# Thermodynamics

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Thermo - Heat (temperature) → Related to thermal energy
Dynamic - Motion → Related to mechanical energy

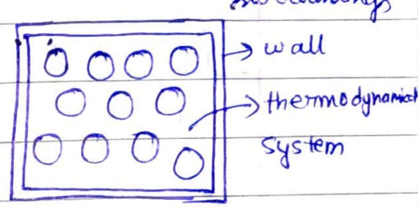
→ Conversion of Thermal Energy to Mechanical Energy.

Ex → **Steam Engine** (steam is used to move the train)

→ Mechanical Energy to Thermal Energy (Rubbing of hands)

⇒ Thermodynamical system :- Group of particles having some temperature, pressure and volume (Ex- Pressure cooker) (Different from sorroundings)

Thermodynamical system → Open / Close




⇒ Sorroundings :- Other than the system

⇒ Walls :- Separates system from sorroundings

Walls → Diathermic wall (Heat flow allowed) / Adiabatic wall (Heat flow not allowed)

## # Thermodynamical Parameters

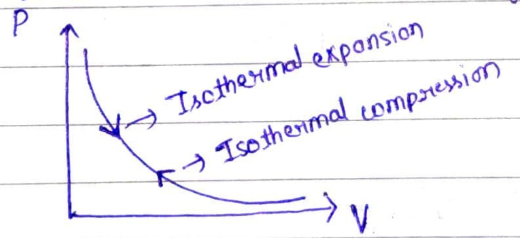
Temperature, Heat (Internal Energy), Pressure, Volume

## # Thermodynamical Processes

(i) Isothermal process :- • Temperature remains constant ($\Delta T = 0$)
(Heat dene ke baad Pressure and volume change ho but Temperature same rahe)

- Walls - Diathermic
- slow process Ex → Melting, Boiling, Slow Compression.
- Equation: $\boxed{PV = nRT}$ n = number of moles, R = Gas constant

  PV = constant $\boxed{PV = RT}$ (one mole of gas)
- Pressure - Volume Indicator Diagram

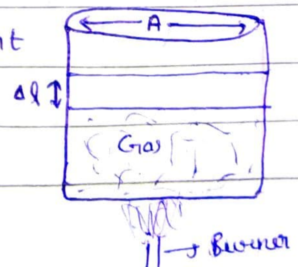



$P \propto \frac{1}{V}$

• Specific heat $= \frac{dQ}{dt} = \infty$

- Work done in Isothermal Process

T = constant




$W =$ force × Displacement
$= P \times A \times \Delta l$

$dW = P \times \Delta V$ $\boxed{dW = P \cdot dV}$

(Volume change nahi hoga to koi work done nahi hoga)

If volume changes from $V_1$ to $V_2$

$$\int dw = \int_{V_1}^{V_2} P.\,dV \qquad W = \int_{V_1}^{V_2} \frac{RT}{V}.dV$$

$$W = RT \int_{V_1}^{V_2} \frac{1}{V}.dV \qquad = RT\left[\log_e V\right]_{V_1}^{V_2}$$

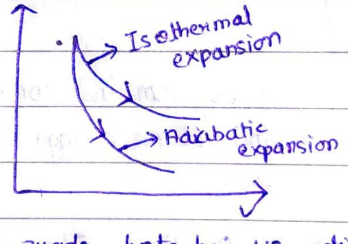
$$W = RT\left[\log_e V_2 - \log_e V_1\right]$$

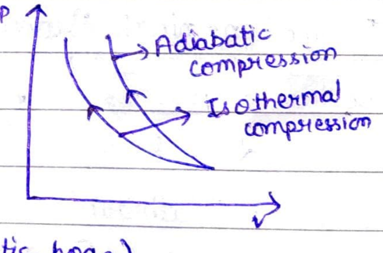
$$\boxed{W = RT \log_e \frac{V_2}{V_1}} \qquad \boxed{W = 2.303\ RT \log_{10} \frac{V_2}{V_1}}$$

$\because P \propto \frac{1}{V}$ $$\boxed{W = 2.303\ RT \log_{10} \frac{P_1}{P_2}}$$

(2) **Adiabatic Process**

- Heat → constant ($\Delta Q = 0$)
- Walls → Adiabatic walls (Non-conducting)
- Sudden Process
- Ex → Propagation of sound wave, Bursting of tyre
- Equation : $\boxed{PV^\gamma = \text{constant}}$ $\left(\gamma = \frac{C_P}{C_V}\right)$
- Specific heat $= \frac{dQ}{dt} = 0$
- PV diagram




(Jiska slope zyada hota hai vo adiabatic hoga)

⇒ Slope of Isothermal process ($\tan\theta$) $\left(\frac{\Delta P}{\Delta V}\right)$

$PV = \text{constant}$

Differentiating both sides, $P.dV + VdP = 0$ $$\boxed{\frac{dp}{dv} = -\frac{P}{V}}$$

⇒ Slope of Adiabatic process

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

Differentiating both sides, $P.\gamma V^{\gamma-1} + V^\gamma.dP = 0$

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

$$\boxed{\frac{dp}{dV} = \frac{-\gamma P}{V}} \qquad \gamma > 1$$

∴ Slope of Adiabatic > Slope of Isothermal

## Work done in Adiabatic Process

$W = P \cdot dV$

If volume changes from $V_1$ to $V_2$

$$\int dW = \int_{V_1}^{V_2} P \cdot dV \qquad (\because PV^{\gamma} = K \quad \therefore P = KV^{-\gamma})$$

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$$W = \int_{V_1}^{V_2} KV^{-\gamma} \cdot dV \qquad \Rightarrow W = \left[\frac{KV^{1-\gamma}}{1-\gamma}\right]_{V_1}^{V_2}$$

$$\Rightarrow W = \frac{1}{1-\gamma}\left[KV_2^{1-\gamma} - KV_1^{1-\gamma}\right]$$

$\because PV^{\gamma} = K$ and $P_1V_1 = P_2V_2 = K$

$P_1V_1^{\gamma} = K \quad \Rightarrow P_1V_1V_1^{\gamma-1} = K \quad \Rightarrow P_1V_1 = KV_1^{1-\gamma}$

Similarly, $P_2V_2 = KV_2^{1-\gamma}$

$$\Rightarrow \boxed{W = \frac{1}{1-\gamma}\left[P_2V_2 - P_1V_1\right]} \qquad (\because PV = RT)$$

$$\Rightarrow W = \frac{1}{1-\gamma}\left[RT_2 - RT_1\right] \qquad \boxed{W = \frac{R(T_2 - T_1)}{1-\gamma}}$$

(3) **Isobaric process** – Pressure constant ($\Delta P = 0$)

(4) **Isochoric process** – Volume constant ($\Delta V = 0$)

## ZEROTH LAW

Thermal Equilibrium :- Do bodies contact mein ho aur unme koi heat ka transfer na ho (Temperature same) toh vo bodies thermal equilibrium mein hai.

- Zeroth law states that if two systems A and B are separately in thermal equilibrium with a third system C, then A and B are also in thermal equilibrium with each other.

Diathermic walls

| | |
|---|---|
| $T_1\ P_1\ V_1$ | A |
| $T_3\ P_3\ V_3$ | C |

Thermal equilibrium $T_A = T_C$

| | |
|---|---|
| $T_2\ P_2\ V_2$ | B |
| $T_3\ P_3\ V_3$ | C |

Thermal Equilibrium $T_B = T_C$

$T_A = T_C$ and $T_B = T_C \quad \therefore T_A = T_B$

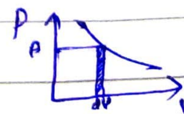
## FIRST LAW OF THERMODYNAMICS

Agar kisi system ko heat de to state change hogi ya temperature change hoga.

**Heat (dQ)**
↓
(Thermal Energy)
Q (Heat)
dQ (change in heat)

**Internal Energy (dU)**
- Potential Energy (State change)
- Kinetic Energy (Temperature change)

**Work done (dW)**
$W = \int P \cdot dV$




Area under the PV curve gives work done.

Agar kisi system ko heat de to ya volume change hogi (work done) ya state ya temperature change hoga (Internal Energy) ya ye sab kuch hoga

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

## Application of $1^{st}$ law

When temperature and state does not change!

(1) In Isothermal Process :- ($\Delta T = 0$ and no state change)

$\therefore$ $\Delta U = 0$ $\quad\quad \therefore \boxed{dQ = dW}$

(a) dQ and dW +ve hain. Positive work done tabhi hoga jab volume badhegi. To heat di usse volume badhi. To ye process **Isothermal Expansion**.

(b) dQ and dW -ve hain. -ve work done volume kam hone par hoga. Volume ko kam karne ke liye jitna work karna pada utni heat nikalni hogi.

$dW = P.dV = P$(Final volume - Initial volume)

To ye process **Isothermal Compression**.

Expansion → +ve work
Compression → -ve work

(2) In Adiabatic Process :- $\Delta Q = 0$

$\boxed{\therefore 0 = dU + dW}$ $\quad\quad \therefore \boxed{dW = -dU}$

Adiabatic Expansion :- Work done +ve hai matlab expansion hua hai matlab volume increase hui. Adiabatic process mein bahar se koi heat nahi aati. To expansion karane ke liye system ki internal energy ka hi use hua jiski vajah se temperature kam ho gaya. Aur dU -ve ho gaya

Adiabatic compression : $\boxed{-dW = dU}$

Work done -ve hai matlab compression hua jiski vajah se temperature badh gaya. Aur dU +ve ho gaya [dU ⇒ (temperature) ⇒ final temperature - Initial temperature]
(Final temp > Initial temp.)

⇒ When state changes

(3) Boiling process

100° Water → 100° steam $\quad (\Delta T = 0)$

Agar 1 glass water ko steam banaye to steam 1 glass se zyada banegi. Kyunki expansion hoga. To work to hoga.

$\because$ $\Delta Q = \Delta U + \Delta W$ $\quad\quad \boxed{\Delta U = \Delta Q - \Delta W}$

(4) Melting process

0°C ice → 0° water

Melting mein expansion bahut kam hota isiliye work done bhi negligible hota hai.
($\Delta W \approx 0$ volume remains same)

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

# Relation between $C_p$ and $C_v$

Molar specific heat capacity $\boxed{dQ = nC\,dT \text{ — (i)}}$

(a) If volume of the system remains constant ($\Delta V = 0$)

$\because$ $dQ = dU + dW$ $\Rightarrow dQ = dW + P.dV$

$\Rightarrow dQ = dU$ (From (i) $dQ = nC_v dT$) ($C_v$ = Specific heat at constant volume)

$\Rightarrow \boxed{dU = nC_v dT}$ — (ii)

(b) If pressure of the system remains constant ($\Delta P = 0$)

$dQ = dU + dW$ $\Rightarrow nC_p dT = nC_v dT + P.dV$ (From (i) and (ii))

($\because PV = nRT$ $\Rightarrow P.dV = nR.dT$)

$\Rightarrow \cancel{n}C_p \cancel{dT} = \cancel{n}C_v \cancel{dT} + \cancel{n}R\cancel{dT}$

Mayer's formula $\boxed{C_p - C_v = R}$ $C_p > C_v$

$C_v$ chhota hai kyunki agar hum kisi system ko heat denge to sirf temperature badhega work done nahi hoga kyunki volume constant hai. $C_p$ mein pressure constant hai mattlab volume increase hogi (expansion) jiski vajah se temperature kam ho jaaega uss temperature ko vaapis badhane ke liye aur heat deni padegi. Jiski vajah se $C_p$ bada hai

Q. 5 moles of oxygen gas heated at a constant volume from $10°C$ to $20°C$. What will be the change in internal energy of the gas?

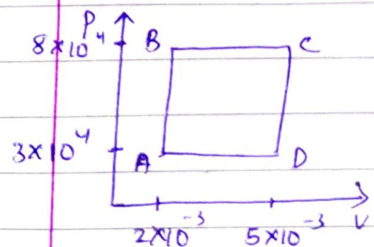
$C_p = 8$ cal / mol / °C $\quad R = 8.36$ J / mol / °C $= \frac{8.36}{4.18} = 2$ cal / mol / °C

$C_v = C_p - R \quad = 8 - 2 = 6$ cal / mol / °C

$Q = nC_v dT \quad = 5 \times 6 \times (20°C - 10°C) = 300$ cal.

Q. A thermodynamic process is shown in figure. The pressure and volume corresponding to some points in the figure $P_A = 3 \times 10^4$ Pa $\quad V_A = 2 \times 10^{-3}$ $m^3$

$P_B = 8 \times 10^4$ Pa $\quad V_B = 5 \times 10^{-3}$ $m^3$. In process AB, 600 J of heat is added to the system and in process BC, 200 J of heat is added to the system. What is the change in internal energy?




Sol $dQ = 600 + 200 = 800$ J

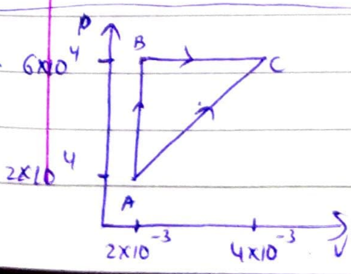
$dQ = dU +$ Area under the curve

$800 = dU + (8 \times 10^4) \times (3 \times 10^{-3})$

$800 = dU + 240$

$dU = 560$ J

Q.




AB → 400 J $\quad$ BC → 100 J

What is the heat absorbed by system during AC

Sol for whole process, $\Delta U = 0$

$dQ = dU + dW \Rightarrow dQ = dW$

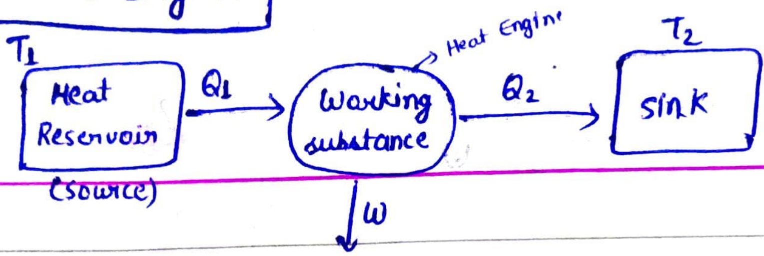
$\Rightarrow Q_{AB} + Q_{BC} - Q_{AC} = Ar(\Delta ABC)$

$\Rightarrow 500 - Q_{AC} = 40 \quad \Rightarrow Q_{AC} = 460$ J

# Heat Engine

$T_1 > T_2$






$Q_1 = W + Q_2$ $\qquad\qquad$ $W = Q_1 - Q_2$

Efficiency of heat engine $(\eta) = \dfrac{\text{Output}}{\text{Input}}$

$$\eta = \frac{W}{Q_1} = \frac{Q_1 - Q_2}{Q_1} \qquad \boxed{\eta = 1 - \frac{Q_2}{Q_1}}$$

$\because$ $Q = ms\Delta T$

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

koi bhi engine 100% efficient nahi hai.

Q. In a heat engine, the temperature of a source and sink are 500K and 375 K. If the heat engine consumes $25 \times 10^5$ J per cycle, find (i) the efficiency of the engine (ii) Work done per cycle (iii) Heat rejected to the sink per cycle.

→ $T_1 = 500\text{K}$ $\qquad$ $T_2 = 375$ $\qquad$ ; $Q_1 = 25 \times 10^5$ J

(i) $\eta = 1 - \dfrac{T_2}{T_1} = 1 - \dfrac{375}{500} = 0.25 = 25\%$

(ii) $W = Q_1 - Q_2$ $\Rightarrow \eta = \dfrac{W}{Q_1}$ $\Rightarrow W = 0.25 \times 25 \times 10^5 = 6.25 \times 10^5$ J

(iii) $Q_2 = Q_1 - W = (25 - 6.25) \times 10^5 = 18.75 \times 10^5$ J.