



**DEPT. OF MECHANICAL ENGINEERING**

**TRIDENT ACADEMY OF TECHNOLOGY,  
BHUBANESWAR**

**LECTURE NOTES**

**ON**

**BASIC MECHANICAL ENGINEERING 2-0-0**

**B. Tech**

**1<sup>ST</sup> / 2<sup>ND</sup> Semester**

**By**

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**Asst. Professor**

**Department of MECH**

## **BASIC MECHANICAL ENGINEERING 2-0-0**

### **MODULE-I (11 classes)**

Thermodynamics: Systems, Properties, Process, State, Cycle, Internal energy, Enthalpy, Zeroth Law, First law and Second Law of Thermodynamics, Basic Concept Entropy, Properties of ideal gas, Properties of pure substances, Enthalpy, Specific volume, Internal energy and dryness fraction of steam, use of Steam tables. Related numerical.

### **MODULE-2 (8 classes)**

Application of Thermodynamics: Single stage air compressor, Steam Power Plant, I.C. Engines (Brief Description on working principles with Schematic diagrams only)

Elements of Fluid Mechanics and Heat Transfer

Properties used in Fluid Mechanics, Fluid Statics, Kinematics and Dynamics (Concepts only), Heat transfer and Classifications (Concepts only)

### **MODULE-3 (7 Classes)**

Introduction to Manufacturing: Classification of engineering materials, Material Properties, Manufacturing processes: Welding, Casting, Forming (Basics only)

### **MODULE-4 (4 Classes)**

Basic Power transmission devices: Belt, Gear drives, clutch, brakes. (Working principle only)

Introduction to Robotics: Robot anatomy, Joints and links and common robot configurations.

### **Essential Reading**

- i. Basic Mechanical Engineering by Pravin Kumar, Pearson
- ii. Basic Mechanical Engineering by A R Israni, P K Shah, BS Publications
- iii. Text book of Elements of Mechanical Engineering, S T Murthy, Universities press
- iv. Basic and applied Thermodynamics by P. K. Nag, Tata McGraw Hill

### **Supplementary reading**

- i. Basic Mechanical Engineering by.D. Mishra, P. KParida, S.S.Sahoo, India Tech Publishing company
- ii. Elements of Mechanical Engineering by J K Kittur and G D Gokak, Willey
- iii. Basic Mechanical Engineering by BasantAgrawal, C M Agrawal, Willey
- iv. Engineering Thermodynamics by P. Chattopadhaya, Oxford University Press

### **COURSE OUTCOMES**

CO1: Comprehending the Law of Thermodynamics

CO2: Being aware of how crucial thermodynamics is to IC engines, power plants, refrigerators, and Heat Pump

CO3: Being aware of fluid mechanics and heat transfer concepts

CO4: Recognizing the functions of Engineering materials

CO5: Have a fundamental understanding of welding, Casting, Forming and other manufacturing techniques.

CO6: Recognizing fundamental power transfer mechanisms and aware of the fundamental robotics system.

# BASIC MECHANICAL ENGINEERING

## THERMODYNAMICS

### INTRODUCTION:

Thermo means heat

Dynamics means motion

Thermodynamics deals with the relation between heat and work.

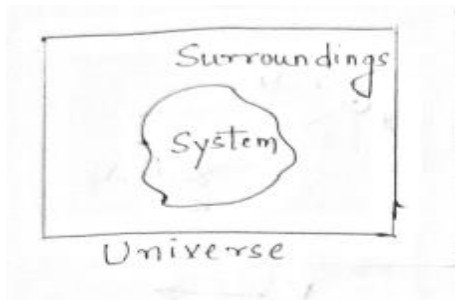
Defination- It is the science of energy transfer and its effect on the physical properties of the substances.

#### Application

- In steam and nuclear power plants.
- Internal combustion engines
- Gas turbines
- Air conditioning
- Gas dynamics
- Jet propulsion
- Compressor
- Chemical process plants etc.

### THERMODYNAMIC SYSTEM

It is defined as the quantity of matter bounded by some closed region upon which focus is concentrated.

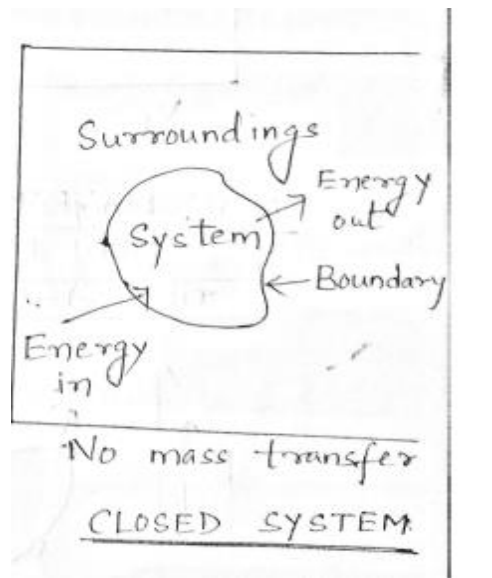


Surroundings: Everything external to the system is called surroundings .

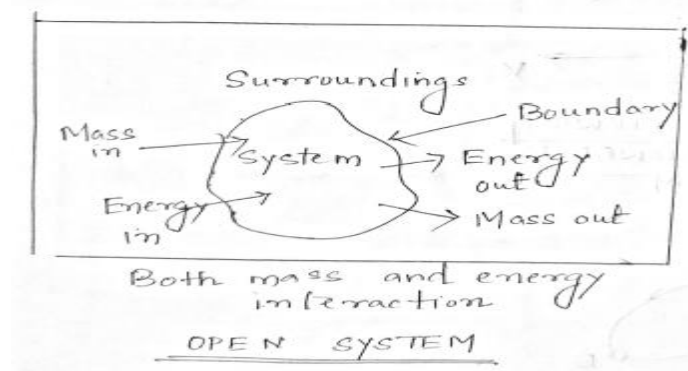
Universe: A system and its surroundings together comprise a universe.

### TYPES OF SYSTEM:

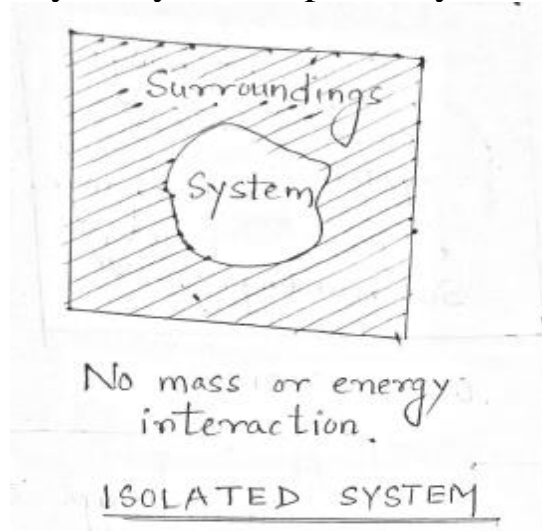
1. CLOSED SYSTEM: There is no transfer of mass across the system boundary but there may be energy transfer into or out of the system..Example- Piston and cylinder without valves , boiling of water in a closed container.



2. OPEN SYSTEM: There is exchange of both energy and mass between the system and the surroundings. Example-Air compressor, Internal Combustion Engines, Turbines, Boilers, Centrifugal Pumps, Nozzles , boiling of water in an open container etc.



3. **ISOLATED SYSTEM:** In isolated system neither energy nor mass transfer occurs between the system and the surroundings. Practically no system is perfectly isolated.



### MACROSCOPIC VERSUS MICROSCOPIC VIEW POINT

MACROSCOPIC APPROACH	MICROSCOPIC APPROACH
1.This is known as classical thermodynamics.	1.This is known as stastical thermodynamics.
2.In this approach a certain quantity of matter is considered without taking into account the events occurring at the molecular level.	2.This approach considers that the system is made up of a very large number of discrete particles known as molecules.
3.The analysis of macroscopic system requires simple mathematical formulae.	3.The behaviour of the system is found by using statistical methods as the number of molecules is very large.
4.In order to describe a system only a few properties are needed.	4.Large number of variables are needed to describe a system. So the approach is complicated.
5.Ex. Pressure, Temperature $P \neq P_1 + P_2 + P_3 + \dots$ $T \neq T_1 + T_2 + T_3 + \dots$	5.Ex. Velocity, Momentum, Impulse, Kinetic Energy, Enthalpy, Entropy, Weight $W = W_1 + W_2 + W_3 + \dots$

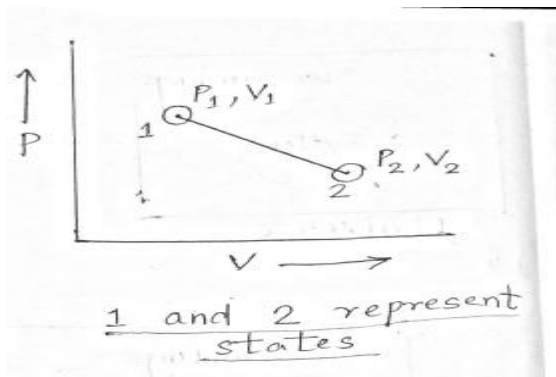
	$H=H_1+H_2+H_3+\dots$ $S=S_1+S_2+S_3+\dots$
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**THERMODYNAMIC PROPERTIES:** Each system has certain characters which determine its physical condition e.g. volume, temperature, pressure, enthalpy, entropy etc. Such characteristics are called properties of the system .

**STATE OF THE SYSTEM:** When all the properties of a system have definite values , the system is said to exist at a definite state . Hence properties are the co-ordinate to describe the particular state of a system.

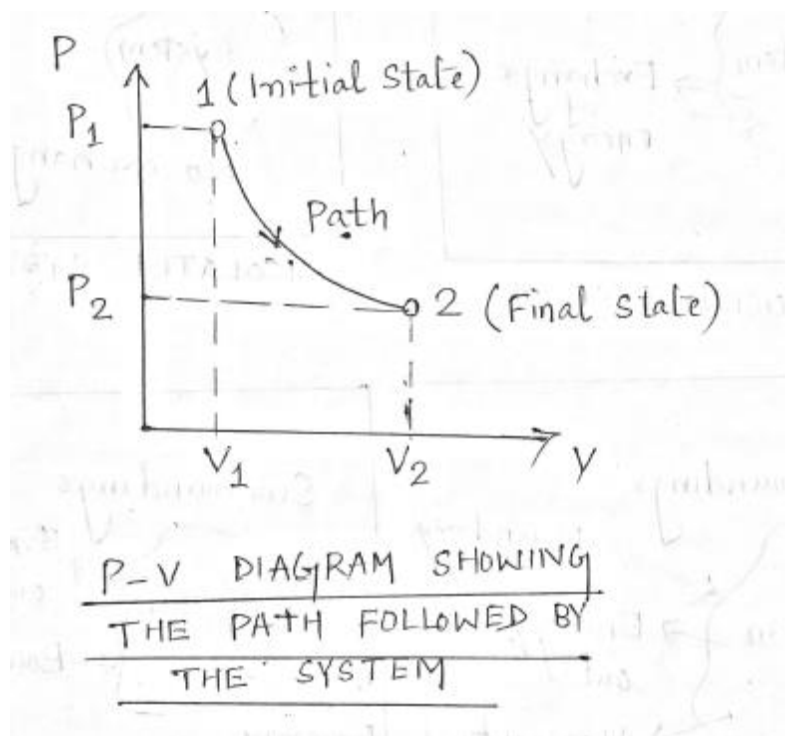
$$P_1=10\text{bar} , V_1= 5\text{m}^3 , T_1=25^\circ\text{C}$$

$$P_2=5\text{bar} , V_2= 15\text{m}^3 , T_2=35^\circ\text{C}$$



**CHANGE OF STATE:** Any operation in which one or more of the properties of a system changes is called a change of state.

**PATH OF CHANGE OF STATE:** The succession of states during the change from an initial state to a final state is called path of change of state.



## CLASSIFICATION OF PROPERTIES OF A SYSTEM

1. **INTENSIVE PROPERTIES:** Intensive properties are those whose value for the entire system does not equal the sum of their values for the part of the system. These properties do not depend on the mass of the system. Example-Temperature, Pressure, Density, Surface Tension, Specific Gravity. Etc.
2. **EXTENSIVE PROPERTIES:** Extensive properties are those whose values for the entire system equals the sum of their values for the parts of the system. These properties depend extensively on mass of the system. Example-Volume, Energy, Weight, Enthalpy, Entropy etc.

$$\text{Weight} = mg$$

$$\text{Kinetic Energy} = mv^2/2$$

$$\text{Potential Energy} = mgh$$

$$\text{Force} = ma$$

### NOTE:

- Specific extensive properties or extensive properties per unit mass are called intensive properties. Example-Specific

Volume, Specific Energy , Specific Enthalpy, Specific Entropy, Specific Weight etc. are extensive properties.

Sp. Kinetic Energy=  $K.E/m = v^2/2$

Sp.Potential Energy= $P.E/m=gh$

Specific Weight= $W/m=g$

Specific Volume= $V/m$

- The ratio of two Extensive properties is also called as intensive properties. Example- Density.

Density= mass/Volume

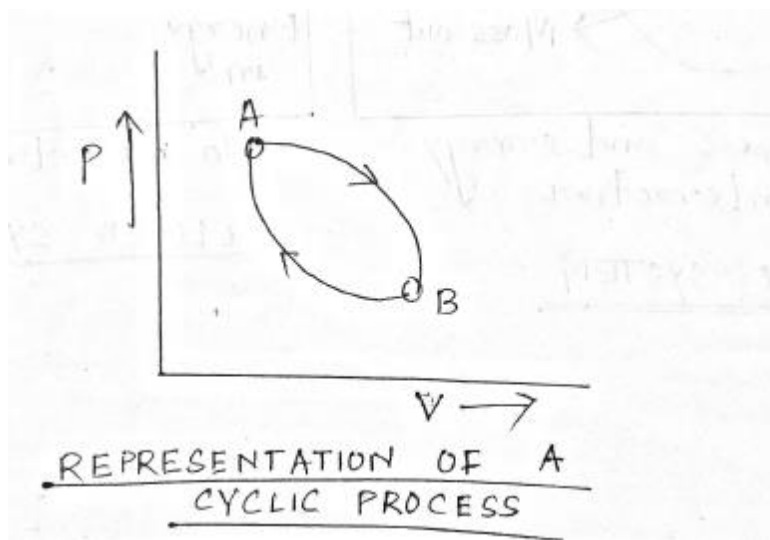
**PHASE OF A SUBSTANCE:** If the chemical composition and physical structure throughout the substance are uniform or homogenous then the substance is said to exist in a phase. There are three types of phases:

- Solid
- Liquid
- Gas

**HOMOGENOUS SYSTEM:** A system consisting of a single phase is called homogenous system.

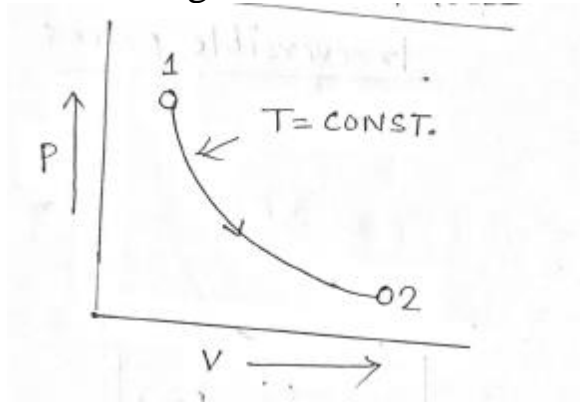
**HETEROGENOUS SYSTEM:** A system consisting of more than one phase is called heterogenous system.

**THERMODYNAMIC CYCLE OR CYCLIC PROCESS:** A cyclic process is one in which the end states are identical i.e. the system after undergoing a series of changes returns to its original condition.



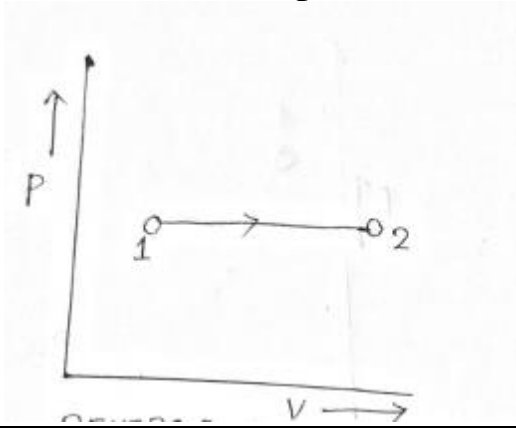
## TYPES OF PROCESSES

1. **ADIABATIC PROCESSES**: Adiabatic process is one in which there is no flow of heat between the system and the surroundings.
2. **ISOTHERMAL PROCESS**: Isothermal process is one in which there is an exchange of heat between the system and the surroundings.

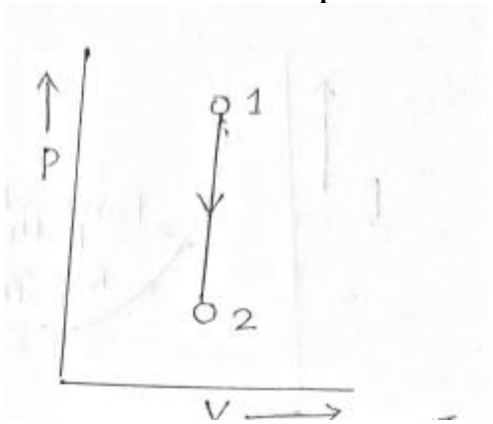


3. **FLOW PROCESS**: A flow process is one in which mass is entering and leaving through the boundary of an open system.
4. **NON FLOW PROCESS**: A non flow process is one in which a fixed mass within a defined boundary is undergoing a change of state. Example- a substance which is being heated in a closed cylinder undergoes a non flow process. Closed system undergoes non flow process.

5. **STEADY FLOW PROCESS**: In a steady flow process mass is crossing the boundary from surroundings at entry and an equal mass is crossing the boundary at the exit so that total mass of the system remains constant.
6. **ISOBARIC PROCESS**: A process in which pressure is constant is called isobaric process.



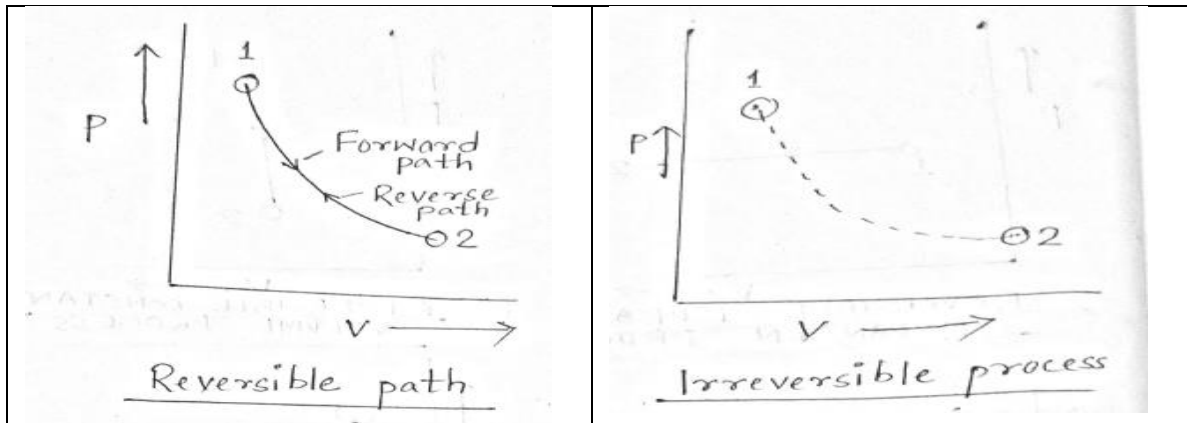
7. **ISOCHORIC PROCESS**: A process in which volume is constant is called isochoric process.



8. **REVERSIBLE PROCESS**: A reversible process is one which can be stopped at any stage and reversed so that the system and surroundings are restored to their initial states.
9. **IRREVERSIBLE PROCESS**: A process in which both system and its surroundings cannot be simultaneously returned to their initial states after the process has been completed.

## **DIFFERENCE BETWEEN REVERSIBLE AND IRREVERSIBLE PROCESS**

<b>REVERSIBLE PROCESS</b>	<b>IRREVERSIBLE PROCESS</b>
1.Reversible process is an ideal process.	2.Irreversible process is a natural process i.e. all the processes occurring in nature are irreversible.
2.Reversible process attains equilibrium state at all the stages of the operation.	2.Irreversible process is in equilibrium only at the initial and final stages of operation.
3.It is a extremely slow process.	3.It occurs at measurable speed.
4.It takes infinite time for the process to occur.	4.It takes place in finite time.
5.This process when undone will leave no history of events in the surroundings.	5.This process when undone will stop the process.
6.Example-Expansion and compression of the spring, Polytropic Expansion and Compression., Eiectrolysis.	6.Example-Combustion, Diffusion, Free Expansion, Heat Transfer, Plastic Deformation.
7.A reversible process is represented by a continuous line	7.An irreversible process is represented by a dotted line joining the end states to indicate that the intermediate states are indeterminate.



**THERMODYNAMIC EQUILIBRIUM:** A system is said to be in thermodynamic equilibrium when there is no change in the macroscopic properties if the system is isolated from the surroundings.

**CLASSIFICATION OF EQUILIBRIUM:**

1. **Mechanical Equilibrium:** A system is said to be in equilibrium if there is no unbalanced external force or pressure force within it.
2. **Chemical Equilibrium:** A system is said to be in chemical equilibrium if there is no chemical reaction within it.
3. **Thermal Equilibrium:** A system is said to be in chemical equilibrium if there is no temperature gradient or difference within it.

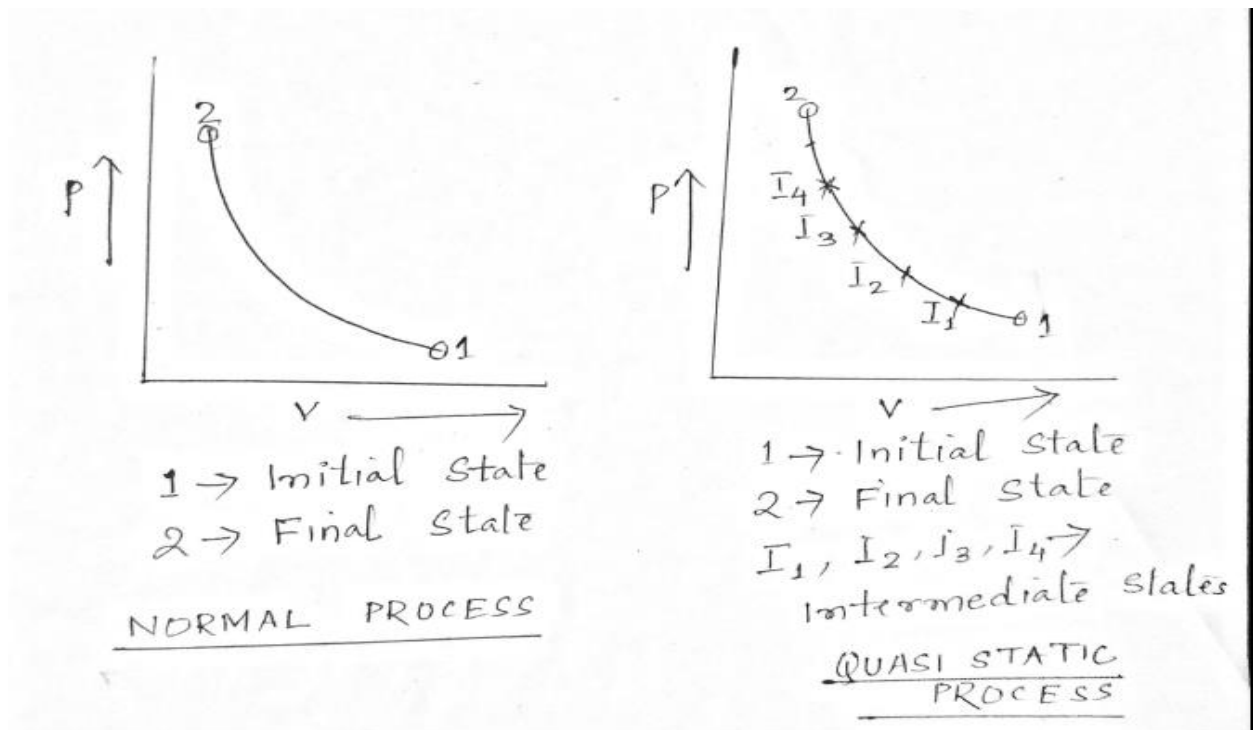
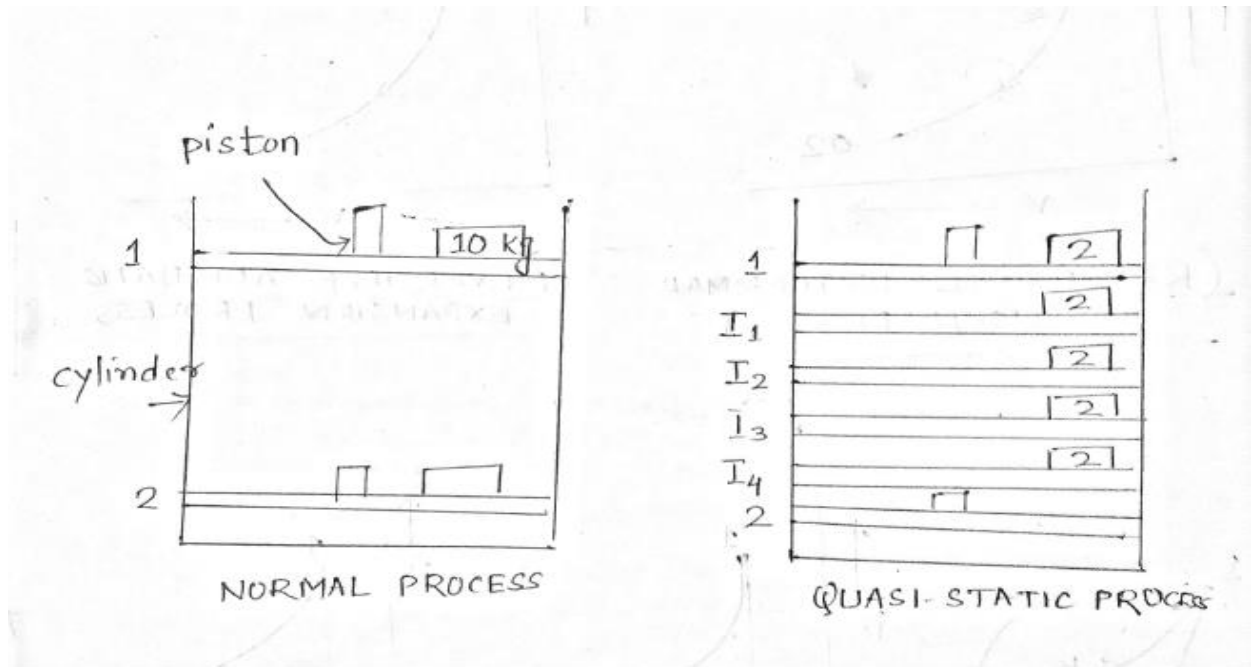
A system is said to be in thermodynamic equilibrium if it satisfies all these three conditions together otherwise it is said to be in thermodynamic non- equilibrium.

**QUASI-STATIC PROCESS:** A quasi-static process can be viewed as a sufficiently slow process that allows the system to adjust itself internally so that properties in one part of the system do not change any faster than those at other parts.

**Def.:** Quasistatic process is one in which system departs from equilibrium state only infinitesimally at every instant.

**Or**

Quasistatic process is a succession of equilibrium states and infinite slowness is its characteristic feature.



## POINT FUNCTIONS VERSUS PATH FUNCTION:

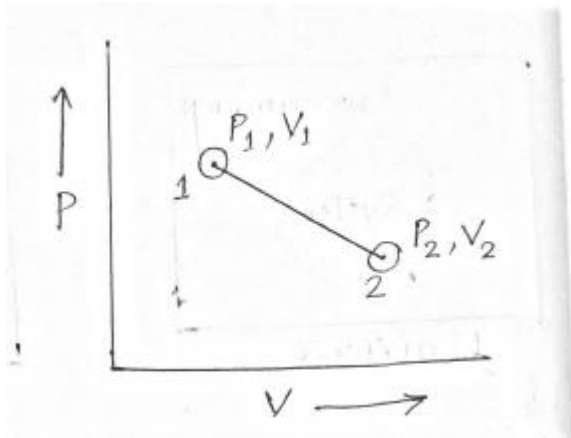
### POINT FUNCTIONS

1. When two properties locate a point on the graph (coordinate axes) then those properties are called as point function.
2. Example- Pressure, Temperature, Volume etc.]
3. They are exact differentials

$$\int dP = P_2 - P_1$$

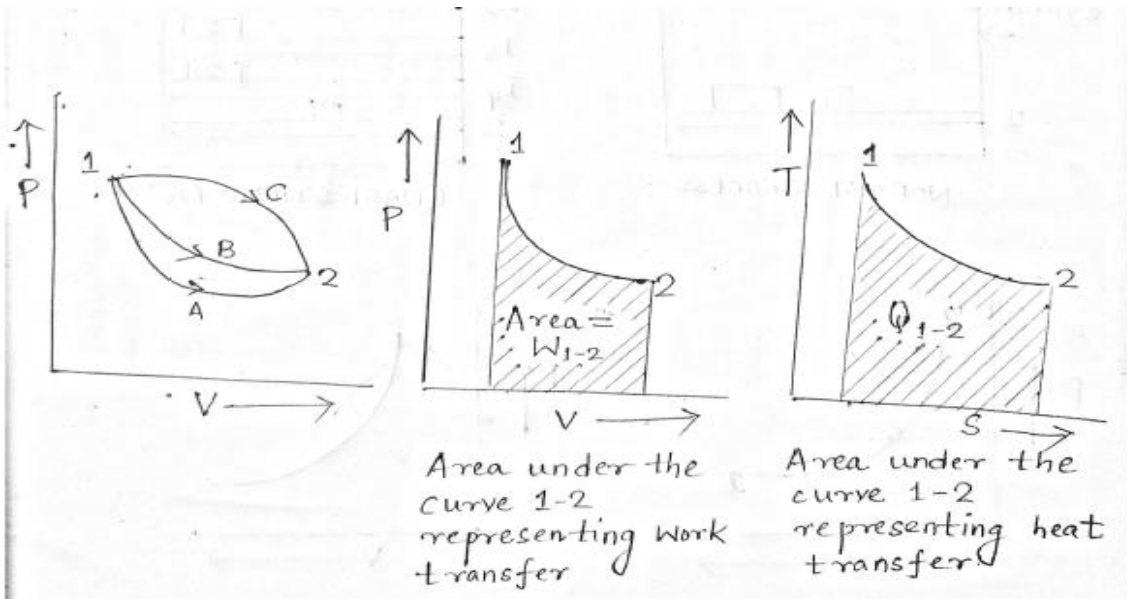
$$\int dV = V_2 - V_1$$

$$\int dT = T_2 - T_1$$



### PATH FUNCTIONS

1. These are certain quantities which cannot be located on a graph by a point but are given by the area under the curve.
  2. Examples-Heat, Work
  3. They are inexact differentials
- $$\int dQ \neq Q_2 - Q_1$$
- $$\int dW \neq W_2 - W_1$$
- ${}_1Q_2 \rightarrow Q_{1-2} \rightarrow$  Heat transfer in going from 1 to 2
- ${}_1W_2 \rightarrow W_{1-2} \rightarrow$  Work done in going from 1 to 2



## **PRESSURE AND ITS MEASUREMENT**

- **PRESSURE:** It is defined as the force per unit area.

$$P = \text{Force/Area} = F/A$$

Its unit is  $\text{N/m}^2$  , Pascal , Bar , Atm.

$$1 \text{ N/m}^2 = 1 \text{ Pascal}$$

$$1 \text{ bar} = 10^5 \text{ pascal or } 10^5 \text{ N/m}^2$$

$$1 \text{ atm.} = 101.325 \text{ KPa}$$

- **TYPES OF PRESSURE:**

**1.Absolute Pressure:** Absolute pressure of a fluid refers to the actual pressure of the fluid .Most pressure measuring devices or gauges read the difference between the actual pressure and local atmospheric pressure . Absolute pressure otherwise called actual pressure may be more than atmospheric pressure or less than atmospheric pressure.

**2.Atmospheric Pressure:**It is defined as the pressure exerted by a mercury column of 760 mm height. The instrument used for measuring this pressure is called barometer.

**3.Gauge Pressure :** It is defined as the pressure which is measured with the help of a pressure measuring instrument , in which the atmospheric pressure is taken as datum. The atmospheric pressure on the scale is marked as zero.

**4.Vacuum Pressure:** It is defined as the pressure below the atmospheric pressure.

**Relation between different types of Pressures:**

$$P_{\text{abs}} = P_{\text{atm}} + P_{\text{gauge}}$$

$$P_{\text{vacuum}} = P_{\text{atm}} - P_{\text{abs}}$$

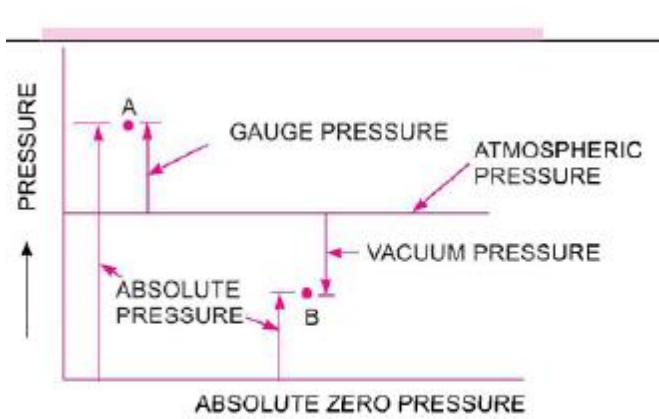


Fig. 2.7 Relationship between pressures.

## MEASUREMENT OF PRESSURE

$$P = \rho g Z$$

where  $Z$  = height of the fluid element

$P$  = Pressure

$\rho$  = Density of the fluid.

**Problem 2.3** Calculate the pressure due to a column of 0.3 of (a) water, (b) an oil of sp. gr. 0.8, and (c) mercury of sp. gr. 13.6. Take density of water,  $\rho = 1000 \text{ kg/m}^3$ .

**Solution.** Given :

Height of liquid column,  $Z = 0.3 \text{ m}$ .

The pressure at any point in a liquid is given by equation (2.5) as

$$p = \rho g Z$$

(a) For water,

$$\rho = 1000 \text{ kg/m}^3$$

$\therefore$

$$\begin{aligned} p &= \rho g Z = 1000 \times 9.81 \times 0.3 = 2943 \text{ N/m}^2 \\ &= \frac{2943}{10^4} \text{ N/cm}^2 = \mathbf{0.2943 \text{ N/cm}^2}. \text{ Ans.} \end{aligned}$$

(b) For oil of sp. gr. 0.8,

From equation (1.1A), we know that the density of a fluid is equal to specific gravity of fluid multiplied by density of water.

$$\begin{aligned} \therefore \text{Density of oil, } \rho_0 &= \text{Sp. gr. of oil} \times \text{Density of water} && (\rho_0 = \text{Density of oil}) \\ &= 0.8 \times \rho = 0.8 \times 1000 = 800 \text{ kg/m}^3 \end{aligned}$$

Now pressure,

$$\begin{aligned} p &= \rho_0 \times g \times Z \\ &= 800 \times 9.81 \times 0.3 = 2354.4 \frac{\text{N}}{\text{m}^2} = \frac{2354.4}{10^4} \frac{\text{N}}{\text{cm}^2} \\ &= \mathbf{0.2354 \frac{\text{N}}{\text{cm}^2}}. \text{ Ans.} \end{aligned}$$

(c) For mercury, sp. gr.

$$= 13.6$$

From equation (1.1A) we know that the density of a fluid is equal to specific gravity of fluid multiplied by density of water

$$\begin{aligned} \therefore \text{Density of mercury, } \rho_s &= \text{Specific gravity of mercury} \times \text{Density of water} \\ &= 13.6 \times 1000 = 13600 \text{ kg/m}^3 \end{aligned}$$

$\therefore$

$$\begin{aligned} p &= \rho_s \times g \times Z \\ &= 13600 \times 9.81 \times 0.3 = 40025 \frac{\text{N}}{\text{m}^2} \\ &= \frac{40025}{10^4} = \mathbf{4.002 \frac{\text{N}}{\text{cm}^2}}. \text{ Ans.} \end{aligned}$$

**Problem 2.4** The pressure intensity at a point in a fluid is given  $3.924 \text{ N/cm}^2$ . Find the corresponding height of fluid when the fluid is : (a) water, and (b) oil of sp. gr. 0.9.

**Solution.** Given :

Pressure intensity,  $p = 3.924 \frac{\text{N}}{\text{cm}^2} = 3.924 \times 10^4 \frac{\text{N}}{\text{m}^2}$ .

The corresponding height,  $Z$ , of the fluid is given by equation (2.6) as

$$Z = \frac{p}{\rho \times g}$$

(a) For water,

$$\rho = 1000 \text{ kg/m}^3$$

$$\therefore Z = \frac{p}{\rho \times g} = \frac{3.924 \times 10^4}{1000 \times 9.81} = 4 \text{ m of water. Ans.}$$

(b) For oil, sp. gr.

$$= 0.9$$

$\therefore$  Density of oil

$$\rho_0 = 0.9 \times 1000 = 900 \text{ kg/m}^3$$

$$\therefore Z = \frac{p}{\rho_0 \times g} = \frac{3.924 \times 10^4}{900 \times 9.81} = 4.44 \text{ m of oil. Ans.}$$

**Problem 2.5** An oil of sp. gr. 0.9 is contained in a vessel. At a point the height of oil is 40 m. Find the corresponding height of water at the point.

**Solution.** Given :

Sp. gr. of oil,  $S_0 = 0.9$

Height of oil,  $Z_0 = 40 \text{ m}$

Density of oil,  $\rho_0 = \text{Sp. gr. of oil} \times \text{Density of water} = 0.9 \times 1000 = 900 \text{ kg/m}^3$

Intensity of pressure,  $p = \rho_0 \times g \times Z_0 = 900 \times 9.81 \times 40 \frac{\text{N}}{\text{m}^2}$

$$\begin{aligned} \therefore \text{Corresponding height of water} &= \frac{p}{\text{Density of water} \times g} \\ &= \frac{900 \times 9.81 \times 40}{1000 \times 9.81} = 0.9 \times 40 = 36 \text{ m of water. Ans.} \end{aligned}$$

**Problem 2.6** An open tank contains water upto a depth of 2 m and above it an oil of sp. gr. 0.9 for a depth of 1 m. Find the pressure intensity (i) at the interface of the two liquids, and (ii) at the bottom of the tank.

**Solution.** Given :

Height of water,	$Z_1 = 2 \text{ m}$
Height of oil,	$Z_2 = 1 \text{ m}$
Sp. gr. of oil,	$S_o = 0.9$
Density of water,	$\rho_1 = 1000 \text{ kg/m}^3$
Density of oil,	$\rho_2 = \text{Sp. gr. of oil} \times \text{Density of water}$ $= 0.9 \times 1000 = 900 \text{ kg/m}^3$

Pressure intensity at any point is given by

$$p = \rho \times g \times Z.$$

(i) At interface, i.e., at A

$$\begin{aligned} p &= \rho_2 \times g \times 1.0 \\ &= 900 \times 9.81 \times 1.0 \\ &= 8829 \frac{\text{N}}{\text{m}^2} = \frac{8829}{10^4} = \mathbf{0.8829 \text{ N/cm}^2}. \text{ Ans.} \end{aligned}$$

(ii) At the bottom, i.e., at B

$$\begin{aligned} p &= \rho_2 \times g Z_2 + \rho_1 \times g \times Z_1 = 900 \times 9.81 \times 1.0 + 1000 \times 9.81 \times 2.0 \\ &= 8829 + 19620 = 28449 \text{ N/m}^2 = \frac{28449}{10^4} \text{ N/cm}^2 = \mathbf{2.8449 \text{ N/cm}^2}. \text{ Ans.} \end{aligned}$$

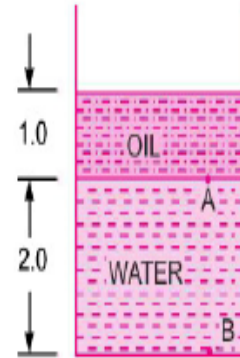


Fig. 2.4

## HOMEWORK

- Calculate the pressure due to a column of 0.4 m of (a) water, (b) an oil of sp. gr. 0.9, and (c) mercury of sp. gr. 13.6. Take density of water,  $\rho = 1000 \frac{\text{kg}}{\text{m}^3}$ . [Ans. (a) 0.3924 N/cm<sup>2</sup>, (b) 0.353 N/cm<sup>2</sup>, (c) 5.33 N/cm<sup>2</sup>]
- The pressure intensity at a point in a fluid is given 4.9 N/cm<sup>2</sup>. Find the corresponding height of fluid when it is : (a) water, and (b) an oil of sp. gr. 0.8. [Ans. (a) 5 m of water, (b) 6.25 m of oil]
- An oil of sp. gr. 0.8 is contained in a vessel. At a point the height of oil is 20 m. Find the corresponding height of water at that point. [Ans. 16 m]
- An open tank contains water upto a depth of 1.5 m and above it an oil of sp. gr. 0.8 for a depth of 2 m. Find the pressure intensity : (i) at the interface of the two liquids, and (ii) at the bottom of the tank. [Ans. (i) 1.57 N/cm<sup>2</sup>, (ii) 3.04 N/cm<sup>2</sup>]

3. A vacuum gauge mounted on a condenser reads 0.66 m Hg. What is the absolute pressure in the condenser in kPa when the atmospheric pressure is 101.3 kPa?

Soln.  $h_v = 0.66 \text{ m Hg}$

$$p_v = h \rho_g g = \left( \frac{0.66 \times 13600 \times 9.81}{1000} \right) = 88.05 \text{ KPa}$$

$$P_{ab} = P_{atm} - p_v = 101.3 - 88.05 = 13.25 \text{ KPa} \quad (\text{Ans})$$

4. Convert the following readings of pressure to kPa, assuming that the barometer reads 760 mm Hg. (a) 90 cm Hg gauge, (b) 40 cm Hg vacuum, (c) 1.2 m  $H_2O$  gauge, (d) 3.1 bar

Soln.  $h_{atm} = 760 \text{ mm of Hg} = 0.76 \text{ m of Hg}$

$$\rho_{Hg} = 13600 \text{ kg/m}^3$$

$$P_{atm} = h \rho_g \times g = 0.76 \times 13600 \times 9.81 = 101325 \text{ N/m}^2 \text{ (pa)} = 101.325 \text{ KPa} \quad (\text{Approx})$$

- (a) 90 cm Hg gauge = 0.9 m Hg

$$\therefore P_{at} = P_{atm} + P_g = 101.325 + \frac{0.9 \times 13600 \times 9.81}{1000} = 221.4 \text{ KPa} \quad (\text{Ans.})$$

- (b) 40 cm Hg vacuum

$$P_{ab} = P_{atm} - P_v = 101.325 - \frac{0.4 \times 13600 \times 9.81}{1000} = 154.6 \text{ KPa} \quad (\text{Ans.})$$

- (c) 1.2 m of  $H_2O$  gauge

$$\rho_{H_2O} = 1000 \text{ kg/m}^3$$

$$P_{ab} = P_{atm} + P_g = 101.325 + \frac{1.2 \times 1000 \times 9.81}{1000} = 113.09 \text{ KPa} \quad (\text{Ans.})$$

- (d) 3.1 bar

$$1 \text{ bar} = 10^5 \text{ N/m}^2 = 10^5 \text{ Pa} = 10^2 \text{ KPa}$$

$$3.1 \text{ bar} = 3.1 \times 10^5 \text{ N/m}^2 = 3.1 \times 10^2 \text{ KN/m}^2 = 310 \text{ KPa} \quad (\text{Ans.})$$

## **MEASUREMENT OF PRESSURE:**

The pressure of a fluid is measured by the following devices:

1. Manometers
2. Mechanical gauges.

**1.Manometers:** Manometers are defined as the devices used for measuring the pressure at a point in a fluid by balancing the column of fluid by the same or another column of fluid.They are classified as :

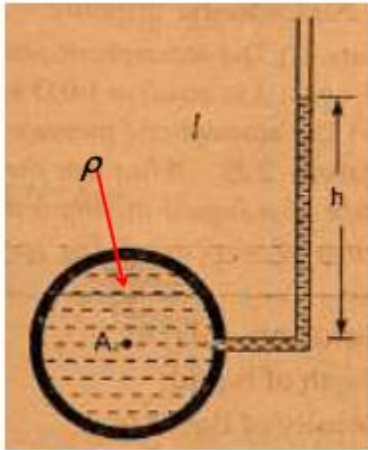
(a) Simple manometer

(b) Differential manometers.

(a) Simple Manometers: A simple manometer consist of a glass tube having one of its ends connected to a point where pressure is to be measured and other end remain open to the atmosphere. Common types of simple manometers are:

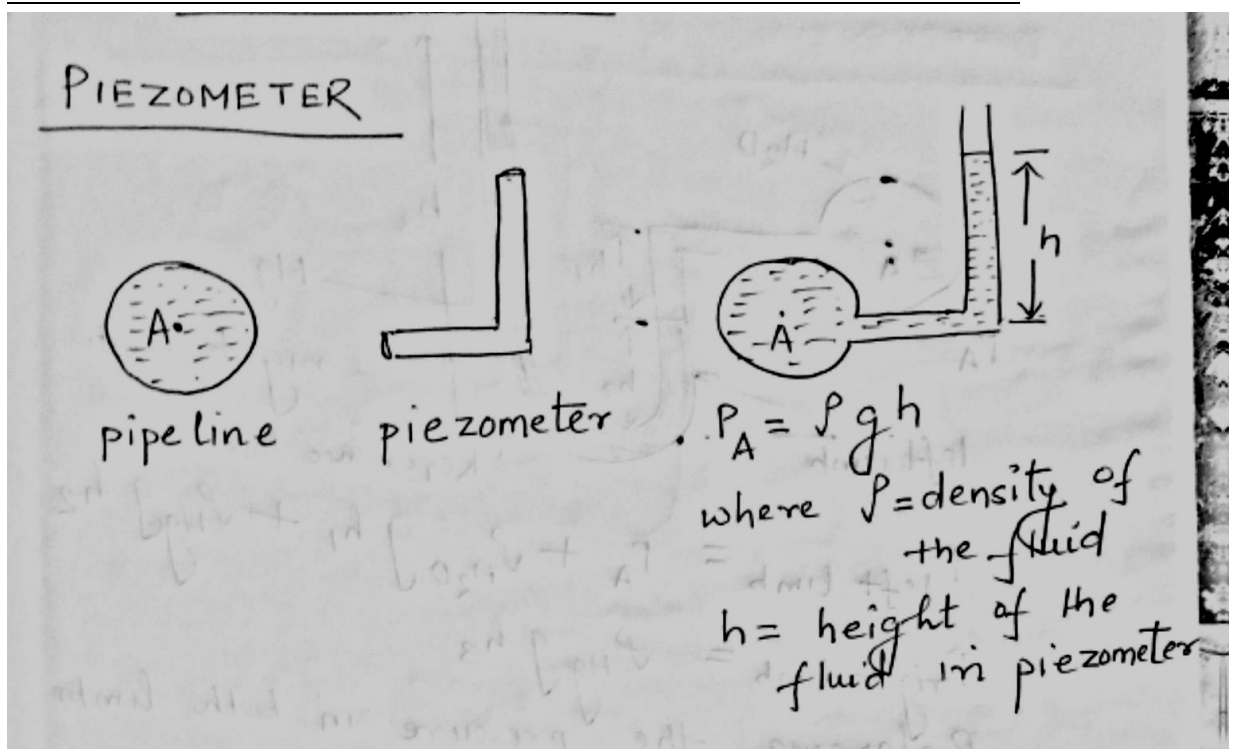
- Piezometer
- U-tube manometer
- Single column manometer

**Piezometer:** It is the simplest form of manometer used for measuring gauge pressures. One end of the manometer is connected to the point where pressure is to be measured and other end is open to the atmosphere



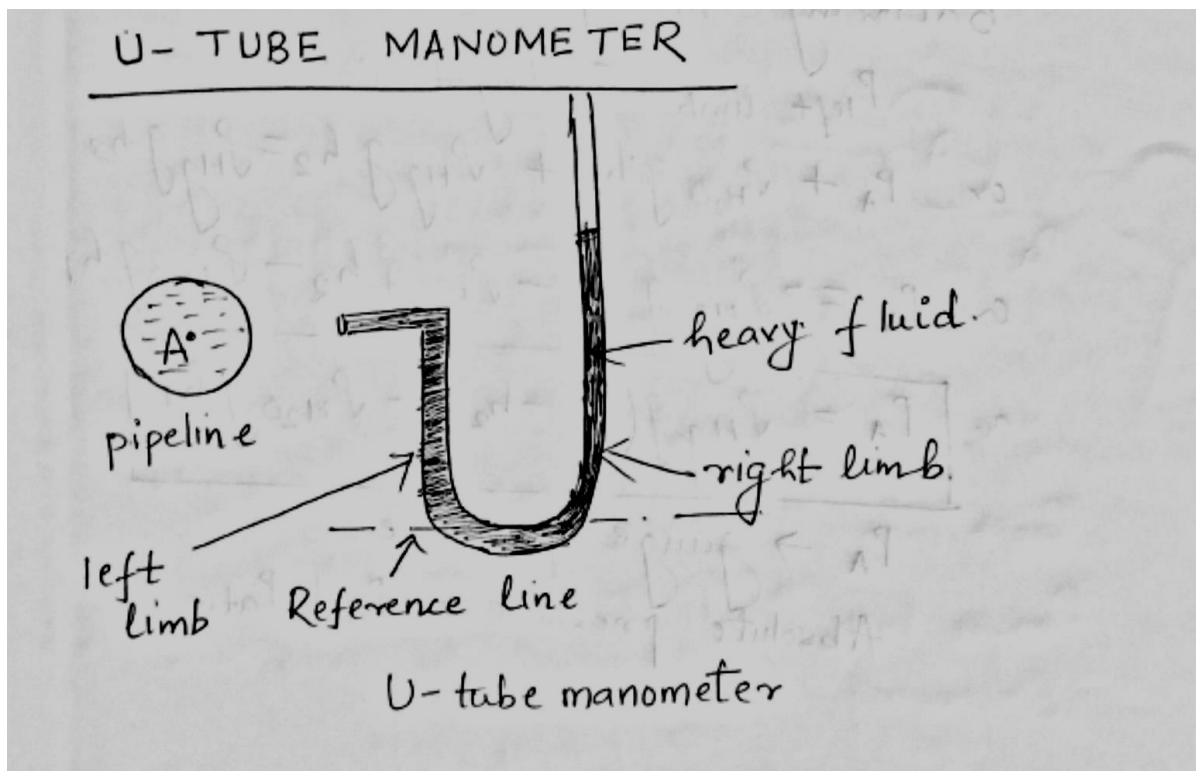
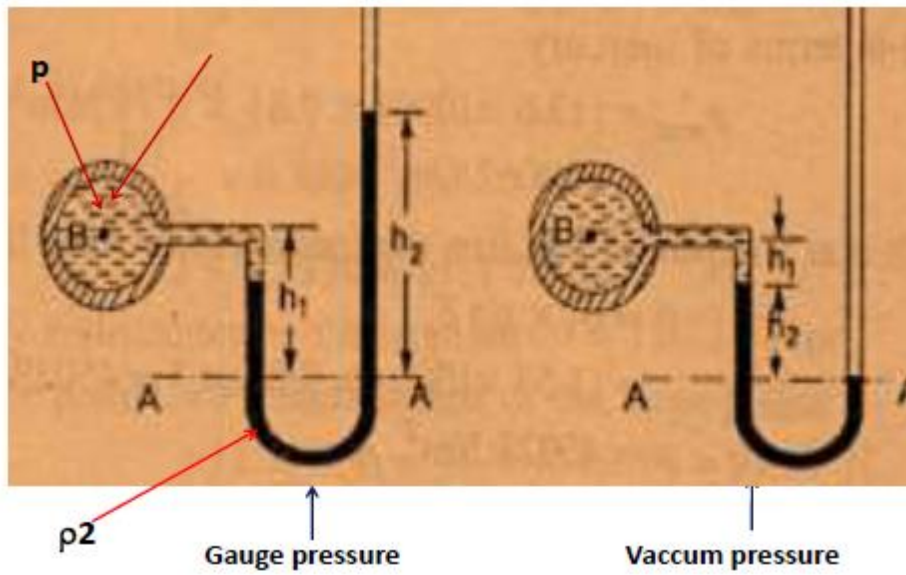
The rise of liquid 'h' gives the pressure at that point

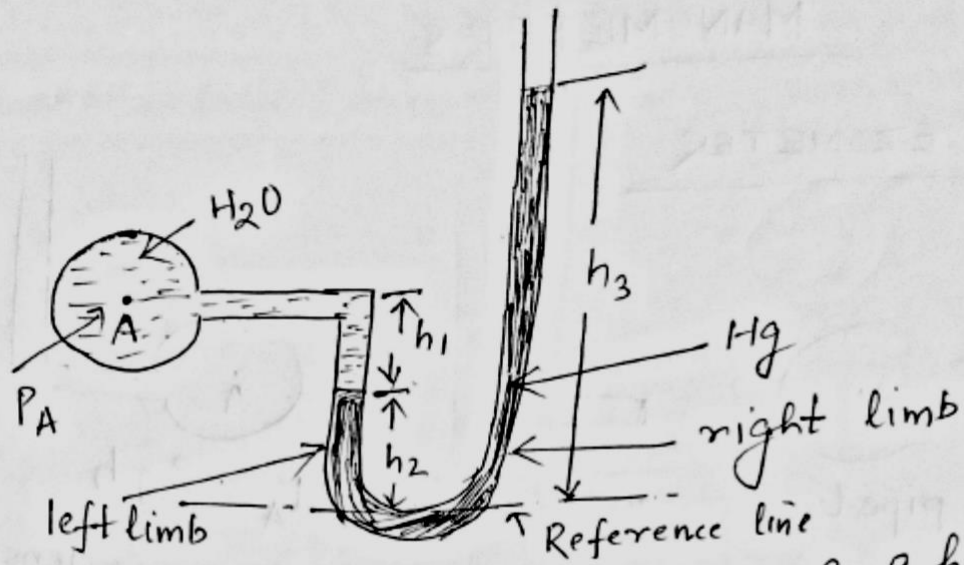
i.e.  $p = \rho \cdot g \cdot h$



**U-Tube Manometer:** It consists of a glass tube bent in U-shape , one end of which is connected to a point at which pressure is to be measured and other end remains open to the atmosphere .The tube generally contains mercury or any other liquid whose specific gravity is greater than the specific gravity of

the liquid whose pressure is to be measured.





$$P_{\text{left limb}} = P_A + \rho_{H_2O} g h_1 + \rho_{Hg} g h_2$$

$$P_{\text{right limb}} = \rho_{Hg} g h_3$$

Balancing the pressure in both limbs

$$P_{\text{left limb}} = P_{\text{right limb}}$$

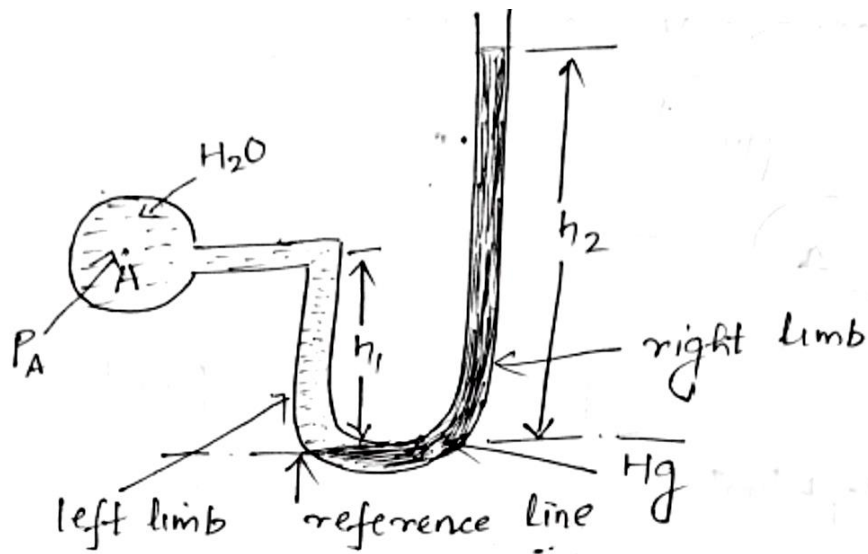
$$\text{or } P_A + \rho_{H_2O} g h_1 + \rho_{Hg} g h_2 = \rho_{Hg} g h_3$$

$$\text{or } P_A = \rho_{Hg} g h_3 - \rho_{Hg} g h_2 - \rho_{H_2O} g h_1$$

$$\text{or } \boxed{P_A = \rho_{Hg} g (h_3 - h_2) - \rho_{H_2O} g h_1}$$

$P_A \rightarrow$  gauge pressure.

Absolute pressure =  $P_A + P_{\text{atm}}$ .



$$P_{\text{left limb}} = P_A + \rho_{H_2O} g h_1$$

$$P_{\text{right limb}} = \rho_{Hg} g h_2$$

Balancing the pressure in both limbs

$$P_{\text{left limb}} = P_{\text{right limb}}$$

$$\text{or } P_A + \rho_{H_2O} g h_1 = \rho_{Hg} g h_2$$

$$\text{or } \boxed{P_A = \rho_{Hg} g h_2 - \rho_{H_2O} g h_1}$$

$P_A \rightarrow$  gauge pressure

Absolute manometer pressure =  $P_A + P_{\text{atm}}$ .

**For measuring Gauge pressure**

Pressure in the left limb =  $p + \rho_1 \cdot g \cdot h_1$

Pressure in the right limb =  $\rho_2 \cdot g \cdot h_2$

For the balance,

Pressure in the left limb = Pressure in the right limb

$$p + \rho_1 \cdot g \cdot h_1 = \rho_2 \cdot g \cdot h_2$$

$$p = (\rho_2 \cdot g \cdot h_2 - \rho_1 \cdot g \cdot h_1)$$

**For measuring Vacuum pressure**

Pressure in the left limb =  $p + \rho_1 \cdot g \cdot h_1 + \rho_2 \cdot g \cdot h_2$

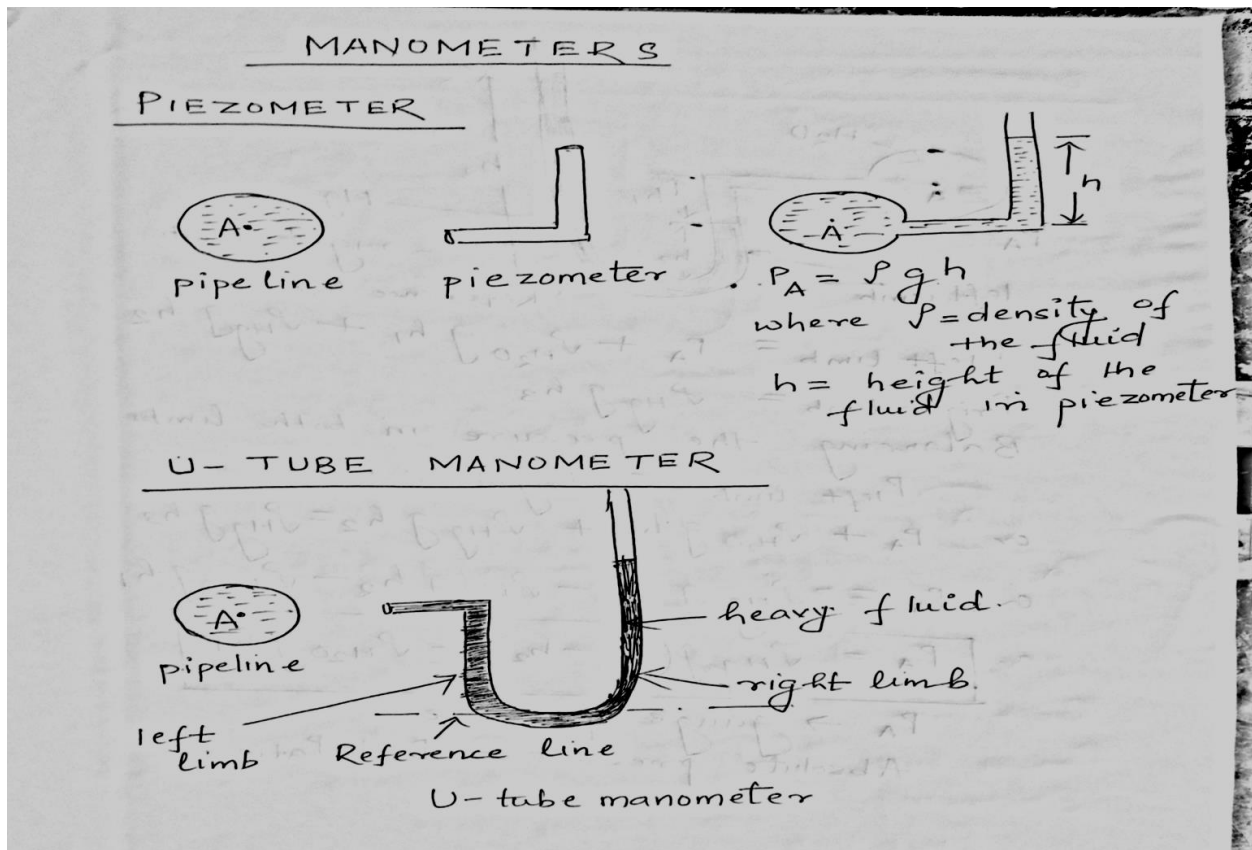
Pressure in the right limb = 0

For the balance,

Pressure in the left limb = Pressure in the right limb

$$p + \rho_1 \cdot g \cdot h_1 + \rho_2 \cdot g \cdot h_2 = 0$$

$$p = - (\rho_2 \cdot g \cdot h_2 + \rho_1 \cdot g \cdot h_1)$$



**Problem 2.9** The right limb of a simple U-tube manometer containing mercury is open to the atmosphere while the left limb is connected to a pipe in which a fluid of sp. gr. 0.9 is flowing. The centre of the pipe is 12 cm below the level of mercury in the right limb. Find the pressure of fluid in the pipe if the difference of mercury level in the two limbs is 20 cm.

**Solution.** Given :

- Sp. gr. of fluid,  $S_1 = 0.9$   
 $\therefore$  Density of fluid,  $\rho_1 = S_1 \times 1000 = 0.9 \times 1000 = 900 \text{ kg/m}^3$   
 Sp. gr. of mercury,  $S_2 = 13.6$   
 $\therefore$  Density of mercury,  $\rho_2 = 13.6 \times 1000 \text{ kg/m}^3$   
 Difference of mercury level,  $h_2 = 20 \text{ cm} = 0.2 \text{ m}$   
 Height of fluid from A-A,  $h_1 = 20 - 12 = 8 \text{ cm} = 0.08 \text{ m}$

Let  $p$  = Pressure of fluid in pipe

Equating the pressure above A-A, we get

$$p + \rho_1 g h_1 = \rho_2 g h_2$$

or  $p + 900 \times 9.81 \times 0.08 = 13.6 \times 1000 \times 9.81 \times .2$   
 $p = 13.6 \times 1000 \times 9.81 \times .2 - 900 \times 9.81 \times 0.08$   
 $= 26683 - 706 = 25977 \text{ N/m}^2 = \mathbf{2.597 \text{ N/cm}^2}$ . Ans.

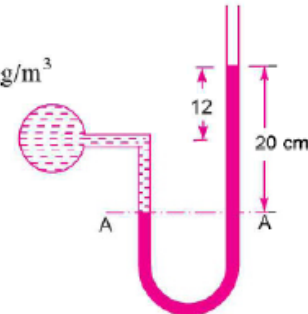


Fig. 2.10

**Problem 2.10** A simple U-tube manometer containing mercury is connected to a pipe in which a fluid of sp. gr. 0.8 and having vacuum pressure is flowing. The other end of the manometer is open to atmosphere. Find the vacuum pressure in pipe, if the difference of mercury level in the two limbs is 40 cm and the height of fluid in the left from the centre of pipe is 15 cm below.

**Solution.** Given :

- Sp. gr. of fluid,  $S_1 = 0.8$   
 Sp. gr. of mercury,  $S_2 = 13.6$   
 Density of fluid,  $\rho_1 = 800$   
 Density of mercury,  $\rho_2 = 13.6 \times 1000$

Difference of mercury level,  $h_2 = 40 \text{ cm} = 0.4 \text{ m}$ . Height of liquid in left limb,  $h_1 = 15 \text{ cm} = 0.15 \text{ m}$ . Let the pressure in pipe =  $p$ . Equating pressure above datum line A-A, we get

$$\rho_2 g h_2 + \rho_1 g h_1 + p = 0$$

$$\therefore p = - [\rho_2 g h_2 + \rho_1 g h_1]$$

$$= - [13.6 \times 1000 \times 9.81 \times 0.4 + 800 \times 9.81 \times 0.15]$$

$$= - [53366.4 + 1177.2] = - 54543.6 \text{ N/m}^2 = - \mathbf{5.454 \text{ N/cm}^2}$$
. Ans.

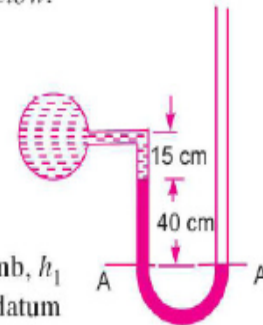
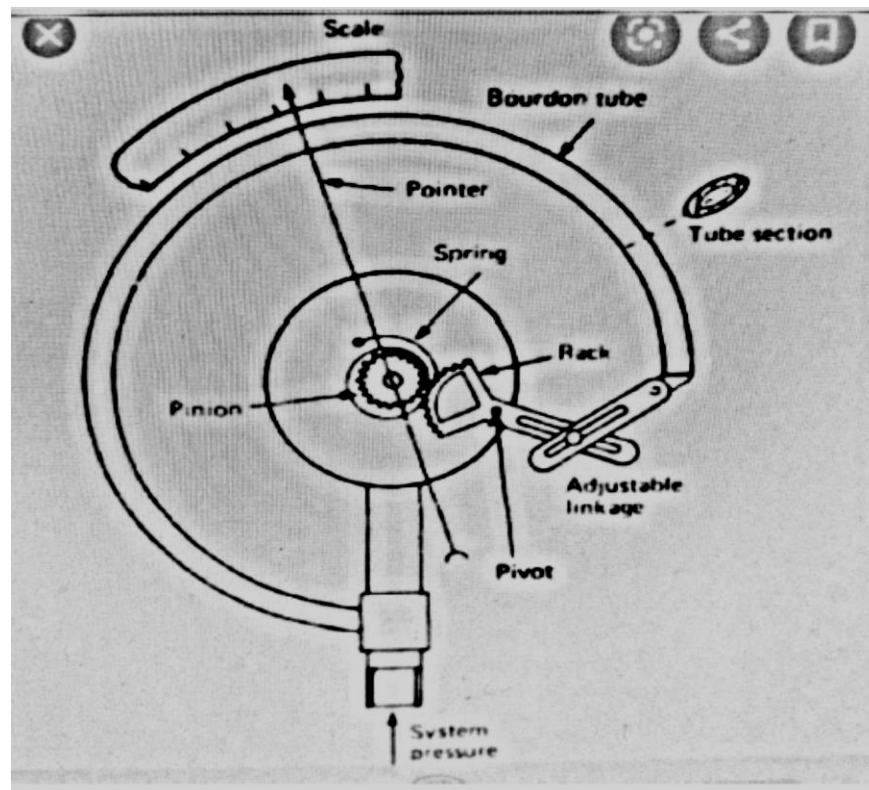


Fig. 2.11

**MECHANICAL GAUGES:** Mechanical gauges are defined as the devices used for measuring the pressure by balancing fluid column by the spring or dead weight. The commonly used mechanical pressure gauges are:

1. Diaphragm pressure gauge
2. Bourdon Tube pressure gauge
3. Dead-Weight pressure gauge
4. Bellows pressure gauge

**BOURDON TUBE PRESSURE GAUGE:**



### **WORKING PRINCIPLE:**

- Bourdon gauge measures the difference between the system pressure inside the tube and atmospheric pressure.
- It relies on the deformation of a bent hollow tube of suitable material which when subjected to the pressure to be measured on the inside and atmospheric pressure on outside, tends to unbend.
- This moves a pointer through a suitable gear and lever mechanism against a calibrated scale.

$$\text{Reading of the Bourdon Tube} = P_{\text{system}} - P_{\text{atmosphere}}$$

Or,

$$P_{\text{system}} = \text{Reading of the Bourdon Tube} + P_{\text{atmosphere}}$$

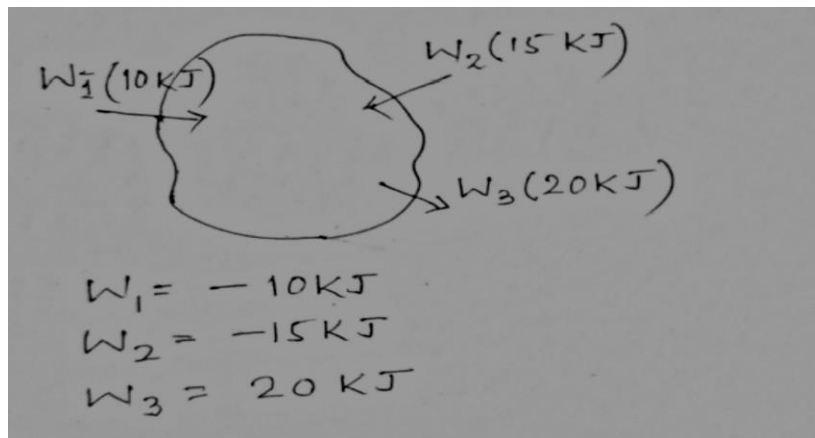
## WORK AND HEAT TRANSFER

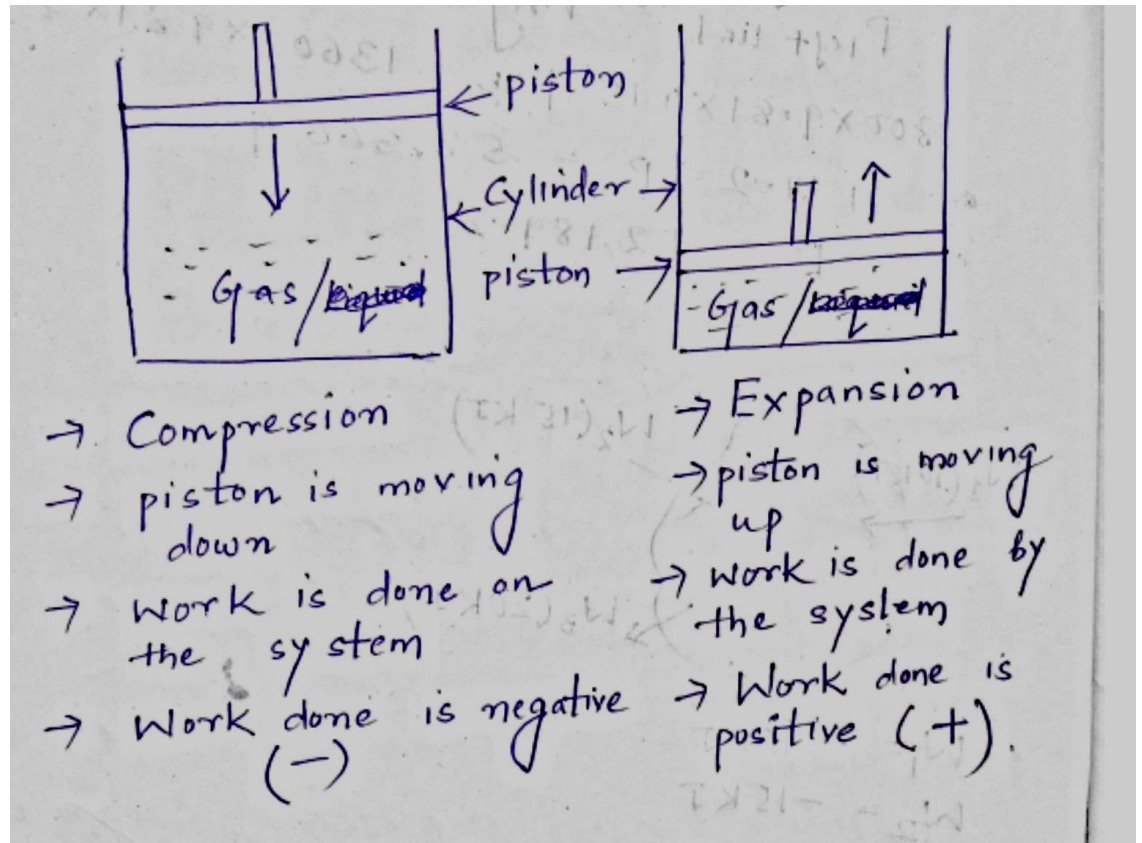
INTRODUCTION : A closed system and its surroundings can interact in two ways: 1. by work transfer 2. By heat transfer which is called energy interactions.

WORK TRANSFER: In physics work is defined as the product of Force and its perpendicular distance.

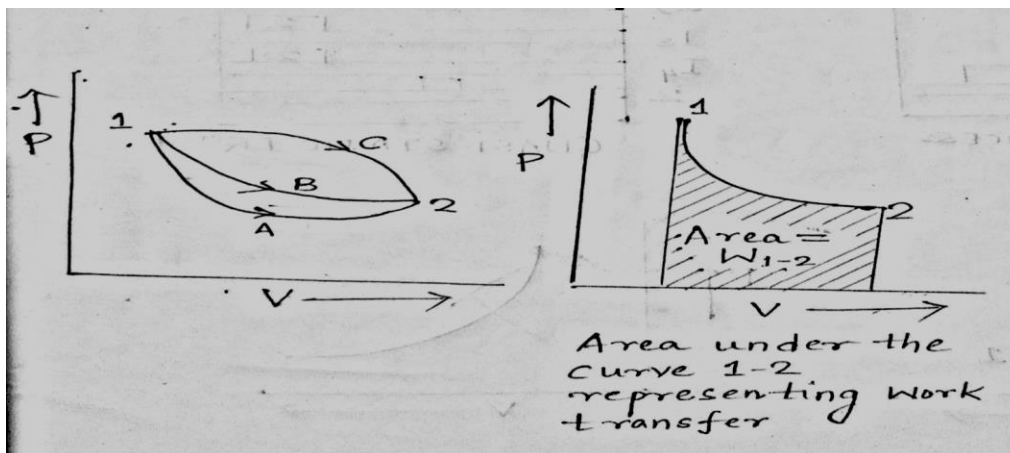
In thermodynamics “Work is defined as the energy in transition which flows from a system to its surroundings when the sole effect external to the system can be reduced to the raising of weight.”

- Unit of Work is Nm or Joule.
- The rate at which work is done by or upon the system is known as Power. The unit of Power is J/sec or Watt.
- SIGN CONVENTION;
  1. When work is done by the system ,it is taken as positive.
  2. When work is done on the system , it is taken as negative.





**PATH FUNCTION:** Work is called Path Function because the amount of work evolved is not a function of end states of the process, and it depends on the path the system follows in going from one state to another.



# DISPLACEMENT WORK

## 3.3 PDV WORK OR DISPLACEMENT WORK

Let  $P_1, V_1, T_1$  are properties of a system of gas in the cylinder at initial state. When the piston moves slowly to a distance 'dl', the properties of that are  $P_2, V_2, T_2$ .

Due to displacement of gas, the infinitesimal amount of work " $\delta W$ " is said to be done by the gas on piston.

$$\delta W = F \times d\ell$$

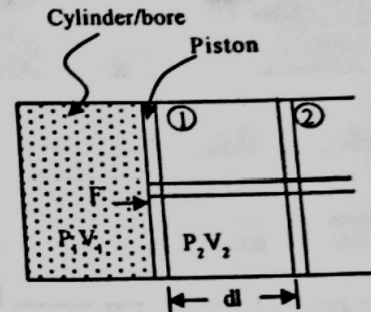
$$= p \times a \times d\ell, \text{ where } a = \text{Area of the cylinder/Piston.}$$

$$= p \times dv$$

$$W = \int_1^2 \delta W = \int_1^2 P \, dv$$

$p$  = pressure at any instance inbetween initial state and final state

$$W_{1-2} = \int_{v_1}^{v_2} P \, dv$$



## 3.5 PDV - WORK IN VARIOUS QUASI-STATIC PROCESS

(a) Constant pressure process (isobaric or isopiestic process),  $P = c$

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

$$W_{1-2} = P(v_2 - v_1)$$

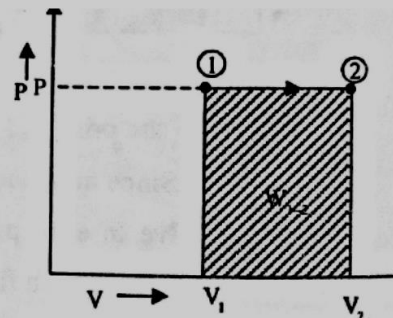


Fig. - 3.8 Expansion process

(b) Constant volume process (isochoric process),  $V = c$

$$W_{1-2} = \int P \, dv$$

since  $dv = 0$

$$W_{1-2} = 0$$

*Note* : When flow process takes place (open system)

Work done in open system  $W_{1-2} = (P_2 - P_1) v$

$$W_{1-2} = \int v \, dp$$

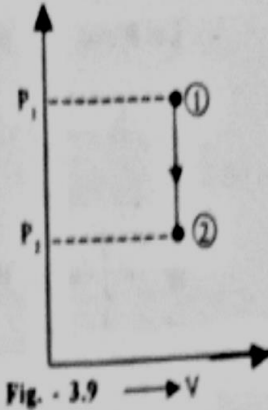


Fig. - 3.9  $\rightarrow v$

(c) CONSTANT TEMPERATURE PROCESS.

Isothermal Process.

$T = \text{Constant}$

$PV = C$

$\Rightarrow P_1 V_1 = P_2 V_2 = C$

Also,  $PV = P_1 V_1 = P_2 V_2 = C$

Taking  $PV = P_1 V_1$

or  $P = \frac{P_1 V_1}{V}$

$W_{1-2} = \int P \cdot dV$

$= \int_{V_1}^{V_2} \frac{P_1 V_1}{V} dV$

$= P_1 V_1 \int \frac{dV}{V}$

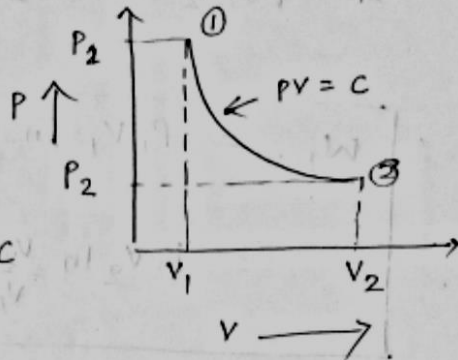
$= P_1 V_1 [\ln V]_{V_1}^{V_2}$

$W_{1-2} = P_1 V_1 \ln \frac{V_2}{V_1} \quad \text{--- (i)}$

We know that  $P_1 V_1 = P_2 V_2$

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

So,  $W_{1-2} = P_1 V_1 \ln \frac{P_1}{P_2} \quad \text{--- (2)}$



Also,  $W_{1-2} = P_2 V_2 \ln \frac{V_2}{V_1} \quad \text{--- (3)}$

$$\& W_{1-2} = P_2 V_2 \ln \frac{P_1}{P_2}$$

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

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

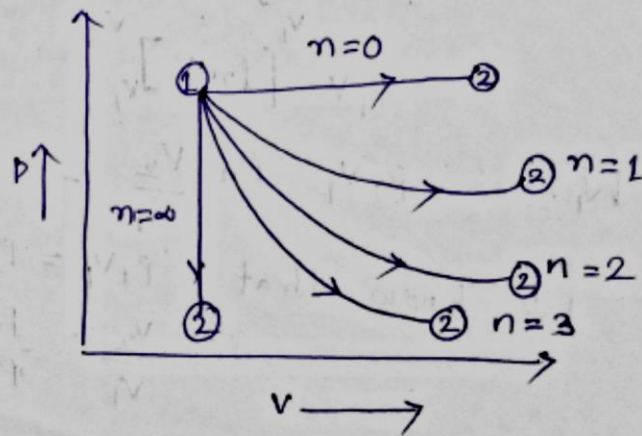
(d) Process in which  $PV^n = \text{Constant}$

Polytropic process.

where  $n$  varies 0 to  $\infty$

When  $n = 0, P = c$

$n = \infty, V = c$



$$PV^\eta = C$$

$$\Rightarrow PV^\eta = P_1 V_1^\eta = P_2 V_2^\eta = C.$$

Now. Taking

$$PV^\eta = P_1 V_1^\eta$$

$$\Rightarrow P = \frac{P_1 V_1^\eta}{V^\eta}$$

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

$$= \int_1^2 \frac{P_1 V_1^\eta}{V^\eta} dV$$

$$= P_1 V_1^\eta \int_1^2 \frac{dV}{V^\eta}$$

$$= P_1 V_1^\eta \int_1^2 V^{-\eta} dV$$

$$= P_1 V_1^\eta \int_{V_1}^{V_2} V^{-\eta} dV$$

$$= P_1 V_1^\eta \left[ \frac{V^{-\eta+1}}{-\eta+1} \right]_{V_1}^{V_2}$$

$$= \frac{P_1 V_1^\eta}{-\eta+1} \left[ V_2^{-\eta+1} - V_1^{-\eta+1} \right]$$

$$= \frac{P_1 V_1^\eta V_2^{-\eta+1} - P_1 V_1 V_1^{-\eta+1}}{-\eta+1}$$

$$= \frac{P_2 V_2^\eta V_2^{-\eta+1} - P_1 V_1^{-\eta+1} V_1^\eta}{-\eta+1}$$

$$W_{1-2} = \frac{P_2 V_2^{\alpha+1-\alpha} - P_1 V_1^{\alpha+1-\alpha}}{-\alpha + 1}$$

$$= \frac{P_2 V_2 - P_1 V_1}{-\alpha + 1}$$

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

$\alpha \rightarrow$  coefficient of polytropic expansion.

3. Determine the quantity of work done if initial pressure and volume are 6 bar and  $6 \text{ m}^3$  and final volume is  $20 \text{ m}^3$ , if it follows.

(i)  $P = C$     (ii)  $V = C$     (iii)  $PV = C$   
(iv)  $PV^{1.4} = C$     (v)  $PV^3 = C$

Soln.(i)  $P = \text{const.}$  (given)

$$\text{We know that, } W_{1-2} = \int_1^2 p dv = P(V_2 - V_1) = 6 \times 10^5 (20 - 6) = 84 \times 10^5 \text{ J (Ans)}$$

(ii)  $V = \text{const}$

$$W_{1-2} = \int_1^2 P dv = 0 \quad \text{Because } dV = 0 \quad \text{(Ans)}$$

(iii)  $PV = C$  i.e.,  $P_1 V_1 = P_2 V_2$

$$W_{1-2} = \int_1^2 P dV = 0 = P_1 V_1 \ln \frac{V_2}{V_1} = 6 \times 10^5 \times 6 \ln \left( \frac{20}{6} \right) = 43.343 \times 10^5 \text{ J (Ans)}$$

(iv)  $PV^{1.4} = c$  i.e.,  $n = 1.4$

$$W_{1-2} = \int_1^2 P dv = \frac{P_1 V_1 - P_2 V_2}{n-1}$$

$$\text{But } P_1 V_1^{1.4} = P_2 V_2^{1.4} \quad \text{or } P_2 = P_1 \left( \frac{V_1}{V_2} \right)^{1.4} = 111 \times 10^5 \text{ N/m}^2$$

$$\therefore W_{1-2} = \frac{(6 \times 6 - 111 \times 20) \times 10^5}{(1.4 - 1)} = -34.5 \times 10^5 \text{ J (Ans)}$$

(v)  $Pv^3 = c$   $P_1 v_1^3 = P_2 v_2^3$

$$P_2 = P_1 \left( \frac{V_1}{V_2} \right)^3 = 6 \times \left( \frac{6}{20} \right)^3 = 0.162 \times 10^5 \text{ N/m}^2$$

$$\therefore W_{1-2} = \int_1^2 P dv = \frac{P_1 V_1 - P_2 V_2}{n-1}$$

$$= \frac{(6 \times 6 - 0.162 \times 20) \times 10^5}{(3-1)} = 16.38 \times 10^5 \text{ J (Ans)}$$

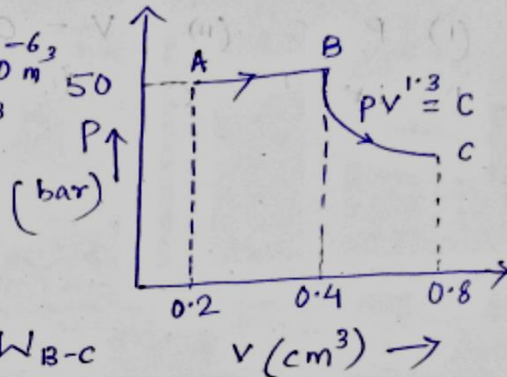
Q. Determine the total work done by a gas system following an expansion process as shown in the fig.

Ans:-

$$V_A = 0.2 \text{ cm}^3 = 0.2 \times 10^{-6} \text{ m}^3$$

$$V_B = 0.4 \text{ cm}^3 = 0.4 \times 10^{-6} \text{ m}^3$$

$$V_C = 0.8 \text{ cm}^3 = 0.8 \times 10^{-6} \text{ m}^3$$



$$W_{ABC} = W_{A-B} + W_{B-C}$$

$$W_{A-B} = P(V_B - V_A)$$

$$= 50 \times 10^5 (0.4 \times 10^{-6} - 0.2 \times 10^{-6})$$

$$= 50 \times 10^5 \times 0.2 \times 10^{-6}$$

$$= 1 \text{ J}$$

$$W_{B-C} = \frac{P_B V_B - P_C V_C}{n-1}$$

But,

$$P_B V_B^{1.3} = P_C V_C^{1.3}$$

$$P_C = P_B \left( \frac{V_B}{V_C} \right)^{1.3}$$

$$= 50 \times 10^5 \left( \frac{0.4 \times 10^{-6}}{0.8 \times 10^{-6}} \right)^{1.3}$$

$$= 20.3 \times 10^5 \text{ Pa}$$

$$\begin{aligned}
 W_{B-c} &= \frac{P_B V_B - P_C V_C}{n-1} \\
 &= \frac{50 \times 10^5 \times 0.4 \times 10^{-6} - 20.3 \times 10^5 \times 0.8 \times 10^{-6}}{1.3-1} \\
 &= \frac{5 \times 0.4 - 2.03 \times 0.8}{0.3} \times 10^5 \\
 &= \left( \frac{2 - 1.624}{0.3} \right) \times 10^5 \\
 &= \cancel{0.1253} \text{ J}
 \end{aligned}$$

$$W_{B-c} = 1.2533 \text{ J}$$

$$\begin{aligned}
 W_{ABC} &= W_{A-B} + W_{B-c} \\
 &= (1 + 1.2533) \text{ J} \\
 &= 2.2533 \text{ J}
 \end{aligned}$$

10. A mass of 1.5 kg of air is compressed in a quasi-static process from 0.1 MPa to 0.7 MPa for which  $p v = \text{constant}$ . The initial density of air is  $1.16 \text{ kg/m}^3$ . Find the work done by the piston to compress the air.

Soln.  $m = 1.5 \text{ kg}$

$$P_1 = 0.1 \times 10^3 \text{ KPa}$$

$$P_2 = 0.7 \times 10^3 \text{ KPa}$$

$$Pv = \text{Constant}$$

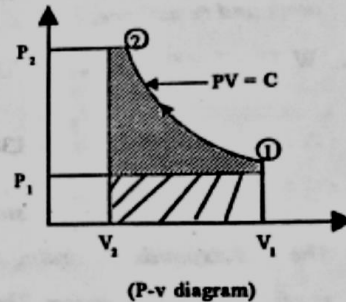
$$\rho_{\text{air}} = 1.16 \text{ kg/m}^3$$

$$V_1 = \frac{m}{\rho} = \frac{1.5}{1.16} = 1.29 \text{ m}^3$$

$$W_{1-2} = \int_1^2 P dV = P_1 V_1 \ln \left( \frac{V_2}{V_1} \right) = P_1 V_1 \ln \left( \frac{P_1}{P_2} \right)$$

$$= 0.1 \times 10^3 \times 1.29 \ln \left( \frac{0.1 \times 10^3}{0.7 \times 10^3} \right) = -251.62 \text{ kJ} \quad (\text{Ans})$$

-Ve sign indicates that the work is done on the system.



14. Work done by a system follows  $V = \frac{150}{p} \text{ m}^3$ , where  $p$  is in bar compute W.D on or by the system as pressure increases to 15 to 120 bar. Also indicate whether it is a compression process or expansion process.

Soln.  $V = \frac{150}{p} \text{ m}^3$ ,  $p$  is in bar (given)

$$\therefore V_1 = \frac{150}{15} = 10 \text{ m}^3 \quad V_2 = \frac{150}{120} = 1.25 \text{ m}^3$$

$$\text{Also } P = \frac{150}{V} \times 10^5 \text{ N/m}^2$$

$$\text{Hence } W_{1-2} = \int_1^2 p dV = \int_{V_1}^{V_2} \frac{150}{V} \times 10^5 dV$$

$$= 150 \times 10^5 \left[ \ln V \right]_{10}^{1.25} = 150 \times 10^5 \ln \left( \frac{1.25}{10} \right) = -3.12 \times 10^7 \text{ J} \quad (\text{Ans})$$

29. A non flow reversible process occurs for which the process follows  $P = (-3V + 16) \times 10^5 \text{ N/m}^2$  where  $V$  is in  $\text{m}^3$ . Compute the work done when  $V$  changes from 3 to 7  $\text{m}^3$ .

Soln.  $W_{1-2} = \int_1^2 Pdv = \int_{v_1}^{v_2} (-3V + 16) \times 10^5 \cdot dV$

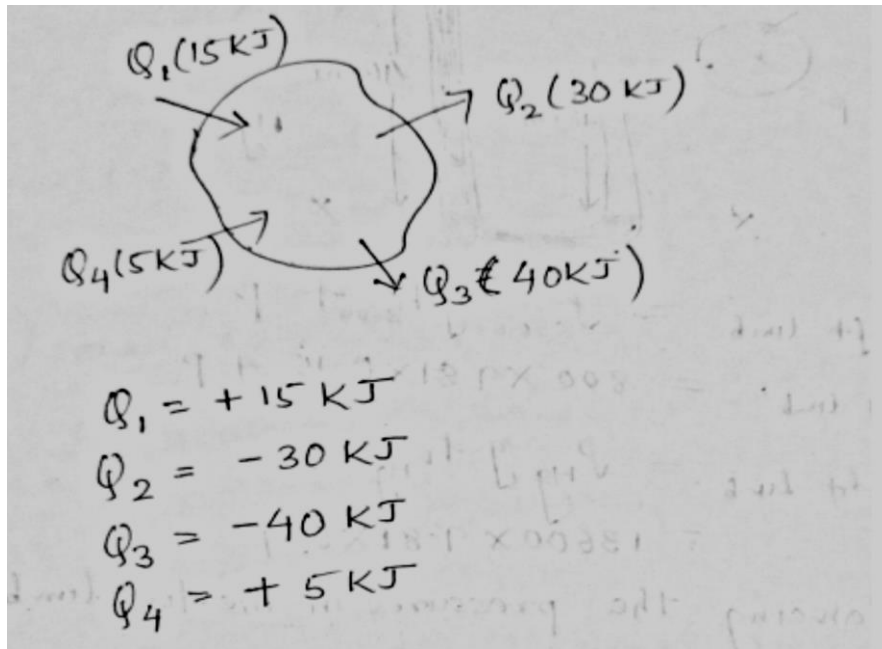
$$= \left[ \frac{-3V^2}{2} + 16V \right]_{v_1=3}^{v_2=7} \times 10^5 = \left[ -\frac{3}{2}(7^2 - 3^2) + 16(7 - 3) \right] \times 10^5$$
$$= [-60 + 64] \times 10^5 = [-60 + 64] \times 10^5 = 4 \times 10^5 \text{ N-m or J} = 400 \text{ kJ} \quad (\text{Ans})$$

## HEAT TRANSFER

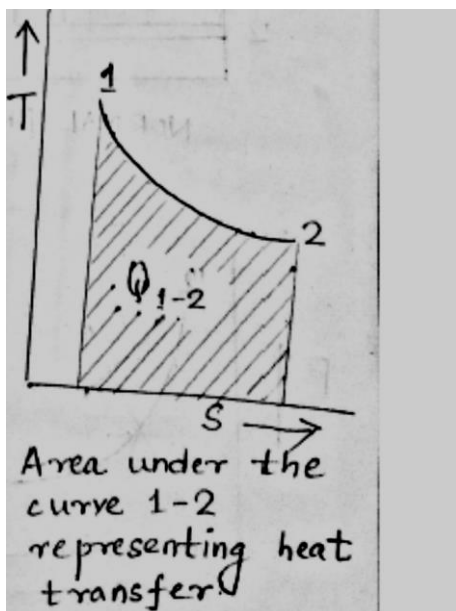
**HEAT:-** Heat is defined as the form of energy that is transferred across a system boundary by virtue of temperature difference.

- **SIGN CONVENTION;**

1. When heat is added to the system ,it is taken as positive.
2. When heat is rejected by the system , it is taken as negative.



**PATH FUNCTION:** Heat is called Path Function because the amount of heat evolved is not a function of end states of the process, and it depends on the path the system follows in going from one state to another.



## **TERMS RELATED TO HEAT TRANSFER (MODES OF HEAT TRANSFER)**

**CONDUCTION:** The transfer of heat between two bodies in direct contact is called Conduction.

Example-

1. Heat will transfer from a hot burner on the stove into a pot or pan.
2. The heat from a hot liquid makes the cup itself hot.
3. Chocolate candy in your hand will eventually melt as heat is conducted from your hand to the chocolate.
4. When ironing a dress ,the heat is transferred from the iron to the dress.

**RADIATION:** Heat may be transferred between two bodies separated by empty space or gases by the mechanism of radiation through electromagnetic waves etc.

Examples-

1. Microwaves
2. A campfire's heat
3. Light from the sun.
4. Remote controls
5. Cordless phones.
6. Sterilization of medical tools etc.

**CONVECTION :**Convection refers to the transfer of heat between a wall and a fluid system in motion.

Example-

1. Boiling Water
2. Air Conditioners
3. Refrigerator
4. Convection Ovens
5. Rainfall and Thunderstorms etc.

**ADIABATIC PROCESS:** A process in which no heat crosses the boundary of the system is called adiabatic process.

**ADIABATIC WALL:** A wall which do not allow heat to flow through it is called adiabatic wall.

**DIATHERMIC WALL:**A wall which permits the heat to flow through it is called diathermic wall.

**SPECIFIC HEAT:** The specific heat of a substance is defined as the amount of heat required to raise a unit mass of a substance through 1°C.

It is denoted by a sybmbol c. Its unit is J/kgK

$$c = \frac{Q}{m\Delta t}$$

Where Q= amount of heat transferred

m = mass of the substance

$\Delta t$  = rise in temperature.

**HEAT CAPACITY (C):** The product of mass and specific heat is called the heat capacity.  $C=mc$

**LATENT HEAT:** The latent heat is the amount of heat transfer required to cause a phase change in unit mass of a substance at a constant pressure and temperature.

**LATENT HEAT OF FUSION( $L_{fu}$ )**: It is the amount of heat transferred to melt unit mass of solid into liquid or to freeze unit mass of liquid to solid.

**LATENT HEAT OF VAPOURIZATION( $L_{vap}$ )** : It is the quantity of heat required to vapourize unit mass of liquid into vapour or condense unit mass of vapour into liquid.

**LATENT HEAT OF SUBLIMATION( $L_{sub}$ )**: It is the amount of heat transferred to convert unit mass of solid to vapour or vice-versa.

Q. A gas having a volume  $0.06 \text{ m}^3$  and pressure  $650 \text{ kPa}$  expands according to the law  $PV^{1.3} = \text{constant}$  until the volume is  $0.09 \text{ m}^3$ . Calculate the work done by the gas.

Ans.  $V_1 = 0.06 \text{ m}^3$   
 $P_1 = 650 \text{ kPa} = 650 \times 10^3 \text{ Pa}$   
 $V_2 = 0.09 \text{ m}^3$

$$PV^{1.3} = C$$

$$\therefore P_1 V_1^{1.3} = P_2 V_2^{1.3}$$

$$\therefore 650 \times 10^3 \times (0.06)^{1.3} = P_2 (0.09)^{1.3}$$

$$\therefore P_2 = 650 \times 10^3 \left( \frac{0.06}{0.09} \right)^{1.3}$$

$$\therefore P_2 = 383.7025 \times 10^3 \text{ Pa}$$

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

$$= \frac{650 \times 10^3 \times 0.06 - 383.7025 \times 10^3 \times 0.09}{1.3 - 1}$$

$$= \frac{39 \times 10^3 - 34.533 \times 10^3}{0.3}$$

$$= 14.89 \times 10^3 \text{ J}$$

$$= 14.89 \text{ kJ}$$

Q. A certain air is compressed quasistatically from 75 kPa,  $0.12 \text{ m}^3$  to 350 kPa,  $0.03 \text{ m}^3$  according to  $PV^n = \text{constant}$ . Find the work done by the system.

Ans.

$$P_1 = 75 \text{ kPa} = 75 \times 10^3 \text{ Pa}$$

$$V_1 = 0.12 \text{ m}^3$$

$$P_2 = 350 \text{ kPa} = 350 \times 10^3 \text{ Pa}$$

$$V_2 = 0.03 \text{ m}^3$$

$$P V^n = \text{const.}$$

$$\text{or } P_1 V_1^n = P_2 V_2^n$$

$$\text{or } 75 \times 10^3 \times (0.12)^n = 350 \times 10^3 (0.03)^n$$

$$\text{or } \left( \frac{0.12}{0.03} \right)^n = \frac{350 \times 10^3}{75 \times 10^3}$$

$$\text{or } (4)^n = 4.666$$

$$\text{or } n \log 4 = \log 4.666$$

$$\text{or } n = \frac{\log 4.666}{\log 4}$$

$$\text{or } \boxed{n = 1.11}$$

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

$$= \frac{75 \times 10^3 \times 0.12 - 350 \times 10^3 \times 0.03}{1.11 - 1}$$

$$= \frac{9 \times 10^3 - 10.5 \times 10^3}{0.11}$$

$$\boxed{W = -13.636 \times 10^3 \text{ J}}$$

Q. Consider a gas enclosed in a piston cylinder arrangement. The gas is initially at 150 kPa and occupies a volume of  $0.03 \text{ m}^3$ . The gas is now heated until the volume of the gas increases to  $0.1 \text{ m}^3$ . Calculate the work done by the gas, if volume of the gas is inversely proportional to pressure.

Ans.

$$P_1 = 150 \text{ kPa} = 150 \times 10^3 \text{ Pa}$$

$$V_1 = 0.03 \text{ m}^3$$

$$V_2 = 0.1 \text{ m}^3$$

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

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

$$P_1 V_1 = P_2 V_2$$

$$\text{or } 150 \times 10^3 \times 0.03 = P_2 \times 0.1$$

$$\text{or } \boxed{P_2 = 45 \times 10^3 \text{ Pa}}$$

$$W = P_1 V_1 \ln \frac{V_2}{V_1}$$

$$= 150 \times 10^3 \times 0.03 \times \ln \left( \frac{0.1}{0.03} \right)$$

$$= 4.5 \times 10^3 \ln \left( \frac{0.1}{0.03} \right)$$

$$\boxed{W = 5.4178 \times 10^3 \text{ J}}$$

Q. A certain air is compressed quasistatically from 75 kPa, 0.12 m<sup>3</sup> to 350 kPa, 0.03 m<sup>3</sup> according to  $PV^n = \text{constant}$ . Find the work done by the system.

Ans.

$$P_1 = 75 \text{ kPa} = 75 \times 10^3 \text{ Pa}$$

$$V_1 = 0.12 \text{ m}^3$$

$$P_2 = 350 \text{ kPa} = 350 \times 10^3 \text{ Pa}$$

$$V_2 = 0.03 \text{ m}^3$$

$$P V^n = \text{const.}$$

$$\text{or } P_1 V_1^n = P_2 V_2^n$$

$$\text{or } 75 \times 10^3 \times (0.12)^n = 350 \times 10^3 (0.03)^n$$

$$\text{or } \left( \frac{0.12}{0.03} \right)^n = \frac{350 \times 10^3}{75 \times 10^3}$$

$$\text{or } (4)^n = 4.666$$

$$\text{or } n \log 4 = \log 4.666$$

$$\text{or } n = \frac{\log 4.666}{\log 4}$$

$$\text{or } \boxed{n = 1.11}$$

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

$$= \frac{75 \times 10^3 \times 0.12 - 350 \times 10^3 \times 0.03}{1.11 - 1}$$

$$= \frac{9 \times 10^3 - 10.5 \times 10^3}{0.11}$$

$$\boxed{W = -13.636 \times 10^3 \text{ J}}$$

## FIRST LAW OF THERMODYNAMICS

**INTERNAL ENERGY:** It is the heat energy stored inside a gas. If certain amount of heat is supplied to a gas, the result is that the temperature of gas may increase or volume of the gas may increase thereby doing some external work or both temperature and volume may increase.

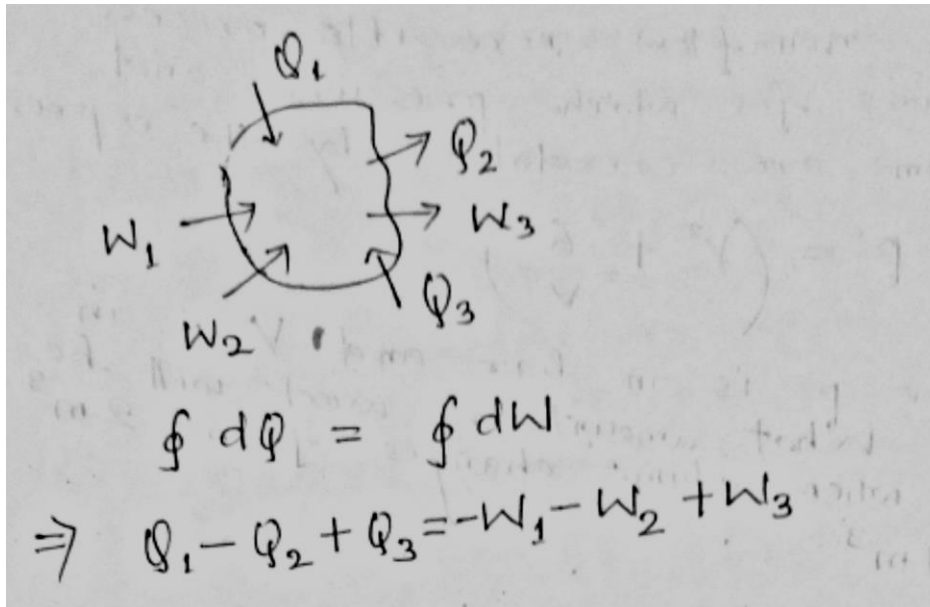
**JOULE'S LAW OF INTERNAL ENERGY:** It states that internal energy of a gas is dependent on the temperature change only and is not affected by the change in pressure and volume. Internal energy is represented by E or U. Change of internal energy is represented by  $\Delta U$  or  $\Delta E$ .

**LAW OF CONSERVATION OF ENERGY:** According to the law of conservation of energy, energy can neither be created nor be destroyed but it changes from one form to another.

**FIRST LAW OF THERMODYNAMICS:** It is based on the law of conservation of energy. According to it, "When a system undergoes a thermodynamic cycle then the heat applied to the system from the surroundings is equal to net work done by the system on its surroundings.

$$\oint dQ = \oint dW$$

Where  $\oint$  represents the sum for complete cycle.



## **APPLICATION OF FIRST LAW TO A PROCESS :**

When a process is executed by a system , the change in stored energy of the system is numerically equal to the net heat interaction minus the net work interaction during the process.

Numerically,

$$\Delta E = Q - W$$

Where Q=amount of heat transferred to the system

W= amount of work transferred from the system during the process

$\Delta E$ = change of internal energy.

Or , **Q =  $\Delta E + W$**

1) During four processes of a cycle heat transfers are 1500 KJ, -1200 KJ, -900 KJ, 1000 KJ and work transfers are 800 KJ, 0, -400 KJ and 0 KJ. Prove that the cycle follows 1st law of thermodynamics.

Ans.  $Q_1 = 1500 \text{ KJ}$ ,  $Q_2 = -1200 \text{ KJ}$   
 $Q_3 = -900 \text{ KJ}$ ,  $Q_4 = 1000 \text{ KJ}$   
 $W_1 = 800 \text{ KJ}$ ,  $W_2 = 0$   
 $W_3 = -400 \text{ KJ}$ ,  $W_4 = 0 \text{ KJ}$

$$\begin{aligned}\sum Q &= Q_1 + Q_2 + Q_3 + Q_4 \\ &= (1500 - 1200 - 900 + 1000) \text{ KJ} \\ &= 400 \text{ KJ}\end{aligned}$$

$$\begin{aligned}\sum W &= W_1 + W_2 + W_3 + W_4 \\ &= (800 + 0 - 400 + 0) \text{ KJ} \\ &= 400 \text{ KJ}\end{aligned}$$

$$\therefore \sum Q = \sum W.$$

Hence the cycle follows 1st law of thermodynamics.

2) In a cyclic process, heat transfers are  $+14.7 \text{ KJ}$ ,  $-25.2 \text{ KJ}$ ,  $-3.56 \text{ KJ}$  and  $+31.5 \text{ KJ}$ . What is the net work for this cyclic process?

Ans  $Q_1 = +14.7 \text{ KJ}$ ,  $Q_3 = -3.56 \text{ KJ}$   
 $Q_2 = -25.2 \text{ KJ}$ ,  $Q_4 = +31.5 \text{ KJ}$

For a cyclic process

$$(\sum Q)_{\text{cycle}} = (\sum W)_{\text{cycle}}$$

$$\therefore \sum W = Q_1 + Q_2 + Q_3 + Q_4$$
$$= (+14.7 - 25.2 - 3.56 + 31.5) \text{ KJ}$$

$$\boxed{\sum W = 17.44 \text{ KJ}}$$

net work of heat

3) During a process 280 KJ of heat was rejected from the system while internal energy remained same. Calculate work transfer during that process.

Ans.  $Q_{1-2} = -280 \text{ KJ}$

$$U_2 - U_1 = 0 \text{ (Since internal energy does not change)}$$

According to 1st law of thermodynamics

$$Q_{1-2} = (U_2 - U_1) + W_{1-2}$$

$$\sim -280 = 0 + W_{1-2}$$

$$\sim \boxed{W_{1-2} = -280 \text{ KJ}}$$

i.e. 280 KJ work is done on the system.

4) During one cycle, the working fluid in an engine engages in two work interactions: 15 KJ to the fluid and 44 KJ from the fluid, and three heat interactions, two of which are known: 75 KJ to the fluid and 40 KJ from the fluid. Evaluate the magnitude and direction of the third heat transfer.

Ans

$$W_1 = -15 \text{ KJ}$$
$$W_2 = 44 \text{ KJ}$$
$$Q_1 = 75 \text{ KJ}$$
$$Q_2 = -40 \text{ KJ}$$
$$Q_3 = ?$$

For a cyclic process

$$\sum W = \sum Q$$

$$\omega \quad W_1 + W_2 = Q_1 + Q_2 + Q_3$$

$$\omega \quad -15 + 44 = 75 - 40 + Q_3$$

$$\omega \quad \boxed{Q_3 = -6 \text{ KJ}}$$

5) A mass of 8 kg gas expands within a flexible container so that the p-v relationship is of the form  $PV^{1.2} = \text{constant}$ . The initial pressure is 1000 kPa and volume is  $1 \text{ m}^3$ .

The final pressure is 5 kPa.

If the specific internal energy of the gas decreases by  $40 \text{ kJ/kg}$ , find the heat transfer in magnitude and direction.

Ans .  $m = 8 \text{ kg}$   
 $P_1 = 1000 \text{ kPa} = 1000 \times 10^3 \text{ Pa}$   
 $V_1 = 1 \text{ m}^3$   
 $P_2 = 5 \text{ kPa} = 5 \times 10^3 \text{ Pa}$ .

$$du = (u_2 - u_1) = -40 \text{ kJ/kg}$$

$$dU = m \cdot du = 8(-40) \text{ kJ/kg}$$

$$= -320 \text{ kJ/kg}$$

$$= -320 \times 10^3 \text{ J/kg}$$

We know that,  $PV^{1.2} = \text{const}$

$$P_1 V_1^{1.2} = P_2 V_2^{1.2}$$

$$\omega V_2 = \frac{P_1 \cdot V_1^{1.2}}{P_2}$$

$$\omega V_2^{1.2} = \frac{1000 \times 10^3 \times 1^{1.2}}{5 \times 10^3}$$

$$\omega V_2^{1.2} = 200$$

$$\omega V_2 = (200)^{1/1.2}$$

$$\omega V_2 = (200)^{0.833}$$

$$\omega V_2 = 82.557 \text{ m}^3$$

Now, Polytropic Work done

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

$$= \frac{1000 \times 10^3 \times 1 - 5 \times 10^3 \times 82.577}{1.2 - 1}$$

$$= 2935.5 \times 10^3 \text{ J}$$

$$= 2935.5 \text{ KJ}$$

Applying 1st law

$$Q_{1-2} = \Delta U + W_{1-2}$$

$$\sim Q_{1-2} = (-320 + 2935.5) \text{ KJ}$$

$$\boxed{Q_{1-2} = 2615.5 \text{ KJ}}$$

$\therefore$  Heat is absorbed by the system

6) A domestic refrigerator is loaded with food and the door is closed. During a certain period the machine consumes 1 kWh of energy and the internal energy of the system drops by 5000 kJ. Find the net heat transfer for the system.

Ans.  $W = -1 \text{ kWh}$   
 $= -3600 \text{ kJ}$

$$\Delta U = U_2 - U_1 = -5000 \text{ kJ}$$

$$Q_{1-2} = ?$$

Applying 1st law

$$Q_{1-2} = \Delta U + W_{1-2}$$

$$\therefore Q_{1-2} = -5000 - 3600$$

$$= -8600 \text{ kJ}$$

$$\therefore \boxed{Q_{1-2} = -8.6 \text{ MJ}}$$

$\therefore$  8600 kJ is liberated by the refrigerator.

**DIFFERENT FORMS OF STORED ENERGY :** In thermodynamics energy can be in two forms:

**1.Energy in Transit:** Work and heat interactions are the forms of energy in transit , observed at the boundaries of a system. They are path functions.

**2.Energy in Storage:** Energy in storage called internal energy is a point function or state function.It is denoted by E or U

**ENTHALPY:** It is defined as the sum of internal energy(E or U) and pressure volume product(PV). It is represented by H. It is a point function.

Mathematically ,  **$H=U+PV$**

**SPECIFIC HEAT AT CONSTANT VOLUME( $C_v$ ):** It is defined as the rate of change of specific internal energy with respect to temperature when the volume is kept constant.

$$C_v = \left( \frac{du}{dT} \right)_v$$

$$\text{or, } du = C_v dT$$

$$\text{or, } dU = mC_v dT$$

**SPECIFIC HEAT AT CONSTANT PRESSURE: ( $C_p$ )** It is defined as the rate of change of specific enthalpy with respect to temperature when the pressure is kept constant.

$$C_p = \left( \frac{dh}{dT} \right)_p$$

$$\text{or, } dh = C_p dT$$

$$\text{or, } dH = mC_p dT$$

**ENERGY OF AN ISOLATED SYSTEM:** An isolated system is one in which there is no interaction of the system with the surroundings.

For an isolated system  $dQ = 0, dW = 0$ .

According to 1<sup>st</sup> law of thermodynamics

$$Q = \Delta E + W$$

$$\text{Or, } \Delta E = 0$$

$$\text{Or } E = \text{Constant}$$

So, the energy of an isolated system is always constant

7) 1.5 kg of liquid having a constant specific heat of  $2.5 \text{ kJ/kgK}$  is stirred in a well insulated chamber causing the temperature to rise by  $15^\circ\text{C}$ . Find  $\Delta E$  and  $W$  for the process.

Ans :-

$$m = 1.5 \text{ kg}$$

$$c = 2.5 \text{ kJ/kgK}$$

$$dq_{1-2} = 0 \text{ (insulated)}$$

$$\Delta T = 15^\circ\text{C}$$

$$T_2 - T_1 = 15^\circ\text{C}$$

$$\Delta E = ?$$

$$W_{1-2} = ?$$

Applying first law of thermodynamics

$$dq_{1-2} = \Delta E + W_{1-2}$$

$$\therefore 0 = mc dT + W_{1-2}$$

$$\therefore 0 = mc(T_2 - T_1) + W_{1-2}$$

$$\therefore 0 = 1.5 \times 2.5 \times 10^3 \times 15 + W_{1-2}$$

$$\therefore W_{1-2} = -56.25 \times 10^3 \text{ J}$$

$$\therefore \boxed{W_{1-2} = -56.25 \text{ kJ}}$$

8) A system composed of 2 kg of liquid expands in a frictionless piston and cylinder machine from an initial state of 1 MPa,  $100^{\circ}\text{C}$  to a final temperature of  $30^{\circ}\text{C}$ . If there is no heat transfer, find the net work for the process. Take  $C_v = 0.718 \text{ kJ/kg K}$ .

Ans:-

$$m = 2 \text{ kg}$$

$$P_1 = 1 \text{ MPa} = 1 \times 10^6 \text{ Pa}$$

$$T_1 = 100^{\circ}\text{C} = (100 + 273) \text{ K} = 373 \text{ K}$$

$$T_2 = 30^{\circ}\text{C} = (30 + 273) \text{ K} = 303 \text{ K}$$

$$Q_{1-2} = 0$$

$$W_{1-2} = 0$$

$$C_v = 0.718 \text{ kJ/kg K}$$

$$= 0.718 \times 10^3 \text{ J/kg K}$$

$$\Delta U = m C_v dT$$

$$= m C_v (T_2 - T_1)$$

$$= 2 \times 0.718 \times 10^3 (303 - 373)$$

$$= -100.52 \text{ kJ}$$

Applying 1st law.

$$Q_{1-2} = \Delta U + W_{1-2}$$

$$\text{or } 0 = -100.52 + W_{1-2}$$

$$\text{or } \boxed{W_{1-2} = 100.52 \text{ kJ}}$$

Q) In the all the work in the expansion is done by on the moving piston, show that the equation representing the path of the expansion in the PV plane is given by  $PV^{1.4} = \text{const.}$

Ans -

$$m = 2 \text{ kg}$$

$$P_1 = 1000 \text{ kPa}$$

$$T_1 = 100^\circ \text{C} = (100 + 273) \text{K} = 373 \text{K}$$

$$T_2 = 30^\circ \text{C} = (30 + 273) \text{K} = 303 \text{K}$$

$$\text{Now, } W_{1-2} = 100.52 \text{ kJ}$$

We know that

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

$$\therefore 100.52 \times 10^3 = \frac{mRT_1 - mRT_2}{n-1}$$

[  $\because PV = mRT$  ]

$$\therefore 100.52 \times 10^3 = \frac{2 \times R (T_1 - T_2)}{n-1}$$

$$\therefore 100.52 \times 10^3 = \frac{2 \times 0.287 \times 10^3 (373 - 303)}{n-1}$$

$$\left( \because R = 0.287 \text{ kJ/K}^\circ\text{K} \right)$$

$$\therefore 100.52 \times 10^3 = \frac{2 \times 0.287 \times 10^3 \times 70}{n-1}$$

$$\omega \quad n-1 = \frac{2 \times 0.287 \times 10^3 \times 70}{100.52 \times 10^3}$$

$$\omega \quad n-1 = 0.39972$$

$$\omega \quad n = 1.39972$$

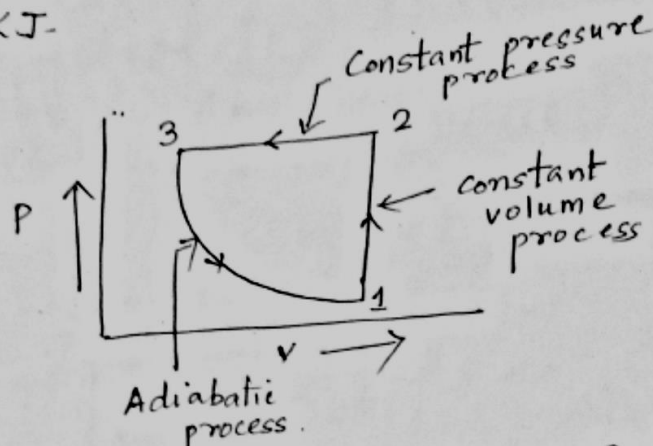
$$\omega \quad \boxed{n \approx 1.4}$$

Hence the law follows  $pV^{1.4} = C$ .

2/A

10) 80 KJ of heat are supplied to a system at constant volume. The system rejects 85 KJ of heat at constant pressure and 15 KJ of work is said to be done on it. The above two processes are then followed by adiabatic process to complete the cycle. Find adiabatic work and internal energy at all end states if initial value is 90 KJ.

Ans



Process 1-2

$$U_1 = 90 \text{ KJ}$$

$$W_{1-2} = 0$$

$$Q_{1-2} = 80 \text{ KJ}$$

Acc. to 1st law

$$Q_{1-2} = (U_2 - U_1) + W_{1-2}$$

$$\text{or } 80 = (U_2 - 90) + 0$$

$$\text{or } \boxed{U_2 = 170 \text{ KJ}}$$

Process 2-3

$$Q_{2-3} = -85 \text{ KJ}$$

$$W_{2-3} = -15 \text{ KJ}$$

Acc. to 1st law

$$Q_{2-3} = (U_3 - U_2) + W_{2-3}$$

$$\text{or } -85 = (U_3 - 170) + (-15)$$

$$\text{or } \boxed{U_3 = 100 \text{ KJ}}$$

Process 3-1

$$Q_{3-1} = 0 \text{ (adiabatic)}$$

Since it complete a cycle

$$\sum Q = \sum W$$

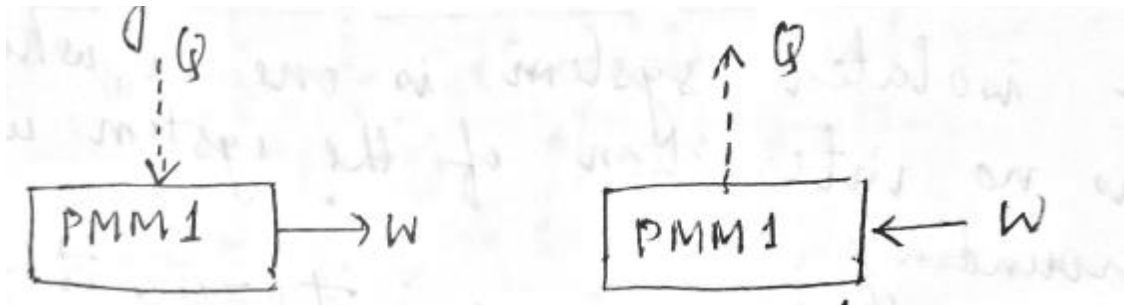
$$\text{or } Q_{1-2} + Q_{2-3} + Q_{3-1} = W_{1-2} + W_{2-3} + W_{3-1}$$

$$80 + (-85) + 0 = 0 + (-15) + W_{3-1}$$

$$\text{or } \boxed{W_{3-1} = 10 \text{ KJ}}$$

## PMM1-(PERPETUAL MOTION MACHINE OF THE FIRST KIND)

A perpetual motion machine of first kind is a device which will produce a continuous supply of work without absorbing energy from the surroundings. OR it is a device which consumes continuously work without discharging any form of energy to the surrounding.



Such type of machine is fictitious one. This clearly violates the first law of thermodynamics or in other words it is impossible to construct PMM1.

## SECOND LAW OF THERMODYNAMICS

**INTRODUCTION:** According to the first law of thermodynamics all forms of energy are interchangeable i.e., one form of energy can be changed into another form. Heat can be changed into work or vice-versa.

But in actual practice all forms of energy in a process cannot be converted into another form. Spontaneous process in nature occur only in one direction. Heat always flow from a body at a lower temperature, water always flows downward, time always flows in the forward direction. The reverse of these never happens spontaneously. This directional law puts a limitation on energy transformation imposed by the first law.

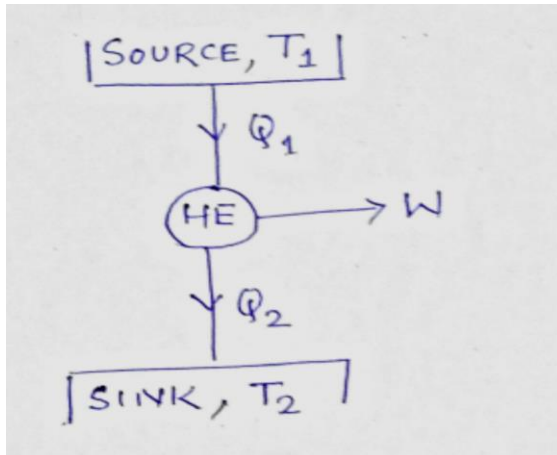
So, there must be some natural principle which governs the direction of process. This governs the direction of process. This process is known as second law of thermodynamics.

**QUALITATIVE DIFFERENCE BETWEEN HEAT AND WORK :** Work is said to be a high grade energy(HGE) and heat is a low grade energy(LGE). The complete conversion of low grade energy into high grade energy in a cycle is impossible.

Work=20 KJ-→ Heat=20KJ Total conversion of work into heat is possible.

Heat=20KJ--→ Work=18KJ. Total conversion of heat into work is not possible. Only a part of heat will be converted into work and the remaining will be lost to the surroundings.

**CYCLIC HEAT ENGINE** : A heat engine cycle is a thermodynamic cycle in which there is a net heat transfer to the system and net work transfer from the system .The system which executes a heat engine cycle is called a heat engine.



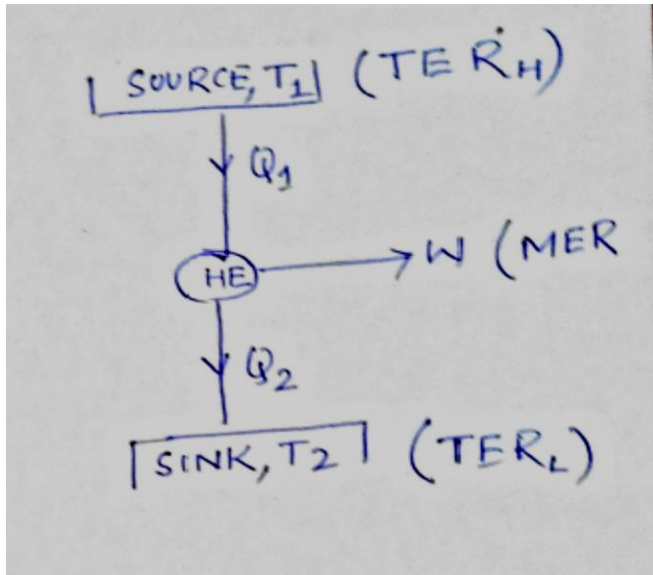
$$\dot{\eta}_{\text{thermal}} = \text{Work output} / \text{heat input} = (Q_1 - Q_2) / Q_1$$

$$\dot{\eta}_{\text{carnot}} = (T_1 - T_2) / T_1$$

**THERMAL ENERGY RESERVOIR(TER):** Thermal energy reservoir is defined as a large body of infinite heat capacity which is capable of absorbing or rejecting an unlimited quantity of heat without an appreciable changes of its thermodynamical properties. But the changes that takes place is very slow and small. It is of two types:

1. TER<sub>H</sub>: TER<sub>H</sub> is the Thermal Energy Reservoir at high temperature from which heat is transferred to the system in a heat engine cycle. It is also called as source.

2. TER<sub>L</sub>: TER<sub>L</sub> is the Thermal Energy Reservoir at low temperature which receives the heat that is being transferred from the system in a heat engine cycle. It is also called as sink.



### **MECHANICAL ENERGY RESERVOIR(MER):**

Mechanical energy reservoir is a large body enclosed by an adiabatic impermeable wall capable of storing work in the form of either potential energy or kinetic energy.

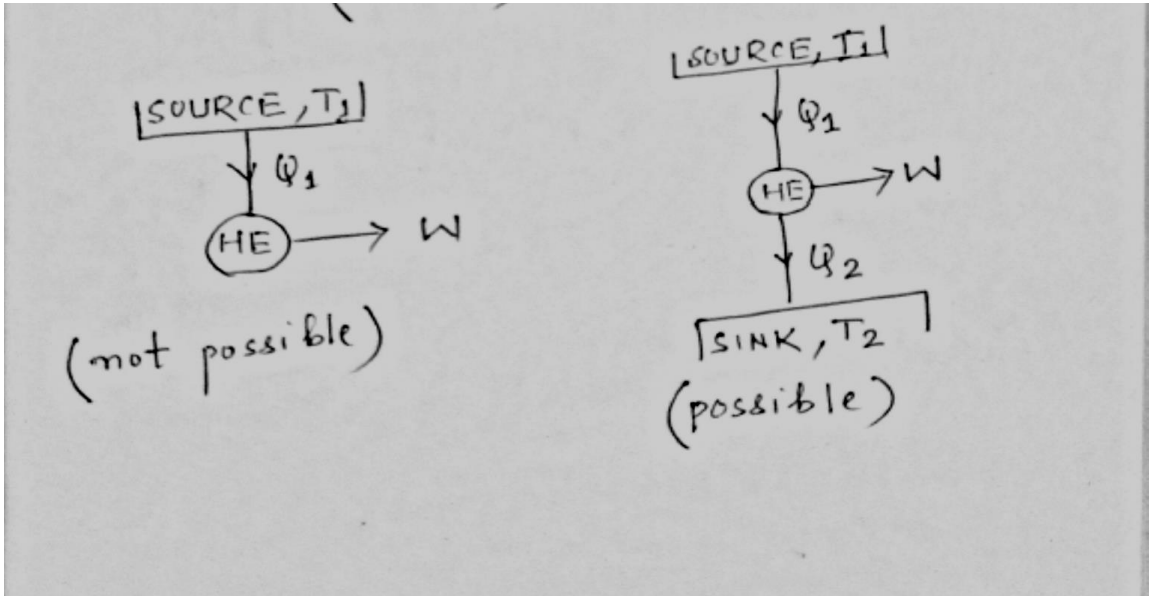
Ex.1. Flywheel(Capable of storing Kinetic Energy)

2.Spring (Capable of storing Potential Energy)

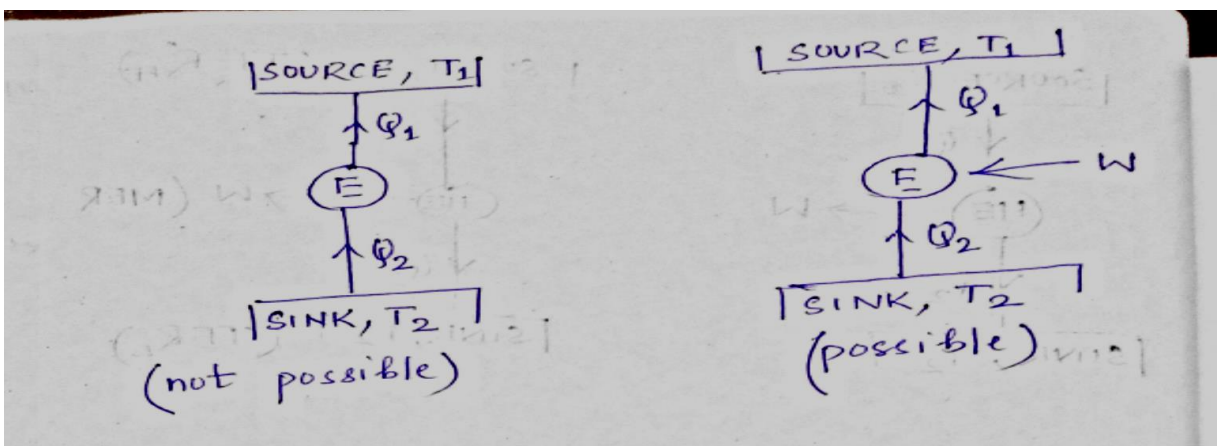
An MER receives and delivers mechanical energy quasistatically.

## DEFINATION OF SECOND LAW:

**1.KELVIN -PLANCK STATEMENT:** It states that it is impossible to construct a heat engine operating in a cycle which will produce work if it exchanges heat only with a single reservoir of fixed temperature.



**2.CLAUSIUS STATEMENT :**It states that it is impossible to construct a device operating in a cycle which transfers heat from a cooler body to hotter body without being work done on it.

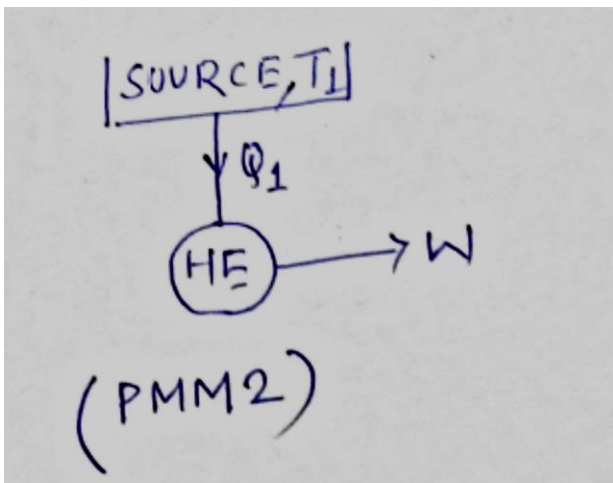


## PERPETUAL MOTION MACHINE OF SECOND KIND (PMM2):

A heat engine which produces net work in a cycle by exchanging heat with a single reservoir is called PMM2. This heat engine violates Kelvin – Plancks statement. Because we know that

$$\dot{\eta}_{\text{thermal}} = (Q_1 - Q_2) / Q_1 = (Q_1 - 0) / Q_1 = 1 = 100\%$$

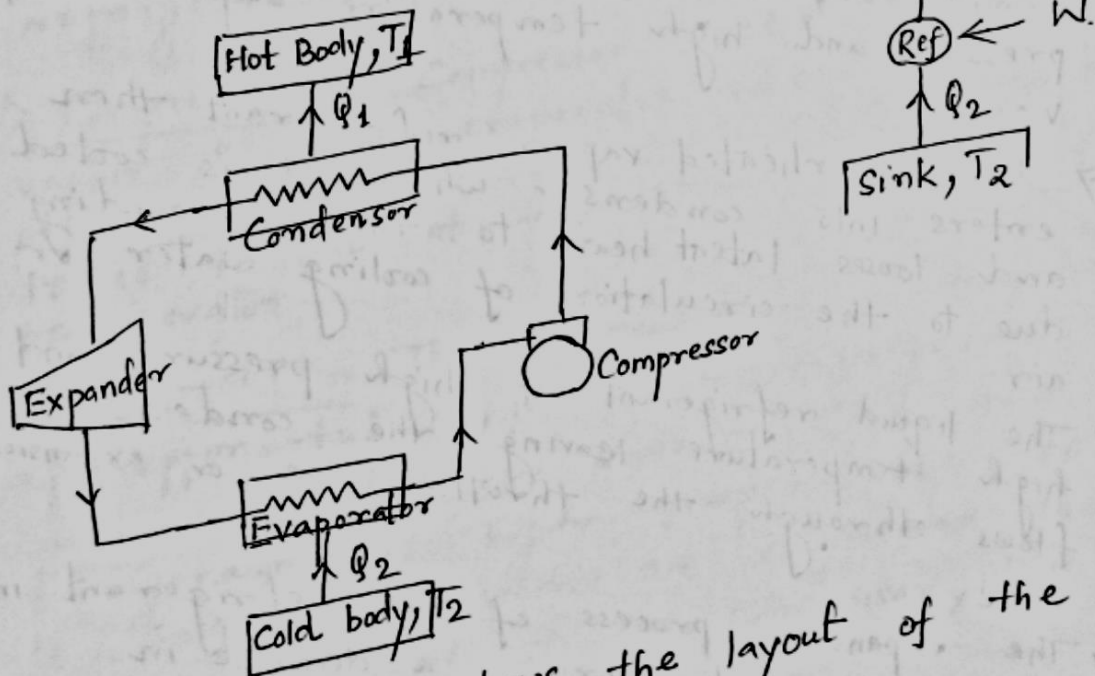
If it exchanges heat with a single reservoir then  $Q_2 = 0$  and hence  $\dot{\eta}_{\text{thermal}} = 100\%$ . In actual practice no machine can have 100% efficiency because of the losses. This is purely a theoretical machine.



**REFRIGERATOR:** Refrigerator is a reversed heat engine whose sole effect is to maintain a body at a temperature lower than the temperature of the surroundings.

## Working Principle

- Refrigerator uses the principle of second law of thermodynamics.
- According to the second law of thermodynamics, heat can flow from a body at higher temperature to a body at lower temperature with some external aid or work as input energy to the device.



- The above fig. shows the layout of the refrigerator.
- The main components of this system are compressor, condenser and evaporator valve!

- The low temperature and low pressure liquid-vapour refrigerant leaving the throttle valve or expansion valve flows into the evaporator pipes located in the evaporator space of the refrigerator.
- This low temperature refrigerant then absorbs heat from the body kept in evaporator space.
- After absorbing heat from the body, the refrigerant becomes either vapour or superheated vapour.
- The vapour refrigerant at low pressure and low temperature leaving the evaporator enters compressor, where it is compressed to high pressure and high temperature superheated vapour.
- The superheated vapour refrigerant then enters into condenser where it is cooled and loses latent heat to the surrounding due to the circulation of cooling water or air.
- The liquid refrigerant at high pressure and high temperature leaving the condenser flows through the throttle valve or expansion valve.
- The expansion process of the refrigerant in the throttle valve brings a decrease in temperature and pressure of the refrigerant to minimum.

→ This low pressure and low temperature refrigerant then passes through the evaporator pipes and absorbs heat from the body and gets evaporated.

### INTERNAL PARTS OF THE REFRIGERATOR

1) Refrigerant :- Refrigerant is a fluid, which flows through all the tubes of the refrigerator. While it flows through the evaporator, it absorbs heat from the space to be cooled and drops all the absorbed heat to the condenser when it flows through the condenser. The commonly used refrigerant is ammonia.

2) Compressor :- Compressor sucks the refrigerant vapour from the evaporator and delivers it at high pressure and high temperature. It is located at the bottom of the refrigerator.

3) Condenser - The condenser is a thin coil of copper tubing, in which refrigerant from the compressor enters. Since the refrigerant has high temperature, it is cooled by atmospheric air. To increase the heat transfer rate of the condenser, it is finned externally.

4) Expansion valve - The refrigerant, which is coming from the condenser enters into the copper tubing called capillary tube. When the refrigerant is passing through the

capillary tube, its pressure and temperature drops down suddenly.

### 5) Evaporator or chiller or freezer

The refrigerant leaving from the expansion valve enters into the evaporator, with very low pressure and temperature. When the refrigerant passes through the evaporator, it absorbs the heat from the space to be cooled. Since it absorbs heat, it evaporates and goes to compressor. This cycle keeps on repeating.

### 6) Temperature control device or thermostat

Thermostat is a sensor, used to control the temperature in the refrigerant. When temperature reaches the set value of thermostat, it cuts the power supply to compressor. When the temperature falls below the certain level, it restarts the compressor.

### 7) Defrost system - It is used for removing excess ice deposition formed on the evaporator. It can be manually operated by a switch on the thermostat or automatically done by electric heater and timer.

## EXTERNAL PARTS OF THE REFRIGERATOR

These parts are visible externally and used to serve the various purposes.

### 1) Freezer compartment - The temperature of this compartment is below zero degree Celsius.

so if we keep water in this compartment, it will become ice.

### 2) Thermostat control.

This device consists of round knob with temperature scale, that helps setting the required temperature inside the refrigerator. With this device, we can save electricity.

3) Refrigerator compartment - It occupies the major space of the refrigerator. It has the temperature above zero degree celcius and also it has number of shelves to keep various food materials in it.

4) Crisper - The highest temperature in the refrigerator compartment is maintained in the crisper.

5) Refrigerator door compartment - It has number of subsections like egg compartment, butter, diary etc. in the main door.

6) Switch → Switch is used to operate light inside the refrigerator. When the door opens, this switch supplies electricity to the bulb and when the door is closed, then it cuts the power supply to this bulb.

The working fluid used in the refrigeration cycle is called a refrigerant.

The object of refrigerator is how much heat be extracted from the sink which is called as refrigerating effect.

The performance rating is to be measured instead of efficiency like engine. This is called as co-efficient of performance.

$COP_{REF} = \text{Refrigerating effect} / \text{Net work transfer}$

$$= Q_2 / W$$

$$COP_{REF} = Q_2 / (Q_1 - Q_2)$$

$$COP_{CARNOT REF} = T_2 / (T_1 - T_2)$$

**HEAT PUMP:** Heat pump is a device whose sole effect is to maintain a body at a temperature higher than the temperature of the surroundings.

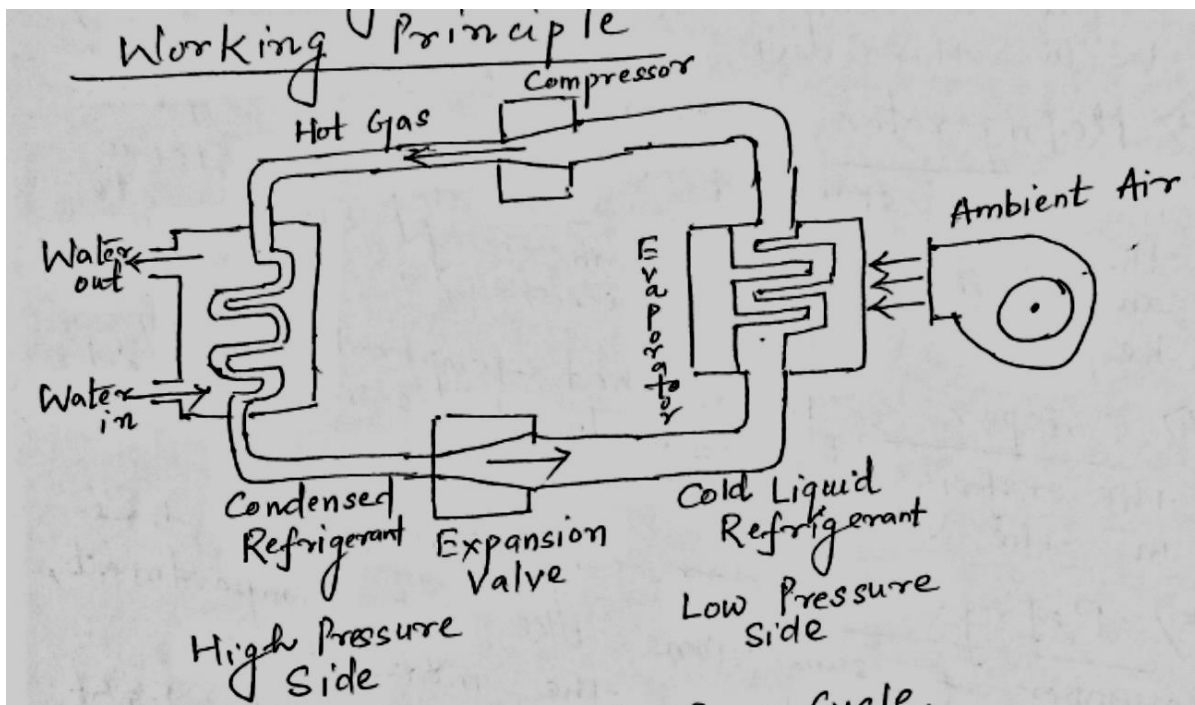
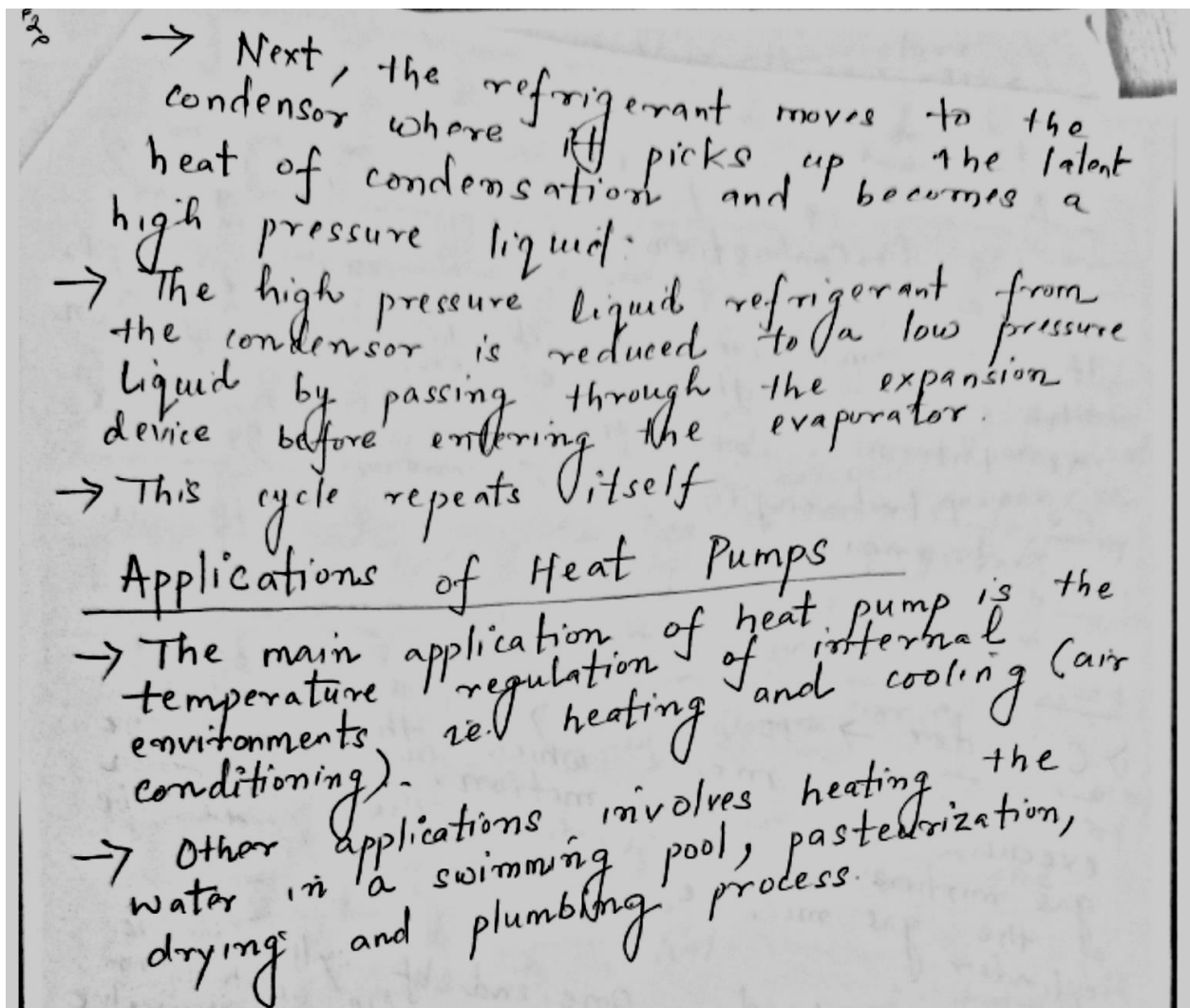


Fig. The Heat Pump Cycle.

- At the beginning of the heat pump cycle, the refrigerant enters the evaporator coil which absorbs the heat from the ambient air.
- Upon absorbing the latent heat of vaporisation from the ambient air, the refrigerant evaporates and becomes a low pressure vapour.
- Now the refrigerant vapour from the evaporator is compressed to a high pressure vapour in the compressor.



In a heat pump the attention is focused on the high temperature body.

The object of the heat pump is how much heat be pumped to the source maintained at a high temperature.

Like refrigerator ,performance rating of the heat pump is to be measured.

$$\text{COP}_{\text{HEAT PUMP}} = Q_1/W$$

$$\text{COP}_{\text{HEAT PUMP}} = Q_1 / (Q_1 - Q_2)$$

$$\text{COP}_{\text{CARNOT HEAT PUMP}} = T_1 / (T_1 - T_2)$$

### RELATION BETWEEN COP<sub>REF</sub> & COP<sub>HEAT PUMP</sub>

Handwritten derivation of the relationship between COP of a heat pump and a refrigerator:

$$\begin{aligned} \text{COP}_{\text{HEAT PUMP}} &= \frac{Q_1}{Q_1 - Q_2} \\ &= 1 + \frac{Q_2}{Q_1 - Q_2} - 1 \\ &= 1 + \frac{Q_1 - Q_2 + Q_2}{Q_1 - Q_2} \\ &= 1 + \frac{Q_2}{Q_1 - Q_2} \end{aligned}$$

The final result is boxed:

$$\text{COP}_{\text{HEAT PUMP}} = 1 + \text{COP}_{\text{REFRIGERATOR}}$$

# FLUID MECHANICS

Fluid mechanics is that branch of science which deals with the behaviour of the fluids (liquids or gases) at rest as well as in motion. It has three parts:

- (i) Fluid Statics - The study of fluids at rest is called fluid statics.
- (ii) Fluid Kinematics - The study of fluids in motion where pressure forces are not considered is called fluid kinematics.
- (iii) Fluid Dynamics - The study of fluids in motion if the pressure forces are also considered for the fluids in motion is known as fluid dynamics.

## PROPERTIES OF FLUID

1) Mass Density: - It is also known as specific mass of a fluid. It is defined as the mass per unit volume. It is usually denoted by  $\rho$  (rho).  
$$\rho = \frac{m}{V}$$
 - Unit  $\rightarrow$   $\text{kg/m}^3$

2) Weight Density: - It is defined as weight per unit volume. It is denoted by  $w$ .  
$$w = \frac{W}{V} = \frac{mg}{V} = \rho g$$
 - Unit  $\rightarrow$   $\text{N/m}^3$

3) Specific Volume: - It is defined as the volume per unit mass of a fluid. It is usually represented by  $v$ .

$$v = \frac{V}{m} = \frac{1}{\rho} \quad \text{Unit} \rightarrow \text{m}^3/\text{kg}$$

A/ratio

4) Specific gravity:- It is defined as the ratio of the density of a fluid to the density of a standard fluid. It is denoted by  $S$ .

$$S = \frac{\rho_{\text{liquid}}}{\rho_{\text{water}}} \quad \text{It has no unit.}$$

5) Relative density - It is defined as the ratio of the densities of two fluids. It is denoted by  $G$ . It has no unit.

$$G = \frac{\rho_{\text{fluid 1}}}{\rho_{\text{fluid 2}}}$$

6) Viscosity - It is defined as the property of a fluid which offers resistance to the movement of one layer of fluid over another adjacent layer of the fluid.

Mathematically,  $\tau \propto \frac{du}{dy}$

$$\text{or } \tau = \mu \cdot \frac{du}{dy}$$

where

$\tau \rightarrow$  shear stress

$\mu \Rightarrow$  constant of proportionality and it is known as co-efficient of dynamic viscosity.

$\frac{du}{dy} \rightarrow$  rate of shear strain or velocity gradient

Types of Viscosity

- (i) Dynamic Viscosity
- (ii) Kinematic Viscosity.

ratio

Dynamic Viscosity - It is defined as the ratio of shear stress and velocity gradient. It is denoted by  $\mu$ . Its unit is  $\text{Ns/m}^2$  or poise.

$$\mu = \frac{\text{Shear Stress}}{\frac{\text{Change of Velocity}}{\text{Change of distance}}}$$

$$1 \text{ Ns/m}^2 = 10 \text{ poise}$$
$$1 \text{ poise} = \frac{1}{10} \text{ Ns/m}^2$$

(ii) Kinematic Viscosity - It is defined as the ratio between the dynamic viscosity and density of fluid. It is denoted by  $\nu$  ( $\text{m}^2/\text{s}$ ). Its unit is  $\text{m}^2/\text{sec}$  or stoke.

$$\nu = \frac{\text{Viscosity}}{\text{Density}} = \frac{\mu}{\rho}$$

$$1 \text{ stoke} = 10^{-4} \text{ m}^2/\text{sec}$$

NEWTON'S LAW OF VISCOSITY - It states that the shear stress ( $\tau$ ) on the fluid element layer is directly proportional to the rate of shear strain. The constant proportionality is called the co-efficient of viscosity. Mathematically, it is expressed as.

$$\tau = \mu \cdot \frac{du}{dy}$$

- Fluids which obey Newton's Law of Viscosity are known as Newtonian fluids.
- Fluids which do not obey Newton's Law of Viscosity are known as Non-newtonian fluids.

## VARIATION OF VISCOSITY WITH TEMPERATURE

→ LIQUIDS - The viscosity of liquid varies inversely with temperature. The viscosity decreases with the increase of temperature. This is because in liquids the shear stress due to intermolecular cohesion decreases with increase in temperature.

→ GASES - The viscosity of gases varies directly with temperature. In gases, the intermolecular cohesion is negligible ~~and~~. The molecular activity increases with temperature and hence the viscosity of gases will increase with the increase in temperature.

## TYPES OF FLUIDS

The fluids may be classified into the following two types:

(1) Ideal Fluid - A fluid which is incompressible and is having no viscosity, is known as an ideal fluid. Ideal fluid is only an imaginary fluid as all the fluids, which exist, have some viscosity.  
Ex. - air, water

(2) Real Fluid - A fluid which possess viscosity is known as real fluid. All the fluids, in actual practice, are real fluids.  
Ex. - water, diesel, petrol, honey.

5  
TUN  
CASSES

Newtonian Fluid - A real fluid, in which the shear stress is directly, proportional to the rate of shear strain (or velocity gradient), is known as a Newtonian fluid. Ex. - Water, air, alcohol, glycerol, thin motor oil.

4) Non-Newtonian Fluid - A real fluid in which the shear stress is not proportional to the rate of shear strain, is known as a Non-newtonian fluid. Ex. - custard, tooth paste, corn starch, paint, shampoo etc.

5) Ideal Plastic Fluid - A fluid, in which shear stress is more than the yield value and shear stress is proportional the rate of shear strain, is known as ideal plastic fluid. Ex. - Water suspension of clay and fly ash.

VAPOUR PRESSURE - A change from the liquid state to the gaseous state is known as vapourisation. Evaporation occurs at the surface of the liquid. If the surface is exposed to the atmosphere, evaporation generally occurs continuously. If, however the surface is within an enclosed space, evaporation will occur only until the air within the enclosed space becomes saturated with vapour. Pressure caused by vapour molecules within such a closed space is called vapour pressure.

AP/11

SURFACE TENSION → Surface Tension is defined as the tensile force acting on the surface of a liquid in contact with a gas or on the surface between two immiscible liquids such that the surface behaves like a membrane under tension. It is denoted by  $\sigma$ . Its unit is N/m.

→ The value of surface tension depends upon the following factors:

- (i) Nature of liquid
- (ii) Nature of surrounding matter (e.g. solid, liquid or gas)
- (iii) Kinetic energy (and hence, the temperature of the liquid molecules).

(i) Surface Tension on Liquid Droplet

$$\sigma = \frac{pd}{4}$$

(ii) Surface Tension on a Hollow Bubble

$$\sigma = \frac{pd}{8}$$

(iii) Surface Tension on a Liquid Jet

$$\sigma = \frac{pd}{2}$$

## CAPILLARITY OR MENISCUS EFFECT

Capillarity is defined as a phenomenon of rise or fall of a liquid surface in a small tube relative to the adjacent general level of liquid when the tube is held vertically in the liquid. The rise of liquid surface is known as capillary rise while the fall of the liquid surface is known as capillary depression. It is expressed in terms of cm or mm of fluid.

→ Capillarity depends upon the:-

- (i) specific weight of the liquid
- (ii) diameter of the tube
- (iii) surface tension of the liquid.

→ Expression for Capillary Rise or Capillary Depression

$$h = \frac{4\sigma \cos \theta}{\rho g d}$$

where  $\sigma$  = surface tension

$\rho$  = density of the fluid

$d$  = diameter of the capillary tube.

The value of  $\theta$  between water and clean glass tube is  $0^\circ$ .

The value of  $\theta$  between mercury and clean glass tube is  $128^\circ$ . (or will be given in the problem)

PASCAL'S LAW - It states that the pressure or intensity of pressure at a point in a static fluid is equal in all directions.

HYDROSTATIC LAW - It states that rate of increase of pressure in a vertical direction is equal to weight density of the fluid at that point.

Mathematically,  $\frac{\partial P}{\partial z} = \rho g$

$\int \partial P = \int \rho g \partial z$

$\int P = \rho g z$

ARCHIMEDES' PRINCIPLE - It states that <sup>wholly or partially</sup> when a body is immersed in a fluid, an upward force is exerted by the fluid on the body. The magnitude of this upward force is equal to weight of the fluid displaced by the body. This upward force is known as ~~force of~~ buoyant force or buoyancy.

TYPES OF FLUID FLOW

1) Steady and Unsteady flow.

Steady flow is defined as that type of flow in which the fluid characteristics like velocity, pressure, density etc. at a point do not change with time.

Mathematically,  $\left(\frac{\partial v}{\partial t}\right)_{x_0, y_0, z_0} = 0, \left(\frac{\partial p}{\partial t}\right)_{x_0, y_0, z_0} = 0, \left(\frac{\partial \rho}{\partial t}\right)_{x_0, y_0, z_0} = 0$

Unsteady flow is that type of flow, in which the velocity, pressure or density at a point changes with respect to time.

$$\text{Mathematically, } \left(\frac{\partial V}{\partial t}\right)_{x_0, y_0, z_0} \neq 0, \left(\frac{\partial P}{\partial t}\right)_{x_0, y_0, z_0} \neq 0$$

## 2) Uniform and Non-uniform flow -

Uniform flow is defined as that type of flow in which the velocity at any given time does not change w.r.t space.

$$\text{Mathematically } \left(\frac{\partial V}{\partial s}\right)_{t = \text{const}} = 0.$$

where  $\partial V$  = change of velocity  
 $\partial s$  = Length of flow in the direction  $s$

Non-uniform flow is defined as the flow in which the velocity at any given time changes with respect to space.

$$\text{Mathematically, } \left(\frac{\partial V}{\partial s}\right)_{t = \text{const}} \neq 0.$$

## 3) Laminar and Turbulent Flows

Laminar flow is defined as that type of flow in which the fluid particles move along well-defined paths or stream line and all the stream lines are straight and parallel.

Turbulent flow is that type of flow in which the fluid particles move in a zig-zag way. Due to the movement of fluid particles in a zig-zag way, the eddies formation takes place which are responsible for high energy loss.

#### 4) Compressive and Incompressible flows

Compressive flow is that type of flow in which the density of the fluid changes from point to point or in other words the density  $\rho$  is not constant.

Mathematically, for compressive flow.  
 $\rho \neq \text{constant}$

Incompressible flows is that type of flow in which the density is constant for the fluid flow.

Mathematically, for incompressible flow.  
 $\rho = \text{constant}$

Liquids are generally incompressible while gases are compressible.

#### RATE OF FLOW OR DISCHARGE ( $Q$ )

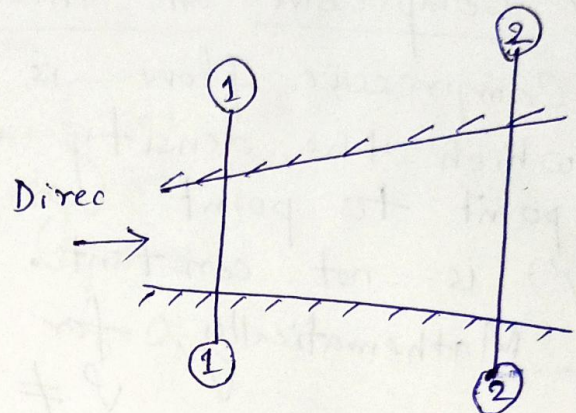
It is defined as the quantity of a fluid flowing per second through a section of a pipe or a channel. For an incompressible fluid the rate of flow or discharge is expressed as the volume of fluid flowing across the section per second. For compressible fluids, the rate of flow is usually expressed as the weight of fluid flowing across the section.

## CONTINUITY EQUATION

This equation is based on the principle of conservation of mass. According to this equation, for a fluid flowing through the pipe at all the cross-section, the quantity of fluid per second is constant.

Mathematically,

$$\rho_1 A_1 V_1 = \rho_2 A_2 V_2$$
$$\sim \boxed{A_1 V_1 = A_2 V_2}$$



## BERNOULLI'S THEOREM

It states that in a steady, ideal flow of an incompressible fluid, the total energy at any point of the fluid is constant. The total energy consists of pressure energy, kinetic energy and potential or datum energy. These energies per unit weight of the fluid are:

$$\text{Pressure energy} = \frac{P}{\rho g}$$

$$\text{Kinetic energy} = \frac{v^2}{2g}$$

$$\text{Datum energy} = z$$

Mathematically, Bernoulli's theorem is written as.

$$\frac{P}{\rho g} + \frac{v^2}{2g} + z = \text{Constant}$$

## NUMERICALS

1) Calculate the specific weight, density and specific gravity of 1 litre of a liquid which weighs 7 N.

Ans  $V = 1 \text{ lit} = 10^{-3} \text{ m}^3$

$$W = 7 \text{ N}$$

specific weight,  $w = \frac{W}{V} = \frac{7}{10^{-3}} = 7 \times 10^3 \text{ N/m}^3$

Density =  $\frac{w}{g} = \frac{7 \times 10^3}{9.81} = 713.5 \text{ kg/m}^3$

Specific gravity,  $S = \frac{\text{Density of liquid}}{\text{Density of water}}$

$$= \frac{713.5}{1000} = 0.7135$$

2) Calculate the density, specific weight and specific gravity of one litre of petrol.

Ans:

$$\text{Volume} = 1 \text{ lit} = 10^{-3} \text{ m}^3$$

$$S = 0.7$$

$$\text{Density } \rho = S \times 1000 = 0.7 \times 1000 = 700 \text{ kg/m}^3$$

$$\text{Specific weight, } w = \rho \times g = 700 \times 9.81 = 6867 \text{ N/m}^3$$

$$\begin{aligned} \text{Weight, } W &= w \times V \\ &= 6867 \times 10^{-3} \\ &= 6.867 \text{ N} \end{aligned}$$

3) If the velocity distribution over a plate is given by  $u = \frac{2}{3}y - y^2$  in which  $u$  is the velocity in metre per second at a distance  $y$  metre above the plate, determine the shear stress at  $y=0$  and  $y=0.15 \text{ m}$ . Take dynamic viscosity of fluid as 8.63 poises.

Ans -  $u = \frac{2}{3}y - y^2$ ,  $\mu = 8.63 \text{ poise}$   
 $= \frac{8.63}{10} = 0.863 \text{ Ns/m}^2$

$$\frac{du}{dy} = \frac{2}{3} - 2y$$

$$\left(\frac{du}{dy}\right)_{y=0} = \frac{2}{3} - 2 \times 0 = 0.667$$

$$\left(\frac{du}{dy}\right)_{y=0.15} = \frac{2}{3} - 2 \times 0.15 = 0.367$$

$$\tau_{y=0} = \mu \cdot \left(\frac{du}{dy}\right)_{y=0}$$

$$= 0.863 \times 0.667$$

$$= 0.5756 \text{ N/m}^2$$

$$\tau_{y=0.15} = \mu \cdot \left(\frac{du}{dy}\right)_{y=0.15}$$

$$= 0.863 \times 0.367$$

$$= 0.3167 \text{ N/m}^2$$

4) Find the kinematic viscosity of an oil having density  $981 \text{ kg/m}^3$ . The shear stress at a point in oil is  $0.2452 \text{ N/m}^2$  and velocity gradient at that point is  $0.2$  per second

Ans -  $\rho = 981 \text{ kg/m}^3$   
 $\tau = 0.2452 \text{ N/m}^2$   
 $\frac{du}{dy} = 0.2 / \text{second}$

$$\tau = \mu \cdot \frac{du}{dy} \Rightarrow \mu = \frac{\tau}{\left(\frac{du}{dy}\right)} = \frac{0.2452}{0.2}$$

$$\Rightarrow \mu = 1.226 \text{ Ns/m}^2$$

$$\nu = \frac{\mu}{\rho} = \frac{1.226}{981} = 0.125 \times 10^{-2} \text{ m}^2/\text{sec}$$

5) Determine the specific gravity of a fluid having viscosity 0.05 poise and kinematic viscosity 0.035 stokes.

Ans:-

$$\mu = 0.05 \text{ poise} \\ = \frac{0.05}{10} = 0.005 \text{ NS/m}^2$$

$$\nu = 0.035 \text{ stokes} \\ = 0.035 \times 10^{-4} \text{ m}^2/\text{sec}$$

$$\nu = \frac{\mu}{\rho} \Rightarrow \rho = \frac{\mu}{\nu} = \frac{0.005}{0.035 \times 10^{-4}} = 1428.5 \text{ kg/m}^3$$

$$\text{specific gravity} = \frac{\text{Density of liquid}}{\text{Density of water}}$$

$$= \frac{1428.5}{1000} = 1.4285$$

6) Determine the viscosity (dynamic) of a liquid having kinematic viscosity 6 stokes and specific gravity 1.9.

Ans:-

$$\nu = 6 \text{ stokes} = 6 \times 10^{-4} \text{ m}^2/\text{sec.}$$

$$\text{sp. gravity } S = 1.9$$

$$\rho = S \times 1000 \\ = 1.9 \times 1000 \\ = 1900 \text{ kg/m}^3$$

$$\nu = \frac{\mu}{\rho} \Rightarrow \mu = \nu \times \rho \\ = 6 \times 10^{-4} \times 1900 \\ = 1.14 \text{ NS/m}^2$$

7) The surface <sup>tension</sup> density of water in contact with air at 20°C is 0.0725 N/m. The pressure inside a droplet of water is to be 0.02 N/cm<sup>2</sup>. Calculate the diameter of the droplet of water.

Ans:

$$\sigma = 0.0725 \text{ N/m}$$

$$P = 0.02 \text{ N/cm}^2$$

$$= 0.02 \times 10^4 \text{ N/m}^2$$

$$P = \frac{4\sigma}{d}$$

$$\text{or } d = \frac{4\sigma}{P} = \frac{4 \times 0.0725}{0.02 \times 10^4} = 0.00145 \text{ m}$$

8) Find the surface tension in a soap bubble of 40 mm diameter when the inside pressure is  $2.5 \text{ N/m}^2$  above atmospheric pressure.

Ans:-  $d = 40 \text{ mm} = 40 \times 10^{-3} \text{ m}$   
 $P = 2.5 \text{ N/m}^2$

$$P = \frac{8\sigma}{d} \Rightarrow \sigma = \frac{Pd}{8} = \frac{2.5 \times 40 \times 10^{-3}}{8}$$

$$\sigma = 0.0125 \text{ N/m}$$

9) Calculate the capillary rise in a glass tube of 2.5 mm diameter when immersed vertically in (a) water and (b) mercury. Take surface tension  $\sigma = 0.0725 \text{ N/m}$  for water and  $\sigma = 0.52 \text{ N/m}$  for mercury in contact with air. The specific gravity of mercury is given as 13.6 and angle of contact =  $130^\circ$ .

Ans.  $d = 2.5 \text{ mm} = 2.5 \times 10^{-3} \text{ m}$

$$\sigma_{\text{water}} = 0.0725 \text{ N/m}$$

$$\sigma_{\text{mercury}} = 0.52 \text{ N/m}$$

$$\text{Specific gravity of mercury} = 13.6$$

$$\rho_{\text{mercury}} = 13.6 \times 1000$$

$$= 13600 \text{ kg/m}^3$$

(a) Capillary rise for water ( $\theta = 0^\circ$ )

$$h = \frac{4\sigma \cos \theta}{\rho g d} = \frac{4 \times 0.0725 \cos 0}{1000 \times 9.81 \times 2.5 \times 10^{-3}}$$

$$= 0.0118 \text{ m}$$

(b) For mercury ( $\theta = 130^\circ$ )

$$h = \frac{4\sigma \cos \theta}{\rho g d} = \frac{4 \times 0.52 \cos 130^\circ}{13.6 \times 1000 \times 9.81 \times 2.5 \times 10^{-3}}$$

$$= -0.004 \text{ m}$$

The negative sign indicates the capillary depression.

10) Calculate the capillary effect in millimeters in a glass tube of 4mm diameter, when immersed in (i) water and (ii) mercury. The temperature of the liquid is  $20^\circ\text{C}$  and the values of the surface tension of water and mercury at  $20^\circ\text{C}$  in contact with air are  $0.073575 \text{ N/m}$  and  $0.51 \text{ N/m}$  resp. The angle of contact for water is zero and that for mercury is  $130^\circ$ . Take density of water at  $20^\circ\text{C}$  as equal to  $998 \text{ kg/m}^3$ .

Ans.

$$d = 4 \times 10^{-3} \text{ m}$$

$$h = \frac{4\sigma \cos \theta}{\rho g d}$$

(i) Capillary effect for water.

$$\sigma = 0.073575 \text{ N/m}$$

$$\theta = 0^\circ$$

$$\rho = 998 \text{ kg/m}^3$$

$$h = \frac{4\sigma \cos \theta}{\rho g d} = \frac{4 \times 0.073575 \cos 0}{998 \times 9.81 \times 4 \times 10^{-3}}$$

$$= 7.51 \times 10^{-3} \text{ m}$$

(ii) Capillary effect for mercury.

$$\sigma = 0.51 \text{ N/m}$$

$$\theta = 130^\circ$$

$$\rho = 5 \times 1000 = 13.6 \times 1000 = 13600 \text{ kg/m}^3$$

$$h = \frac{4\sigma \cos \theta}{\rho g d} = \frac{4 \times 0.51 \cos 130^\circ}{13600 \times 9.81 \times 4 \times 10^{-3}}$$

$$= -2.46 \times 10^{-3} \text{ m}$$

The negative sign indicates the capillary depression.

11) Find out the minimum size of glass tube that can be used to measure water level if the capillary rise in the tube is to be restricted to 2 mm. Consider surface tension of water in contact with air as  $0.073575 \text{ N/m}$

Ans.  $h = 2 \text{ mm} = 2 \times 10^{-3} \text{ m}$

$$\sigma = 0.073575$$

$$\theta \text{ for water} = 0^\circ$$

$$\rho = 1000 \text{ kg/m}^3$$

$$h = \frac{4\sigma \cos \theta}{\rho g d} = \frac{4 \times 0.0725 \cos 0^\circ}{1000 \times 9.81 \times 2 \times 10^{-3}}$$

$$= 0.015 \text{ m}$$

12) A hydraulic press has a ram of 30 cm diameter and a plunger of 4.5 cm diameter. Find the weight lifted by the hydraulic press when the force applied to the plunger is 500 N.

Ans. Diameter of ram,  $D = 30 \text{ cm} = 0.3 \text{ m}$   
 Diameter of plunger,  $d = 4.5 \text{ cm} = 0.045 \text{ m}$   
 Force on plunger,  $F = 500 \text{ N}$   
 Weight lifted,  $W = ?$

According to Pascal's Law

Pressure intensity due to plunger  $\approx$  Pressure intensity due to ram

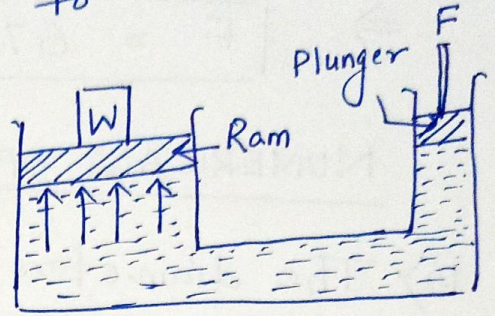
$$\Rightarrow \frac{F}{a} = \frac{W}{A}$$

$$\Rightarrow \frac{F}{\frac{\pi d^2}{4}} = \frac{W}{\frac{\pi D^2}{4}}$$

$$\Rightarrow \frac{500}{d^2} = \frac{W}{D^2}$$

$$\Rightarrow \frac{500}{(0.045)^2} = \frac{W}{(0.3)^2}$$

$$\Rightarrow W = 22.222 \text{ kN}$$



13) A hydraulic press has a ram of 20cm diameter and a plunger of 3cm diameter. It is used for lifting a weight of 30 kN. Find the force required at the plunger.

Ans: Dia. of ram,  $D = 20 \text{ cm} = 0.2 \text{ m}$

$$\text{Area of ram, } A = \frac{\pi D^2}{4} = \frac{\pi (0.2)^2}{4} = 0.0314 \text{ m}^2$$

Dia. of plunger,  $d = 3 \text{ cm} = 0.03 \text{ m}$ .

$$\text{Area of plunger, } a = \frac{\pi d^2}{4} = \frac{\pi (0.03)^2}{4} = 7.068 \times 10^{-4} \text{ m}^2$$

$$\begin{aligned} \text{Weight lifted, } W &= 30 \text{ kN} \\ &= 30 \times 1000 \\ &= 30000 \text{ N} \end{aligned}$$

According to Pascal's Law

$$P_{\text{plunger}} = P_{\text{ram}}$$

$$\therefore \frac{F}{a} = \frac{W}{A}$$

$$\Rightarrow \frac{F}{7.068 \times 10^{-4}} = \frac{30,000}{0.0314}$$

$$\Rightarrow \boxed{F = 675.2 \text{ N.}}$$

### NUMERICALS OF CONTINUITY EQUATION

14) The diameters of a pipe at the sections 1 and 2 are 10 cm and 15 cm respectively. Find the discharge through the pipe if the velocity of water flowing through the pipe at section 1 is 5 m/sec. Determine also the velocity at section 2.

Ans.  $D_1 = 10 \text{ cm} = 0.1 \text{ m}$

$$A_1 = \frac{\pi D_1^2}{4} = \frac{\pi (0.1)^2}{4} = 0.007854 \text{ m}^2$$

$$V_1 = 5 \text{ m/sec}$$

$$D_2 = 15 \text{ cm} = 0.15 \text{ m}$$

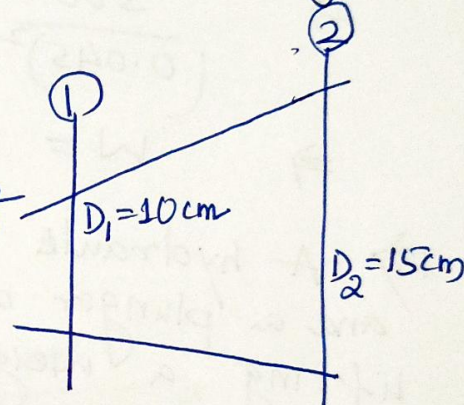
$$A_2 = \frac{\pi D_2^2}{4} = \frac{\pi (0.15)^2}{4} = 0.01767 \text{ m}^2$$

Acc. to the eqn of continuity.

$$A_1 V_1 = A_2 V_2$$

$$\therefore 0.007854 \times 5 = 0.01767 \times V_2$$

$$\therefore V_2 = \frac{0.007854 \times 5}{0.01767} = 2.22 \text{ m/sec}$$



## **HEAT TRANSFER**

Thermal energy is transferred from a hotter body to a colder body. The basic driving force of heat is the temperature difference or temperature gradient. Heat transfer is possible in three ways. These are as follows:

- Conduction
- Convection
- Radiation

In fluids, heat is often transferred by convection. The motion of the fluid itself carries heat from one place to another. Another way by which heat can be transferred is the conduction which does not involve any motion of a substance but rather, is a transfer of energy within a substance (or between substances in contact). The third way to transfer energy is the radiation which involves absorbing or giving off thermal waves.

### **HEAT TRANSFER BY CONDUCTION**

Heat energy can be transferred from one substance to another when they are in direct contact. This type of heat transfer takes place in solid objects. Heat transfer in this method is linearly related to the temperature difference. This method of heat transfer is called as conduction.

Conduction method of heat transfer is mainly seen in solid objects. It happens when any hot material comes in contact with a cold material. When heat is transferred through conduction, the substance itself does not move; rather, heat is transferred internally by vibrations of atoms and molecules. Electrons can also carry heat. Metals have many free electrons which move around randomly. They can transfer heat from one part of the metal to another. So, metals are generally good conductor of heat.

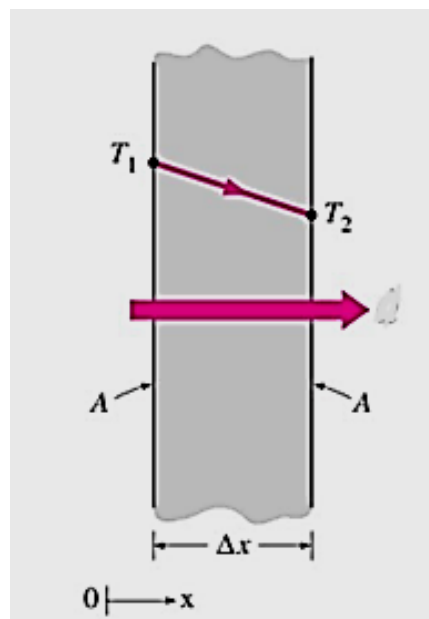
Some solid materials are better conductor of heat than the others. For example, metals are good conductors of heat while a material like wood is not. When a metal is heated at one end, the other end also becomes hot while that does not happen with a piece of wood. Good conductors of electricity are often good conductors of heat.

Since the atoms are closer together, solids conduct heat better than the liquids or gases. This means that two solid materials in contact would transfer heat from one to the other better than a solid in contact with a gas or a gas with a liquid.

### **Fourier's Law of Conduction**

The main condition of heat transfer by conduction is the temperature difference. Heat always flows from a hotter body to a colder body.

Fourier's law states that the rate of heat transfer is the product of area normal to the heat flow path, temperature gradient and thermal conductivity of the material.



Mathematically, this can be written as

$$q = \frac{dQ}{dt} = -KA \frac{dt}{dx}$$

where

q = rate of heat transfer

K = thermal conductivity of the conducting material

A = area normal to the heat flow path

dt/dx = temperature gradient or the rate of change of temperature with reference to the distance in the direction of heat flow.

As the heat always flows in the direction of decreasing temperature, so temperature gradient dt/dx is negative.

### **Thermal Conductivity**

Thermal conductivity is the physical property of a substance which is responsible for the heat transfer by conduction.

The unit of thermal conductivity is watt per metre Kelvin (W/m K).

Thermal conductivity is different for different materials. It is highest for solids, lowest for gases and lies in between in case of liquids.

As the thermal conductivities of gases and liquids are less, so the heat transfer in these mediums is negligible by conduction.

## **HEAT TRANSFER BY CONVECTION**

Molecules of a liquid and gas are not confined to a certain point. They change their position. In this case, heat energy is transported from one point to another by the movement of these molecules. This phenomenon of heat transfer is called as convection.

Heat transfer in fluids is generally done through convection. Hotter part of the fluid is not as dense as the cooler part, so there is an upward buoyant force on the hotter fluid, making it rise while the cooler and denser fluid sinks. Convection current is set up in the fluid.

Convection may take place naturally through the creation of convection current or by applying some external force.

### **Newton's Law of Cooling**

The rate of heat transfer by convection is the product of heat transfer area, difference of temperature between surface and that of fluid and a constant called as convective heat transfer coefficient.

The equation can be written as

$$q = h A \Delta T$$

where

$q$  = average rate of heat transfer by convection in watts or joule per second

$A$  = heat transfer area in square metre .

$\Delta T$  = difference of temperature between surface and that of the fluid in degree Celsius

$h$  = convective heat transfer coefficient in watt per square metre degree Kelvin

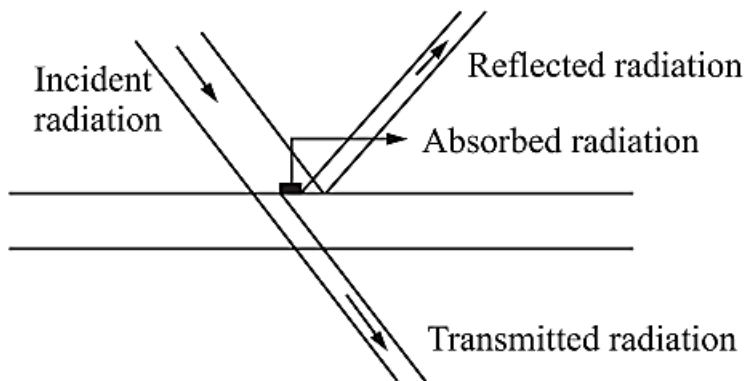
## HEAT TRANSFER BY RADIATION

Thermal energy is radiated in the form of electromagnetic waves. When a body absorbs these electromagnetic waves then heat transfer takes place. This type of heat transfer is called as radiation.

We feel the hotness of sun through radiation. As discussed in earlier two methods of heat transfer, some medium is required for heat transfer. But in case of radiation, no material medium is required to transfer heat from one point to another. Heat transfer by radiation can take place in vacuum also.

### Absorption, Reflection and Transmission of Radiation

When electromagnetic waves fall on the surface of a body, then some part of the energy is reflected or scattered, some part is absorbed and some part is transmitted.



~~\_\_\_\_\_~~ Total radiation utilised in different ways.

---

The fraction of incident radiation which is absorbed by the body is called as the absorptivity  $\alpha$ . The fraction which is reflected is called as reflectivity  $\rho$  and the fraction which is transmitted is called as transmissivity  $\tau$ .

For anybody  $\alpha + \rho + \tau = 1$

Different bodies have different absorptivity, reflectivity and transmissivity. Accordingly, the body may be classified as black body, white body and transparent body.

### **Black Body**

When all the incident radiations are absorbed by the body and there is no reflection and transmission, the body is called as black body.

In this case  $\alpha = 1$ ,  $\rho = 0$  and  $\tau = 0$

Black body plays a vital role in the study of radiation. But practically, there is no black body. Some part of the energy is reflected and transmitted. All the energy cannot be absorbed. Theoretically, the heat retransfer equation by radiation is based upon black body and then, it is refined according to the situation. The Stefan–Boltzmann law is based upon black body.

### **White Body**

A body which reflects all the incident radiation and does not absorb or transmit is called as a white body.

In this case ,  $\alpha = 0$ ,  $\rho = 1$  and  $\tau = 0$

### **Gray and Coloured Body**

If the absorptivity of the body doesn't vary with the wavelength and temperature of the incident radiation, then the body is called as **Gray body**. **It absorbs some fraction of incident light that falls on its surface.**

If the absorptivity of the body varies with the wavelength of the radiation, the body is called as **coloured** body.

### **Transparent and Opaque Body**

When a part of the incident radiation is transmitted, the body is called as the transparent body.

Ex- Gases like Oxygen, hydrogen, Nitrogen etc.

When there is no transmitted of radiation takes place, the body is called as opaque body.

Ex- Wood, Plastic , stone , Metals

### **Emissive Power**

The amount of radiant heat emitted by a body per unit area unit time at a given temperature is called as Emissive power. And its SI unit is  $W/m^2$ .

### **Emissivity**

The emissivity of a substance depends upon its nature and the characteristic of its surface.

The ratio of emissive power of any surface and that of a hypothetical black body is called as emissivity of that surface. It is denoted by  $e$ .

By definition, a black body has a surface emissivity of one.

### **Stefan–Boltzmann Law**

In 1879, Stefan proposed that the total emissive power of a radiating surface of a black body is proportional to the fourth power of the absolute temperature of the surface.

Mathematically, this law may be written as  $q = \sigma AT^4$

where  $q$  = rate of heat emission by radiation

$A$  =area of the emitting body in square metre

T = absolute temperature in degree Kelvin

$\sigma$  = a constant known as Stefan–Boltzmann constant

If heat transfer takes place from a black body to another body, then the net transfer of heat by radiation is given by

$$Q = \sigma A F (T_1^4 - T_2^4)$$

Here, F is a factor which depends upon the geometry of the two surfaces.

$T_1$  = Temperature of Black body

$T_2$  = Temperature of another body

# MANUFACTURING

→ Manufacturing is defined as the process of value addition upon any material, which is termed as Raw material in order to get the finished product.

→ Manufacturing Science can be divided into 5 groups

(1) Foundry Technology

(2) Welding Technology

(3) Forming Technology

(4) Machining Technology

(5) Non-conventional machining technology.

1) FOUNDARY TECHNOLOGY :- In this process the material is first liquified by properly heating in a suitable furnace. Then the liquid is poured into a previously prepared mould cavity where it is allowed to solidify. After that the solidified component is taken out of this cavity and cleaned to the shape.

2) WELDING TECHNOLOGY - Welding is a process in which two or more parts are assembled and joined together by subjecting it to heat and pressure to get desired shape.

3) FORMING TECHNOLOGY - Forming is a process in which the desired shape and size are obtained through the plastic deformation of a material.

4) MACHINING TECHNOLOGY - In this process the desired shape and size are obtained by removal of material with the help of cutting tool on different types of machine.

5) NON-CONVENTIONAL MACHINING TECHNOLOGY

This process is adopted to remove the material from difficult to machine materials in order to produce a complicated shape

Ex. EDM, AJM, EBM, PAM, WJM

CASTING:- It is a process in which the material is first liquified by heating it to a proper temperature in a certain heating unit termed as furnace. Then the liquid metal is poured into the mould cavity, where it is allowed to solidify subsequently. Then the product is taken out of the mould cavity, cleaned and finished to get the desired shape.

PATTERN → A pattern is the replica of the object to be casted with some modifications.

- It is a mould forming tool
- It is used for ~~making~~ generating cavity (known as mould) in the moulding sand.
- There are many materials ~~at~~ which are used for making patterns like wood, metals, plastic, wax, plaster of paris etc.

# SAND MOULDS

## IMPORTANT TERMINOLOGY

- 1) Moulding Box - It is a box shape container where mould will be kept.
- 2) Ramming - It is the process of filling the sand on the mould box to achieve the desired shape.
- 3) Fettling - It is the operation which is performed to remove and cut the unwanted portion of the component, cleaning and finishing the casting.
- 4) Flask - A moulding flask is one in which hold the sand mould intact.
- 5) Drag - Lower moulding flask is known as drag.
- 6) Cope - Upper moulding flask is known as Cope.
- 7) Parting Line - The dividing line between the two moulding flasks (Drag and Cope) is known as Parting Line.
- 8) Bottom Board - This is a board normally made of wood, which is used at the start of the mould making. The pattern is first kept on the bottom board, sand is sprinkled on it and then the ramming is done.

✓ Facing Sand - The small amount of carbonaceous material sprinkled on the inner surface of the moulding cavity to give better surface finish to the castings.

10) Moulding Sand - It is the freshly prepared refractory material used for making the mould cavity. It is a mixture of silica, clay and moisture in appropriate proportions.

11) Backing Sand - It is what constitutes most of the refractory material found in the mould. This is made up of used and burnt sand.

12) Core - It is used for making hollow castings.

13) Pouring Basin - A small funnel-shaped cavity at the top of the mould into which the molten metal is poured.

14) Sprue - The passage through which the molten metal reaches the mould cavity from the pouring basin.

15) Runner - The passage ways in the parting plane through which the molten metal is regulated before they reach the cavity.

16) Gate → The actual entry point through which the molten metal enters the mould cavity.

16) Chaplet - Chaplets are used to support cores inside the mould cavity to take care of its own weight and overcome the metallostatic forces.

17) Chill - Chills are metallic objects, which are placed in the mould to increase the cooling rate of casting to provide uniform or desired cooling rate.

18) Riser - It is a reservoir of molten metal provided in the casting so that the hot metal can flow back into the mould cavity when there is a reduction in volume of metal due to solidification.

~~STEPS INVOLVED IN IN.~~

TYPES OF CASTING

- 1) Centrifugal casting.
- 2) Shell moulding.
- 3) Investment mould casting or lost-wax process.
- 4) Die casting.

# CENTRIFUGAL CASTING

- In centrifugal casting, centrifugal force plays a major role in shaping and feeding the casting.
- In this process mould is rotated rapidly about its central axis as the metal is poured into it.
- In this process no core is used.
- The centrifugal force is utilized in two ways:
  - (i) It is utilised to distribute liquid metal over the outer surface of a mould. Hollow cylinders and other annular shapes are formed in this way.

(2) Centrifugal force tends the poured metal and the freezing metal to fly outward, away from the axis of rotation, and this tendency creates high pressure on the metal or casting while it is freezing the lighter slag, oxides and other inclusion being lighter, gets separated from the metal and segregates towards the centre.

- There are three types of centrifugal casting
  - (i) True centrifugal casting
  - (ii) Semi " "
  - (iii) Centrifuge casting

## Applications

- (i) Parts such as cast iron pipes, alloy steel pipes, tubing / annular sections, bushings and rings

(ii) Liners for I.C. Engine, rings, short or long pots and other annular components

## SHELL MOULDING

→ It is a process in which the sand mixed with a thermosetting resin is allowed to come into contact with a heated metallic-pattern plate, so that a thin and strong shell of mould is formed around the pattern. Then the shell is removed from the pattern and the cope and drag are removed together and kept in a flask with the necessary back up material and the molten metal is poured into the mould.

Some of the other binders are

- (i) Phenol formaldehyde
- (ii) Urea formaldehyde

Following are the steps in the shell moulding.

- 1) Hot metal pattern is clamped at the top of the box containing a mixture of sand and thermo-setting plastic resin
- 2) The box is inverted and kept in this position for some time, hot pattern melts resin in contact with it.
- 3) Box is again turned to original position. A thin shell of resin bonded sand sticks to the pattern and rest falls

1) Pattern with shells is placed in oven and heated to cure resin bond.

(5) Shell is stripped from pattern with the help of ejector pins or any suitable ejection technique.

(6) Two shells are assembled, clamped and properly packed with sand in a suitable box, this forms a shell mould ready to fill the metal.

## INVESTMENT Moulding

It is also termed as lost wax process.

A pattern is made of soft material. ~~It~~

Aluminium is used to make the die. There after wax or plastic is injected into the die to form an expandable pattern. The expandable pattern is cleaned in alcohol to remove grease and dirt.

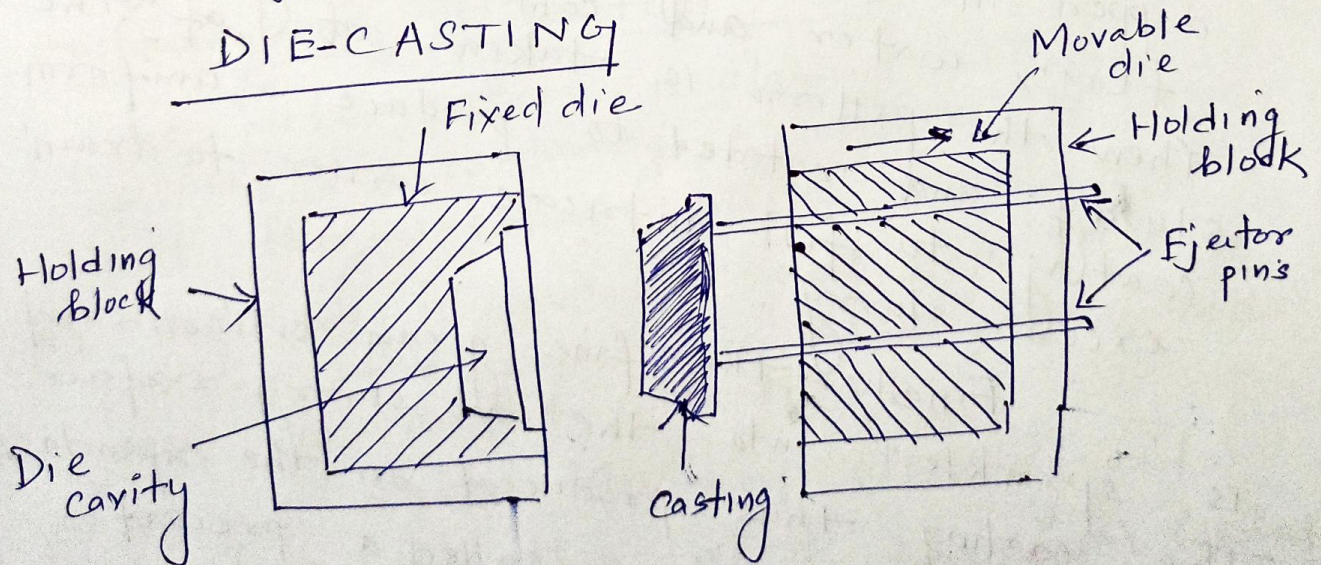
After drying, the pattern is dipped in a slurry composed of silica flour, water and some bonding agent.

Then the pattern is taken out of the slurry and rotated to produce a uniform coating to fill intricate corner to drain excess slurry.

Finally the fine grain silicon sand is sprinkled into the wet slurry surface. The coating thus produced on the expandable pattern after drying is called a precoat.

The pattern with the precoat is then placed on a steel base and is covered by an opened steel container. Both the pattern and the container are secured to the base by molten wax. Then, the container is filled with a slurry of heavy and hardening refractory concentrate. The concrete sets in after a lapse of 20 hrs when the container is placed in a properly controlled ~~heat~~ heating oven. Thus most of the wax or plastic melts away and flows out of the mould leaving a cavity with the shape of the desired casting. The residual wax is removed by firing the mould in a furnace about 24 hrs. The liquid metal is poured into the metal. After cooling the container is removed and the hard refractory investment is knocked off by a hammer or other vibratory means.

## DIE-CASTING



→ Die-casting may be defined as the production of casting under pressure in permanent metal moulds. It is also called pressure die-casting.

→ Because of <sup>the</sup> high pressure involved in die-casting, any narrow sections, complex shapes and fine surface details can easily be produced.

→ In die casting, the die consists of two parts: One part is called the stationary half or cover die, which is fixed to the diecasting machine.

→ The second part is called the moving half or ejector die that is moved out for the extraction of the casting.

→ A die casting machine performs the following functions.

(a) Holding two die halves firmly together

(b) Closing the die

(c) Injecting molten metal into die

(d) Opening the die

(e) Ejecting the casting out of the die

### Procedure

- 1) The two parts of the die are made part.
- 2) The lubricant is sprayed on the die cavity manually or by the auto lubrication system so that the casting will not stick to the die.
- 3) The two die halves are closed and clamped.
- 4) The required amount of metal is injected into the die.

(5) After the casting is solidified under pressure, the die is opened and the casting is ejected.

## WELDING

Welding is a process of permanent joining two materials together by means of heat or pressure.

### Types of Welding

1) Plastic Welding or Pressure Welding - In the plastic welding, the pieces of metal to be welded or joined are heated to a plastic state and then forced together by external pressure. Ex - Forge welding, resistance welding, thermit welding, etc.

2) Fusion Welding - In the fusion welding or non-pressure welding, the material at the joint is heated to a molten state and allowed to solidify. Ex - gas welding, arc welding, thermit welding, etc.

### WELDING PROCESSES

1) Gas Welding - Gas welding is a fusion welding process in which the heat of combustion of oxygen/air and fuel gas such as acetylene, hydrogen, butane etc. is used to form the weld with the addition of a filler material.

2) ARC WELDING - It is a process in which welding is produced by heating with an electric arc mostly without the application of pressure and with or without the use of filler ~~metal~~ metal depending on base metal thickness.

3) TUNGSTEN INERT GAS WELDING (TIG) or GAS TUNGSTEN ARC WELDING (GTAW)

→ In this arc welding process, welding heat is produced from an electric arc established between the tungsten electrode and the job. A shielding gas (argon, helium, nitrogen etc.) is used to avoid atmospheric contamination of molten weld pool. Filler metal is required is fed separately.

4) METAL INERT GAS (MIG) or GAS METAL ARC WELDING (GMAW)

In this welding process, welding heat is produced from an electric arc established between the continuously fed metal electrodes and the job. Argon, helium, carbon dioxide or a gas mixture shields the arc and molten metal from atmospheric contamination.

5) RESISTANCE WELDING : Resistance welding is a group of welding process in which welding heat is obtained from the resistance of the work to the flow of electric current.

and by the application of pressure. In this process no filler metal or flux is added. The heat generated in resistance welding can be expressed as

$$H = I^2 R T$$

where,  $H$  = Total heat generated in work in Joule

$I$  = Electric current passed in Amp.

$R$  = Resistance of the joint

$T$  = Time for which the electric current

6) SPOT WELDING - Spot welding is a resistance welding process in which overlapping workpiece are joined by the fusion at one or more spots by the generation of heat due to resistance of few  $\mu$  of electric current through the workpiece that is held together under the force of the two electrodes

7) SEAM WELDING - SEAM WELDING IS A resistance welding process in which overlapping sheet are joined by local fusion progressively along a joint, by rotating circular electrodes. Fusion takes place because of heat which is generated from the resistance to electric current flowing through the workpieces which are held together under pressure by electrodes

## 8) PROJECTION WELDING

Projection welding is a variety of spot welding process in which small projections are made in one of the workpiece. Then the parts to be welded are clamped between flat copper alloy electrodes. On the passage of high current, the projections melt and create the weld upon application of electrode pressure.

## 9) THERMIT WELDING

It is one type of thermochemical welding process where exothermic reactions takes place which produces necessary heat for welding. In this process due to the chemical reaction between aluminium and iron-oxide, a very high temperature is developed which is sufficient for the welding process.

10) PLASMA ARC WELDING - Plasma arc welding is a welding process in which welding heat is obtained from a constricted arc set up between a tungsten electrode and water cooled nozzle and job. The process employs two inert gases, one from arc plasma and the second shields the arc plasma. No pressure is applied and filler metal may/may not be added.

## 11) ELECTRON BEAM WELDING - (EBW)

EBW is electron beam welding. The heat for fusion is obtained from the high velocity narrow beam electrons. The kinetic

energy of electrons are converted into heat as they strike the work piece there by causing the work piece metal to melt and fuse

12) ULTRASONIC WELDING - Ultrasonic welding will join similar or dissimilar metal by applying a high frequency vibratory energy to overlapping metal plate at the area to be joined. No flux, electric current filler metal heat is applied. The frequency of oscillation is generally in the range of 10KHz to 75KHz. The oscillating shear stress causes plastic deformation at the interface of two work pieces, breaking up oxide films and contaminants and thus allowing good contact to form a good solids state bond. Here the welding variables are clamping force, vibrating power and time.

13) FRICTION WELDING - In this welding process, welding heat is obtained by the friction between the ends of the two parts to be joined. The machine for friction welding is similar to a centre lathe when one end centre is fixed and other end is rotated.

14) EXPLOSIVE WELDING - In explosive welding, detonation of explosive are used to accelerate a part to move towards the other plate at a fast rate, so that the impact create joint. As the plate moves at a high stress waves are created between

The plates, which clean all the oxides and scales present in the interface and make a clean joint. Generally the low deformation velocity (2.4 km/sec to 3.6 km/sec) explosives are used for explosive welding. The thicker plates require high velocity.

## FORMING

- Forming is the manufacturing process in which the shape of material is changed by plastic deformation with the help of suitable stresses (like tension, compression or shear stress)
- During forming process, the material is deformed and displaced without any removal of material.
- Examples of forming process - Drawing, Extrusion, forging, rolling etc.

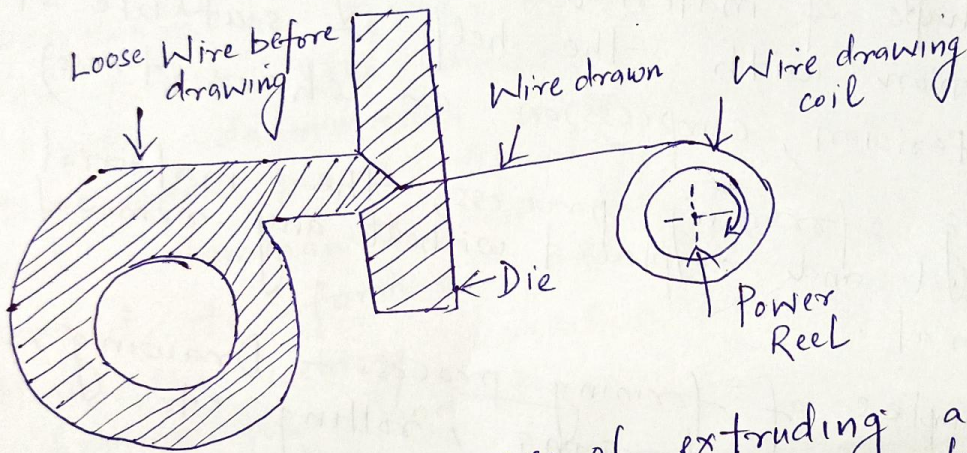
DRAWING - Drawing is pulling metal through a die or a set of dies to achieve a reduction in diameter by means of tensile force applied to the exit side of the die. The process requires a very large force in order to pull the metal through the die. To reduce the frictional force between the die and the metal the die is kept well lubricated. Rods, tubes are often given cold finishing operation to reduce the size, increase strength, improved finish and better accuracy.

# CLASSIFICATION OF DRAWING OPERATIONS

Drawing operations can be classified as:

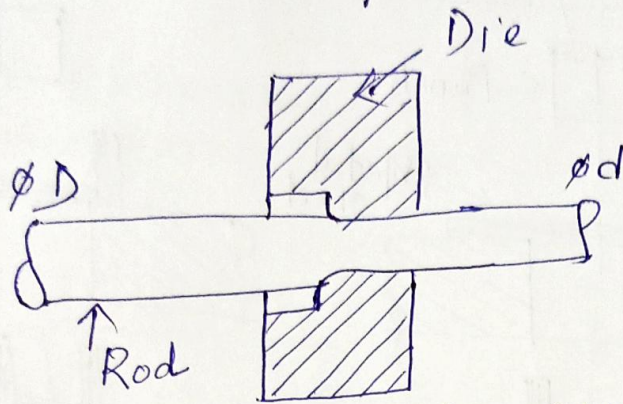
- (i) Wire drawing
- (ii) Rod drawing
- (iii) Tube drawing
- (iv) Deep drawing
- (v) Shallow drawing

## WIRE DRAWING



Wire drawing is a process of extruding a rod through a die thereby causing reduction in cross-sectional area of rod. The rod may be pulled through a single or several dies of decreasing diameter in order to obtain very thin wire. Raw material used for wire drawing is generally a rolled bar obtained by hot rolling process. The rods to remove scale and coated with lubricants in order to avoid corrosion and oxidation. Dies are made of chilled cast iron, hardened alloy steel or cemented tungsten carbide.

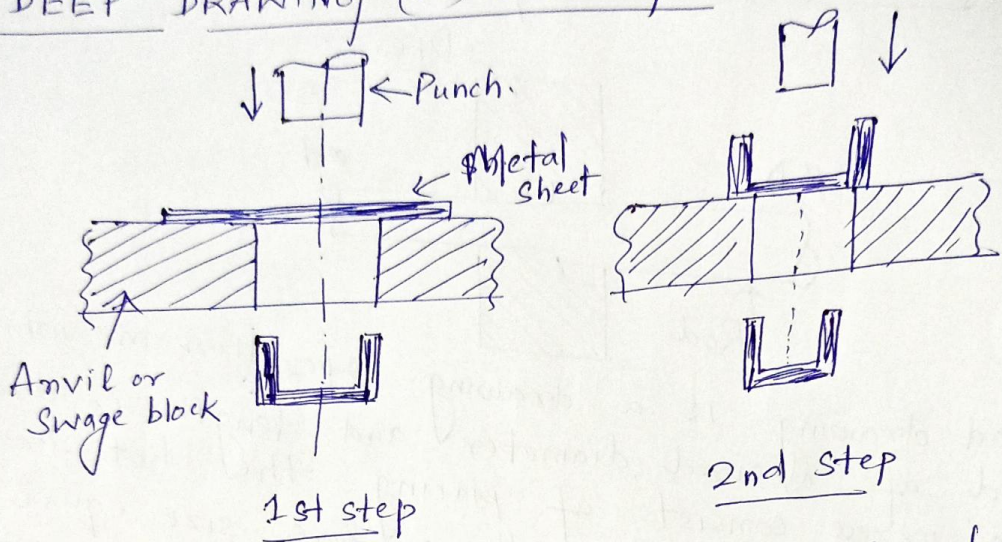
## (2) ROD DRAWING:



Rod drawing is a drawing operation in which rod of desired diameter and length is drawn. The process consists of placing the hot drawn bar through a die with a bore size equal to the size of the diameter of finished product. The rod to be drawn should be straight and the maximum length of rod depends upon the carriage movement of the drawing machine. The drawing speed and force required depends upon the size of the rod to be drawn.

(3) TUBE DRAWING - Tube drawing operation is similar to rod drawing except that instead of rod, tubes are drawn out of the die with or without mandrel. This method produces tubes having smaller diameters or thinner walls that can be obtained from hot rolling. Tube drawing is used to get dimensional accuracy, smooth surface and improved properties of tubes already made by hot rolling process.

#### (4) DEEP DRAWING (OR) CUPPING



Process of making cup shaped parts from the sheet metal blank is called deep drawing or cupping. The working principle of deep drawing is that the metal blank is initially heated to a plastic state and placed on the die or cavity. Then the force is given by using a punch, so the required shape of cup according to shape of cavity is produced.

EXTRUSION → Extrusion is a process in which a heated billet or slug of metal is forced by high pressure through an orifice that is shaped to provide the desired form to the finished part. Ex. an everyday process of squeezing of toothpaste from a collapsible tube is an example of extrusion.

#### CLASSIFICATION OF EXTRUSION

Extrusion process is classified as:

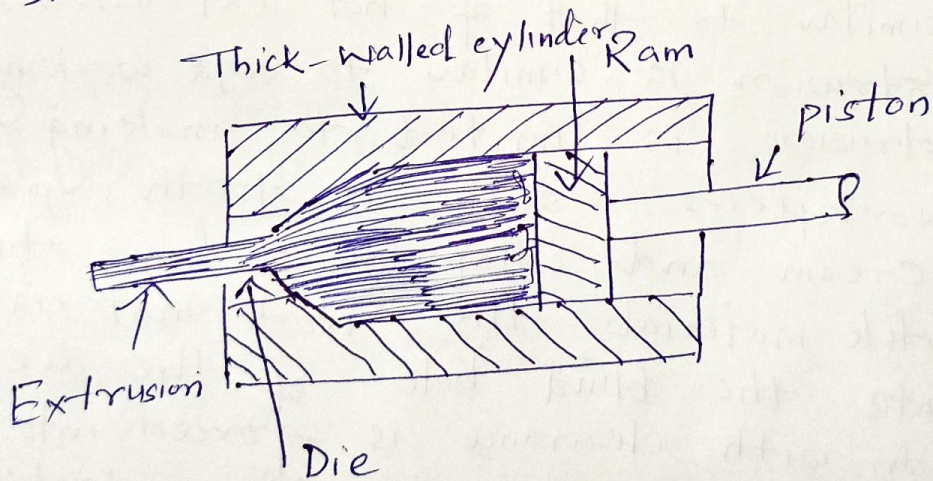
- (i) Hot Extrusion :- (a) Forward or direct extrusion
- (b) Backward or indirect extrusion

- (ii) Cold Extrusion or Impact extrusion.
- (iii) Hydrostatic extrusion.

## HOT EXTRUSION

### 1. Forward or Direct Extrusion

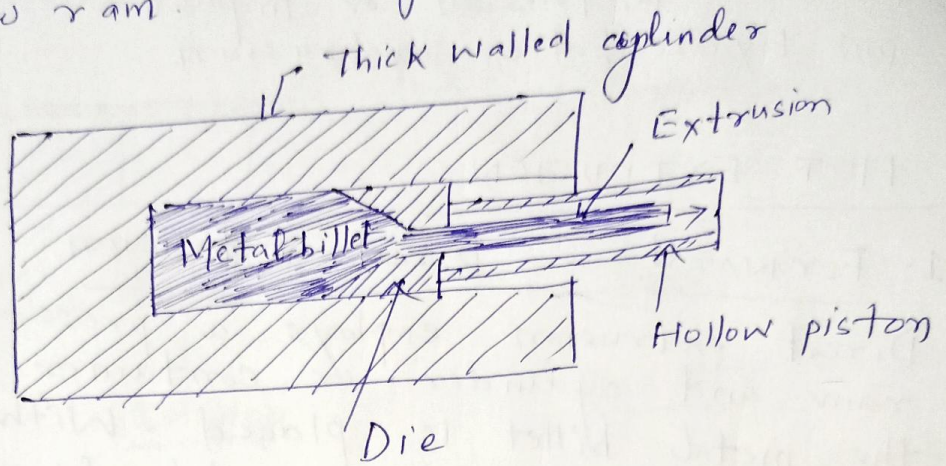
Direct extrusion employs a press-operated ram and cylinder or container into which the metal billet is placed. With application of ram pressure, the metal first plastically fills the cylinder shape and it is then forced out through the die opening until a small amount remains in the container.



### 2. Indirect or Backward Extrusion

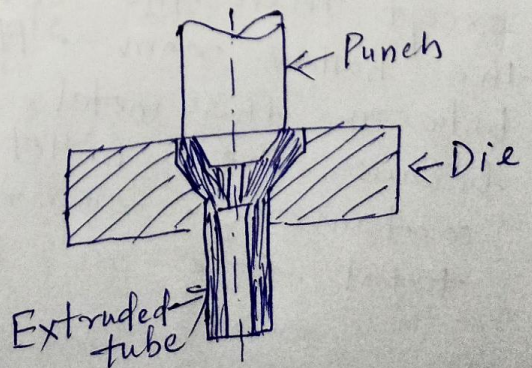
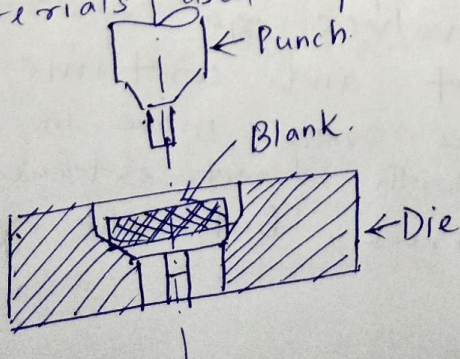
Indirect extrusion is similar to direct extrusion except that the extruded part is forced through the hollow ram. It involves no friction between the metal billet and container walls, because the billet does not move in the container. Compared with direct extrusion less total force is required, but the equipment

is mechanically more complicated in order to accommodate the passage of the extruded shape through the centre of hollow ram.



### IMPACT EXTRUSION (OR) COLD EXTRUSION

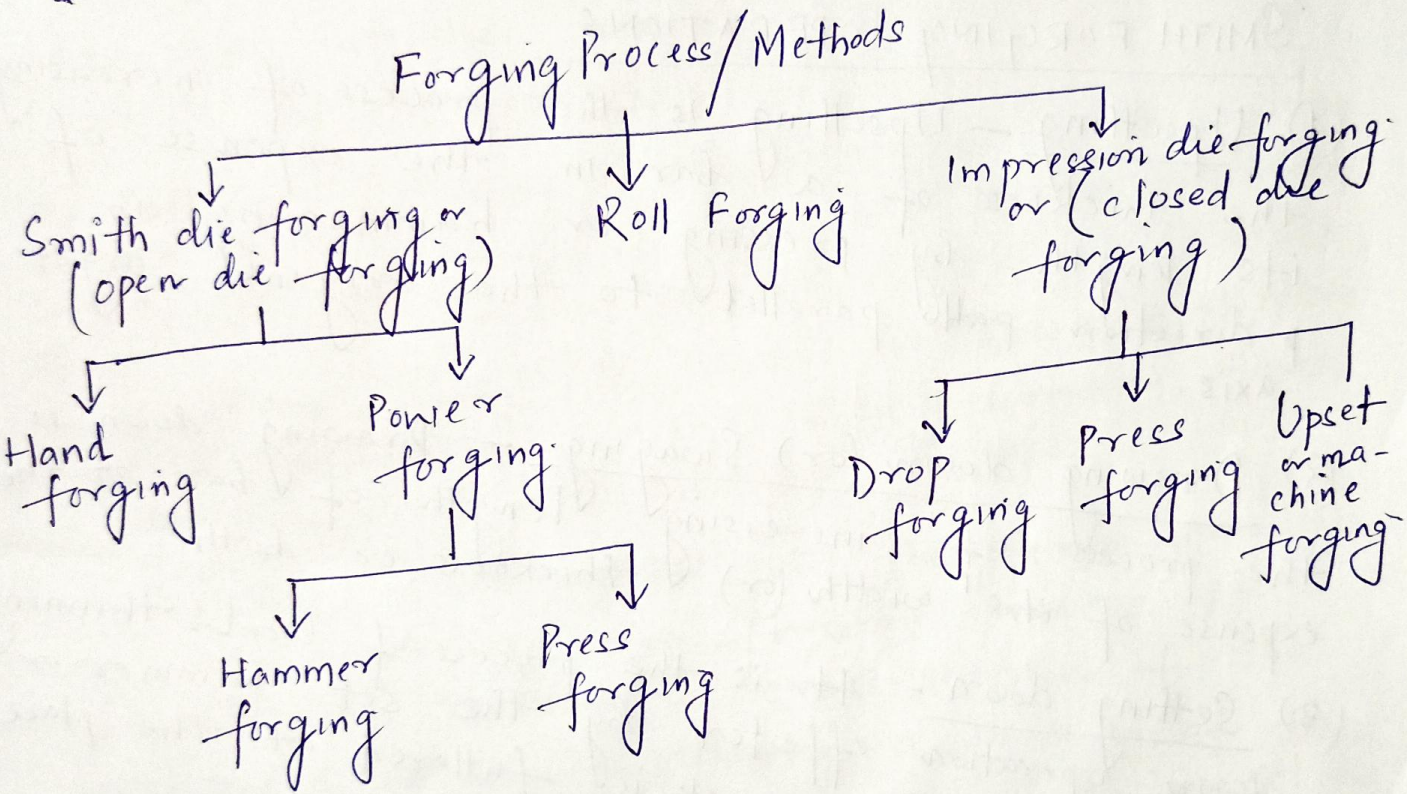
As the principle of cold extrusion is exactly similar to that of hot extrusion, ~~so is~~ impact extrusion is similar to cold working process. Impact extrusion is limited to making of small workpieces such as tooth paste, shaving cream and collapsible medicine tubes from the ductile materials. The work material is placed into the blind hole of the die and a ram punch with clearance is forced into the die which causes the metal to flow plastically around the punch and finally in tube. Lead, aluminium, zinc and tin are some of the materials used for impact extrusion.



# FORGING

Forging can be defined as the controlled plastic deformation of metals at elevated temperatures into a predetermined size or shape using compressive forces exerted through some type of die by a hammer, a press or an upsetting machine

## CLASSIFICATION OF FORGING



## SMITH DIE FORGING OR OPEN DIE FORGING OR FLAT-DIE FORGING

Smith forging involves heating the stock in the Blacksmith's forging or hearth and then heating it over an anvil. To get the desired shape, the operator has to manipulate the component between the blows.

## SMITH DIE FORGING (or) OPEN DIE FORGING (or) FLAT DIE FORGING

Smith forging involves heating the stock in the Blacksmith's furnace or hearth and then heating it over an anvil. To get the desired shape, the operator has to manipulate the component in between the blows.

### SMITH FORGING OPERATIONS

- (1) Upsetting - Upsetting is the process of increasing the thickness of a bar in the expense of its length by pressing or hammering in a direction parallel to the original ingot axis.
- (2) Drawing down (or) Swaging - Drawing down is the process of increasing length of bar at the expense of its width (or) thickness or both.
- (3) Setting down - It is the process of local thinning down operation effected by the set hammer or set. Usually the work is fullered at the place where the setting down commences.
- (4) Punching - Punching is the process of producing holes, generally by using a hot punch over the small round hole of the anvil, over a cylindrical die, or over a hole of correct size in the sewage block.

(5) Bending - Bending is a process of turning a part over the anvil horn in special form such as the swage block edges or by inserting the end in the small round hole and bending the bar with a wrench or tong. When metal is bent, the layers of metal on the inside are shortened and those on the outside are stretched. This causes a bulging of the sides at the inside and radii on the outside of the bend.

(6) Cutting - Cutting is a process in which a long workpiece of stock is cut into several specified lengths or a forging is separated from its stock. For cutting, metal is heated in blacksmith fire to high temperature and then hammer blows are directed on the chisel head.

7) Fullering - It is the term applied to the first operation in an impression die forging process. It consists of reducing cross-section of the workpiece or lengthening a portion of the stock in preparation for subsequent operations.

8) Trimming - It is the operation of removing flash from a forging.

9) Coining and ironing - These are sizing operations performed in dies by applying pressure to all or part of the forging to obtain closer tolerances, smoother surfaces, or to eliminate draft. Specific coining dies are used for this operation.

POWER HAMMERS :- All power hammers employ the same general principle of operation, a falling weight striking the blow, with the entire energy being absorbed by the work. If further blows are necessary, the striking weight is raised from the succeeding blow.

POWER PRESS or FORGING PRESS :- Forging presses for smithy work are usually of hydraulic type. The water passes from a large capacity tank to a pump and then it is delivered on the press with aid of an accumulator and distributor at 200 to 300 bar. The accumulated water pressure flows into a main cylinder and presses on the top of the large piston. Since the cross-section area of the piston in main cylinder is large the press ram is forced down upon the material to be forged which lies on the anvil. The action of working fluid on the piston rods in pull back cylinder raises the ram up. ~~To perform~~ Forging presses are available in the range from 30 tonnes to 1000 tons or 1500 tons.

IMPRESSION DIE FORGING or CLOSED DIE FORGING

Complex shape with great accuracy forgings cannot be obtained in open die forging. The complex forgings can be made in impression die forging which makes use of cavities in specially prepared dies to produce

forged shapes in large quantities. The finished forgings are duplicates of each other. Since the die is not fully closed, it is called as impression die. Closed die forgings are of three types: Drop forging, press forging and upset or machine forging.

ROLLING - Rolling is the most rapid method of forming metals into desired shapes by plastic deformation with the help of rolls. Rolling is of two types - hot and ~~rolling~~ cold rolling. In hot rolling the crystals are elongated in the direction of rolling and they start to reform after leaving the zone of stress in hot rolling. But in cold rolling they retain substantially the shape given to them by the action of the rolls.

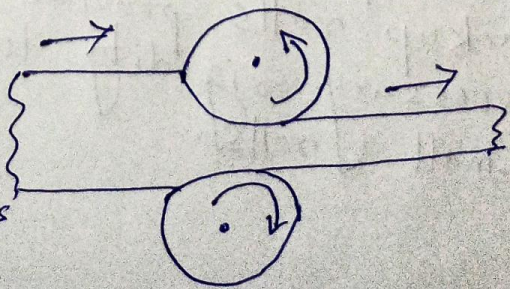
In hot rolling, the metal is heated to a plastic state and it is passed in between the two rollers which are operated in the opposite direction whereas in cold rolling the metal is not heated and it retains the shape given by the action of rolls.

### IMPORTANT ROLLING MILLS

1) Two high rolling mill:

This mill has two rolls. Both the rolls rotate in an opposite directions.

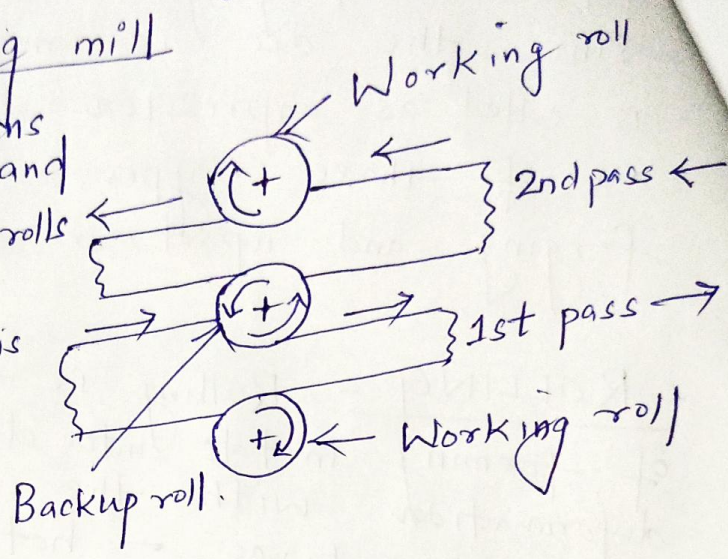
The principle of this process



is reduction of cross-sectional area of stock and increasing the length.

### (2) Three High rolling mill

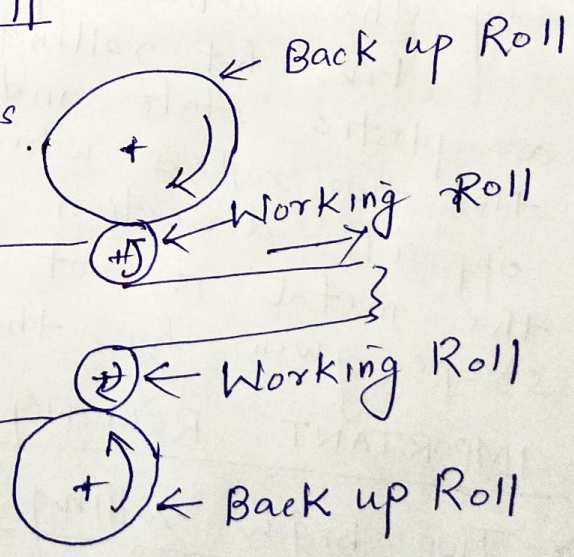
This arrangement contains three rolls. The upper and lower rolls are drive rolls while the middle roll rotates by friction. This type is used for rolling of two continuous passes in a rolling sequence without reversing the drive.



After all the metal has passed through the bottom roll set, the end of the metal is entered into the other set of rolls for the next pass.

### (3) Four High Rolling Mill

This arrangement contains four rolls. Two <sup>small</sup> rolls are the working rolls whereas other two rolls are the Backup rolls. The backup rolls provide necessary rigidity to the small rolls.



# ENGINEERING MATERIALS

- Engineering materials refers to the group of materials that are used in the construction of manmade structures and components
- The primary function of an engineering material is to withstand applied loading without breaking and without exhibiting excessive deflection.

## CLASSIFICATION OF ENGINEERING MATERIALS

Engineering materials can be classified into two types:

- (I) Metals
- (II) Non metals

## PHYSICAL PROPERTIES OF METALS

- Shiny in nature
- Metal is a good conductor of heat and electricity
- Density and melting point is high.
- Malleable
- Ductile
- At room temperature, it is in solid form except for mercury.
- Opaque

## PHYSICAL PROPERTIES OF NON-METALS

- Poor conductors of heat and electricity.
- Non-ductile
- Brittle
- Maybe solids, liquids or gases at room temperature
- These are not sonorous

# CLASSIFICATION OF METALS

Metals can be classified as (1) Ferrous metals  
(2) Non-ferrous metals

## FERROUS METALS

- These are metals and alloys containing high proportion of the element iron.
- They are the strongest materials available.

## NON-FERROUS METALS

- Non-ferrous metals are those which do not contain iron.
- They are mainly used for getting high strength and for special applications.

## CLASSIFICATION OF <sup>NON-</sup>FERROUS METALS

Non-ferrous metals are classified as follows

### 1) Metals

- Aluminium
- Cadmium
- Chromium
- Cobalt
- Copper
- Gold
- Lead
- Magnesium
- Manganese
- Molybdenum
- Nickel
- Titanium
- Tungsten
- Vanadium
- Zinc

### 2) Alloys

- Brass (Copper and Zinc)
- Tin bronze (Copper and tin)
- Aluminium bronze (Copper and aluminium)
- Aluminium alloys
- Magnesium alloys
- Zinc based 'die-casting' alloys
- Tin lead alloys

# CLASSIFICATION OF FERROUS METALS

1) Steel

- Low carbon steel
- Medium carbon steel
- High carbon steel.
- Alloy steel.

2) Cast Iron

- Grey cast iron
- White cast iron
- Malleable cast iron
- High-duty cast iron
- Alloy cast iron

3) Wrought Iron

## STEEL

- Steel is an alloy of iron with about 1% carbon.
- It may also contain other elements such as manganese, silicon etc
- Steel is hard, tough and corrosion-resistant.
- A steel in which elements other than carbon are added in sufficient quantity, in order to obtain special properties, is known as an Alloy steel.
- The alloying of steel is generally done to increase strength, hardness, toughness, resistance to abrasion and wear, improve electrical and magnetic properties
- The various alloying elements are nickel, cobalt, silicon, chromium, vanadium, titanium, manganese, tungsten etc

## CAST IRON

→ Cast irons are of ferrous alloys with carbon contents above 2.14 wt %

→ The design and production advantages of cast iron include:

- Low tooling and production cost
- Good machinability without burning
- Ability to cast into complex shapes
- Excellent wear resistance and high hardness.
- High damping capabilities

→ Composition of Cast Iron.

Carbon - 3% to 4%  
Silicon - 1% to 3%  
Manganese - 0.5% to 1%  
Sulphur - upto 0.1%  
Phosphorus - upto 1.0%

→ Types of Cast Iron.

1) Grey Cast Iron - Composition  
Carbon = 3 to 3.5%  
Silicon = 1% to 2.75%  
Manganese = 0.4 to 1%  
Phosphorus = 0.15% to 1%  
Sulphur = 0.02% to 0.15%

2) White Cast Iron - Composition  
Carbon = 2% to 2.3%  
Silicon = 0.85% to 1.2%

Manganese = 0.1% to 0.4%  
Phosphorus = 0.05% to 0.2%  
Sulphur = 0.12% to 0.35%

### 3) Malleable Cast Iron

Composition -

Carbon = 2.5%

Silicon = 1%

and remaining are other impurities like manganese, sulphur and phosphorus

## MECHANICAL PROPERTIES OF MATERIALS

- 1) Elasticity - Elasticity is a property of the material to regain its original shape after deformation on removal of load.
- 2) Plasticity - Plasticity enables the material to permanently retain the deformation on removal of load.
- 3) Strength - Strength is the ability of the material to resist the externally applied loads without failure.
- 4) Stiffness (Rigidity) - Stiffness enables the material to resist deformation under loads.
- 5) Ductility - Ductility is the property which enables the material ~~to resist deformation~~ under loads to be drawn into wire when tensile force is applied.

Ductility helps the material to absorb large overloads. Operations like drawing, heading etc. require ductility in the materials.

- 6) Malleability - Malleability is the ability of material to be drawn into thin sheets under compressive force. Ex Gold, aluminum
- 7) Resilience - Resilience of a material is its capacity to absorb energy within the elastic range. Resilience enables material to resist shock and impact and hence it is desired in springs.
- 8) Toughness - Toughness enables the material to absorb energy in the plastic range. It enables the material to be twisted or bent under a sudden load before rupture.
- 9) Hardness - Hardness enables the material to resist indentation, wear or plastic deformation.
- 10) Creep - Creep is the continuous deformation of a metal under a steady load at high temperature. Creep is exhibited by metals such as nickel, copper and iron at higher temperature. Resistance to creep can be increased by adding certain elements like tungsten, nickel, cobalt and manganese.

Strain hardening - When drawing ductile materials like mild steel, copper, brass and aluminum through dies ~~are~~ or when rolling them between rollers, plastic deformation takes place and this increases the yield point stress and ultimate strength. This is known as strain hardening.

12) Damping capacity - It is the ability of a material to damp vibrations by absorbing the kinetic energy of vibration. Cast iron has greater damping capacity than steel.

13) Hardenability - It is the property of steel which determines the depth and distribution of hardness obtained by heat treatment process. Hardenability can be improved by using alloying elements like boron, vanadium, manganese, chromium and molybdenum.

14) Machinability - It is the ease with which the metal can be removed in machining operations like turning, drilling etc.

15) Endurance - It is the property of a material by virtue of which it can withstand varying stresses.

16) Impact strength - It is the property of a material by virtue of which it can resist or absorb shock energy before it fractures.

17) Castability :- It is the property of a material, which indicates the ease with which it can be cast into different shapes and sizes.

18) Weldability - It is the property of a material, which indicates the ease with which two similar (or) dissimilar metals are welded.

19) Formability - It is the property of a material, which indicates the ease with which it can be formed into different shapes and sizes.

20) Fatigue - Fatigue is defined as the fracture which takes place under repeatedly applied fatigue stresses.

### NON-METALLIC MATERIALS

Non-metallic materials are of two types :-

1. ~~Polymers~~ Natural <sup>non-metallic materials</sup>
2. ~~Plastics~~ Synthetic <sup>non-metallic materials</sup>

Examples of Natural non-metallic materials are wood, rubber, cotton, wool, leather, silk etc.

Examples of Synthetic non-metallic materials are plastics, fibres and elastomers.

# POLYMERS

- The term polymer is derived from two Greek words poly (means many) and meros (means unit).
- Polymers are composed of a large number of repeating units called monomers.
- The monomers are joined end-to-end in a polymerization reaction.
- Polymers are of two types
  - Natural polymers
  - Synthetic polymers
- Wood, rubber, cotton, wool, leather and silk are natural polymers whereas plastics (polyethylene, polystyrene, nylon, terylene, dacron), fibres and elastomers are ~~not~~ synthetic polymers.

POLYMERIZATION → The process of linking monomers together is called polymerization. In polymerization, the monomers molecules combine end-to-end to form a large molecules known as polymers.

## CLASSIFICATION OF POLYMERS

Polymers are classified into two groups. They are :

- (1) Thermoplastic polymers
- (2) Thermosetting polymers

## THERMOPLASTIC POLYMERS

- Thermoplastic polymers consists of a very long chain of carbon atoms covalently bonded together.
- They soften during heating and becomes hard upon cooling.
- These materials are normally fabricated by the simultaneous application of heat and pressure.
- These polymers can be reheated and reformed into new shapes many number of times without significant changes in their properties.
- Thermoplastics are relatively soft and ductile.
- Ex (i) Polyvinyl chloride (PVC) and Polystyrene are used in pipes and plastic doors.
- (2) Polystyrene are used in fluorescent light reflectors.
- (3) Polymethyl methacrylate are used in plastic lenses.

## THERMOSETTING POLYMER

- Thermosetting polymers have a highly cross-linked structure in which all the atoms are connected by strong covalent bond.
- They ~~soften~~ become soft when they are heated initially and then become hard permanently upon cooling.

once set, additional heating does not produce softening. Thermosetting polymers cannot be reheated and reformed into new shapes

→ These polymers are generally stronger but are more brittle and reformed into new shapes

→ Thermosets have poor ductility and impact properties

→ Examples - Plastics, Elastomers, fibers, Coatings, Adhesives, foams and films

## MODULE -III

**Rope /Belt:** It often used as a replacement for gears. , they are less noisy, and absorb shocks and vibration. In contrast to other system that friction is no good, here we rely on the friction to transmit power. What is belt Drive?

1. A belt is a looped strip of flexible material, used to mechanically link two or more rotating shafts.
2. They may be used as a source of motion, to efficiently transmit power, or to track relative movement. Belts are looped over pulleys.
3. In a two pulley system, the belt can either drive the pulleys in the same direction, or the belt may be crossed, so that the direction of the shafts is opposite.

Advantage:

- They are simple. They are economical.
- Parallel shafts are not required.
- Overload and jam protection are provided.
- Noise and vibration are damped out. Machinery life is prolonged because load fluctuations are cushioned (shock-absorbed).
- They are lubrication-free. They require only low maintenance.
- They are highly efficient (90–98%, usually 95%). Some misalignment is tolerable.
- They are very economical when shafts are separated by large distances.

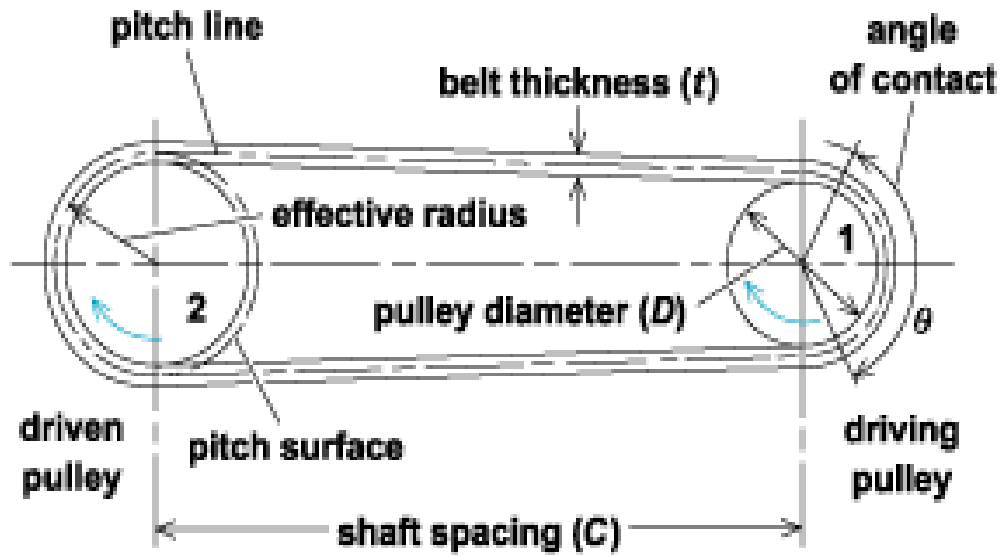
Types of Belt:

- Flat Belt
- Vee Belt
- Timing Belt

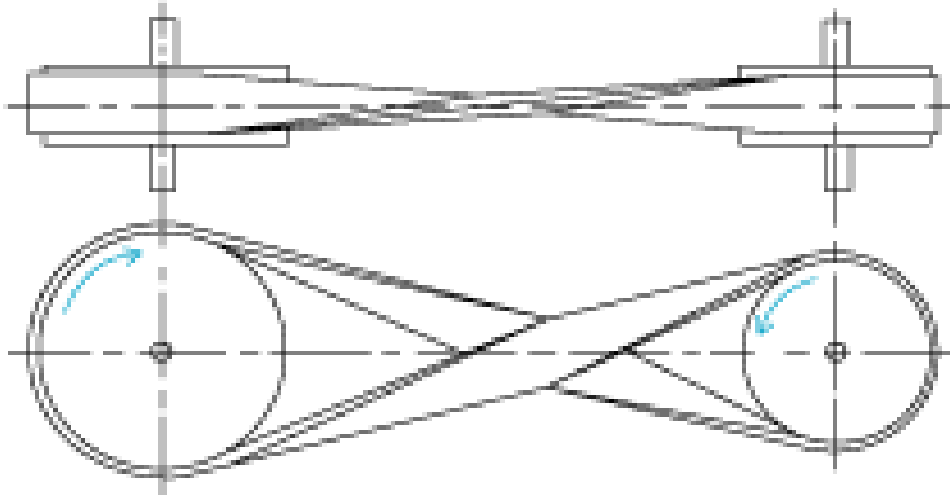
- Round Belt

### BELT DRIVE ARRANGEMENT

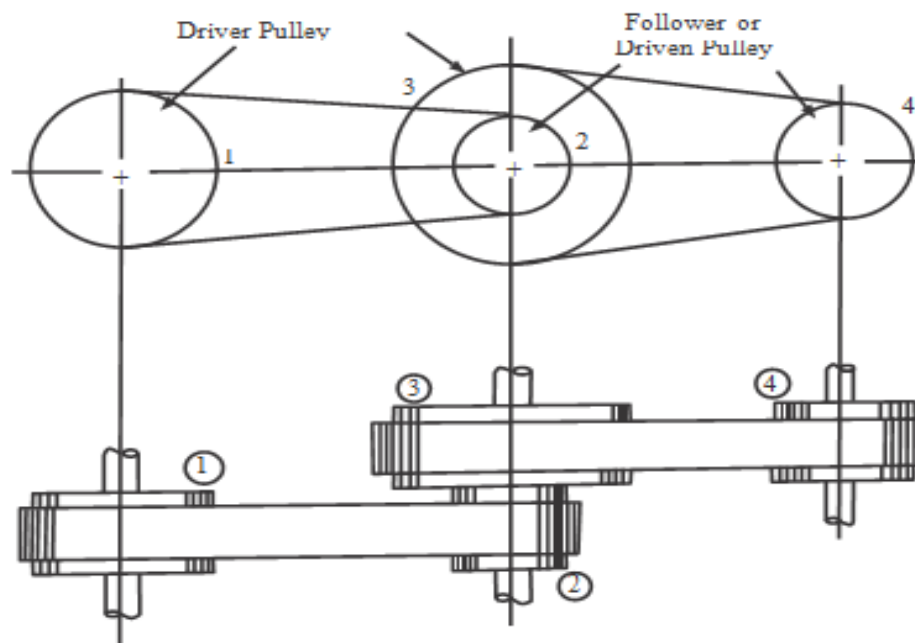
#### OPEN BELT DRIVE



#### CROSS BELT DRIVE



#### COMPUND BELT DRIVE



## MATERIAL PROPERTY OF BELT DRIVE

- High coefficient of friction
- High flexibility
- Durability
- High Strength

## What is Gear Train?

When two or more gears are made to mesh with each other to transmit power from one shaft to another, such a combination is called '*gear train or train of toothed wheels*'.

### Types of Gear Train

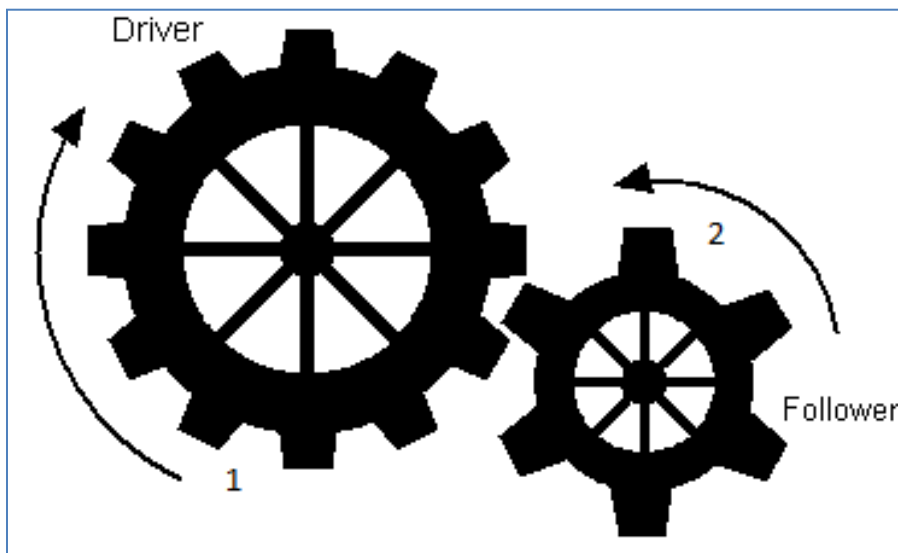
1. Simple gear train,
2. Compound gear train,
3. Reverted gear train, and
4. Epicyclic gear train.

## SIMPLE GEAR TRAIN

Definition:

When there is only one gear on each shaft as shown in fig., it is known as *simple gear train*.

- When the distance between two shafts is small, the two gears 1 and 2 are made to mesh with each other to transmit motion from one shaft to other as shown in fig.
- Since the gear 1 drives 2, therefore gear 1 is called the *driver* and the gear 2 is called the *driven or follower*.



## WHAT IS SPEED RATIO :

Since the speed ratio of gear train is the ratio of the speed of the driver to the speed of the driven or follower and the ratio of speeds of any pair of gears in mesh is the inverse of their number of teeth, therefore

**SPEED RATIO**:  $\text{SPEED OF DRIVER}(N1)/\text{SPEED OF DRIVEN}(N2)$   
 $=\text{NO OF TEETH ON DRIVEN}(T2)/\text{NO OF TEETH OF DRIVER}(T1)$

### USE OF MULTIPLE GEARS :

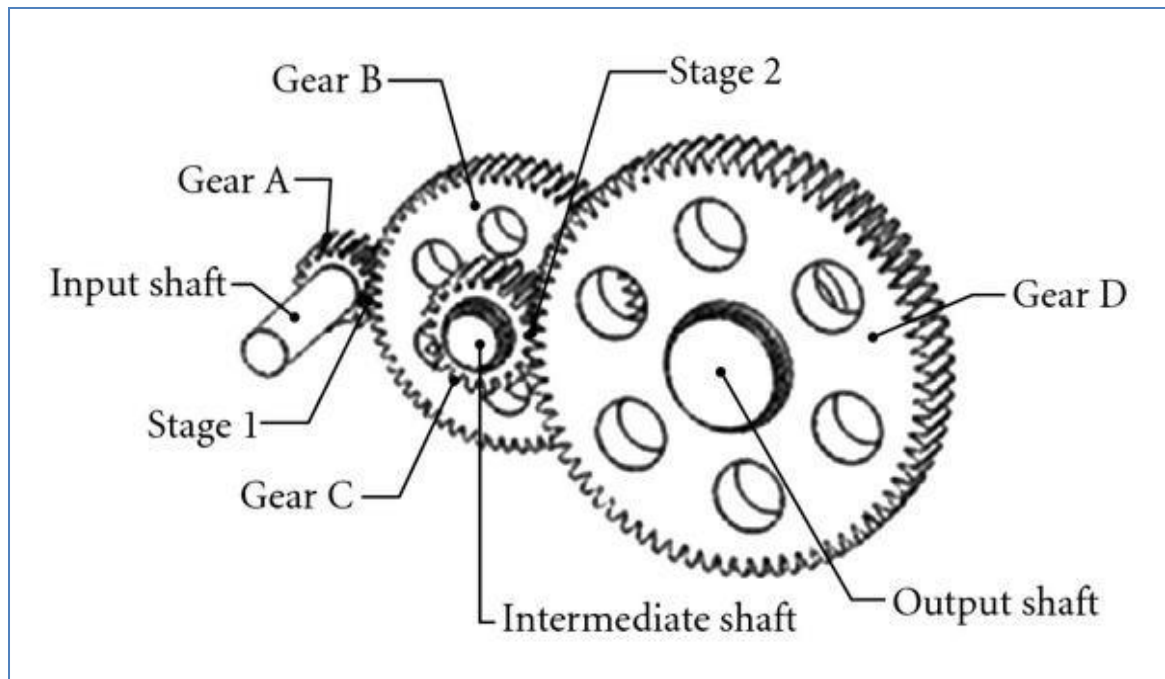
Sometimes, the distance between the two gears is large. The motion from one gear to another, in such a case, may be transmitted by either of the following two methods :

1. By providing the large sized gear.
2. By providing one or more intermediate gears.
  - A little consideration will show that the former method is very inconvenient and uneconomical; whereas the latter method is very economical.
  - It may be noted that when the number of intermediate gears odd, the motion of both gears is like but if the number of intermediate gears even, the motion of both gears is unlike.

### WHAT IS COMPUND GEAR

- Whenever the distance between the driver and the driven has to be bridged over by intermediate gears and at the same time a great speed ratio is required, then the advantage of intermediate gears is intensified by providing compound gears on intermediate shafts.

- **In this case, each intermediate shaft has two gears rigidly fixed to it so they may have the same speed.**
- **One of these two gears meshes with the driver and the other with the driven attached to the next shaft as shown in fig. in Next Page**

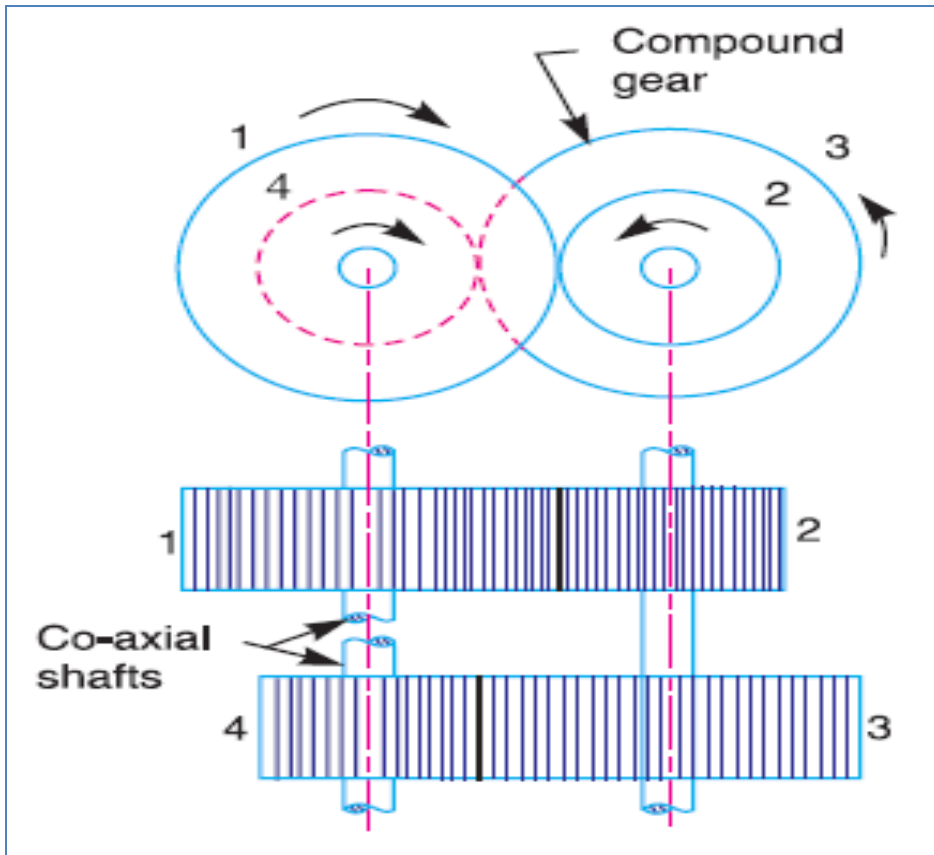


## Reverted gear train

### □ Definition:

When the axes of the first gear and the last gear are co-axial, then the gear train is known as *reverted gear train* as shown in figure.

- Here the gear 1 drives the gear 2 in the opposite direction.
- Since the gear 2 and 3 form a compound gear and the gear 3 will rotate in the same direction as of gear 2.
- the gear 3 will drive the gear 4 in the same direction as of gear 1.
- hence the motion of the first gear and the last gear is *like*.



**ABOVE FIGURE SHOWS COMPOUND GEAR  
HEAR FIRST AND LAST GEAR ARE IN SAME AXIS**

# ROBOTICS

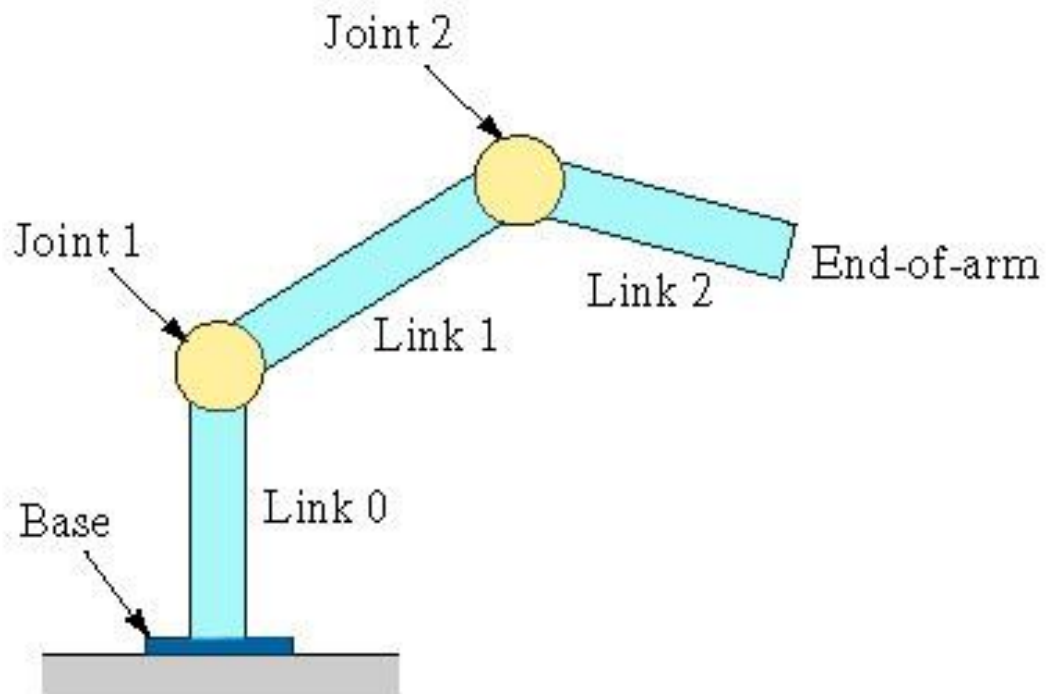
**ROBOT** : Robot is a humanoid having artificial Intelligence performing different hazardous and non-hazardous activities.

**Robot Anatomy :**

**Robot consists of following**

- Joints provide relative motion
- Links are rigid members between joints
- Various joint types: linear and rotary
- Each joint provides a “degree-of-freedom”
- Most robots possess five or six degrees-of-freedom
- Sensors
- Motors
- Actuators

THE BASIC SCHEMATIC DIAGRAM OF ROBOT IS SHOWN IN  
FIGURE IN NEXT PAGE



## ROBOT ACCESSORIES

- **Manipulator / Rover** : This is the main body of the Robot and consists of links, joints and structural elements of the Robot.
- **End Effector** : This is the part that generally handles objects, makes connection to other machines, or performs the required tasks. It can vary in size and complexity from a endeffector on the space shuttle to a small gripper

## Robot Configurations

- **Cartesian/Rectangular Gantry(3P)** : These Robots are made of 3 Linear joints that orient the end effector, which are usually followed by additional revolute joints.

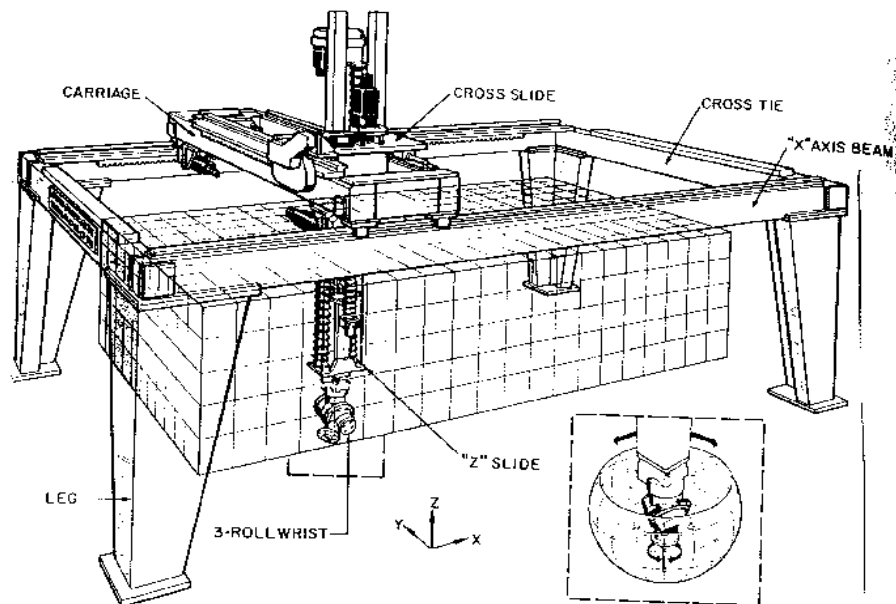
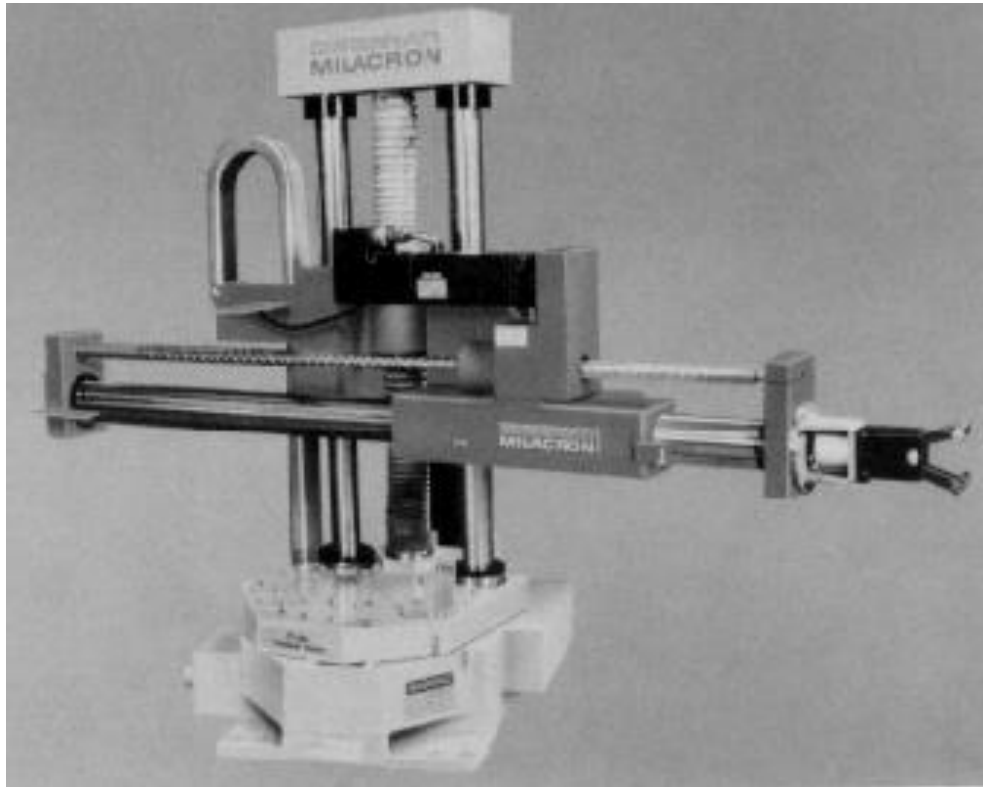


Figure 9.3. Gantry configuration robot. (Courtesy of Cincinnati Milacron.)

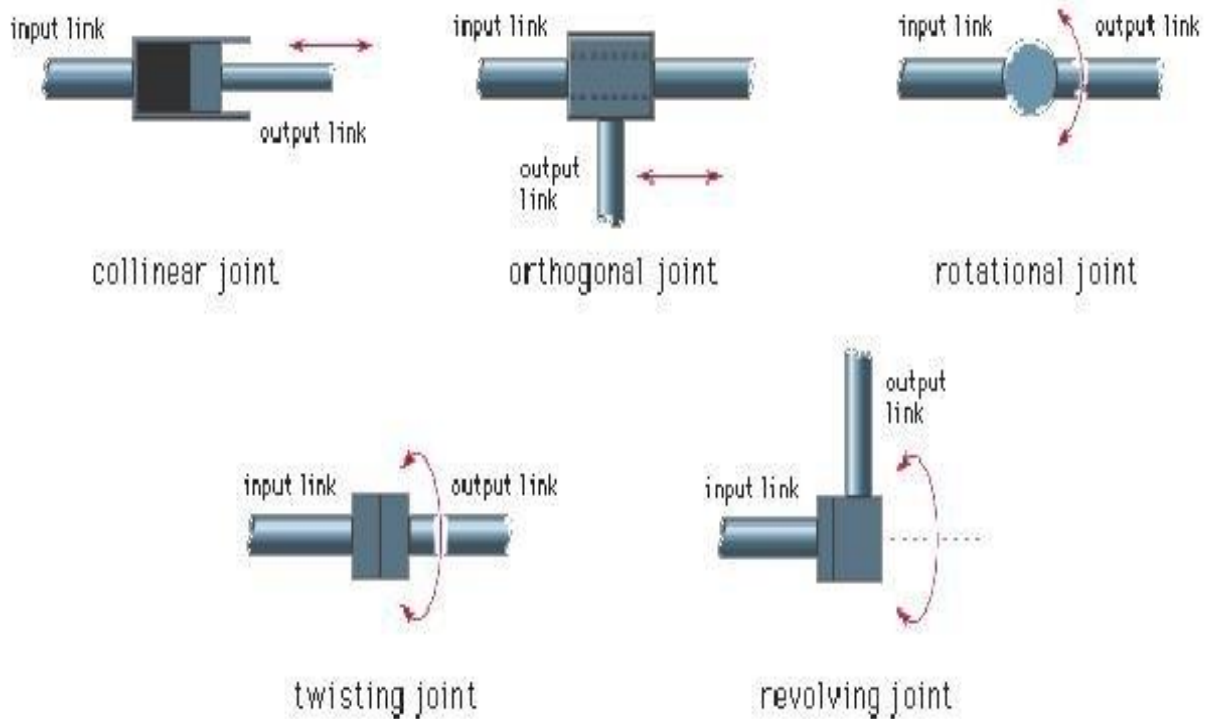
- **Spherical joint (2RP)**: They follow a spherical coordinate system, which has one



- **Spherical joint (2RP):** They follow a spherical coordinate system, which has one .
- **Articulated/anthropomorphic(3R) :**An articulated robot's joints are all revolute, similar to a human's arm.



## JOINTS AND LINKS OF ROBOT



### Prismatic/Revolute

These degrees of freedom, independently or in combination with others, define the complete motion of the end-effector. These motions are accomplished by movements of individual joints of the robot arm. The joint movements are basically the same as relative motion of adjoining links. Depending on the nature of this relative motion, the joints are classified as *prismatic* or *revolute*

## **BRAKE**

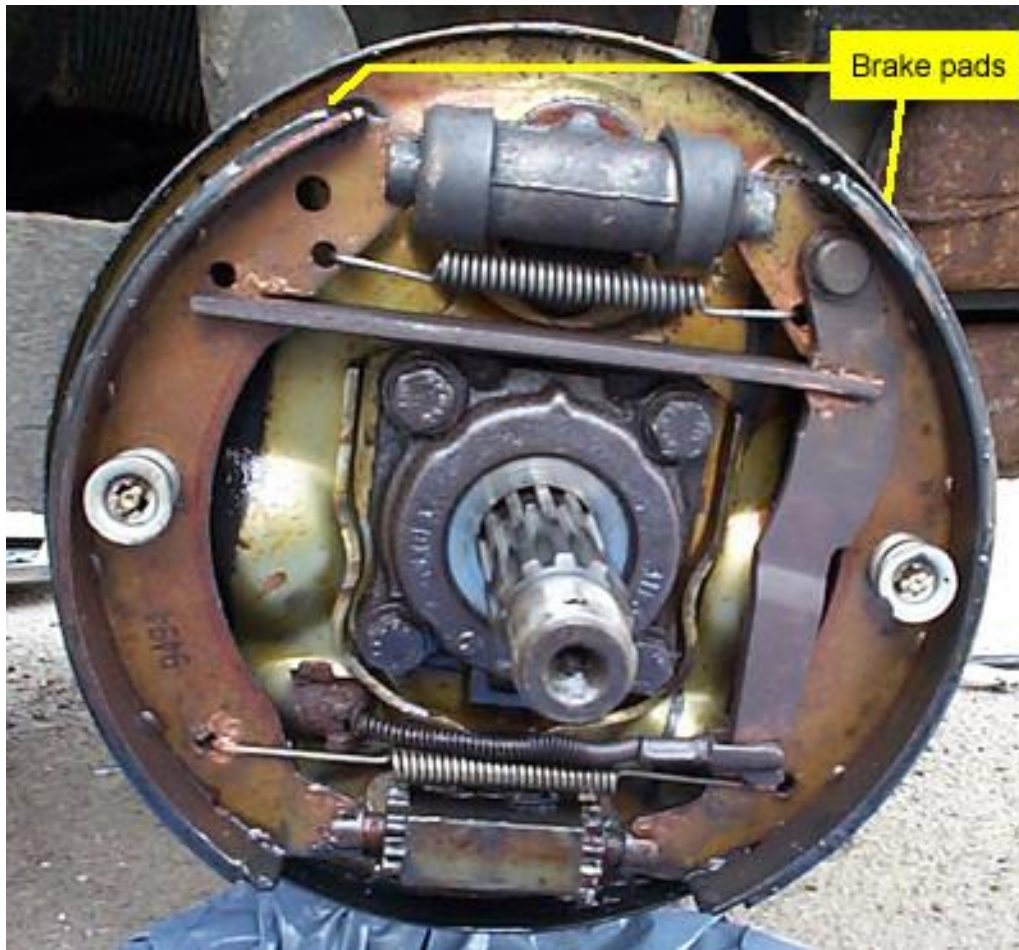
**BRAKE** is a mechanism in automobiles which reduces velocity of vehicle and used to stop the vehicle as well.

**Principle:** *Kinetic energy is converted into heat energy and subsequently vehicle is stopped.*

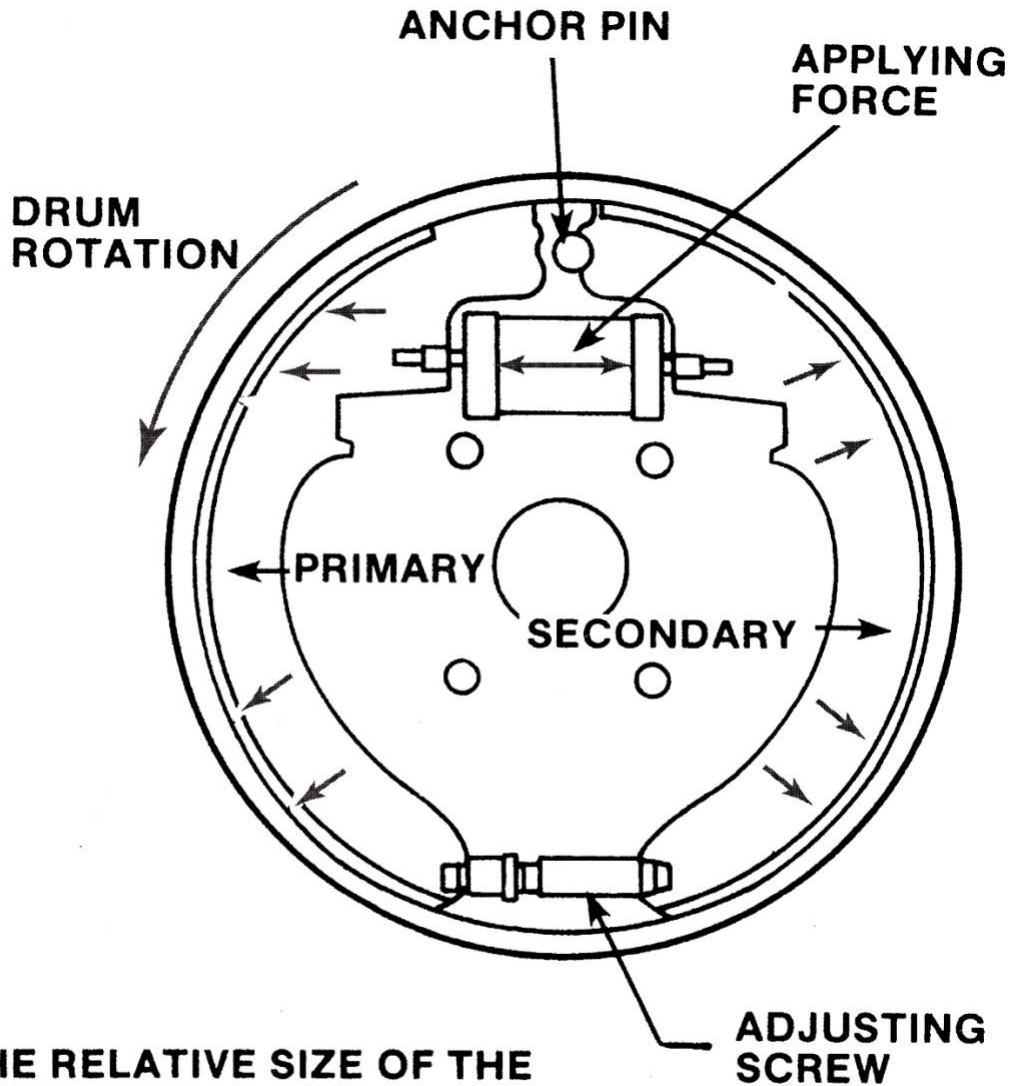
### **Types of Brakes**

- **VACUM BRAKES.**
- **PNEMATIC BRAKES.**
- **HYDRAULIC BRAKES.**
- **MECHANICAL BRAKES**
- **ELECTRCAL BRAKES**

### **Fig of Brake**



**Brakes and description**



**THE RELATIVE SIZE OF THE ARROWS INDICATES THE INCREASE OF BRAKE FORCE OR PRESSURE.**

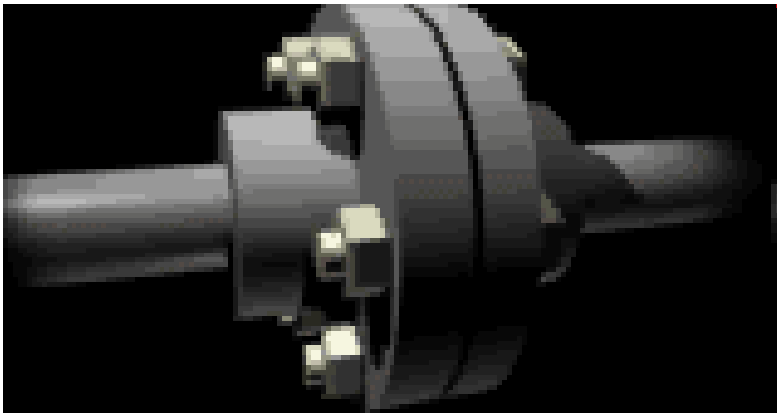
### **What is Brake Shoes**

- **BRAKE SHOE IS A PRESSED STEEL CONSTRUCTIONS OF CURVED SHAPE SO THAT THEY ACCURATELY FIT INSIDE DRUM GEOMETRY.**
- **PORTION OF THE SHOE NEAR THE EXPANDER END IS KNOWN AS “SHOE TOE”.**
- **PORTION NEAR ANCHOR END REFERED AS “SHOE HEEL”.**

## **Coupling:**

**Coupling is a device used to connect two shafts together at their ends for the purpose of transmitting power.**

- **To provide connection of shafts of units made separately**
- **To allow misalignment of the shafts or to introduce mechanical flexibility.**
- **To reduce the transmission of shock loads**
- **To introduce protection against overloads.**
- **To alter the vibration characteristics**

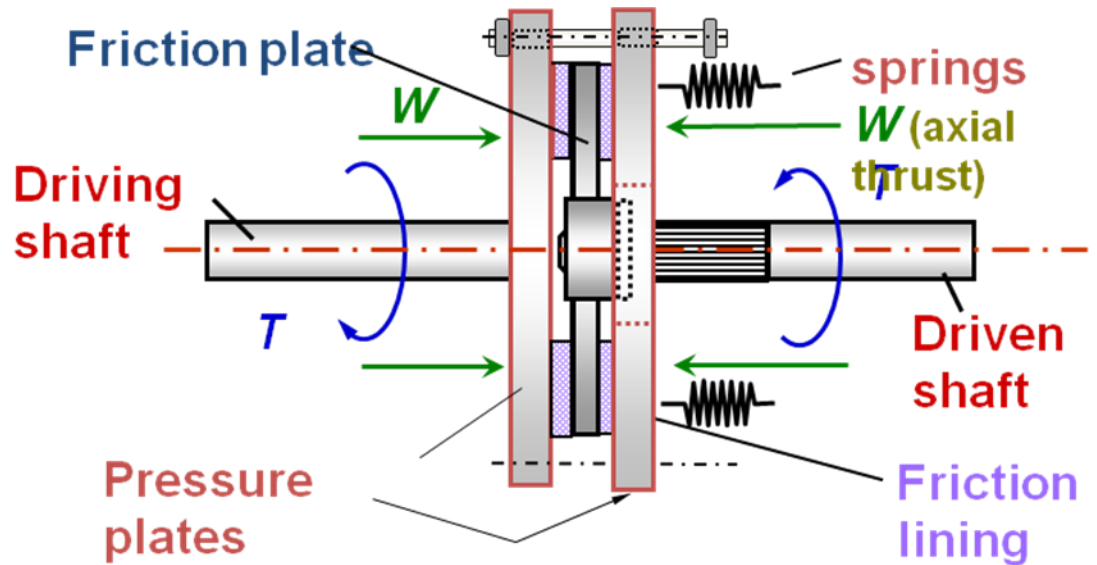


## **Different Types Of Coupling**

- 1. Rigid Coupling**
- 2. Flexible Coupling**

## **CLUTCH**

**A clutch enables two co-axial shafts to be engaged or disengaged while at rest or in relative motion.**



### **Multi plate clutches**

**In a multi plate clutch, the torque is transmitted by friction between several pairs of co-axial annular driving faces maintained in contact by an axial thrust.**

**Both sides of each plate are lined with friction material, so that a single-plate clutch has two pairs of driving faces in contact.**

