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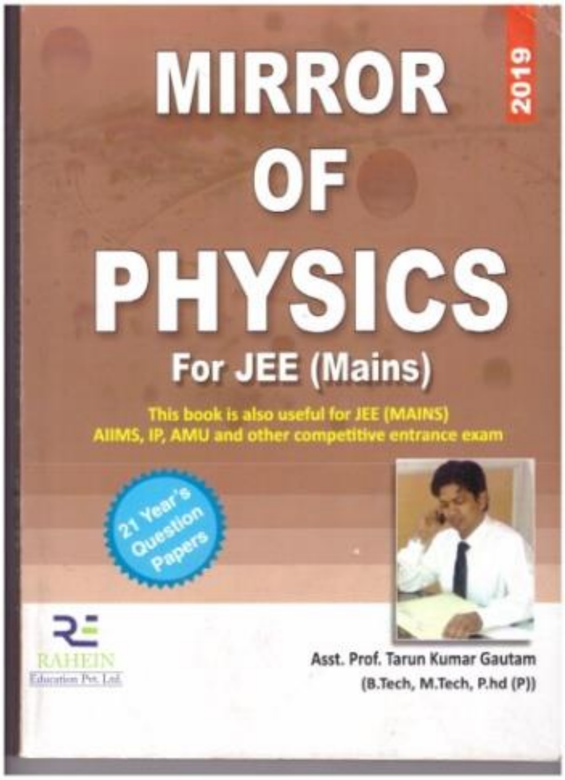
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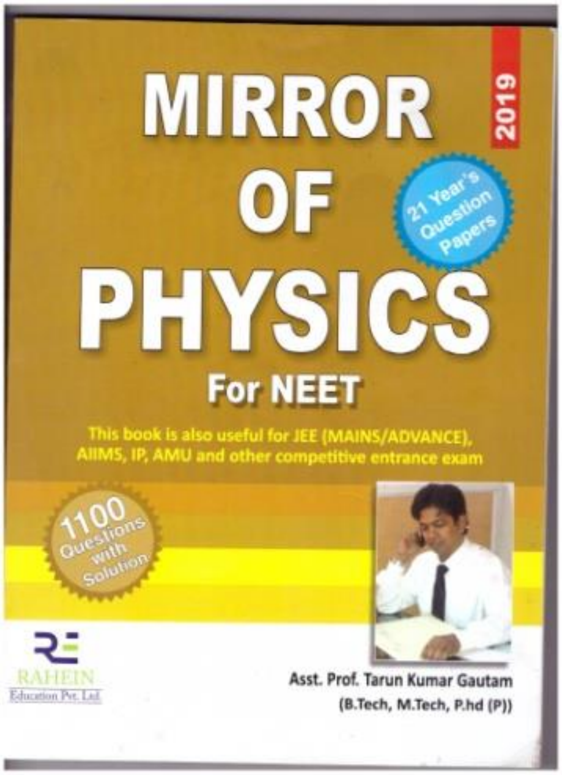
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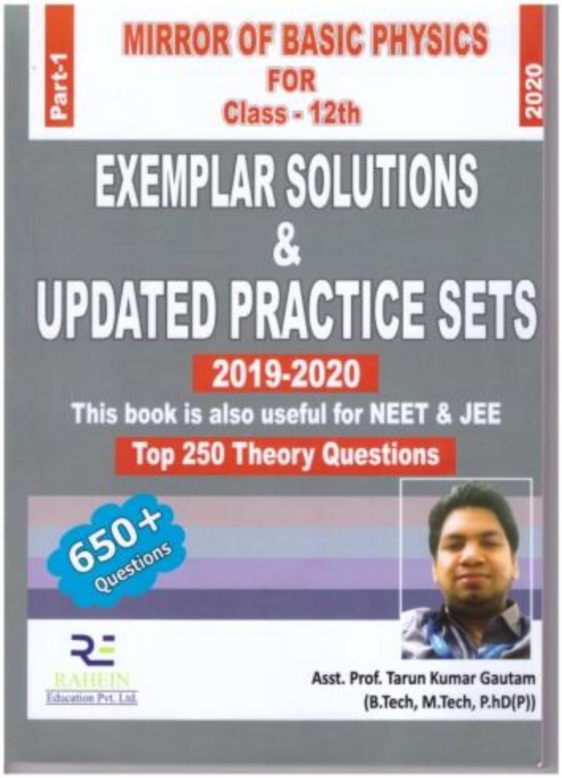
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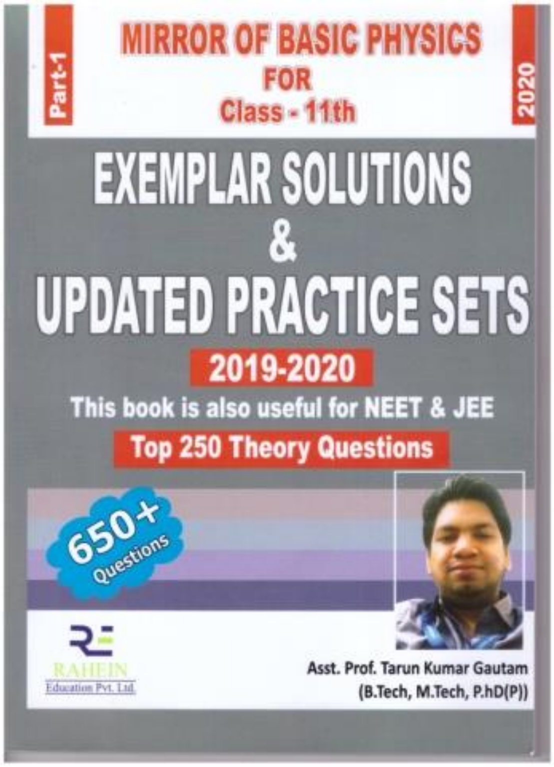
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# Chapter- 12

## (Thermodynamics)

### Thermodynamics

It is a Branch of Physics which deal with Study of change of heat energy.

### Internal Energy

Internal Energy of a System the energy which is formed due to motion of molecular configuration. It is denoted by 'U'

They are of two type

1) Potential Internal Energy. ($U_P$)
2) Kinetic Internal Energy ($U_K$)

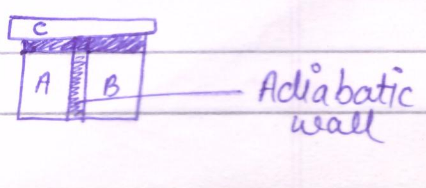
$$U_P + U_K = U$$

### Heat

- Heat is Energy that flow from higher temperature to lower temperature.
- Energy always move from Higher Potential to low Potential

### Zeroth Law of Thermodynamics

When the Thermodynamics system A and B separate in thermal equilibrium with third thermodynamics system C, then the System A & B are in the thermal equilibrium with each other.



## Thermodynamic Variable

Thermodynamic Variable of a system are parameters which describe equilibrium states of system.

$$\boxed{PV = n \times R \times T}$$

## Quasi Static Process

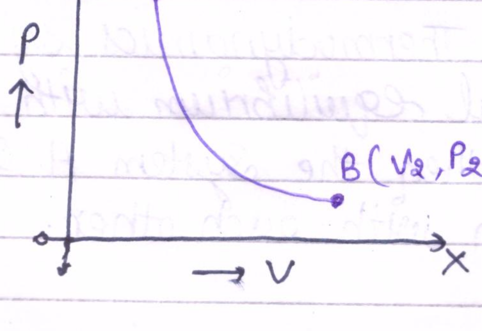
A process or change in the state variable of thermodynamics system which is infinitely slow is called "Quasi Static Process"

## Thermodynamics Process

1) Isothermal Process , $\Delta T = 0$
2) Adiabatic Process , $\Delta Q = 0$
3) Isobaric Process , $\Delta P = 0$
4) Isochoric or Isovolumeric process , $\Delta V = 0$

## Indicator Diagram or P-V Diagram

Process change is shown by the diagram called "Indicator diagram"



# Isothermal Change

A change in Pressure and Volume of gas without any change in temp. is called "Isothermal Change"

Ex – Melting of Ice

$$\longrightarrow \quad PV = nRT$$

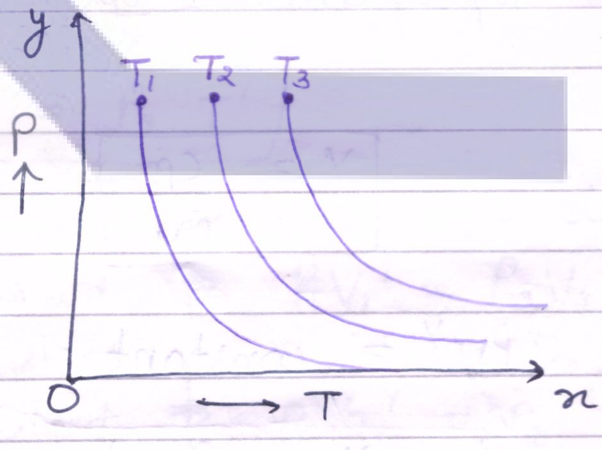
$$PV = RT \qquad [\because n = 1]$$

where, R = gas constant
T = Temperature (constant)

$$PV = RT = \text{constant}$$

$$PV = \text{constant}$$

So, $\boxed{P_1V_1 = P_2V_2}$



for Ideal Gas in Isothermal Process, there is no change in internal energy of gas

$$\boxed{\Delta U = 0}$$

# Adiabatic Process

A change in Pressure & volume of a gas when no heat is allowed to enter into or escape from the gas is called "Adiabatic change."

Ex - Expansion of steam in cylinder of Steam Engine.
Ex - Sudden bursting of tube of bicycle.
Ex - Sudden compression or expansion of gas in a container with non conducting walls.

$\boxed{\Delta Q = 0}$ , No change in Heat.

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

$\gamma = \text{Specific heat} = \dfrac{\text{specific heat at const. Pressure}}{\text{Specific heat at const. volume}}$

$$\boxed{\gamma = \frac{C_P}{C_V}}$$

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

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

(II) $PV = nRT \Rightarrow n = 1$

$PV = RT \rightarrow \boxed{P = \dfrac{RT}{V}}$

$$\left[\frac{RT}{V}\right] V^{\gamma} = \text{constant}$$

$$\frac{RTV^{\gamma}}{V} = \text{constant}$$

$$TV^{\gamma-1} = \text{constant}$$

So, $\boxed{T_1V_1^{\gamma-1} = T_2V_2^{\gamma-1}}$

(III) $PV = nRT \Rightarrow n=1$

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

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

$$P\left[\frac{RT}{P}\right]^{\gamma} = \text{constant}$$

$$\frac{PR^{\gamma}T^{\gamma}}{P^{\gamma}} = \text{constant}$$

$$P^{1-\gamma}T^{\gamma} = \text{constant}$$

So, $\boxed{P_1^{1-\gamma}T_1^{\gamma} = P_2^{1-\gamma}T^{\gamma}}$

Note :

1) $PV^{\gamma} = \text{constant} \Rightarrow P_1V_1^{\gamma} = P_2V_2^{\gamma}$
2) $TV^{\gamma-1} = \text{constant} \Rightarrow T_1V_1^{\gamma-1} = T_2V_2^{\gamma-1}$
3) $P^{1-\gamma}T^{\gamma} = \text{constant} \Rightarrow P_1^{1-\gamma}T_1^{\gamma} = P_2^{1-\gamma}T_2^{\gamma}$

## Slope of Isothermal & Adiabatic Process

① Isothermal :- $PV = \text{constant} = K$

Differentiate Both side with respect to time

$$\left(\frac{dP}{dt}\right)\cdot V + \left(\frac{dV}{dt}\right)\cdot P = \frac{dK}{dt} = 0$$

$$(dP)V + (dV)P = 0$$

$$(dP)V = -(dV)P$$

$$\boxed{\text{Slope of Isothermal} = \frac{dP}{dV} = \frac{-P}{V}}$$

② Adiabatic :- $PV^\gamma = \text{constant} = K$

$$\left(\frac{dP}{dt}\right)(V^\gamma) + \frac{d(V^\gamma)}{dt}\cdot P = 0$$

$$\left(\frac{dP}{dt}\right)V^\gamma + \gamma V^{\gamma-1}\left(\frac{dV}{dt}\right)\cdot P = 0$$

$$(dP)V^\gamma + \gamma\frac{V^\gamma}{V}(dV)P = 0$$

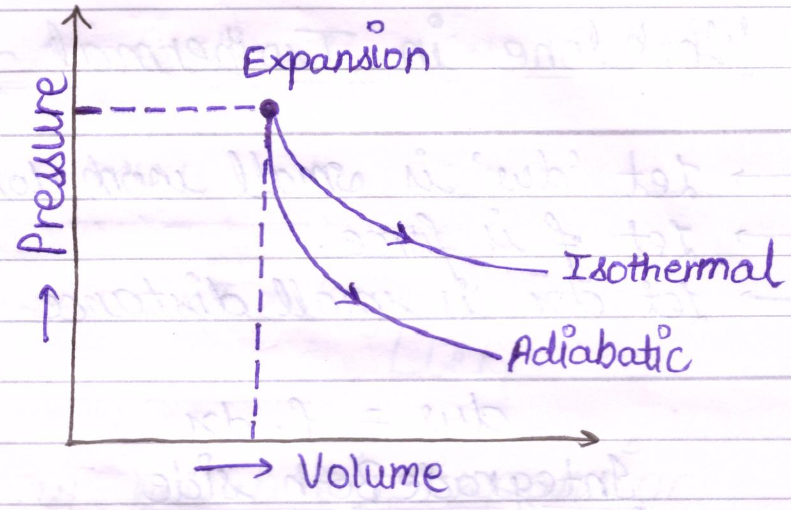
$$(dP)\cancel{V^\gamma} = -\gamma\frac{\cancel{V^\gamma}}{V}(dV)\cdot P$$

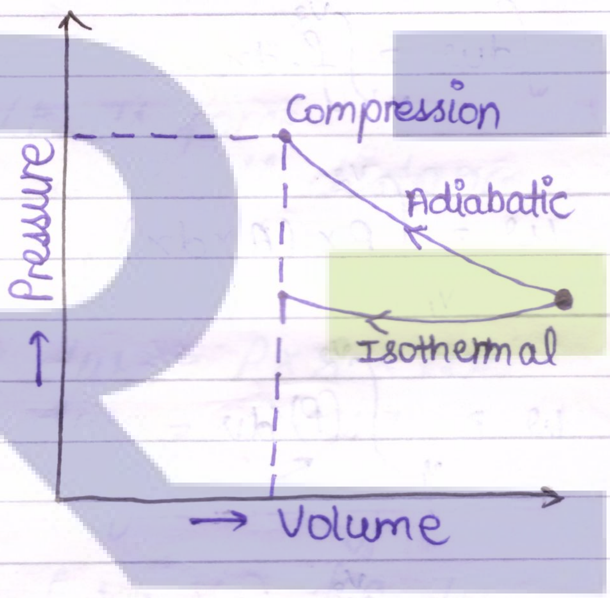
$$\left(\frac{dP}{dV}\right) = -\gamma\frac{P}{V}$$

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

Slope of Isothermal $= \frac{dP}{dt}$

$$\boxed{\text{So, } \left[\text{Slope of Adiabatic}\right] = \gamma \times \left[\text{Slope of Isothermal}\right]}$$





## Workdone in Isothermal & Adiabatic Process

$$\longrightarrow W = P.V$$

Let, dw is small workdone
Let, dv is small volume
Let, P is pressure

so, $dw = P.dv$

Integrade Both side

$$\int dw = \int P.dv$$

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

# Workdone in Isothermal expansion :

→ Let 'dw' is small work done

→ Let f is force.

→ Let dx is small distance

$$dw = f \cdot dx$$

Integrade Both side

$$\int dw = \int_{v_1}^{v_2} f \cdot dx$$

$P = f/A$ $[f = P \times A]$

$$w = \int_{v_1}^{v_2} P \times (A \times dx)$$

$[A \times dx = dv]$
Small volume

$$w = \int_{v_1}^{v_2} (P)\, dv$$

$PV = nRT$ , $n = 1$

$PV = RT$

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

$$w = \int_{v_1}^{v_2} \frac{RT}{V}\, dv \Rightarrow RT \int_{v_1}^{v_2} \frac{dv}{V}$$

$$w = RT[\log V]_{v_1}^{v_2}$$

$$w = RT[\log v_2 - \log v_1]$$

$$w = RT \log_e \left[\frac{v_2}{v_1}\right]$$

$$w = 2.303 \times RT \log \left[\frac{v_2}{v_1}\right]$$

$$P_1V_1 = P_2V_2$$

$$\boxed{\frac{P_1}{P_2} = \frac{V_2}{V_1}}$$

$$\boxed{W = 2.303 \times RT \times \log\left[\frac{P_1}{P_2}\right]}$$

## Workdone in Adiabatic Expansion

- → Let 'dw' is small work done
- → Let f /F is force
- → Let dx is small distance

$$dw = F \times dx$$
$$dw = P \times A \times dx$$
$$dw = P \times dv$$

Integrade both side

$$\int dw = \int_{V_1}^{V_2} P . dv$$

$$W = \int_{V_1}^{V_2} (P)\, dv$$

$$\boxed{PV^{\gamma} = K} \longrightarrow \boxed{P = \frac{K}{V^{\gamma}}}$$

$$W = \int_{V_1}^{V_2} \frac{K}{V^{\gamma}}\, dv$$

$$W = K \int_{V_1}^{V_2} \frac{dv}{V^{\gamma}}$$

$$w = K\int_{v_1}^{v_2} v^{-\gamma} \cdot dv$$

$$w = K\left[\frac{v^{-\gamma+1}}{-\gamma+1}\right]_{v_1}^{v_2}$$

$$w = K\left[\frac{v^{1-\gamma}}{1-\gamma}\right]_{v_1}^{v_2}$$

$$\boxed{w = \frac{K}{1-\gamma}\left[V_2^{1-\gamma} - V_1^{1-\gamma}\right]}$$

As we know,

$$\underline{PV^{\gamma} = K}$$

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

Put the value of K

$$w = \frac{1}{1-\gamma}\left[P_2V_2^{\gamma} \cdot V_2^{1-\gamma} - P_1V_1^{\gamma} \cdot V_1^{1-\gamma}\right]$$

$$w = \frac{1}{1-\gamma}\left[P_2V_2^{\cancel{\gamma}+1-\cancel{\gamma}} - P_1V_1^{\cancel{\gamma}+1-\cancel{\gamma}}\right]$$

$$\boxed{w = \frac{1}{1-\gamma}\left[P_2V_2 - P_1V_1\right]}$$

$$w = \frac{1}{1-\gamma}\left[RT_2 - RT_1\right]$$

$$\boxed{w = \frac{R}{1-\gamma}\left[T_2 - T_1\right]}$$

Note :

Isothermal

1) $w = 2.303\ RT \log\left[\frac{V_2}{V_1}\right]$

2) $w = 2.303\ RT \log\left[\frac{P_1}{P_2}\right]$

Adiabatic

1) $w = \frac{1}{1-\gamma}\left[P_2V_2 - P_1V_1\right]$

2) $w = \frac{1}{1-\gamma} R\left[T_2 - T_1\right]$

## Ist Law of Thermodynamics

It is follow conservation of energy.

$$\boxed{dQ = du + dw}$$

→ change in heat of system is equal to sum of change in internal energy & change in work done.

$dQ$ → small change in heat
$du$ → small internal energy
$dw$ → small work done

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

$$\boxed{\Delta w = P(\Delta V)}$$

$$\boxed{\Delta Q = \Delta U + P(\Delta V)}$$

(a) Isothermal Process

$\Delta T = 0$, $\Delta U = 0$, $\Delta Q = \Delta U + \Delta W$

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

(b) Adiabatic Process

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

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

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

(c) Isochoric Process

$\Delta V = 0$, $\Delta Q = \Delta U + \Delta W$

$$\Delta Q = \Delta U + P(\Delta V)$$

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

(d) Cyclic Process

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

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

(e) Melting Point

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

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

$L_f \rightarrow$ latent heat of fusion

$\rightarrow$ $\boxed{mL_f = \Delta U + \Delta W}$

(f) Boiling Point

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

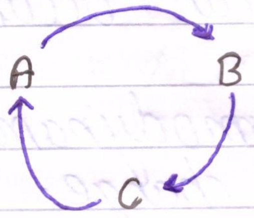
$\Delta Q = mL_v$

$L_v$ = Latent heat of vapourisation

$$\boxed{mL_v = \Delta U + \Delta W}$$

# Cyclic and Non Cyclic Process

* Cyclic Process : It consists of series of changes which return the system back to initial state.



* Non Cyclic Process : It consists of series of changes which does not return the system back to initial state.

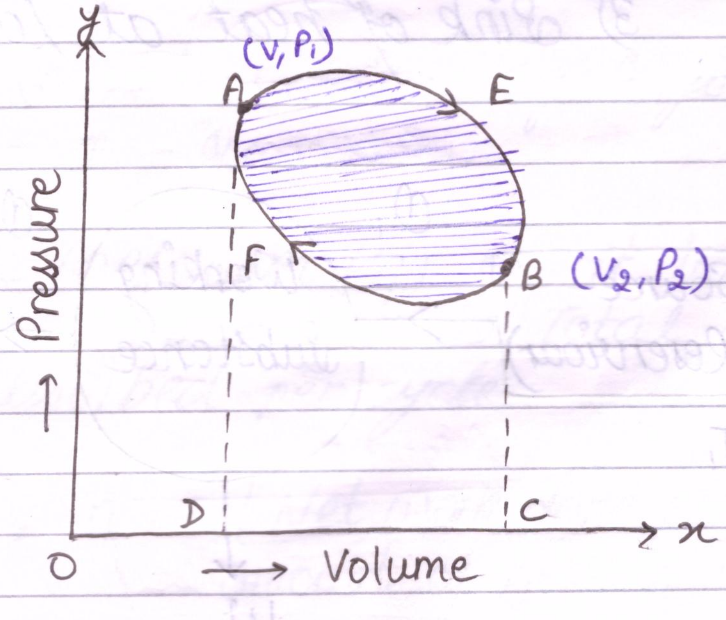
## Work done in Cyclic Process

Workdone by gas ⇒ $W_1$ = Area [AEBCDA]

Workdone on gas ⇒ $W_2$ = −area [BFADCB]

$W = W_1 - W_2$

$W$ = Area [AEBFA]



## Limitations of Ist Law of Thermodynamics

1) First Law of Thermodynamics doesn't indicate in which change can occur.

2) First Law of Thermodynamics gives not idea about extent of change.

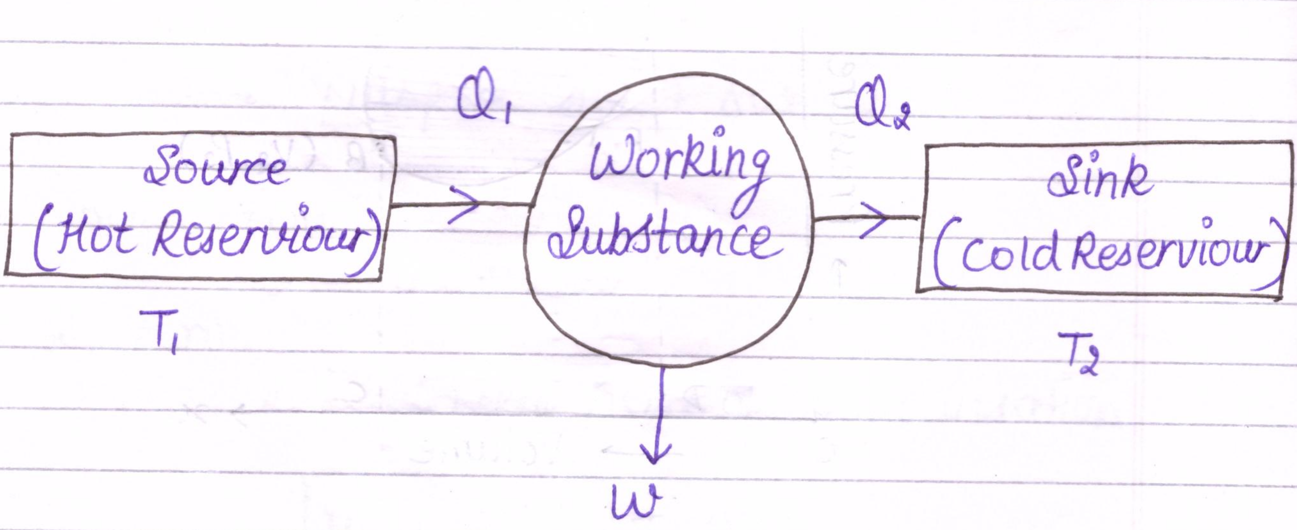
3) First Law of Thermodynamics doesn't given information about source of heat [wheather it is cold or hot body].

## Heat Engine

It is a device which convert heat energy into machenical energy.

Parts of Heat Engine.

1) Source of heat at high temp.
2) Working Substance
3) Sink of heat at Lower temp.



→ Let $Q_1$ is Amount of heat absorbed by working Substance from Source at $T_1$ in One Complete Cycle.

→ Let $Q_2$ is Amount of heat rejected to sink at $T_2$ in the Cycle.

w = Net work done by working Substance.

$$dQ = Q_1 - Q_2$$

$\boxed{dU = 0}$ [working substance return to its initial state so, $dU = 0$]

According to Ist Law of Thermodynamics

$$dQ = dU + dw$$

$$dU = 0$$

$$\text{So,} \quad dQ = dw$$

Net amount of heat absorbed

external workdone by Engine.

→ $w = Q_1 - Q_2$

Thermal Coefficient ($\eta$) ⇒ It is ratio of net work done / cycle to Total amount of heat absorbed per cycle.

$$\left[\frac{Q_1 - Q_2}{Q_1} \times 100\right] = \eta = \frac{[\text{Net work done per cycle}]}{\text{amount of heat absorbed per cycle}}$$

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

$$\boxed{\eta = \left[\frac{Q_1 - Q_2}{Q_1}\right] \times 100}$$

if $Q_2 = 0$

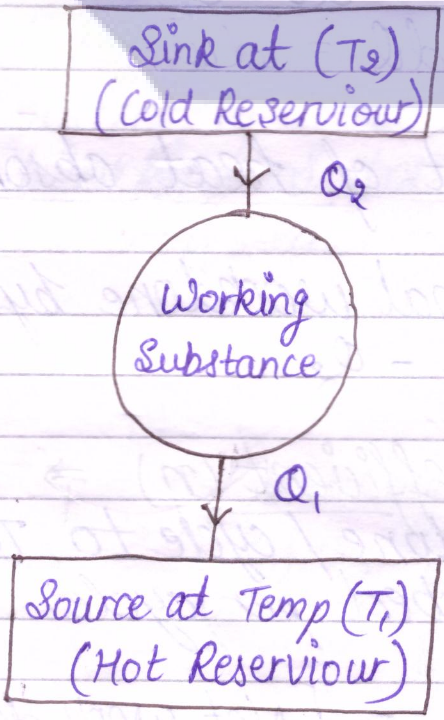
$$\eta = 100\%$$

Types of Heat Engine → Steam Engine

i) External Combustion Engine (12% to 16%)
2) Internal Combustion Engine (52%)

## Principle of Refrigirator

Refrigerator is a divice used for cooling thing. It is also called "heat pump".



$Q_2$ = Amount of heat extracted per cycle from cold reserviour at Lower Temp. ($T_2$)

$Q_1$ = Amount of heat released / cycle to source

$W$ = workdone / cycle on the system.

Net amount of heat absorbed $\Rightarrow dQ = Q_2 - Q_1$
Work done on System $\Rightarrow dw \Rightarrow -w$

According to Ist Law of the Thermodynamics

$$dQ = dU + dw$$

$dU = 0$ for cyclic Process

So,
$$dQ = 0 - w$$
$$Q_2 - Q_1 = -w$$
$$\boxed{w = Q_1 - Q_2}$$

Coefficient of Performance : It is defined as ratio of quantity of heat removed per cycle from the contents of refrigerator ($Q_2$) to energy spent per cycle ($w$) to remove this heat.

$$\beta = \frac{Q_2}{w}$$

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

Divide by $Q_1$

$$\beta = \frac{\frac{Q_2}{Q_1}}{\frac{Q_1}{Q_1} - \frac{Q_2}{Q_1}} = \frac{\frac{Q_2}{Q_1}}{\left(1 - \frac{Q_2}{Q_1}\right)}$$

In cyclic : $\frac{Q_2}{Q_1} = \frac{T_2}{T_1}$

So,

$$\beta = \left(\frac{\frac{T_2}{T_1}}{1-\frac{T_2}{T_1}}\right) = \frac{T_2}{T_1-T_2}$$

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

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

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

Relation between ($\beta$) & ($\eta$)

$$\Rightarrow \quad \eta = \frac{Q_1-Q_2}{Q_1}$$

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

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

$$\Rightarrow \quad \beta = \frac{Q_2}{Q_1-Q_2}$$

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

$$= \quad \frac{Q_1}{Q_1} - \frac{Q_2}{Q_1} = \frac{Q_2}{\beta_1 \times Q_1}$$

$$= \quad 1 - \frac{Q_2}{Q_1} = \frac{Q_2}{Q_1} \times \frac{1}{\beta}$$

$$= 1 - [1-\eta] = \left[\frac{1-\eta}{\beta}\right]$$

$$= \eta = \frac{1-\eta}{\beta}$$

$$\boxed{\beta = \frac{1-\eta}{\eta}}$$

## Second Law of Thermodynamics

Kelvin Plank Statement : It is immpossible to construct a heat balancing engine which would absorb heat from a reserviour and convert 100% of heat absorbed into work.

Calaurious Statement : It is immpossible to design a self design acting machine unaided by any external agency which would transfer heat from a body at a lower Temp to another body at higher temperature.

Relation B/w $C_p$ and $C_v$ [Mayor's formula]

Let gas be heated at constant volume through small range of Temp ($dT$)

$\rightarrow$ $dQ = m \times C_v \times dT$ [$m = 1$]
$\rightarrow$ $dQ = C_v \times dT$

$C_v$ → Molar Specific heat at constant volume
as volume remain constant, $dv = 0$

$$\therefore dw = P(dv)$$
$$dw = P \times 0 = 0$$

Acc. to Ist law of thermodynamics

$$dQ = dU + dw$$
$$C_v dT = dU + 0$$

$$\boxed{dU = C_v . dT}$$

Let gas be now heated, at constant pressure through small range of Temp (dT)

$$dQ' = m \times C_p \times dT$$
$$dQ' = 1 \times C_p \times dT$$
$$\boxed{dQ' = C_p \times dT}$$

So, $\boxed{dw' = P(dv)}$

$$dQ' = dU' + dw'$$
$$C_p dT = dU' + P(dv)$$
$$C_p dT = C_v(dT) + P(dv)$$
$$(C_p - C_v)\cancel{dT} = R(\cancel{dT})$$

$$\boxed{C_p - C_v = R}$$

Ques A gram molecule of gas 27°C expands Isothermally untice its volume is doubled. Find the amount of workdone and heat absorbed.

Ans $R = 8.31\ J mol^{-1} K^{-1}$

$T = 27^\circ C = 27 + 273 \Rightarrow 300K$

$V_2 = 2V_1$ , $w = ?$

$$w = 2.303\ RT \log\left[\frac{V_2}{V_1}\right]$$

$$w = 2.303 \times 8.31 \times 300 \log \left[\frac{2V_1}{V_1}\right]$$

$$\boxed{w = 1.727 \times 10^3 \, J}$$

**Ques** A sample of gas ($\gamma = 1.5$) is taken through an adiabatic process in which volume is compressed from 1600 cc to 400 cc. If the initial pressure is 150 KPa. what is the final pressure and how much work done on gas in process?

**Ans** $\gamma = 1.5$, adiabatic process

1600 to 400 cc

$V_1 = 1600$ , $V_2 = 400$

$P_1 = 150 \, KPa = 150 \times 10^3 \, Pa$

$P_2 = ?$

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

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

$$P_2 = 150 \times 10^3 \times \left[\frac{1600}{400}\right]^{1.5}$$

$$\boxed{P_2 = 1200 \, K \, Pa}$$

**Ques** A gas is suddenly can pressed to 1/4th of its volume. Calculate the rise in Temp when original Temp is 27°C. , $\gamma = 1.5$ ?

**Ans** $V_2 = 1/4 \, V_1$

$\gamma = 1.5$

$T_1 = 27^\circ C = 27 + 273 \Rightarrow 300 \, K$

$(T_2 - T_1) = ?$

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

$$T_2 = T_1 \left[\frac{V_1^{\gamma-1}}{V_2^{\gamma-1}}\right]$$

$$T_2 = T_1 \left[\frac{V_1}{V_2}\right]^{\gamma-1}$$

$$T_2 = \left[\frac{V_1}{\frac{1}{4}V_1}\right]^{1.5-1} \Rightarrow 300[4]^{0.5} \Rightarrow 300[4]^{1/2}$$

$$T_2 = 600$$

$$\Delta T = T_2 - T_1$$

$$= 600 - 300 = 300$$