VISUAL PHYSICS

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SHORT NOTES

CHAPTER

Laws of Thermodynamics

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Thermodynamics

→ Branch of science which deals with exchange of heat energy between bodies and conversion of the heat energy into mechanical energy & vice versa.

Thermodynamic System

Open system

→ exchange of both energy and matter with surrounding

Closed system

→ Exchange of energy only with surrounding

Isolated system

→ It exchanges neither energy nor matter with surrounding

→ The 'body' which is subjected to a thermodynamic process is known as thermodynamic system.

Thermodynamic Variables and Equation of state:

A thermodynamic system is described by specifying

→ pressure
→ volume
→ temperature
→ Internal energy & number of moles.

→ Relationship between thermodynamics variables is called equation of states.

Thermodynamic Equilibrium:

→ when variables attain a steady value i.e. they are independent of time.

(i) Mechanical equilibrium:
No unbalanced fore between the system and its surrounding.

(ii) Thermal equilibrium:
There is a uniform temperature in all parts of system and same that of surrounding.

(iii) chemical equilibrium:
This is a uniform chemical composition throughout the system and the surrounding

Thermodynamic Process:

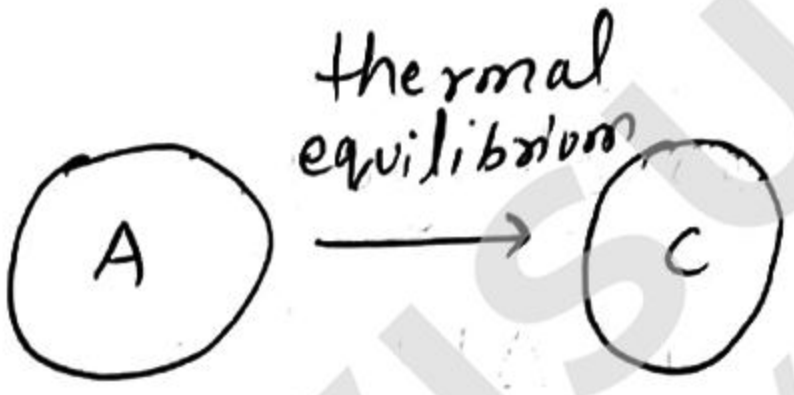
through thermodynamic process state of a system involves change of thermodynamic variables such as pressure, P, volume V and temperature T of system

Some Important processes:

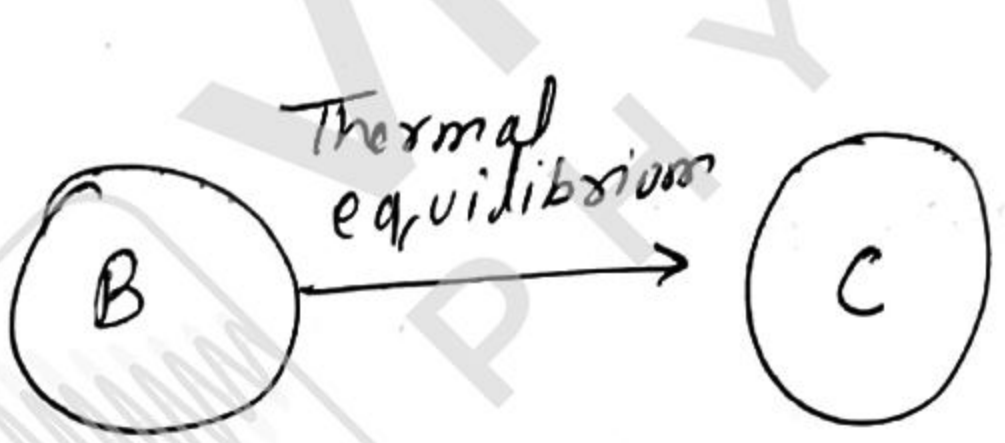
→ Isothermal process
→ adiabatic process
→ Isobaric process
→ Isochoric
→ Cyclic and non-cyclic process
→ reversible & irreversible process.

Zeroth Law of Thermodynamics:

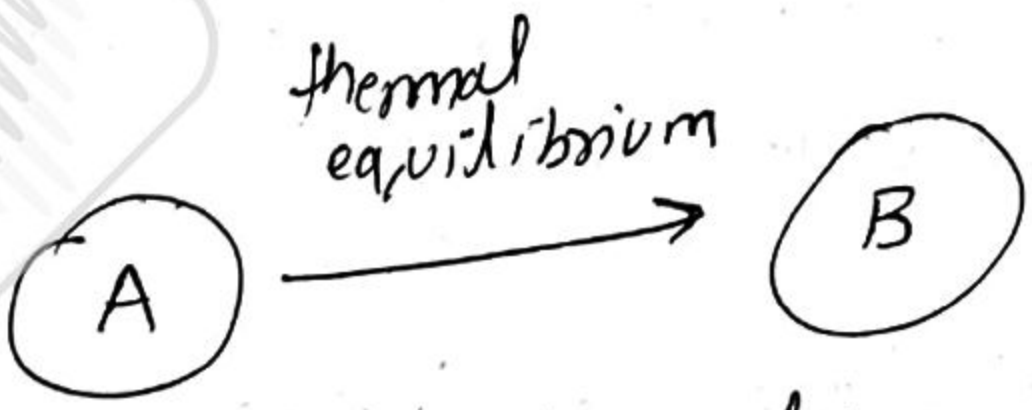
if



&



then



if A & C are in thermal equilibrium
if B & C are in thermal equilibrium
then A & B are in thermal equilibrium also.

First law of thermodynamics:

Internal energy (U):

→ Energy contained within the system due to the relative positioning and motion, i.e. due to molecular motion and molecular configuration.

→ Sum all all the energy possessed inside the system is internal energy

Δ → means change

$$\Delta U = \Delta Q + \Delta W$$ → first law of thermodynamics

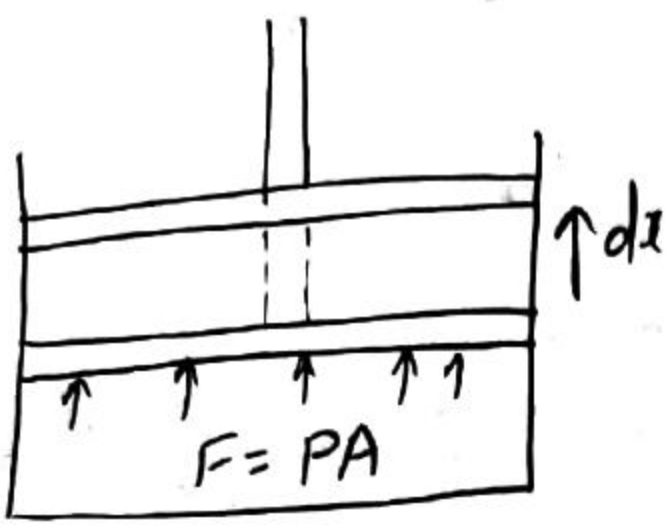
* In Easiest form: Energy of the universe is conserve.

ΔQ → positive → Heat given to the system
→ negative → Heat is extracted from the system

ΔW → positive → Work done on the system
→ Negative → Work done by system

heat and work are path function means they depend on path itself.

Work done by a gas:



Now small work

$$dW = F\,dx$$

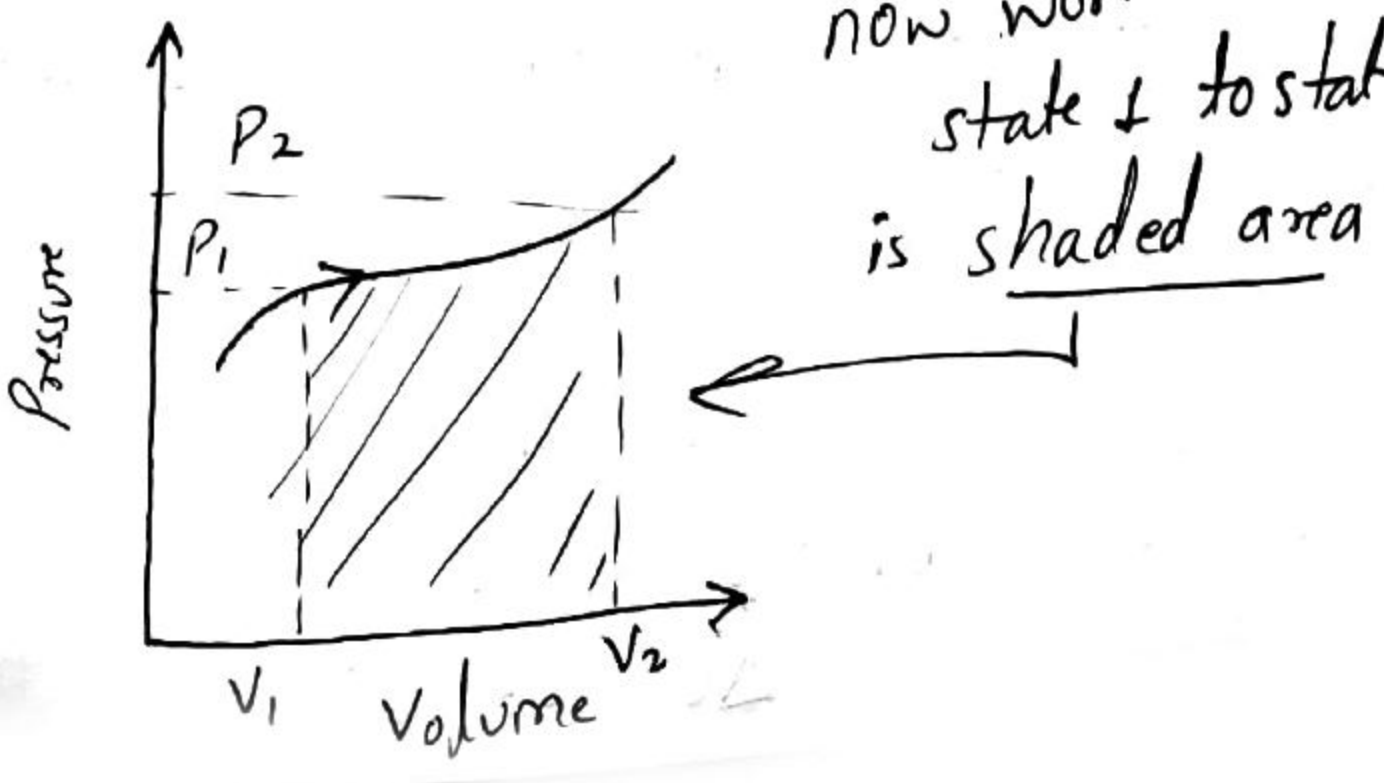
$$\Rightarrow \quad dW = PA\,dx$$

now total work from one state to state 2

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

$$\Rightarrow \quad \boxed{W = \int_{V_1}^{V_2} P\,dV}$$

* Area of Pressure to volume graph will give work



Important points on Internal Energy (U)

As energy due to molecular motion is called Internal kinetic energy U_K

And energy due to molecular configuration is called Internal potential energy U_P

So, $\boxed{U = U_K + U_P}$

U → total internal energy

(i) For an ideal gas, $U_P = 0$

& $U_K = \left(\frac{f}{2}\right) \mu RT$ [μ → no. of moles]

f → degree of freedom.

(ii) Now change in internal energy

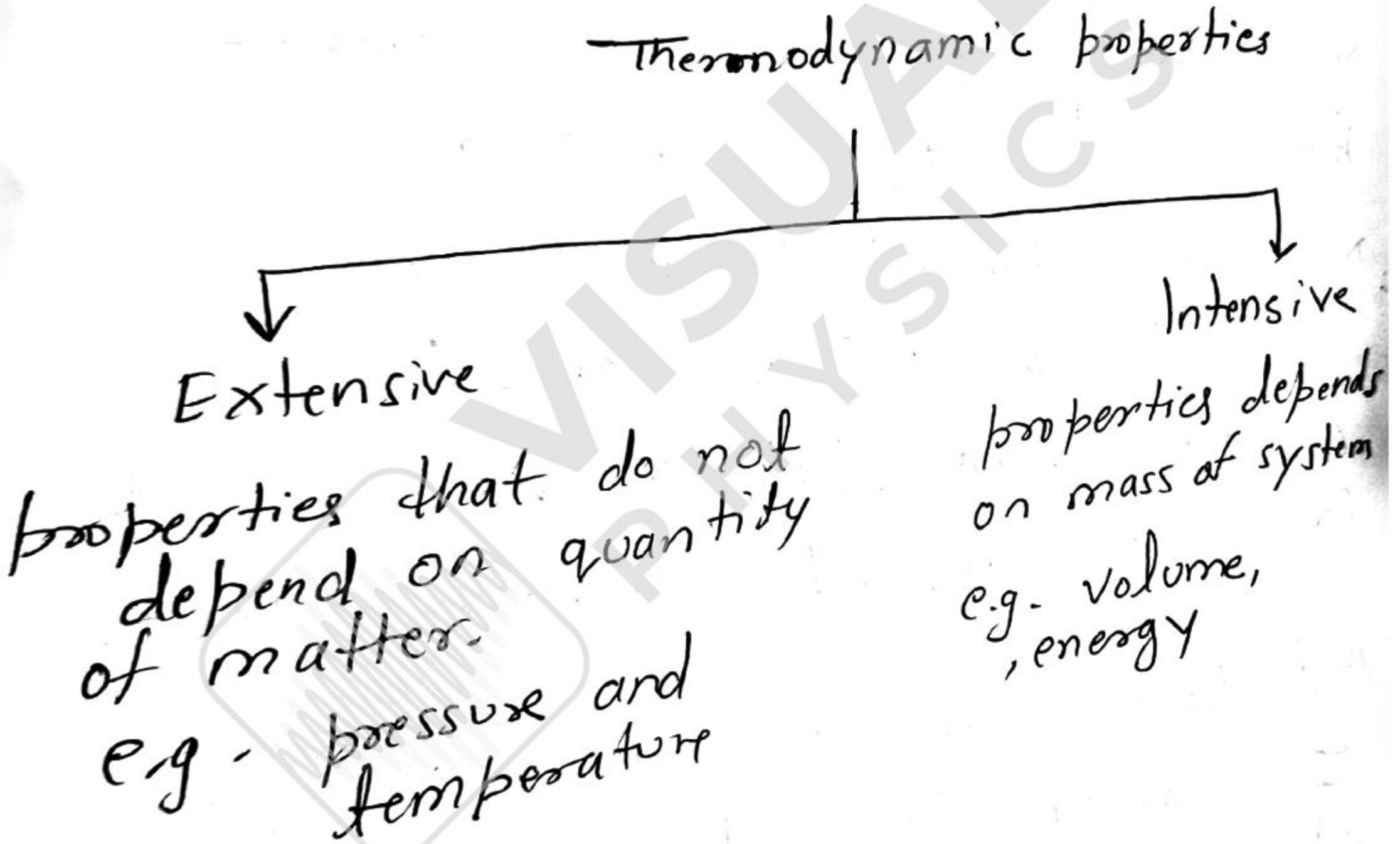
$$\Delta U = \mu C_v \Delta T$$

as $C_v = \frac{f}{2} R$

(iii) change in internal energy does not depend on the path of process.

(iv) change in internal energy in a cyclic process is always zero.

$$\Delta U = U_f - U_i = 0$$


Thermodynamic properties
Extensive
properties that do not depend on quantity of matter.
e.g. pressure and temperature
Intensive
properties depends on mass of system
e.g. volume, energy

Joule's law:

Whenever heat is converted into mechanical work mechanical work is converted into heat, ratio of work done to heat produced remain constant.

i.e. $\frac{W}{Q} = J$ → mechanical equivalent

$$\boxed{J = 4.186\,kJ/kcal}$$

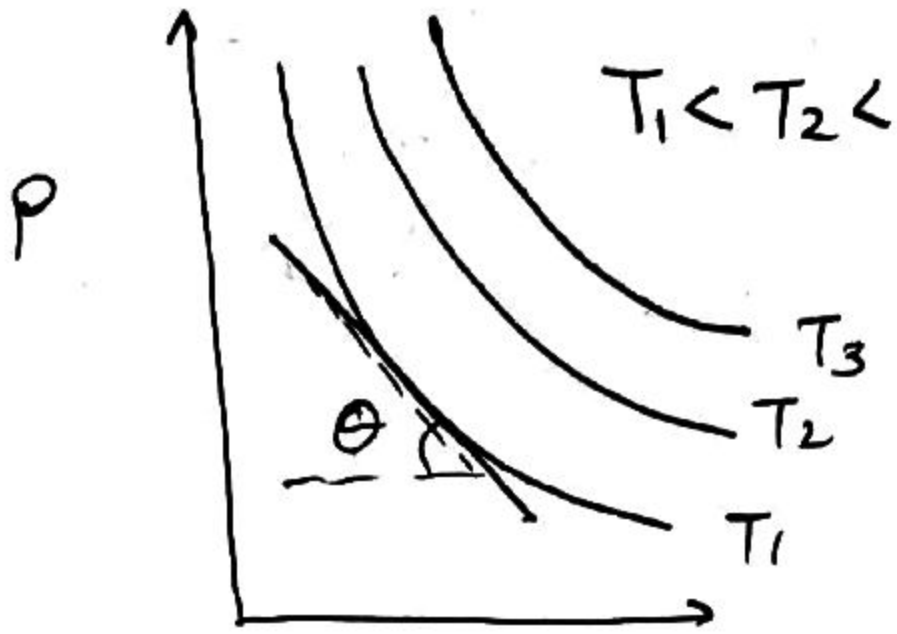
Isothermal process:

→ if temperature remains constant throughout the process is known as Isothermal.

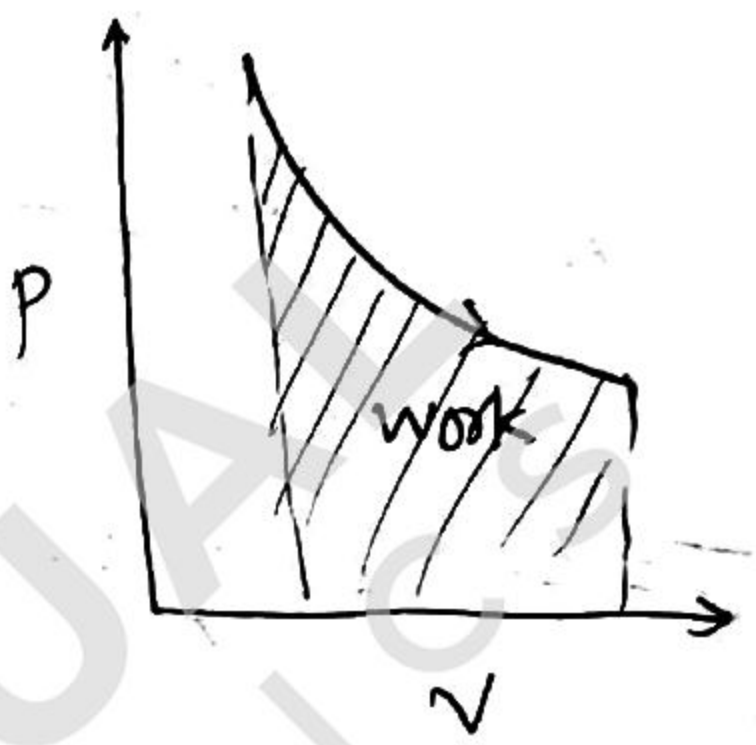
Equation of state:

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

Melting & Boiling process are example of Isothermal process.



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



as $C = \frac{Q}{m\Delta T} \Rightarrow \boxed{C \to \infty}$

specific heat

work done:

$$W = \int_{V_1}^{V_2} P\,dV = \int_{V_1}^{V_2} \frac{\mu R T}{V}\,dV$$

$PV = \mu RT$

$\mu \to$ no. of moles (also 'n')

$$W = \mu R T \ln\left(\frac{V_2}{V_1}\right)$$

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

now $\Delta U \propto \Delta T$

hence $\Delta U = 0$

$\Rightarrow$ $\Delta Q = -\Delta W$

heat given to system

work done by the system

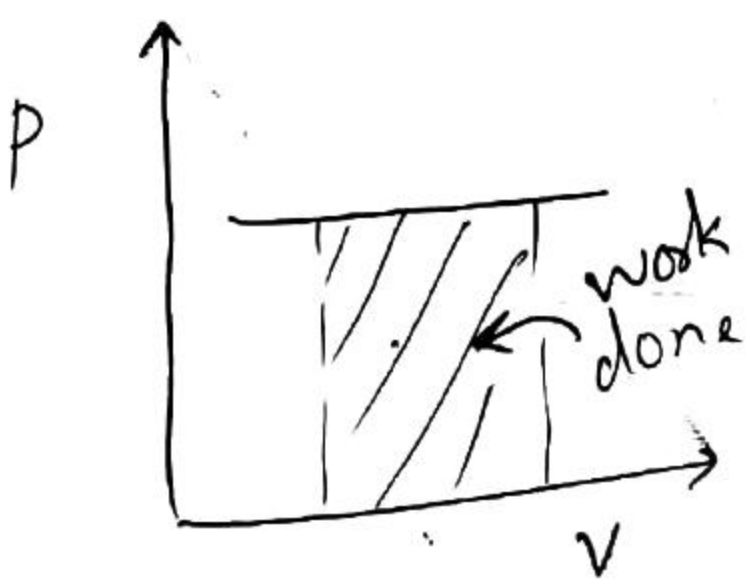
or vice-versa

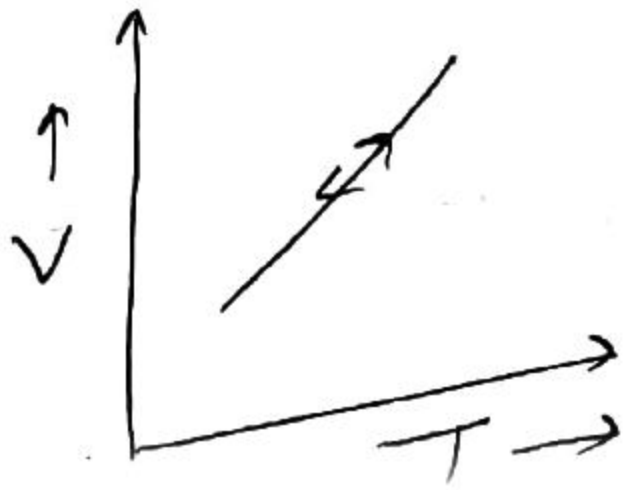
Isobaric Process:

Pressure constant throughout the process

As $PV = \mu RT$

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





Now $C_p = \left(\frac{f}{2} + 1\right) R$

Specific heat at constant pressure

Work done:

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

$$\boxed{\Delta W = P(V_2 - V_1)}$$

as $\Delta W = \mu R (T_2 - T_1)$

as, $\Delta U = \mu C_v \Delta T = \frac{\mu R}{(\gamma - 1)} \Delta T$

by System

$\leftarrow \Delta W = \mu R \Delta T$

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

$= \frac{\mu R}{(\gamma - 1)} \Delta T + \mu R \Delta T$

$$\boxed{\Delta Q = \mu C_p \Delta T}$$

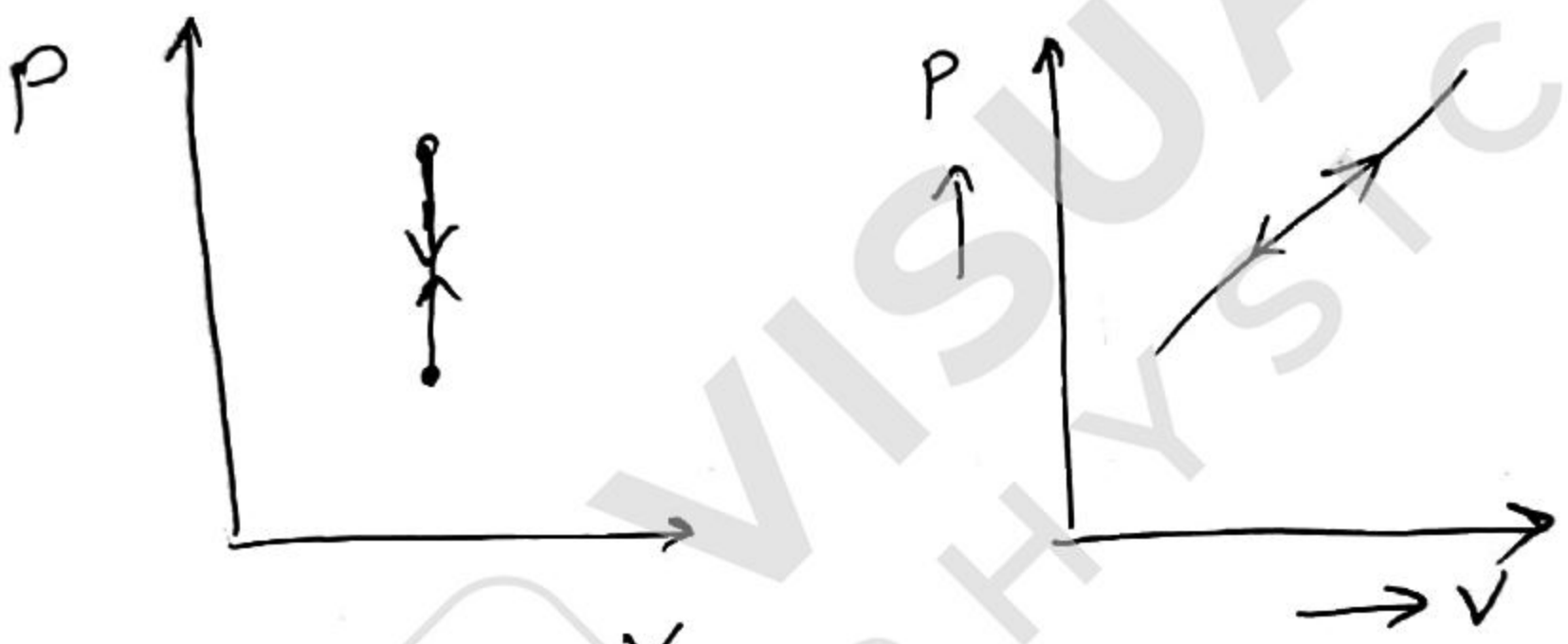
Isochoric or Isometric process:

→ process in which volume remains constant.

$$P \propto T$$

as $PV = \mu RT$

→ $\boxed{P \propto T}$



So for specific heat:

$$C_v = (f/2)R$$

↙

specific heat at constant volume.

. Now for constant volume

$\boxed{\Delta W = 0}$ as $\Delta W \propto \Delta V$

$$\Delta Q = \Delta U$$

$$\Delta Q = \mu C_v \Delta T$$

$$\boxed{\Delta Q = \frac{\mu R}{\gamma - 1} \Delta T}$$

Adiabatic process :

→ process in which no exchange of heat take place between system and surrounding

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

now $dU = \mu C_v dT$ & $dW = PdV$

$$\mu C_v dT + PdV = 0$$

$$PV = \mu RT \quad , PdV + VdP = \mu R dT$$

$$\frac{\mu C_v (PdV + VdP)}{\mu R} + PdV = 0$$

$$\frac{PdV + VdP}{\gamma - 1} + PdV = 0$$

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

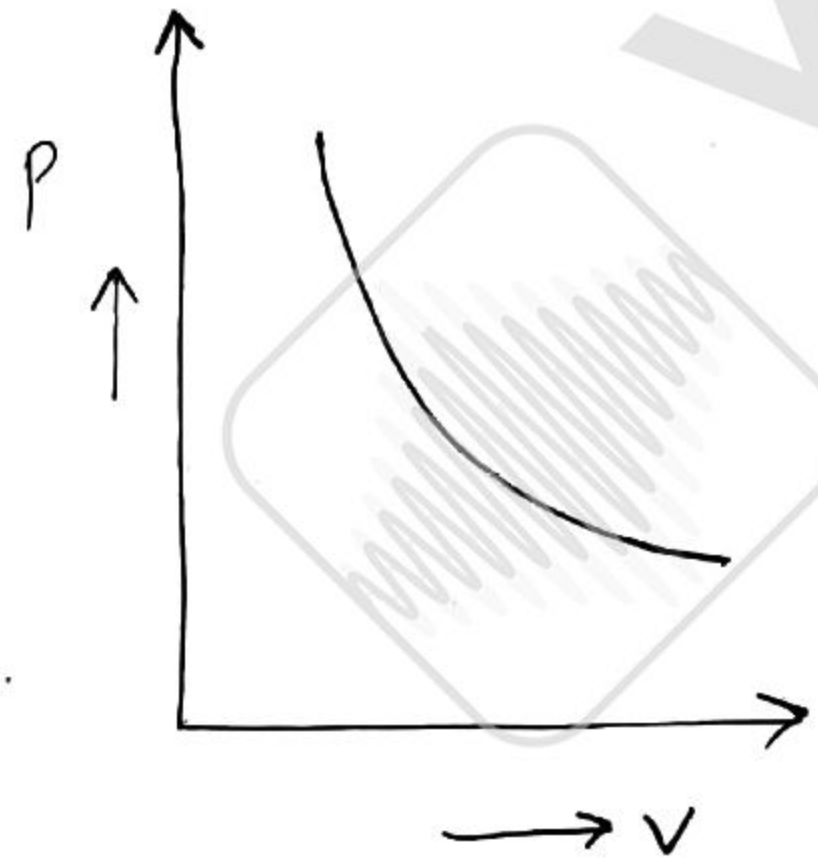
$$\gamma p dV + V dP = 0$$

Now $\boxed{PV^{\gamma} = \text{Constant}}$

from $PV = \mu RT$

$$\boxed{TV^{\gamma-1} = \text{Constant}}$$

And also $\boxed{\frac{T^{\gamma}}{P^{\gamma-1}} = \text{Constant}}$



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

Work done:

$$W = \int_{V_1}^{V_2} P\,dV = \int_{V_1}^{V_2} \frac{k}{V^{\gamma}}\,dV$$

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

as $P = \frac{k}{V^\gamma}$,

$$\Rightarrow \boxed{W = \frac{P_1 V_1 - P_2 V_2}{(\gamma - 1)}} \quad \nearrow \quad W = \frac{-\mu R \Delta T}{(\gamma - 1)}$$

★ Free expansion is an adiabatic process

★ Sudden compression is an adiabatic process

Now as for free expansion:

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

$\Delta Q \to 0$ & $\Delta W \to 0$

↳ no work is done

↙ no exchange of heat

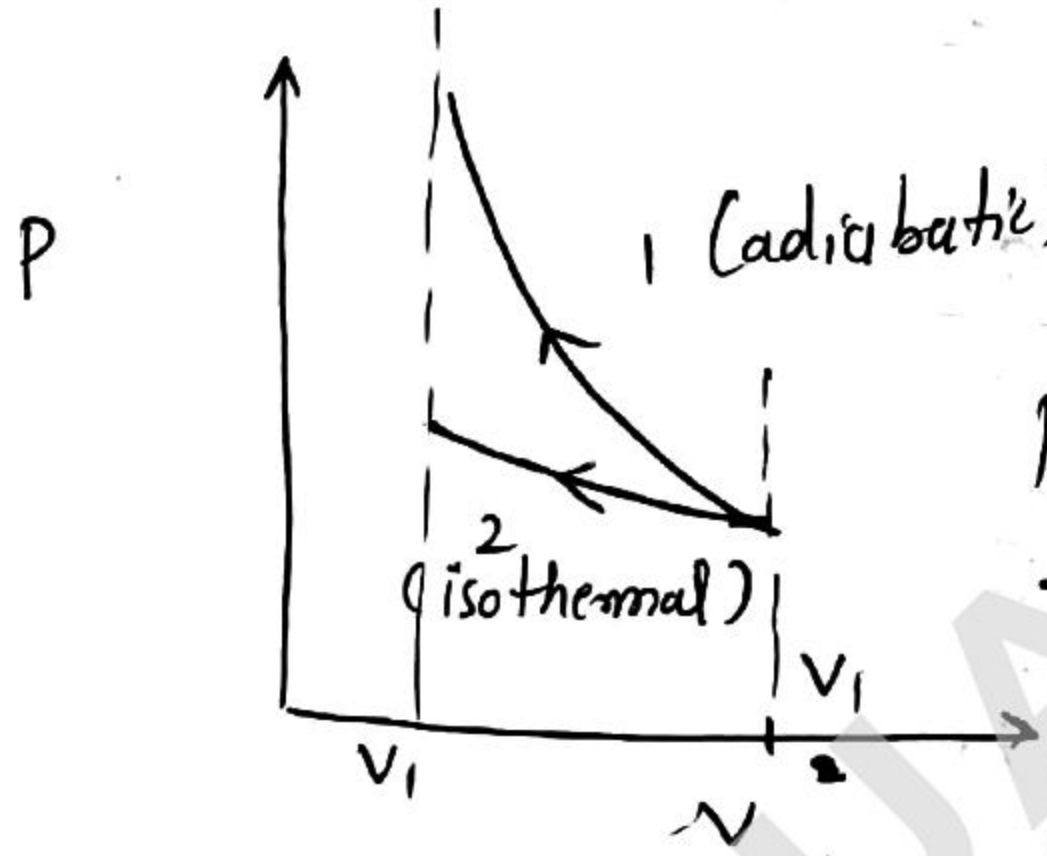
$$\Rightarrow \Delta U = 0$$

or $U_f = U_i$

★ this implies no change in Temperature as well.

Comparison between Isothermal and adiabatic

Compression :



$W_{adiabatic} > W_{isother}$

$P_{adiabatic} > P_{isothermal}$

$T_{adiabatic} > T_{isothermal}$

for same volume change

Expansion :

① → adiabatic
② → isothermal

$W_{isothermal} > W_{adiabatic}$

$P_{isothermal} > P_{adiabatic}$

$T_{isothermal} > T_{adiabatic}$

Polytropic process

$$PV^{\gamma} = \text{constant} \quad (\text{adiabatic})$$

In general process follows:

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

$$n \neq 1 \text{ or } \gamma$$

Work done:

$$W = \int_{V_1}^{V_2} P\,dV = \int_{V_1}^{V_2} \frac{k}{V^n}\,dV$$

$$W = \frac{P_1V_1 - P_2V_2}{(n-1)}$$

$$W = \frac{-R(\mu \Delta T)}{(n-1)}$$

$$\boxed{W = -\frac{\mu R \Delta T}{(n-1)}}$$

Specific heat:

$$Q = \Delta U + W$$

Now for $\mu = 1$

$$C\Delta T = C_v \Delta T - \frac{R\Delta T}{(n-1)}$$

$$\boxed{C = C_v - \frac{R}{(n-1)} = \frac{R}{(\gamma-1)} - \frac{R}{(n-1)}}$$

Reversible and Irreversible process:

Reversible process → which can be reversed in such a way that all changes occuring in the direct process are exactly repeated in opposite order with no change in universe.

For this:

→ No dissipative forces like friction, viscosity etc

→ The process should take place infinitely slow

→ Temperature difference between system and surrounding should not differ appreciably.

Irreversible process:

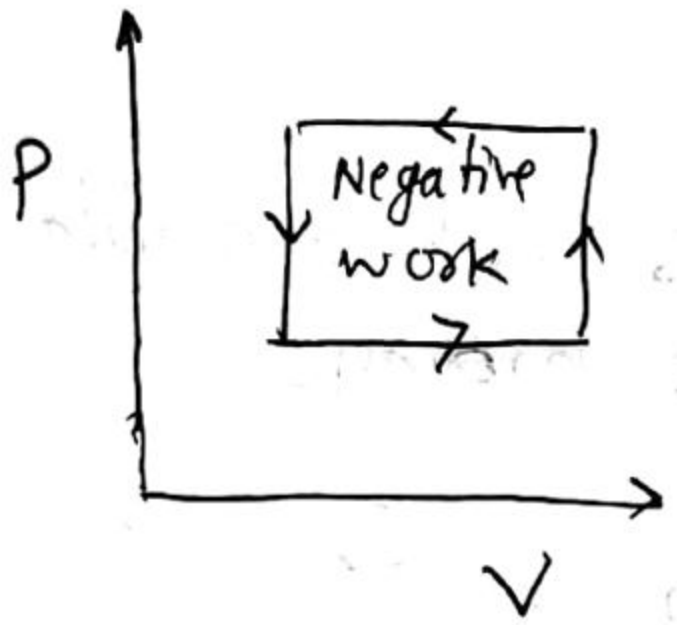
→ Any process which is not reversible exactly is an irreversible process.

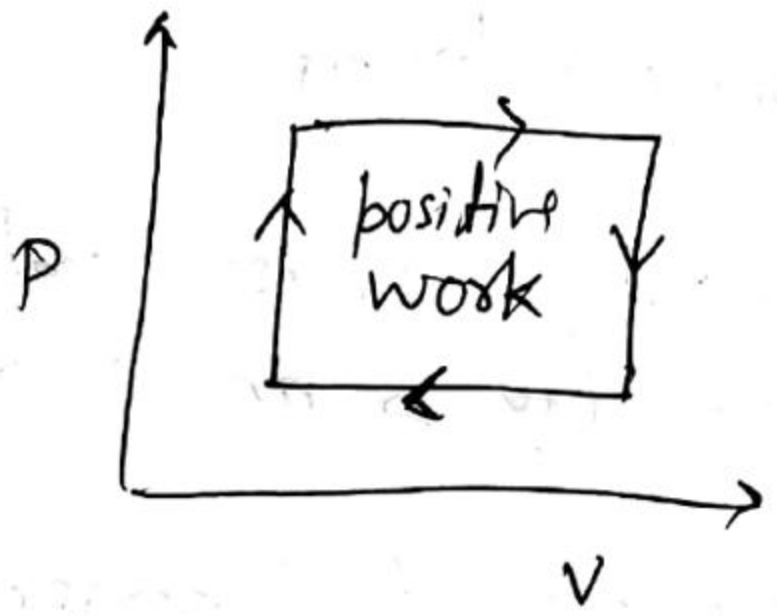
* All practical processes such as free expansion, Joule-Thomson expansion, electrical heating of a wire are also irreversible.

Cyclic and Non-Cyclic process:

→ Cyclic process consists of a series of changes that returns the system back to its initial state.

→ Series of process which do not bring system back to initial state is non-cyclic process.

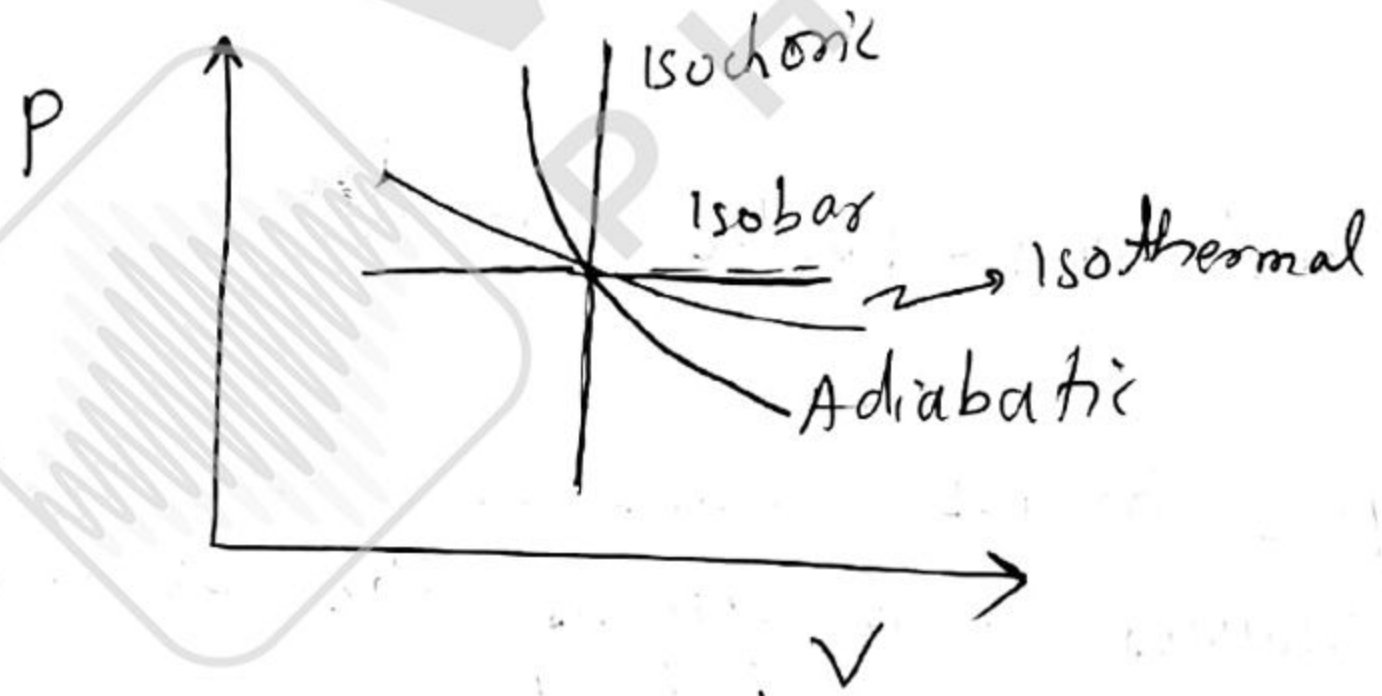


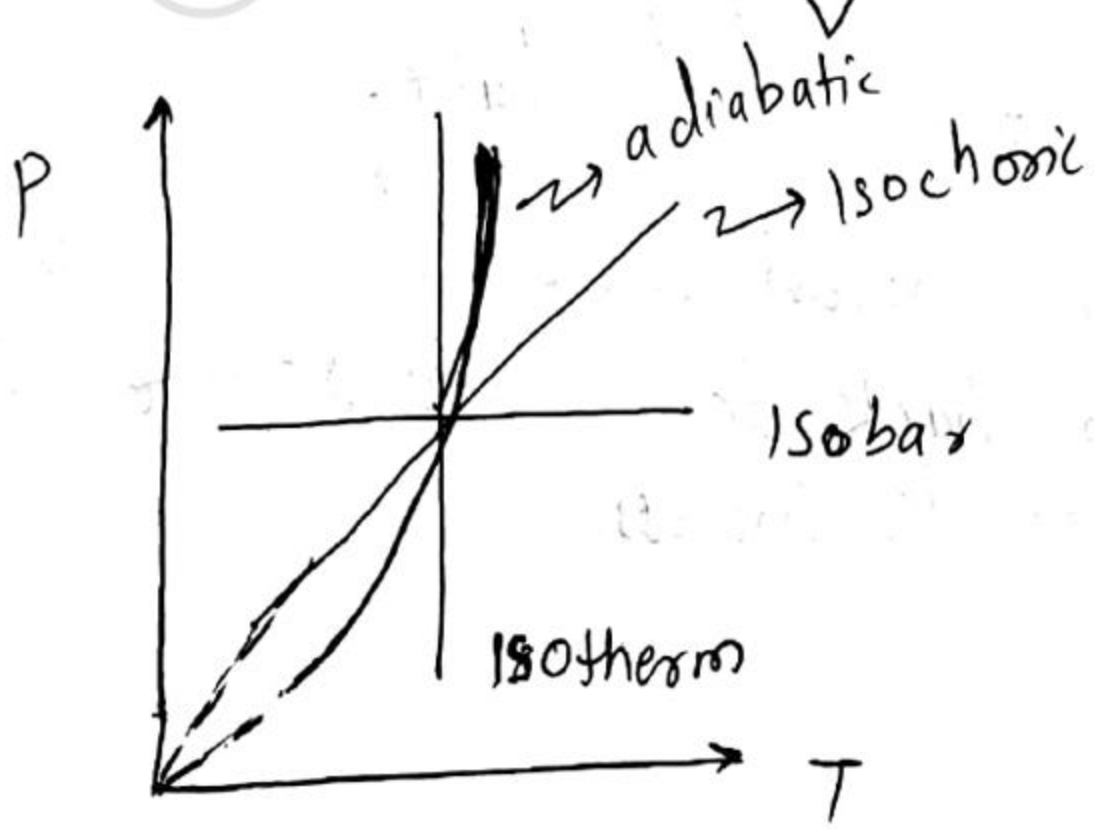


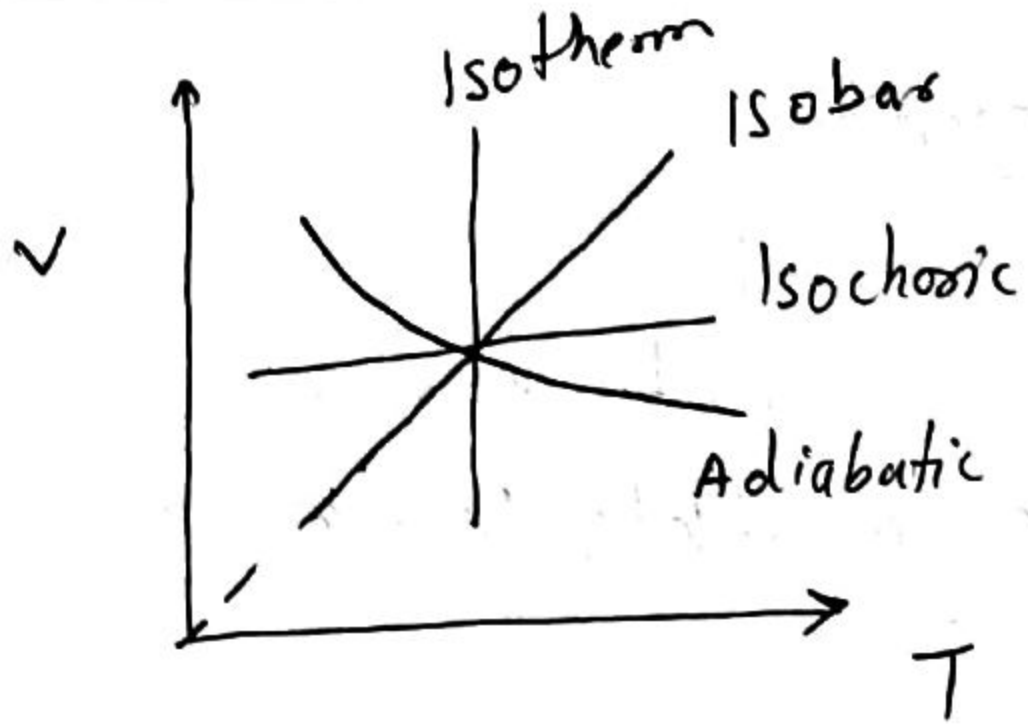
efficiency of a cyclic process :

$$\eta = \frac{\text{Work done per cycle}}{\text{Gross heat supplied per cycle}}$$

General representation of various processes







Entropy & 2nd law:

Entropy: It is an extensive property (S) of a thermodynamic system it quantifies the number of microscopic configurations that are consistent macroscopic quantities that characterize the system.

→ In more common terms the radamness or measure of randomness of the system and/or surrounding.

★ second law of thermodynamics states that state of entropy of entire universe (system + surrounding) as isolated system, will always increase over time.

→ It also state $\Delta S \rightarrow$ never be zero

change of entropy

Kelvin - planck statement:

No process is possible whose sole result is the absorption of heat from a reservior and the complete conversion of heat into work.

Clausius statement:

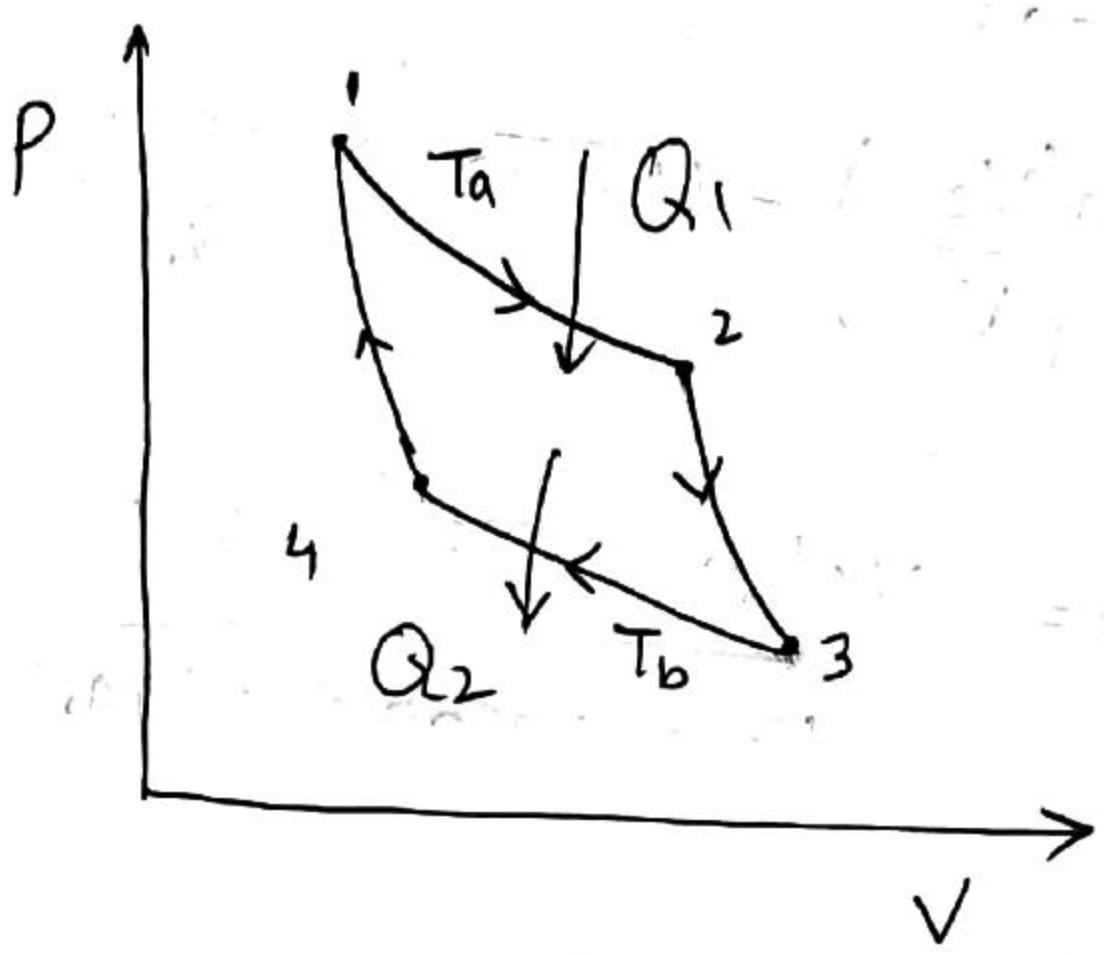
No process is possible whose result is the transfer of heat from a colder object to a hotter object

★ It can be proved that the two statements above are completely equivalent.

Carnot Theorem:

Any system working between two given temperatures T_1 (hot reservoir) and T_2 (cold reservoir) can never have efficiency more than carnot engine working between same reservoirs

Carnot cycle:



1 → 2 isothermal expansion

2 → 3 adiabatic expansion

3 → 4 isothermal compression

4 → 1 adiabatic compression

$T_a = T_1 = T_2$

$T_b = T_3 = T_4$

now 1 → 2 Isothermal process

$$Q_1 = W_{1\to2} = \mu R T_a \ln\left(\frac{V_2}{V_1}\right)$$

2 → 3 adiabatic process

$$W_{2\to3} = \frac{\mu R}{\gamma - 1}(T_a - T_b)$$

3 → 4 Isothermal process

$$W_{3\to4} = -\mu R T_2 \ln\left(\frac{V_3}{V_4}\right) = Q_2$$

4 → 1 adiabatic process

$$W_{4\to1} = \frac{-\mu R}{\gamma - 1}(T_a - T_b)$$

Now net work

$$W = W_{1\to2} + W_{2\to3} + W_{3\to4} + W_{4\to1}$$

$$W = \mu R T_1 \ln\left(\frac{V_2}{V_1}\right) - \mu R T_2 \ln\left(\frac{V_3}{V_4}\right)$$

Net efficiency = $\frac{\text{Net workdone by gas}}{\text{Heat absorbed by gas}}$

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

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

$$\eta = 1 - \frac{\mu R T_2 \ln\left(\frac{V_3}{V_4}\right)}{\mu R T_1 \ln\left(\frac{V_2}{V_1}\right)}$$

as,

$$T_1 V_2^{\gamma-1} = T_2 V_3^{\gamma-1}$$

$$\frac{V_2}{V_3} = \left(\frac{T_2}{T_1}\right)^{\frac{1}{\gamma-1}}$$

Similarly for the process $4 \to 1$

$$\frac{V_1}{V_2} = \left(\frac{T_2}{T_1}\right)^{1/\gamma-1}$$

So, $$\eta = 1 - \frac{T_2}{T_1} \frac{\ln\left[\left(\frac{T_2}{T_1}\right)^{\frac{1}{\gamma-1}}\right]}{\ln\left[\left(\frac{T_2}{T_1}\right)^{1/\gamma-1}\right]}$$

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