = 13 \text{ kJ} \quad (\text{Ans})$$

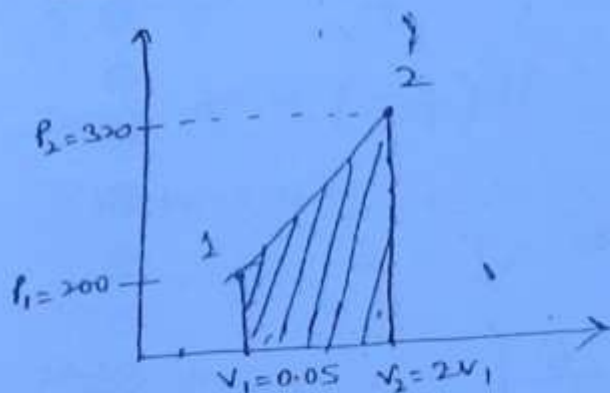
Spring Work

$$= \frac{1}{2} kx^2$$

$$= \frac{1}{2} \times 150 \times 0.2^2$$

$$= 3 \text{ kJ}$$

Alternate Method



$$P_2 = 200 + P_s$$

$$P_s = \frac{F_s}{A} = \frac{kx}{A} \quad \text{--- (1)}$$

$$\text{Also, } V_2 - V_1 = Ax$$

$$\Rightarrow x = \frac{V_2 - V_1}{A} = \frac{\Delta V}{A}$$

$$\therefore P_s = \frac{k}{A} \cdot \frac{\Delta V}{A}$$

$$\text{or } P_s = \frac{k}{A^2} \cdot \Delta V$$

$$\text{Thus, } P_2 = 200 + \frac{k}{A^2} \cdot \Delta V$$

$$W = \frac{1}{2} (200 + 320)(2V_1 - V_1)$$

$$= \frac{1}{2} \times 520 \times 0.05$$

$$\therefore W = 13 \text{ kJ} \quad (\text{Ans})$$

Chapter - (1)

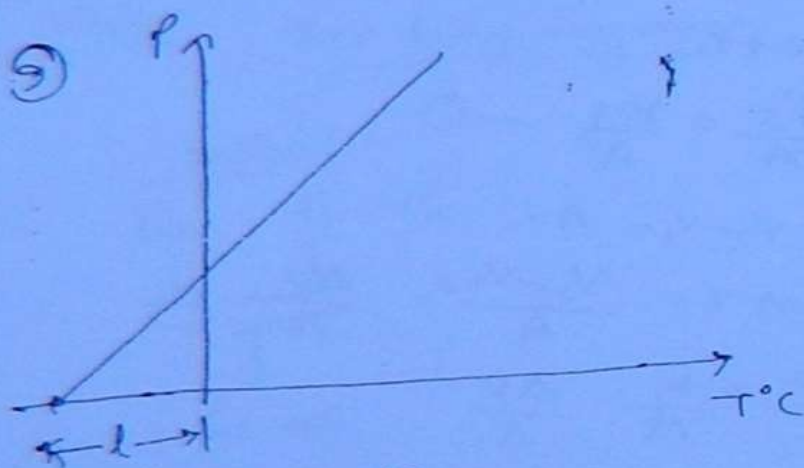
- 1 - a
- 2 - c
- 3 - b
- 4 - d
- 5 - a
- 6 - b
- 7 - c

- 8 - c
- 9 - d
- 10 - c
- 11 - b
- 12 - c
- 13 - d
- 14 - d

- 15 - d
- 16 - c
- 17 - d
- 18 - c
- 19 - d
- 20 - ~~b~~ d

33/1

1-2-7
3-8



$$Pv = mRT$$

$$P = \frac{mk}{v} \cdot T, \text{ Here, } m, k \text{ \& } v \text{ are constants.}$$

$$\therefore P = CT$$

$$\therefore P = 0 \quad \therefore \underline{\underline{T = 0K}}$$

convert in $^{\circ}C$

$$K = ^{\circ}C + 273.15$$

$$\therefore 0 = ^{\circ}C + 273.15$$

$$\Rightarrow ^{\circ}C = -273.15, \text{ Hence (d) is ans.}$$

13

(a) $\int f dx$ & (b) $\int v df$

Both are works and work ~~is not~~ ^{is not} a property.

$$\boxed{\begin{aligned} dz &= M dx + N dy \\ \left(\frac{\partial M}{\partial y}\right)_x &= \left(\frac{\partial N}{\partial x}\right)_y \end{aligned}}$$

30

The equation $dz = M dx + N dy$ is exact, when

$$\left(\frac{\partial M}{\partial y}\right)_x = \left(\frac{\partial N}{\partial x}\right)_y$$

Solving option (d) 1.

$$\frac{dT}{T} - \frac{v df}{T}$$

$$\frac{1}{T} \cdot dT + \left(-\frac{v}{T}\right) df$$

$$M dx + N dy$$

$$M = \frac{x}{T}; \quad x = T; \quad N = -\frac{v}{T}; \quad y = P.$$

Now, $\left(\frac{\partial M}{\partial y}\right)_x = \left[\frac{\partial}{\partial P} \left(\frac{1}{T}\right)\right]_T$

$\therefore T$ is constant

$$\left(\frac{\partial M}{\partial y}\right)_x = 0$$

Again,

$$\left(\frac{\partial N}{\partial x}\right)_y = \left[\frac{\partial}{\partial T} \left(-\frac{v}{T}\right)\right]_P$$

from ideal gas equation

$$PV = mRT \quad \therefore \frac{v}{T} = \frac{mR}{P}$$

$$\therefore \left(\frac{\partial N}{\partial x}\right)_y = \left[\frac{\partial}{\partial T} \left(-\frac{mR}{P}\right)\right]_P$$

$\therefore P$ is constant

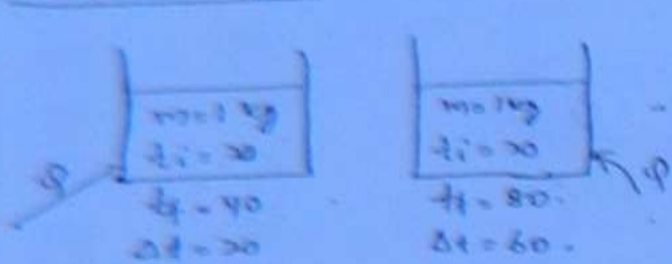
$$\therefore \left(\frac{\partial N}{\partial x}\right)_y = 0$$

$$\left(\frac{\partial M}{\partial y}\right)_x = \left(\frac{\partial N}{\partial x}\right)_y = 0$$

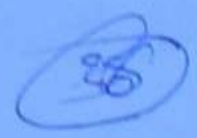
Hence, these are exact differentials. So, it is a property.

← HEAT →

The energy transfer due to temperature difference is known as heat transfer.



$Q \propto \Delta t$
 $Q \propto m$
 $Q \propto m(\Delta t)$



$\therefore Q = mc(\Delta t)$

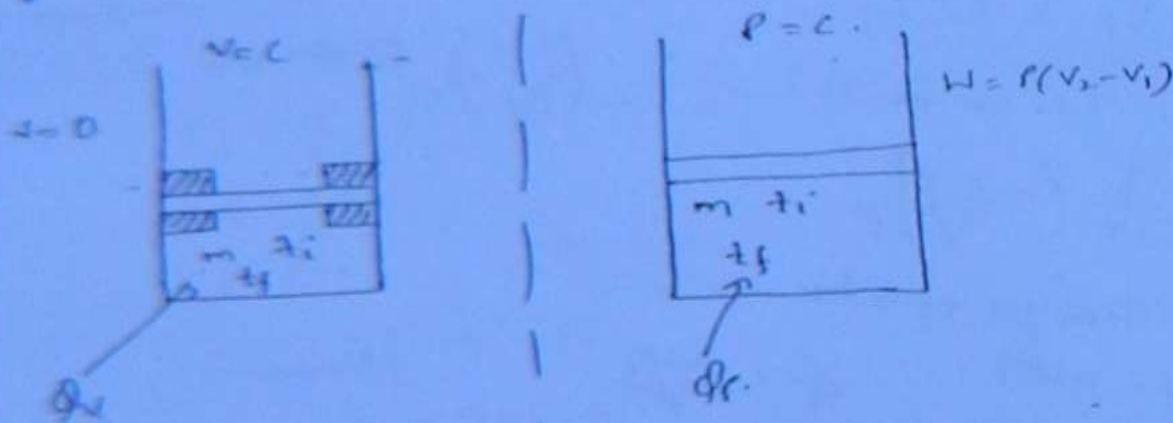
→ (specific heat)

when $m=1$; $\Delta t=1$

$Q = C$

$C = \frac{Q}{m\Delta t} \text{ units } \left(\frac{\text{kJ}}{\text{kg K}} \right)$

Specific heat (C) → It is the amount of heat required to raise the temperature of unit mass of substance through unit degree temperature difference.



$Q_p > Q_v$

$\therefore \frac{Q_p}{\Delta t} > \frac{Q_v}{\Delta t}$

$\therefore C_p > C_v$

$\therefore \gamma = \frac{C_p}{C_v} > 1$

$\therefore \gamma > 1$

Specific heat at constant pressure (C_p) is greater than specific heat at constant volume (C_v) because ' C_p ' includes internal energy and external work whereas ' C_v ' includes internal energy only.

FIRST LAW OF THERMODYNAMICS \rightarrow 39

(Law of Conservation of Energy):-

Statement:- For a closed system undergoing a cycle net heat transfer (ΣQ) is equal to net work transfer (ΣW)

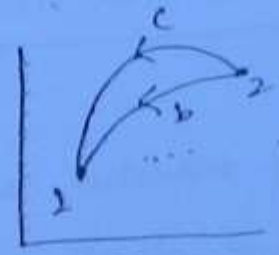
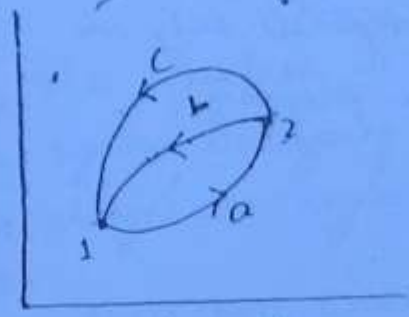
$$\boxed{\Sigma Q = \Sigma W}$$

\rightarrow valid for a cycle...

(Results)

Consequences of first law of Thermodynamics:-

① Heat transfer is a path function.



$$\begin{aligned} \cancel{(\delta Q)_{1a2}} + (\delta Q)_{2b1} &= \cancel{(\delta W)_{1a2}} + (\delta W)_{2b1} \\ (\delta Q)_{1a2} + (\delta Q)_{2c1} &= \cancel{(\delta W)_{1a2}} + (\delta W)_{2c1} \\ \hline (\delta Q)_{2b1} - (\delta Q)_{2c1} &= (\delta W)_{2b1} - (\delta W)_{2c1} \end{aligned}$$

$$\begin{aligned} (\delta W)_{2b1} &\neq (\delta W)_{2c1} \\ \therefore (\delta W)_{2b1} - (\delta W)_{2c1} &\neq 0 \end{aligned}$$

$$\therefore (\delta Q)_{2b1} - (\delta Q)_{2c1} \neq 0$$

Hence, $(\delta Q)_{2b1} \neq (\delta Q)_{2c1}$

Though, for paths 'b' and 'c', end points are same but heat transfer is not same and hence heat transfer is a path function.

* Important points with respect to heat transfer and work transfer

- 1) Both are path functions.
- 2) Both are not properties.
- 3) Both are inexact differentials.
- 4) Both are boundary phenomenon. (38)

$$\boxed{d\delta = \delta}$$

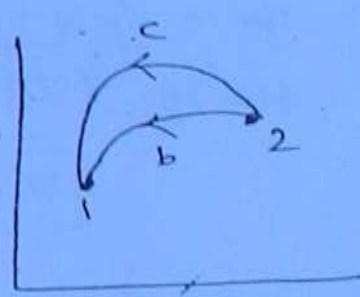
consequences continued....

Energy is a property.

$$dQ_{2b1} - dQ_{2c1} = (dW)_{2b1} - (dW)_{2c1}$$

$$dQ_{2b1} - dW_{2b1} = dQ_{2c1} - dW_{2c1}$$

$$\boxed{(dQ - dW)_{2b1} = (dQ - dW)_{2c1}}$$



~~quantity~~

The quantity $(dQ - dW)$ is same for paths 'b' and 'c' and hence it does not depend on path and it depends only on end points. Therefore, $(\delta Q - \delta W)$ must be a property and this property is known as energy.

$$(dQ - dW)_{2b1} = (dQ - dW)_{2c1} = dE$$

$$(\delta Q - \delta W)_{2b1} = dE$$

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

This is the first law of thermodynamics for a closed system undergoing a process (reversible or irreversible).

$$\boxed{dQ = dE + PdV}$$
 It is the first law of

thermodynamics for a closed system undergoing reversible process because $\delta W = PdV$ is valid for a reversible process.

Now,

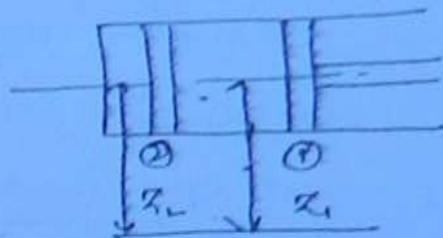
$$E = \underbrace{K.E + P.E}_{\text{Macroscopic}} + \underbrace{U}_{\text{Microscopic}}$$

(28)

$$dE = d(K.E) + d(P.E) + dU.$$

Let the system is initially ~~and~~ finally at rest, so $K.E = 0$ and again finally it is also at rest, $\therefore K.E = 0$ again.

The height is also same \therefore change in Potential Energy, $d(P.E) = 0$.



$$\therefore dE = dU.$$

Now,

$$dQ = dE + dU$$

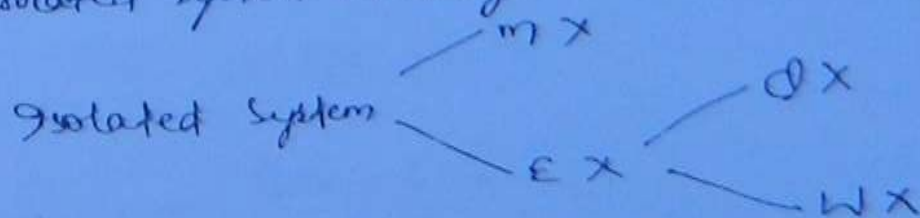
$$\therefore \boxed{dQ = dU + dW}$$

This equation is first law of thermodynamics equation for a system undergoing a process when kinetic and potential energy changes are neglected.

INTERNAL ENERGY (U) :-

It is the energy associated with molecules. It is an extensive property. and it is generally expressed in J. Specific Internal Energy = U/m and it is an intensive property. It is generally expressed in kJ/kg.

③ Energy of an isolated system is always constant.



* To show that $(C_p - C_v) = R$ for an ideal gas :-
(Meyer's Eqⁿ):

$$H = U + PV$$

(3)

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

$$m c_p dT = m c_v dT + d(mRT) \quad (\text{for an ideal gas})$$

$$\Rightarrow m c_p dT = m c_v dT + m R dT$$

$$\Rightarrow C_p = C_v + R.$$

or $\boxed{C_p - C_v = R} \rightarrow \text{Meyer's Equation}$

Now,

$$\frac{C_p}{C_v} = \gamma \Rightarrow C_p = \gamma \cdot C_v.$$

$$\therefore \gamma C_v - C_v = R$$

$$\Rightarrow \boxed{C_v = \frac{R}{\gamma - 1}} \quad \text{--- (2)}$$

$$\therefore C_p = \gamma \cdot C_v$$

$$\therefore \boxed{C_p = \frac{\gamma \cdot R}{\gamma - 1}} \quad \text{--- (3)}$$

for Air

$$\begin{aligned} C_p &= 1.005 \text{ kJ/kg K} \\ C_v &= 0.718 \text{ kJ/kg K} \\ R &= 0.287 \text{ kJ/kg K} \\ \gamma &= 1.4. \end{aligned}$$

③ Isothermal Process:-

$$dQ = dU + dW$$

for an ideal gas, $U = f(T)$.

Here, $T = \text{constant}$

$$\therefore U = \text{constant} \Rightarrow dU = 0 \quad (4)$$

$$\therefore dQ_T = 0 + dW$$

$$\Rightarrow \boxed{dQ_T = dW}$$

When an ideal gas undergoes isothermal process, heat transfer is equal to work transfer.

④ Adiabatic Process:-

$$\cancel{dQ = dU + dW} \quad Q = 0.$$

There is no heat transfer in adiabatic process.

⑤ Polytropic Process:-

$$dQ = dU + dW$$

for an ideal gas, $dU = m c_v dT$.

$$\& \text{ Polytropic work} = dW = \left(\frac{P_1 V_1 - P_2 V_2}{n-1} \right)$$

$$\therefore dQ = m c_v dT + \frac{P_1 V_1 - P_2 V_2}{(n-1)}$$

$$= m \frac{R}{\gamma-1} dT + \frac{P_1 V_1 - P_2 V_2}{n-1}$$

$$= \frac{mR}{\gamma-1} (T_2 - T_1) + \frac{P_1 V_1 - P_2 V_2}{n-1}$$

$$\therefore mRT = PV \quad \therefore mRT_2 = P_2 V_2 \quad \& \quad mRT_1 = P_1 V_1$$

$$\therefore dQ = \frac{P_2 V_2 - P_1 V_1}{\gamma-1} + \frac{P_1 V_1 - P_2 V_2}{n-1}$$

$$= \frac{P_1 V_1 - P_2 V_2}{n-1} + \frac{P_2 V_2 - P_1 V_1}{\gamma-1}$$

$$\begin{aligned} \rightarrow dQ &= P_1 V_1 - P_2 V_2 \left[\frac{1}{n-1} - \frac{1}{\gamma-1} \right] \\ &= P_1 V_1 - P_2 V_2 \left[\frac{\gamma-1 - (n-1)}{(n-1)(\gamma-1)} \right] \\ &= \frac{P_1 V_1 - P_2 V_2}{n-1} \left[\frac{\gamma-n}{\gamma-1} \right] \end{aligned}$$

(92)

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

VV1

Polytropic Specific heat (C_{poly}) :-

$$dQ_V = dU = m c_v dT \quad (\text{for ideal gas})$$

$$dQ_V = m c_v dT \quad \text{--- (1)}$$

$$dQ_P = dH = m c_p dT \quad (\text{for ideal gas})$$

$$dQ_P = m c_p dT \quad \text{--- (2)}$$

Note for polytropic process:

$$dQ_{\text{poly}} = \left(\frac{\gamma-n}{\gamma-1} \right) \times \left(\frac{P_1 V_1 - P_2 V_2}{n-1} \right)$$

$$\therefore PV = mRT$$

$$\therefore dQ_{\text{poly}} = \frac{(\gamma-n)}{(\gamma-1)} \left[\frac{mRT_1 - mRT_2}{n-1} \right]$$

$$= \frac{(\gamma-n)}{(\gamma-1)} \frac{mR}{n-1} (T_1 - T_2)$$

$$= \frac{(\gamma-n)}{(\gamma-1)} \cdot \frac{mR}{(n-1)} (-dT)$$

$$\therefore (dT = T_2 - T_1) \quad \text{Also, } \frac{R}{\gamma-1} = c_v$$

$$\therefore dQ_{\text{poly}} = \frac{(\gamma-n)}{(\gamma-1)} m c_v (-dT)$$

$$\text{or } dQ_{\text{poly}} = \frac{(n-\gamma)}{(n-1)} \cdot m c_v (dT).$$

Rearranging above equation.

$$dQ_{\text{poly}} = m \left[\frac{n-\gamma}{n-1} c_v \right] dT.$$

$$\therefore C_{\text{poly}} = \frac{n-\gamma}{n-1} \cdot c_v.$$

(12)

for ' $n > 1$ ' and ' $n < \gamma$,' C_{poly} is negative i.e. though heat is supplied, there is a decrease in temperature. This is because in such a polytropic process, work transfer is more than heat transfer and this excess work transfer comes from internal energy of the system and as there is a decrease in internal energy the temperature also decreases.

* To show that $PV^\gamma = \text{constant}$ for adiabatic process:-

$$dQ = dU + dW$$

for reversible process,

$$dQ = dU + PdV.$$

Heat gas undergoing adiabatic process.

$$dU = m c_v dT, \quad dQ = 0$$

$$\therefore 0 = m c_v dT + PdV$$

$$\text{or, } PdV = -m c_v dT \quad \text{--- (1)}$$

Now

$$H = U + PV$$

$$\rightarrow dH = dU + \underbrace{PdV + VdP}_{dQ}$$

$$\therefore dH = dQ + VdP$$

for ideal gas:-

$$dH = m c_p dT$$

$$\text{adiabatic} \Rightarrow dQ = 0.$$

$$\therefore m c_p dT = 0 + V dp.$$

$$\Rightarrow m c_p dT = V dp \quad \text{--- (2)}$$

(48)

Dividing eqⁿ (1) by eqⁿ (2):-

$$\frac{m c_p dT}{-m c_v dT} = \frac{V dp}{p dV}$$

$$\Rightarrow -\gamma = \frac{V}{dV} \cdot \frac{dp}{p}$$

$$\Rightarrow -\gamma \cdot \frac{dV}{V} = \frac{dp}{p}$$

$$\Rightarrow \frac{dp}{p} + \gamma \frac{dV}{V} = 0.$$

$$\Rightarrow \ln p + \gamma \ln V = \ln C$$

$$\Rightarrow \ln p + \ln V^\gamma = \ln C$$

$$\Rightarrow \ln p V^\gamma = \ln C.$$

$$\therefore \boxed{p V^\gamma = C}$$

The equation " $p V^\gamma = C$ " is valid for an ideal gas undergoing reversible adiabatic process.

CONVENTIONAL QUESTIONS:-

IAS
40 marks

Q.1 A fluid is contained in a cylinder by spring loaded friction piston so that pressure in the fluid is a linear function of volume, i.e. $P = a + bV$, where 'a' and 'b' are constants. Internal energy of the fluid is given by $U = 34 + 3.15 PV$, where 'U' is in kJ, 'P' in kPa and 'V' in m^3 . If the fluid changes from initial state of $P_1 = 170$ kPa, $V_1 = 0.03 m^3$ to a final state of $P_2 = 400$ kPa, $V_2 = 0.06 m^3$, find the magnitude and direction of heat transfer and work transfer. (45)

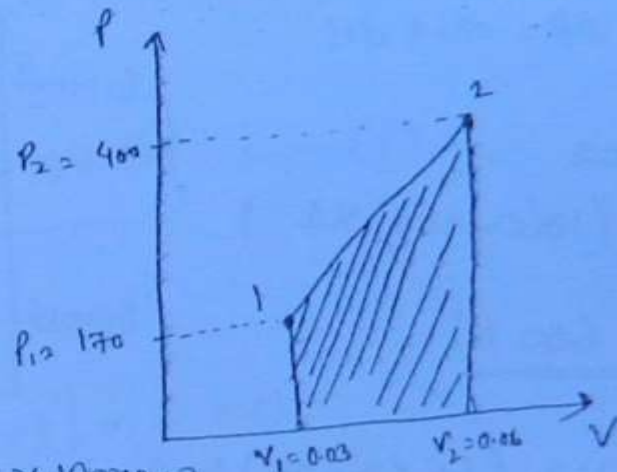
Soln:

$$W = \text{Area under curve} \\ = \frac{1}{2} \times (170 + 400) \times 0.03 \\ =$$

$$\Delta U = U_2 - U_1 = 3.15 P_2 V_2 - 3.15 P_1 V_1 \\ = 3.15 \times 400 \times 0.06 - 3.15 \times 170 \times 0.03$$

$$\therefore \Delta U =$$

$$dQ = dU + dW$$

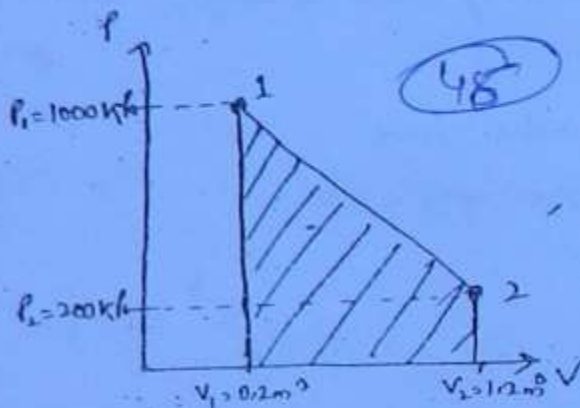


Q. 1.1) A gas of mass 1.5 kg undergoes a reversible expansion process which follows the relationship $P = a + bV$, where 'a' and 'b' are constants. The initial and final pressures are 1000 kPa and 200 kPa respectively and the corresponding volumes are $V_1 = 0.2 \text{ m}^3$ and $V_2 = 1.2 \text{ m}^3$. The specific internal energy, $u = (1.5 PV - 85) \text{ kJ/kg}$ where 'P' is in kPa and small 'v' is m^3/kg . Calculate net heat transfer and maximum internal energy of the gas.

P1 $dQ = dU + dW$

$W = \text{Area}$
 $= \frac{1}{2} (1000 + 200) \times 1$

$W = 600 \text{ kJ}$



Now $u = (1.5 PV - 85) \text{ kJ/kg}$

$u = U/m \Rightarrow U = u \times m$

$\therefore U = m [1.5 PV - 85]$
 $= [1.5 PVm - m \cdot 85]$

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

$\therefore U = (1.5 PV - 1.5 \times 85)$

$\therefore (m = 1.5 \text{ kg})$

$\therefore \boxed{U = (1.5 PV - 127.5)}$

$dU = U_2 - U_1$

Now $U_2 = 1.5 P_2 V_2 - 127.5$

$U_1 = 1.5 P_1 V_1 - 127.5$

$dU = U_2 - U_1 = 1.5 (P_2 V_2 - P_1 V_1)$

$$\therefore dU = 1.5 [200 \times 1.2 - 1000 \times 0.2]$$

$$= 60 \text{ kJ.}$$

Now

$$dQ = dU + dW$$

$$= (60 + 600) \text{ kJ}$$

$$\therefore \boxed{dQ = 660 \text{ kJ}} \quad \text{(A)}$$

Now 2nd part 1-

$$U = 1.5 PV - 127.5.$$

(17)

$$\therefore P = a + bV$$

$$\therefore U = 1.5 (a + bV)V - 127.5$$

$$\Rightarrow \boxed{U = 1.5 [aV + bV^2] - 127.5} \quad \text{--- (1)}$$

for max^m U, $\frac{dU}{dV} = 0.$

$$\frac{dU}{dV} = 1.5 [a(1) + b(2V)] = 0 = 0$$

$$\Rightarrow 1.5 [a + 2bV] = 0.$$

$$\therefore (a + 2bV) = 0$$

$$\text{or, } a = -2bV$$

$$\Rightarrow \boxed{V = \frac{-a}{2b}}$$

$$P_1 = a + bV_1 \Rightarrow 1000 = a + b \times 0.2$$

$$P_2 = a + bV_2 \Rightarrow \frac{200 = a + b \times 1.2}{800 = -b}$$

$$\text{or } \boxed{b = -800}$$

Again

$$200 = a + 1.2b \Rightarrow \text{(200 - 1.2(-800))}$$

$$\Rightarrow a = 200 - 1.2(-800)$$

$$\therefore \boxed{a = 1160}$$

Now $V = \frac{-1160}{2 \times (-800)} \Rightarrow V = 0.725 \text{ m}^3$

$$U = 1.5 [1160 \times 0.725 + (-800) 0.725^2] - 127.5$$

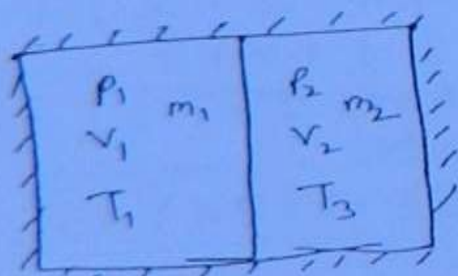
$\therefore U_{\text{max}} = 503.25 \text{ KJ.}$ (Ans) (48)

Q.13 An insulated rigid pressure vessel is divided into two portions by a thin partition. First part of vessel is occupied by an ideal gas at a pressure P_1 , volume V_1 and temperature T_1 . The other part is occupied by the same ideal gas but at a pressure P_2 , volume V_2 and temperature T_2 . Suddenly the partition is removed and two portions mix with each other. Show that the final pressure P_3 and final temp T_3 are given by

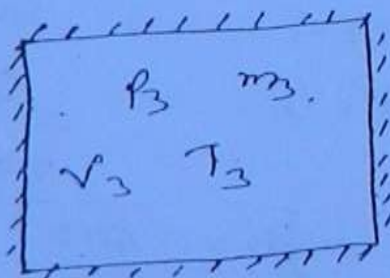
$$P_3 = \frac{P_1 V_1 + P_2 V_2}{V_1 + V_2}$$

$$T_3 = \frac{P_1 V_1 + P_2 V_2}{\frac{P_1 V_1}{T_1} + \frac{P_2 V_2}{T_2}}$$

Ans: $PV = nRT \Rightarrow m = \frac{PV}{RT}$



Initial



Final

$$m_3 = m_1 + m_2$$

$$\frac{P_3 V_3}{R T_3} = \frac{P_1 V_1}{R T_1} + \frac{P_2 V_2}{R T_2}$$

$$\frac{P_3 V_3}{T_3} = \left(\frac{P_1 V_1}{T_1} + \frac{P_2 V_2}{T_2} \right)$$

$$\Rightarrow T_3 = \frac{P_3 V_3}{\left(\frac{P_1 V_1}{T_1} + \frac{P_2 V_2}{T_2} \right)} \quad \text{--- (1)}$$

Now $dQ = dU + dW$

for constant vol^m, closed system, $dW = 0$.

Also, \therefore the system is insulated

$$\therefore dQ = 0$$

$$\therefore 0 = dU + 0$$

$$\Rightarrow dU = 0$$

$$\Rightarrow U_f - U_i = 0 \Rightarrow U_f = U_i$$

Now $U_3 = U_1 + U_2$

$$m_3 C_v T_3 = m_1 C_v T_1 + m_2 C_v T_2$$

$$\Rightarrow \frac{m_3 R T_3}{\cancel{C_v}} = \frac{m_1 R T_1}{\cancel{C_v}} + \frac{m_2 R T_2}{\cancel{C_v}}$$

$$\Rightarrow P_3 V_3 = P_1 V_1 + P_2 V_2 \quad \text{--- (2)}$$

Also, $V_3 = V_1 + V_2$

$$\therefore P_3 (V_1 + V_2) = P_1 V_1 + P_2 V_2$$

$$\Rightarrow \boxed{P_3 = \frac{P_1 V_1 + P_2 V_2}{V_1 + V_2}} \quad \text{proved}$$

$$\& \boxed{T_3 = \frac{P_1 V_1 + P_2 V_2}{\left(\frac{P_1 V_1}{T_1} + \frac{P_2 V_2}{T_2} \right)}} \quad \text{proved}$$

from eqⁿ (2)

Q: A fluid system contained in a piston-cylinder machine passes through a complete cycle of four processes. The summation of heat transfer is -340 kJ/cycle . The system completes 200 cycles per minute. Complete the following table and also find the net work transfer in kWatt.

Process	$Q \text{ (kJ/min)}$	$W \text{ (kJ/min)}$	$dU \text{ (kJ/min)}$
1-2	0	4340	-4340
2-3	42000	0	42000
3-4	-4200	69000	-73200
4-1	-105800	-141340	35540

Soln:

For Process (1-2):-

$$dQ = dU + dW$$

$$0 = dU_{12} + 4340$$

$$\Rightarrow dU_{12} = -4340$$

(5)

For 2-3 (Process):-

$$dQ = dU + dW$$

$$42000 = dU + 0 \Rightarrow dU_{23} = 42000$$

For 3-4 (Process):-

$$dQ = dU + dW$$

$$\Rightarrow -4200 = dU_{34} + 73200$$

$$\Rightarrow dW_{34} = 69000$$

Now,

$$\Sigma Q = -340 \text{ kJ/cycle}$$

& There are 200 cycles/minute.

$$\therefore \Sigma Q = -340 \times 200 = -68000 \text{ kJ/min}$$

Also $\Sigma Q = Q_{12} + Q_{23} + Q_{34} + Q_{41}$
 $\Rightarrow -68000 = 0 + 42000 + (-4200) + Q_{41}$
 $\Rightarrow \underline{Q_{41} = -105800}$

Again $\Sigma Q = \Sigma W = -68000$

$\Sigma W = W_{12} + W_{23} + W_{34} + W_{41}$
 $\Rightarrow W_{41} = -68000 - 4340 - 0 - 69000$

$\therefore \underline{W_{41} = -141340}$

Now for process (4-1)

$dQ = dU + dW$
 $\Rightarrow dU = dQ - dW$
 $= -105800 + (-141340)$

$\Rightarrow \underline{dU_{41} = 35540}$

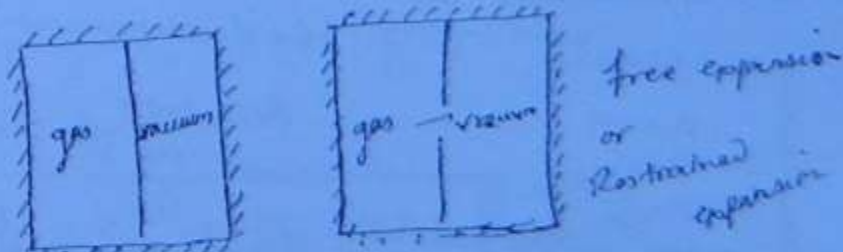
Now $W_{net} = \Sigma W = -68000 \text{ kJ/min}$

$W_{net} = -\frac{68000}{60} \text{ kJ/sec} = \text{kW}$

$W_{net} = -11333 \text{ kW}$ (Ans)

THEORY

\Rightarrow * FREE EXPANSION \rightarrow The expansion of a gas against vacuum is known as free expansion.



Free expansion work is equal to zero because as the gas is expanding against vacuum, there is no resistance offered from

Surroundings and hence work is equal to zero.



(54)

$$dQ = dU + dW$$

$$0 = dU + 0$$

$$\Rightarrow dU = 0$$

$$U_f - U_i = 0 \Rightarrow U_f = U_i$$

If an ideal gas undergoes free expansion

$$U = f(T)$$

$$\Rightarrow U_i = U_f \Rightarrow T_i = T_f$$

Also,

$$H = U + PV$$

$$H = f(T) + mRT$$

$$\therefore H = \phi(T)$$

$$\text{As, } T_i = T_f \Rightarrow H_i = H_f$$

Note:

When an ideal gas undergoes free expansion :-

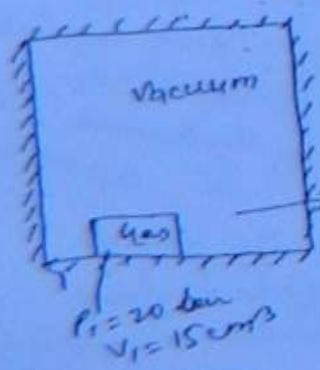
- (i) $U_i = U_f$
- (ii) $T_i = T_f$
- (iii) $H_i = H_f$

PROBLEM

Ques

An ideal gas at 20 bar and 40°C is contained in a small cylinder having a volume of 15 cm³. This cylinder is placed inside a large container having a volume of 1500 cm³. The large container is perfectly insulated and evacuated. By an appropriate means, the gas is allowed to discharge and fill the large container. Find the final pressure after the entire assembly reaches the equilibrium.

$$T_1 = T_2 \text{ (for free expansion)}$$



$$PV = mRT$$

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

from mass conservation

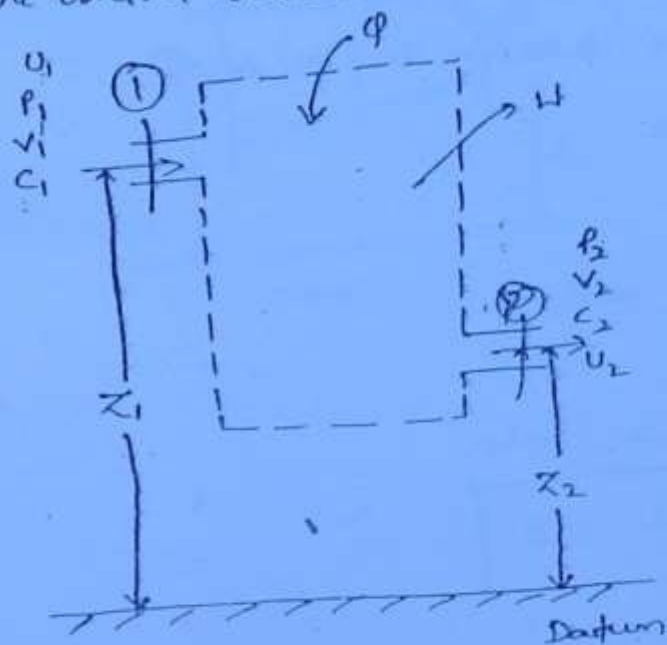
$$m_1 = m_2$$

STEADY FLOW ENERGY EQUATION (SFEE) :-

A flow is said to be steady flow if properties do not vary with respect to time at any given section.

For steady flow, there is no accumulation of mass and energy in the control volume i.e. mass entering is equal to mass leaving and energy entering = energy leaving the control volume.

(53)



$$\left. \begin{aligned} W &= W_{\text{ext flow}} + W_{cv} \\ &\quad + W_{\text{int flow}} \\ W &= -P_1 V_1 + W_{cv} + P_2 V_2 \end{aligned} \right\}$$

For steady flow, $E_1 = E_2$.

$$\frac{1}{2} m C_1^2 + mgZ_1 + U_1 + Q = \frac{1}{2} m C_2^2 + mgZ_2 + U_2 + W$$

$$\Rightarrow \frac{1}{2} m C_1^2 + mgZ_1 + U_1 + Q = \frac{1}{2} m C_2^2 + mgZ_2 + U_2 + (-P_1 V_1) + W_{cv} + P_2 V_2$$

$$\frac{1}{2} m C_1^2 + mgZ_1 + U_1 + P_1 V_1 + Q = \frac{1}{2} m C_2^2 + mgZ_2 + U_2 + P_2 V_2 + W_{cv}$$

$$H_1 + \frac{1}{2} m C_1^2 + mgZ_1 + Q = \frac{1}{2} m C_2^2 + H_2 + mgZ_2 + W_{cv}$$

Dividing the above equation by 'm' :-

$$h_1 + \frac{C_1^2}{2} + gZ_1 + q = h_2 + \frac{C_2^2}{2} + gZ_2 + w_{cv}$$

→ 1st law of thermodynamics for steady flow open system.

Here, C_1 and C_2 are velocities at 1 and 2 respectively.

$$\frac{P_1 V_1}{RT_1} = \frac{P_2 V_2}{RT_2}$$

$$\Rightarrow P_1 V_1 = P_2 V_2$$

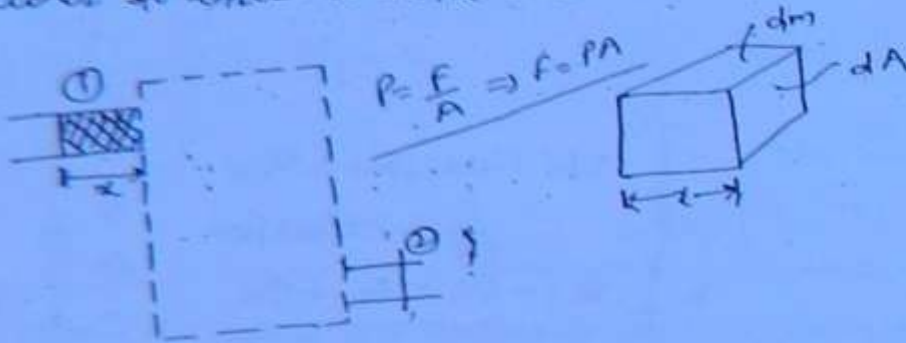
$$\Rightarrow 20 \times 15 = 100 \times V_2$$

$$\therefore \boxed{V_2 = 0.2 \text{ kgm}} \quad (\text{Ans}) \dots$$

—: FLOW WORK!—

(24)

It is the work transfer involved in causing the fluid element either to enter or leave the control volume to known as flow work.



$$\text{Work} = F \times x$$

$$= P dA \times x$$

$$\text{Work} = P dV$$

$$dV = dA \times x$$

$$v = \frac{dV}{dm}$$

$$\text{Work} = P dV$$

$$\frac{\text{Work}}{\text{mass}} = \frac{P dV}{dm}$$

$$\frac{\text{work}}{\text{mass}} = P v$$

$$\text{Total Work} = P v \cdot m$$

$$\boxed{\text{Total work} = P V}$$

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

$$\therefore \underline{V = v \cdot m}$$

If the entry occurs at '1', then the entry flow work = $(-P_1 V_1)$

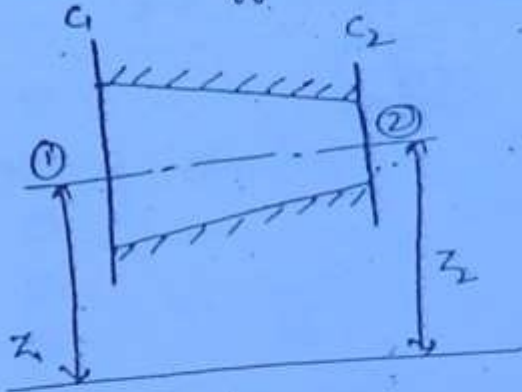
If the exit occurs at '2', then the exit flow work = $(+P_2 V_2)$.

This is the first law of thermodynamics equation for open system under steady flow conditions.

(56)

Special Cases:-

① Nozzle:- Nozzle is a device which is used for increasing kinetic energy at the expense of pressure energy.



$$h_1 + \frac{C_1^2}{2} + z_1 g + \cancel{q} = h_2 + \frac{C_2^2}{2} + z_2 g + \cancel{w}$$

∴ Insulated, $q=0$.

for a nozzle, $w_{cv} = 0$.

Also, $z_1 = z_2$ ∴ P.E are same.

Nozzle

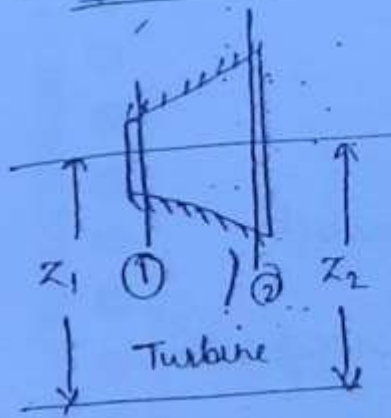
∴ Thus,

$$\boxed{h_1 + \frac{C_1^2}{2} = h_2 + \frac{C_2^2}{2}}$$

when $C_1 \ll C_2$, then

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

② Turbine:-



$$h_1 + \frac{C_1^2}{2} + z_1 g + \cancel{q} = h_2 + \frac{C_2^2}{2} + z_2 g + w_{cv}$$

Assumptions:-

- ① Steady flow
- ② Perfectly insulated, so ∴ $q=0$.
- ③ Neglecting P.E changes.
- ④ Neglecting K.E changes.

$$h_1 = h_2 + w_{cv}$$

or, $\boxed{w_{Turbine} = h_1 - h_2}$

③ Compressor:-

Compressor work is always negative, since work is done on the system.

$$W_{\text{comp}} = h_2 - h_1$$

(Assumptions are same as in case of turbine).

$$W_{\text{Turbine}} = h_1 - h_2$$

$$W_{\text{comp}} = -W_{\text{Turbine}} = -(h_1 - h_2)$$

$$\therefore W_{\text{comp}} = h_2 - h_1$$

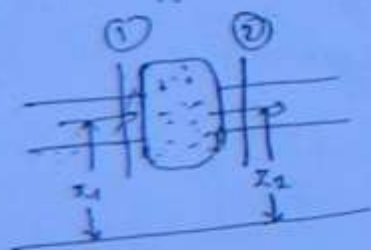
④ Throttling valve:-

Examples of throttling:-

- (i) flow through a partially opened valve.
- (ii) flow through a very small opening (orifice).
- (iii) flow through a porous plug.

Characteristics of throttling:-

- (i) No heat transfer.
- (ii) No work transfer.
- (iii) Highly irreversible process.
- (iv) Enthalpy remains constant. (It is isenthalpic process).



$$h_1 + \frac{C_1^2}{2} + z_1 g + q = h_2 + \frac{C_2^2}{2} + z_2 g + w$$

$$h_1 + \frac{C_1^2}{2} = h_2 + \frac{C_2^2}{2}$$

In comparison to enthalpy, values, i.e. changes are negligible.

$$\therefore h_1 = h_2$$

Ideal Gas ($PV = mRT$)

Perfect Gas

C_p & C_v are constants



Semi-Perfect Gas

C_p & C_v ^{vary} with temp

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

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

$$\text{or } m = nM$$

\therefore Ideal gas equation

$$PV = mRT \\ = nMR$$

$$MR = \bar{R} \text{ (universal gas constant)}$$

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

$$\text{Isothermal work} = mRT \ln \frac{V_2}{V_1}$$

$$= (n\bar{R}T \ln \frac{V_2}{V_1})$$

$$R = \frac{\bar{R}}{M} = \frac{8.314}{M}$$

$$\bar{R} = 8.314 \text{ kJ/kg.K}$$

R = characteristic gas constant

- | | | | |
|--------|--------|--------|--------|
| 1 - a | 14 - b | 27 - b | 37 - a |
| 2 - c | 15 - c | 28 - c | 38 - a |
| 3 - a | 16 - c | 29 - c | 39 - a |
| 4 - c | 17 - b | 30 - b | 40 - a |
| 5 - c | 18 - c | | 41 - a |
| 6 - a | 19 - c | | |
| 7 - a | 20 - c | | |
| 8 - c | 21 - a | | |
| 9 - a | 22 - b | | |
| 10 - b | 23 - c | | |
| | 24 - c | | |
| | 25 - a | | |
| | 26 - c | | |
| | 27 - a | | |
| | 28 - c | | |
| | 29 - a | | |
| | 30 - b | | |

(Assignment)
153

1) ToC, $n = 70$, $T = 354K$, $V_2 = 1m^3$, $W = -206 kJ$

$$W = nRT \ln \frac{V_2}{V_1}$$

$$\Rightarrow -206 = 70 \times 8.314 \times 354 \ln \left(\frac{V_2}{V_1} \right)$$

$$\Rightarrow \ln \left(\frac{V_2}{V_1} \right) = \frac{-206}{70 \times 8.314 \times 354}$$

$$\Rightarrow \left(\frac{V_2}{V_1} \right) = e^{(9.989845 \times 10^{-4})} = 1.001 \approx 1$$

$$\therefore \left(\frac{V_2}{V_1} \right) = 1 \quad \therefore V_2 = V_1$$

2) ~~404 = dW~~ $dQ_T = dW$

$P_i = P_o$ and $T_i = T_o$
 $T = \text{const}$ (Isothermal Process).
 $P_f = P_i$

$$PV = nRT = C$$

$$PV = C$$

$$P_i V_i = P_f V_f$$

$$\frac{V_f}{V_i} = \frac{P_i}{P_f}$$

$$W = Q = nRT \ln \frac{V_f}{V_i}$$

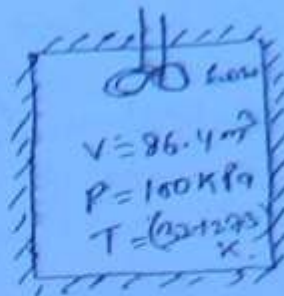
$$W = Q = nRT \ln \frac{P_i}{P_f}$$

$$Q = 1 \times R \times T_o \ln \left(\frac{P_i}{P_f} \right)$$

$$Q = RT_o \ln \left(\frac{P_o}{P_i} \right)$$

$$Q = -RT_o \ln \left(\frac{P_f}{P_o} \right)$$

③ $W = -60 \text{ W} = \frac{-60 \times 60}{60} = -60 \text{ J/s}$
 $V = 86.4 \text{ m}^3$
 $T_1 = 32^\circ\text{C}, T_2 = ?$
 $C_v = 0.718, R = 0.287 \text{ J/kg K}$
 $P_1 = 100 \text{ kPa}$
 $T_1 = (273 + 32) \text{ K} = 305 \text{ K}$



$$W = -60 \text{ J/s} = \frac{-60 \times 60 \times 60 \times 4}{1000} \text{ kJ}$$

$$= \underline{\underline{-864 \text{ kJ}}}$$

Air can be treated as an ideal gas.

$$\therefore dU = m c_v dT$$

$$dQ = dU + dW$$

$$\therefore \text{Insulated, } \therefore dQ = 0$$

$$\therefore 0 = m c_v dT + (-864)$$

$$\Rightarrow \cancel{dU} \quad m c_v dT = 864$$

$$\Rightarrow dT = \frac{864}{m c_v} \quad \text{--- (1)}$$

Now for ideal gas $PV = mRT$

$$\Rightarrow m = \frac{PV}{RT} = \frac{100 \times 86.4}{0.287 \times 305}$$

$$\therefore \underline{\underline{m = 98.7 \text{ kg}}}$$

$$\therefore dT = \frac{864}{98.7 \times 0.718} = 12.19 \approx \underline{\underline{12^\circ\text{C}}}$$

⑦ $dQ = dU + dW$

$$T_1 = 15^\circ\text{C}, T_2 = 45^\circ\text{C}, P = 100 \text{ kPa}$$

for constant volume process, $v = C$

$$dQ_v = dU = m c_v dT$$

$$= 1 \times 3.5107 \times 30 = \underline{\underline{105.32 \text{ kJ}}}$$

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

$$\Rightarrow C_v = \frac{C_p}{\gamma} = \frac{1.042}{1.376} = \underline{\underline{3.5107}}$$

④ Area of cycle = Area enclosed by the curve:-

$$\text{1st case, Area of } \Delta = \frac{1}{2}bh \\ = \frac{1}{2} \times 8 \times 3 = \underline{\underline{12}}$$

$$\text{2nd case, Area} = \frac{1}{2} \times 6 \times 4 = 12$$

but for clockwise dirⁿ ~~work~~ work is \oplus ve
and for anticlockwise dirⁿ work is \ominus ve,

$$\frac{C_p \cdot R}{C_p - C_v}$$

⑤ A-2, B-4, C-1, D-3.



$$m = 1 \text{ kg}, T_1 = 15^\circ\text{C}, p = 100 \text{ kPa}, T_2 = 45^\circ\text{C}$$

$$C_p = 1.042 \text{ kJ/kg}\cdot\text{K}, R = 0.2968$$

$$Q_v = m C_v dT \\ = 1 \times 0.7452 \times 30 \\ =$$

$$\frac{C_p \cdot R}{C_p - C_v}$$

$$\frac{(C_p - C_v) \cdot R}{1.042 - 0.2968} \\ = 0.7452$$

$$(C_p - C_v) \delta = R$$

$$(5.19 - C_v) = \frac{8.314}{4}$$

$$\therefore C_v = (5.19 - 2.0785) = \underline{\underline{3.11}}$$

$$dq = du + dw$$

$$du = \frac{100 \times 60 \times 30}{1000} = \underline{\underline{-180 \text{ kJ}}}$$

$$dw = (-180 \text{ kJ})$$

$$du = m C_v dT \\ = 30 \times 0.7 \times dT$$

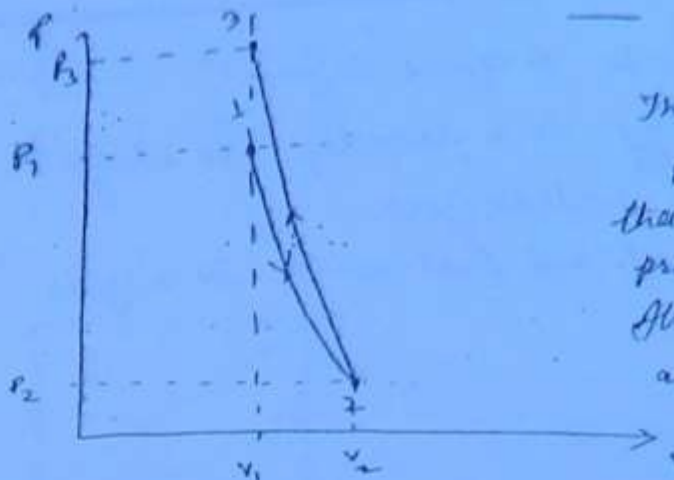
$$du = (dw)$$

$$\Rightarrow 30 \times 0.7 \times dT = 180$$

$$\Rightarrow dT = \underline{\underline{+8.57}}$$

$$\therefore T_2 = T_1 + dT \\ = 21 + 8.57 \\ = \underline{\underline{29.57^\circ\text{C}}}$$

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The slope of adiabatic process is always greater than the slope of isothermal process.
 Also, expansion work is $\ominus ve$ and compression work is $\oplus ve$

here is greater

60k

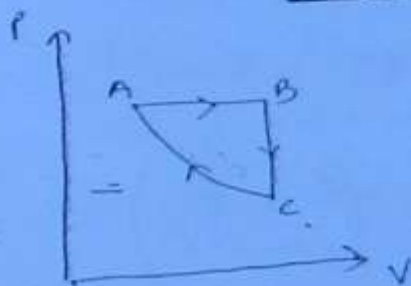
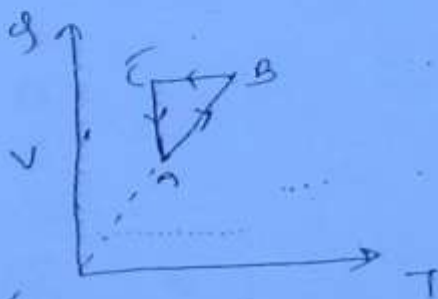
$\therefore W < 0$ (\because Win $\ominus ve$)

$+ P_3 V_3$

17) The total work done by the gas is $(300 \times 0.01) = 3 \text{ kJ}$
 Out of this total work, $(100 \times 0.01) = 1 \text{ kJ}$ is used in displacing atmospheric air.

Therefore the work that could be utilised = $(3 - 1) = \underline{2 \text{ kJ}}$

19



$PV = nRT$

$V = \frac{nR}{P} \cdot T$

$y = m \cdot x$

$m = \frac{nR}{P} = \text{const}$

m is const if P is constant $\therefore AB \rightarrow P = C$

$BC \rightarrow V = C$

$CA \rightarrow T = C$

$AB \rightarrow P = C$

20) For isothermal process of an ideal gas open system work is equal to closed system work because a rectangular hyperbola is symmetric about 'x' and 'y' axis and hence it gives same areas.

21) Change in property for any cycle is equal to zero.

Since internal energy is a property, so change in internal energy for a cycle will be zero.

As the ~~start~~ initial and final points in a cycle are same.

Q - 2

$$\text{Q} = 300 \text{ kJ} = \frac{300 \times 60 \times 15}{1000} = 2700 \text{ kJ}$$

$$\Delta Q = 0$$

Q 25 Assignment

$$P_1 = 10 \text{ bar}, V_1 = 1 \text{ m}^3, T_1 = 300 \text{ K}$$

$$V_2 = 2 \text{ m}^3$$

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

$$\left(P_1 + \frac{a}{V_1^2}\right)V_1 = \left(P_2 + \frac{a}{V_2^2}\right)V_2$$

$$\Rightarrow \left(10 + \frac{a}{1}\right) \times 1 = \left(P_2 + \frac{a}{2^2}\right) \times 2$$

$$= (10 + a) = \frac{4P_2 + a}{2}$$

$$\Rightarrow 20 + 2a = 4P_2 + a$$

$$\Rightarrow a = \frac{4P_2 - 20}{1}$$

$$\Rightarrow P_2 = \frac{a + 20}{4} = \frac{a}{4} + 5$$

$$\boxed{P_2 = \frac{a}{4} + 5}$$

$\because a > 0$ and also its value is slightly greater than 0, $\therefore \frac{a}{4}$ will be very less.

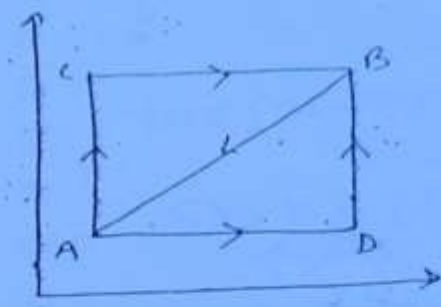
$\therefore P_2$ will be slightly more than 5 bar.

27

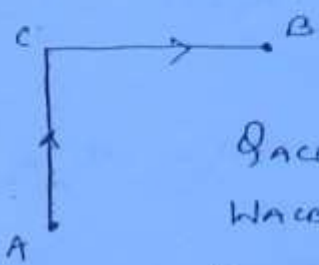
E-G-I-K-N
F-H-J-L-M

Boundary and transient
both are same and can be
used for both heat and work

28



62

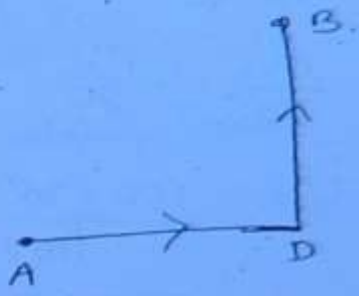


$Q_{ACB} = 180$
 $W_{ACB} = 130$

$dQ_{ACB} = dU_{ACB} + dW_{ACB}$

$\Rightarrow 180 = (U_B - U_A) + 130$

$\therefore (U_B - U_A) = 50$ — ①



$Q_{ADB} = ?$

$W_{ADB} = 40 \text{ kJ}$

$dQ_{ADB} = dU_{ADB} + dW_{ADB}$

$dQ_{ADB} = 50 + 40$

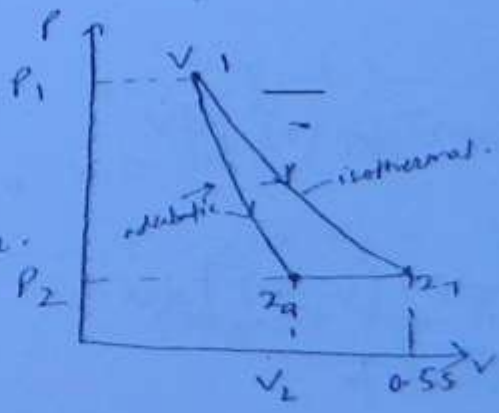
$\therefore dQ_{ADB} = 90 \text{ kJ}$ (A)

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$P_1 V_1 = P_2 V_2$
 $P_1 / V_1 = \frac{P_2}{10} \times 0.55$
 $V_1 = 0.055 \text{ m}^3$

for adiabatic $P_1 V_1^\gamma = P_2 V_2^\gamma$
 $\Rightarrow P_1 \times (0.055)^\gamma = \frac{P_1}{10} \times (V_2)^\gamma$

All values are greater
than 0.55 but only
value 0.45 is lesser.



6

$$\begin{aligned}
 T_1 &= 293 \text{ K} \\
 P_1 &= 100 \text{ kPa} \\
 V_1 &= 15 \text{ m}^3
 \end{aligned}$$

$$\begin{aligned}
 T_2 &= ? \\
 P_2 &= 150 \\
 V_2 &= 25 \text{ m}^3
 \end{aligned}$$

$$PV = nRT$$

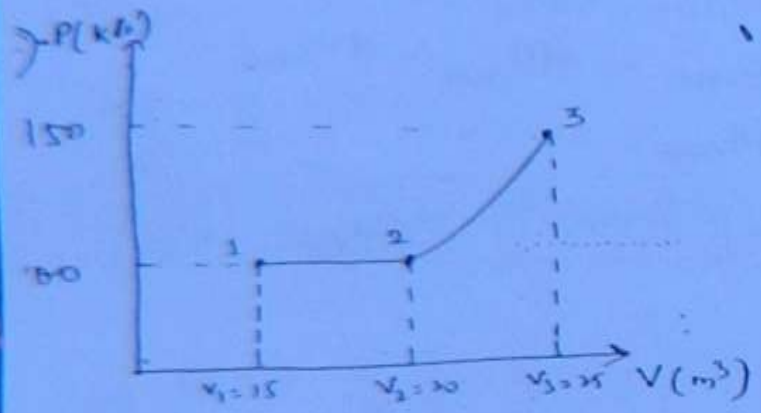
$$m = \frac{PV}{RT}$$

$$m_1 = m_2$$

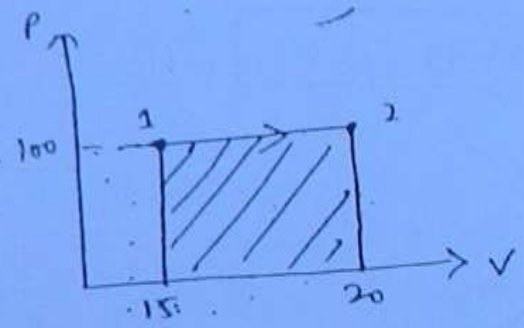
$$\frac{P_1 V_1}{RT_1} = \frac{P_2 V_2}{RT_2}$$

$$\begin{aligned}
 \Rightarrow T_2 &= \frac{150 \times 25 \times 293}{100 \times 15} \\
 &= 732.5 \approx \underline{\underline{733 \text{ K}}}
 \end{aligned}$$

64



$$P = P_0 + 2(V - V_0)^2$$



$$\begin{aligned}
 W_{12} &= P(V_2 - V_1) \\
 &= 100(20 - 15) \\
 &= \underline{\underline{500 \text{ kJ}}}
 \end{aligned}$$

Again

$$W = \int P dV$$

$$W_{23} = \int_{V_2}^{V_3} [P_0 + 2(V - V_0)^2] dV$$

$$= \int_{V_2}^{V_3} [100 + 2(V - 20)^2] dV$$

$$W_{23} = \int_{20}^{25} 100 dV + 2(V-20)^2 dV$$

$$= \int_{20}^{25} \left[100V + \frac{2}{3}(V-20)^3 \right] dV$$

$$\boxed{1 \text{ bar} = 100 \text{ kPa}}$$

$$= 100 \times (25-20) + \frac{2}{3} \left[(25-20)^3 - (20-20)^3 \right]$$

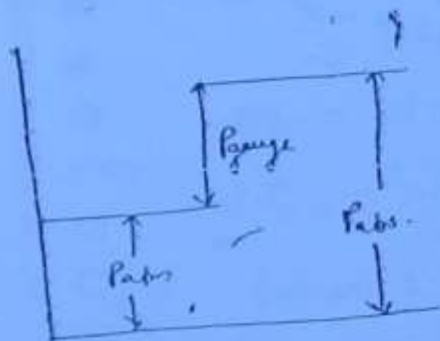
$$= 500 + \frac{2}{3} (5)^3 = 500 + 83 = 583 \text{ kJ}$$

(65)

$$\therefore W_{\text{total}} = W_{12} + W_{23}$$

$$= (500 + 583) \text{ kJ} = \underline{\underline{1083 \text{ kJ}}}$$

38) In the equation $PV = mRT$, 'P' is in absolute scale.



$$P_{\text{abs}} = P_g + P_{\text{atm}}$$

$$P_g = 1 \text{ bar (gauge)}$$

$$T_1 = 288 \text{ K}$$

$$P_{\text{abs}} = P_g + P_{\text{atm}}$$

$$P_1 = 1 + 1.013$$

$$P_1 = 2.013 \text{ bar}$$

$$PV = mRT$$

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

$$= \frac{2.013 \times 100 \times 2500}{0.287 \times 288 \times 10^{-6}}$$

($\because 1 \text{ bar} = 100 \text{ kPa}$)

$$\Rightarrow m = 6.08 \times 10^{-3} \text{ kg}$$

For a constant volume process,

$$dQ = dU$$

$$dQ = mC_v dT = mC_v (T_2 - T_1)$$

$$= 6.08 \times 10^{-3} \times 0.718 \times (278 - 288)$$

$$\Rightarrow dQ = -43.7 \times 10^{-3} \text{ kJ} = -43.7 \text{ joule}$$

(Negative sign indicates rejection of heat)

$$P_1 = 2.013$$
$$T_1 = 288$$

$$P_2 = ?$$
$$T_2 = 298$$

$$PV = nRT$$

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

66

$$\Rightarrow P_2 = \frac{T_2 \times P_1}{T_1} = \frac{298 \times 2.013}{288}$$

$$\therefore P_2 = 1.943 \text{ bar}$$

$$\therefore (P_2)_{\text{gauge}} = P_2 - P_{\text{atm}}$$
$$= 1.943 - 1.013$$

$$\therefore (P_2)_{\text{gauge}} = \underline{0.93 \text{ bar}} \quad (\text{Ans.})$$

5

$$P_1 = ?$$
$$T_1 = 288$$

$$P_2 = 1 \text{ bar (gauge)}$$
$$T_2 = 298$$

$$P_2 \text{ abs} = 1 + 1.013 = \underline{2.013 \text{ bar}}$$

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

$$\Rightarrow P_1 = \frac{2.013 \times 288}{298} = 2.085 \text{ bar}$$

$$(P_1)_{\text{gauge}} = (P_1)_{\text{abs}} - P_{\text{atm}}$$
$$= 2.085 - 1.013$$

$$\therefore (P_1)_{\text{gauge}} = \underline{1.07 \text{ bar (gauge)}}$$