Physics Notes

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Class:10+1
Unit: VIII
Topic: Thermodynamics

SYLLABUS: UNIT-VIII

Thermal equilibrium and temperature (Zeroth law of thermodynamics), Heat, work and internal energy; Thermal expansion-thermometry; First law of thermodynamics, specific heat, specific heat of gases as constant volume and pressure (manoatomic, diatomic gases); specific heat of solids (Dulong and Petit's law).

Thermodynamical variables and equation of state, phase diagrams; ideal gas equation, isothermal and adiabatic processes; reversible and irreversible processes; Carnot engine and refrigerator or heat pump. Efficiency and coefficient of performance of heat engines; second law of thermodynamics (statement only) and some practical application.

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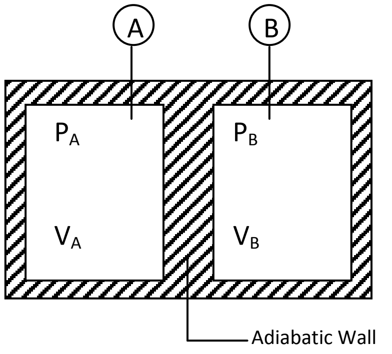
Q.1. **a) What do you mean by 'Thermal Equilibrium'?**
b) Which law of Thermodynamics defines temperature? Explain the law.

Ans.a) **Thermal Equilibrium**:-

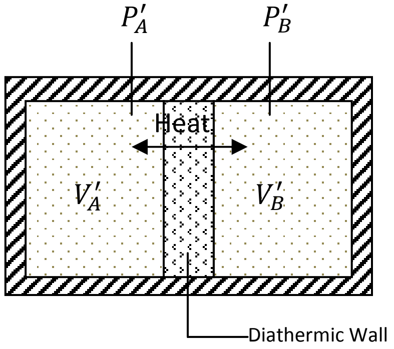
Two systems are said to be in thermal equilibrium, when they have attained same temperature.

Explanation:-

Two gas samples are separated by adiabatic wall. Pressure, volume values are (P_A, V_A) and (P_B, V_B).



Now, Adiabatic wall is replaced by 'diathermic' wall. Pressured, Volume are (P'_A, V'_A) and (P'_B, V'_B)

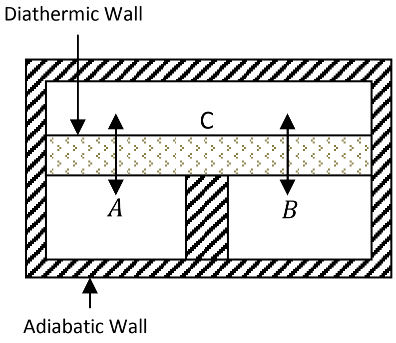


Now, two systems Ⓐ and Ⓑ are in thermal equilibrium. (In other words, systems Ⓐand Ⓑare at same temp.)

Examples:-

① When a cup of tea at 60^0C is placed in a room having temperature 20^0C, Heat flows from cup to surrounding. Heat flows till temperature of cup becomes equal to temperature of surroundings. At this stage, both cup and room are in thermal equilibrium.

② When temperature of the body at 37^0C and thermometer at 20^0C. The heat flows from human body to thermometer. Heat flows till temperature of the thermometer and temperature of the body becomes equal. AT this stage, both thermometer and body are said to be in thermal equilibrium.



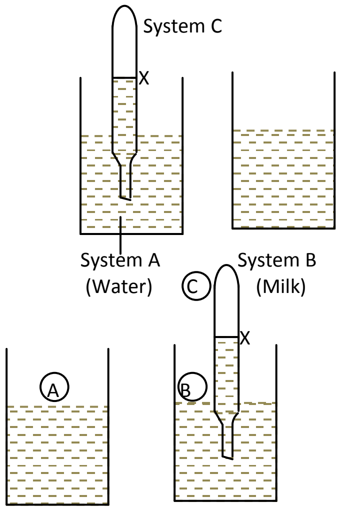
b) **Zeroth Law of Thermodynamics defines temperature**:-

It is called zeroth law because it came after first and second law of thermodynamics and was fundamental to define temperature.

According to this law, when the thermodynamics system *A* and *B* are separately in thermal equilibrium with a third thermodynamic system *C*, then the system *A* and *B* are in thermodynamic equilibrium with each other.

Examples:-

In hot water and milk, reading of temperature of water and milk is same.



Q. 2. What is Thermodynamics process? Draw P-V graph for following Thermodynamics process

- **a) Isochoric Process**
- **b) Isobaric Process**
- **c) Isothermal Process**
- **d) Adiabatic Process**

Ans. **<u>Thermodynamic Process</u>**:-

Thermodynamic process is said to take place when some changes occur in the state of a thermodynamic system i.e. the thermodynamic parameter of the system change with time i.e. Pressure, Temperature, Volume.

a) **<u>Isochoric Process</u>**:-

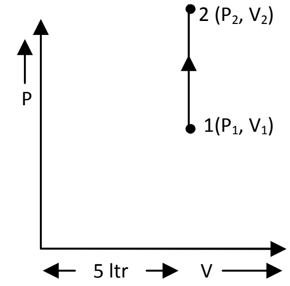
Volume → Constant

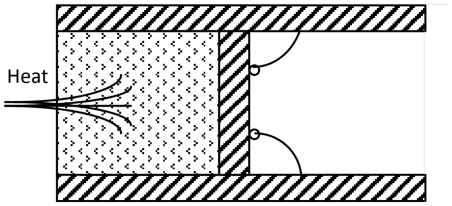
$$\underset{\downarrow}{P.V} = n.\underset{\downarrow}{R}.\underset{\downarrow}{T}$$

Constant

$$\boxed{P\ \alpha\ T}$$

As one moves from point ① to ② on graph pressure and temperature increases but volume remains constant.





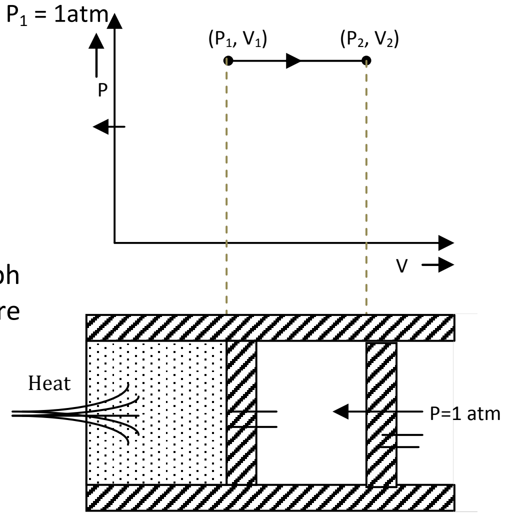
b) **<u>Isobaric Process</u>**:-

Pressure → Constant

$$\underset{\underset{\text{Constant}}{\downarrow}}{P}.V = n.\underbrace{R.T}_{\text{Constant}}$$

$$\boxed{V\ \alpha\ T}$$

As one moves from point ① to ② on graph temperature and volume increases but pressure remains constant i.e. 1 atm.



c) and (d) will be taken up in Q3 and Q6.

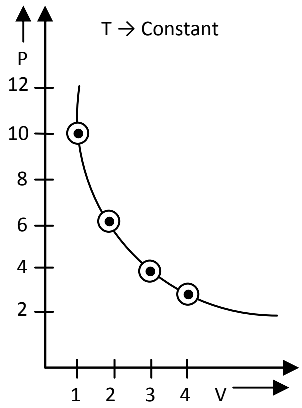
Q.3. Discuss the following for Isothermal process

a) Isothermal process definition.

b) Conditions for Isothermal process

c) P-V graph for different temp.

d) Examples



Ans.a) **<u>Isothermal Process</u>**:-

A change in pressure and volume of a gas without any change in its temperature i.e.

P.V $= n.R.T.$ (Constant Temperature)

P.V = Constant

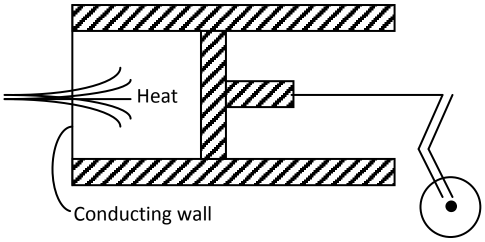
P $= \frac{Constant}{V}$ $\left[y = \frac{10}{x} type\right]$

As *x* increases, *y* decreases

b) **<u>Necessary Conditions</u>**:-

i) Conducting walls for free exchange of heat

ii) Slow process so that time is available to exchange heat with surroundings.



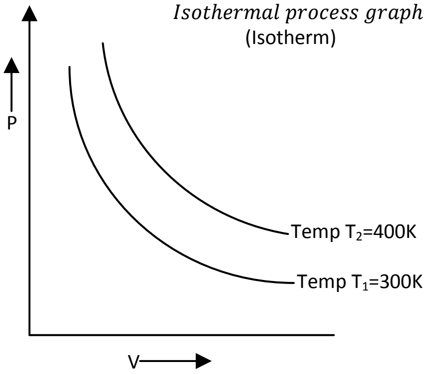
d) **<u>P-V graph</u>**:-

P.V $= n$.R.T for temperature T_1 (say 300K)

$$\boxed{P = \frac{n.R.T}{V}}$$

And $P = \frac{n.R.T_2}{V}$ for T_2 (say 400K)

As temperature increases, Isotherm moves upwards.



<u>Examples</u>:-

1. Melting process, 0^0C ice becomes 0^0C water but temperature is constant.
2. Boiling process, 100^0C water becomes 100^0C steam, but temperature is constant.
3. When a gas in a cylinder with perfectly conducting walls and perfectly conducting frictionless piston is compressed or allowed to expand so slowly so that heat produced in compression and heat spent in expansion is exchanged with the surroundings, the changes are isothermal changes.

Q.4. Find work done in an Isothermal Process.

Ans. **Work**:-

$$dW = F.dx$$

$$= \left(\frac{F}{A}\right).\ (dx.A)$$

$$= P.\ dV$$

Integrating both sides

$$\int dW = \int P.dV$$

$$W = \int P.dV \qquad (P.V = nRT)$$

$$= \int \frac{nRT}{V}.\ dV$$

$$= n.R.T \int_{V_1}^{V_2} \frac{1}{V}.dV \qquad \left[\int \frac{1}{x}.dx = log x\right]$$

$$= n.R.T\ |\log V|_{V_1}^{V_2}$$

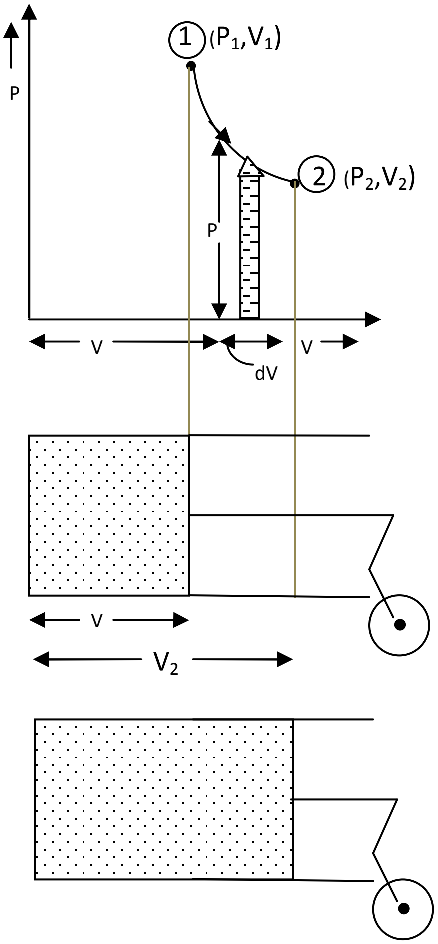
$$\boxed{W_{iso} = n.R.T \log\left(\frac{V_2}{V_1}\right)}$$

OR

$$\boxed{W_{iso} = n.R.T \log\left(\frac{P_1}{P_2}\right)}$$

Temp T → Constant

$P_1.V_1 = P_2.V_2$



Q.5. Derive expression for slope of Isothermal process.

Ans. Slope of P-V graph, $\frac{dP}{dV} \rightarrow ?$

P.V = n.R.T

P.V = Constant

Differentiate both sides

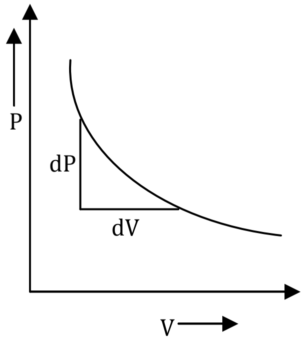
d(P.V) = d(Constant)

= 0

P.dV + V.dp = 0 [d(x.y) = x.dy + y.dx]

V.dp = - p.dV

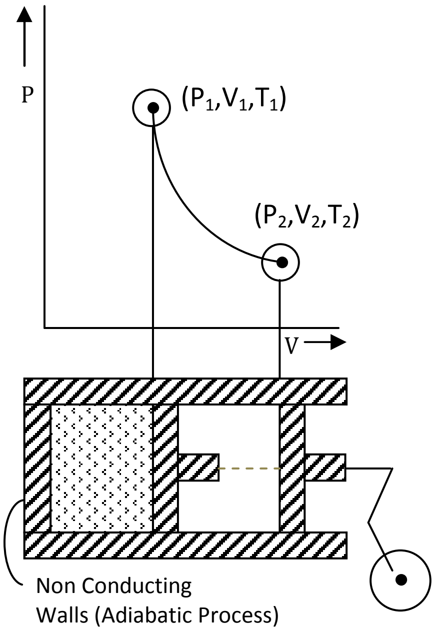
$$\boxed{\frac{dP}{dV} = \frac{-P}{V}}$$



Q.6. Discuss the following for Adiabatic process

a) Adiabatic process
b) Isothermal process conditions
c) P-V, V-T, P-T relationship/graph
d) Examples

$\boxed{P.V^{\gamma} = \text{Constant}}$



Ans.a) **<u>Adiabatic Process</u>**:-

A change in pressure and volume of a gas in which temperature also changes is called an adiabatic change. In such a change, no heat is allowed to enter into or escape from the gas for adiabatic process,

$$\boxed{P.V^{\gamma} = \text{Constant}}$$

[Type = $y.x^4$ = type]

If $\gamma = 1$, then it is isothermal
If $\gamma = 1.4$ it is adiabatic process.

b) **<u>Essential Conditions</u>**:-

i) No heat exchange, non-conducting walls.
ii) Fast process, no time to exchange heat with surroundings

c) **<u>P-V, V-T, P-T relation</u>**:-

i) **<u>P-V</u>**:-

$$P.V^{\gamma} = \text{Constant i.e. } P_1.V_1^{\gamma} = P_2.V_2^{\gamma}$$

ii) **<u>V-T</u>**:-

$$P.V^{\gamma} = \text{Constant} \rightarrow ①$$

$$P.V = n.R.T \rightarrow ②$$

Divide ① by ②

$$\frac{V^{\gamma}}{V} = \frac{Constant}{n.R.T}$$

$$\boxed{V^{\gamma-1}.T' = \text{Constant}} \text{ i.e. } \boxed{V_1^{\gamma-1}.T_1 = V_2^{\gamma-1}.T_2}$$

iii) **<u>P-T</u>**:-

$$P.V^{\gamma} = \text{Constant} \rightarrow ①$$

$$P.V = n.R.T \rightarrow ②$$

$$P\left(\frac{n.R.T}{P}\right)^{\gamma} = \text{Constant}$$

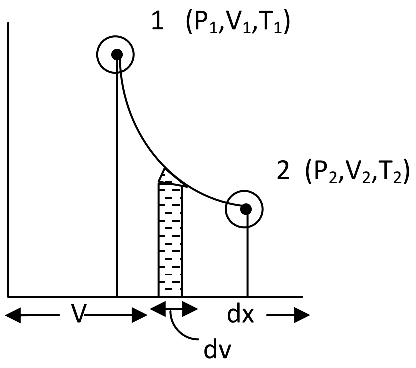
$$\boxed{P^{1-\gamma}.T^{\gamma} = \text{Constant}} \text{ i.e. } \boxed{P_1^{1-\gamma}.T_1^{\gamma} = P_2^{1-\gamma}.T_2^{\gamma}}$$

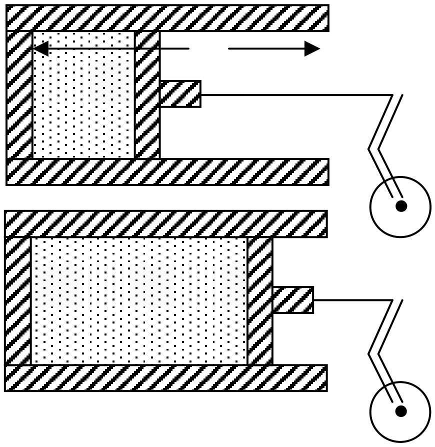
d) **<u>Examples</u>**:-

i) Bursting of tube of a bicycle tyre.
ii) Propagation of sound waves in.

Q.7. Find work done in an Adiabatic process.

Ans. Work done in an Adiabatic Process:





$$dW = F.dx$$

$$= \frac{F}{A}.(dx.A) \qquad \text{[Multiply and divide by A]}$$

$$dW = P.dV$$

Integrating both sides

$$\int dW = \int P.dV$$

$$W = \int P.dV$$

$$= \int \frac{K}{V^{\gamma}}.dV$$

$$= K\int V^{-\gamma}\ .dV \qquad \left[\int x^{n}\ .dx = \frac{x^{n+1}}{n+1}\right]$$

$$= K\left|\frac{V^{-\gamma+1}}{-\gamma+1}\right|_{V_1}^{V_2}$$

$$= \frac{K}{1-\gamma}\left(V_2^{1-\gamma} - V_1^{1-\gamma}\right) \qquad \left[P_1.V_1^{\gamma} = P_2.V_2^{\gamma} = K\right]$$

$$W = \frac{P_2V_2^{\gamma}.V_2^{1-\gamma} - P_1V_1^{\gamma}.V_1^{1-\gamma}}{1-\gamma}$$

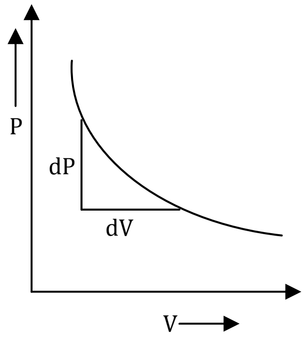
$$= \frac{P_2\,V_2^{1} - P_1\,V_1^{1}}{1-\gamma} \qquad \begin{bmatrix} P_1.V_1 = n.R.T_1 \\ P_2.V_2 = n.R.T_2 \end{bmatrix}$$

$$= \frac{n.R.T_2 - n.R.T_1}{1-\gamma}$$

$$\boxed{W_{adia} = \frac{n.R\ (T_2 - T_1)}{1-\gamma}}$$

Q.8. Derive expression for slope of Adiabatic process.

Ans. **Slope of P-V graph**:-



$$P.V^{\gamma} = \text{Constant}$$

Differentiate both sides

$$d(P.V^{\gamma}) = d\,(\text{Constant})$$

$$P.d(V^{\gamma}) + V^{\gamma}.d(P) = 0$$

$$P.\gamma.V^{\gamma}.dV + V^{\gamma}.dP = 0 \qquad [d(x^n) = n\,x^{n-1}\,dx]$$

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

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

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

$$\boxed{\left(\frac{dP}{dV}\right)_{adi} = -\gamma\left(\frac{P}{V}\right)} \quad \text{and} \quad \boxed{\left(\frac{dP}{dV}\right)_{iso} = \left(\frac{-P}{V}\right)}$$

Slope of adiabatic process is Y times that of isothermal.

Q.9. Compare 'Isothermal' and 'Adiabatic' Process.

Ans.

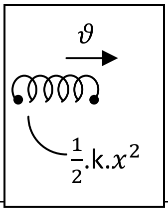
Isothermal	**Adiabatic**
1. Temperature (T) remains Constant i.e. ΔT = 0.	1. Heat Content (Q) remains constant i.e. ΔQ = 0. No heat exchange.
2. System is thermally **conducting** to the surrounding.	2. System is thermally **isolated** from the surrounding.
3. The Changes occur **slowly**.	3. The changes occur **suddenly**.
4. Internal Energy (V) remains constant.	4. Internal Energy changes $U \neq$ Constant ∴ $\Delta U \neq 0$.
5. Specific heat becomes **infinite**.	5. Specific heat becomes **zero**.
6. Isothermal changes, **PV = Constant**.	6. Adiabatic change, **$P.V^{\gamma}$= Constant**.
7. Slope, $\frac{dp}{dV} = \frac{-P}{V}$.	7. Slope, $\frac{dp}{dV} = -\gamma\left(\frac{P}{V}\right)$.
8. Co-eff of Isothermal elasticity, E_{iso} = P.	8. Co-eff of adiabatic elasticity E_{adia} = γ.P.

Q.10. a) What is internal energy of a gas?
b) Compare internal energy of an 'Ideal gas' and 'Real gas'
c) Discuss methods/ways to change internal energy of gas in cylinder.

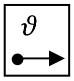
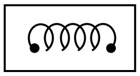
Ans.a) **Internal Energy**:-

Internal Energy of a system is the total energy possessed by the system due to Molecular Motion and Molecular Configuration. (elastic potential energy)

$$\boxed{U = U_{Kinetic} + U_{Potential}}$$



b) **Comparison of internal energy of an 'Ideal gas' & 'Real gas'**:-

Ideal Gas:-	**Real Gas**:-
1) No interactions/Intermolecular attraction  So, Elastic P.E = 0	1) Interatomic/Intermolecular attraction exist  So, $U_{potential} = \frac{1}{2}.k.x^2 \neq 0$
2) U = $U_K + U_P$ $\boxed{U = U_K + 0}$	2) U = $\underset{\neq 0}{\underset{\downarrow}{U_K}} + \underset{\neq 0}{\underset{\downarrow}{U_P}}$
3) Total energy of ideal gas depends on 'Temperature' only.	3) Total energy of real Gas depends on 'Temperature' and 'Volume' of gas.

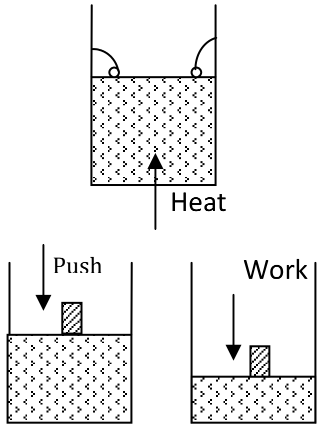
c) **Two Methods of changing internal energy**:-

No.1:- Heating

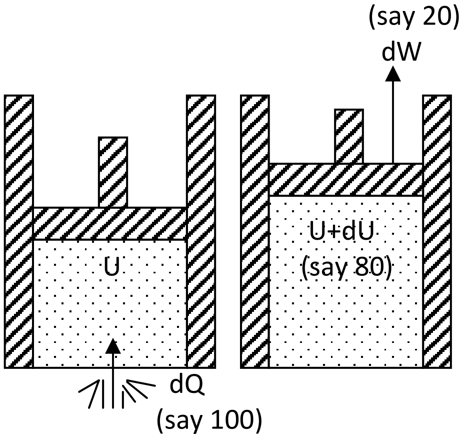
Heat supplied increases internal energy.

No.2:- By doing work

Work done increases internal Energy.



Q.11. a) State and explain 1st Law of Thermodynamics?
b) Applications of 1st Law of Thermodynamics.
c) Limitations of 1st Law of Thermodynamics.



Ans.a) **<u>1st Law of Thermodynamics</u>**:-

'Energy (Heat) supplied to system is used to increase internal energy and remaining is used to do work'.

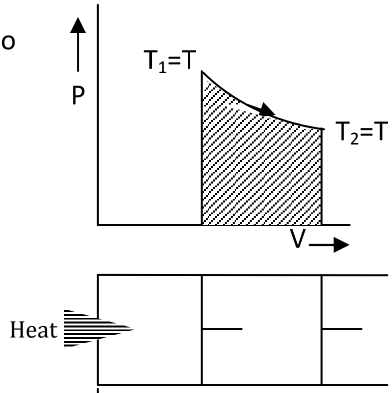
i.e. $\boxed{dQ \quad = dU \quad + dW}$

↓ ↓ ↓

path function, point function, path function

<u>Discussion</u>:-

1. <u>Work</u>:- Path function i.e. depends on path traced.
2. <u>Internal Energy</u>:- Depends upon temperature only.
   dU → change in internal energy depends on initial and final temperature only. Does not depend on path i.e. it is not a path function. It is a point function.
3. <u>Sign</u>:-
   - Work done by system → +ve
   - Work done on system → -ve
   - Heat supplied to system → +ve
   - Heat given by the system → -ve
   - Increase in internal energy → +ve
   - Decrease in internal energy → -ve
4. 1st Law of Thermodynamics gives concept of internal energy.
5. 1st Law of Thermodynamics deals with conversion of heat to work or work to heat.



b) <u>Applications</u>:-

1. **<u>Isothermal Process</u>**:-

T → Constant
U → Constant
dU → 0
1st Law, dQ = dU + dW

↓ ↓

0 Area under P-V graph

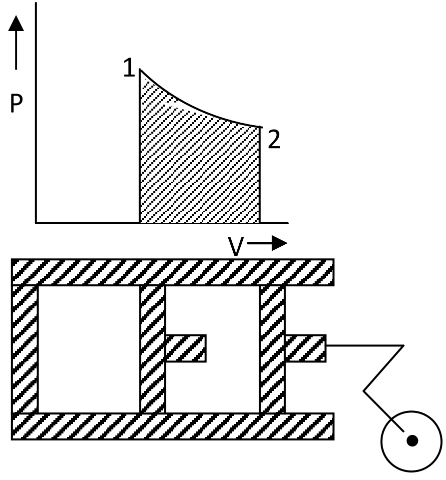
dQ = dW

2. **<u>Adiabatic Process</u>**:-

dQ = dU + dW
0 = dU + dW

↓ ↓

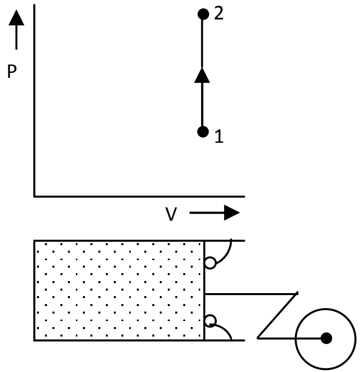
-ve +ve for given graph
Say (-20) say (+20)



4. **Isochoric Process**:-

$$dQ = dU + \underset{\substack{\downarrow \\ 0,\ \text{No expansion/compression}}}{dW}$$

$$\boxed{dQ = dU}$$



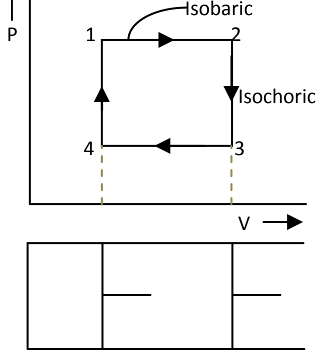
5. **Cyclic Process**:-

dU = 0 as dT = 0

dQ = dU + dW

dQ = 0 + dW

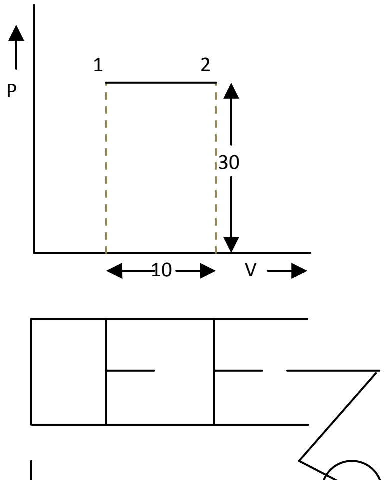
$$\boxed{dQ = dW}$$



Q.12. Explain cyclic and non-cyclic process? Examples.

Ans. **Non-Cyclic Process**:-

Process 1-2 is non-cyclic as piston is not coming back to initial position

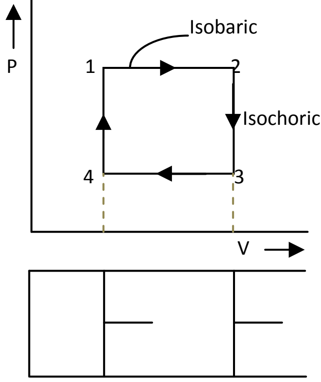


W_{1-2} = 30 x 10

= 300 sq units (Area under graph)

Cyclic Process:-

Process 1-2-3-4-1 is cyclic as piston comes back to initial position.



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

= (30 x 10) + 0 + (-15 x 10) + 0

= +150 (Area enclosed by loop)

- Loop must be always clockwise for (+ve) work.
  If loop is anti-clockwise then work is (-ve).

Q.13. **a) What is heat engine? Explain its working.**
b) Efficiency of heat engine.

Ans.a) **Heat Engine**:-

'Device which converts heat to work'.

Working:-

In a steam engine, steam acts as the working substance. In a diesel engine, a mixture of fuel vapours and air acts as the working substance. The working substance absorbs some heat from an external reservoir (the source) at some high temperature. It then undergoes a cyclic change consisting of several processes. In some of the processes, the working substance releases some heat energy to the external reservoir (the sink) at some lower temperature. Difference of temperature between source and sink is used to do work.

b) $\underline{\eta}$

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

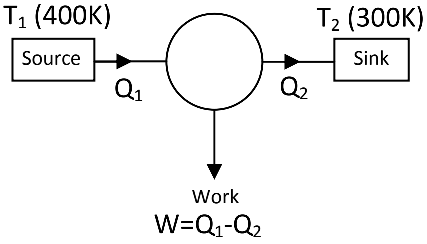
$$= \frac{W}{Heat\ taken}$$

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

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

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

$$\eta = 1 - \frac{Q_2}{Q_1} = 1 - \frac{T_2}{T_1} = 1 - \frac{30\cancel{0}}{40\cancel{0}} = 25\%$$



- Efficiency of steam engine is only of the order of 10%.

Q14. **a) State and explain 2nd law of thermodynamics?**
b) Reversible and irreversible process? Examples?

Ans. **2nd Law of Thermodynamics**:

a) i) **Kelvin Planck Statement**:

It is impossible to construct a heat engine which would absorb heat from a reservoir and convert 100% of heat absorbed into work.

ii) **Clausius Statement**:

It is impossible to design a self acting machine unaided by any external agency, which would transfer heat from a body at low temperature to another body at high temperature.

b) i) **Reversible Process**:

A thermo dynamical process taking a system from initial state *i* to final state *f* is reversible, if the process can be turned back such that both, the system and the surroundings return to their original states, with no other change in the universe.

ii) **Irreversible Process**:

A process, which does not satisfy any of the conditions for reversible process, is called an *irreversible process*.

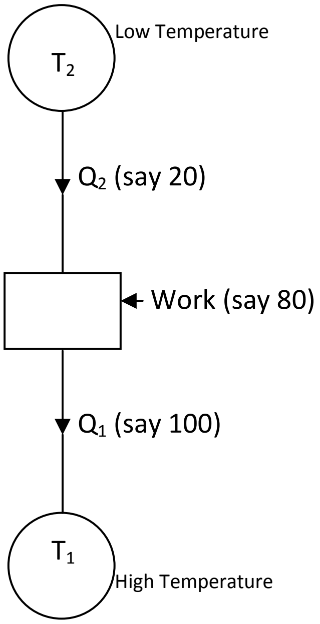
Q.15. a) What is a refrigerator? Explain its working.
b) β, Coeff. of performance of refrigerator.

Ans.a) **Refrigerator**:-

'A device which is used for cooling objects'.

OR

'A refrigerator is a device used to pump heat from low temperature to higher temperature using external agencies work.



$$\boxed{W + Q_2 = Q_1}$$

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

Working:-

In a refrigerator, the working substance would absorb a certain quantity of heat Q_2 from sink at lower temperature T_2 and reject a larger amount of heat Q_1 to the source at higher temperature T_1 with the help of an external agency supplying the necessary energy to the system.

a) Sudden expansion of gas from high pressure to low pressure, resulting in cooling of gas, converting it into a vapour liquid mixture.
b) This mixture absorbs heat from the region to be cooled and becomes vapours.
c) The vapours get heated on account of external work done on the system by the supply to electricity.
d) The heated vapours then release heat to the surroundings, bringing them to initial state after completing one cycle.

b) **β** Co-eff of performance, β $= \frac{Q_2}{W}$

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

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

$$= \frac{1}{\frac{T_1}{T_2} - 1} \quad \left(\frac{Q_1}{Q_2} = \frac{T_1}{T_2}\right)$$

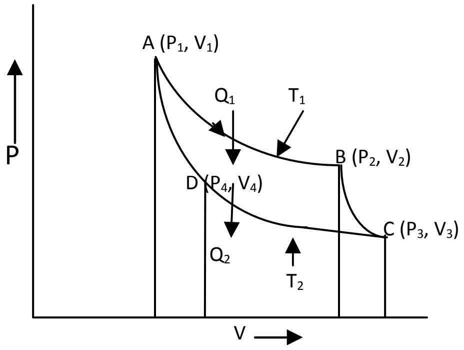
OR

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

NOTE: Higher the heat taken (Q_2), better the performance of refrigerator.

Lower is work done (W), low consumption of energy, better the performance of refrigerator.

Q.16. Explain Carnot cycle, engine?



Ans.1. **<u>Process AB</u>**:-

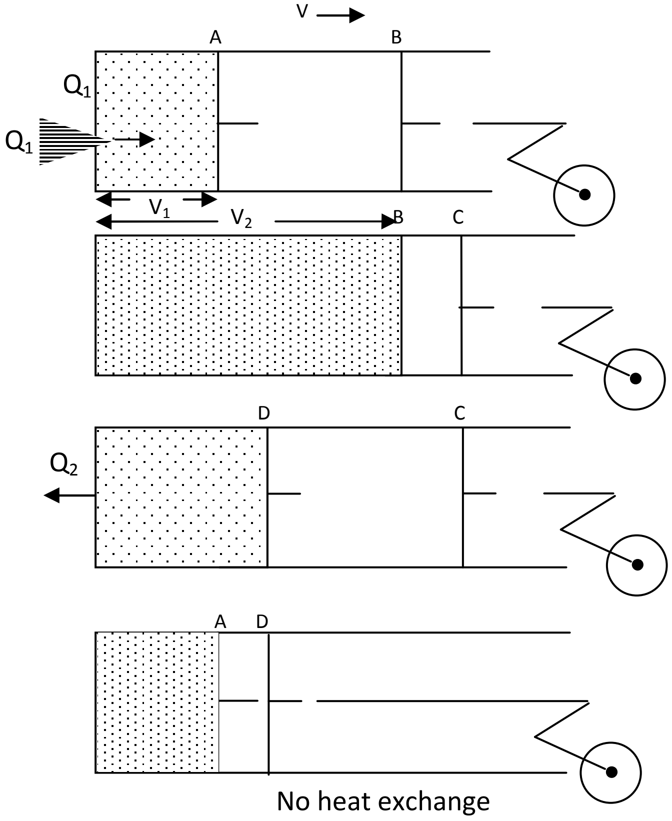
Isothermal Process, Constant Temperature, (say T_1)

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

$$\Delta Q = 0 + \Delta W$$

$$\boxed{Q_1 = W_1}$$

$$\boxed{W_1 = n.R.\,T_1 \log\left(\frac{V_2}{V_1}\right)}$$



No heat exchange

2. **<u>Process BC</u>**:-

Adiabatic Process, $\Delta Q = 0$

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

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

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

$$\boxed{W_2 = \frac{n.R.(T_2 - T_1)}{1-\gamma}}$$

3. **<u>Process CD</u>**:-

Isothermal Process, Constant Temperature (say T_2)

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

$$\Delta Q = 0 + \Delta W$$

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

$$\boxed{Q_2 = W_3}$$

$$\boxed{\underset{\substack{\downarrow \\ \text{Is –ve}}}{W_3} = n.R.T_2 \log\left(\frac{V_4}{V_3}\right)}$$

4. **Process DA**:-

Adiabatic, $\Delta Q = 0$

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

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

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

$$\boxed{W_4 = \frac{n.R.(T_1-T_2)}{1-\gamma}}$$

$\downarrow$

Is -ve

5. **Work done in Cycle**:-

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

$$= n.R.T_1 \log\left(\frac{V_2}{V_1}\right) + \cancel{\frac{n.R.(T_2-T_1)}{1-\gamma}} + n.R.T_2 \log\left(\frac{V_4}{V_3}\right) + \cancel{\frac{n.R.(T_1-T_2)}{1-\gamma}}$$

$$\boxed{\begin{aligned} \text{Work} &= n.R.T_1 \log\left(\frac{V_2}{V_1}\right) + n.R.T_2 \log\left(\frac{V_4}{V_3}\right) \\ &= n.R.T_1 \log\left(\frac{V_2}{V_1}\right) - n.R.T_2 \log\left(\frac{V_3}{V_4}\right) \end{aligned}}$$

6. **Heat**:-

$$Q_{net} = Q_1 - Q_2$$

7. $$\frac{Q_2}{Q_1} = \frac{W_3}{W_1}$$

$$= \frac{\cancel{n.R.}T_2 \cancel{\log}\left(\frac{V_3}{V_4}\right)}{\cancel{n.R.}T_1 \cancel{\log}\left(\frac{V_2}{V_1}\right)}$$

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

8. Efficiency, $\eta = 1 - \frac{Q_2}{Q_1}$

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