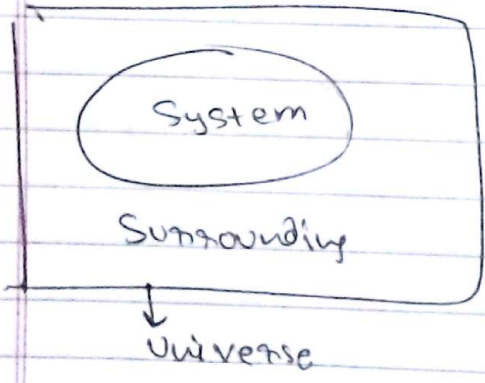


→ ef. Pressure - avg. rate of change of momentum due to all molecular collisions made on a unit area

(1) Macroscopic - A certain quantity of matter is considered, without the events occurring at the molecular level being taken into account. → effects can be perceived by human sense.

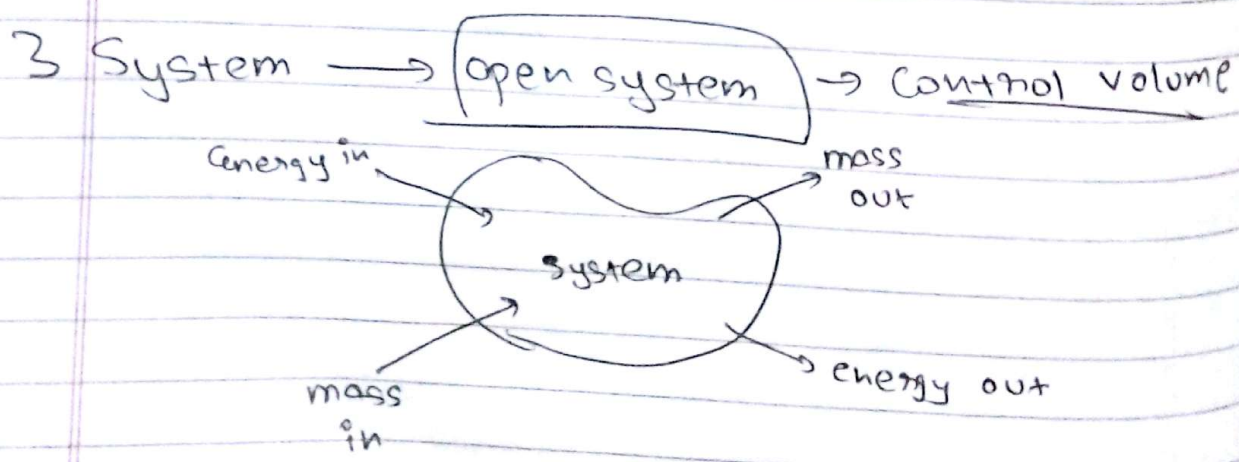
(2) Microscopic - Matter is composed of myriads of molecules. If it is a gas, each molecule at a given instant has a certain position, velocity and energy.   
 [The behaviour of gas is described by summing up behaviour of each molecule.]

→ System - A quantity of matter or a region in space upon which attention is concentrated in the analysis of problem.



System is separated from Surrounding by a boundary.

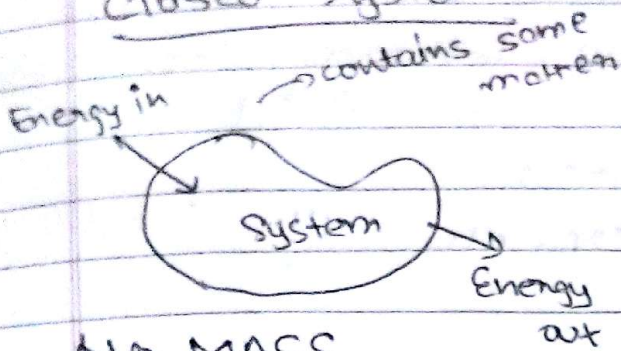
→ Boundary may be either fixed or moving.





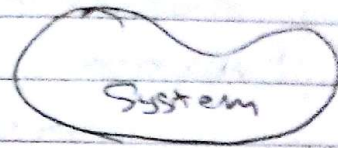
Volume can change

### Closed System



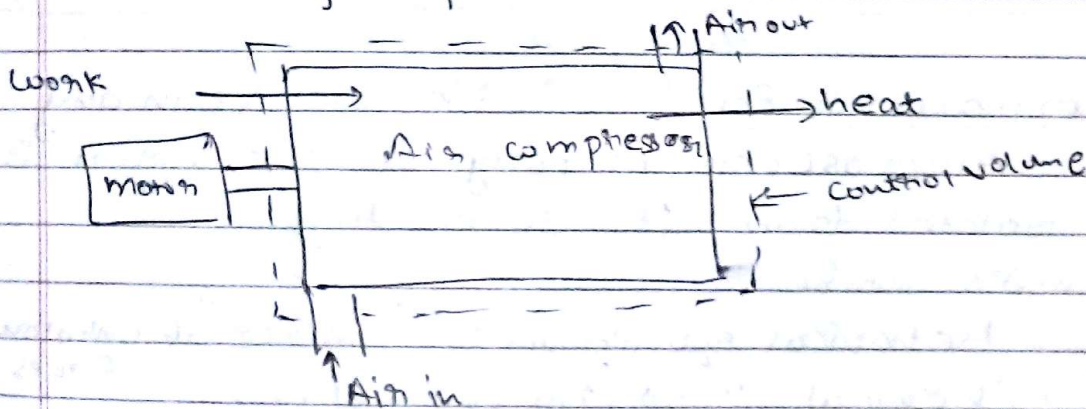
NO MASS TRANSFER

### Isolated System



NO MASS OR ENERGY TRANSFER

→ For analysis of an open system, (air compressor) attention is focused on certain volume in space surrounding compressor known as control volume.



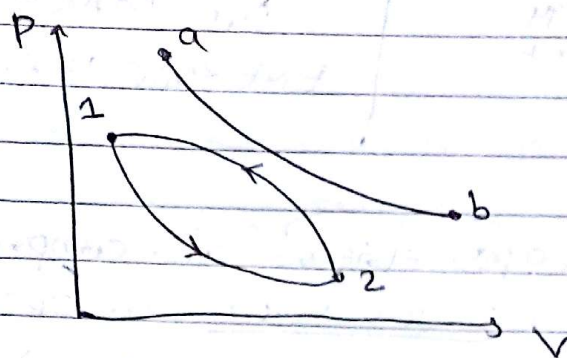
→ State - When all the properties of a system (temp., press, vol. etc) have a definite values, then system is said to exist at definite State.

→ Process - one or more properties of a system changes (change of state) through a definite path is called process.

→ Cycle - Series of State changes such that the final state is identical with initial state.



- Intensive (Independent of mass)  
→ pressure, temperature etc.  
density
- Extensive (related to mass)  
→ volume, energy etc.



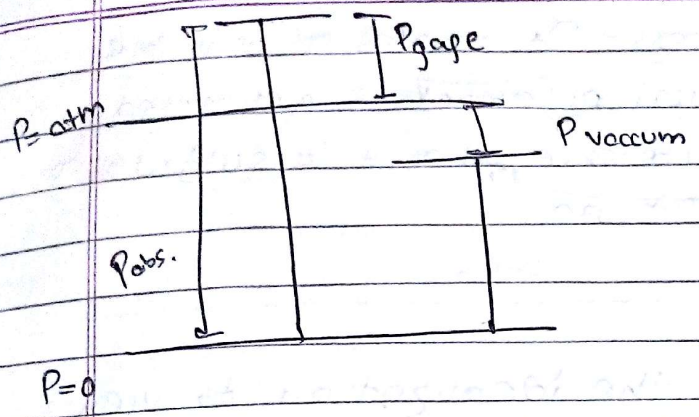
a-b - a process  
a-b-c-d-a cycle

Thermodynamic Equilibrium: No change in any macroscopic property if the system is isolated from its surroundings.  
3 cond's satisfied.

- Mechanical equilibrium → (absence of unbalanced forces)
  - Chemical " → (no chemical rxn)
  - Thermal " → (no heat flow b/w system and surroundings)  
↳ Temp. of system do not change
- Chemical composition do not change

Quasi-static process - When the process proceeds in such a way that the system remains infinitesimally close to an equilibrium state at all the times.





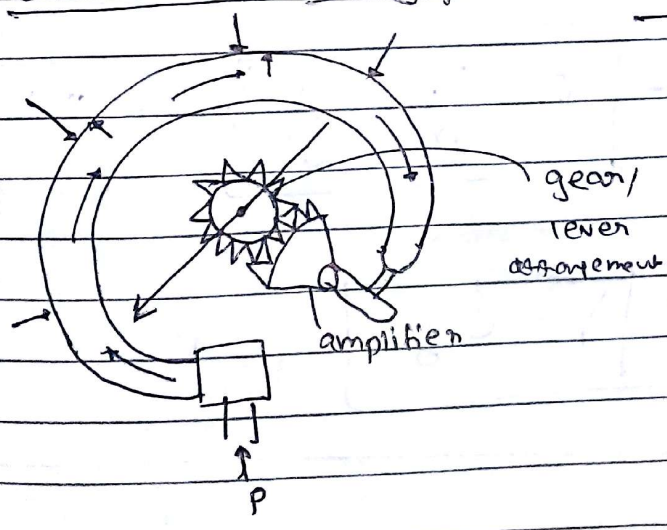
$$P_{gage} = P_{obs} - P_{atm}$$

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

Unit  $1 \text{ atm} = 1.01325 \text{ bar}$   
 $1 \text{ atm} = 101325 \text{ Pa}$   
 $1 \text{ atm} = 14.696 \text{ Psi}$  [pound force per square inch]

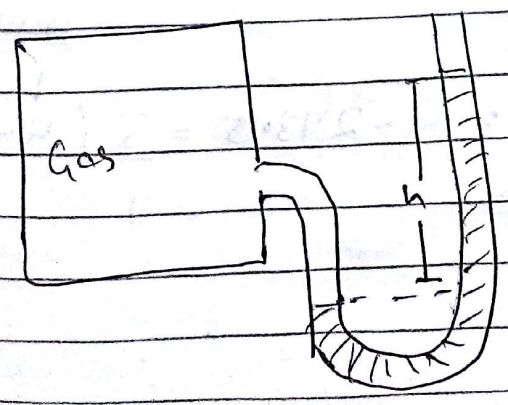
### Pressure measuring devices

#### i. Bourdon tube gage



→ it relies on the deformation of a bent hollow tube when subjected to the pressure to be measured inside and (atmospheric pr. outside) tends to unbend.

#### ii. Manometer → used to $P_{atm}$



Press. in a stationary fluid remains constant in horizontal dir.



3. Piezoelectric transducers - It works on principle that an electrical potential is generated in a crystalline substance when it is subjected to mechanical pressure.

# Continuum - It is the idealization to view substance as a continuous homogeneous matter with no void space. This allows us to treat properties as point func. and assume property is varying continuously in space with no jump discontinuities.

$$S.G = \frac{\rho_{\text{matter}}}{\rho_{\text{water}}}$$

Specific volume -  $\boxed{v = \frac{V}{m} = \frac{1}{\rho}} = \text{m}^3/\text{kg}$

Specific weight -  $\boxed{\gamma = \rho g}$   
(weight per unit volume)

Temperature Scale :

$$C = \frac{5}{9} (F - 32) = K - 273.15 = \frac{5}{9} (R - 491.67)$$

Rankine



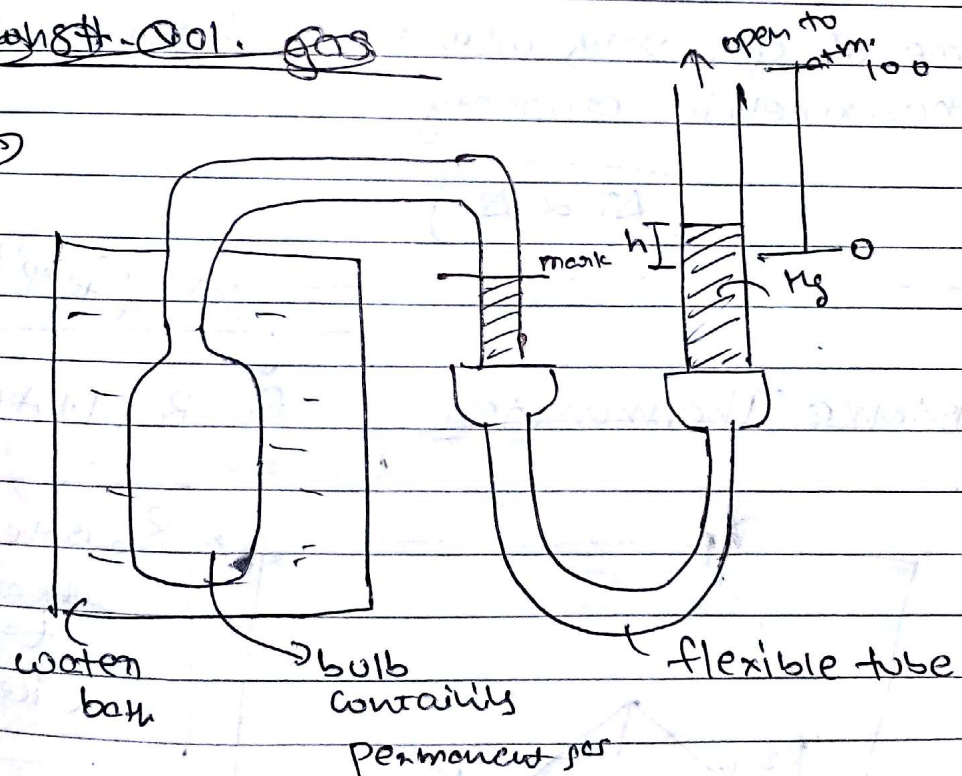
$$\frac{C - \text{melting point}}{b.p. - m.p.} = \frac{F - m.p.}{b.p. - m.p.}$$

$$\frac{C - 0}{100 - 0} = \frac{F - 32}{212 - 32} \Rightarrow C = \frac{5}{9}(F - 32)$$

## # Gas thermometer

- constt. vol. gas thermometer
- constt. pr. gas "

~~1/6 Constt. Vol. gas~~



During use, with the bulb in contact with system at diff. temp, the level of Hg can be adjusted to keep either the vol. or press. of gas constant.



# i. Constant volume gas thermometer

$$p = p_i (1 + \alpha T)$$

gas  
press.

where

$$\alpha = \frac{p_s - p_i}{100 p_i}$$

steam pt. press.      ice pt. press.

## ii. Constant pressure gas thermometer

to maintain constant 'h'

Volume of gas vary with temp becomes  
thermometric property

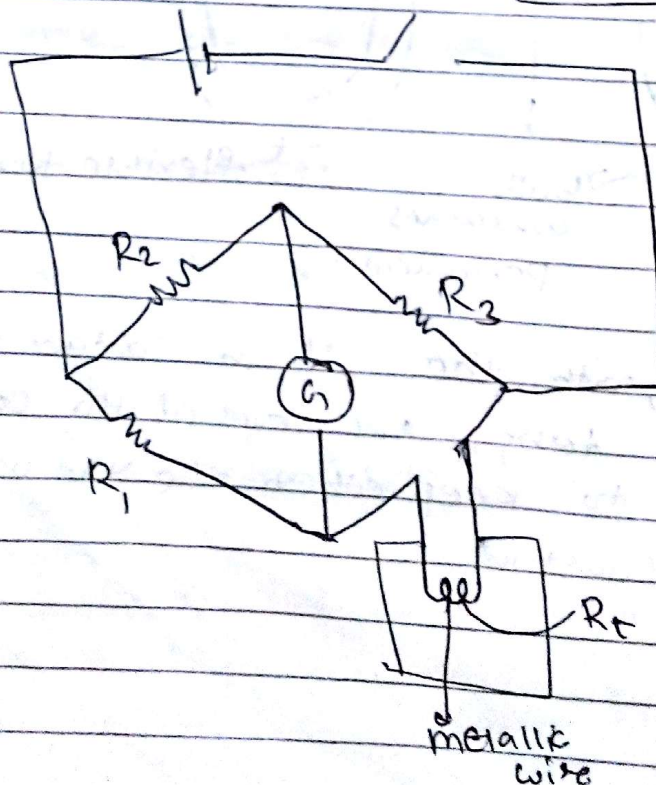
$$\Delta T \propto \Delta V$$

## iii. Resistance Thermometer

resistance at temp 't'

$$R_t = R_0 (1 + A t + B t^2)$$

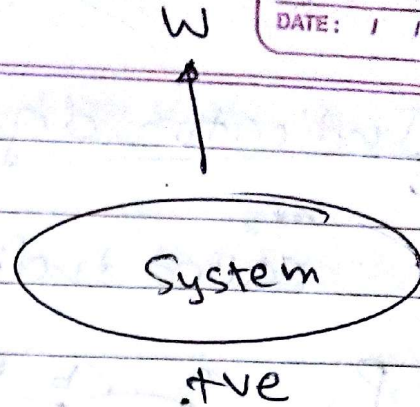
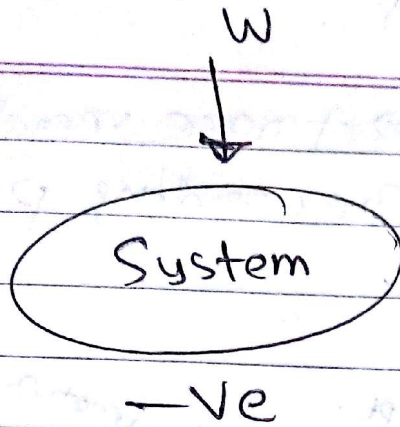
wheatstone  
bridge



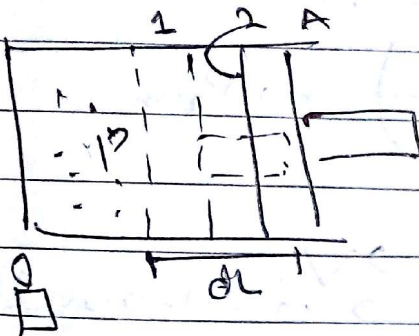
\*  $R_0$  is the resistance  
when at  
 $t = 0^\circ$   
(ice pt.)



WORK:



Displacement work:



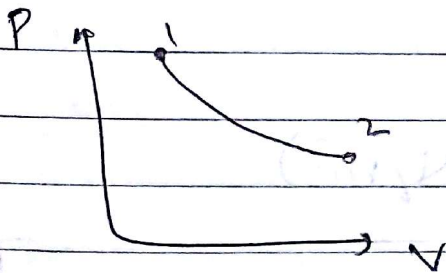
$$\delta W = F \cdot dL$$

$$= P A \cdot dL$$

$$\delta W = P dV_{\text{sweep}}$$

$$W_{\text{disp}} = \int_1^2 P dV$$

$$= P (V_2 - V_1)$$



Polytropic process

$$PV^n = \text{const.}$$

$$W_{\text{disp}} = C \int_1^2 \frac{dV}{V^n}$$

$$W = \frac{P_1 V_1 - P_2 V_2}{n-1}$$







For four stroke :  $P_i = \frac{P_m L A N}{2}$

Engine with

$P_m \uparrow$  deliver more effective power

## ENGINES

EC Engine  
(Steam Engine)

IC Engine

Spark  
ignition  
engine

Compression  
ignition  
engine

## Joule's Experiment

Mechanical equivalent of heat  $\rightarrow J$

$J = 4.1868$   $\frac{\text{N-m}}{\text{Cal}}$  work heat

$J = \frac{1 \text{ N-m}}{J}$

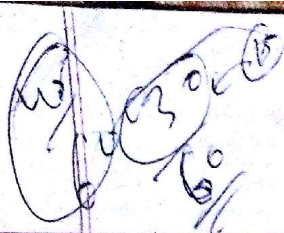
$J = \frac{\sum W}{\sum Q}$

$J \sum Q - \sum W = 0$  only for cyclic process

For non cyclic

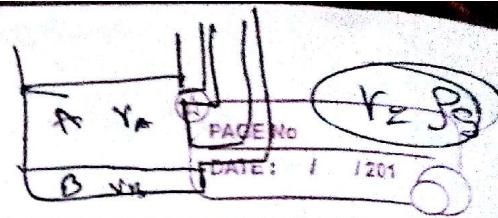
$J \sum Q - \sum W = E_2 - E_1$





Pressure head equivalent  $\Rightarrow$

$$h_A = \frac{P_A}{\gamma_B}$$



## # Properties of property



Observable characteristic of a system.

$\rightarrow \Delta V$  depends on end state and not on path

$\rightarrow$  magnitude <sup>changes by an amount</sup> which depends on end state

$\rightarrow$  In cyclic process, the net change in each property of system is zero.

$$\int_1^2 \underbrace{dQ - dW}_{\text{depends on path}} = \int_1^2 dE$$

change in internal stored energy  
(depends on end state)

## # Air standard Otto cycle



$$PV = C$$

$$P_1 V_1 = P_2 V_2 = C$$

$$W = \int P \cdot dV$$

$$= \int_{V_1}^{V_2} \frac{C}{V} \cdot dV$$



## TIPS

① For indicator dig. ques.

Take

S in KPa per m

P in kW

1 Mega = 1000 kilo



### 3.5 FREE EXPANSION WITH ZERO WORK TRANSFER

Work transfer is identified only at the boundaries of a system. It is a boundary phenomenon, and a form of energy in transit crossing the boundary. Let us consider a gas separated from the vacuum by a partition (Fig. 3.17). Let the partition be removed. The gas rushes to fill the entire volume. The expansion of a gas against vacuum is called *free expansion*. If we neglect the work associated with the removal of partition, and consider the gas and vacuum together as our system (Fig. 3.17a), there is no work transfer involved here, since no work crosses the system boundary, and hence

$$\int_1^2 \delta W = 0, \quad \text{although} \quad \int_1^2 p dV \neq 0$$

If only the gas is taken as the system (Fig. 3.17b), when the partition is removed there is a change in the volume of the gas, and one is tempted to calculate the work from the expression  $\int_1^2 p dV$ . However, this is not a quasi-static process, although the initial and final end states are in equilibrium. Therefore, the work cannot be calculated from this relation. The two end states can be located on the  $p$ - $V$  diagram and these are joined by a dotted line (Fig. 3.17c) to indicate that the process had

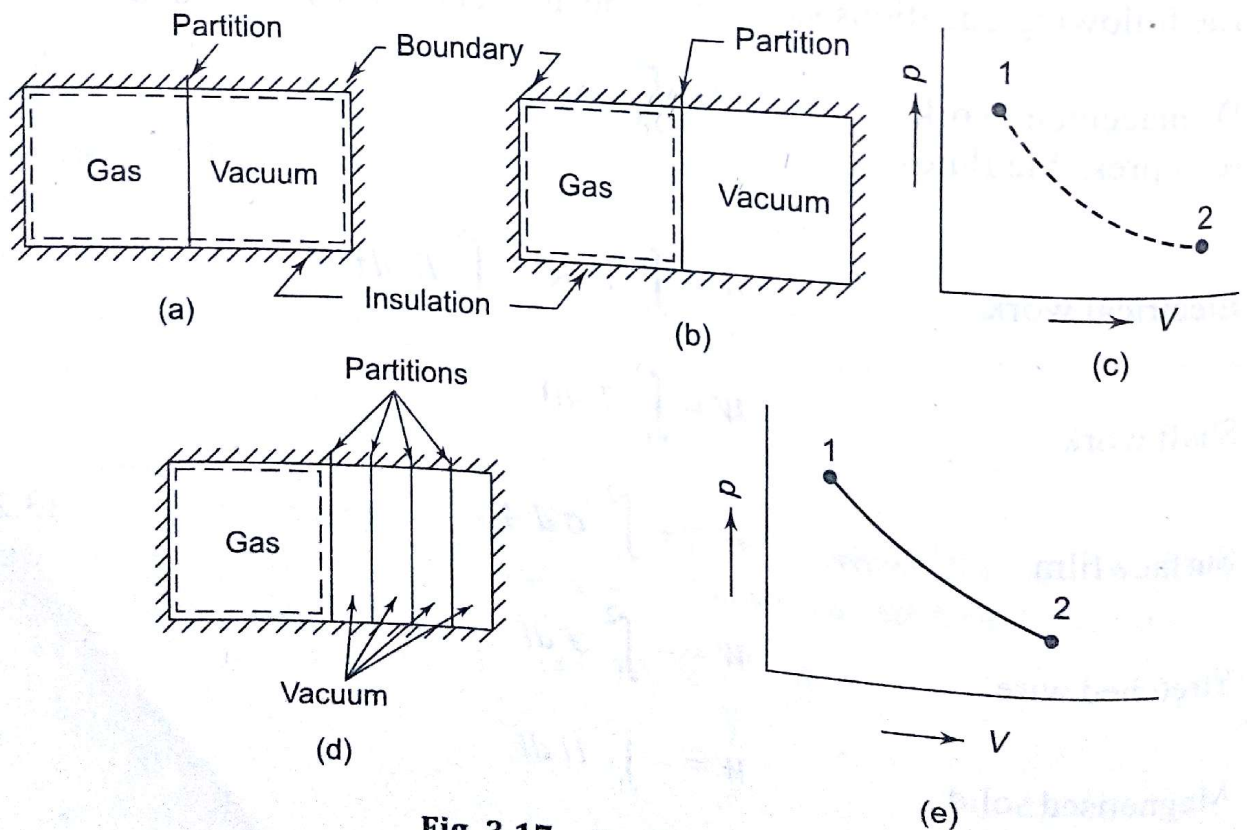


Fig. 3.17 Free Expansion



occurred. However, if the vacuum space is divided into a large number of small volumes by partitions and the partitions are removed one by one slowly (Fig. 3.17d), then every state passed through by the system is an equilibrium state and the work done can then be estimated from the relation  $\int_1^2 p dV$  (Fig. 3.17e). Yet, in free expansion of a gas, there is no resistance to the fluid at the system boundary as the volume of the gas increases to fill up the vacuum space. Work is done by a system to overcome some resistance. Since vacuum does not offer any resistance, there is no work transfer involved in free expansion.



### 3.3 INDICATOR DIAGRAM

An indicator diagram is a trace made by a recording pressure gauge, called the indicator, attached to the cylinder of a reciprocating engine. This represents the work done in one engine cycle. Figure 3.11 shows a typical engine indicator.

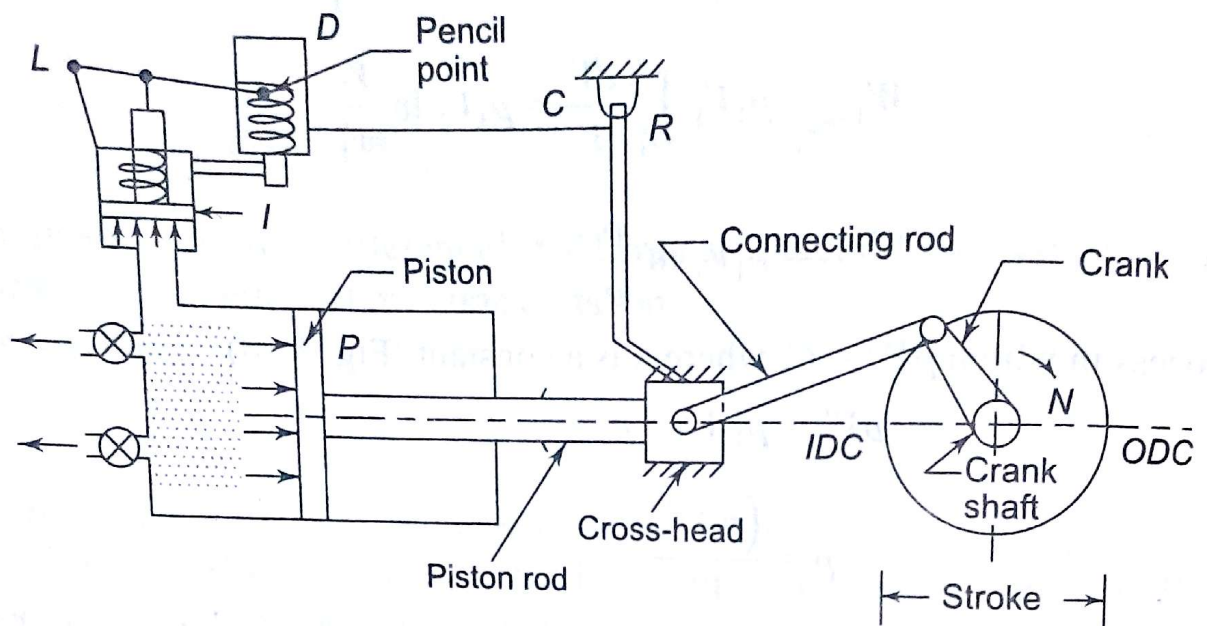


Fig. 3.11 Engine Indicator

The same gas pressure acts on both the engine piston  $P$  and the indicator piston  $I$ . The indicator piston is loaded by a spring and it moves in direct proportion to the change in pressure. The motion of the indicator piston causes a pencil held at the end of the linkage  $L$  to move upon a strip of paper wrapped around drum  $D$ . The drum is rotated about its axis by cord  $C$ , which is connected through a reducing motion  $R$  to the piston  $P$  of the engine. The surface of drum  $D$  moves horizontally under the pencil while the pencil moves vertically over the surface and a plot of pressure upon the piston vs. piston travel is obtained.

Before tracing the final indicator diagram, a pressure reference line is recorded by subjecting the indicator to the atmosphere and tracing a line at a constant pressure of one atmosphere.

[The area of the indicator diagram represents the magnitude of the net work done by the system in one engine cycle.] The area under the path 1-2 represents work done by the system and the area under the path 2-1 represents work done upon the system (Fig. 3.12). The area of the diagram,  $a_d$ , is measured by means of a planimeter, and the length of the diagram,  $l_d$ , is also measured. The mean effective pressure (m.e.p.)  $p_m$  is defined in the following way

$$p_m = \frac{a_d}{l_d} \times K$$

where  $K$  is the indicator spring constant ( $\text{N/cm}^2 \times \text{cm travel}$ ). Work done in one engine cycle

$$= (p_m \cdot A) L$$



An engine is said to be *double-acting*, if the working fluid is made to work both sides of the piston. Such an engine theoretically develops twice the amount of work developed in a single-acting engine. Most reciprocating steam engines are double-acting, and so are many marine diesel engines. Internal combustion engines for road transport are always single-acting.



## \* TYPES OF WORK

eg. ① Car battery  
② Tea kettle  
③ Water intake  
④ Piston-cylinder

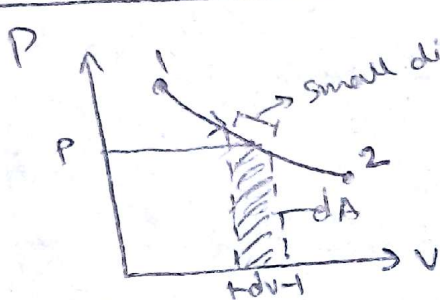
(1) Closed system work (non-flow work)  
(displacement work)

2, Open system work (flow work)

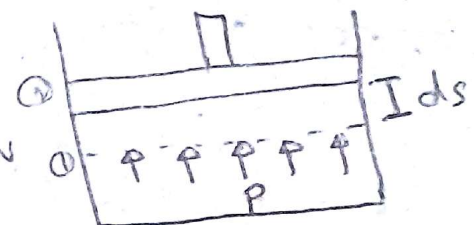
↓ [energy possessed by fluid by virtue of its pressure]

① CLOSED SYSTEM WORK: Consider a gas in a piston cylinder device. system is allowed to move a distance 'ds' in a quasi-static manner.

$$dW = Fds = PAds = PdV$$



let  
(Quasi-static process)  
1 → 2



$$W_{1-2} = \int_1^2 P dV$$

closed system work = Area under P-V curve projected on Volume axis

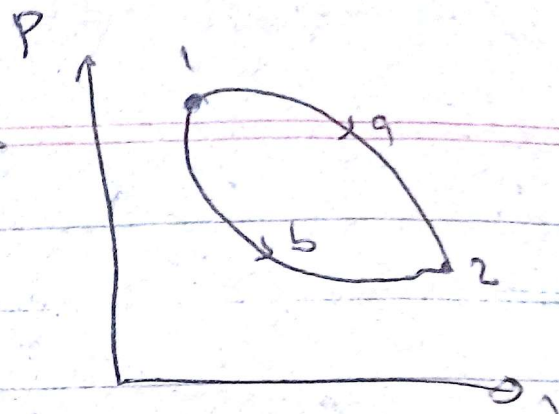
Conditions for applying  $W = \int P \cdot dV$

- closed system
- work should cross the boundary
- reversible process (Quasi-static)



⑧ Work is path function

Area under 1-a-2  $\neq$  Area under 1-b-2



⑨ Properties are state or point functions

↓ change

Volume, Pressure  
( $dV$ ) ( $dP$ )



## WORK DONE IN VARIOUS PROCESSES [CLOSED SYSTEM]

① Isochoric  $\therefore W = 0 \Rightarrow W = \int P dV$   $[dV = 0]$

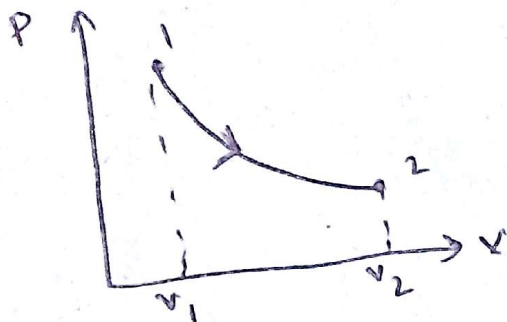
② Isobaric:  $W = P(V_2 - V_1) \Rightarrow W = \int_{V_1}^{V_2} P dV$

③ Isothermal:  $[P_1 V_1 = P_2 V_2] = C \quad W = \int \frac{C}{V} \cdot dV$

$$W = P_1 V_1 \ln\left(\frac{V_2}{V_1}\right) = P_1 V_1 \ln\left(\frac{P_1}{P_2}\right)$$

③

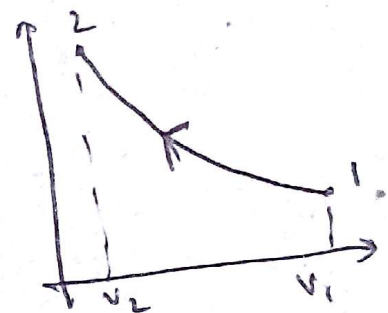
Isothermal Expansion



$$W = nRT \ln\left(\frac{V_2}{V_1}\right)$$

(+ve)

Isothermal Compression



$$W = nRT \ln\left(\frac{V_2}{V_1}\right)$$

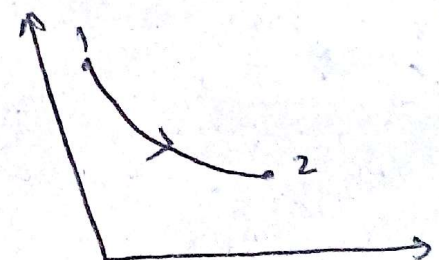
(-ve)

③ Adiabatic process

$$PV^\gamma = C$$

$$\boxed{\gamma > 1} \text{ always}$$

$$W_{1-2} = \frac{P_1 V_1 - P_2 V_2}{\gamma - 1}$$





## Polytropic process

$$PV^n = C$$

$$\boxed{\gamma > n \neq 1}$$

For closed system

$$\boxed{W = \frac{P_1 V_1 - P_2 V_2}{n-1}}$$

GENERAL EQN. FOR ALL PROCESSES IS

$$\boxed{PV^k = C}$$

① Const. pressure ( $k=0$ )

② Const. Volume  $PV^k = C \Rightarrow (PV^k)^{1/k} = C^{1/k}$

$$P^{1/k} V = C \quad k \rightarrow \infty \quad \boxed{V=C}$$

③ Isothermal  
 $k=1$

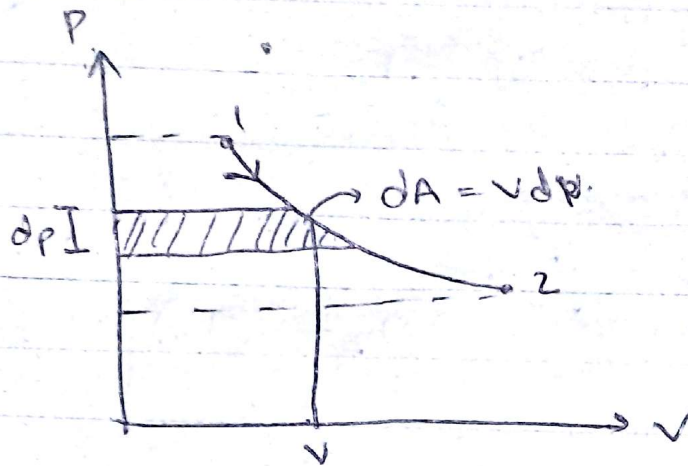
SLOPE OF ADIABATIC CURVE > SLOPE OF ISOTHERMAL CURVE



## ii) OPEN SYSTEM WORK

- ① water pump  
 ② scooter engine  
 ③ Boilers, turbines, heat exchangers

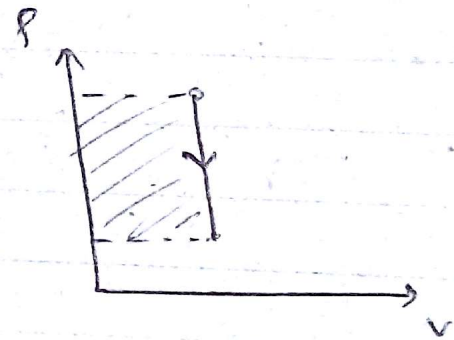
Open system work = Area under  $P-v$  curve on pressure axis



$$W = - \int v dp$$

### 1) Isochoric

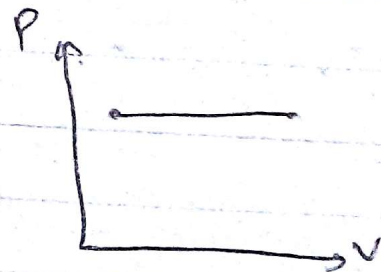
$$W = -V(P_2 - P_1)$$



### 2) Const. press.

$$W = -V \int dp$$

$$W = 0$$



3) Isothermal (work done in open system is equal to closed system)

(4, Adiabatic)

$$W = \frac{\gamma (P_1 V_1 - P_2 V_2)}{\gamma - 1}$$

(5, Polytropic)

$$W = \frac{n (P_1 V_1 - P_2 V_2)}{n - 1}$$



Although the system approach is quite valid, there is another approach which is found to be highly convenient. Instead of concentrating attention upon a certain quantity of fluid, which constitutes a moving system in flow processes, attention is focused upon a certain fixed region in space called a control volume through which the moving substance flows. This is similar to the analysis of Euler in fluid mechanics.

To distinguish the two concepts, it may be noted that while the system (closed boundary usually changes shape, position and orientation relative to the observer, the control volume boundary remains fixed and unaltered. Again, while matter usually crosses the control volume boundary, no such flow occurs across the system boundary.

The broken line in Fig. 5.1 represents the surface of the control volume which is known as the control surface. This is the same as the system boundary of the open system. The method of analysis is to inspect the control surface and account for all energy quantities transferred through this surface. Since there is mass transfer across the control surface, a mass balance also has to be made. Sections 1 and 2 allow mass transfer to take place, and  $Q$  and  $W$  are the heat and work interactions respectively.

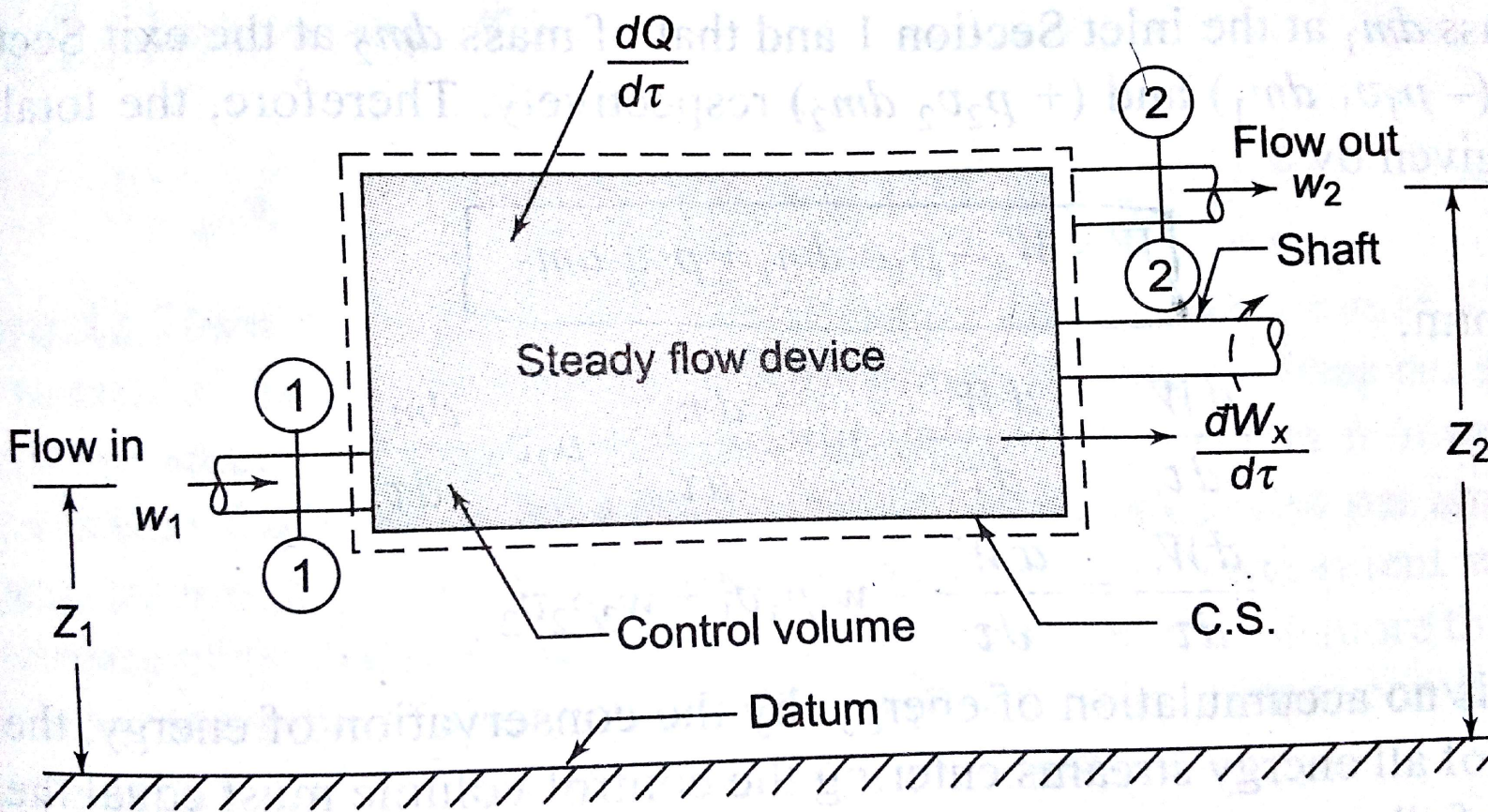


Fig. 5.2 Steady Flow Process



similarities between them:

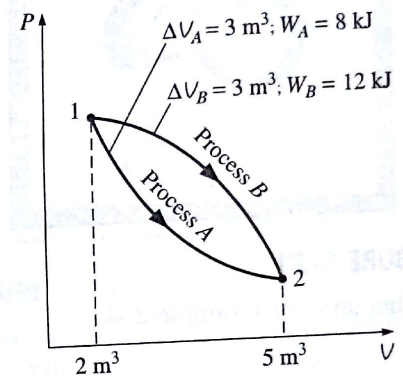
1. Both are recognized at the boundaries of a system as they cross the boundaries. That is, both heat and work are *boundary* phenomena.
2. Systems possess energy, but not heat or work.
3. Both are associated with a *process*, not a state. Unlike properties, heat or work has no meaning at a state.
4. Both are *path functions* (i.e., their magnitudes depend on the path followed during a process as well as the end states).

**Path functions** have **inexact differentials** designated by the symbol  $\delta$ . Therefore, a differential amount of heat or work is represented by  $\delta Q$  or  $\delta W$ , respectively, instead of  $dQ$  or  $dW$ . Properties, however, are **point functions** (i.e., they depend on the state only, and not on how a system reaches that state), and they have **exact differentials** designated by the symbol  $d$ . A small change in volume, for example, is represented by  $dV$ , and the total volume change during a process between states 1 and 2 is

$$\int_1^2 dV = V_2 - V_1 = \Delta V$$

That is, the volume change during process 1–2 is always the volume at state 2 minus the volume at state 1, regardless of the path followed (Fig. 2–19). The total work done during process 1–2, however, is

$$\int_1^2 \delta W = W_{12} \quad (\text{not } \Delta W)$$



**FIGURE 2–19**

Properties are point functions; but heat and work are path functions (their magnitudes depend on the path followed).