# State and Property

Intensive
(size doesn't matter).

Extensive
(size matters)

Mostly used → Pressure (P), Volume (V), Temperature (T), Entropy, Enthalpy, Internal energy.

## ⊛ Three forms of internal Energy:

Intermolecular potential energy (Between molecules).

Molecular kinetic energy (translational and rotational velocity of each molecules).

Intra-molecular energy (within molecular/atomic structures).

func of temp

⊛ **Enthalpy** → combination of internal and pressure energy of the fluid. $H = U + pV$ (extensive) | SI → kj/kg.
$h = u + pv$ (intensive)

⊛ **Entropy** → Molecular disorder / randomness.

⊛ State → condition of a system;
depends on properties → if even one property changes state changes.

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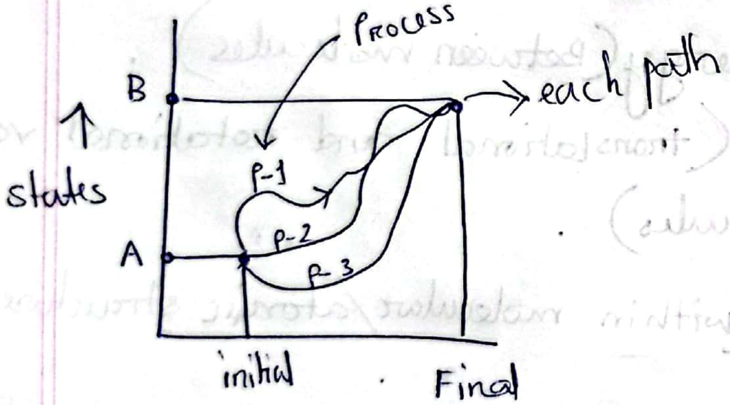
**Equilibrium:** no unbalanced potentials.

thermodynamic equilibrium requirements ↓

- ⊛ Thermal Equilibrium → NO HEAT FLOW.
- ⊛ Mechanical " → No unbalanced forces acting.
- ⊛ Chemical " → No change in chemical composition

⊛ Process → thermodynamic states — from initial state to final

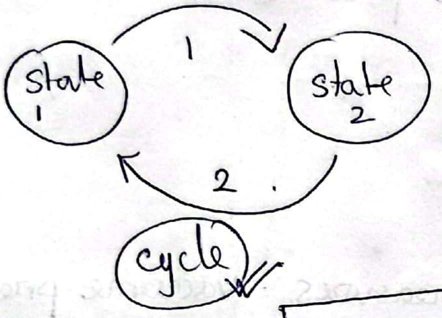
⊛ Path → series of states during a process.

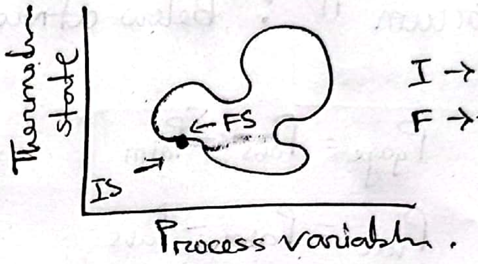



## ⊛ Path & Process :

1. Isothermal (T)
2. Isobaric (P)
3. Isochoric (V)
4. Isentropic (S).
5. Isenthalpic (h).
6. Isosteric (Concentration)
7. Adiabatic (no heat gain or removal).

**Cycle or Cyclic process :** Process that return the system to the initial state. (Zero change of any property)
Initial state same as Final state.




I → initial
F → final.

**Quasi-static** or **Quasi-equilibrium**

Quasi-static → deviation from thermodynamic equilibrium is infinitesimal

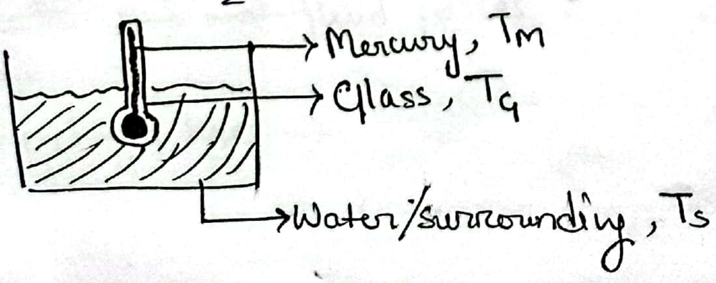
Quasi-equilibrium → slow process that allows the system to adjust itself internally so that properties in one part change not faster than others.

CS → Non flow process.
OS → flow process

**Zeroth law :**

→ Basis of Temperature Measurement,

if $T_1 = T_2$ and $T_2 = T_3$ then, $Q_3 = 0$.




If $T_S = T_G$.
and $T_G = T_m$
them, $T_m = T_s$.

Formula $P_{atm} = P_{abs} + P_{vac}$

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Absolute pressure : actual pressure

Gage " : Diff between absolute pressure and the local atmospheric pressure.

Vaccum " : Below atmospheric pressure.

$$P_{gage} = P_{abs} - P_{atm}$$

$$P_{vac} = P_{atm} - P_{abs}$$

Vaccum gage is a MACHINE that measures vaccume pressure.

MATH : ~~Atmospheric~~ Pressure measured by a vaccum gage is 5.8psi where atm pressure is 14.5psi. So what is the absolute pressure.

Here, $P_{vac} = 5.8$ psi

$P_{atm} = 14.5$ psi

So, $P_{abs} = P_{atm} - P_{vac}$

$= 14.5 - 5.8$

$= 8.7$ psi

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$E = U + KE + PE$

1st law for Closed System $\longrightarrow J\oint \delta Q = \oint \delta W$

For non-cyclic process $\longrightarrow Q - W = \Delta E$.

Heat transfer $\longrightarrow Q = U_2 - U_1 = mC_v(T_2 - T_1)$ [Const - V]

$Q = m C_p(T_2 - T_1)$ [Const - P]

$\boxed{C_p - C_v = R}$ $\quad C_v = \frac{R}{k-1}$ $\quad C_p = \frac{kR}{k-1}$

Gas laws : $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$

$P_2/P_1 = (V_1/V_2)^{\gamma}$

$T_2/T_1 = (V_1/V_2)^{\gamma-1} = (P_2/P_1)^{(\gamma-1/\gamma)}$

$PV = mRT$

$P = \frac{m}{V}RT = \rho RT$

~~Turbine~~ → low pressured fluid $\xrightarrow{\text{compressed}}$ high pressure

Rotary Compressor / Turbin → high pressured fluid $\xrightarrow{\text{expand}}$ low pressure

Nozzle → duct where velocity rises, pressure drops.

Diffuser → " " " drops, " rises.

Heat exchayer → transfers heat from one fluid to another without work done

Throttling → ~~wet~~ fluid passes a pore and pressure drops.

Heat exchayer types → radiator (automobile)
condenser (steam power + refrigerator)
evaporator (refrigerator).

3 types of Energy:- Kinetic (KE) – associated with motion
Potential (PE) – " " a mass that's in rest
Internal (U) – sum of all the molecules energy of a system.

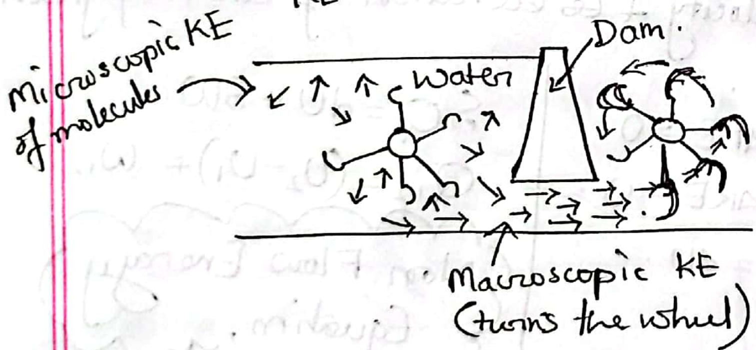
External

So, E = External + Internal

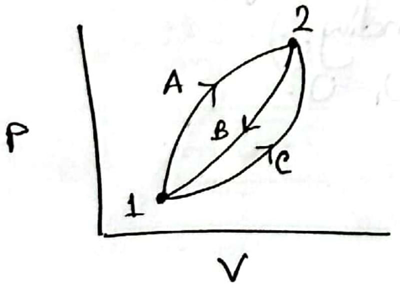
or, $\boxed{E = (KE + PE) + U}$

Statement (1st TD):- Energy can neither be created nor destroyed, though it can be transformed from one form to another.

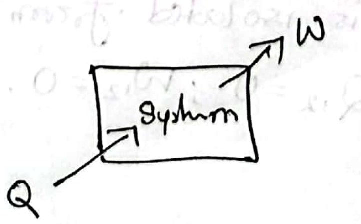
NOTE:
KE of ~~the~~ an object → organized + orderly (direction straight)
KE " molecules → disorganized + random.




1st TD in closed system: $J \oint \delta Q = \oint \delta W$. [Joule's experiment]




cyclic process.




$Q - W = \Delta E$.

non-cyclic process

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## Closed System (non cyclic) (1st TD law)

$$E = U + KE + PE$$
$$\Rightarrow dE = dU + dKE + dPE$$
$$\Rightarrow (\delta Q - \delta W) = dU + dKE + dPE$$

Now, $dU \Rightarrow \int_1^2 dU = U_2 - U_1 = m(u_2 - u_1)$.

$d(KE) = mVdV \Rightarrow \int_1^2 d(KE) = \frac{1}{2} m (V_2^2 - V_1^2)$.

$d(PE) = mgdZ \Rightarrow \int_1^2 d(PE) = mg(Z_2 - Z_1) = mgh$.

$$Q_{12} - W_{12} = \left[(U_2 - U_1) + \frac{1}{2} m (V_2^2 - V_1^2) + mg(Z_2 - Z_1)\right]$$
$$q_{12} - w_{12} = \left[(u_2 - u_1) + \frac{1}{2}(V_2^2 - V_1^2) + g(Z_2 - Z_1)\right]$$

**Stationary system** → velocity + elevation of center of gravity is constant.

So, $Z_1 = Z_2 \rightarrow \Delta PE = 0$

$V_1 = V_2 \rightarrow \Delta KE = 0$.

So, $\Delta E = \Delta U$.

$$\delta Q = dU + \delta W$$
$$Q_{12} = (U_2 - U_1) + W_{12}$$

Non Flow Energy Equation.

(*) **Law of conservation of energy** → U is unchanged when the system is isolated from surrounding.

as, $Q_{12} = 0$ ; $W_{12} = 0$. $\therefore U_2 - U_1 = 0$.

PMM-I / 2nd TD না মেনে চললে PMM-II.

Sub:

(*) Perpetual Motion Machine → that do not follow 1st Law of TD.
(It's imaginary).

Application of Non-flow process.

Poly tropic process $\boxed{(pV^n) = \text{constant}}$

$Q_{12} = U_2 - U_1 + W_{12}$.

$= U_2 - U_1 + \dfrac{P_1V_1 - P_2V_2}{n-1}$.

So, $Q = \dfrac{mR(T_1 - T_2)}{n-1} + mC_v(T_2 - T_1)$.

(*) Specific Heat: C (Heat capacity).

Amount of heat that raise temp by 1° per unit mass.

$\delta Q \rightarrow$ amount of heat

$\delta T \rightarrow$ temp.

$m \rightarrow$ mass (kg).

$C = \left(\dfrac{1}{m}\right)\left(\dfrac{\delta Q}{dT}\right)$.

At Constant V, $C_v$

$\delta W = PdV = 0 \; [\because dV = 0]$

$\delta Q = dU + \delta W = dU$.

So, $C_v = \dfrac{1}{m} \cdot \left(\dfrac{dU}{dT}\right)_v$

*** $\Rightarrow \boxed{dU = m C_v dT.}$

ISOCHORIC.

At const. P, $C_p$

$\delta Q = dU + PdV$.

$= (U_2 - U_1) + P(V_2 - V_1)$.

$= (U_2 + PV_2) - (U_1 + PV_1)$.

$= H_2 - H_2$. $\boxed{\because H = U + pdV}$.

$\delta Q = dH$.

$C_p = \dfrac{1}{m} \cdot \left(\dfrac{dH}{dT}\right)_p$.

So, $\boxed{\delta Q = dH = m C_p dT.}$ ***

ISOBARIC.

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SPECIFIC HEAT RATIO : $\gamma \cancel{k} = \frac{C_p}{C_v}$

$C_p - C_v = R.$

$C_v = \frac{R}{k-1}$

$C_p = \frac{kR}{k-1}$

$R \rightarrow 8.314\ JK^{-1}\ mol^{-1}$

universal gas const.

GAS LAWS :

$(P_1V_1)/T_1 = (P_2V_2)/T_2$

$\Rightarrow P_1V_1^n = P_2V_2^n.$

For adiabetic $[\Phi=0]$ + frictionless – isentropic process.

$n = \gamma = 1.4.$

So, $P_1V_1^\gamma = P_2V_2^\gamma.$

$\cancel{P_2/P_1 = V_1/V_2}$

$\boxed{\frac{P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^\gamma}$ $\boxed{\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1}}$ $\boxed{\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}}$

$\boxed{PV = mRT.}$

$\boxed{P = \rho RT.}$

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**ISOTHERMAL** $Q_{12} = \int_1^2 p\,dV$.

$$Q_{12} = P_1 V_1 \ln \frac{V_2}{V_1}$$

$$= P_1 V_1 \ln \frac{P_1}{P_2}$$

$$\boxed{Q_{12} = W_{12} = P_1 V_1 \ln \frac{V_2}{V_1} = P_1 V_1 \ln \frac{P_1}{P_2}}$$

$$\boxed{U_2 - U_1 = 0}$$

**ADIABETIC.**

$$\boxed{U_1 - U_2 = \frac{P_1 V_1 - P_2 V_2}{\gamma - 1} = \frac{mR(T_1 - T_2)}{\gamma - 1}}$$

↳ Poly tropic process.

$$\boxed{Q_{12} = (U_2 - U_1) + \frac{P_1 V_1 - P_2 V_2}{n-1} = \frac{mR(T_1 - T_2)}{(n-1)} + mC_v(T_2 - T_1)}$$

**ISOCHORIC** $\xrightarrow{V}$ $Q_{12} = U_2 - U_1 = mC_v(T_2 - T_1)$

**ISOBARIC** $\xrightarrow{P}$ $Q_{12} = H_2 - H_1 = mC_p(T_2 - T_1)$.

Sub: 2nd law of TD.

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Reversible: A process that have no change in either system or surrounding by reversing. (No real process is reversible).

Conditions: ① No friction

② No heat transfer accross finite temp diff.

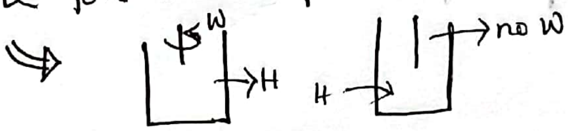
Irreversible — Not reversible.

Example: Frictionless motion, slow frictionless adiabatic expansion, spring extension.

## Limits of 1st TD:

① No complete transformation of heat into work but work completely transform to heat.

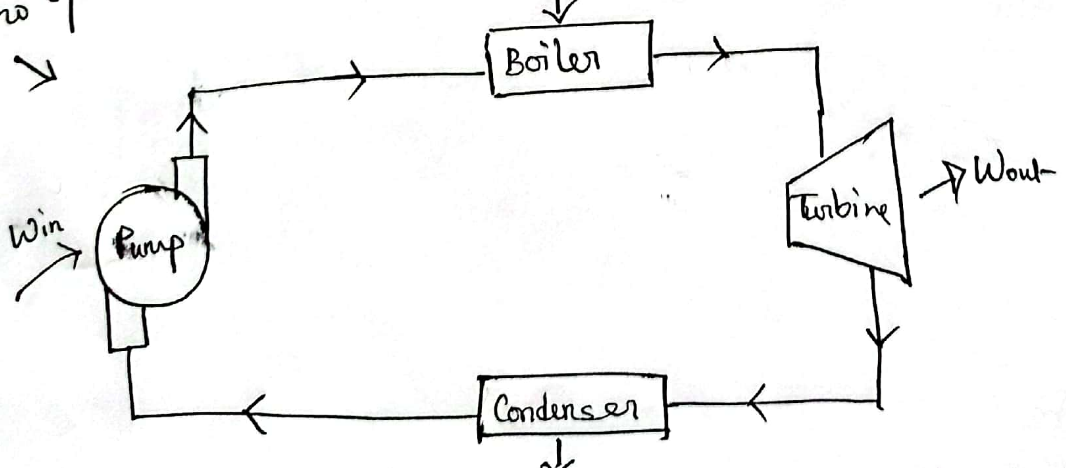
② Not possible for some process — not reversible.




## Heat Engine:

Energy source - high temp reservoir ($T_H$)

Thermo cycle.




Energy sink - low temp reservoir. ($T_L$)

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## Thermal Efficiency of HE :

$$\eta = \frac{W}{Q_H} = \frac{Q_H - Q_L}{Q_H} = 1 - \frac{Q_L}{Q_H}$$

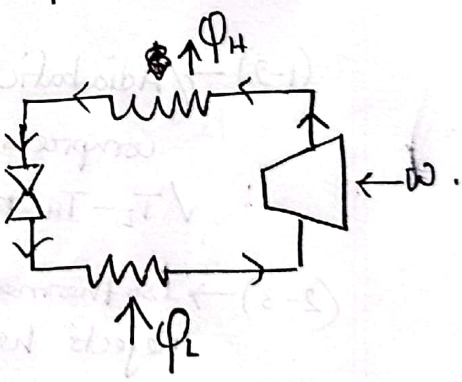
Normally, $W < Q_H$.

Can never be 100% so, $Q_L > 0$. ; usually 30% - 50%.

**KELVIN PLANCK Statement :** "It is impossible to construct a system which will operate in a cycle, extract heat from a reservoir and do an equivalent amount of work on the surrounding."

## Refrigeration / AC (split) cycle :

① Compressor - 1 low pressure + low temp — Isentropic
② Compressed.
④ High pressure + high temp
⑤ Superheating ✓
⑥ Release heat — → Isobaric
⑦ Throttling valve — → Isenthalpic
⑧ Expands
⑨ Low pressure + low temp.
⑩ subcooling ✓
⑪ Evaporator + absorbs heat → Isobaric.




$$COP_{Heat\ pump} = \frac{Q_H}{W}.$$

$$COP_{Refrigr/AC} = \frac{Q_L}{W}.$$

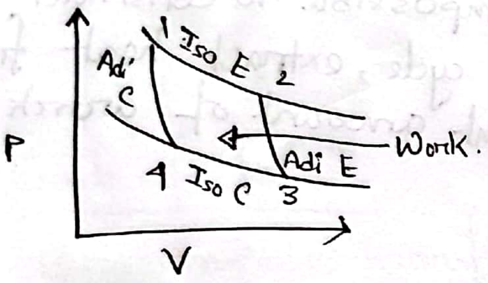
$$COP_{HP} = COP_R + 1.$$

as, $\frac{Q_H}{W} = \frac{Q_L + W}{W}.$ $[\because Q_H = Q_L + W]$

Sub :

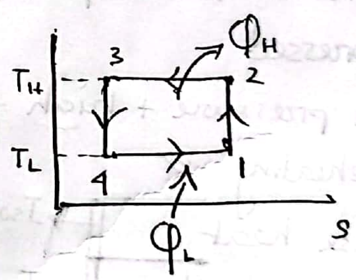
**CLAUSIUS STATEMENT :** It is impossible to construct a system that operates in a cycle and transfers heat from a lower temp body to a higher temp body without work being done on the system by surrounding.

**CARNOT CYCLE**



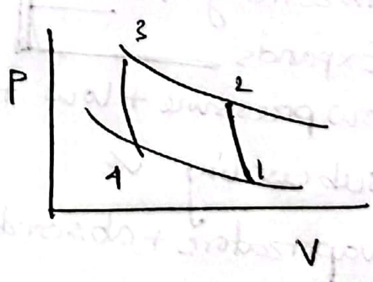

**Reverse Carnot → Refrigeration cycle :** (carnot)

same as : refigeration cycle




(1-2) → Adiabatic/Isentropic compression.
✓ $T_L - T_H$ rise - Heat = const

(2-3) → Isothermal compression
Rejects heat




(3-4) → Isentropic expansion
$T_H - T_L$ drops. Heat = const.

(4-1) → Isothermal expansion
Heat absorbed

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**COP:** Coefficient of Performance. is an index of performance of a thermodynamic cycle or a thermal system.

[As it can be greater than 1, it is used instead of $\eta$] $\longrightarrow COP_R = \frac{Q_L}{W}$.

1 British thermal Unit $h^{-1}$ = 0.293 W.

For AC → VCR (Compression)
VAR (Absorption).
Air Refrigeration

**Refrigerant** (ASHRAE)

R – 125 → No. of flourene atoms
$\to$ H+1
↳ No. of Carbon atom – 1

→ $C_2HF_5$

$CHFCl_2$ → dichloro-fluromethane → R-21.

$CHF_2Cl$ → chlorodifluromethane → R-22.

$C_2H_2F_4$ → tetrafluroethane → R-134a.

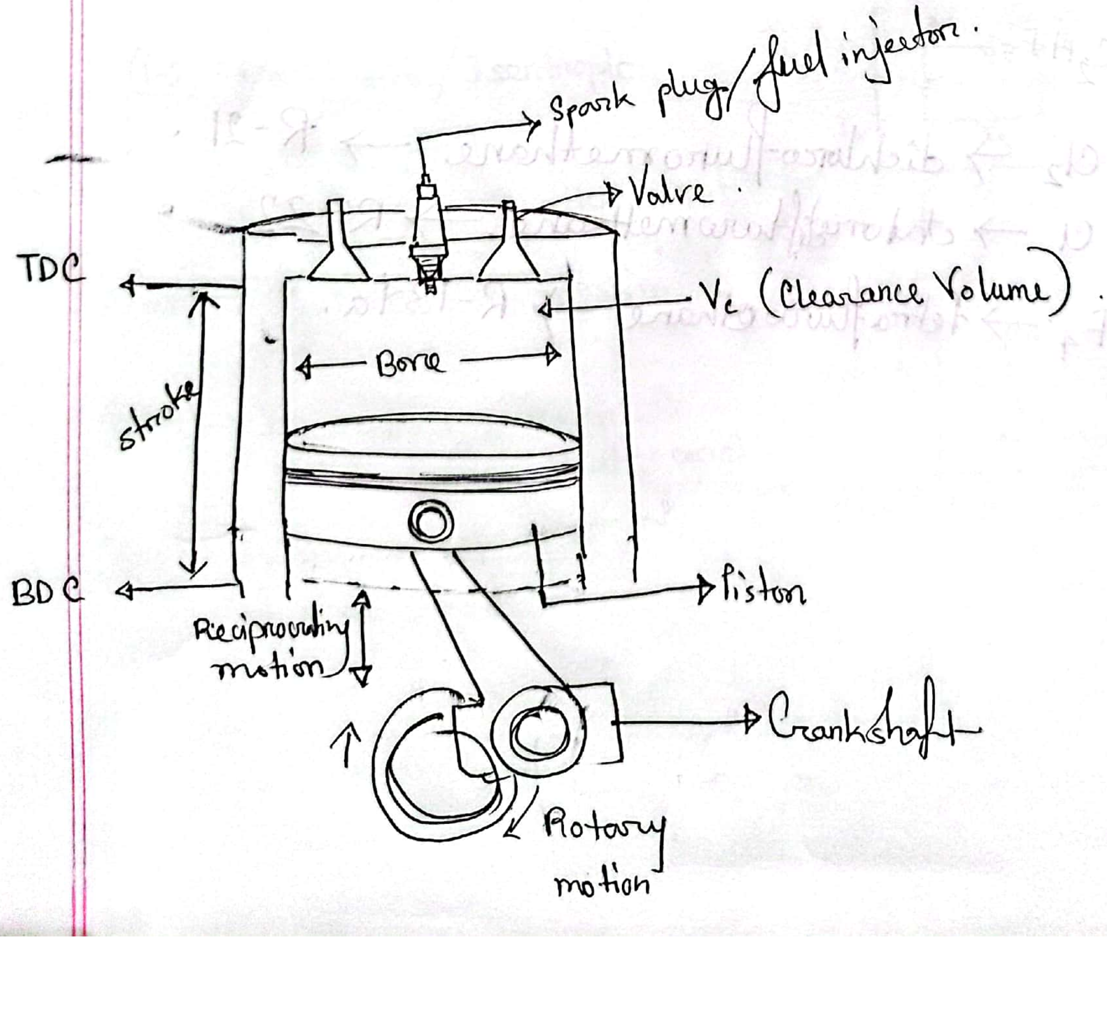
EC → external. Combustion
IC engine → internal combustion
CI → Compression Ignition engine

Sub:

S.I → Spark Ignition engine

Engine (thermal E $\xrightarrow{\text{Combustion of HC (exothermic)}}$ Mechanical E).

- External (EC) [Product of combustion != working fluid. i.e. steam engine, sterling Engine]
- Internal (IC) [Product == working fluid. i.e. Petrol, diesel, biofuel engine]
  - Reciprocating [Pistons transfer power to the crankshaft via reciprocating ⇅/⇄] PETROL, DIESEL.
  - Rotary. [Pistons transfers P to crankshaft by rotating]. ROTARY ENGINE



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## Formulae :

Stroke = 2r of crankshaft (r - radius).

Piston Displacement = Volume between TDC and BDC.

Engine Capacity (Total piston Displacement) = No. of Pistons × Piston Displacement.

Swept Volume, $V_s$ = total $V - V_c$.

Compression ratio, $r = \frac{(V_s + V_c)}{V_c}$ $\left[\frac{\text{Total } V}{V_c}\right]$

[NOTE: Normally for SI → 8-12
" CI → 12-24]

Mean Effective Pressure, $= \frac{\text{Work done}}{\text{total Volume}}$

Volumetric efficiency = Volume of air in cylinder / Total Volume

Petrol Engine < Disel Engine < (Turbocharger + Supercharger) [air compressing device]

**Power :**

Indicated Power (IP): Power developed within the engine cylinder.

Brake Power (BP): Delivered Power at the crankshaft; always BP < IP.
Because of frictional + pumping losses and reciprocating mechanism.

Engine Torque: Force of rotation acting about the crankshaft axis at any given instant.

[NOTE:- High BP + low torque → easy to accelerate but speed বেশি বেড়ে গেলে maintain করা difficult

Low BP + High torque → difficult to accelerate but highest speed এ maintain করা যায়

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## Engine Classification :

No. of cylinders : V4, V6 etc.

Arrangement of cylinders : Inline, Vtype, Opposed.

" " valves : Overhead camshaft, Pushrod camshaft, valveless.

Cooling : Water cooled, air cooled.

Strokes : 2, 4.

Fuel : Gasoline, Diesel, Ethanol, CNG

Ignition : Spark, Self or Compression.

Firing order : (For 4 cylinders) → 1-2-4-3

1-3-4-2

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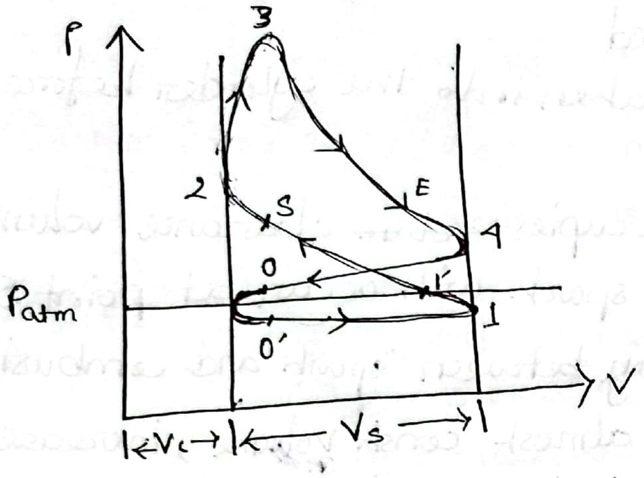
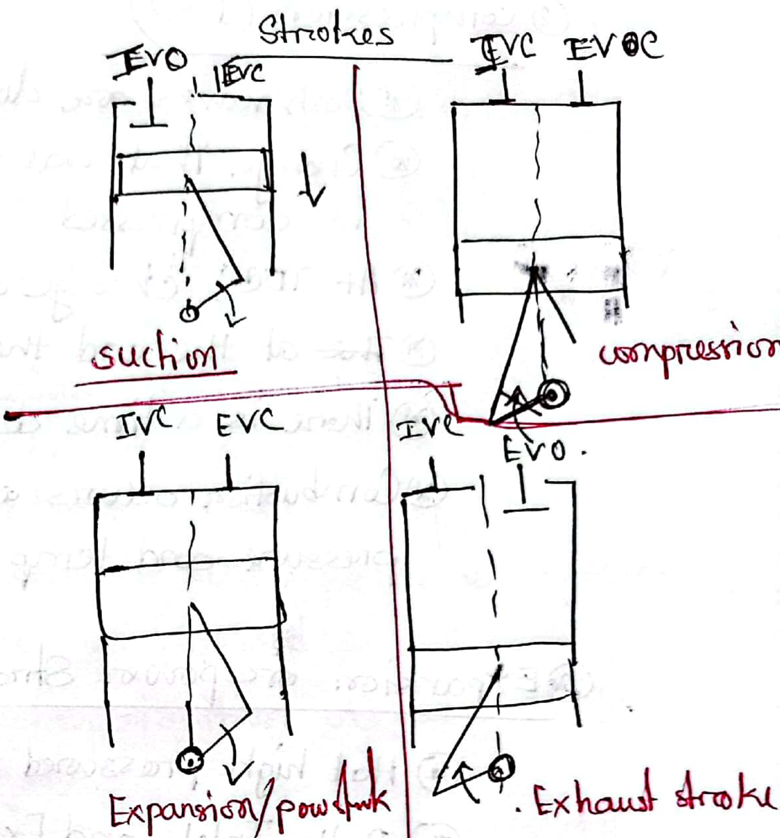
# 4-stroke SI Engine :




P.V diagram




IVC → Inlet valve Closed
EVC → Exhaust " "
IVO → Inlet " Opened
EVO → Exhaust " "

The ~~cb~~ cycle is completed in 4 strokes of the pistons for 2 revolutions of the crankshaft. So, 720° CA is required for a complete cycle.

Steps:

① **Induction/Suction Stroke: (0-1)**

- Before the TDC, inlet valve opens at point 0.
- Piston moves from TDC to BDC, mixture of air and fuel enters the cylinder via IV.
- Pressure reduces in the cylinder than that of atmosphere. So ~~the~~ charge flows ~~from~~ through induction system.
- Valve should close at point 1 which does not happen until piston moves to point 1'.

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② Compression (1′-2)

- Both valves are closed
- Charge that was taken into the cylinder before is compressed
- At TDC, charge occupies ~~Volum~~ clearance volume.
- ~~The~~ at the end the spark will occur at point S.
- There is a time delay between spark and combustion.
- Combustion occurs at almost const. volume, increased pressure and temp. during the process (2-3)

③ Expansion or power Stroke (3-4).

- Hot high pressured burnt gases pushes the piston to BDC.
- Both Inlet and Exhaust valves are closed.
- At point E, just before BDC happens, the gaseous products are exhausted as exhaust valve opens.
- Power is obtained
- Pressure and temp. decreases.
- Expansion completes at point 4.

④ Exhaust stroke (4-0′)

- Piston moves from BDC to TDC sweeping burnt gase through EV while IV is closed.
- At this time pressure slightly rises than $P_{atm}$.
- EV closes at point 0′.
- $V_c$ is full of exhaust gas from previous cycle which are called residual gases.

Later, the mixture will be compressed consisting both fresh and residual gases.

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## 4 stroke CI engine:

Same as SI but ~~com~~ high compression ratio is used in the CI.

① Suction Stroke : * IV opens and air enters (no fuel).
* Piston moves from TDC to BDC.

② Compression:
* IV and EV remains closed.
* Air is compressed.
* Air pressure + temp. rises.
* As the piston reaches to TDC, fuel is injected finely into the hot compressed air.
* After a short delay, ignition occurs.
* Pressure rises (gas).

③ Expansion:
* Work done is occured by gas pressure as piston sweeps maximum cylinder volume.
* Temp. and pressure of burnt gas fall as it expands just before piston approaches BDC.

④ Exhaust stroke: * EV opens at BDC and products (burnt gases) are rejected.
* BDC to TDC, IV opens again and cycle repeated.

Valve timing →

IVO about 30° before TDC
IVC " 50° after BDC
EVO " 45° before BDC
EVC " 30° after TDC.

Fuel injection 15° before TDC.

Sub: 2stroke Vs 4 Stroke

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| 2 Stroke | 4 Stroke |
| --- | --- |
| ① Simpler, Compact, lighter and cheaper. | ① Complicated, heavy, expensive |
| ② Power stroke ~~twice per~~ per crankshaft revolution. | ② Power stroke ~~once per~~ at 2 crankshaft revolution. |
| ③ Torque output is smother | ③ Torque output is not smoother |
| ④ In low rpm power produced is lower. | ④ Higher power |
| ⑤ Lubrication system is simpler | ⑤ Complicated. |
| ⑥ Less Volumetric efficiency | ⑥ High Volumetric efficiency |
| ⑦ Develops less power and torque | ⑦ High power + torque. |
| ⑧ Greater tendency to build up carbon deposit on the cylinder wall | ⑧ No. |
| ⑨ Overheats faster | ⑩ Takes time to overheat. |

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## Air standard cycle :

The cycle we use to evaluate important engine terms with mathematical equations is known as ideal cycle or air standard cycle.

### Assumptions (in short) :

① Working fluid is always - ideal gas, pure air with const. specific heat.

② Fixed mass of air is the working fluid throughout the entire cycle.

③ Closed loop.

④ Combustion process is replaced by const. heat addition process.

⑤ Cycle is reversible.

⑥ Compression and expansion are reversible adiabatic

⑦ No chemical change.

⑧ Frictionless operation.

Sub: Otto Cycle. (- Nicolaus Otto . 1876)

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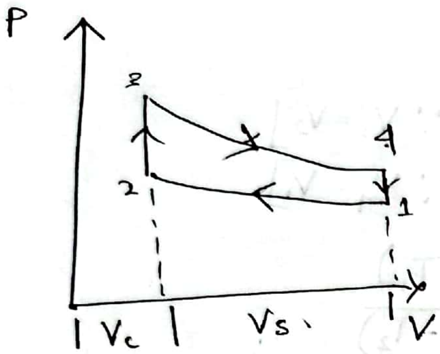
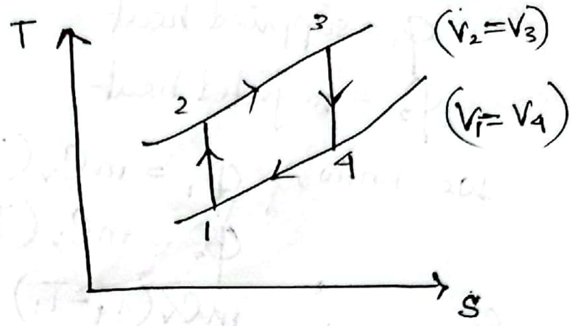
Happens in Petrol and Gas engines.

[Low volumetric Efficiency]




P-V diagram




T-s diagram

(1-2) reversible adiabatic or isentropic compression and air is compressed. No heat transfered

* Piston moves upwards

(2-3) Const. volume heating

* piston is at TDC
* Heat is supplied to air.

$Q_1$ (supplied)

(3-4) Adiabatic or isentropic expansion.

* Pressure + temp is high.
* Piston is pushed to BDC.
* Work is done. (No heat transfer).

$Q_2$ (rejected)

(4-1) Constant volume heat rejection.

---

$V_s$ = Swept Volume

$V_c$ = Clearance Volume

$V$ = total Volume.

Compression ratio, $r = \frac{V}{V_c} = \frac{(V_s+V_c)}{V_c} = \frac{V_1}{V_2}$ [let. $V=V_1$ and $V_c=V_2$]

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Thermal efficiency of any cycle $\Rightarrow \eta = \dfrac{W}{Q_{1(\text{supplied})}} = \dfrac{Q_1 - Q_2}{Q_1} = 1 - \dfrac{Q_{2(\text{sink})}}{Q_1}$

$Q_1$ = supplied heat

$Q_2$ = rejected heat

we know, $Q_1 = mC_v(T_3 - T_2)$ $[\because V_3 = V_2]$

$Q_2 = mC_v(T_4 - T_1)$. $[\because V_4 = V_1]$

So, $\eta = 1 - \dfrac{\cancel{mC_v}(T_4 - T_1)}{\cancel{mC_v}(T_3 - T_2)} = 1 - \dfrac{(T_4 - T_1)}{(T_3 - T_2)}$

For, isentropic (1-2),

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

$$\Rightarrow T_2 = T_1 r^{\gamma-1}$$

Similarly, for (3-4) $T_3 = T_4 r^{\gamma-1}$

So, for Otto cycle,

$$\eta = 1 - \frac{(T_4 - T_1)}{(T_4 r^{\gamma-1} - T_1 r^{\gamma-1})} = 1 - \frac{\cancel{(T_4 - T_1)}}{\cancel{(T_4 - T_1)} r^{\gamma-1}}$$

$$\eta = 1 - \frac{1}{r^{\gamma-1}}$$ (Ans)

Sub :

For mean effective pressure,

We know, $W = Q_1 - Q_2 = mC_v(T_3 - T_2) - mC_v(T_4 - T_1)$.

$= mC_v[(T_3 - T_2) - (T_4 - T_1)]$

Again for, (2-3), $\frac{P_2}{T_2} = \frac{P_3}{T_3}$

$\Rightarrow T_3 = \frac{P_3}{P_2} T_2 = \alpha T_2 = \alpha T_1 r_0^{\gamma-1}$

Similarly for (3-4), $T_4 = \cancel{\alpha T_1 r_0^{\gamma-1}} \frac{P_4}{P_1} T_1$.

$= \cancel{\frac{T_3}{r_0^{\gamma-1}}} = \cancel{\frac{T_3}{r_0^{\gamma-1}}} = \cancel{\frac{\alpha T_1 r_0^{\gamma-1}}{r_0^{\gamma-1}}} = \alpha T_1$

putting the value,

$W = mC_v[(\alpha T_1 r_0^{\gamma-1} - T_1 r_0^{\gamma-1}) - (\alpha T_1 - T_1)]$

$= mC_v[T_1 r_0^{\gamma-1}(\alpha - 1) - T_1(\alpha - 1)]$

$= mC_v[(\alpha - 1)(T_1 r_0^{\gamma-1} - T_1)]$

We know,

mean effective pressure, $P_m = \frac{W}{V_s}$

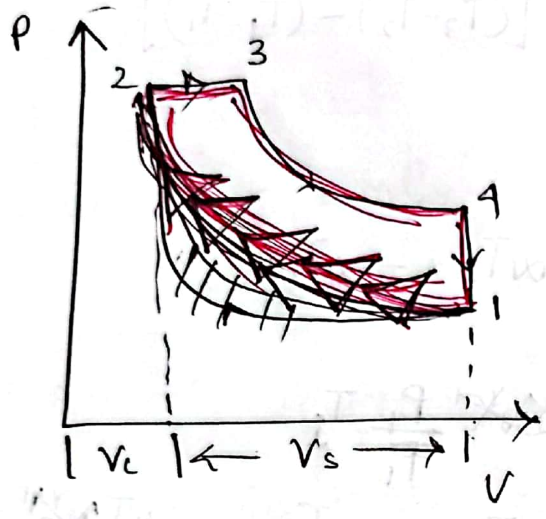
and $V_s = V - V_c = V_1 - V_2 = 1 - \frac{V_2}{V_1} = \frac{mRT_1}{P_1}\left(1 - \frac{1}{r_0}\right)$.

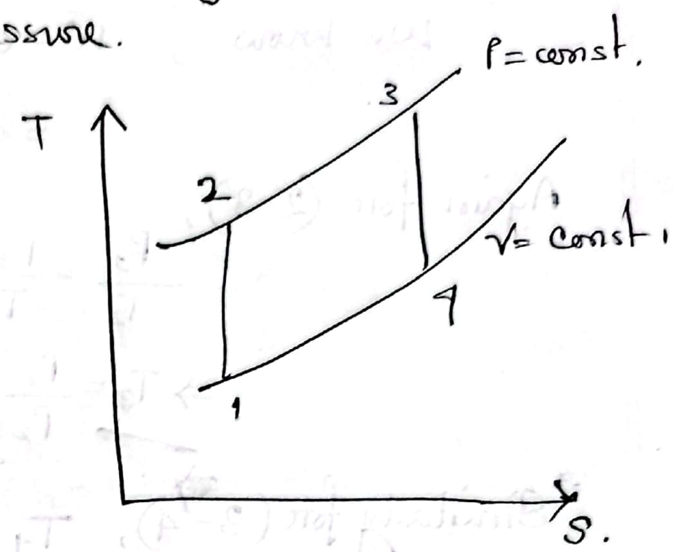
So, $P_m = \frac{\cancel{m} C_v[(\alpha-1)(T_1 r_0^{\gamma-1} - T_1)] \cdot P_1}{\cancel{m} RT_1 \left(1 - \frac{1}{r_0}\right)} = \frac{C_v}{R} \cdot \frac{\cancel{T_1}(\alpha - 1)(r_0^{\gamma-1} - 1) P_1 r_0}{\cancel{T_1}(r_0 - 1)}$

$$\boxed{\Rightarrow P_m = \frac{P_1(\alpha-1)(r_0^{\gamma-1} - 1) r_0}{(\gamma-1)(r_0-1)} = \frac{P_1(\alpha-1)\left(1 - \frac{r_0}{r_0^{\gamma}}\right)\frac{r_0^{\gamma}}{r_0}}{(\gamma-1)(r_0-1)} = \frac{P_1(\alpha-1)\eta r_0^{\gamma}}{(\gamma-1)(r_0-1)}}$$

(Ans)

Slow speed compression ~~and~~ - ignition engine.
Heat is added at const. pressure.




(1-2) Isentropic compression
(2-3) Const. Pressure, Heat is supplied ($Q_1$)
(3-4) Isentropic expansion, no heat transfer
(4-1) Const. Volume, Heat is rejected ($Q_2$)

So, $Q_1 = mC_p(T_3 - T_2)$
$Q_2 = mC_v(T_4 - T_1)$.

Thermal Efficiency, $\eta = 1 - \dfrac{Q_2}{Q_1}$

$$= 1 - \frac{\cancel{m}C_v(T_4 - T_1)}{\cancel{m}C_p(T_3 - T_2)}$$

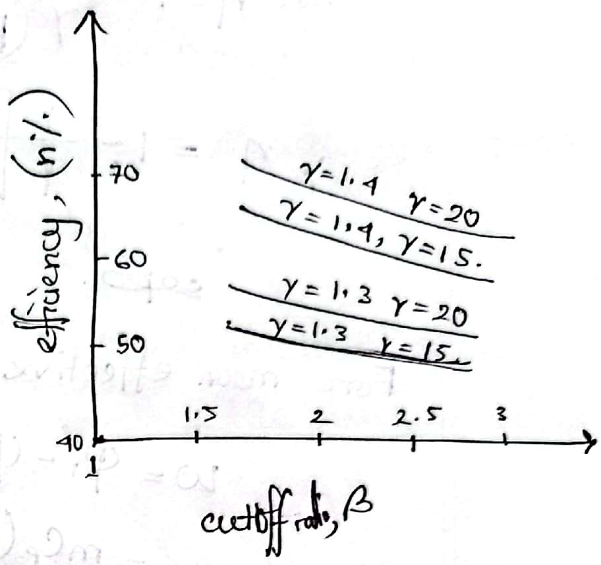
$$= 1 - \frac{(T_4 - T_1)}{\gamma(T_3 - T_2)}$$

Sub :

Here, $r = \dfrac{V}{V_c} = \dfrac{V_1}{V_2}$

At point 3, fuel supply is cut off.

So, cut off ratio, $\beta = \dfrac{V_3}{V_2}$




For (1-2), $\dfrac{T_2}{T_1} = \left(\dfrac{V_1}{V_2}\right)^{\gamma-1} = r^{\gamma-1}$.

For (2-3),

$$\frac{V_2}{T_2} = \frac{V_3}{T_3}.$$

$$T_3 = \beta T_1 r^{\gamma-1}$$

~~Similarly for (3-4), $T_4 = \beta T_1$.~~

$$\text{So, } \eta = 1 - \frac{(\beta T_1 - T_1)}{\gamma\left(\beta T_1 r^{\gamma-1} - T_1 r^{\gamma-1}\right)}$$

$$= 1 - \frac{(\beta - 1)}{\gamma(\beta-1) r^{\gamma-1}}$$

$$= 1 -$$

Similary, for (3-4), $\dfrac{T_4}{T_3} = \left(\dfrac{V_3}{V_4}\right)^{\gamma-1}$

$$\Rightarrow T_4 = T_3\left(\frac{\beta}{r}\right)^{\gamma-1}$$

$$= \beta T_1 \beta^{\gamma-1}$$

$$= T_1 \beta^{\gamma}$$

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So, $\eta = 1 - \dfrac{(T_1 \beta^{\gamma-1} - T_1 \beta)}{\gamma(\beta T_1 r^{\gamma-1} - T_1 r^{\gamma-1})}$

$\Rightarrow \eta = 1 - \dfrac{1}{\gamma}\left[\dfrac{(\beta^{\gamma}-1)}{r^{\gamma-1}(\beta-1)}\right]$

~~cops~~.

For mean effective pressure,

$$W = \phi_1 - \phi_2$$

$$= mC_p(T_3 - T_2) - mC_v(T_4 - T_1)$$

$$= mC_p\left(T_1 \beta r^{\gamma-1} - T_1 r^{\gamma-1} - \frac{(T_1\beta^{\gamma-1} + T_1)}{\gamma}\right)$$

$$= mC_p T_1\left(r^{\gamma-1}(\beta-1) - \frac{(\beta^{\gamma-1}-1)}{\gamma}\right)$$

$$\cancel{= mC_pT_1}$$

Swept Volume, $V_s = V_1 - V_2 = V_1\left(1 - \frac{1}{r}\right) = \frac{mRT_1}{P_1}\left(\frac{r-1}{r}\right)$.

Mean effective pressure, $P_m = \dfrac{W}{V_s} = \dfrac{\cancel{m}C_p\cancel{T_1}\left(r^{\gamma-1}(\beta-1) - \frac{(\beta^{\gamma-1}-1)}{\gamma}\right) \cdot P_1 r}{\cancel{m}R\cancel{T_1}(r-1)}$

$$= \frac{\gamma}{\gamma-1} \cdot \frac{P_1 \cdot r}{(r-1)} \cdot \left[r^{\gamma-1}(\beta-1) - \frac{1}{\gamma}(\beta^{\gamma-1}-1)\right]$$

$$= \frac{\cancel{\gamma} \cdot P_1}{(\gamma-1)(r-1)}\left[\gamma r^{\gamma}(\beta-1) - r(\beta^{\gamma-1}-1)\right]$$

$$= \frac{P_1 \; \gamma r^{\gamma}(\beta-1)}{(\gamma-1)(r-1)}\left[1 - \frac{(\beta^{\gamma-1}-1)}{r^{\gamma-1}\,\gamma(\beta-1)}\right]$$

$$= \frac{P_1 \gamma r^{\gamma}(\beta-1)}{(\gamma-1)(r-1)}\eta.$$

# SI Vs CI

Sub: Petrol Engine Vs Diesel Engine

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## PETROL (SI)

1. In SI ; air and petrol is charged and compressed.
2. Compression ratio is 8-12
3. Low thermal efficiency and fuel savings.
4. Low volumetric efficiency as throttle valve is there
5. Expensive
6. Spark plug, Carburetor etc present
7. Higher accelerating power

## DIESEL (CI).

1. Only Air is compressed.
2. Compression ratio is 12-24
3. High.
4. Higher volumetric effiency. as no throttle valve is there
5. Cheaper
6. ~~Has~~ capability to control fuel injection accurately.
7. High torque.

---x---

## OTTO CYCLE

1. $\eta = 1 - \frac{1}{r^{\gamma-1}}$
2. For Compression ratio efficiency is greater
3. No cut off ratio is related

## DIESEL CYCLE

1. $\eta = 1 - \frac{1}{r^{\gamma-1}}\left[\frac{\beta^{\gamma}-1}{\gamma(\beta-1)}\right]$
2. ~~The~~ For the same $r$, $\eta$ is less.
3. $\eta$ increases with decrease of $\beta$ but with const $r$ and $\gamma$ $\beta$ decreases.

Sub: Thermodynamics Formulae

Day

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$P_{atm} = P_{abs} + P_{vac}$. $[P_{atm} > P_{abs}]$

$P_{gage} = P_{abs} - P_{atm}$. $[P_{atm} < P_{abs}]$

$$SFEE \Rightarrow Q - W = mg(Z_2 - Z_1) + \frac{1}{2}m(C_2^2 - C_1^2) + m(h_2 - h_1)$$

$$q - w = g(Z_2 - Z_1) + \frac{1}{2}(C_2^2 - C_1^2) + (h_2 - h_1).$$

SFEE → Turbine, $w = h_2 - h_1$ $[\because q = 0;\ z_2 = z_1;\ C_2 \approx C_1]$

Nozzle, $h_1 + \frac{C_1^2}{2} = h_2 + \frac{C_2^2}{2}$ $[\because q = 0,\ w = 0,\ z_1 = z_2]$

Throttling, $h_1 = h_2$ $[\because q = 0,\ w = 0,\ z_1 = z_2,\ C_1 \approx C_2]$

Heat Exchanger, $q = h_2 - h_1$ $[\because w = 0,\ z_1 = z_2,\ C_1 \approx C_2]$

1st TD:

$$\delta Q = dU + \delta W$$

$$Q_{12} = (U_2 - U_1) + W_{12}$$

$$C_p - C_v = R.$$

$$\frac{C_p}{C_v} = \gamma;\quad C_v = \frac{C_p}{\gamma};\quad C_p = \frac{\gamma}{\gamma - 1};\quad C_v = \frac{1}{\gamma - 1}$$

$$\frac{P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^{\gamma};\quad \frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma - 1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma - 1}{\gamma}}$$

$$PV = mRT$$

$$P = \rho RT$$

Isothermal: $dQ = P_1 V_1 \ln\frac{V_2}{V_1}$

$$W = Q = P_1 V_1 \ln\frac{P_1}{P_2}.$$

$$dU = 0.$$

Adiabatic:

$$dQ = \frac{mR(T_1 - T_2)}{(n-1)} + mC_v(T_2 - T_1)$$

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Isochoric: $dQ = U_2 - U_1 = mC_v(T_2 - T_1)$

Isobaric: $dQ = dH = mC_p(T_2 - T_1)$

$$\eta = \frac{Q_H - Q_L}{Q_H} = \frac{W}{Q_H} = 1 - \frac{Q_L}{Q_H}$$

$$W = Q_H - Q_L$$

$$COP_{HP} = \frac{Q_H}{W} = COP_R + 1$$

$$COP_R = COP_{AC} = \frac{Q_L}{W}$$

Ashrace $\longrightarrow$ R-(C-1)(H+1)(F).

Engine capacity $\rightarrow$ No. of piston $\times$ Piston displacement.

$$V = V_s + V_c$$

$$r = \frac{V}{V_c}.$$

$$P_m = \frac{W}{V_s}$$

Otto Cycle

$$\eta = 1 - \frac{1}{r^{\gamma-1}}$$

$$P_m = \frac{P_1(\alpha-1)}{(\gamma-1)(r-1)} \cdot \eta r^\gamma$$

Diesel Cycle

$$\eta = 1 - \frac{1}{r^{\gamma-1}}\left[\frac{\beta^\gamma - 1}{\gamma(\beta-1)}\right]$$

$$P_m = \frac{P_1(\beta-1)}{(\gamma-1)(r-1)} \eta \gamma r^{\gamma-1}$$

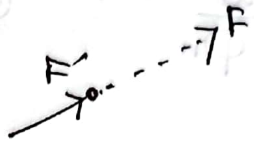
With LOVE

-DONA

For 2D cases $\cdot\; F = (\Sigma F_x)\hat{i} + (\Sigma F_y)\hat{j}$ ; Conditions: $\boxed{\Sigma F_x = 0,\ \Sigma F_y = 0}$

FBD ⟶ ① Outline
External forces ② Forces shown
③ Identify forces.

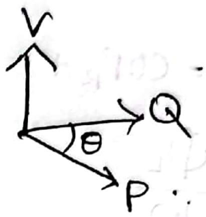
Principle of Transmissibility.



$F' = F$.

Vector Product ⟶ V

$V = Q \times P$.

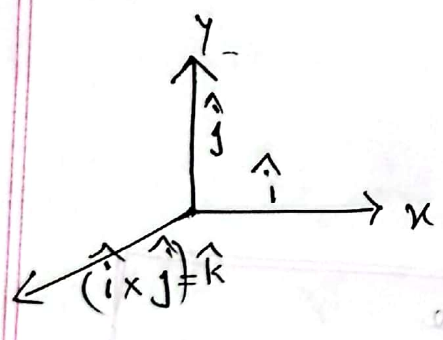


⊗ not commutative. Here, $(Q \times P) \neq (P \times Q)$.

But $Q \times P = -(P \times Q)$.

✓ distributive. $P \times (Q_1 + Q_2) = (P \times Q_1) + (P \times Q_2)$

⊗ not associative, $(P \times Q) \times S \neq P \times (Q \times S)$.



$(\hat{i} \times \hat{j}) = \hat{k}$

| | | |
|---|---|---|
| $\hat{i} \times \hat{i} = 0$ | $\hat{j} \times \hat{i} = -\hat{k}$ | $\hat{k} \times \hat{i} = \hat{j}$ |
| $\hat{i} \times \hat{j} = \hat{k}$ | $\hat{j} \times \hat{j} = 0$ | $\hat{k} \times \hat{j} = -\hat{i}$ |
| $\hat{i} \times \hat{k} = -\hat{j}$ | $\hat{i} \times \hat{j} = \hat{k}$ | $\hat{k} \times \hat{k} = 0$ |

$$V = P \times Q \Rightarrow \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ P_x & P_y & P_z \\ Q_x & Q_y & Q_z \end{vmatrix}$$

Scalar

commutative ✓
distributive ✓

Not associative. $(P \cdot Q) \cdot S$ = undefined

$\hat{i} \cdot \hat{i} = \hat{j} \cdot \hat{j} = \hat{k} \cdot \hat{k} = 1$

$i \cdot j = j \cdot k = k \cdot i = 0$.

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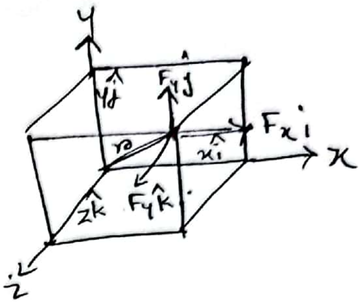
$M = F \times d$. (Torque).

$= d \cdot F \sin\theta$.

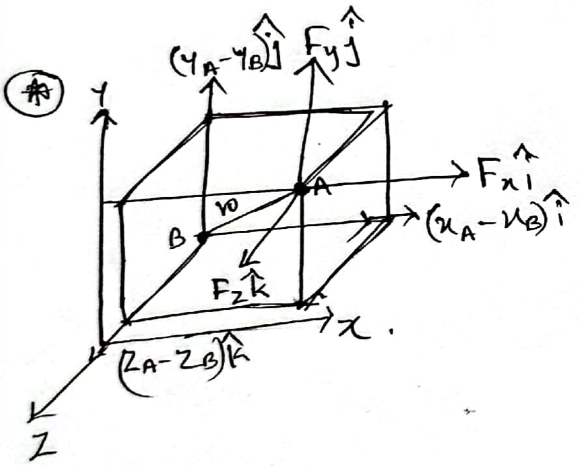



## Varignon's Theorem :

$$F_1 \times r + F_2 \times r \cdots\cdots = r \times (F_1 + F_2 + \cdots)$$

$$\bar{M}_o = M_x\hat{i} + M_y\hat{j} + M_z\hat{k}$$

$$= \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ x & y & z \\ F_x & F_y & F_z \end{vmatrix} = (yF_z - zF_y)\hat{i} + (zF_x - xF_z)\hat{j} + (xF_y - yF_x)\hat{k}$$




For, 2D, $M_o = xF_y - yF_x$.

$$= (x_A - x_B)F_y - (y_A - y_B)F_x.$$

Moment $= F \cancel{\times r}\, , r$ .