BASIC MECHANICAL ENGINEERING

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BASIC MECHANICAL ENGINEERING
(23ES1006)

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 – II (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 – III (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.

TEXT BOOKS

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

REFERENCE BOOKS:

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

Learning Outcomes

- Comprehending the Law of Thermodynamics
- Being aware of how crucial thermodynamics is to IC engines, power plants, refrigerators, and Heat Pump
- Being aware of fluid mechanics and heat transfer concepts
- Recognizing the functions of Engineering materials
- Have a fundamental understanding of welding, Casting, Forming and other manufacturing techniques.
- Recognizing fundamental power transfer mechanisms and aware of the fundamental robotics system.

BASIC MECHANICAL ENGINEERING

CHAPTER 1:

Concept of Thermodynamics & Properties of Gases

Learning Objectives

- ❑ *To describe the basic concepts of thermodynamics*
- ❑ *To state the gas laws and solve related problems*
- ❑ *To state the laws of thermodynamics*
- ❑ *To apply the laws of thermodynamics for different engineering applications*

Thermodynamics

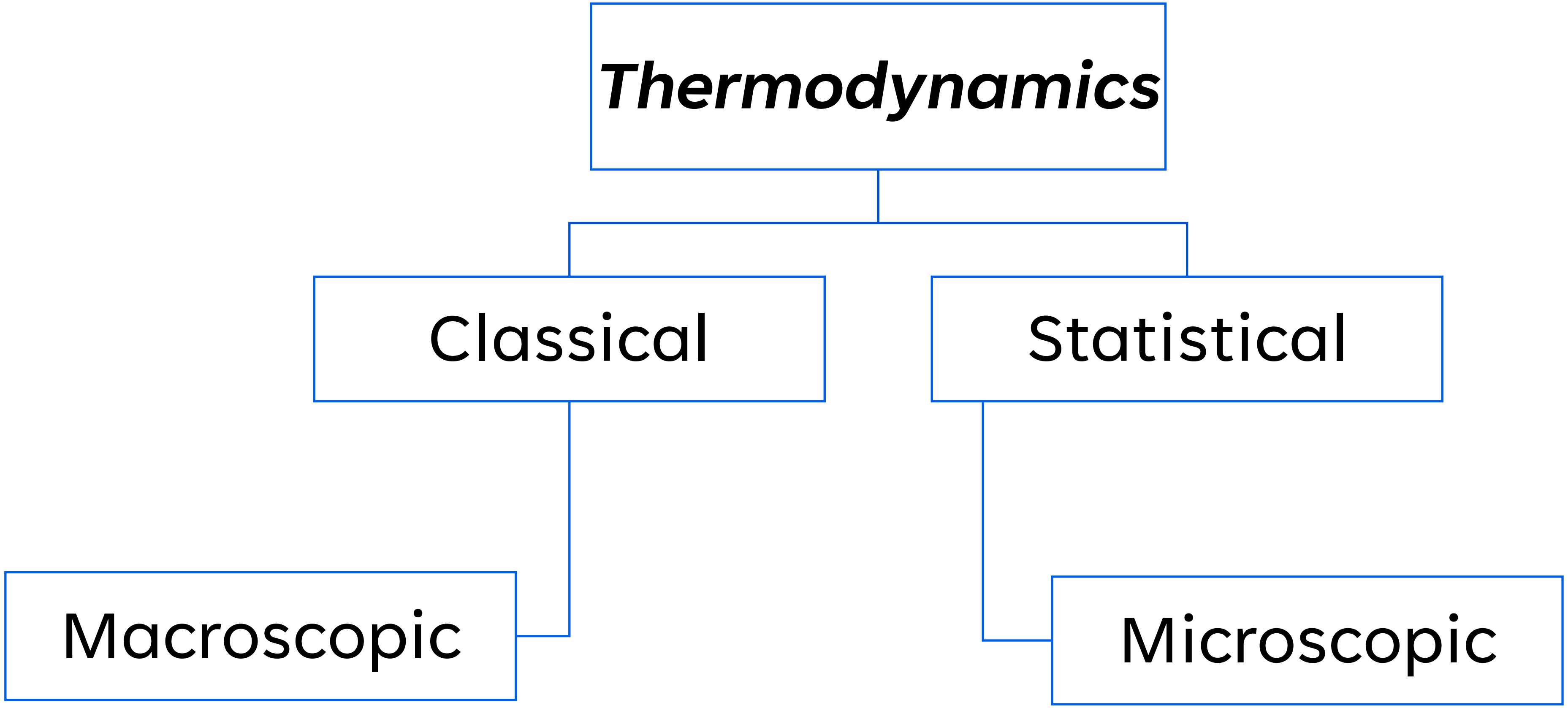
Thermodynamics

Thermo
(Heat)

Dynamics
(Movements)

- Thermodynamics is the science which deals with energy transfer and its effect on physical properties of substances.
- Thermodynamics is a branch of science and engineering that deals with interaction of energy mainly in the forms of heat and work.

Thermodynamics



Macroscopic (Classical Thermodynamics)

- In this approach, a certain quantity or volume of the matter is considered, without taking into account the events occurring at the molecular level.
- This approach to the study of thermodynamic properties does not require knowledge of the behavior of individual particles.
- It is only concerned with the effects of the action of many combined molecules, and these effects can be perceived by human senses.
- The macroscopic observations are completely independent of the assumptions regarding the nature of matter.

Microscopic (Statistical Thermodynamics)

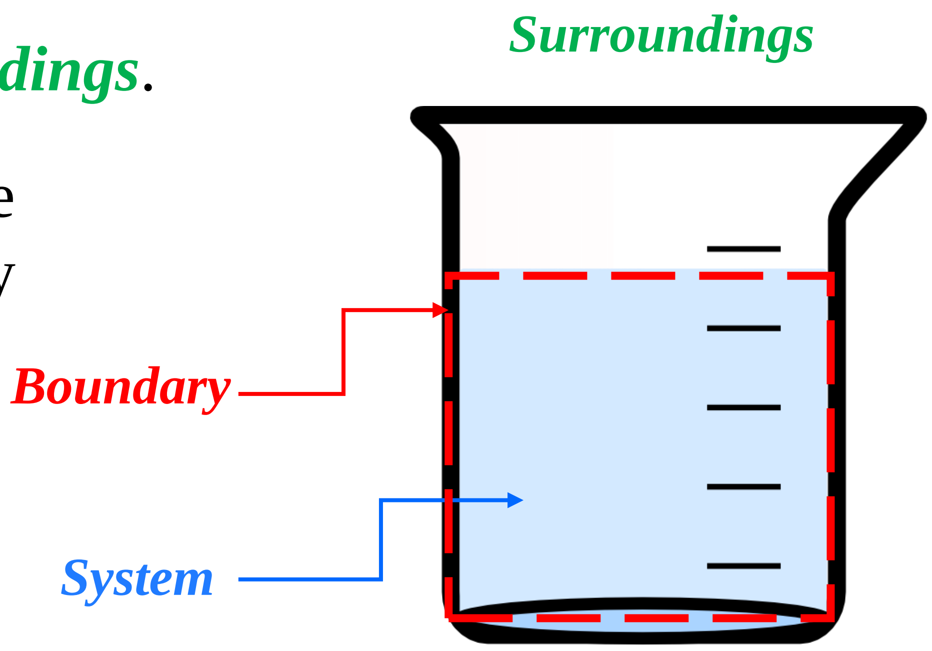
- From the microscopic viewpoint, it is assumed that matter is composed of a large number of small molecules and atoms.
- This approach to the study of thermodynamics requires knowledge of the behavior of individual particles.
- It is concerned with the effects of the action of many molecules, and these effects cannot be perceived by human senses.
- The microscopic observations are completely dependent on the assumptions regarding the nature of matter.

System, Surrounding and Boundary

A ***system*** is a region containing energy and/or matter that is separated from its surroundings by arbitrarily imposed walls or boundaries. In a thermodynamic analysis, the ***system*** is the subject of the investigation.

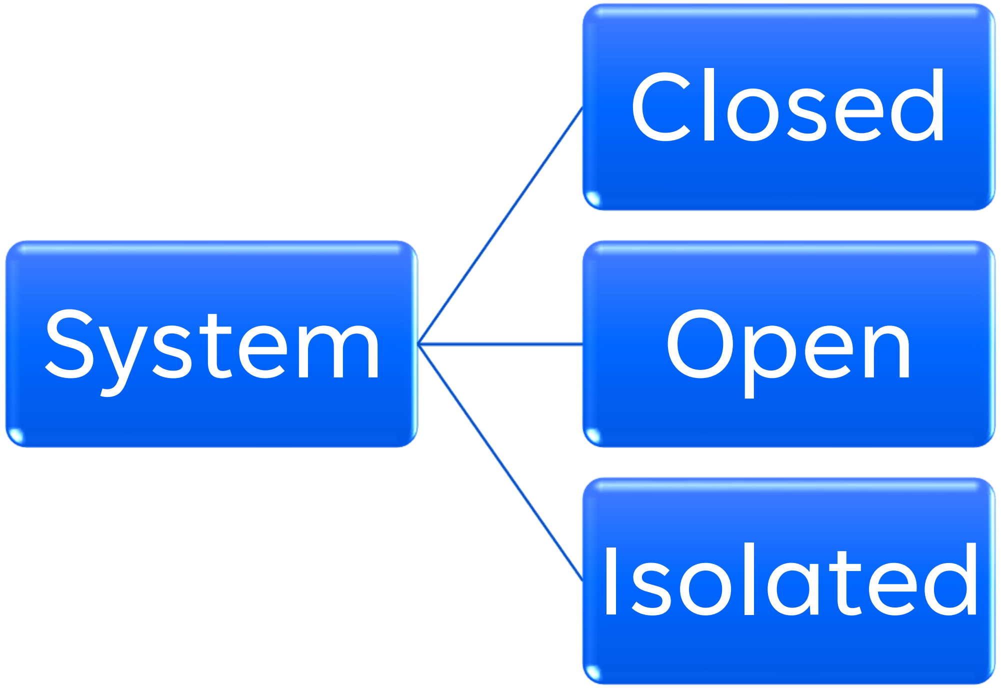
Everything external to the system is the ***surroundings***.

A ***boundary*** is the surface that separates the system and surrounding, through which energy and mass may enter or leave the system.
The control surface may be movable or fixed.



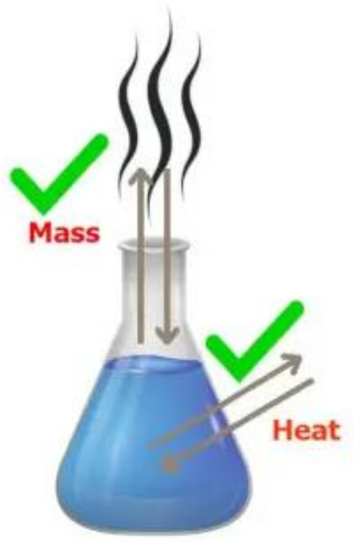
System

In the study of thermodynamics, systems are classified based on their interactions with the surroundings. The three main types of thermodynamic systems are:



Open System

A system that can exchange both energy and matter with its surroundings. Both mass and energy can flow across the system boundaries.



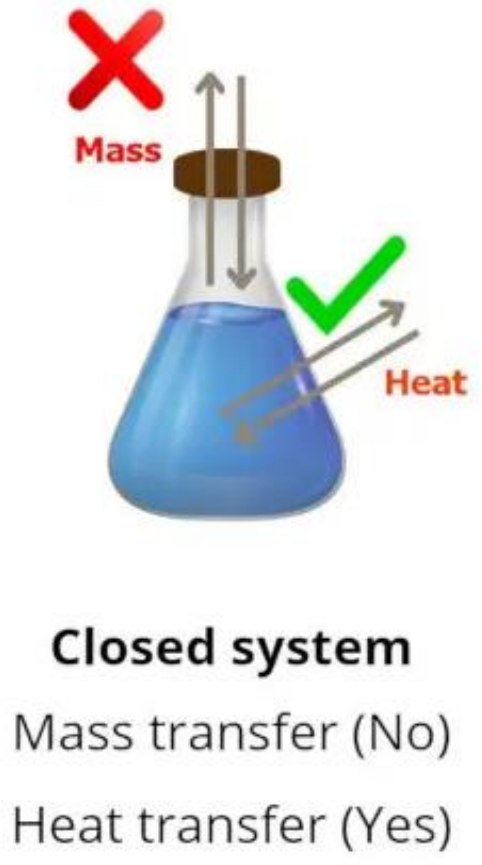
Open system

Mass transfer (yes)

Heat transfer (yes)

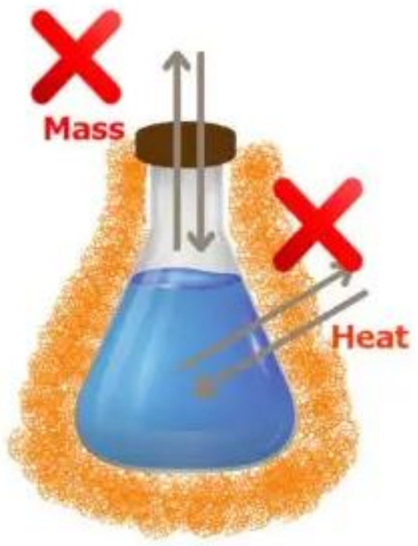
Closed System

A system that can exchange energy with its surroundings, but not mass. The total mass of a closed system remains constant, but energy can be transferred across its boundaries.



Isolated System

A system that does not exchange energy or matter with its surroundings. The total energy and mass within an isolated system remain constant.



Isolated system

Mass transfer (No)

Heat transfer (No)

Properties of a System

Any characteristic of a system by which its physical condition is defined called as property.

Example: Pressure, temperature, volume, mass, viscosity, thermal conductivity etc.

- Properties
  - Intensive
  - Extensive

ARP

Intensive Property

- The properties which doesn’t change with respect to change in mass and size of the system is called *intensive properties*.
- Intensive properties are those that are *independent* of the mass of a system.

Example: Pressure, Temperature, density, viscosity, etc.

Extensive Property

- The properties which changes with respect to change in mass and size of the system is called *extensive properties*.
- Extensive properties are those that are *dependent* of the mass of a system.

Example: Mass, volume, kinetic energy, internal energy, etc.

Specific Property

- It is defined as the ratio of extensive property per unit mass.

Example: $\frac{Volume}{mass} = Specific\ volume$

- The ratio of extensive property to extensive property is intensive property.

Example: $\frac{Mass}{Volume} = Density$

State

- At any instant of time, the condition of a system is called a *state*.
- The state at a given instant of time is defined by the properties of the system such as pressure, volume, temperature, etc.
- A property is any quantity whose numerical value depends on the state but not on the history of the system.

Equilibrium

- Thermodynamic equilibrium is a state in which a thermodynamic system has settled into a stable configuration with respect to its properties, and there is no net change in those properties over time.

- It is a state of balance where the system's variables, such as temperature, pressure, and chemical potential, remain constant.

Thermal equilibrium: Temperature should be same throughout the system.

Mechanical equilibrium: Unbalanced forces should be absent, e.g., change in pressure.

Chemical equilibrium: No chemical reaction and mass transfer occur.

Process

A system is said to undergo a Process, When any property of a system changes its value and there is a change in the state.

Path

The path represents the collection of all the intermediate states that a thermodynamic system passes through as it undergoes a process from its initial state to its final state.

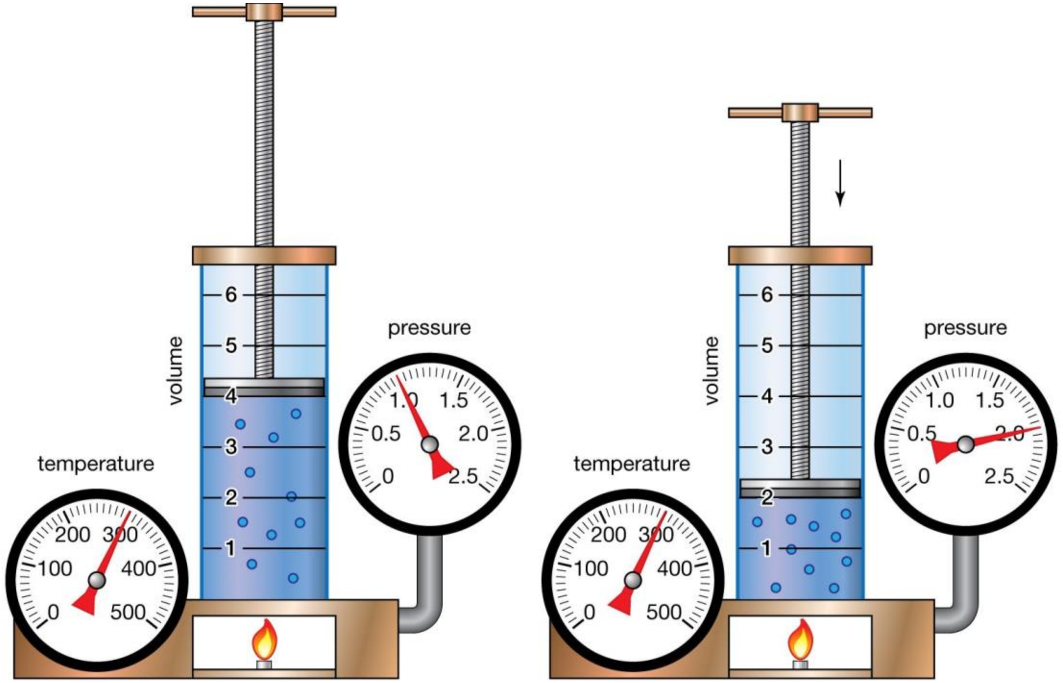
The path is the loci of series of state changes from initial state to final state during a process.

Cycle

When a system from a given initial state goes into a sequence of processes and finally returns to its initial state, it is said to have undergone a cycle.

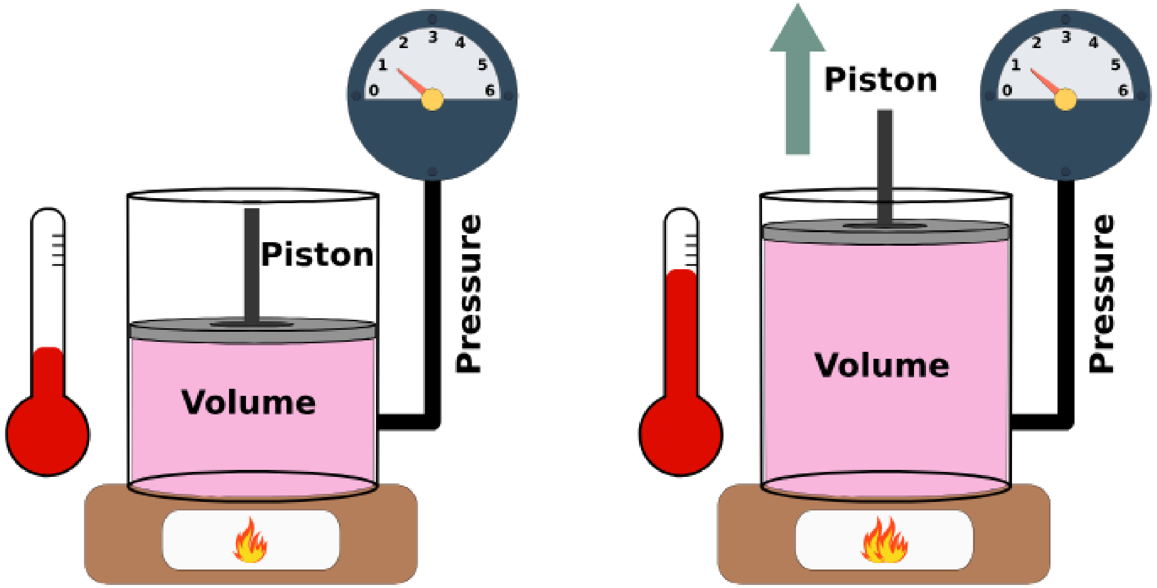
Boyle's law

Boyle's law is a gas law which states that the pressure exerted by a gas (of a given mass, kept at a constant temperature) is inversely proportional to the volume occupied by it.



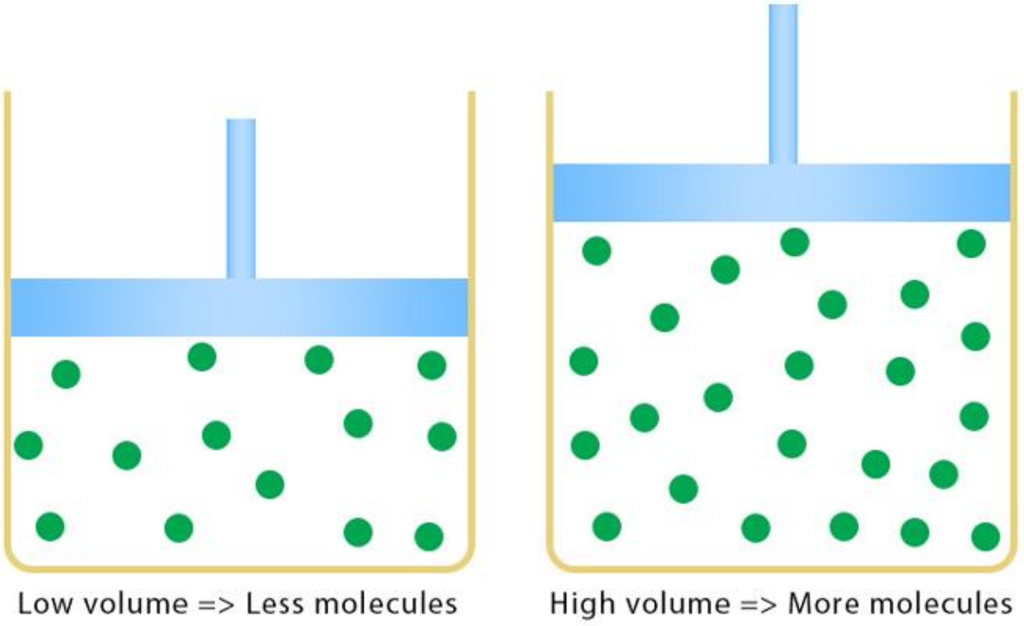
Charles law

Charles law states that the volume of an ideal gas is directly proportional to the absolute temperature at constant pressure.



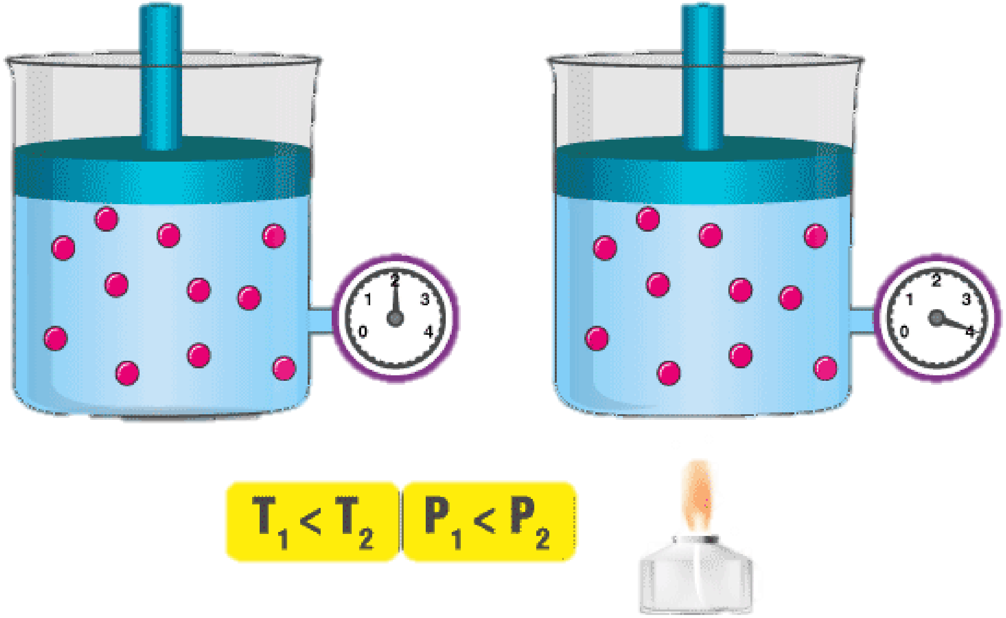
Avogadro’s law

Avogadro’s law is a gas law which states that the total number of atoms/molecules of a gas is directly proportional to the volume occupied by the gas at constant temperature and pressure.



Gay-Lussac's Law

Gay-Lussac's law is a gas law which states that the pressure exerted by a gas (of a given mass and kept at a constant volume) varies directly with the absolute temperature of the gas.



Ideal gas law

The ***ideal gas law*** states that the product of the pressure and the volume of one gram molecule of an ideal gas is equal to the product of the absolute temperature of the gas and the universal gas constant.

It is the combination of Charles's law, Boyle's Law, Avogadro's law, and Gay-Lussac's law.

$$\mathbf{PV = nRT}$$

Thermodynamic Process

$$PV = nRT$$

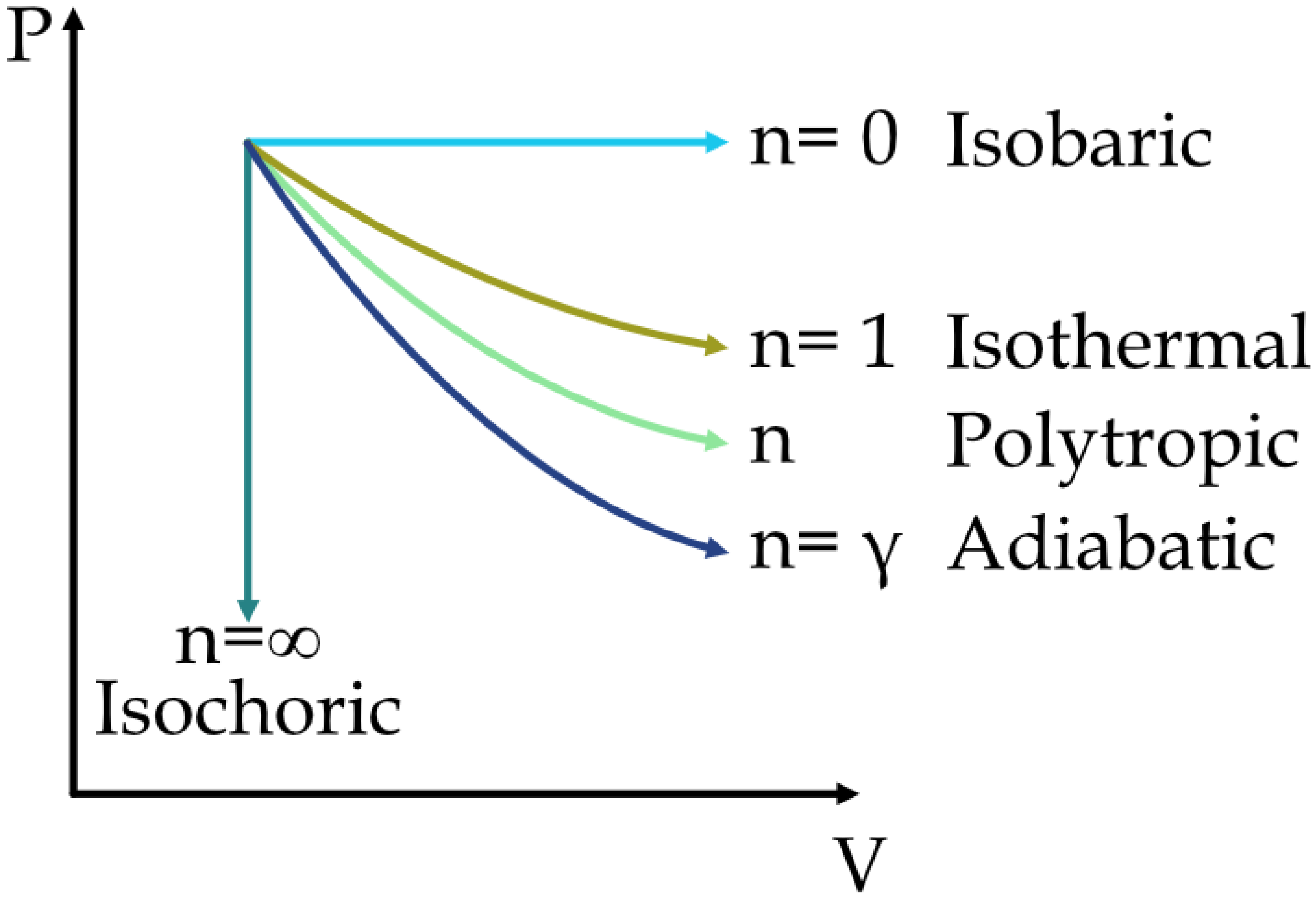
1. Constant volume (Isochoric/Isometric)
2. Constant pressure (Isobaric/isopiestic)
3. Constant temperature (Isothermal)
4. Adiabatic process
5. Polytropic process

For monoatomic gas, $\gamma = 1.66$

For diatomic gas, $\gamma = 1.40$

For triatomic gas, $\gamma = 1.33$

Slope of Thermodynamic Process



$1 < n < \gamma$

Thermodynamic Process

1. *Reversible process*

A reversible process is one that can be reversed without any net effect on the system or its surroundings.

A process is said to be reversible if it is possible for its effects to be eliminated in the sense that there is some way by which both the system and its surroundings can be exactly restored to their respective initial states.

2. *Irreversible process*

A process is said to be reversible if there are no means by which the system and its surroundings can be exactly restored to their respective initial states.

Condition for reversible process

i. Gas should be ideal.

ii. There should not be any friction between the glass molecules.

iii. There should not be friction between the components of the system.

iv. The process should be infinitely slow.

Quasi-static Process:

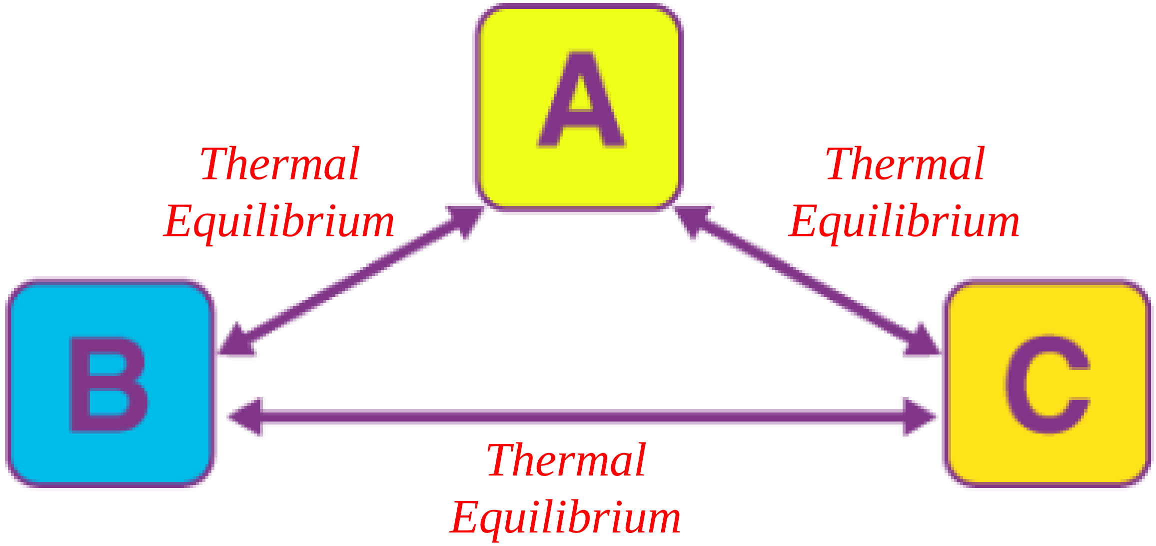
- When a process proceeds in such a way that the system remains extremely close to an equilibrium state at all times, it is called a quasi static process.
- It is a infinitely slow process in which each state is equilibrium

Note: All quasi-static process are not reversible, frictionless quasi-static is reversible.

Zeroth Law of Thermodynamics

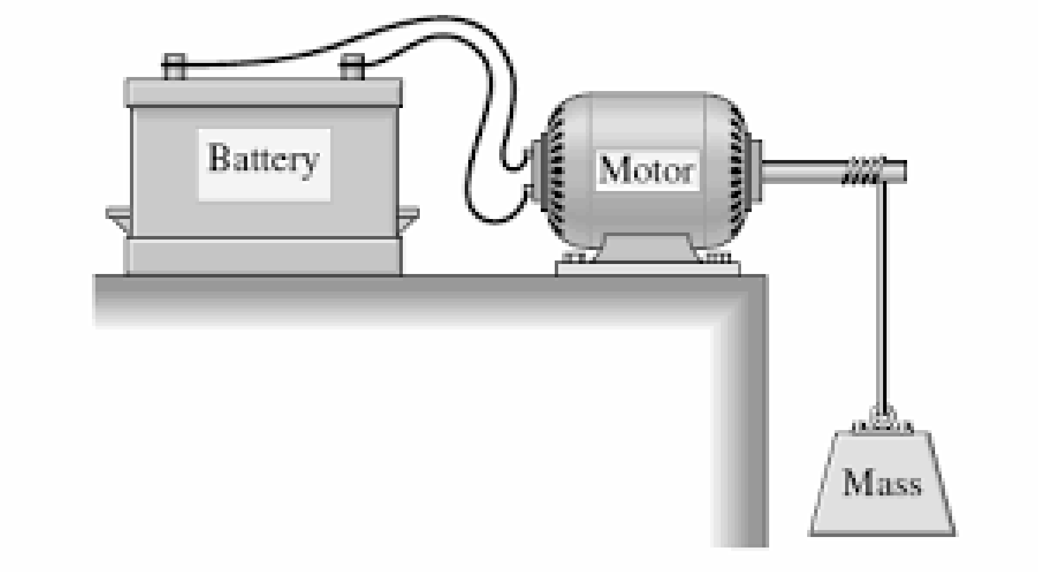
- ✓ The ***zeroth law*** states that if two thermodynamic systems are both in thermal equilibrium with a third system, then the two systems are in thermal equilibrium with each other.

- ✓ If system A is in thermal equilibrium with system B and system A is also in thermal equilibrium with system C, system B and system C are in thermal equilibrium with each other.



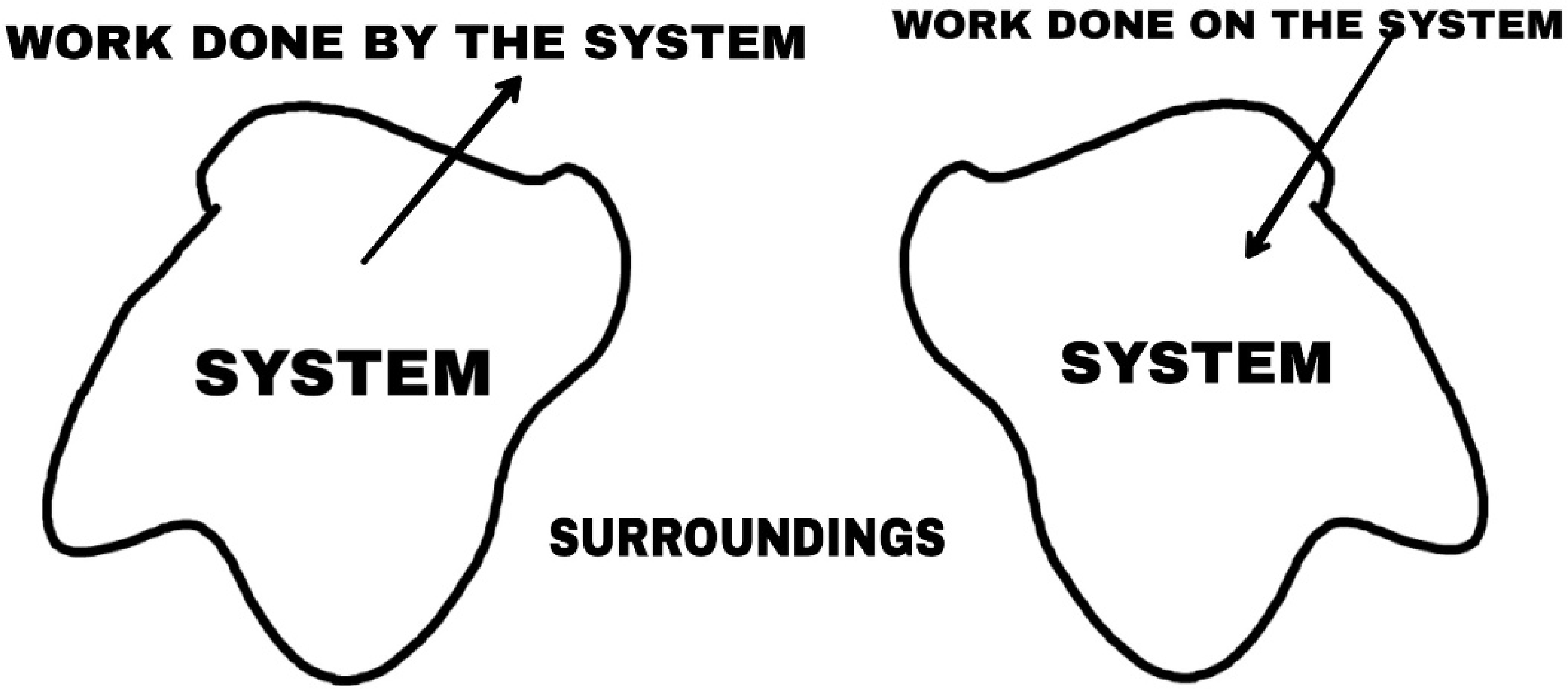
Thermodynamic Work

- *Work* is said to be done by a system if sole effect external to system can be reduced raising of weights. Weights may or may not be raised but net effects can be equated to raising of weights.
- *Work* in thermodynamics may be defined as any quantity of energy that flows across the boundary between the system and surroundings which can be used to change the height of a mass in the surroundings



- Work transfer is recognized when it crosses the boundary, hence work transfer is a *boundary phenomena*.

Sign convention

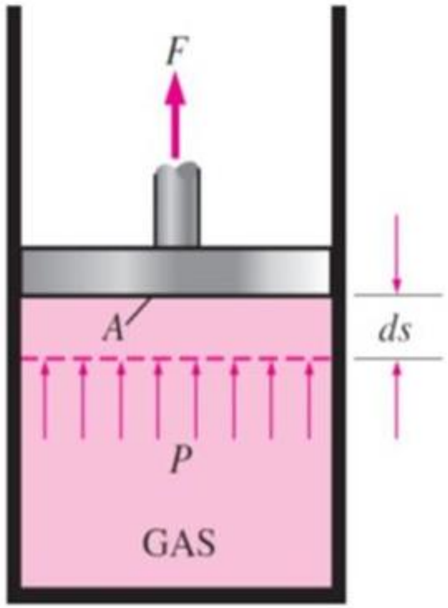


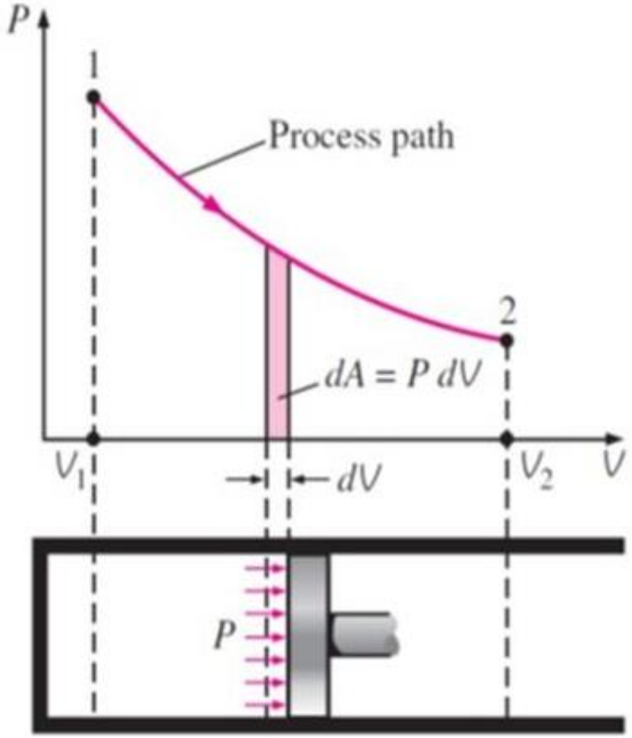
(a) Work done by the system positive

(b)Work done on the system negative

Closed system work

- Pdv work
- Non-flow work
- Displacement work
- Moving boundary work





W = $\int Pdv$ is valid for *closed system & reversible process*.

Work Transfer in Various non-Flow Process

1. Constant volume (Isochoric/Isometric) $W = 0$
2. Constant pressure (Isobaric/isopiestic) $W = P\,(V_2 - V_1) = mR\,(T_2 - T_1)$
3. Constant temperature (Isothermal) $W = P_1V_1 \ln\left(\frac{V_2}{V_1}\right)$
4. Adiabatic process

$$W = \frac{P_1V_1 - P_2V_2}{\gamma - 1}$$

5. Polytropic process

$$W = \frac{mR(T_2 - T_1)}{n - 1}$$

Type of work transfer

- Electrical work Transfer

$$W_e = VIt$$

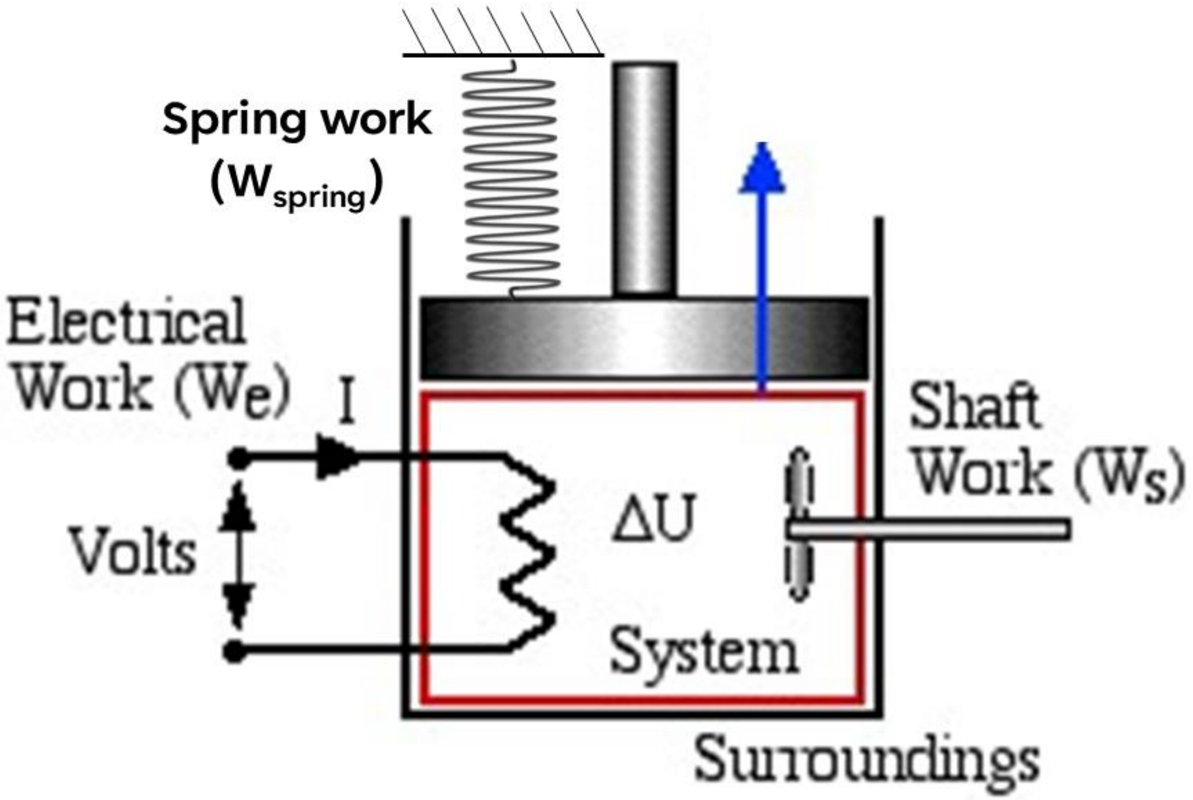
- Shaft work

$$W_S = \frac{2\pi NT}{60}\, t$$

- Spring work

$$W_{Spring} = \frac{kx^2}{2}$$

Total work = $W_e + W_S + W_{Spring}$



Numerical problems

Q1: A $3m^3$ rigid tank contains nitrogen gas at 500kPa and 300K. Now heat is transferred to the nitrogen in the tank and the pressure of nitrogen rises to 800kPa. The work done during this process is

a) 500 kJ

b) 1500 kJ

c) 0 kJ

d) 900 kJ

Numerical problems

Q2: A frictionless piston-cylinder device contains a gas initially at 0.8MPa and $0.015 m^3$. It expands quasi-statically at constant temperature to a final volume of $0.030 m^3$ The work output (in kJ) during this process will be

Numerical problems

Q3: A gas is contained in a cylinder fitted with piston loaded with a small number of weights. The initial pressure is 1.3 bar and the initial volume is $0.03 m^3$. The gas is now heated until volume of the gas increases to $0.1 m^3$. calculate the work done by the gas in the following process:

i. Pressure remains constant

ii. Temperature remains constant

iii. $PV^{1.3}$ = constant during process

Numerical problems

Q4: A certain amount of an ideal gas initially at a pressure P_1 and temperature T_1. First, it undergoes a constant pressure process 1 – 2 such that $T_2 = 3T_1/4$. Then, it undergoes a constant volume process 2 – 3 such that $T_3 = T_1/2$. The ratio of the final volume to the initial volume of the ideal gas is

a) 0.25

b) 0.75

c) 1

d) 1.5

Numerical problems

Q5: A Monoatomic ideal gas (Molecular weight = 40) is compressed adiabatically from 0.1 MPa 300K to 0.2MPa. The universal gas constant is 8.314KJ/kgK. The work of the compression of gas in KJ/kg is. (Take $2^{\gamma-1/\gamma}$= 1.32).

a) 29.7

b) 19.9

c) 13.3

d) 0

Numerical problems

Q6: A spherical balloon has dia 25cm and contains air at a pressure of 1.5bar. The dia of the the balloon increases to 30cm due to heating and during the process $P \propto d$. Calculate the work done by the air.

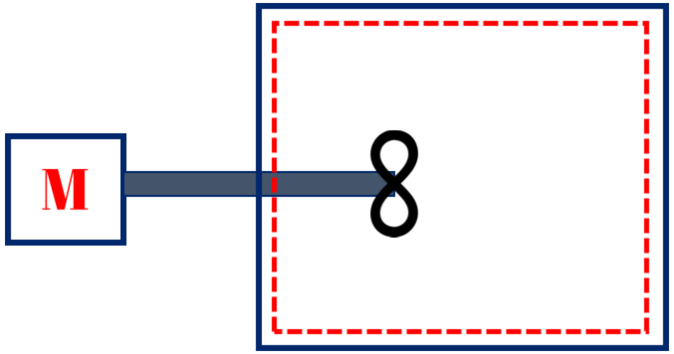
Numerical problems

Q7: An ideal gas undergoes a reversible process in which the pressure varies linearly with volume. The condition at the start (subscript 1) and at the end (subscript 2) of the process with usual notation are: $p_1 = 100$ kPa, $V_1 = 0.2$ m^3 and $p_2 = 200$ kPa, $V_2 = 0.1$ m^3 and the gas constant, $R = 0.275$ kJ/kg-K. The magnitude of the work required for the process (in kJ) is ________

Special Case of Work Transfer

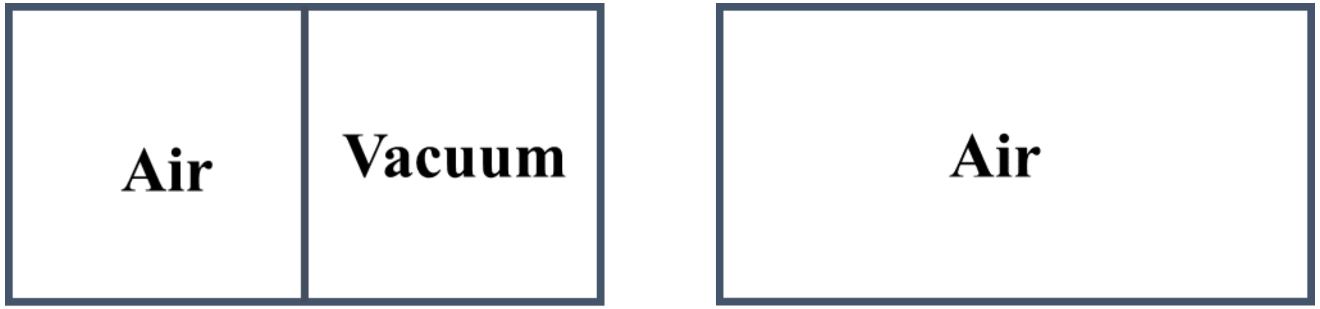
1. Paddle wheel work

$$W \neq 0 \quad PdV = 0$$



2. Free Expansion

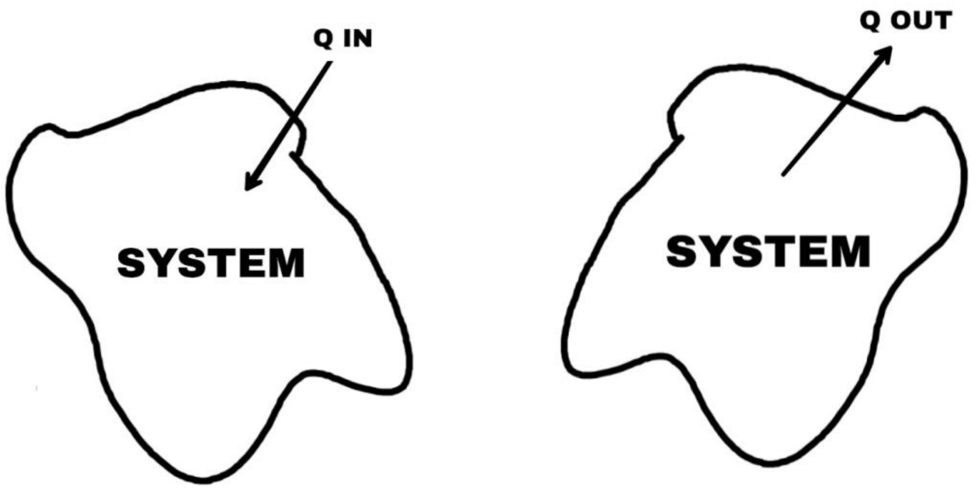
$$W = 0 \quad PdV \neq 0$$



Heat

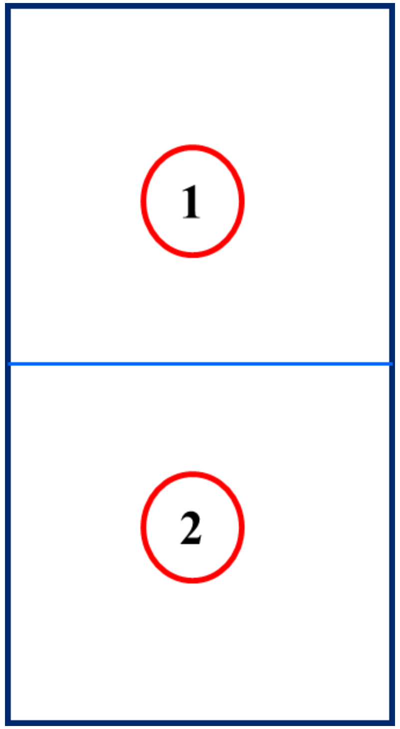
Heat is a form of energy which crosses the boundary due to temperature difference.

Heat is recognised when it cross the boundary and hence it is a boundary phenomena.

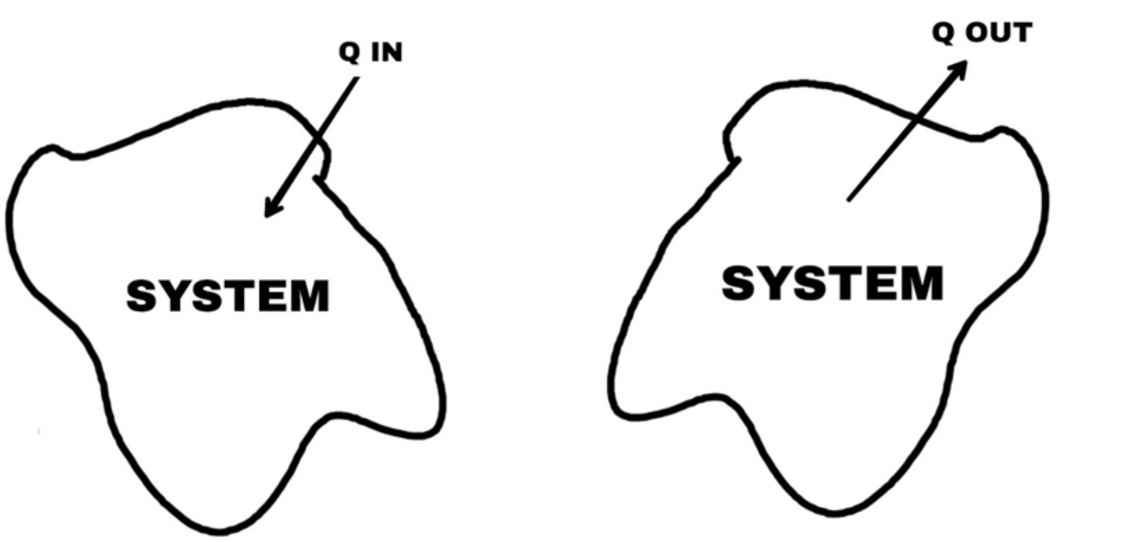


(a) Heat to the system-positive

(b) Heat from the system - negative



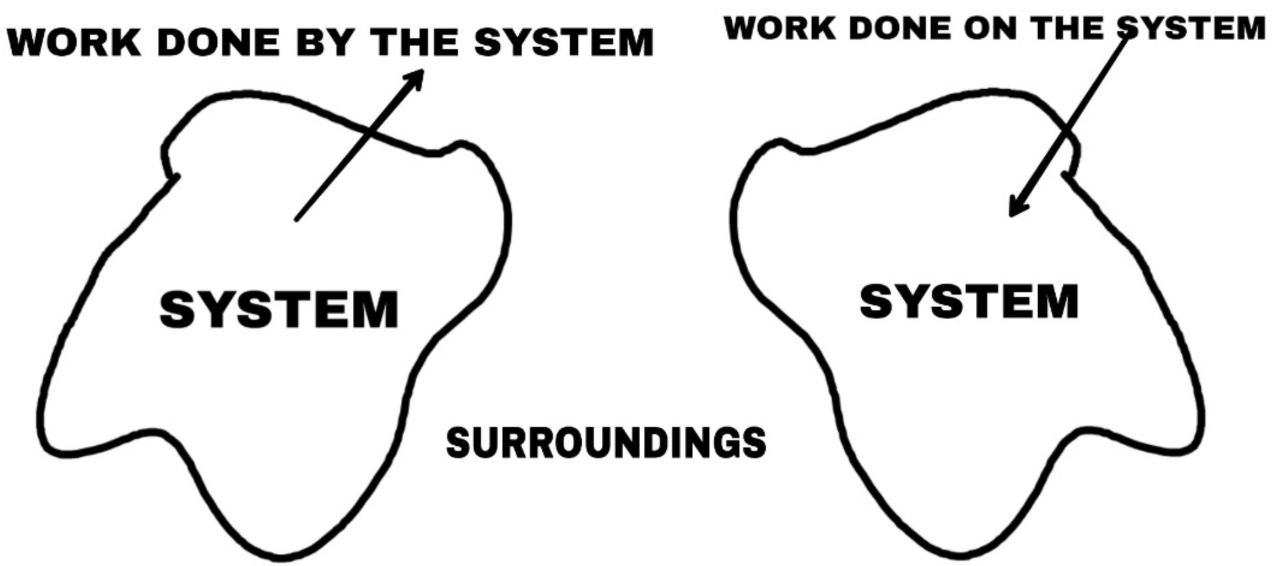
Sign convention



(a) Heat to the system-positive

(b) Heat from the system - negative

Heat



(a) Work done by the system positive

(b)Work done on the system negative

Work

Specific Heat at Constant Volume (Cv)

The rate of change of internal energy with respect to absolute temperature at constant volume is known as specific heat at constant volume (*Cv*).

$$C_v = \left(\frac{\partial u}{\partial T}\right)_v$$

Where *u* is internal energy and *T* is absolute temperature.

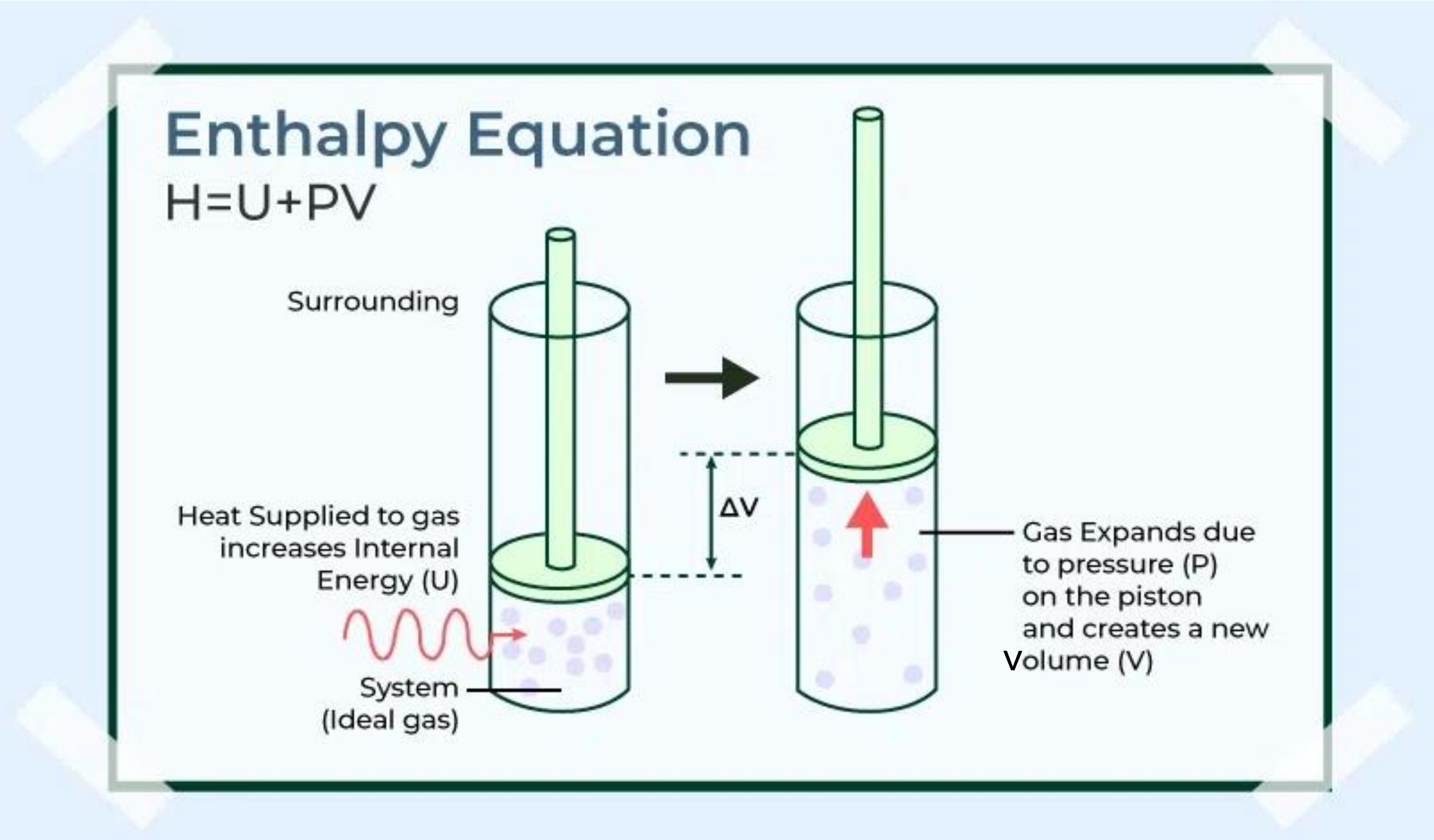
Specific Heat at Constant Pressure (C_P)

The rate of change of enthalpy with respect to absolute temperature when pressure is constant is known specific heat at constant pressure (C_P).

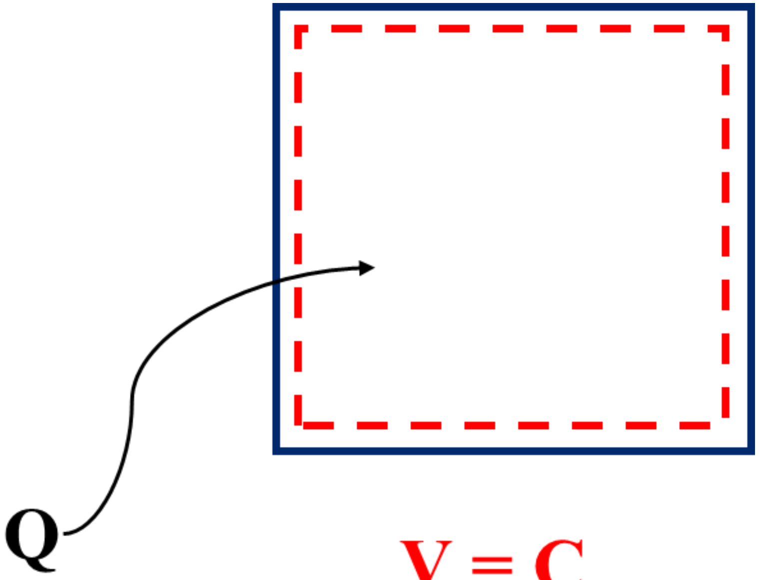
$$C_p = \left(\frac{\partial h}{\partial T}\right)_p$$

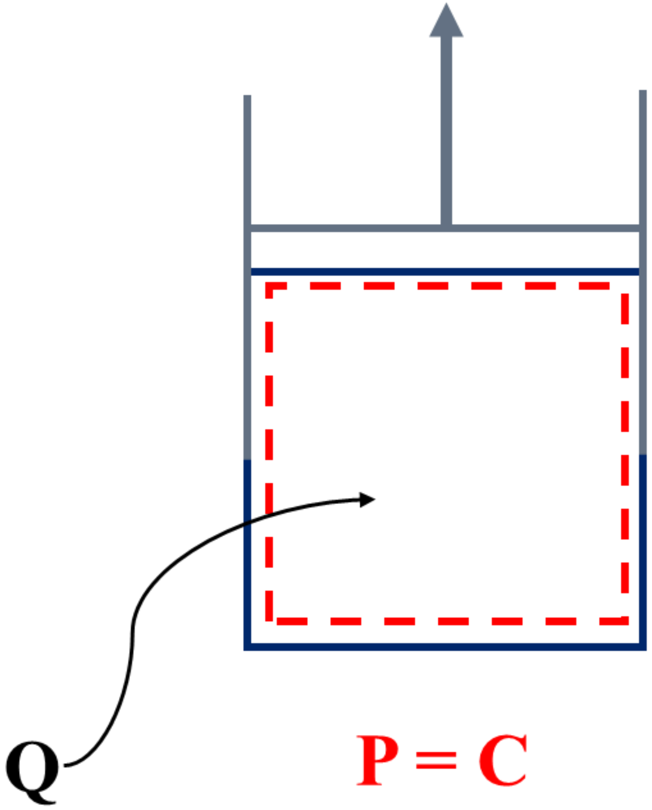
Enthalpy

Enthalpy is total energy of heat in the system which is equivalent to the sum of total internal energy and resulting energy due to its pressure and volume.



Specific heats of Gases





$$Q_P > Q_V$$

Specific heats of Solids & Liquid

For solid and liquids the change in volume w.r.t pressure is almost negligible and hence for solid and liquids

$$C_p = C_v = C$$

Ideal Gas Relations

- $C_p - C_v = R$

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

- $C_p = \gamma\left(\frac{R}{\gamma - 1}\right)$

First Law of Thermodynamics

- When a closed system is undergoing in a cycle, net heat transfer is proportional to work transfer.

$$\oint dQ \propto \oint dW$$

- When a small amount of work (dw) is supplied to a closed system undergoing a cycle, the work supplied will be equal to the heat transfer or heat produced (dQ) in the system.

$$\oint dQ = J \oint dW$$

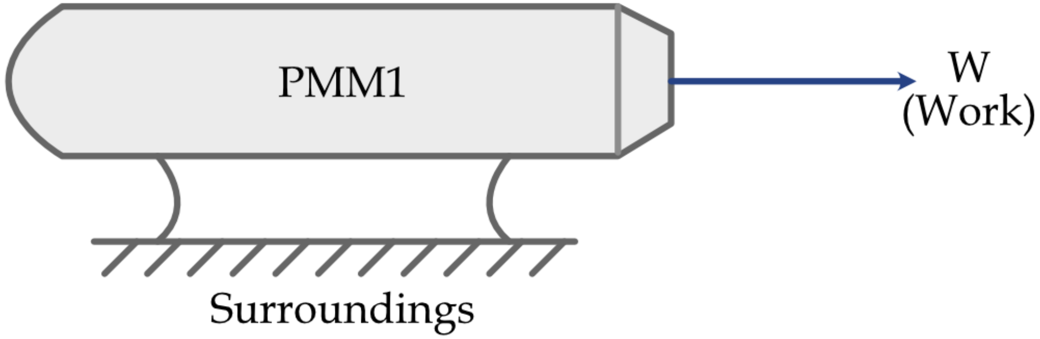
Energy is a thermodynamic property

$$\oint dQ \propto \oint dW$$

- *The quantity* $dQ - dW = 0$ *for a cycle and this quantity must be a change in value of property and this property is called energy.*

First Kind of Perpetual Motion Machine (PMM1)

PMM 1 is a hypothetical machine that can continuously produce work without any energy input from its surroundings.



Numerical problems

Q1: A non-flow process undergoes a process during which work transfer from the system is 36 kJ and heat received by the system is 90 kJ. Determine the change in internal energy.

$a)\ -54\ kJ$

b) -80 kJ

c) 54 kJ

d) +60 kJ

Numerical problems

Q2: The heat transferred in a thermodynamic cycle of a system consisting of four processes are successively 0, 8, 6 and – 4 units. The net change in the internal energy of the system will be

a) -8
b) 0
c) 10
d) -10

Numerical problems

Q3: A system undergoes a change of state during which 80 kJ of heat is transferred to it and it does 60 kJ of work. The system is brought back to its original state through a process during which 100 kJ of heat is transferred to it. The work done by the system is

a) $40\ kJ$
b) 60 kJ
c) 120 kJ
d) 180 kJ

Numerical problems

Q4: The contents of a well-insulated tank are heated by a resistor of 23Ω in which 10A current is flowing. Consider the tank along with its contents as a thermodynamic system. The work done by the system and the heat transfer to the system are positive. The rates of heat (Q), work (W) and change in internal energy (ΔU) during the process in kW are

a) $Q = 0, W = -2.3, \Delta U = +2.3$

b) $Q = +2.3, W = 0, \Delta U = +2.3$

c) $Q = -2.3, W = -2.3, \Delta U = -2.3$

d) $Q = 0, W = +2.3, \Delta U = -2.3$

Numerical problems

Q5: A 100 W electric bulb was switched on in a $2.5 \times 3 \times 3$m size thermally insulated room having temperature of 20°C. Room temp at the end of 24 hours will be

a) 321°C
b) 341°C
c) 450°C
d) 470°C

Numerical problems

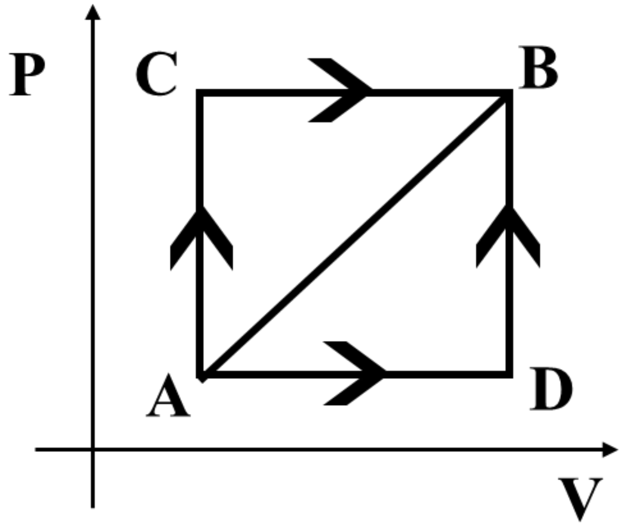
Q6: A 2kW baseboard electric resistance heater in a vacant room is turned on and kept on for 15min. The mass air in the room is 75kg, and the room is tightly sealed so that no air can leak in or out. The temperature rise of air at the end of 15min is

a) 8.5°C
b) 24.0°C
c) 12.4°C
d) 33.4°C

Numerical problems

Q7: when a system is taken from state A to state B along the path A-C-B, 180J of heat flows into the system and it does 130kJ of work. How much heat will flow into the system along the path A-D-B if the work done by it along the path is 40kJ ?

a) 40kJ
b) 90kJ
c) 60kJ
d) 135kJ



Numerical problems

Q8: A system is taken through a series of processes as a result of which it is restored to the initial state. The work and heat interactions for some of the processes are measured and they are as given below

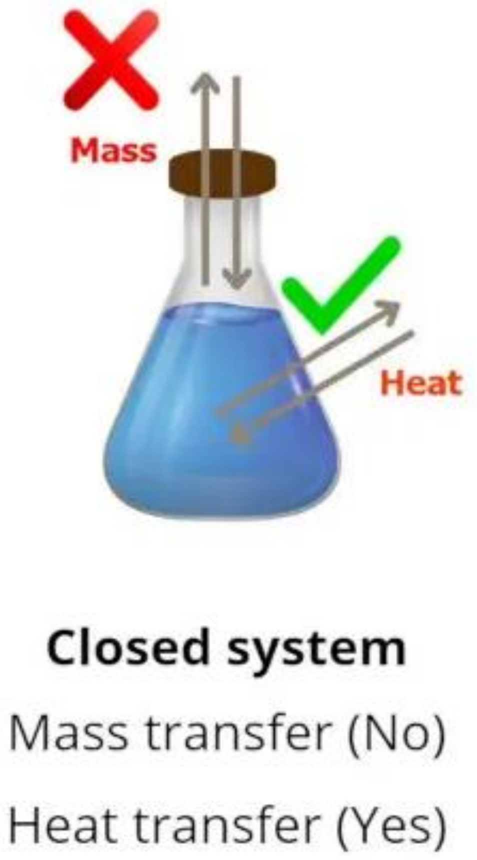
Process	W (kJ)	Q (kJ)	U (kJ)
1-2	100	100	--
2-3	--	-150	200
3-4	-250	--	--
4-1	300	--	50

Free Expansion

- *Free expansion is also called as constant internal energy process.*
- *Free expansion is irreversible and adiabatic.*

Closed System

A system that can exchange energy with its surroundings, but not mass. The total mass of a closed system remains constant, but energy can be transferred across its boundaries.



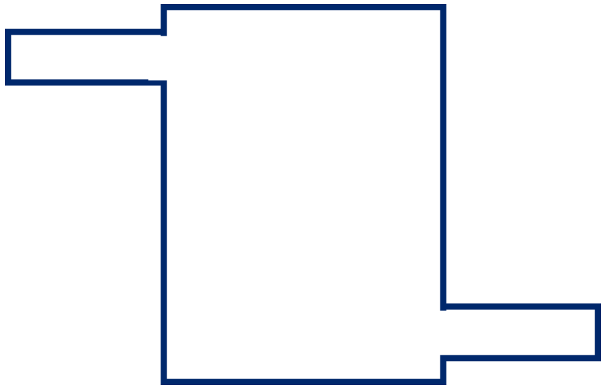
Open System

A system that can exchange both energy and matter with its surroundings. Both mass and energy can flow across the system boundaries.

Open system

Mass transfer (yes)

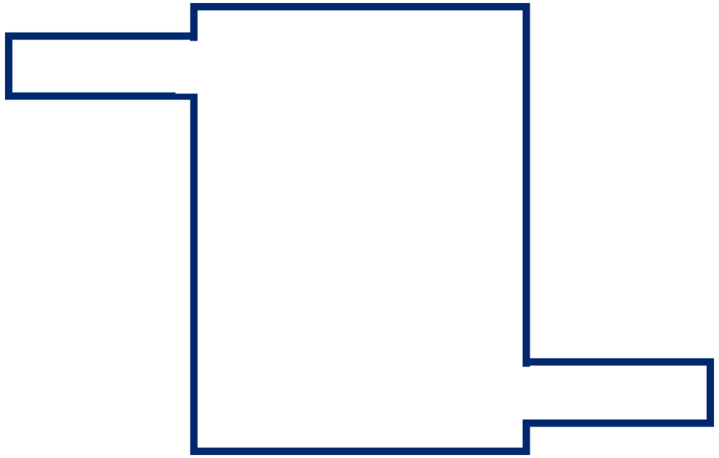
Heat transfer (yes)



- *It has fixed volume, also called controlled volume.*
- *The process in open system is called flow process.*
- *Boundary of open system is called control surface.*

Flow work / Flow Energy

- The work required to push a fluid unit into or out of the control volume is called as flow energy.



W = $\int -Vdp$ is valid for *open system & reversible process*.

Work Transfer in Various Flow Process

1. Constant volume (Isochoric/Isometric) $W = V(P_1 - P_2)$
2. Constant pressure (Isobaric/isopiestic) $W = 0$
3. Constant temperature (Isothermal) $W = P_1 V_1 \ln\left(\frac{V_2}{V_1}\right)$
4. Adiabatic process

$$W = \gamma\left(\frac{P_1V_1 - P_2V_2}{\gamma - 1}\right)$$

5. Polytropic process

$$W = n\left(\frac{P_1V_1 - P_2V_2}{n - 1}\right)$$

Type of flow

- ***Steady Flow***
  - A flow is said to steady if the fluid properties don't change w.r.t time.
- ***Unsteady Flow***
  - A flow is said to unsteady if the fluid properties changes w.r.t time.

Numerical problems

Q1: An air conditioning system handling 1 kg/sec of air at 37°C and consumes a power of 20 kW and rejects heat of 38 kW. The inlet and outlet velocities of air are 50 and 80 m/sec, respectively. Find the exit air temperature, assuming adiabatic conditions. Take Cp of air as 1.005 kJ/kg.

SOLUTION

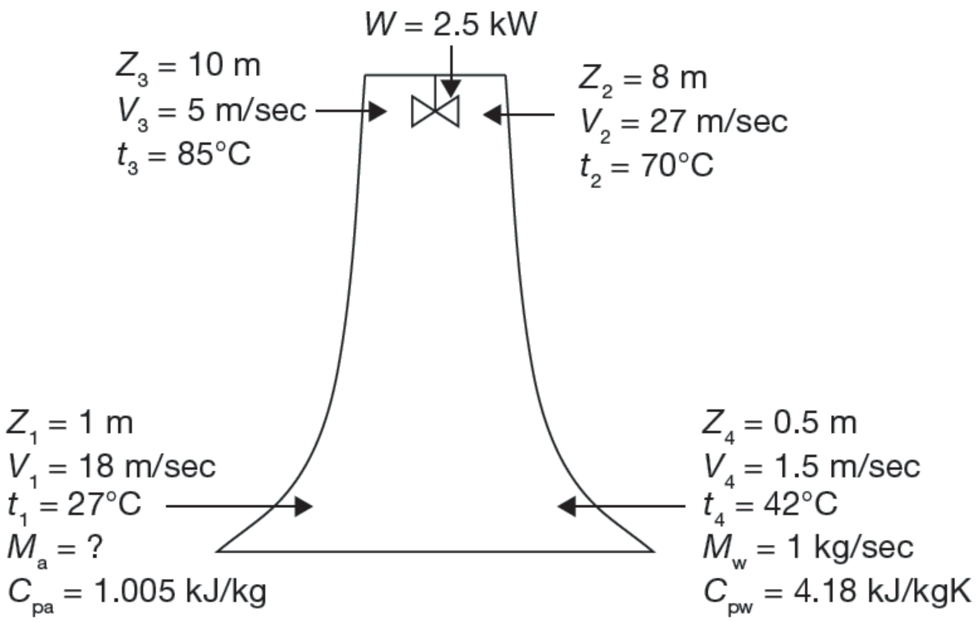
$$m\left(h_1 + \frac{V_1^2}{2\times1000}\right) + \frac{dW}{dt} = m\left(h_2 + \frac{V_2^2}{2\times1000}\right) + \frac{dQ}{dt}$$

$$C_p(t_1 - t_2) + \frac{V_1^2 - V_2^2}{2000} = -20\,kW + 38\,kW$$

$$1.005\,kJ/kgK(37°C - t_2) = 18 - \frac{50^2 - 80^2}{2000};\ t_2 = \mathbf{17.149°C}$$

Numerical problems

In a cooling tower of a power plant (Figure 1.10), air enters at a height of 1 *m* above the ground and leaves at 8 *m*. The inlet and outlet velocities are 18 and 27 *m*/sec, respectively. Water enters at a height of 10 *m* and leaves at a height of 0.5 *m*. The velocity of water at entry and exit are 5 and 1.5 *m*/sec, respectively. Water temperatures are 85 and 420°C at inlet and exit, respectively. Air temperatures are 27 and 700°C at entry and exit, respectively. The cooling tower is fully insulated and a fan of 2.5 *kW* drives air through the cooler. Find the air per sec required for 1 *kg*/sec of water flow. The values of C_p of air and water are 1.005 and 4.18 *kJ/kgK*, respectively.



SOLUTION

$$\dot{m}_a\left(h_1+\frac{V_1^2}{2}+Z_1g\right)+\dot{m}_w\left(h_3+\frac{V_3^2}{2}+Z_3g\right)=\dot{m}_a\left(h_2+\frac{V_2^2}{2}+Z_2g\right)+\dot{m}_w\left(h_4+\frac{V_4^2}{2}+Z_4g\right)+\frac{dW}{dt}$$

$$\dot{m}_a\left[(h_1-h_2)+\frac{V_1^2-V_2^2}{2}+(Z_1-Z_2)g\right]=\dot{m}_w\left[(h_4-h_3)+\frac{V_4^2-V_3^2}{2}+(Z_4-Z_3)g\right]+\frac{dW}{dt}$$

$$\dot{m}_a\left\{1.005\,kJ/kg.K(27\,kJ/kg-70\,kJ/kg)+\frac{(18\,m/\sec)^2-(27\,m/\sec)^2}{2000}+\frac{(1\,m-8\,m)\times 9.81\,m/\sec^2}{1000}\right\}$$

$$=1\left\{4.18\,kJ/kg.K(42\,kJ/kg-85\,kJ/kg)+\frac{(1.5\,m/\sec)^2-(5\,m/\sec)^2}{2000}+\frac{(0.5\,m-10\,m)\times 9.81\,m/\sec^2}{1000}\right\}+(-2.5\,kJ)$$

$$\dot{m}_a=\mathbf{4.193\,kg/sec}$$

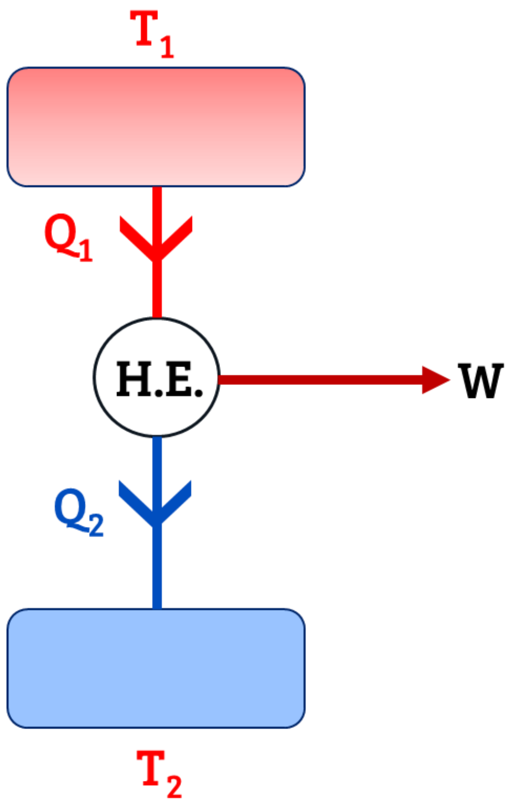
Thermal Energy Reservoir

Heat Source: It is a thermal energy reservoir which supplies thermal energy without undergoing any temperature change.

Heat Sink: It is a thermal energy reservoir which absorbs thermal energy without undergoing any temperature change.

Heat Engine

A heat engine is a system that converts heat to usable energy (work)



$$\eta = \frac{Output}{Input}$$

$$= \frac{W_{net}}{Q_{in}}$$

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

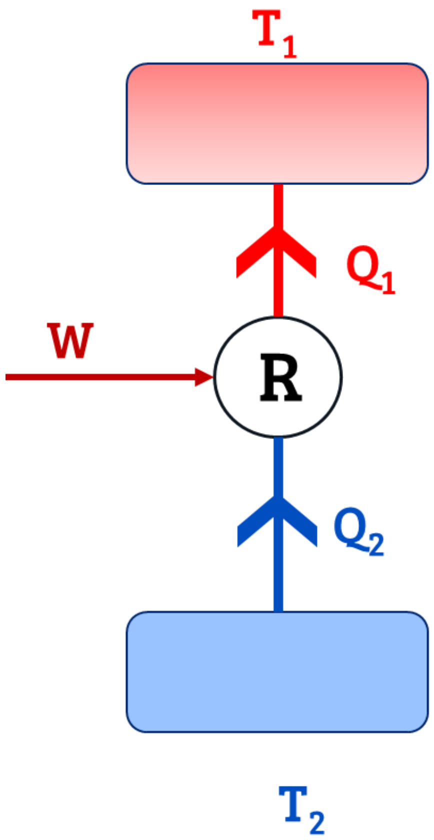
Refrigerator

Performance of a refrigerator
(Coefficient of performance (COP))

$$\text{COP} = \frac{Desired\ Effect}{Energy\ input}$$

$$COP = \frac{Q_2}{W_{net}}$$

$$COP_R = \frac{Q_2}{Q_1 - Q_2}$$



Heat Pump

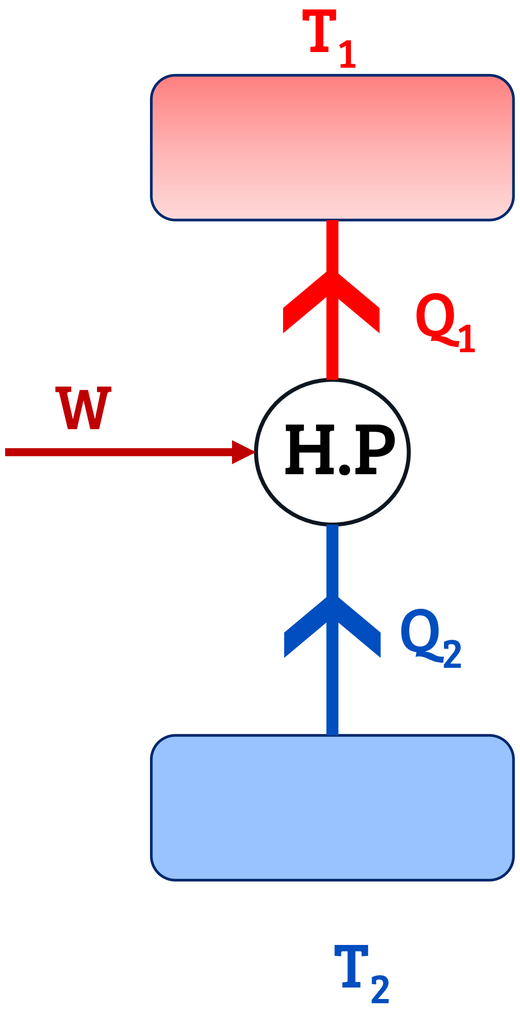
Performance of a refrigerator

(Coefficient of performance (COP))

$$\text{COP} = \frac{Desired\ Effect}{Energy\ input}$$

$$COP = \frac{Q_1}{W_{net}}$$

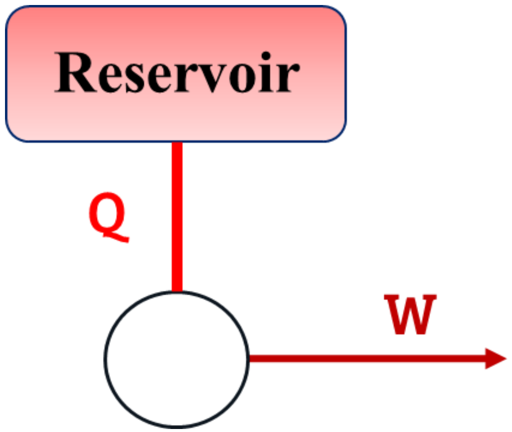
$$COP_{HP} = \frac{Q_1}{Q_1 - Q_2}$$



2^{nd} Law of Thermodynamics

Kelvin-Planck Statement

It is impossible for any system to operate in a thermodynamic cycle and deliver a net amount of energy by work to its surroundings while receiving energy by heat transfer from a single thermal reservoir.



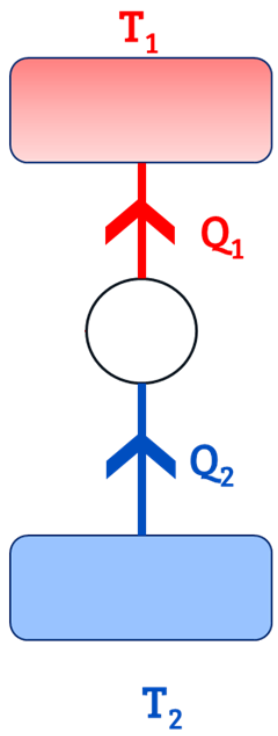
Note:

PMM-II is impossible because its efficiency is 100%.
PMM-II violates 2^{nd} law of Thermodynamics.

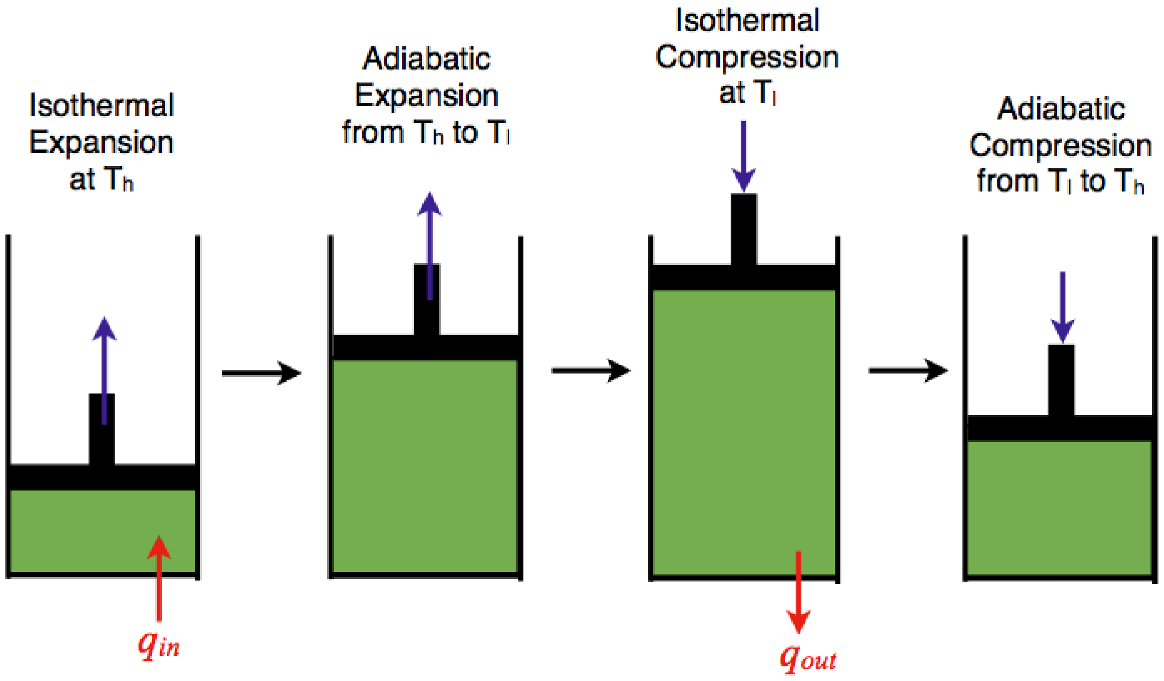
2^{nd} Law of Thermodynamics

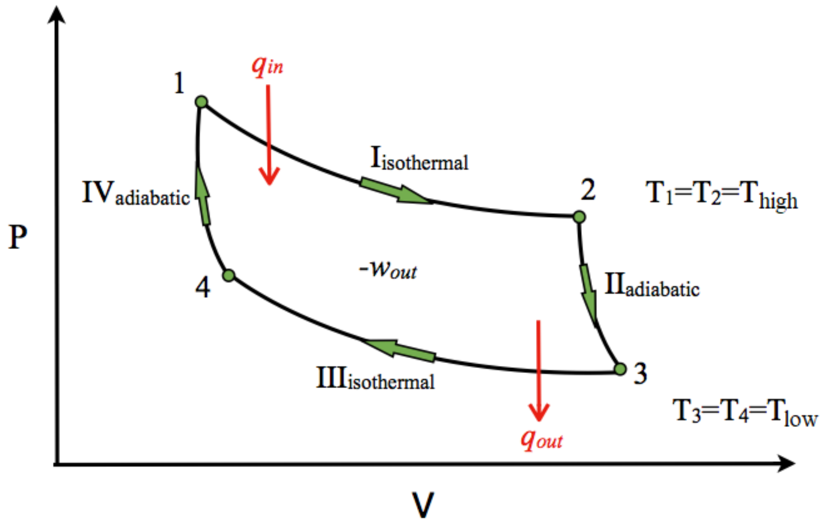
Clausius Statement

It is impossible to construct a device that operates in a cycle and produces no effect other than the transfer of heat from a lower-temperature body to higher-temperature body without any external work input.



Carnot Cycle





1-2: Reversible isothermal heat supply
2-3: Reversible adiabatic expansion
3-4: Reversible isothermal heat rejection
4-1: Reversible adiabatic compression

Carnot Cycle

1-2: Reversible isothermal heat supply
2-3: Reversible adiabatic expansion
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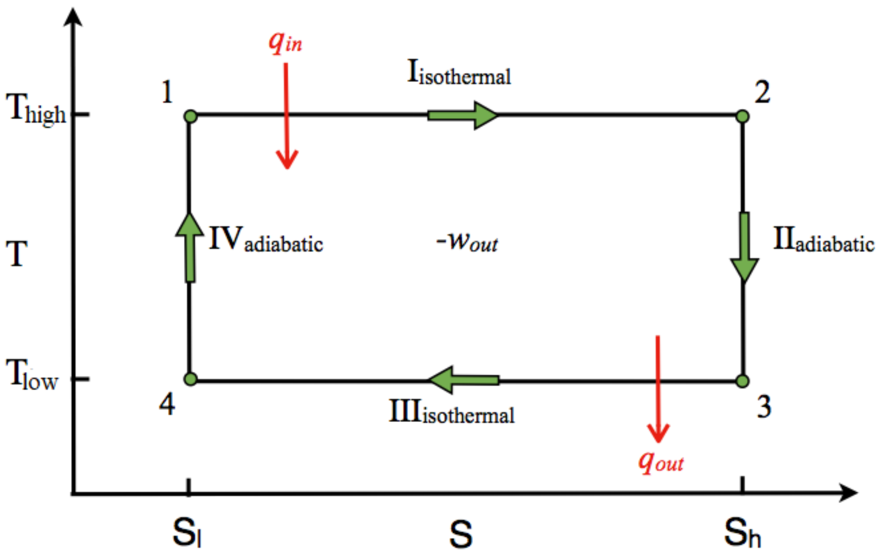


Process	w	q	ΔU	ΔH
I	$-nRT_{high}\ln\left(\frac{V_2}{V_1}\right)$	$nRT_{high}\ln\left(\frac{V_2}{V_1}\right)$	0	0
II	$n\bar{C}_v(T_{low}-T_{high})$	0	$n\bar{C}_v(T_{low}-T_{high})$	$n\bar{C}_p(T_{low}-T_{high})$
III	$-nRT_{low}\ln\left(\frac{V_4}{V_3}\right)$	$nRT_{low}\ln\left(\frac{V_4}{V_3}\right)$	0	0
IV	$n\bar{C}_v(T_{high}-T_{low})$	0	$n\bar{C}_v(T_{hight}-T_{low})$	$n\bar{C}_p(T_{high}-T_{low})$

Carnot Theorem

- For a given temperature limit, efficiency of all reversible heat engine cycle is always greater than efficiency of irreversible heat engine cycle.
- For a given temperature limits, efficiency of all reversible heat engine is same.
- Efficiency of reversible heat engine depends only on temperature limits and independent of working substance used.

$$\eta = 1 - \frac{Q_2}{Q_1} = 1 - \frac{T_2}{T_1}$$

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

Valid only for reversible cycle

Performance of reversible cycle

1. Reversible heat engine

$$\eta = 1\text{-}\ \frac{Q_2}{Q_1} = 1 - \frac{T_2}{T_1}$$

2. Reversible refrigerator

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

3. Reversible heat pump

$$COP_{HP} = \frac{Q_1}{Q_1 - Q_2} = \frac{T_1}{T_1 - T_2}$$

Two reversible heat engine in series

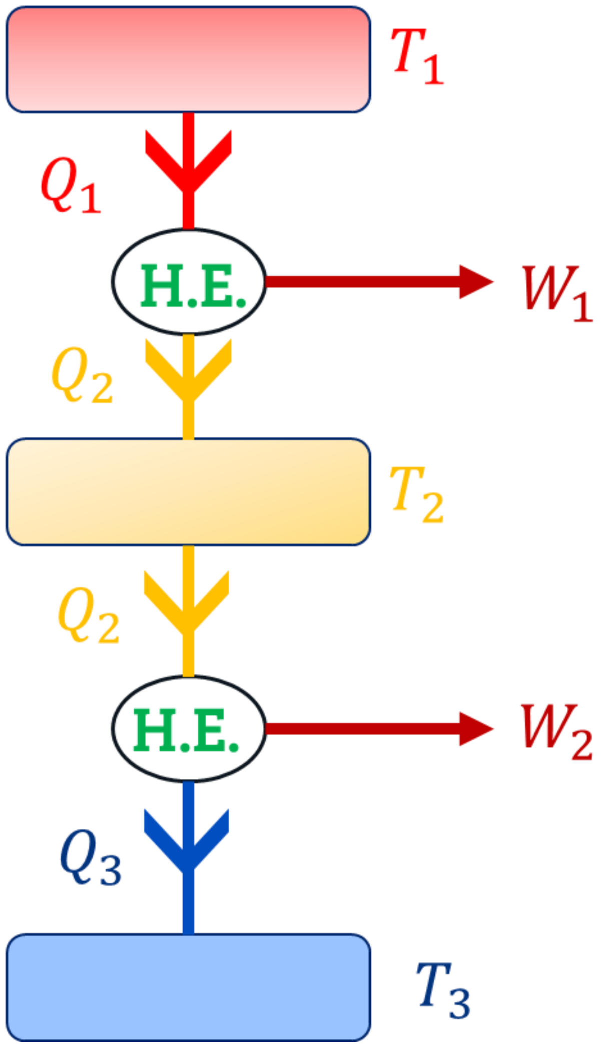
Case 1: $\eta_1 = \eta_2$

$$T_2 = \sqrt{T_1 \times T_3}$$

Case 2: $W_1 = W_2$

$$T_2 = \frac{T_1 + T_2}{2}$$

$$\eta_o = \eta_1 + \eta_2 - n_1\eta_2$$



Two reversible Refrigerator in series

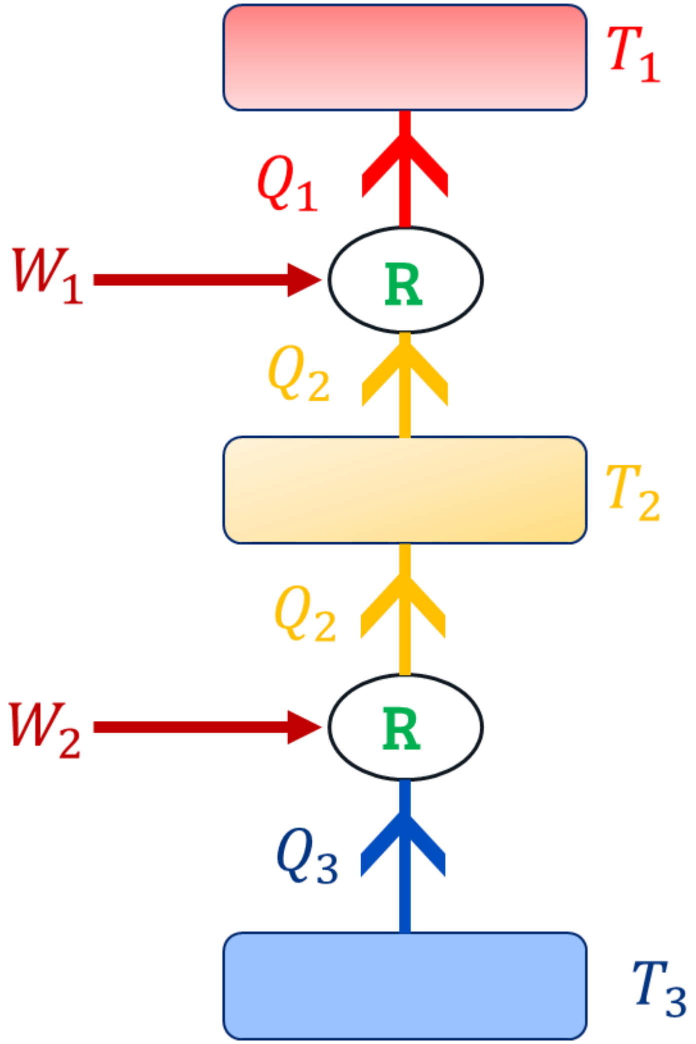
Case 1: $COP_1 = COP_2$

$$T_2 = \sqrt{T_1 \times T_3}$$

Case 2: $W_1 = W_2$

$$T_2 = \frac{T_1 + T_2}{2}$$

$$COP_o = \frac{COP_1 \times COP_2}{1+COP_1+COP_2}$$



Numerical problems

Q1: A typical new household refrigerator consumes about 680kWh of electricity per year and has a coefficient of performance of 1.4. The amount of heat removed by this refrigerator from the refrigerated space per year is _______ ?

Numerical problems

Q2: The drinking water needs of an office met by cooling tab water in a refrigerated water fountain from 23 to 6°C at an average rate of 10 kg/h. If the COP of this refrigerator is 3.1, the required power input to this refrigerator is

Numerical problems

Q3: We wish to produce refrigeration at -30°C and ambient temperature. The work output of engine operating between 200°C and 30°C ambient is used to operate the refrigerator. Determine the ratio of heat transferred from 200°C reservoir to the heat transferred from the-30°C reservoir?

Numerical problems

Q4: A heat engine operating between two reservoirs at 1000 K and 300 K is used to drive a heat pump which extracts heat from the reservoir at 300 K at a rate twice that at which the engine rejects heat to it. If the efficiency of the engine is 40% of the maximum possible and the COP of the heat pump is 50% of the maximum possible, what is the temperature of the reservoir to which the heat pump rejects heat? What is the rate of heat rejection from the heat pump if the rate of heat supply to the engine is 50 kW ?

Numerical problems

Q5: A heat engine is used to drive a heat pump. The heat transfers from the heat engine and from the heat pump are used to heat the water circulating through the radiators of a building. The efficiency of the heat engine is 27% and the COP of the heat pump is 4. Evaluate the ratio of the heat transfer to the circulating water to the heat transfer to the heat engine.

Entropy

Clausius Inequality:

$$\oint \frac{dQ}{T} \leq 0$$

$$\oint \frac{dQ}{T} = 0 \rightarrow \text{Reversible cycle}$$

$$\oint \frac{dQ}{T} < 0 \rightarrow \text{Ireversible cycle}$$

$$\oint \frac{dQ}{T} > 0 \rightarrow \text{Impossible cycle}$$

Entropy

- The amount of heat contained in a substance and the degree to which it is ordered are described by the property of a state known as ***entropy***.
- The higher the disorder, the greater is the entropy.

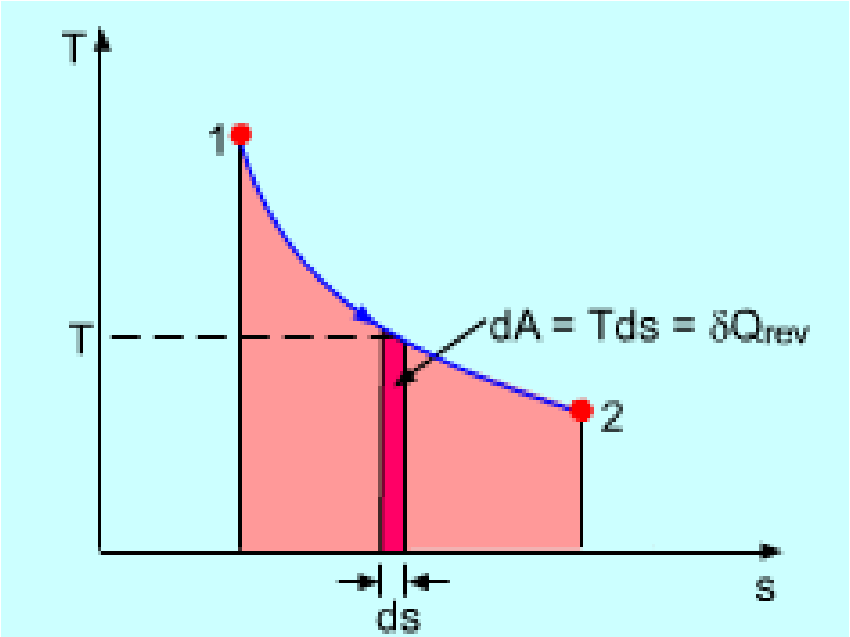
$$S_{solids} < S_{liquids} < S_{gas}$$

Entropy is denoted by "*S*" and change in entropy by "*ds*"

$$\oint \frac{dQ}{T} = 0$$

$$ds = \left(\frac{dQ}{T}\right)_{Rev}$$

Temperature-entropy diagram (T-S diagram)



Note:

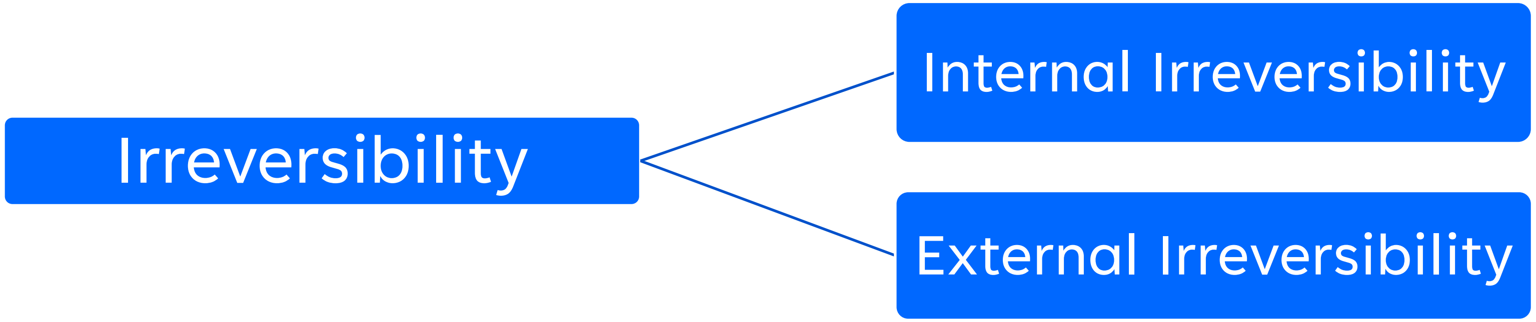
- The area under the curve on T-S diagram represents the heat transfer in reversible process.
- In reversible process, entropy may increase, decrease or may be constant depending upon the heat transfer.
- Reversible adiabatic is isentropic.

Entropy in irreversible process

$$\oint \frac{dQ}{T} < 0 \rightarrow \text{Ireversible cycle}$$

$$dS = \left(\frac{dQ}{T}\right)_{Irr} + S_{gen}$$

S_{gen} is the entropy generated during a process due to internal irreversibility.



- A process in the absence of internal irreversibility is called *Internal reversible* process.
- A process in the absence of external irreversibility is called *externally reversible* process.
- A process in which both the internal and external irreversibility are not present then it is called *totally reversible process* or *reversible process*.

Tds Equation

$$Tds = dU + PdV$$

$$Tds = dH - Vdp$$

- *Tds equations are also called as property relations.*
- *Tds equations are valid for any process i.e., reversible and also irreversible.*
- *Tds equations are applicable for both closed and open system.*

Third Law of Thermodynamics

The third law of thermodynamics states that the entropy of a perfect crystal at a temperature of zero Kelvin (absolute zero) is equal to zero.

The third law of thermodynamics implies that it is not possible for a process to bring the entropy of a given system to zero in a finite number of operations.

BASIC MECHANICAL ENGINEERING

Heat Transfer

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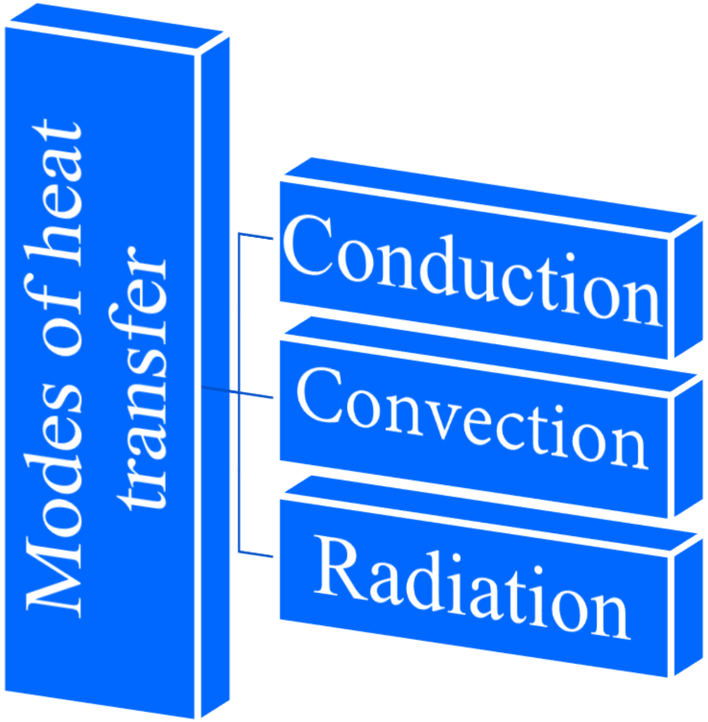
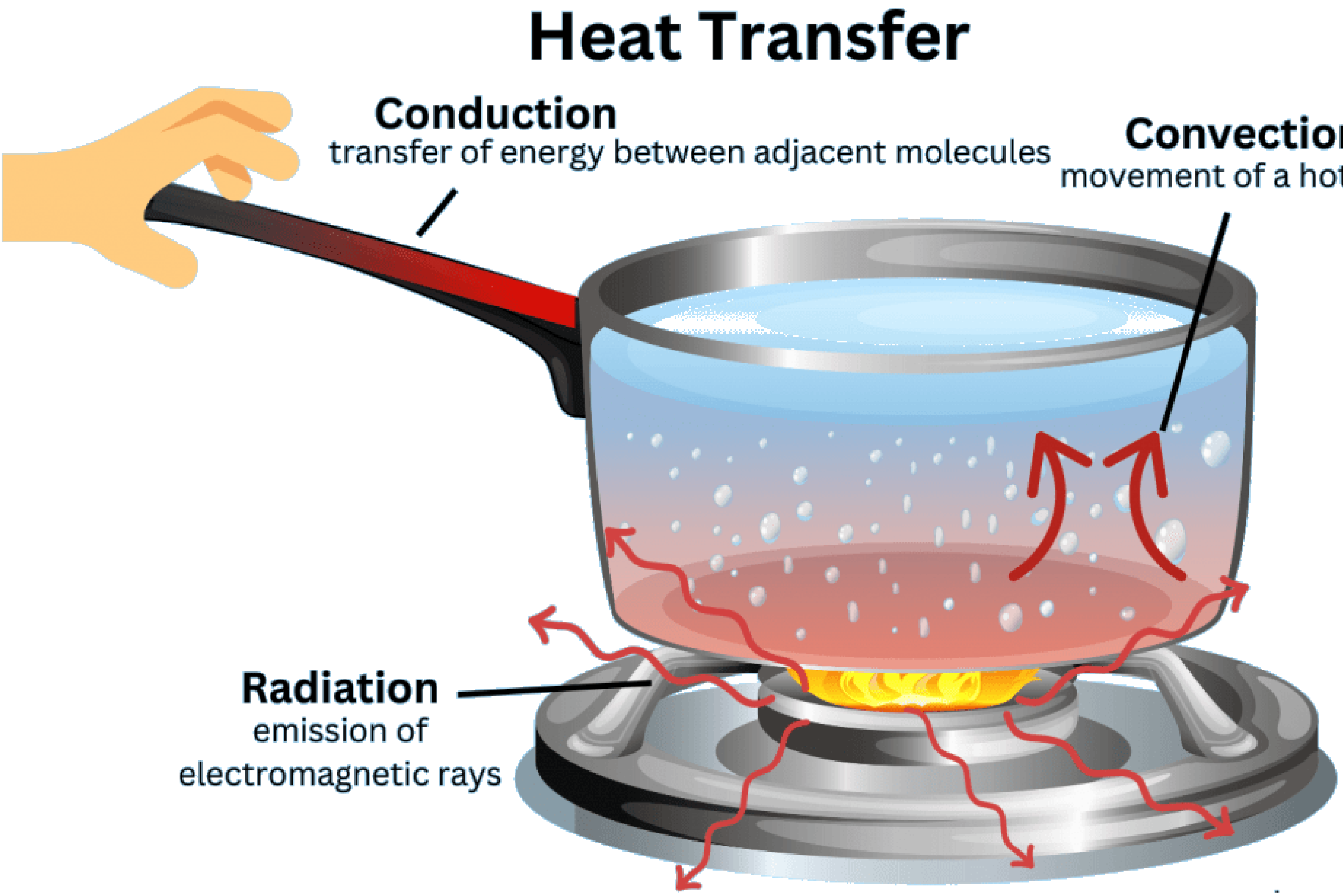
Introduction

Heat transfer describes the flow of heat (thermal energy) due to temperature differences and the subsequent temperature distribution and changes.

There are three modes of heat transfer

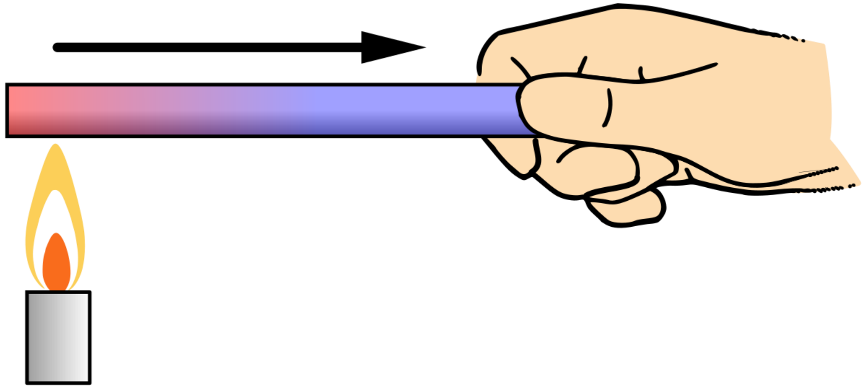



Heat Transfer
Conduction
transfer of energy between adjacent molecules
Convection
movement of a hot fluid
Radiation
emission of
electromagnetic rays

Conduction

Conduction is the heat transfer from one part of a substance to another part of the same substance, or from one substance to another in physical contact with it.

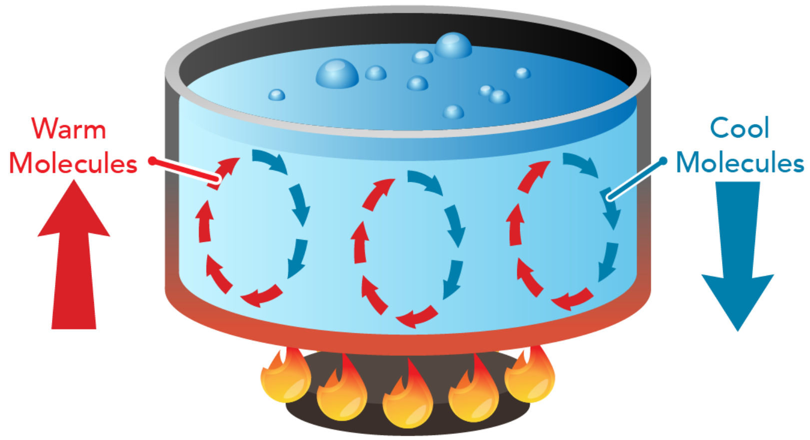
It does not involve any movement of macroscopic portions of matter relative to one another.



Convection

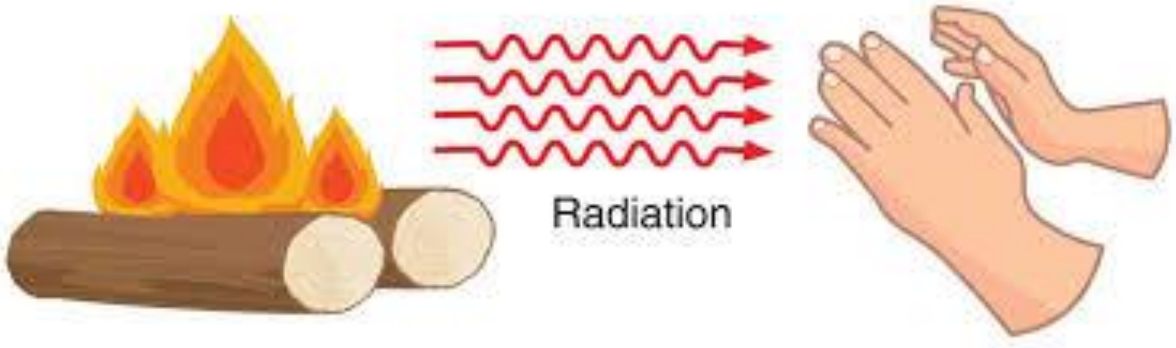
Convection is a process of energy transport affected by the circulation or mixing of a fluid medium.

The energy transfer in convection is mainly due to bulk motion of fluid particles.



Radiation

Radiation is the transmission of heat in the form of radiant energy or wave motion from one body to another across an intervening space.



Fourier law of heat conduction

Assumptions

- ✓ Steady state condition
- ✓ One directional
- ✓ No internal heat generation
- ✓ Boundary surfaces are isothermal i.e., constant uniform temperature are maintained at the two faces.

Fourier law of heat conduction

It sates that rate of heat conduction between two surfaces is directly proportional to area normal to the heat flow and temperature gradient.

$$Q = -kA\frac{dT}{dx}$$

- K is the thermal conductivity of material which indicates ability of material to conduct heat.
- -ve sign in the Fourier law is provided for satisfying 2^{nd} law of thermodynamics.
- Heat flows in the direction of negative temperature gradient and that serves to make the heat flow positive.

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Newton's law of cooling

It sates that when a fluid at a temperature is in contact with a solid surface at a different temperature, the heat flux from the surface to the fluid is directly proportional to the temperature difference between the surface and the fluid.

$$\frac{Q}{A} = q = h\,(T_s - T_\infty)$$

Stefan – Boltzman Law

The total emissive power "E" of a surface is defined as the total radiant energy emitted by the surface in all directions over the entire wavelength range per unit time.

According to Stephen-Boltzman law, the amount of radiant energy emitted per unit time form unit area of black surface is proportional to the fourth power of its absolute temperature.

$$E = \sigma A T^4$$

σ = radiation coefficient or Stephen-Boltzman constant

$= 5.67 \times 10^{-8}\ W/m^2K^4$

Numerical problems

The inner surface of a plain brick wall is at 60°C and the outer surface is at 20°C Calculate the rate of heat transfer per m^2 of the surface area of the wall, which is 260 mm thick. The thermal conductivity of the brick is 0.55 W/mK.

Numerical problems

Air at 30°C is flowing over a flat plate of size 0.5m*0.2m. If the convection heat transfer coefficient is 150 W/m^2 °C, determine the heat transfer rate from the air to one side of the plate when the plate is maintained at 130 °C.

Numerical problems

Consider a body with emissivity, e = 0.65, a surface area of 400 cm^2, and a temperature of 200 ºC. This body is kept in a room at a temperature of 30 ºC. Using the Stefan Boltzmann law, calculate the net radiation by the body.

BASIC MECHANICAL ENGINEERING

Fluid Mechanics

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FLUID

A ***fluid*** is a liquid, gas, or other material that may continuously move and deform under an applied shear stress, or external force.

Fluid Mechanics

- ***Fluid mechanics*** is a branch of science which deals with the behaviour of fluids at rest as well as motion.
- This branch deals with static, kinematics and dynamic aspect of fluid.
- The study of fluid at rest is known as ***fluid statics***.
- The study of fluids in motion, where pressure forces are not considered, is called ***fluid kinematics***.
- The study of fluids, where pressure forces are considered for the fluids in motion, is called ***fluid dynamics***.

Properties of fluids

Mass density (ρ):

Mass Density (ρ) is defined as the mass of a substance per unit volume.

$$Mass\ density\ (\rho) = \frac{Mass\ (m)}{Volume\ (V)}$$

Specific Weight (ω or γ):

Specific weight is defined as the weight of matter per unit volume.

$$Specific\ weight\ (\gamma) = \frac{Weight\ (W)}{Volume\ (V)}$$

Properties of fluids

Specific volume (V_s):

Specific volume is defined as the volume occupied by unit mass of fluid..

$$Specific\,Volume\ (\boldsymbol{V_s}) = \frac{Volume\ (V)}{Mass\ (m)}$$

Specific gravity or Relative density (s):

Specific gravity is defined as the ratio of the mass density of a fluid to some standard fluid (water) mass density.

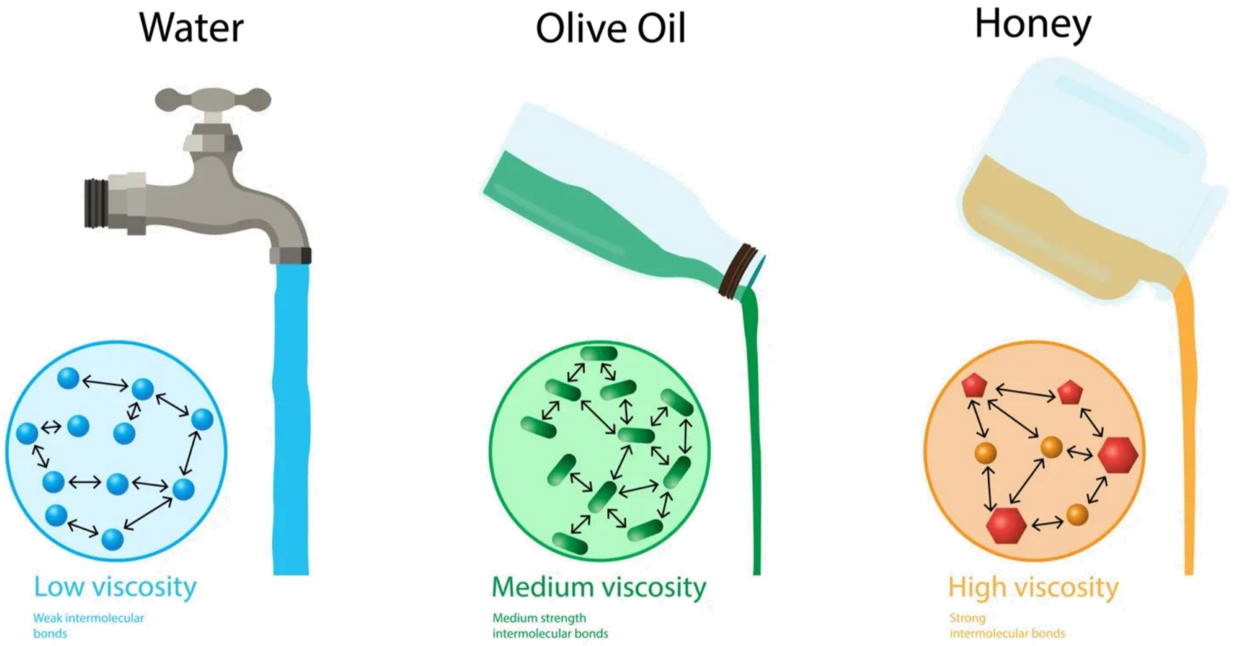
$$Specific\ gravity\ (s) = \frac{\rho_{fluid}}{\rho_{water}}$$

Properties of fluids

Viscosity :

A property by virtue of which it offers resistance to the motion of one layer of fluid over the adjacent layer.

It a measure of resistance to flow i.e., shear or angular deformation.



Newton's Law of Viscosity

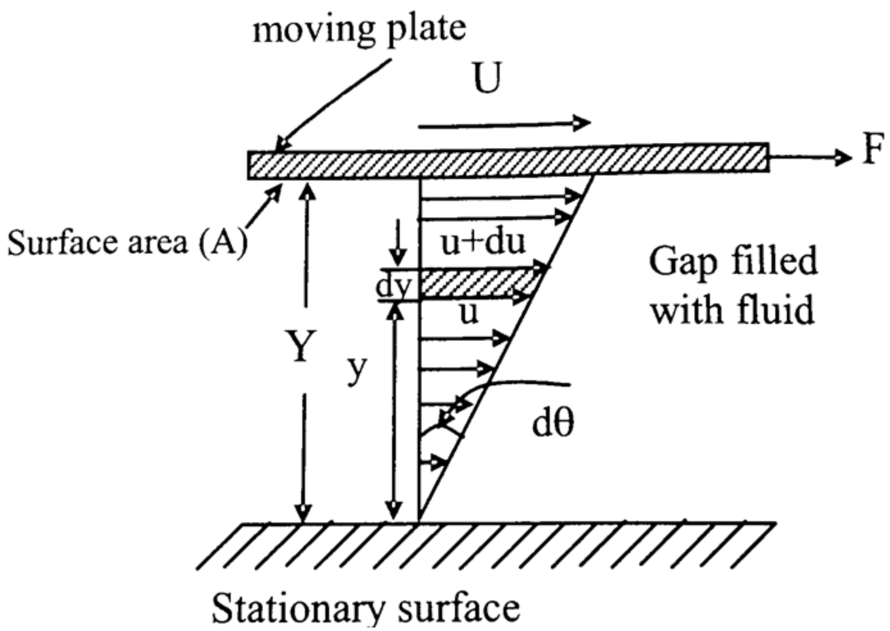
It states that shear stress is directly proportional to time rate of deformation (angular deformation rate of velocity gradient on fluid).

$$\tau \propto \frac{du}{dy} \qquad \tau = \mu \frac{du}{dy}$$

τ = *Shear stress*

$\frac{du}{dy}$ = *velocity gradient (or) rate of shear strain*

μ = *Dynamic viscosity (or) coefficient of viscosity*



Dynamic viscosity (μ)

SI system: Pa.sec (or) N.sec/m^2 (or) kg/m.sec

CGS system: Poise (or) Dyne.sec/cm^2

1 poise = 0.1 Pa.sec

Kinematic viscosity (υ)

$$\upsilon = \frac{Dynamic\ viscosity}{density} = \frac{\mu}{\rho}$$

SI system: m^2/sec

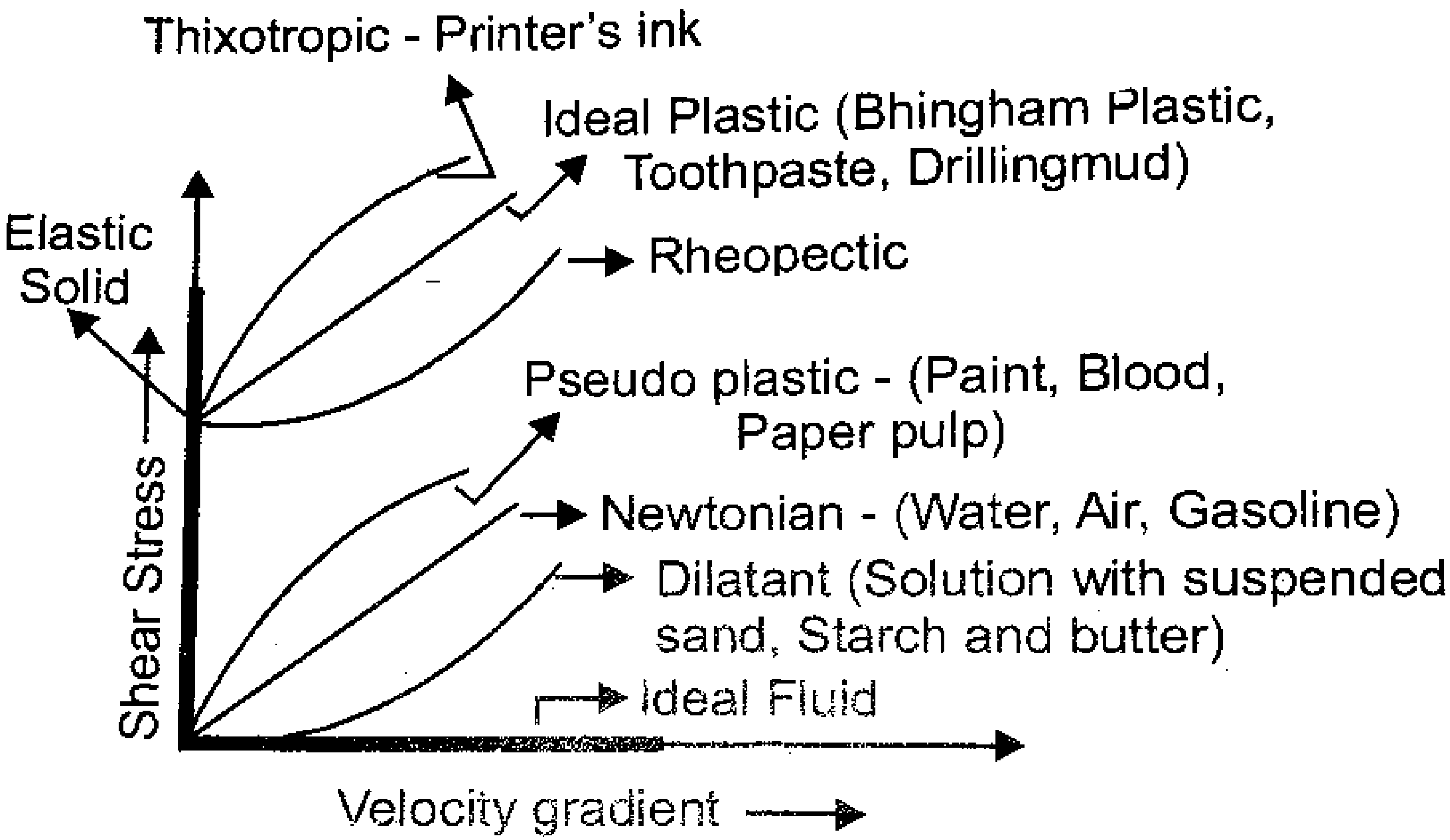
CGS system: cm^2/sec (or) stroke

1stroke= 10^{-4} m2/sec

Numerical problems

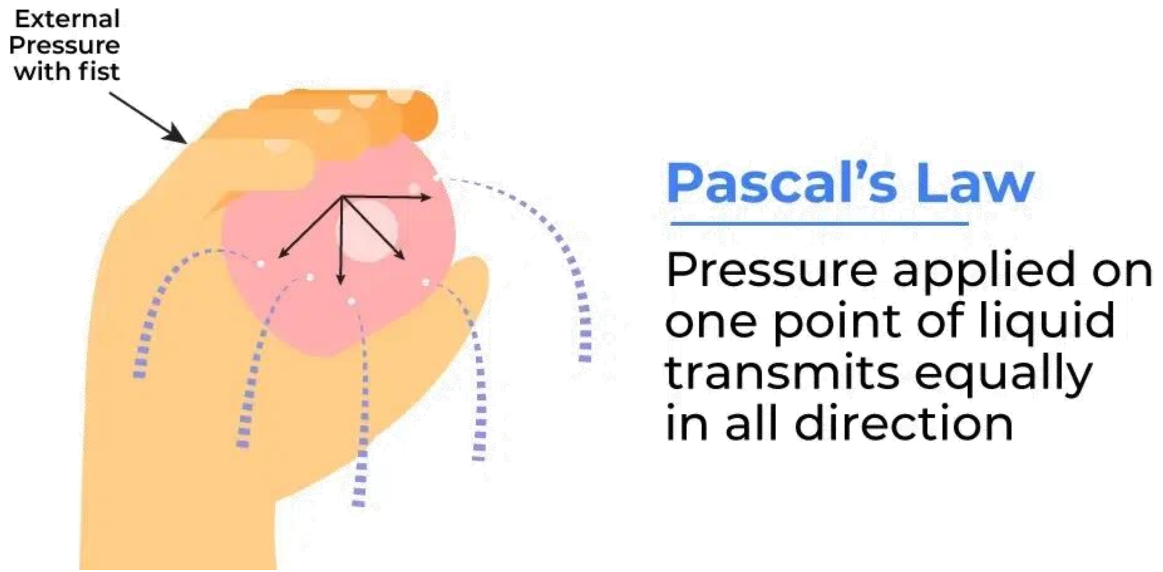
A plate 0.05mm distant from a fixed plate moves at 1.2m/s and requires a shear stress of 2.2 N/m^2 to maintain this velocity. Find the viscosity of the fluid between in the plates.

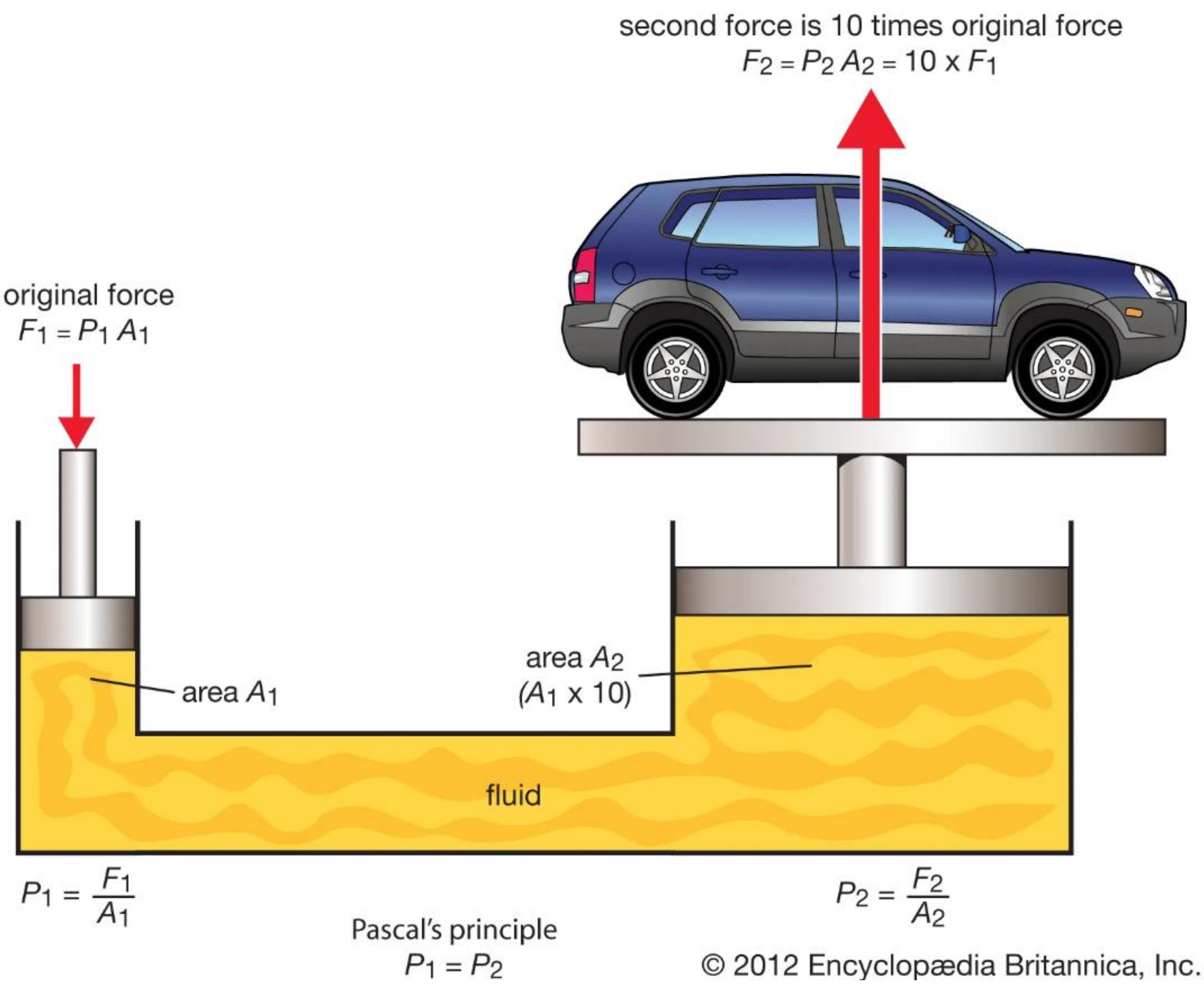
Type of Fluid



Pascal’s Law

Pascal’s principle, in fluid (gas or liquid) mechanics, statement that, in a fluid at rest in a closed container, a pressure change in one part is transmitted without loss to every portion of the fluid and to the walls of the container.




second force is 10 times original force
$F_2 = P_2 A_2 = 10 \times F_1$
original force
$F_1 = P_1 A_1$
area A_1
area A_2
$(A_1 \times 10)$
fluid
$P_1 = \frac{F_1}{A_1}$
$P_2 = \frac{F_2}{A_2}$
Pascal's principle
$P_1 = P_2$
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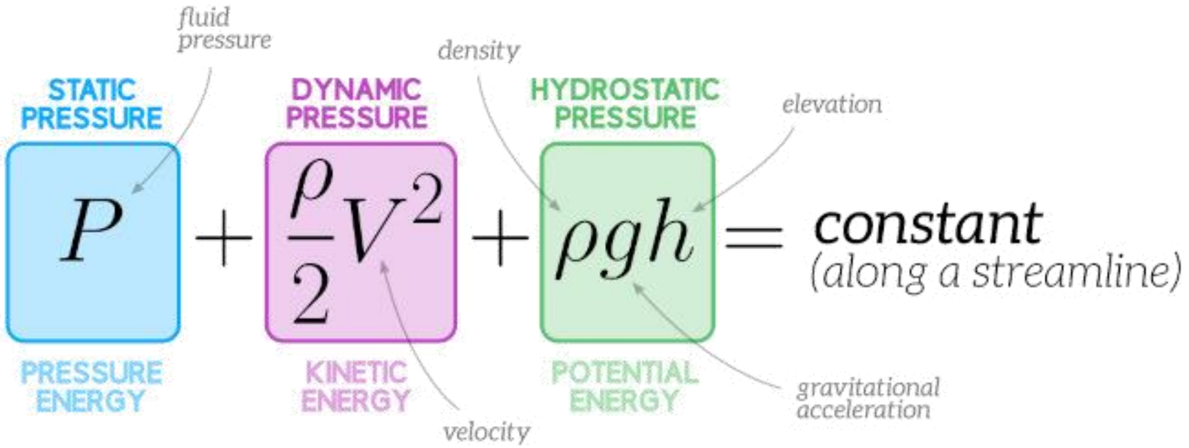
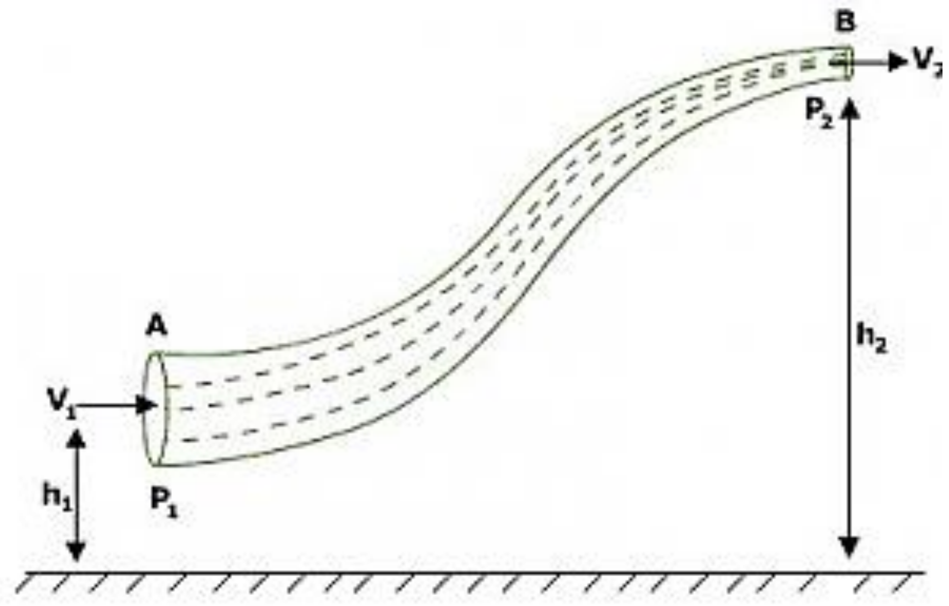
Bernoulli's principle

Bernoulli's principle states that "*The total energy of the moving fluid comprising the gravitational potential energy of elevation, the energy associated with the fluid pressure and the kinetic energy of the fluid motion, remains constant.*"





Types of flow

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

Unsteady Flow: Unsteady flow is that type of flow in which the fluid characteristics such as velocity, pressure, density, etc. at a point change with time.

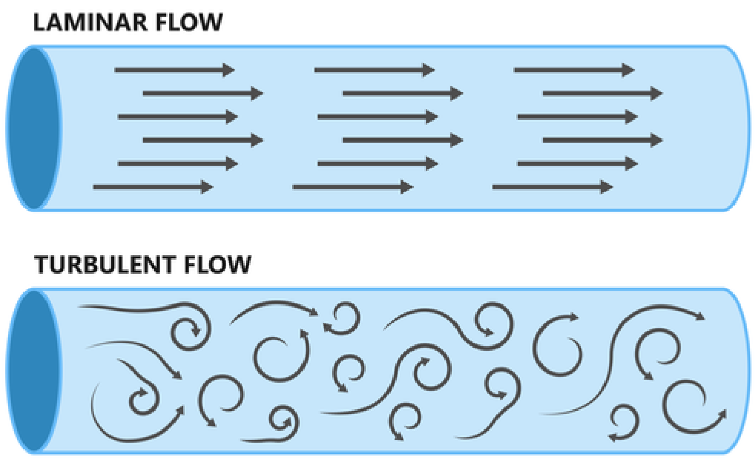
Uniform Flow: Uniform flow is that type of flow in which velocity of the fluid does not change with respect to space.

Non-uniform Flow: Non-uniform flow is that type of flow in which velocity of the fluid changes with respect to space.

Types of flow

Laminar Flow: Laminar flow is that type of flow in which the fluid particles move along well-defined paths of streamline and all the streamlines are straight and parallel to each other. This type of flow is also known as streamline or viscous flow.

Turbulent Flow: Turbulent flow is that type of flow in which fluid particles move in a zig–zag way. This zig–zag motion of the fluid particles results in eddies formation which is responsible for energy loss.



Types of flow

Compressible Flow: Compressible flow is that type of flow in which density of fluid changes from point to point.

Incompressible Flow: Incompressible flow is that type of flow in which density of fluid remains constant throughout the flow.

Rotational Flow: In rotational flow, fluid particles moving on stream lines also rotate about their axes.

Irrotational Flow: In irrotational flow fluid particles do not rotate about their axes, they smoothly move in stream line.

BASIC MECHANICAL ENGINEERING

Engine

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Heat Engine

A heat engine is a system that converts heat or thermal energy to mechanical energy, which can be used to do mechanical work.

- Heat Engine
  - Internal combustion engine
  - External combustion engine

EC Engine

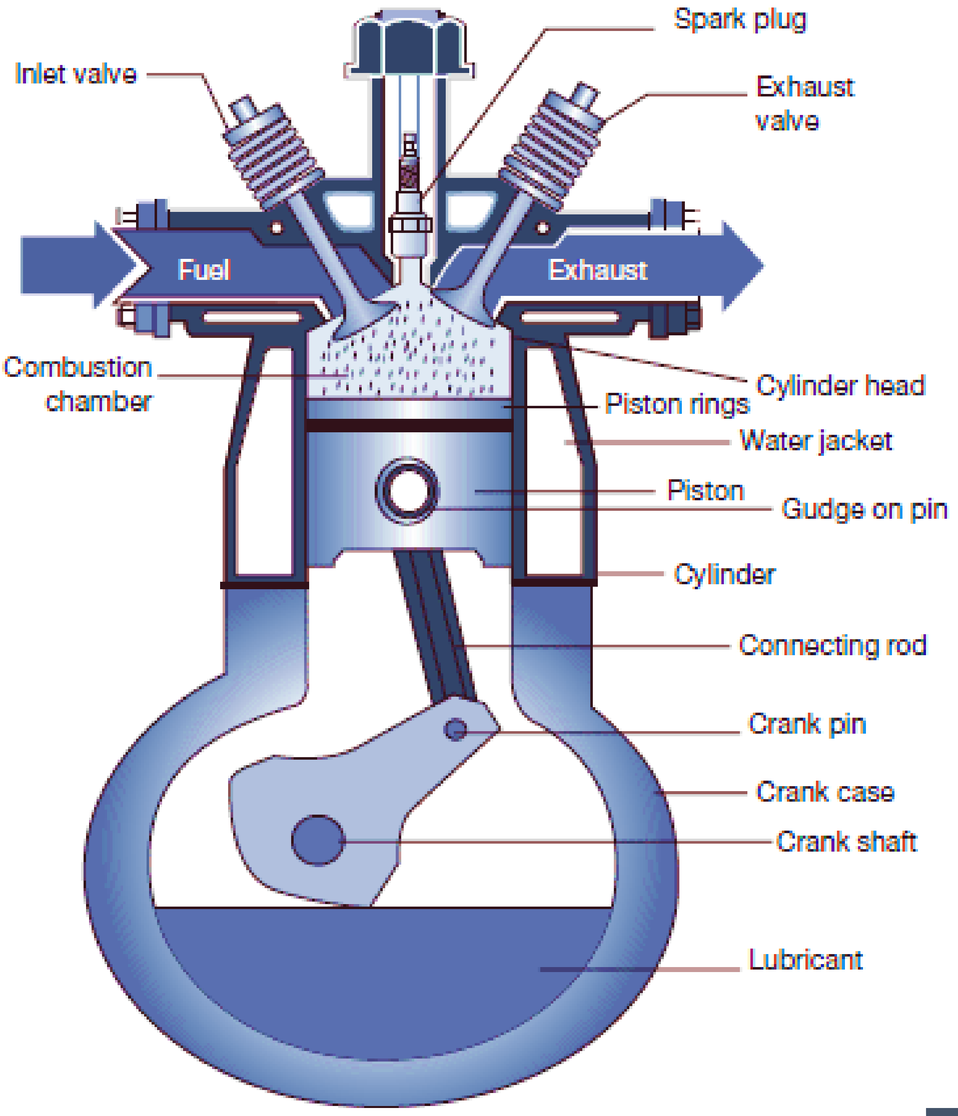
An external combustion engine (ECE) is a type of heat engine that uses an external heat source to heat a working fluid and that heat is used for inducing useful mechanical work.

Example : Steam engine, steam turbine, etc.

IC Engine

An internal combustion engine (ICE) is a type of heat engine that produces heat inside the engine and that heat is used for inducing useful mechanical work.

Example : diesel engine, wankel engine, etc.


Spark plug
Inlet valve
Exhaust valve
Fuel
Exhaust
Combustion chamber
Cylinder head
Piston rings
Water jacket
Piston
Gudge on pin
Cylinder
Connecting rod
Crank pin
Crank case
Crank shaft
Lubricant

Classification of I.C. Engines

There are several bases for classification of I.C. Engines, some of the important bases can be explained as:

▶▶ Number of strokes per cycle

▶▶ Nature of thermodynamic cycle

▶▶ Ignition systems

▶▶ Fuel used

▶▶ Arrangement of cylinders

▶▶ Cooling systems

▶▶ Fuel supply systems

Number of Strokes Per Cycle

I.C. Engines can be classified as four-stroke engines (4S) and two-stroke engines (2s). In four-stroke engines, the thermodynamic cycle is completed in four strokes of the piston or two revolutions of the crankshaft whereas, in two-stroke engines, the thermodynamic cycle is completed in two strokes of the piston or one revolution of the crankshaft.

Nature of Thermodynamic Cycle

I.C. Engines can be classified as Otto cycle, Diesel cycle, and Dual cycle engine. In an Otto cycle engine, heat addition and heat rejection occur at constant volume; therefore, this is also known as constant volume engine, whereas, in the Diesel cycle engine, heat addition occurs at constant pressure and heat rejection occurs at constant volume. In Dual cycle, heat addition occurs partly at constant volume and partly at constant pressure, but heat rejection occurs fully at constant volume.

Ignition Systems

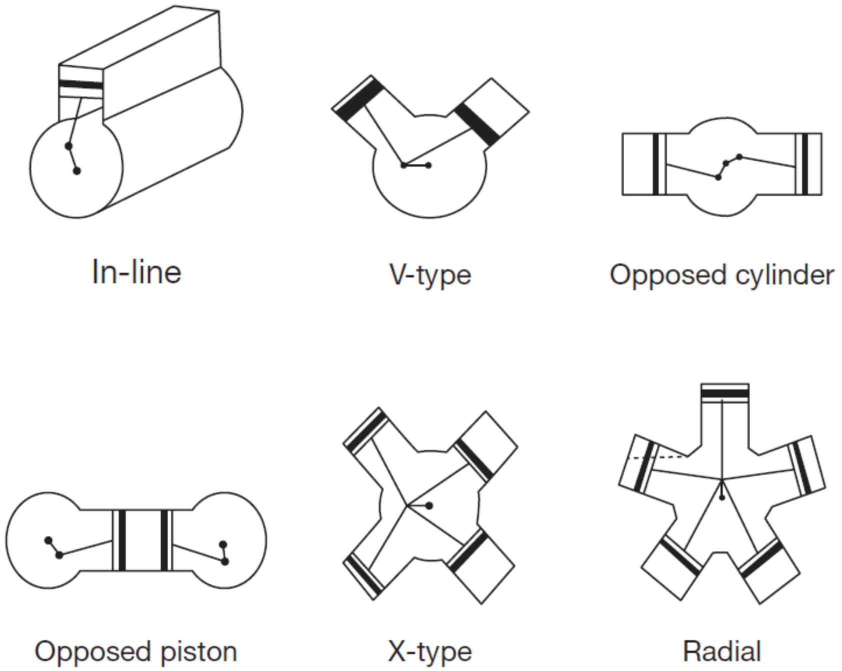
There are two modes of ignition of fuel inside the cylinder—spark ignition and self or compressed ignition. In spark ignition, sparking starts at the end of compression stroke from spark plug while in compressed ignition the temperature of the fuel increased to the self-ignition point by compressing the air alone and at the end of compression, fuel is injected into the cylinder.

Fuel Used

On the basis of fuel used, I.C. Engines can be classified as (a) gas engines like CNG, natural gas, etc. (b) Petrol engine, (c) Diesel Engine, and (d) Bi-fuel engine. In a bi-fuel engine, two types of fuel are used like gaseous fuel and liquid fuel.

Arrangement of Cylinders

According to the arrangement of cylinders, I.C. Engines can be classified as (a) In-line engines, (b) V-engines, (c) Opposed cylinder engines, (d) Opposed piston engines, (e) X-type engines, and (f) Radial engines.



Cooling Systems

There are two types of cooling systems in I.C. Engines—water cooling and air cooling. In water cooling, coolant and radiators are provided to cool the cylinder. In air cooling, fins are provided on the surface of the cylinder to radiate the heat into the atmosphere. Low power engines like motorbikes are equipped with air cooling systems, whereas large power producing engines like a car, bus, truck, etc. are equipped with water cooling systems.

Fuel Supply Systems

On the basis of fuel supply systems, I.C. Engines can be classified as:

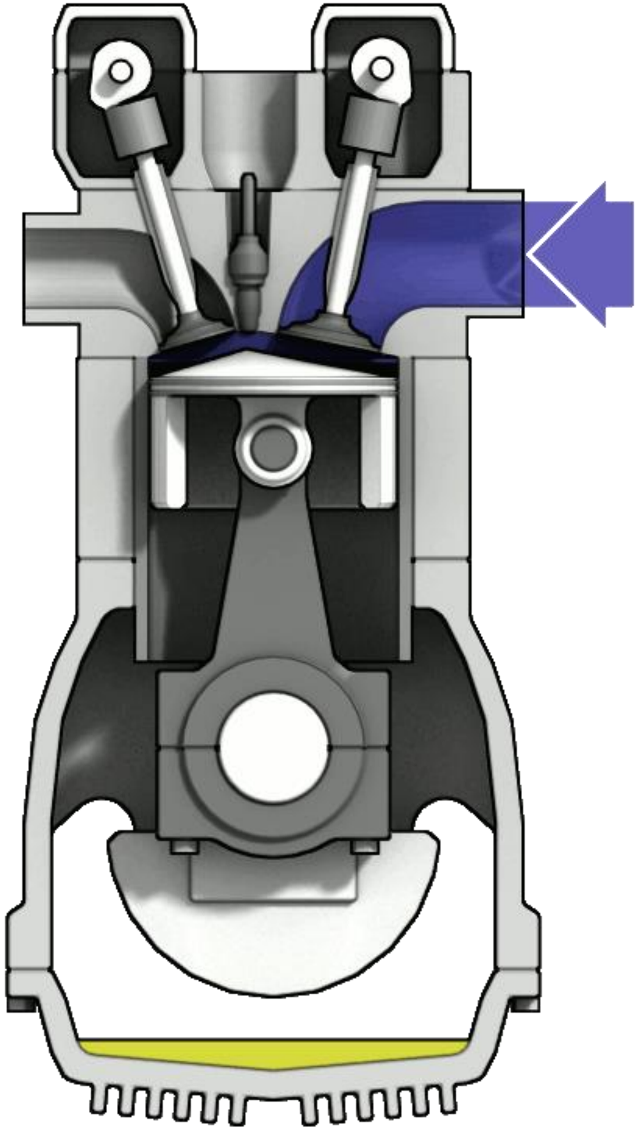
(a) Carburetor engine,

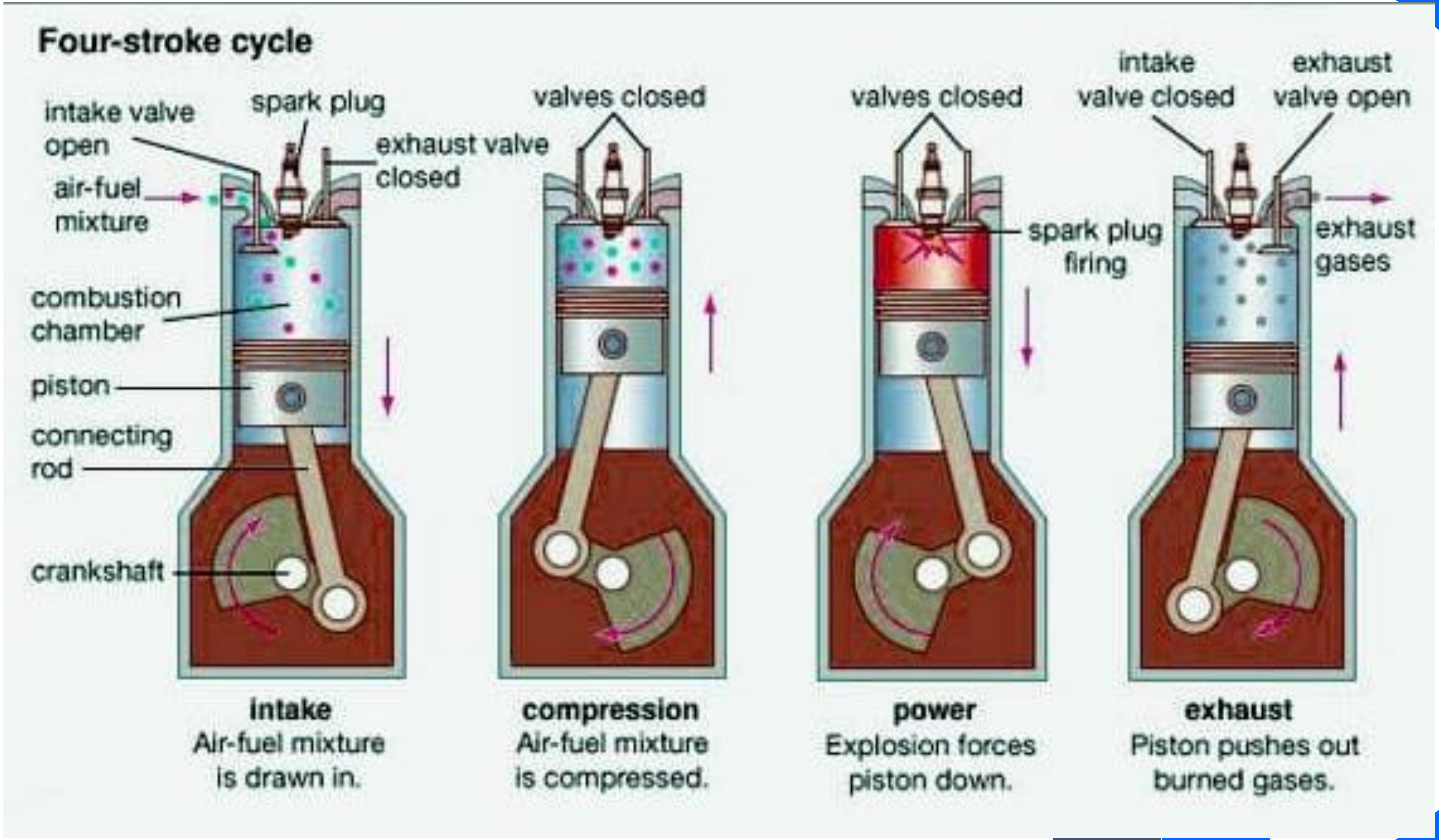
(b) Air injection engine, and

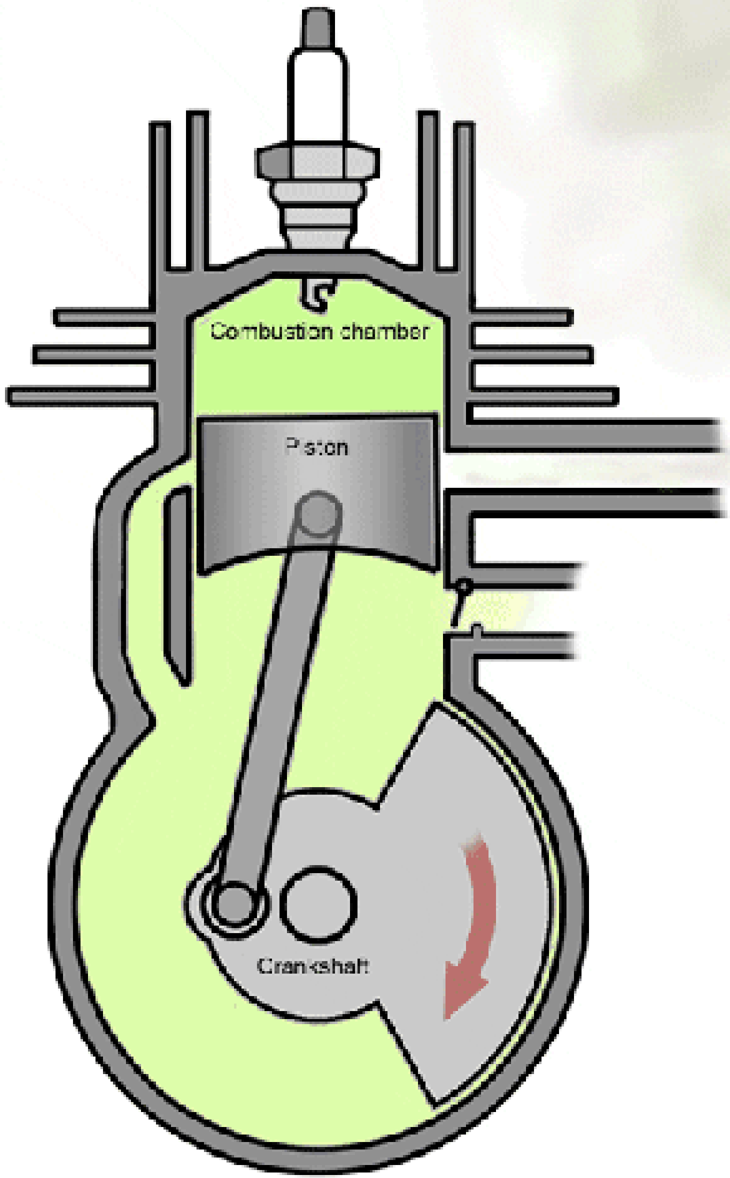
(c) Airless or solid or Mechanical injection engines

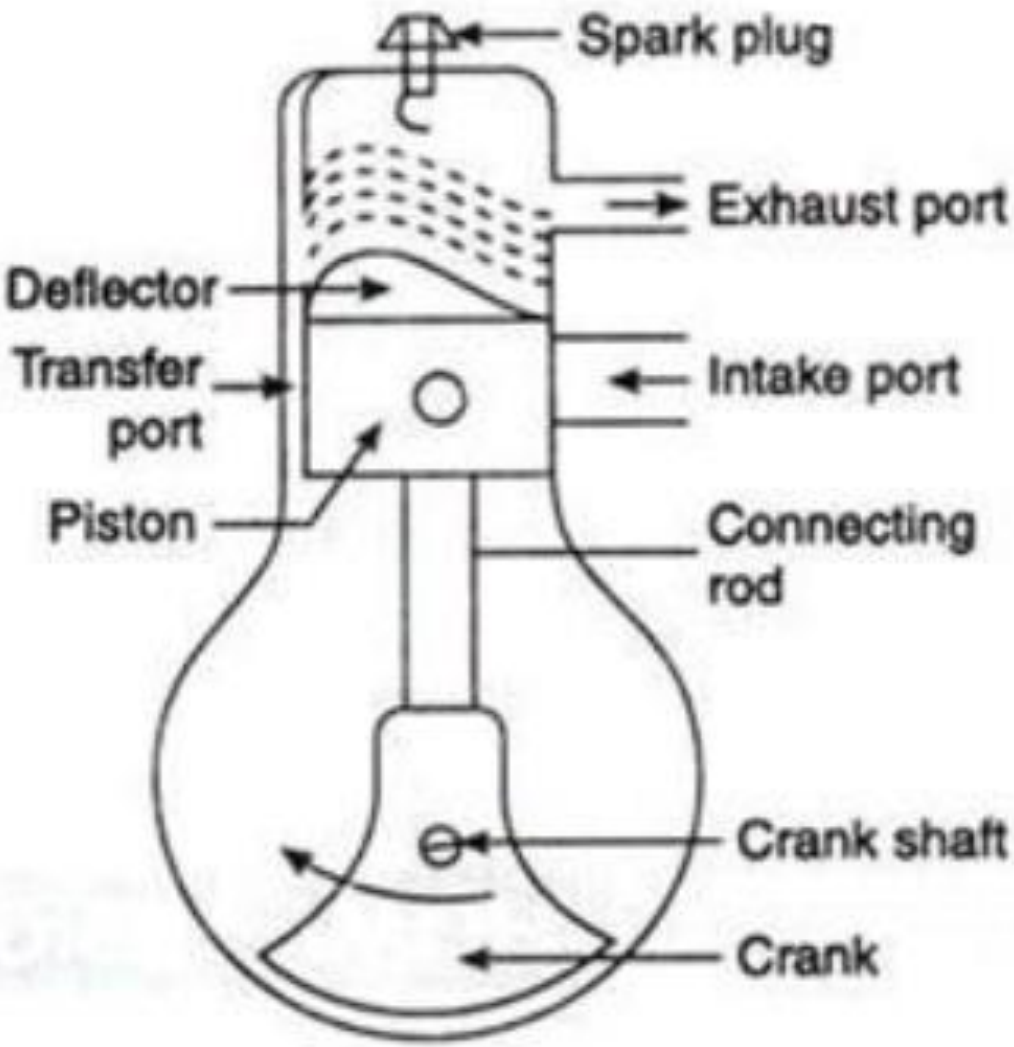
In a carburetor engine, air and fuel are properly mixed into the carburetor and then fed into the cylinder. In air injection engines, fuel is supplied to the cylinder with the help of compressed air. In mechanical injection engines, the fuel is injected into the cylinder with the help of mechanical pump and nozzle.

1

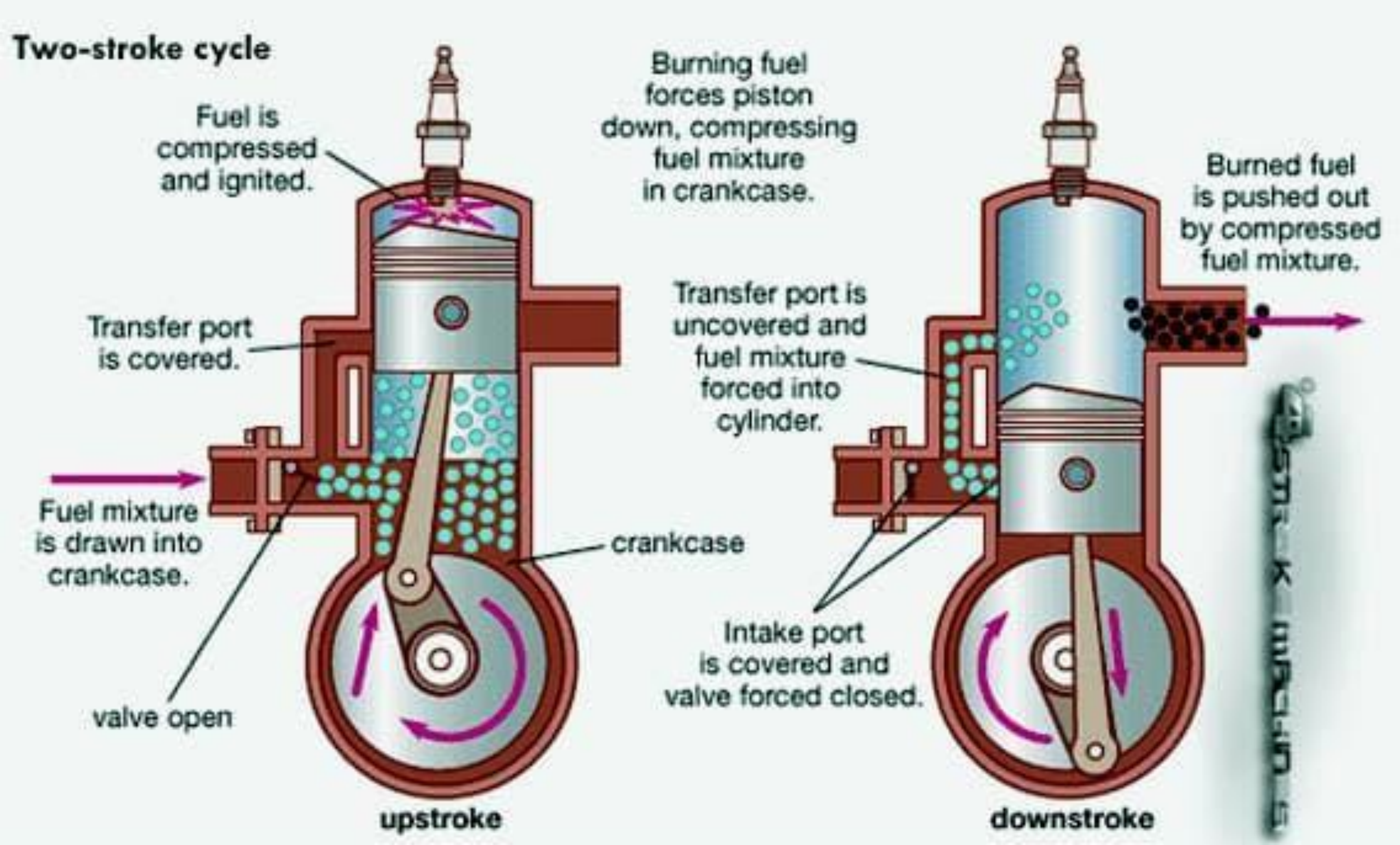



Four-stroke cycle
intake valve open
spark plug
exhaust valve closed
air-fuel mixture
combustion chamber
piston
connecting rod
crankshaft
valves closed
valves closed
spark plug firing
intake valve closed
exhaust valve open
exhaust gases
intake
Air-fuel mixture is drawn in.
compression
Air-fuel mixture is compressed.
power
Explosion forces piston down.
exhaust
Piston pushes out burned gases.


Combustion chamber
Piston
Crankshaft



Spark plug
Exhaust port
Deflector
Transfer port
Intake port
Piston
Connecting rod
Crank shaft
Crank


Two-stroke cycle
Fuel is compressed and ignited.
Burning fuel forces piston down, compressing fuel mixture in crankcase.
Burned fuel is pushed out by compressed fuel mixture.
Transfer port is covered.
Transfer port is uncovered and fuel mixture forced into cylinder.
Fuel mixture is drawn into crankcase.
crankcase
Intake port is covered and valve forced closed.
valve open
upstroke
downstroke

Difference between 4 stroke and 2 stroke engine

Description	4- Stroke Engine	2- Stroke Engine
Completion of Cycle	Requires 4 different strokes or 2 revolutions	Requires only 2 strokes or 1 revolution
Power stroke	For every 2 revolutions	For every 1 revolutions
Admission of charge	Directly enters into the cylinder	First enters into the crankcase & then transferred to cylinder
Valves	Consists of inlet and exhaust valves operated by cam mechainsm	Consists of ports which are opened & closed by piston movement
Cooling & Lubricatioin	Required lesser cooling and lubrication	Requires greater cooling & lubrication
Fuel Consumption	Less	More
Mechanical Efficiency	Less	High
Weight	Heavy and bulky	Lighter and compact

Difference between 4 stroke and 2 stroke engine

Four-stroke Engines	Two-stroke Engines
1. The thermodynamic cycle is completed in four strokes of the piston and two revolutions of the crankshaft. Thus, one power stroke is obtained in two revolutions of the crankshaft.	1. The thermodynamic cycle is completed in two strokes of the piston and one revolution of the crankshaft. Thus, one power stroke is obtained in one revolution of the crankshaft.
2. Turning moment is not so uniform during all the four strokes and hence, the heavier flywheel is required.	2. Comparatively, turning moment is more uniform and hence lighter flywheel can be employed.
3. The power produced from same size engine is less than two-stroke engine due to one power stroke in two revolutions of the crankshaft. Or for same power output engine required is heavier and bulkier.	3. The power produced from same size engine is more than the four-stroke engine due to one power stroke in each revolution of the crankshaft.
4. Less cooling and lubrication is required due to one power stroke in two revolutions and hence less wears and tear occurs.	4. Larger cooling and lubrication is required due to one power stroke in each revolution and hence more wear and tear occurs.
5. It consists of valves and valve actuating mechanism such as cam, camshaft, rocker arm, spring, valve, and valve seat.	5. It has ports in place of valves.
6. It has higher volumetric efficiency as the time available for induction of charge is more.	6. Volumetric efficiency is lower due to lesser time available for induction.
7. It has a higher thermal efficiency due to complete combustion of the fuel.	7. It has a lower thermal efficiency due to the partial wastage of fuel through the exhaust port and incomplete combustion.

Comparison Between S.I. and C.I. Engines

S.I. Engines	C.I. Engines
1. It is based on Otto cycle or constant volume heat addition and rejection cycle.	1. It is based on a Diesel cycle or constant pressure heat addition and constant volume heat rejection cycle.
2. A high volatile and high self-ignition temperature fuel, i.e., gasoline is used.	2. Comparatively low volatile and low self-ignition temperature fuel, i.e., diesel is used.
3. A gaseous mixture of fuel and air is inducted during the suction stroke. A carburetor is necessary to provide the mixture.	3. Fuel is injected at high pressure at the end of compression stroke. A fuel pump and injector units are used.
4. Throttle controls the quantity of fuel-air mixture introduced.	4. The quantity of fuel is regulated in the pump. Air quantity is not controlled. There is quality control.
5. For combustion of the charge, it requires an ignition system with a spark plug in the combustion chamber.	5. Autoignition occurs due to the high-temperature of air resulting from high-compression.
6. Compression ratio ranges from 6 to 10.	6. Compression ratio ranges from 16 to 20.
7. Due to light weight and homogeneous combustion, they are high-speed engines.	7. Due to heavy weight and heterogeneous combustion, they are comparatively low-speed engines.
8. It has a lower thermal efficiency due to lower compression ratio but delivers more power for same compression ratio.	8. It has a higher thermal efficiency due to high-compression ratio and delivers lesser power for the same compression ratio.

BASIC MECHANICAL ENGINEERING

Manufacturing Process (Casting)

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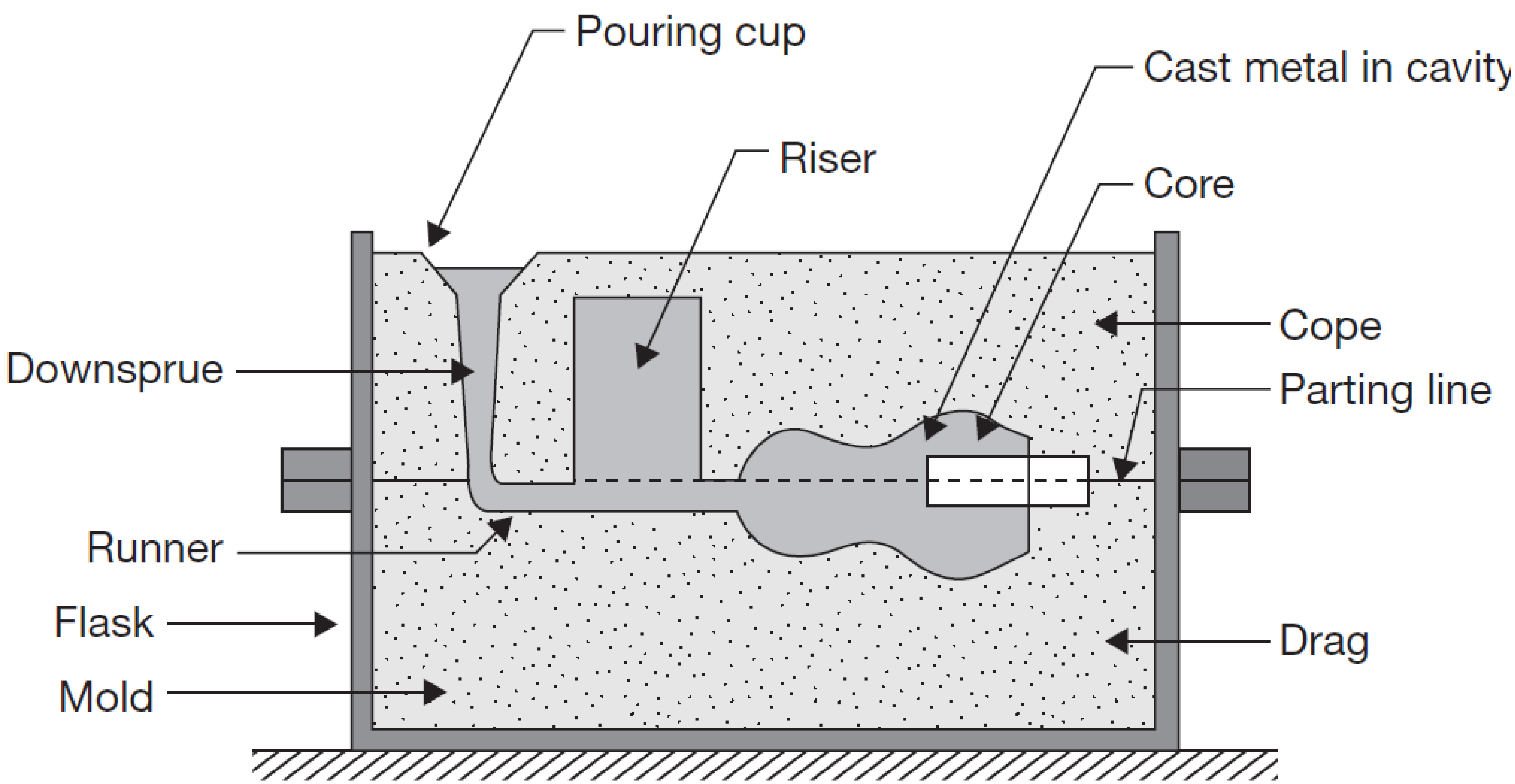
PARALA MAHARAJA ENGINEERING COLLEGE BRAHMAPUR BPUT, ODISHA ESTD-2009

Casting

Casting is a manufacturing process in which a liquid material is usually poured into a mold, which contains a hollow cavity of the desired shape, and then allowed to solidify. The solidified part is also known as a casting, which is ejected or broken out of the mold to complete the process.


Pouring cup
Cast metal in cavity
Riser
Core
Cope
Downsprue
Parting line
Runner
Flask
Drag
Mold

Flask: It is a rigid box opens at top and bottom that holds the complete mold. Flask may be divided into three parts—the upper, middle, and lower; these three parts are known as cope, cheek, and drag, respectively.

Core: A sand or metal shape that is inserted into the mold to create internal hole or recess.

Mold Cavity: It is a cavity of casting shape in the mold connected to runner and riser. It is used to pour the molten metal in which metal solidifies and gets the shape of the cavity.

Parting Line: It is dividing a line of Cope and drag.

Runners: It is a horizontal channel which connects the down sprue and gates.

Riser: An additional opening in the mold that provides additional metal to compensate for shrinkage and also helps to remove gas or vapor formed during pouring the molten metal into the cavity.

Gating System: It is a network of channels that delivers the molten metal to the mold cavity.

Pouring Cup/Basin: It is located at the top surface of the mold and connected to an upper part of down sprue. It prevents the splitting of molten metal.

Down sprue: It is a vertical portion of the gating system. It facilitates the streamline flow of molten metal.

Gate: It controls the amount of flow of molten metal at the entrance of cavity.

Pattern allowances

The surface finish of the casting product may not be as good as required, therefore, extra dimensions in the pattern are provided. The extra dimensions or extra materials provided for the pattern are known as allowances. The following allowances are provided for pattern making:

(a) Draft Allowance/Taper allowance.

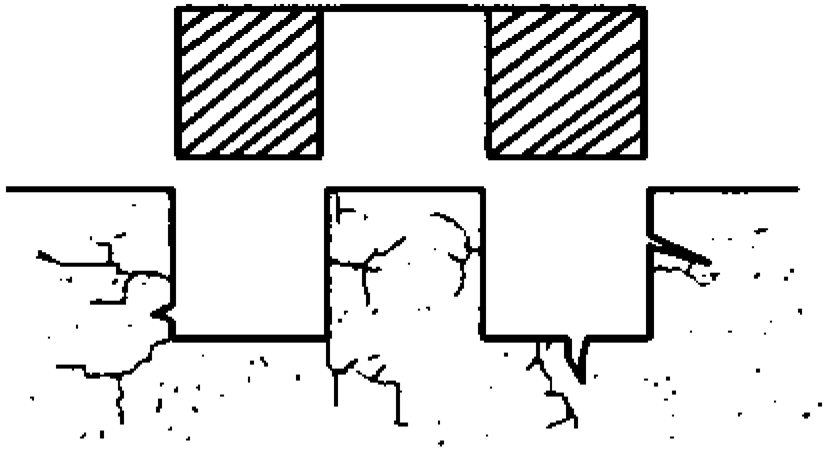
(b) Machining allowance.

(c) Shrinkage allowance.

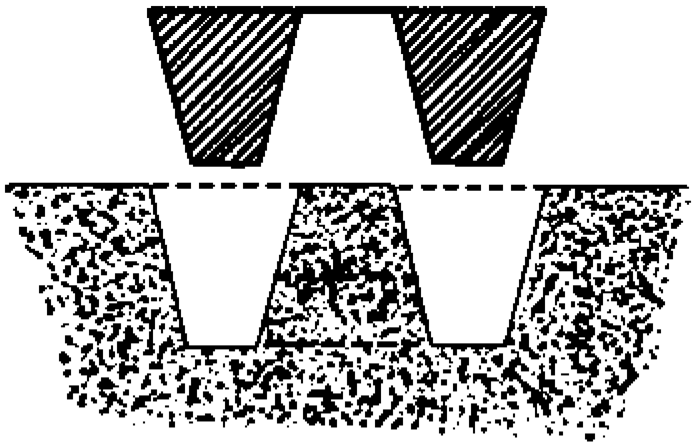
(d) Distortion allowance.

(e) Shaking allowance/Rapping allowance.

Draft Allowance: To exit out the pattern from the mold easily, the surfaces of the pattern are made taper. The larger dimension side of the pattern is at the parting line. The taper provided may be 10 to 30. When small jerk is given to pattern to exit out from the mold; air enters into the small clearance created due to the jerk and breaks the contact between pattern and mold surfaces. The inner side surface of the pattern is provided more taper angle because during solidification metal shrink towards the core. The amount of draft allowance depends on the material used for mold making the shape, the size of the pattern, etc.



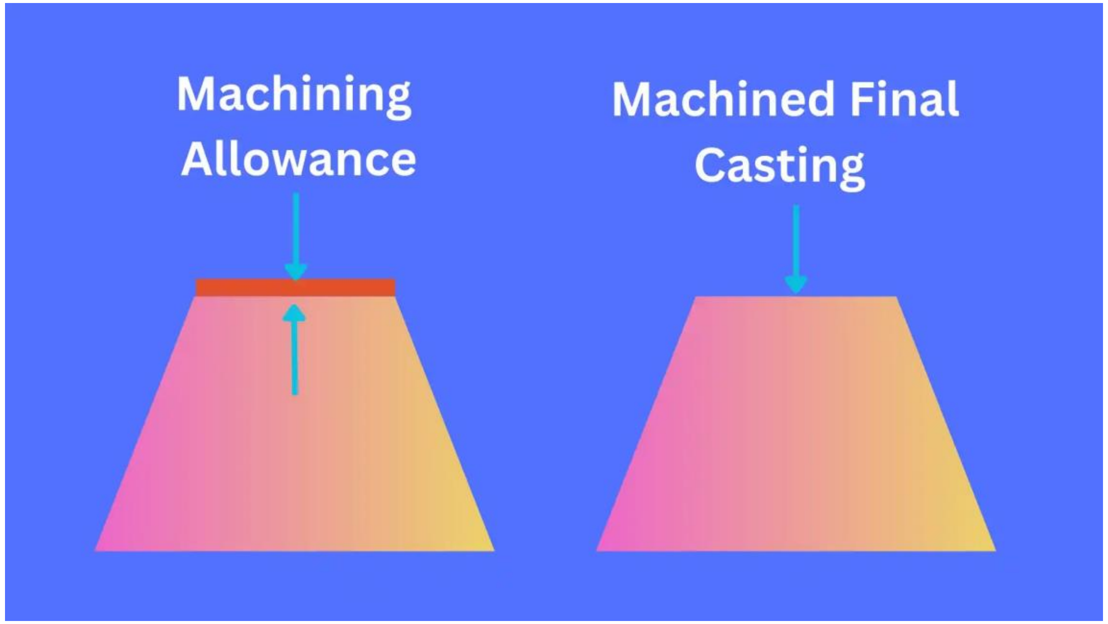
Distorted Casting



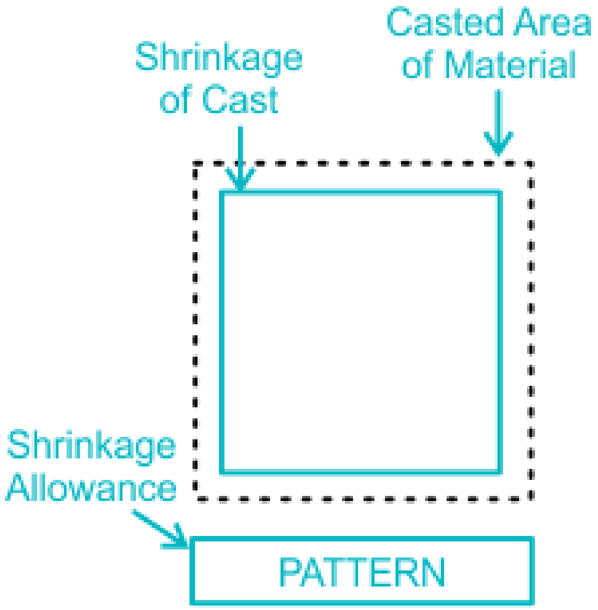
Taper Casting

Shaking/Rapping Allowance: To remove the pattern from the mold, the pattern is rapped with the help of draw spike so that they can be detached from the mold. But to the rapping, the cavity in the mold gets enlarged. Therefore, the pattern is made smaller than the casting, which is known as shaking allowance. This is a negative allowance.

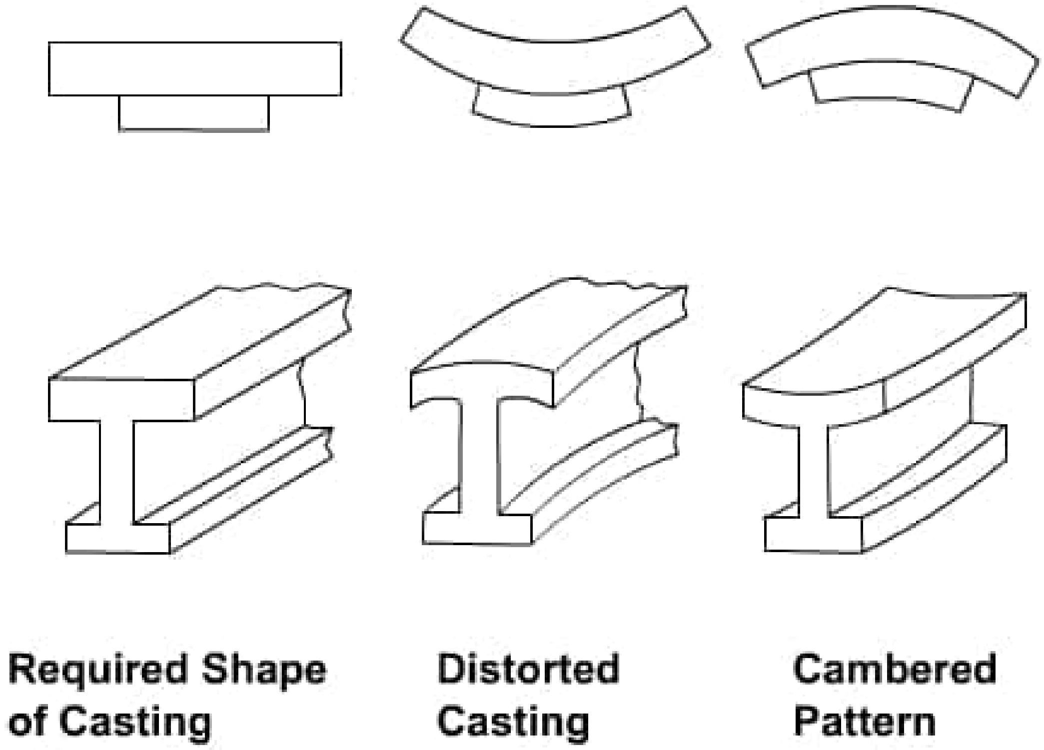
Machining Allowance: The dimensional accuracy and surface finish of the casting (especially sand casting) is poor. Therefore, machining is required for good surface finish and dimensional accuracy; to compensate the removal of unwanted materials, extra materials are provided to the pattern, which is known as machining allowance. Machining allowance depends on the type of casting process, for example, machining allowance in die-casting is very small in comparison to sand casting.



Shrinkage/Contraction Allowance: Most of the metals occupy more volume in a molten state in comparison to solid state. When molten metal is poured into a mold cavity there is shrinkage in metal during solidification. When metal is transferred from molten state to solid state there is shrinkage and from hot solid state to room temperature solid state, there is additional shrinkage. So the volume of the pattern is larger than the casting. The extra dimension provided to the pattern to compensate the shrinkage is known as shrinkage allowance.



Distortion Allowance: Distortion in casting occurs in the process of cooling. It occurs due to thermal stresses developed due to differential solidification. It applies to the casting of irregular shape. To eliminate this defect, an opposite allowance of equal amount is provided in the pattern, which is known as Distortion Allowance.



Types of Pattern

(a) Solid pattern or Single piece pattern.

(b) Split pattern.

(c) Loose piece pattern.

(d) Gated pattern.

(e) Match plate pattern.

(f) Sweep pattern.

(g) Skeleton pattern.

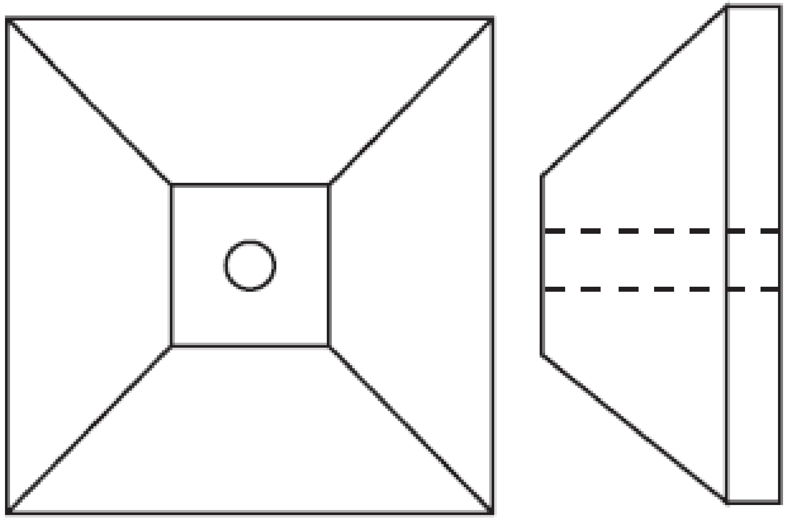
(h) Cope and Drag pattern.

(i) Segmental pattern.

(j) Follow board pattern.

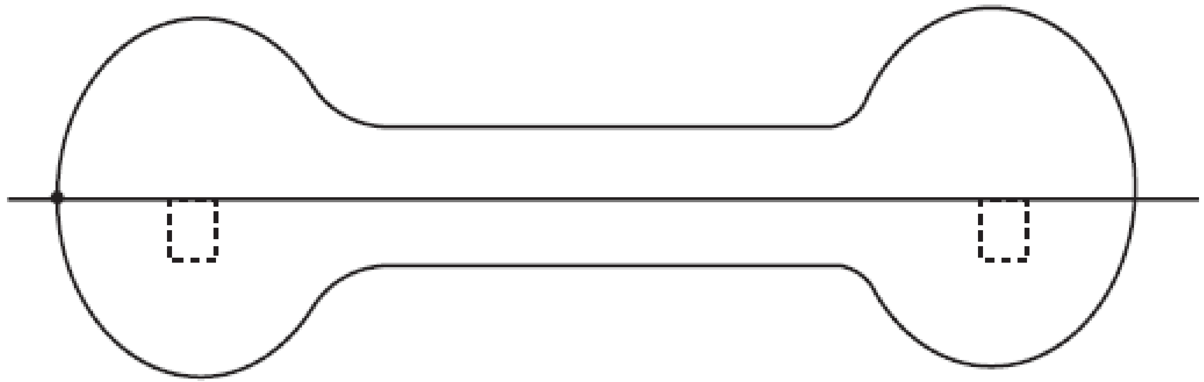
Types of Pattern

Solid Pattern/Single Piece Pattern: A single piece pattern is used for a simple casting. In this pattern, no joint or partition is used. It can be molded in a single molding box.



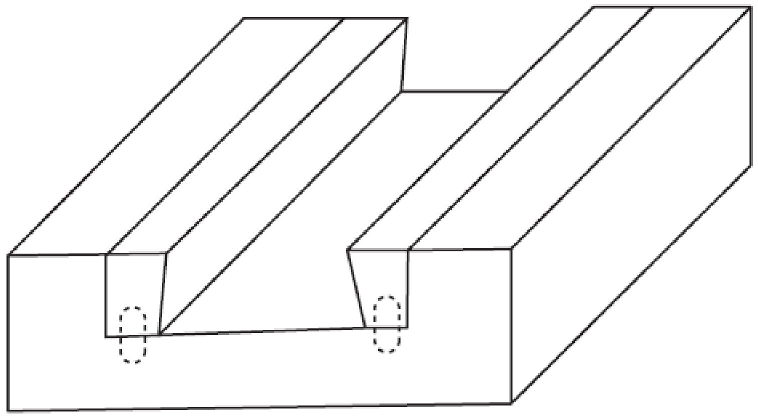
Types of Pattern

Split Pattern: If the design of the pattern is not simple, it difficult to withdraw as a single piece from the mold. The pattern is made into two pieces or into a split form and joined together by dowels.



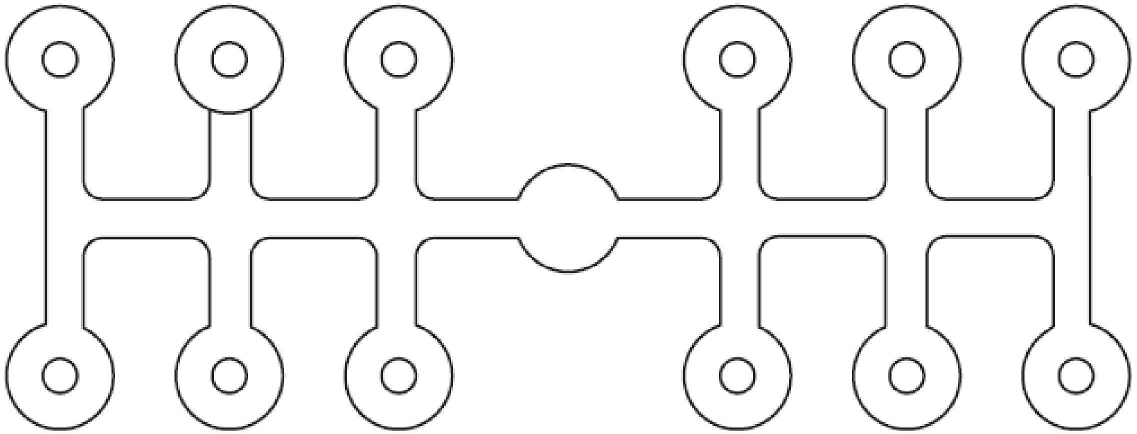
Types of Pattern

Loose Pieces Pattern: Some single piece patterns are made to have loose pieces in order to enable their easy withdrawal from the mold. These pieces form an integral part of the pattern during molding. After the mold it completes, the pattern is withdrawn leaving the pieces in the sand, which are later withdrawn separately through the cavity formed by the pattern.



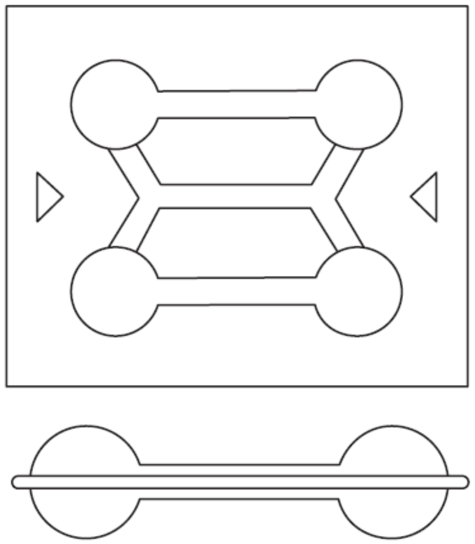
Types of Pattern

Gated Pattern: In a mass production, where many castings are required, gated pattern may be used. Such patterns are made of metal to give them strength and to eliminate any warping tendency. The connecting parts between the patterns from the gates or runners for the passage of molten metal into the mold cavity, are the integrated parts of these patterns.



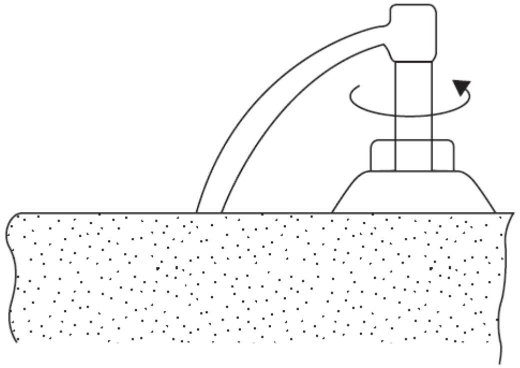
Types of Pattern

Match Plate Pattern: Match plates provide a substantial mounting for patterns and are widely used with machine molding. In the Figure 20.8, a match plate is shown upon which are mounted the patterns for two small dumb bells. It consists of a flat metal or wooden plate, to which the patterns and gates are permanently fastened. On either end of the plate are holes to fit into a standard flask.



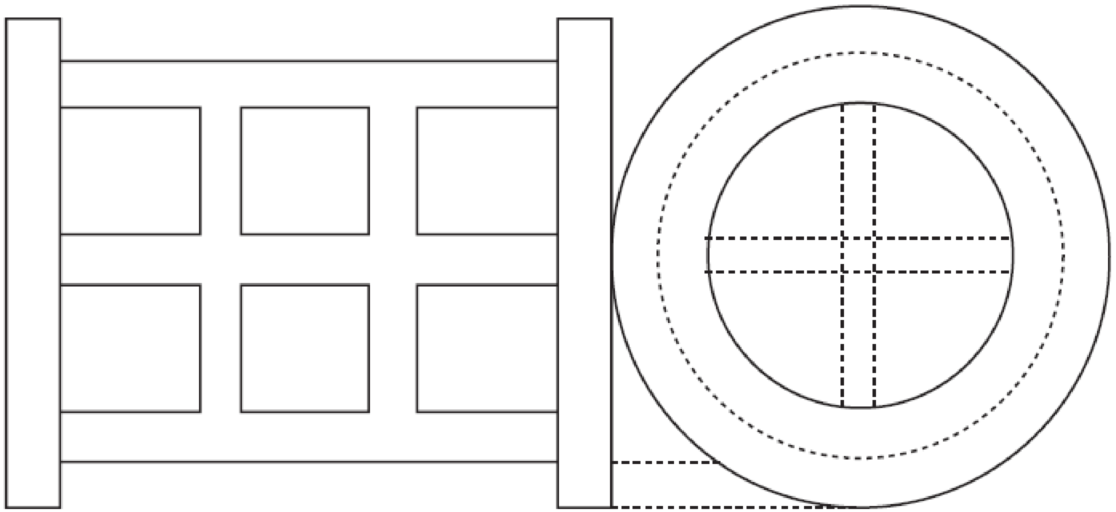
Types of Pattern

Sweep Pattern: Sweeps can be used for preparing molds of large symmetrical castings of circular cross-section. The sweeping equipment consists of a base, suitably placed in the sand mass, a vertical spindle and a wooden template, called a sweep. The sweep may have a different shape of casting desired. The sweep is rotated about the spindle to form the cavity. Then the sweep and spindle are removed. The filling sand patches the hole of the spindle. Cores are fitted, as required.



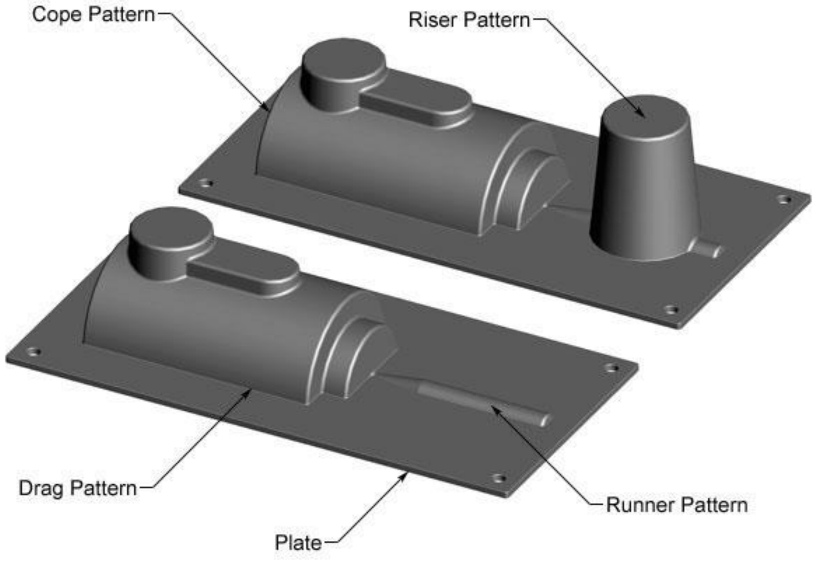
Types of Pattern

Skeleton Pattern: Skeleton pattern requires a large amount of wooden work. It is used for large size casting. A pattern consists of a wooden frame and strips, called skeleton pattern. It is filled with loam sand and rammed properly, and surplus sand is removed. Both halves of the pattern are symmetrical



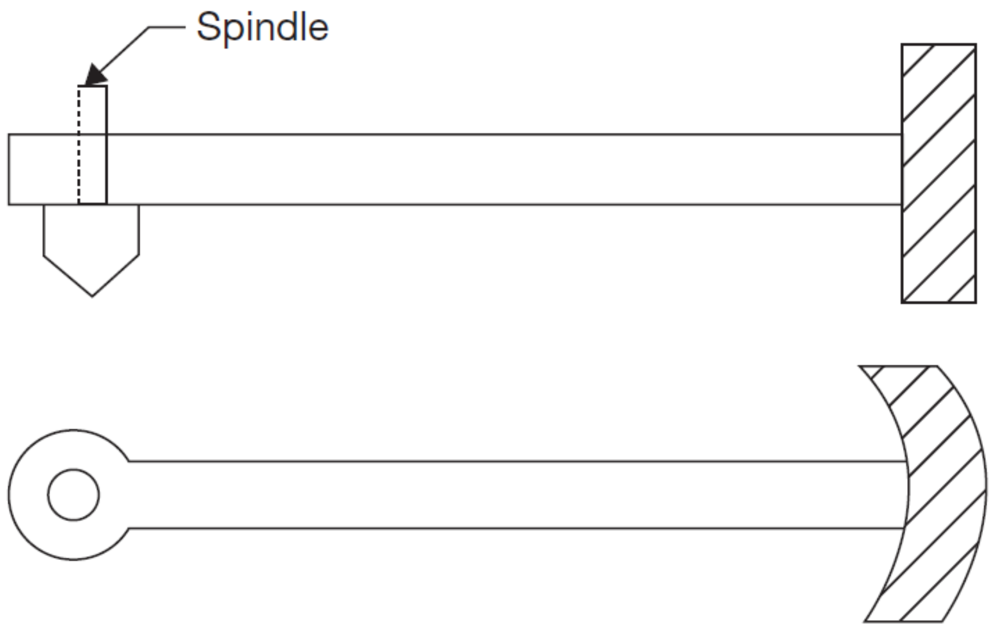
Types of Pattern

Cope and Drag Pattern: Cope and drag pattern is used for heavy casting which is difficult to handle in a single piece. This pattern is made in two parts in cope and drag and finally assembled together to form a complete mold cavity.



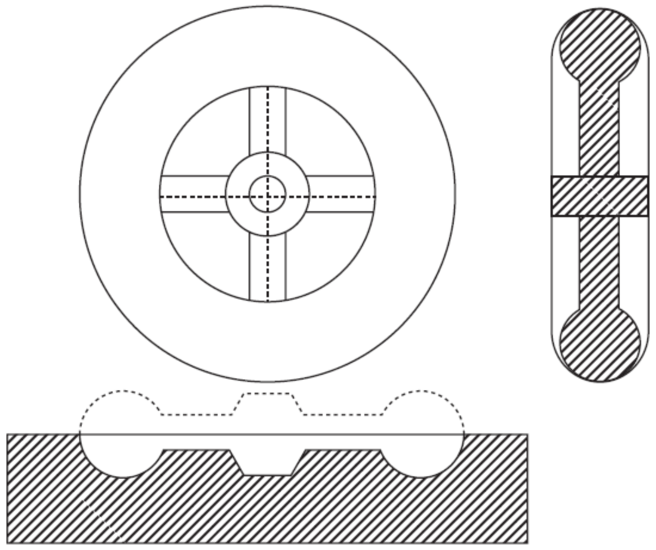
Types of Pattern

Segmental Pattern : A segmental pattern is a pattern used to make circular or round castings, such as rings, wheels, gear blanks, and rims, using a segment of wood or metal instead of a solid pattern. This pattern is frequently used for circular castings.

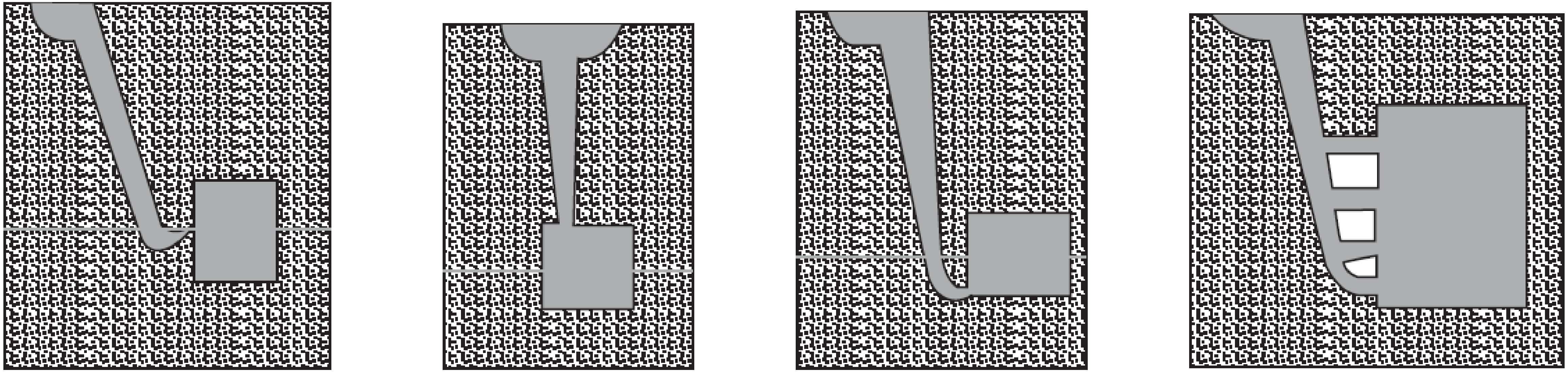


Types of Pattern

Follow Board Pattern: Follow board is a wooden board, which is used to support a thin section pattern. The pattern may have a cavity shape or projection shape. Due to thin section during ramming, there is a chance of breaking of pattern, therefore, a support of the same shape follow board is required.

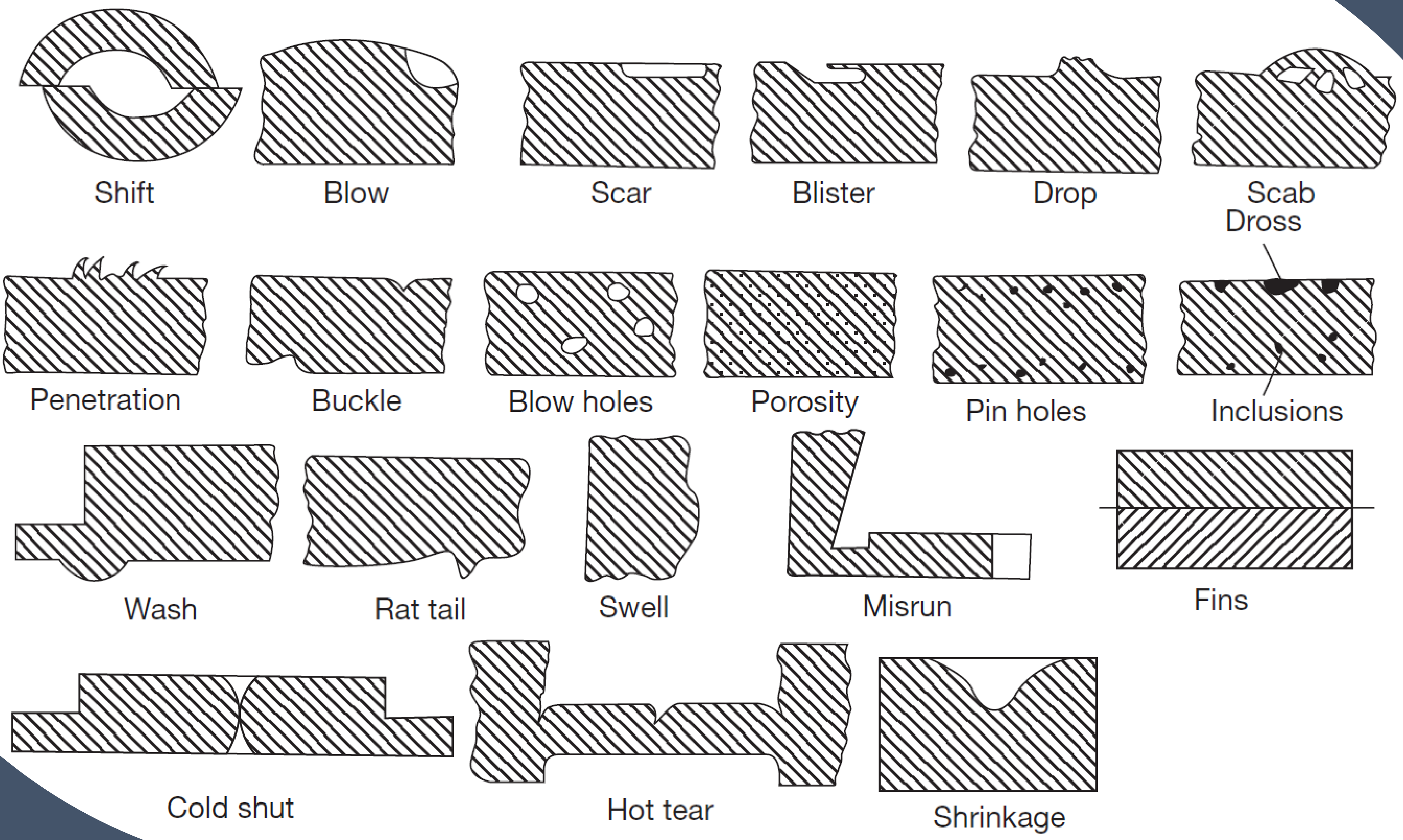


Types of Gates



(a) Parting line gate (b) Top gate (c) Bottom gate (d) Side gate

Casting Defects



Casting Defects

Shifts: Misalignment of flask, i.e., cope and drag and mismatching of core cause shifts. These can be prevented by proper alignments and placing of the core.

Blow: Blow is a small, round holes appearing at the surface of the casing covered with a thin layer of metal.

Scar: It is a shallow blow, which is usually found on a flat casting surface.

Swell: Swell is an enlargement of the mold cavity due to metal pressure. It caused due to defective ramming of the mold. To avoid swells, the sand should be rammed properly and evenly.

Blister: This is scar covered by a thin layer of a metal.

Casting Defects

Drop: When the upper surface of the mold cracks and pieces of sand fall into the molten metal, this defect occurs. This is caused by low strength and soft ramming of sand, insufficient fluxing of molten metal and insufficient reinforcement of sand projections in the cope.

Scab: Liquid metal penetrates the surface layer of sand. Scabs can be identified as rough, irregular projection on the surface containing embedded sand. They are caused using too fine sand, sand having low permeability and high moisture content, and by uneven mold ramming or slow running of molten metal over the sand surface thereby producing intense local heating.

Porosity: Porosity is entrapped gases in the form of fine small bubbles throughout the casting.

Casting Defects

Metal Penetration and Rough Surface: This defect appears as an uneven and rough external surface of the casting. The metal penetration between the sand grains occurs due to low strength, large grain size, high permeability and soft ramming of sand.

Buckle: This defect is similar to the rat-tail but differs from it in the sense that it is in the form of V-shaped depression in the surface of the casting.

Blowholes: Blowholes are smooth, round holes appearing in the form of a cluster of a large no. of small holes below the surface of a casting. Possible causes are excess moisture in the molding sand, moisture on chills, chaplets, and insufficiently baked and improperly vented core.

Casting Defects

Pinholes: Pinholes are numerous small holes, usually less than 2 mm, visible on the surface of the casting cleaned by shot blasting. They are caused by sand with high moisture content, absorption of hydrogen or carbon monoxide gas or when steel is poured from wet ladles.

Inclusions: Inclusions is mixing of foreign particles such as sand and slag in the casting.

Wash: It is a low projection on drag surface of a casting starting near the gate. This results due to the displacement of sand by the high-velocity metal in the bottom part of gating.

Rat-tails: These defects appear as streaks or slight ridges on large flat surfaces. They occur due to the expansion of sand by the heat of the molten metal..

Casting Defects

Mis-run: A mis-run is the incomplete filling of the mold that results when the metal lacks fluidity or temperature.

Fins: Fins usually occur at the parting line of the mold or core sections due to improper clamping of the flask. The remedy is to give sufficient weight on the top for proper assembly of the flasks and molds.

Cold Shut: It is the type of mis-run occurs in the center of a casting having gates at its two sides. Imperfect fusion is a result of from low-temperature of two streams of metal.

Hot Tears: They are internal and external cracks having a ragged edge occurring immediately after the metal has solidified.

Shrinkage Cavity: Shrinkage cavity is a void or depression in the casting caused mainly by uncontrolled solidification of the metal. The may also be produced if pouring temperature is high.

BASIC MECHANICAL ENGINEERING

Manufacturing Process (Welding)

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Welding

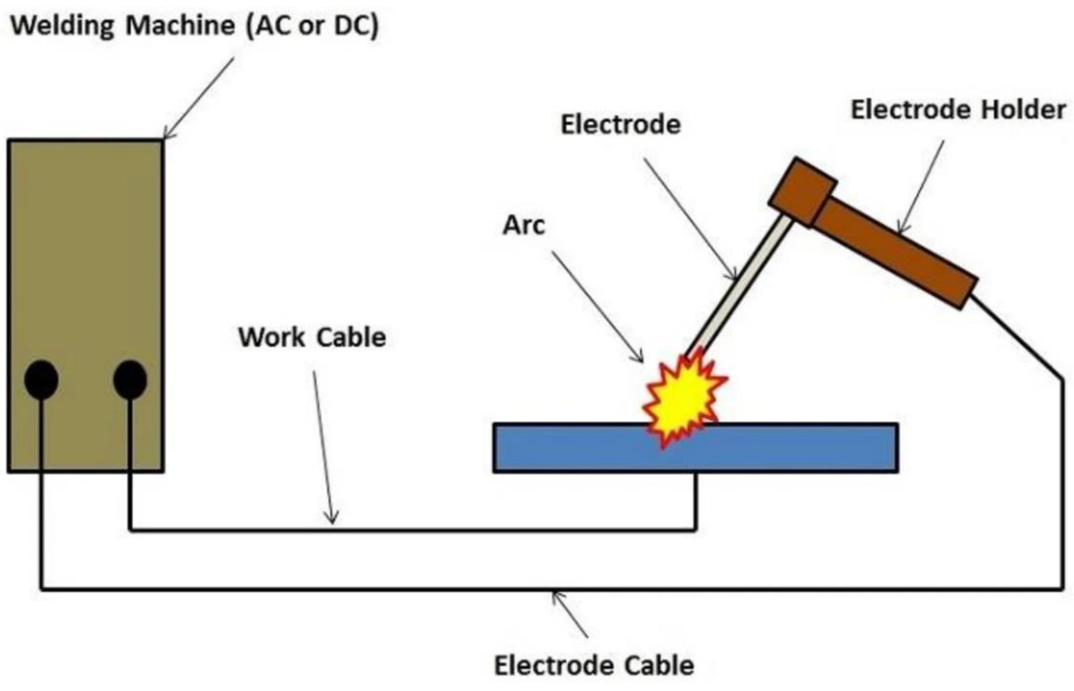
Welding is the process of joining similar or dissimilar metals with the help of heat and pressure or heat alone or pressure alone with or without filler metal.

Classification of welding

- Welding
  - Arc welding
  - Resistance welding
  - Gas welding
  - Thermochemical Welding
  - Radiant energy welding

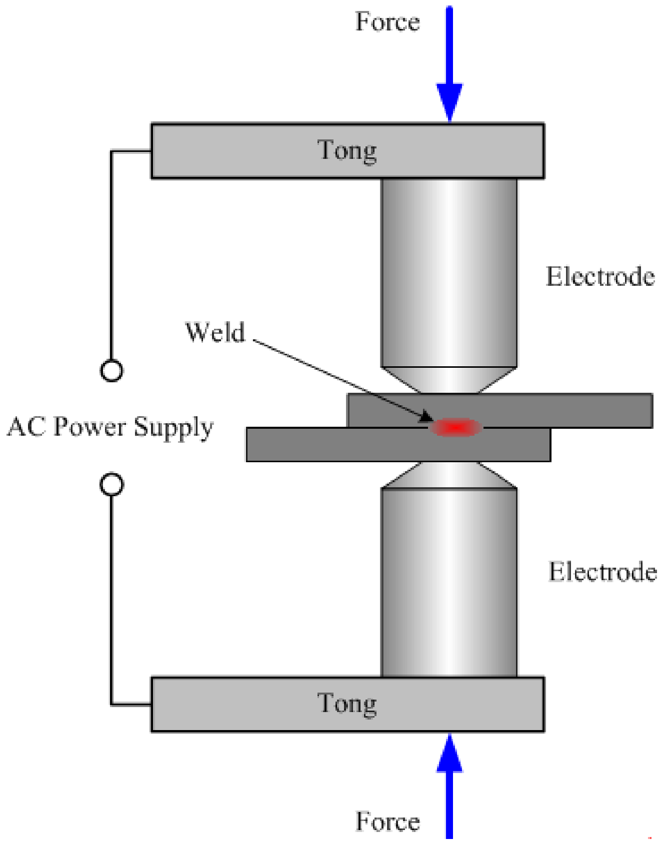
Arc welding

Arc welding is a welding process that is used to join metal to metal by using electricity to create enough heat to melt metal, and the melted metals, when cool, result in a binding of the metals.



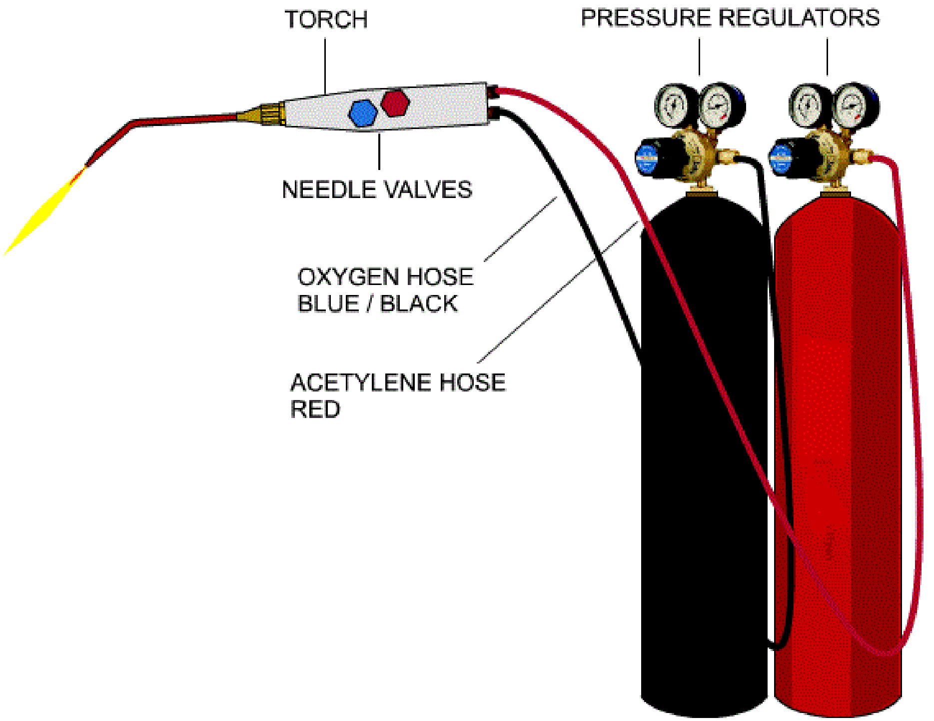
Resistance welding

Resistance welding is the joining of two metals using pressure and electrical current, for a set length of time, through the area of the metal to be joined



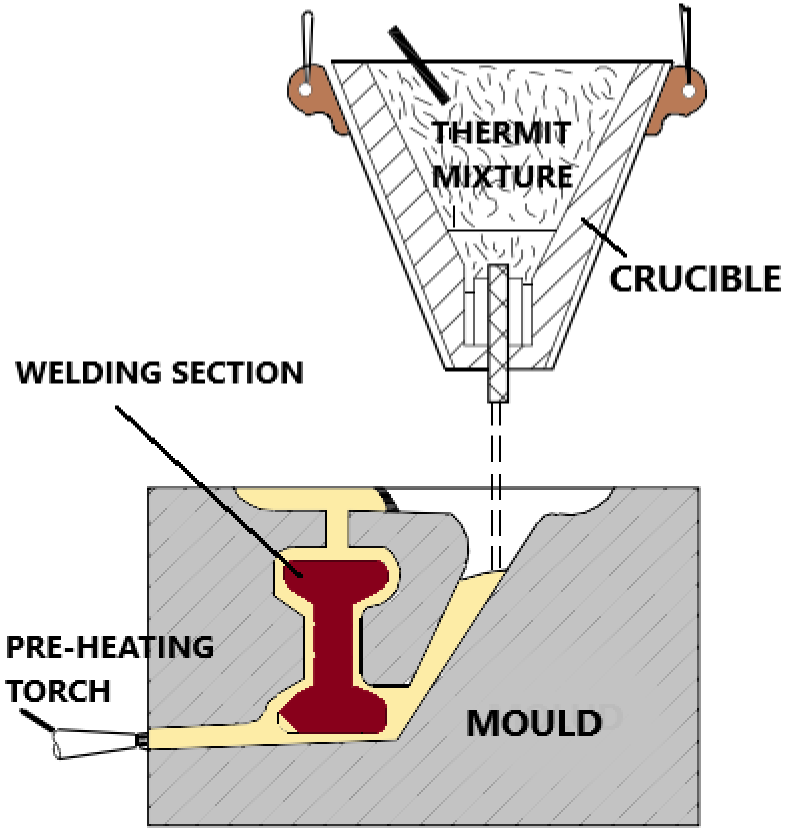
Gas welding

Gas welding is a process that uses heat generated from burning a combination of different gases to melt and fuse metals. Although it is possible to join the metal workpieces without any additional filler material, the use of filler rods is encouraged to guarantee strong and lasting welds.



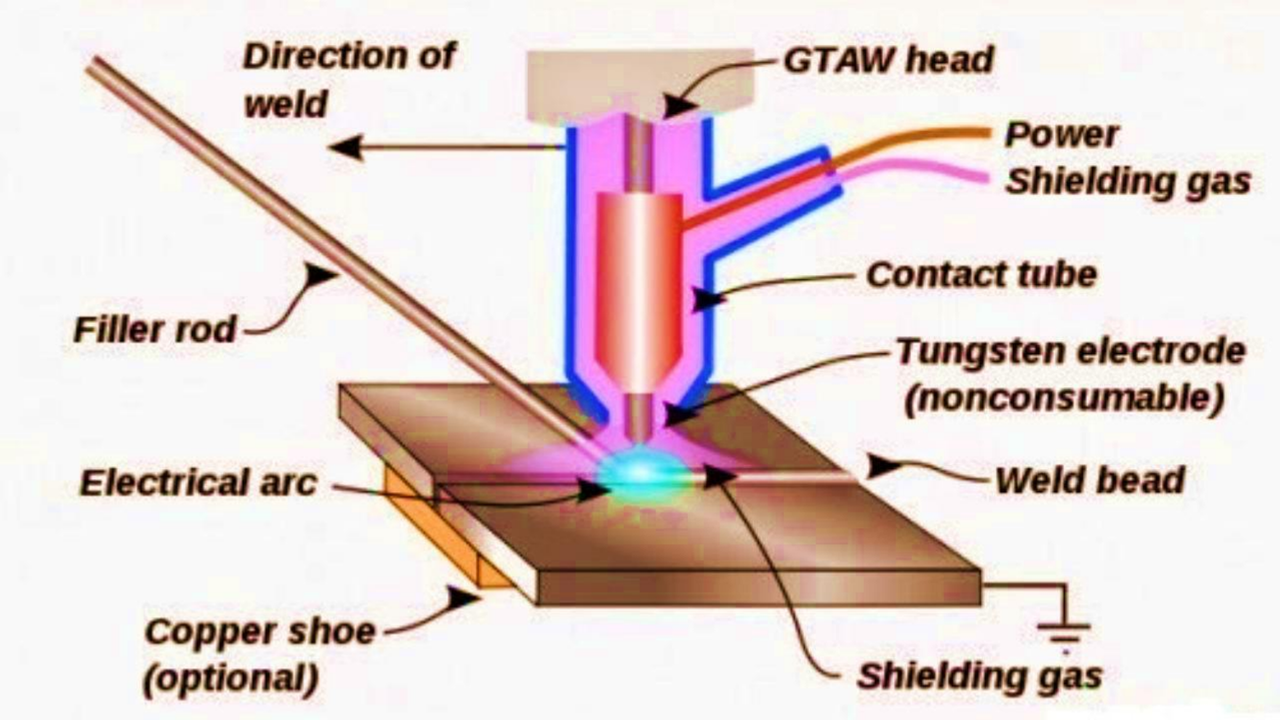
Thermochemical welding

Thermochemical welding, also known as thermit welding, is a chemical welding process that uses an exothermic reaction to create heat. The reaction involves the combustion of Thermit, a mixture of aluminum powder and iron oxide.



Radiant energy welding

Radiant energy welding is a type of welding process that uses electromagnetic waves, such as ultraviolet, infrared, or visible light, to heat the workpiece and fuse the material together.



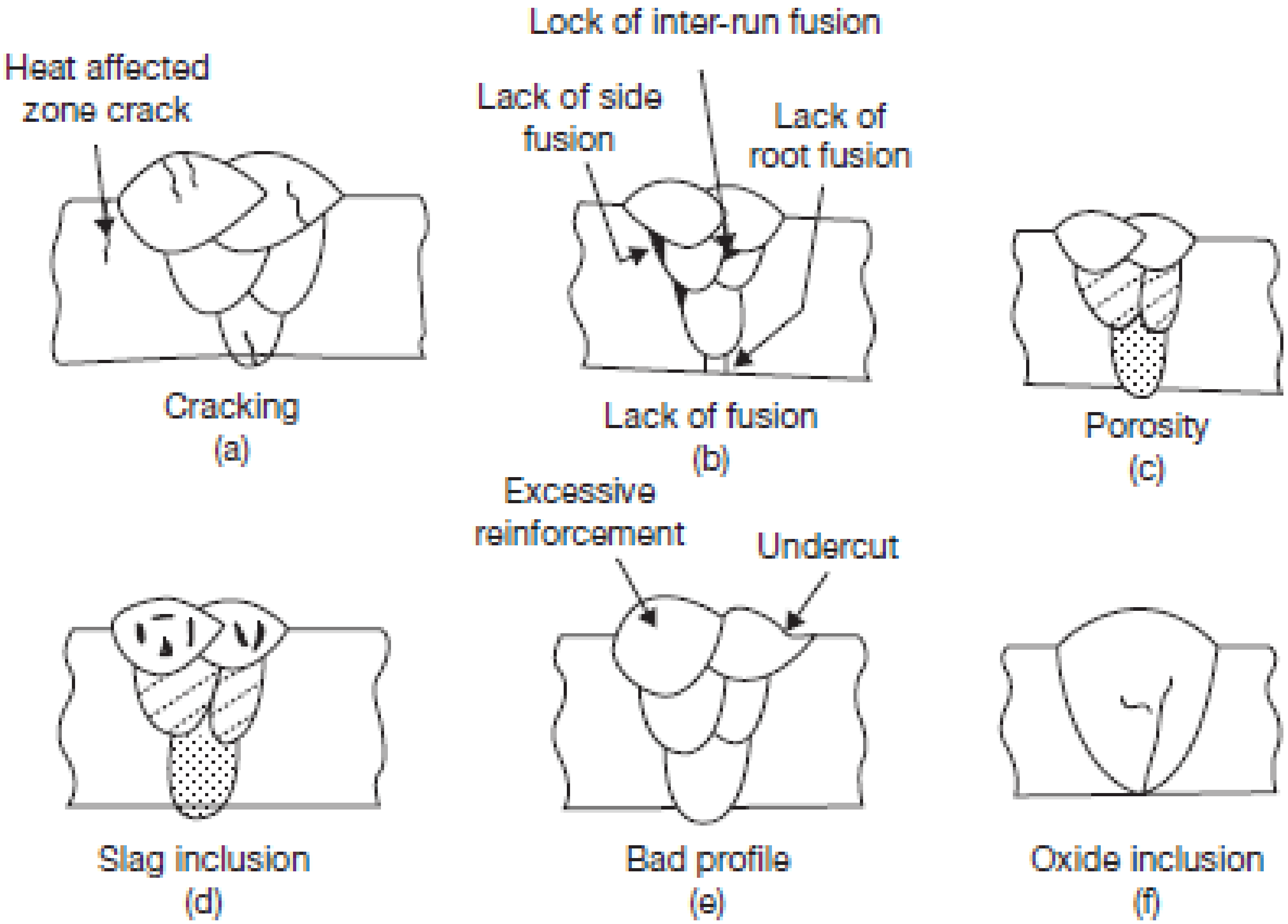
Advantages

- Welding establishes strong, durable, and permanent joint links.
- It is a simple process that results in a great finish.
- The technique, when used with filler material, produces a stronger weld than the base material.
- It can be performed at any place.
- It is an economical and affordable process.
- It is used in various sectors like construction, automobile, and many more industries.

Disadvantages

- It is hazardous when performed under the safety and security guidelines.
- It is a difficult task to dismantle the joined material through welding.
- Requires skilled labor and electric supply.

Welding Defects



Welding Defects

Cracks: Cracks occur in the welded joint due to improper welding and solidification of different metals. Cracks may be of following types.

Micro Cracks: Very small Cracks, which can be seen with the help of microscope only.

Macrocracks: These cracks can be seen by naked eye.

Lack of Fusion: Wrong weld parameters, such as poor weld design, feed rate, welding speed, current, and voltage, lead the problem of fusion and penetration. A proper arc length, good weld design may prevent the problem of poor fusion and improper penetration.

Welding Defects

Porosity: Porosities are voids, holes or cavities of usually spherical shapes. It is caused by gas entrapped in weld metal during solidification, and chemical reactions during welding contaminates such as dirt, oil, grease, rust, paint, etc. Blowholes are voids of large size.

Slag Inclusion: Slag inclusion in the form of oxides, Sulphur, and flux in the weld causes poor strength and leads to corrosion in the metal. It occurs due to inadequate cleaning of the welding areas.

Spatter: Spatters are small bead thrown in all directions during welding. It occurs due to very large current and wrong electrode selection.

Distortion: Distortion is a result of the improper rate of heating and cooling in the weld zone or adjacent metal leading to the generation of stresses. Proper clamping and smaller diameter electrode may reduce the problem.

BASIC MECHANICAL ENGINEERING

Power Transmission Devices

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Introduction

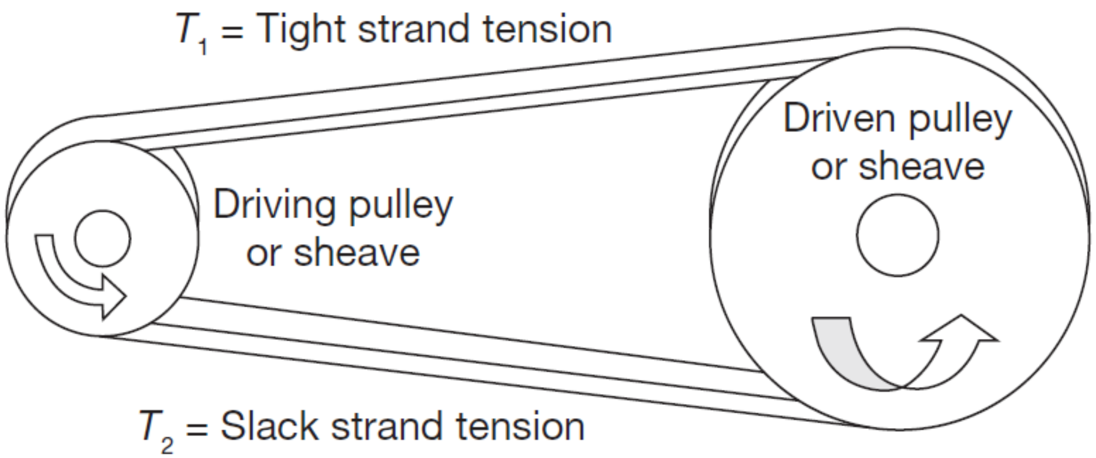
- Power transmission is a process to transmit motion from one shaft to another by using some connection between them like belt, rope, chain, and gears.
- To connect the shafts, mainly two types of connectors are used, one is flexible and other is rigid.
- In a flexible type of connection, there is a relative velocity between shaft and connectors due to slip and strain produced in the connectors.
- But in the case of rigid connection, there is no relative velocity between the connector and shaft.

Introduction

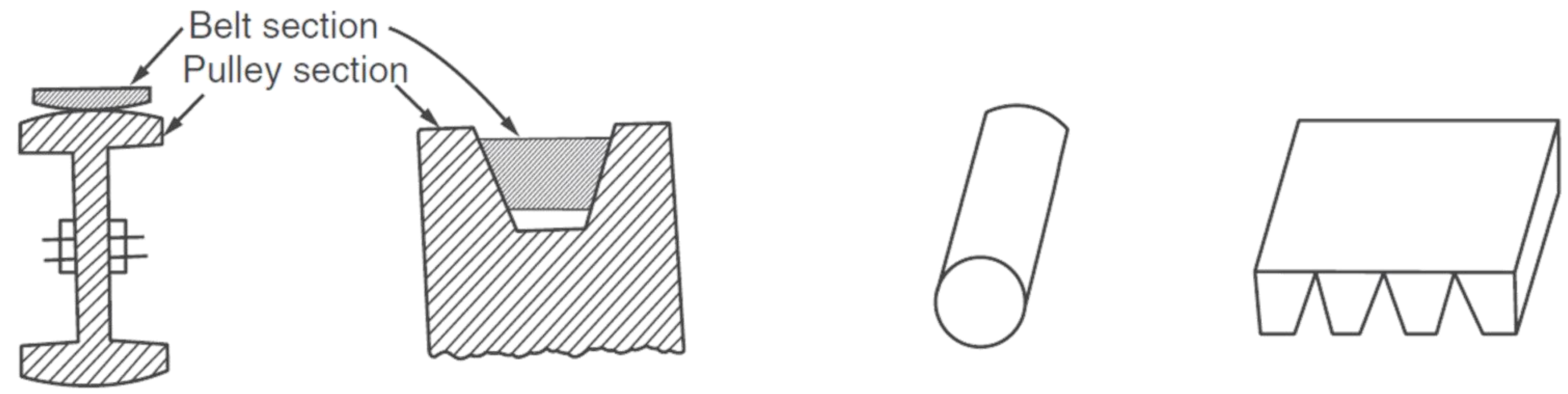
- Belt, rope, and chain are flexible connectors where gears are rigid connectors.
- Generally, belt, rope, and chain drives are used when the distance between the shafts are large and gears are used when the distance between the shafts is very small.
- The efficiency of a gear drive is much more than that of the belt, rope, chain drive due to the absence of slipping effect.

Belt Drive

- A belt drive is a mechanical system that uses an endless belt and pulleys to transmit power between two or more shafts, often at different distances.
- In belt drive, the velocity of two shafts can be varied by variation of diameter of the pulley on which belt is mounted.
- The effective radius of rotation of a pulley is obtained by adding half the belt thickness to the radius of the pulley.



Type of Belt Cross-sections



(a) Flat belt (b) V-belt (c) Round belt (d) Toothed belt

- In flat belt drive, the rim of the pulley is slightly crowned which helps to keep the belt running centrally on the pulley rim.
- For V-belt drive, grooves are made on the rim of the pulley for wedging action. The belt does not touch the bottom of the groove.
- Round belts are generally made of rubber. This type of belt is generally used for light loads, such as in a sewing machine or a vacuum cleaner.
- Timing belts or toothed belts use their teeth for power transmission, as opposed to friction. This configuration results in no slippage, and therefore, the driving and driven shafts remain synchronized

Velocity Ratio

Velocity ratio is the ratio of the speed of the driven pulley to that of the driving pulley.

Let N_1 is rotational speed of the driving pulley,

N_2 is rotational speed of the driven pulley,

D_1 is diameter of driving pulley,

D_2 is diameter of driven pulley,

t is the thickness of the belt.

$$V = \frac{\pi(D_1 + 2t)N_1}{60} = \frac{\pi(D_2 + 2t)N_2}{60}$$

i.e., $D_1 N_1 = D_2 N_2$; where t is very small in comparision to D, therefore it can be negelected.

$$V.R = \frac{N_2}{N_1} = \frac{D_1}{D_2}$$

Flat Belt Drives

Belts are classified into many types according to usage, position, shape like flat, v-belt, round ropes, etc., but Belt drives are different from the belts, these are described as the combination of pulleys according to their position and also their carrying or transmitting power from one pulley to another pulley. Flat belts drives are classified as:

(a) Open belt drive

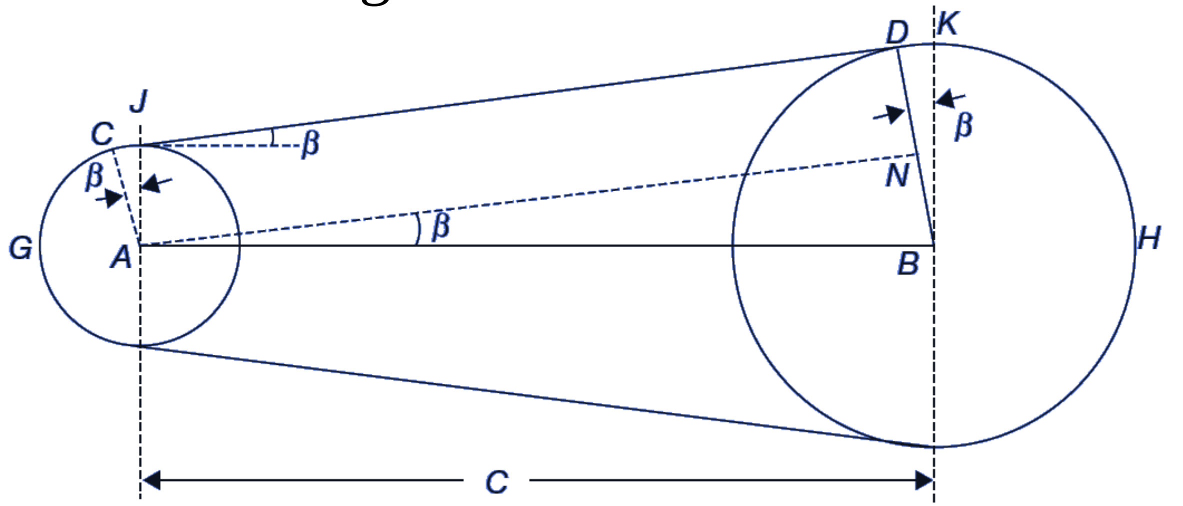
(b) Crossed belt drive

(c) Quarter turn belt drive

(d) Compound belt drive

Open Belt Drive

The open belt drive is used to provide the same direction of rotation to the driven shaft as the direction of rotation of the driving shaft.



Let L is length of belt for open drive,

r is the radius of the smaller pulley,

R is radius of larger pulley,

C is center distance between pulleys,

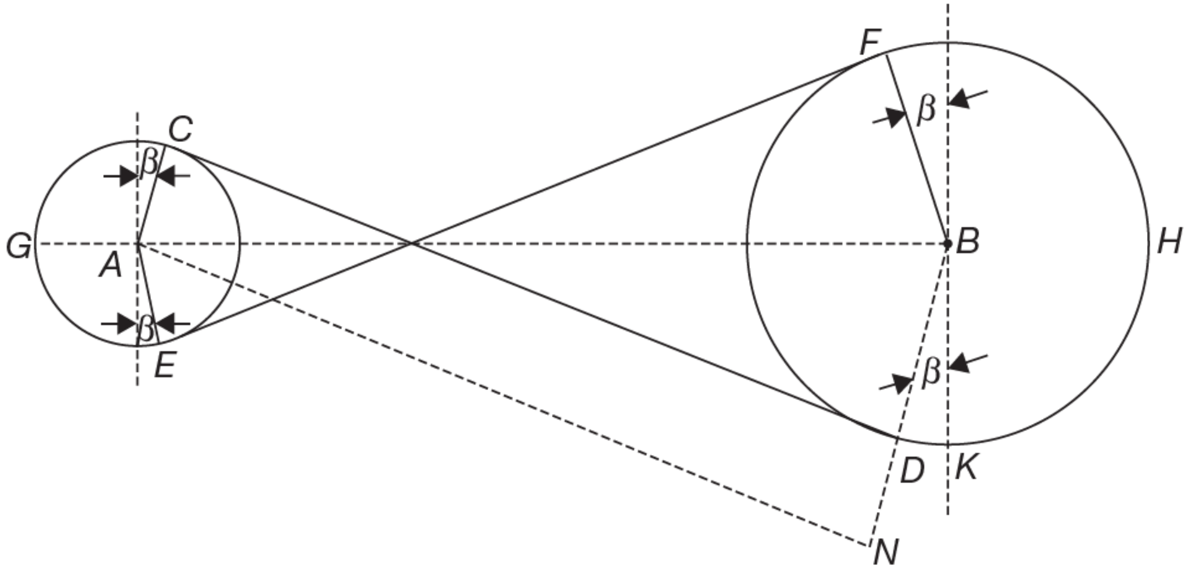
β is angle subtended by each common tangent on the center of the pulley (CD or EF),

AB is the line joining the centers of pulleys.

$$L = \pi(R+r) + 2C + \frac{(R-r)^2}{C}$$

Crossed Belt Drive

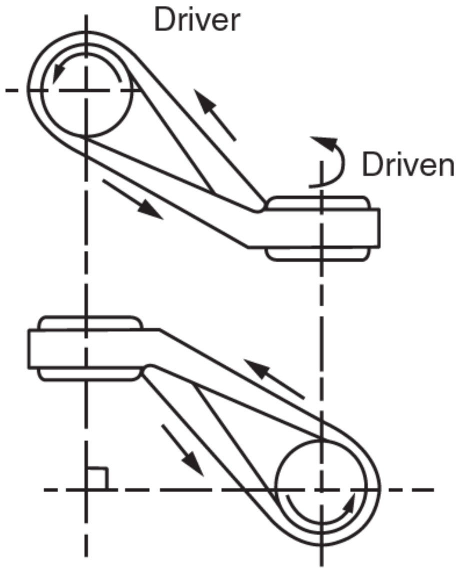
The cross-belt drive is used to provide reverse direction of rotation to the driven shaft as the direction of rotation of the driving shaft.

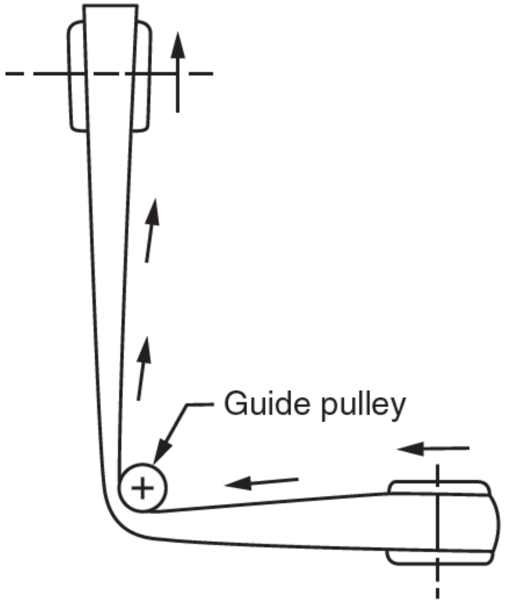


$$L = \pi(R + r) + 2C + \frac{(R + r)^2}{C}$$

Quarter Turn Drive

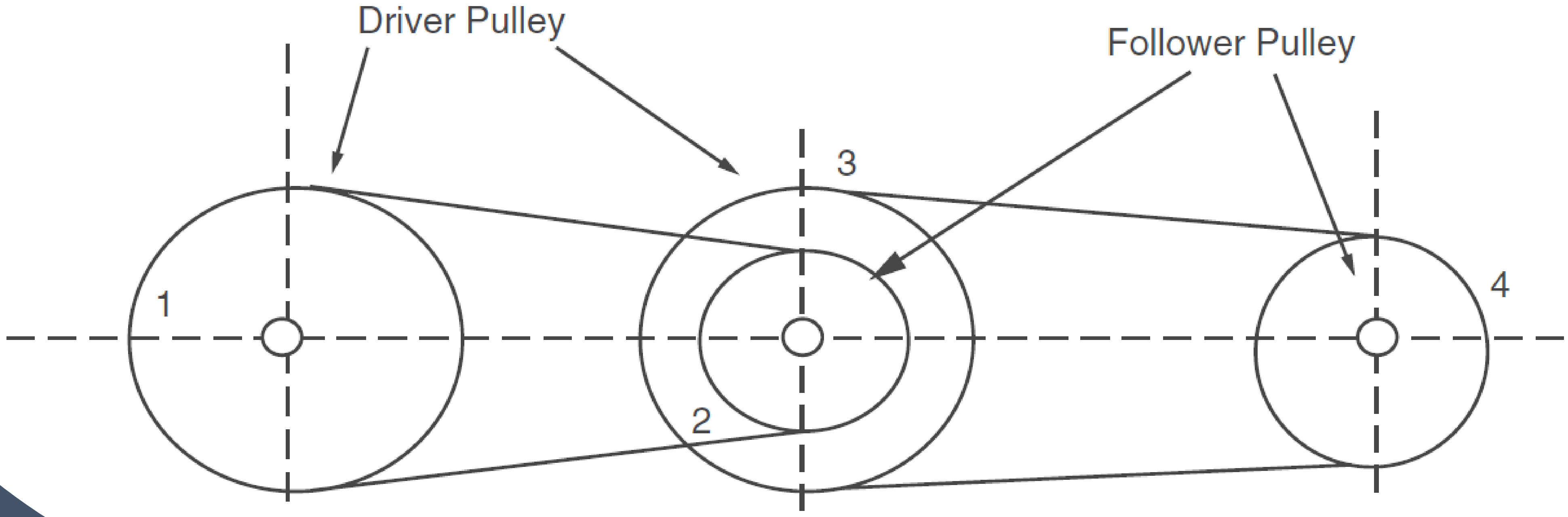
In quarter turn drive, the two axes of pulleys are the right angle to each other. These drives are used in industries for parallel power to tangential power transmission.





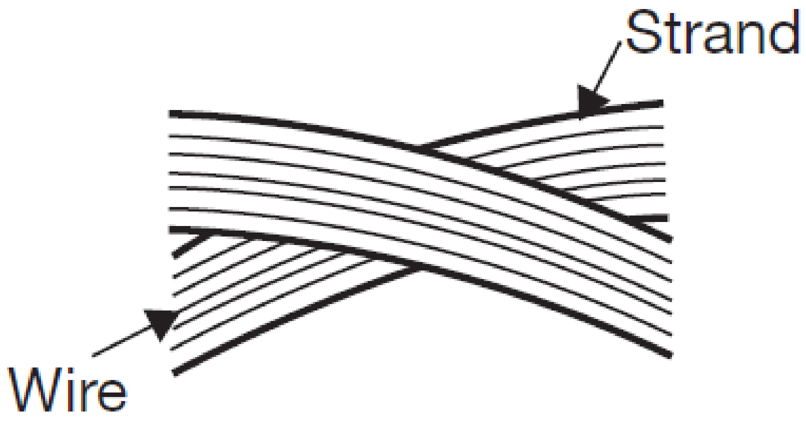
Compound Belt Drives

In these, the axes of pulleys are not parallel to each other compound belt drives and these compound belt drives are used to transmit power in any direction and it uses a number of pulleys.



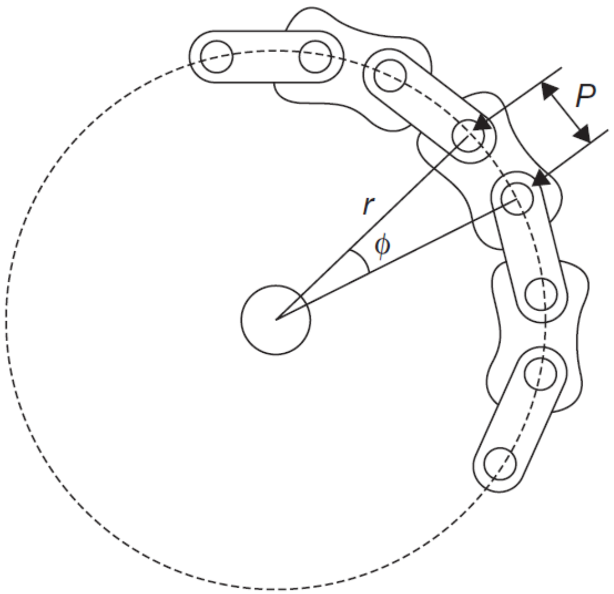
Rope Drive

Rope drive is very similar to belt drive. It is classified as (i) Fiber ropes, and (ii) Wire ropes. Fiber ropes are made of manila or cotton. Wire ropes are made of steel wires. A group of wires makes a strand and strands make a rope



Chain Drive

- To overcome the problem of slip in belt drive or rope drive, chain drive is used.
- The velocity ratio in chain drive remains constant. But, chain drive is heavier than the belt drive and there is gradual stretching in its strength.



Let T is a number of teeth on a sprocket,
φ is angle subtended by a chord of the link at the center.
r is the radius of the pitch circle.

$$\frac{p}{2} = r \sin \phi / 2 = 2r \sin \frac{1}{2}\left(\frac{360^0}{T}\right) = 2r \sin \frac{180^0}{T}$$

$$\text{or,} \quad r = \frac{p}{2 \sin \frac{180^0}{T}} = \frac{p}{2} \operatorname{cosec} \frac{180^0}{T}$$

Gear

Gear is a rotating circular machine part having teeth which mesh with another toothed part to transmit rotational power, speed, torque, direction of rotating axis.

Gears may be classified into five main categories: Spur, Helical, Bevel, Hypoid, and Worm.

Type of Gear

Spur gear

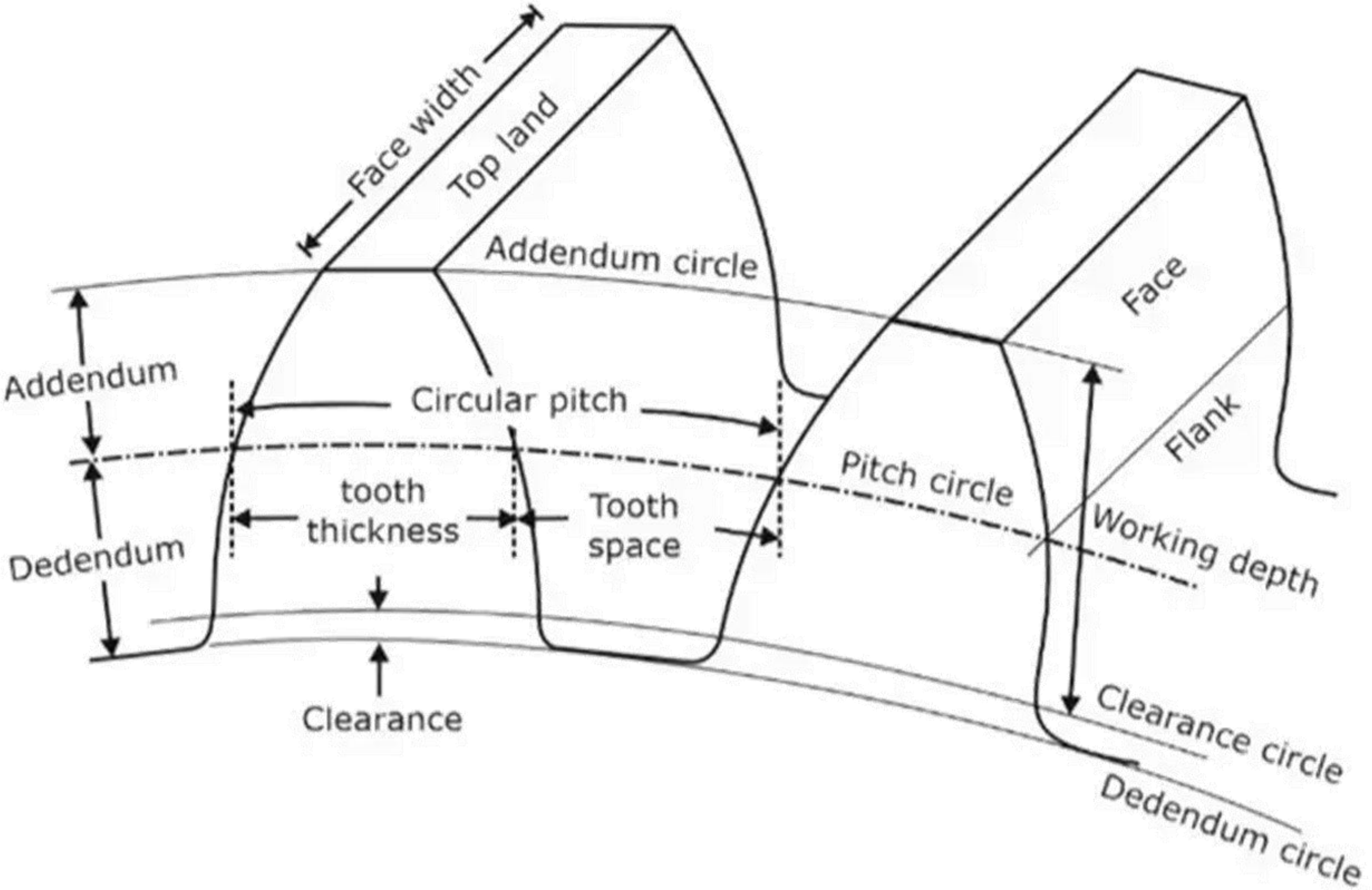
Helical gear

Hypoid gear

Bevel gears

worm gears

Nomenclature of Gear



GEAR TERMINOLOGY

Pitch Circle: The circle passing through the point of contacts of two gears is known as pitch circle.

Pitch Diameter, D: Diameter of pitch circle is known as pitch diameter.

$$D = \frac{N}{P_d} = \frac{N \times P_c}{\pi}$$

Circular Pitch, Pc: It is the distance measured along the circumference of the pitch circle from a Point on one tooth of the corresponding point on the adjacent tooth.

$$P_c = \frac{\pi D}{N} = \frac{\pi}{P_d}$$

Diametral Pitch, Pd: It is the number of teeth per unit length of the pitch circle diameter.

$$P_d = \frac{T}{D}$$

GEAR TERMINOLOGY

Module, m: It is the ratio of pitch diameter to the number of teeth.

$$m = \frac{D}{T} = \frac{1}{P_d} = \frac{P_c}{\pi}$$

Gear Ratio: It is the ratio of a number of teeth on gear and pinion.

$$G = \frac{T}{t}$$

Velocity Ratio: It is the ratio of the angular velocity of the driving gear to driven gear.

$$VR = \frac{\omega_1}{\omega_2} = \frac{N_1}{N_2} = \frac{D_2}{D_1} = \frac{T_2}{T_1}$$

Here, subscripts 1 and 2 are used for driving and driven gears, respectively.

GEAR TERMINOLOGY

Addendum Circle: It is a circle passing through the tips of the teeth.

Addendum: It is the radial height of tooth above the pitch circle. Its standard value is one module.

Dedendum Circle: It is a circle passing through roots of the teeth.

Dedendum: It is a radial depth of a tooth below the pitch circle.

Full Depth of Teeth: It is the total depth of the tooth space, i.e., Full depth = Addendum + Dedendum

Working Depth of Teeth: The maximum depth at which a tooth penetrates into tooth space of the mating gear is known as working depth of teeth.

GEAR TERMINOLOGY

Space Width: It is the width of the space between two consecutive teeth on pitch circle.

Tooth Thickness: It is the thickness of the tooth measured along the pitch circle.

Backlash: It is the difference between the space width and the tooth thickness along the pitch circle.

Face Width: It is the length of tooth parallel to the gear axis.

Top Land: It is the surface of the top of the tooth.

GEAR TERMINOLOGY

Bottom Land: The surface of the bottom of the tooth between the adjacent fillets.

Face: It is the tooth surface between the pitch circle and the top land.

Flank: It is the curved portion of the tooth flank at the root circle.

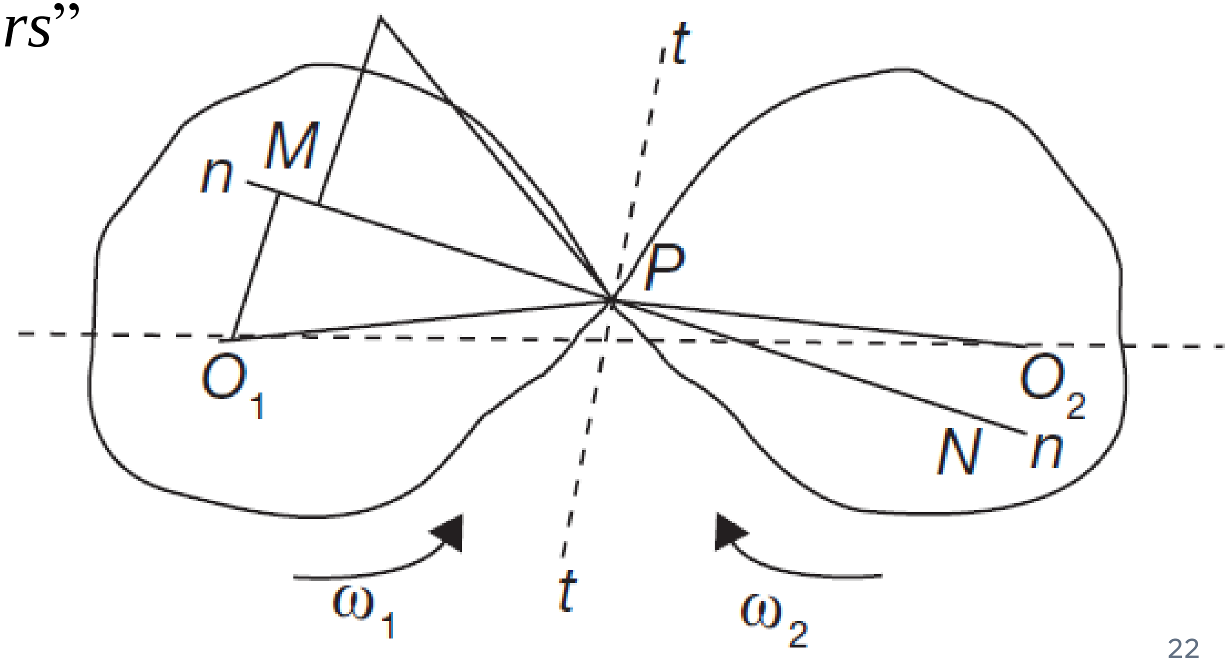
Pressure Angle, φ: The angle between the pressure line and the common tangent at the pitch point is known as the pressure angle or angle of obliquity.

Path of Contact or Contact Length: Locus of the point of contact of teeth of two mating gears from the beginning of the engagement to the end of engagement is known as the path of contact or the contact length.

LAW OF GEARING

The law of gearing gives the condition for the tooth profiles for constant angular velocity for two mating ears, which can be explained as: "*If angular velocities of two mating gears remain constant, the common normal at the point of the two teeth should always pass through a fixed point P which divides the line joining the centers in the inverse ratio of angular velocities of the gears*"

$$\frac{\omega_1}{\omega_2} = \frac{O_2N}{O_1M} = \frac{O_2P}{O_1P}$$



BASIC MECHANICAL ENGINEERING

GEAR

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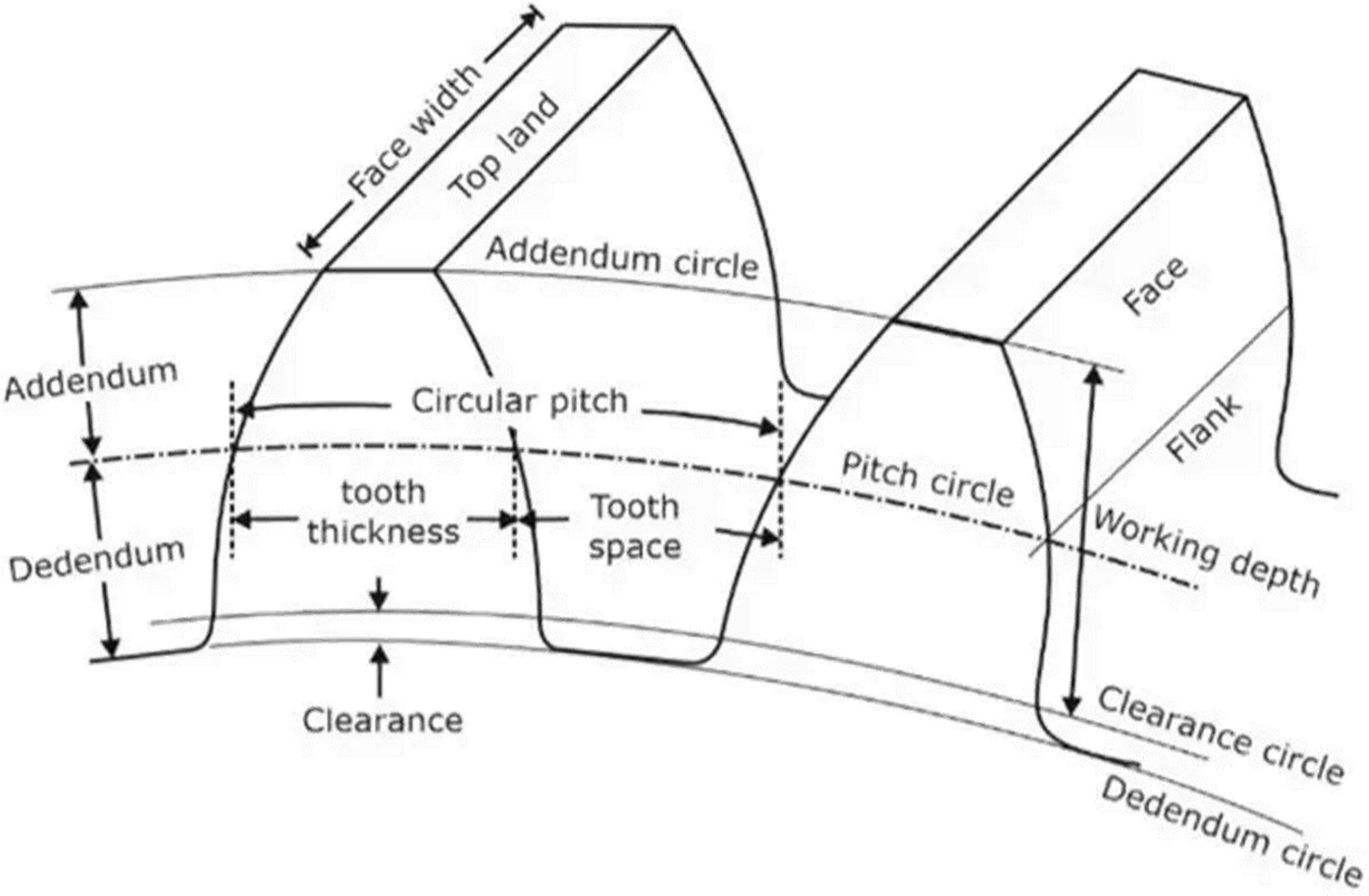

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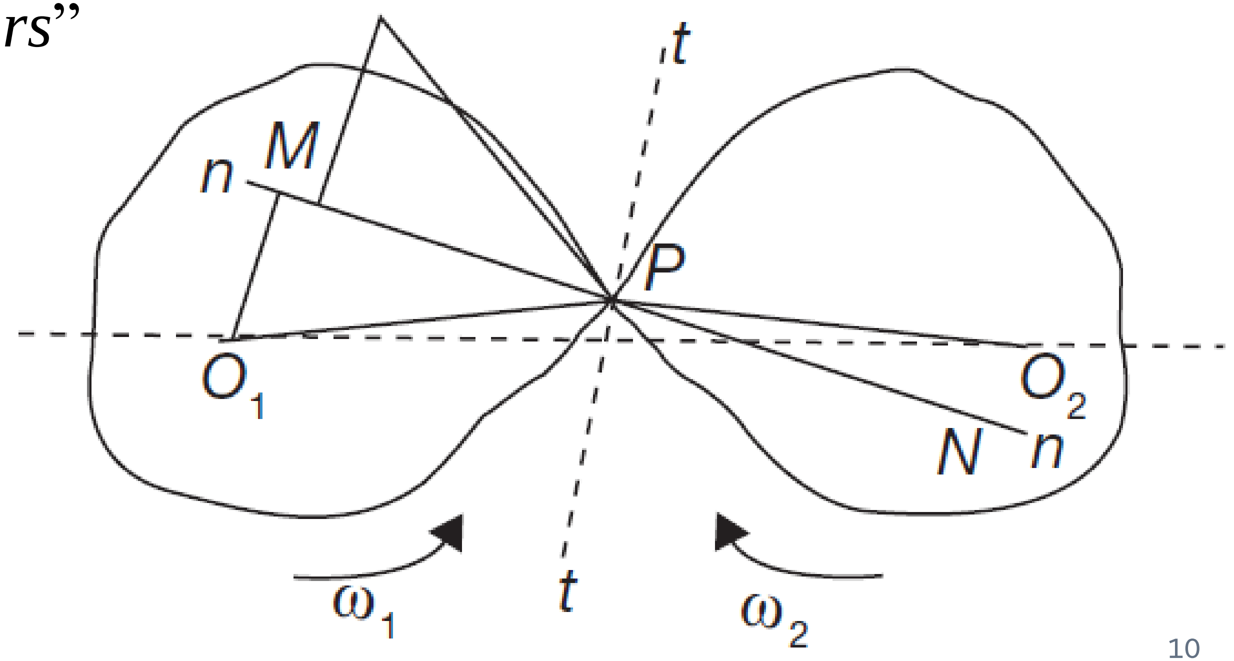

BASIC MECHANICAL ENGINEERING

CLUTCH & BRAKES

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Introduction

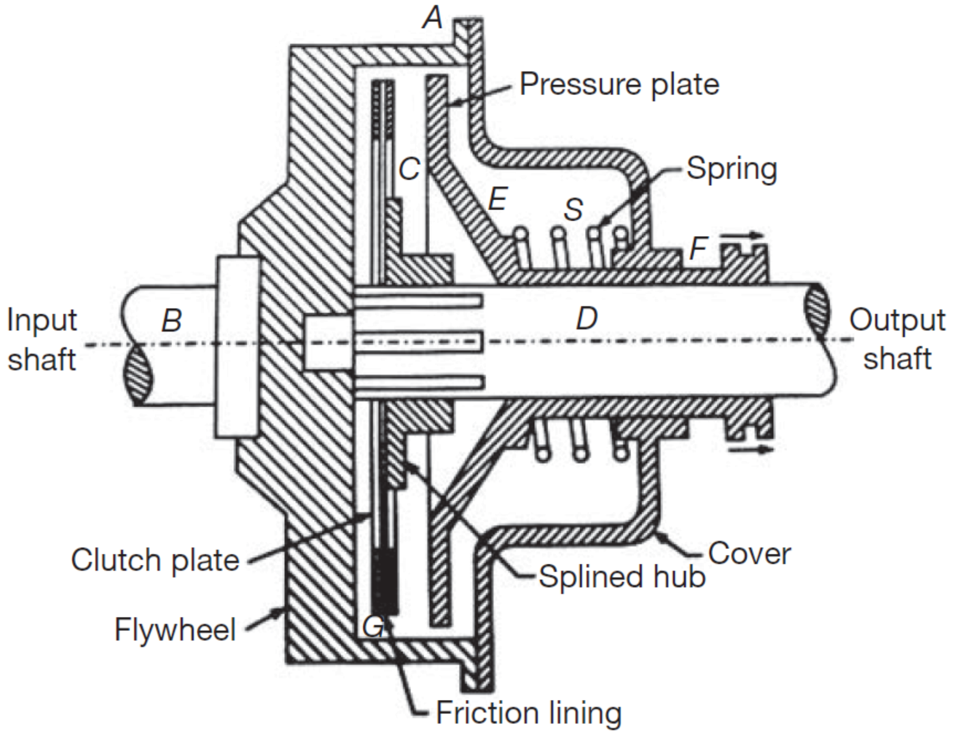
Clutch is a device which is used to engage and disengage the driven shaft from driving shaft during the motion to change the gears meshing without stopping the driving shaft. Its operation is based on the friction between two surfaces; friction torque is applied by the driving shaft on the driven shaft.

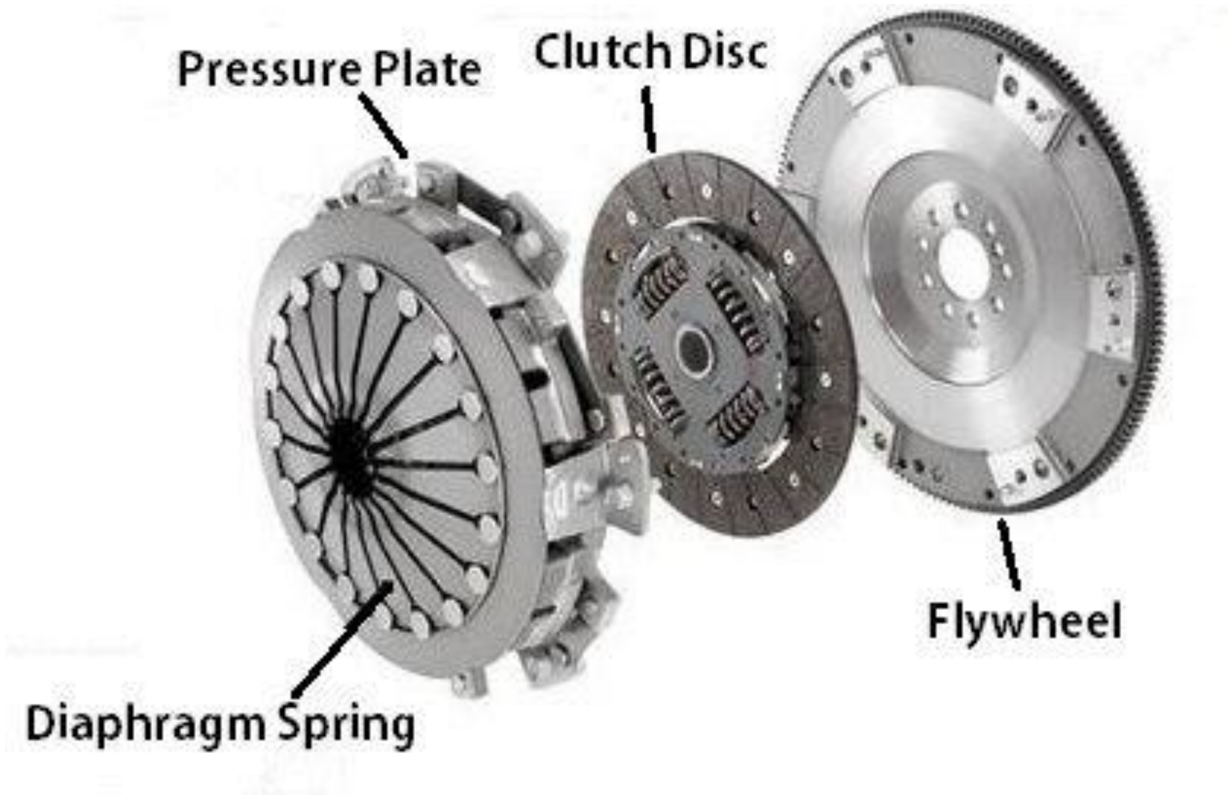
Clutch may be classified as:

1. *Single plate clutch or disc clutch.*
2. *Multi-plate disc clutch.*
3. *Conical clutch.*
4. *Centrifugal clutch.*

Single Plate Clutch

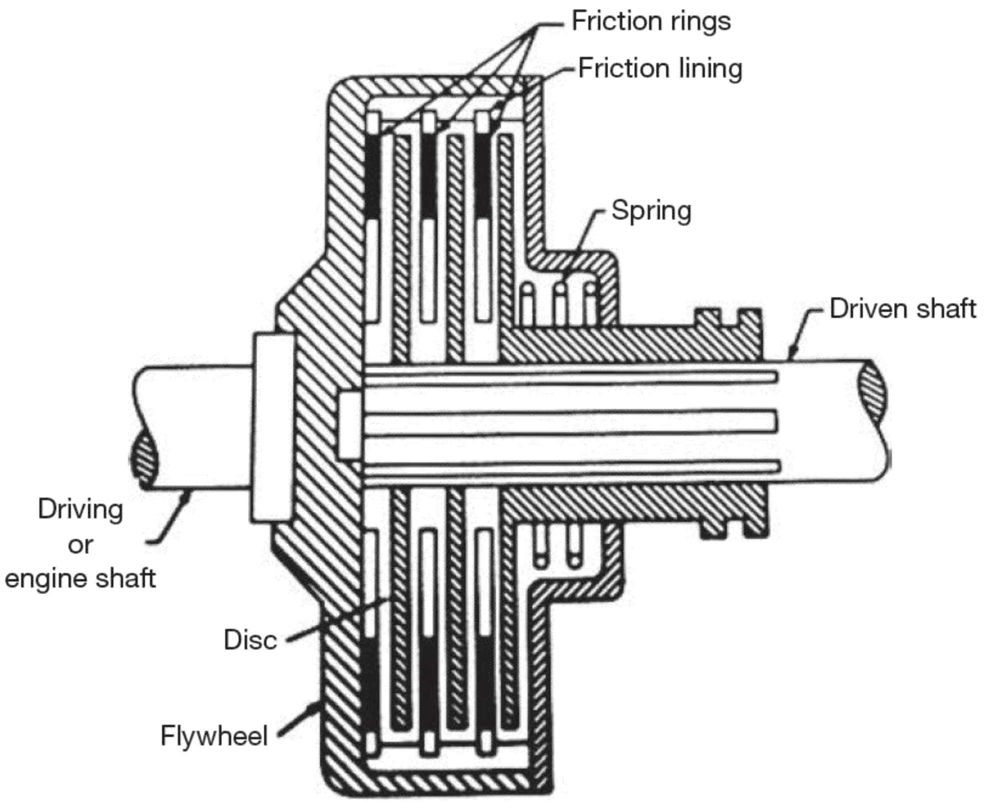
A single plate clutch is a type of friction clutch that uses one friction plate to transfer power from the engine to the transmission in vehicles and machinery.





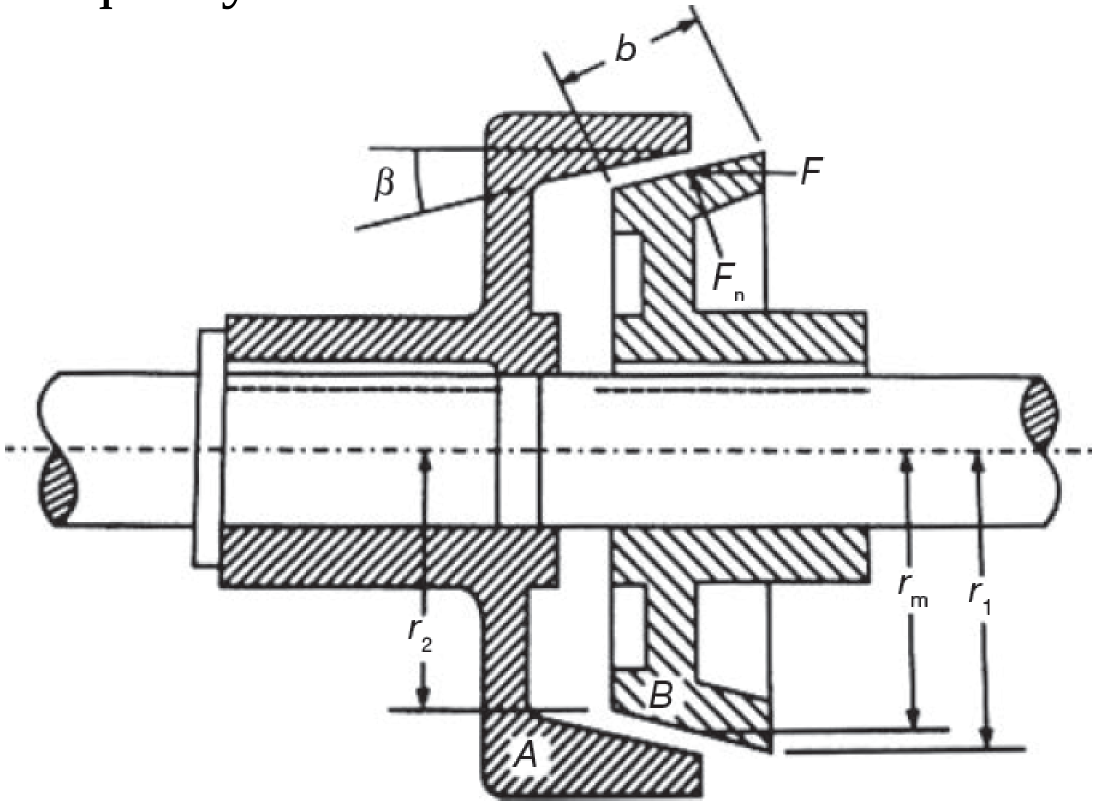
Multi-plate Disc Clutch

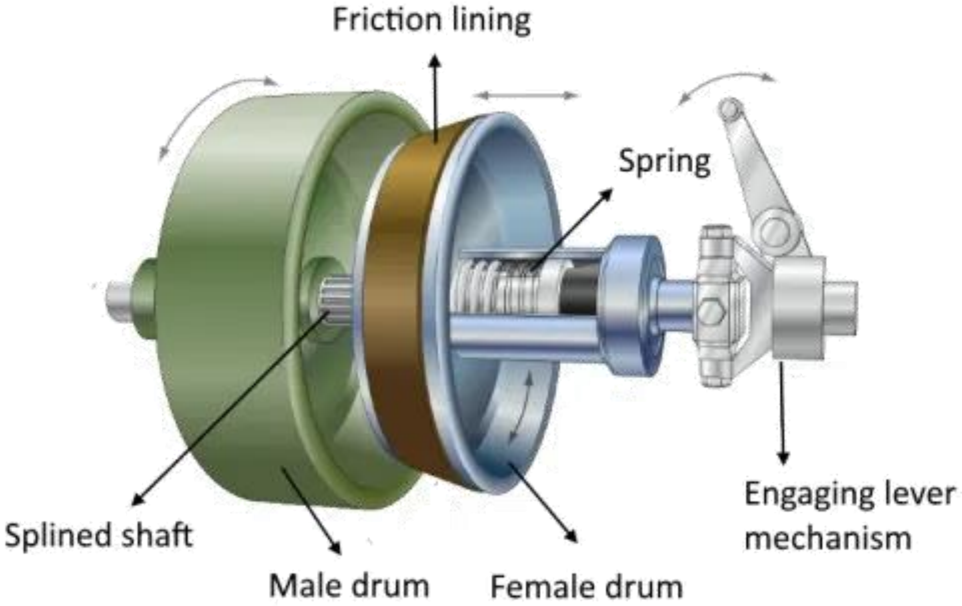
The function of multi-disc clutch is similar to the single plate clutch but the number of discs in the multi-disc clutch is more than one.



Cone Clutch

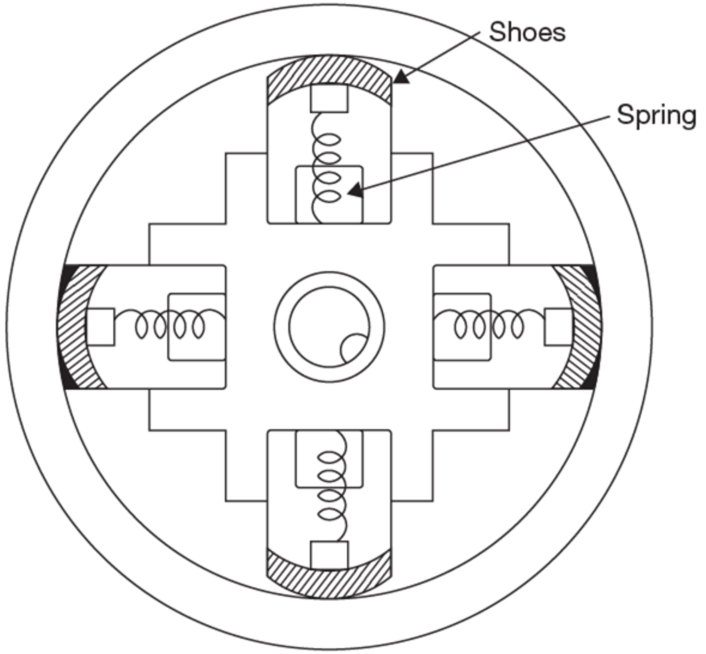
A cone clutch serves the same purpose as a disk or plate clutch; however, instead of mating two spinning disks, the cone clutch uses two conical surfaces to transmit torque by friction.

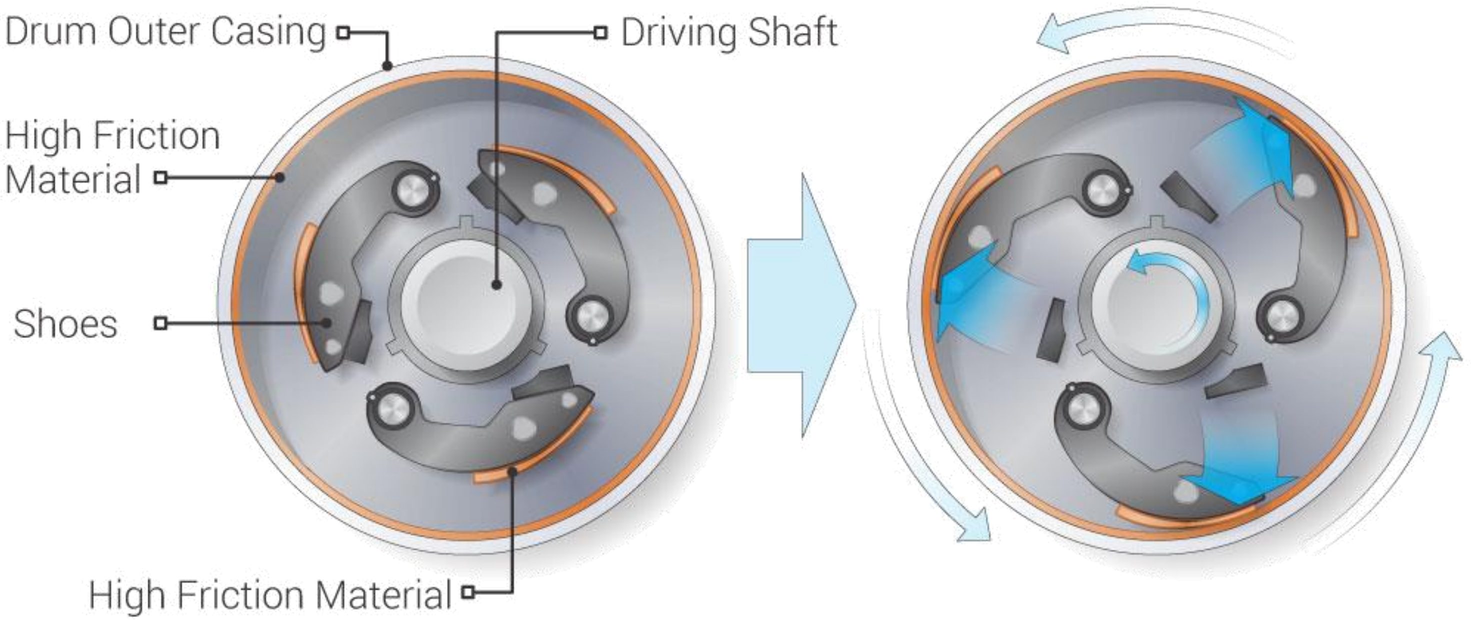




Centrifugal Clutch

Centrifugal clutch works on the principle of centrifugal force. When the driving shaft rotates at high speed, the shoes move radially outward. The outer surfaces of the shoes are covered with friction material which engages the pulley. Thus, pulley rotates with the driving shaft.





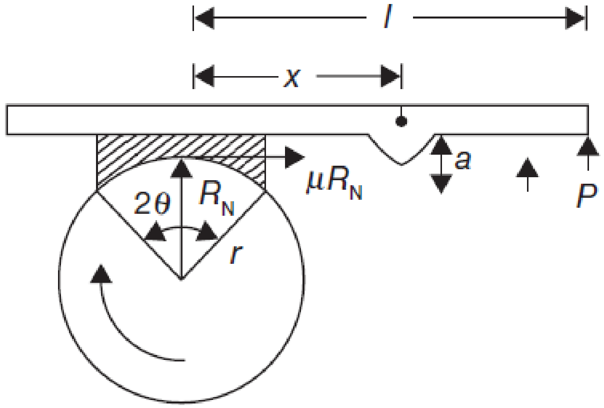
BRAKES

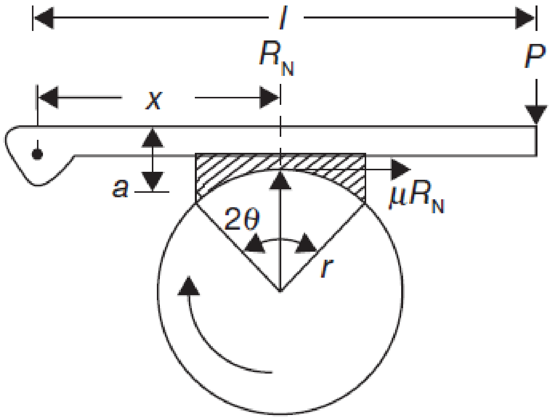
Brake is a device which is used to bring the body into rest while it is in motion or to hold a body in a state of rest by applying resisting force. There are four types of brakes as given below:

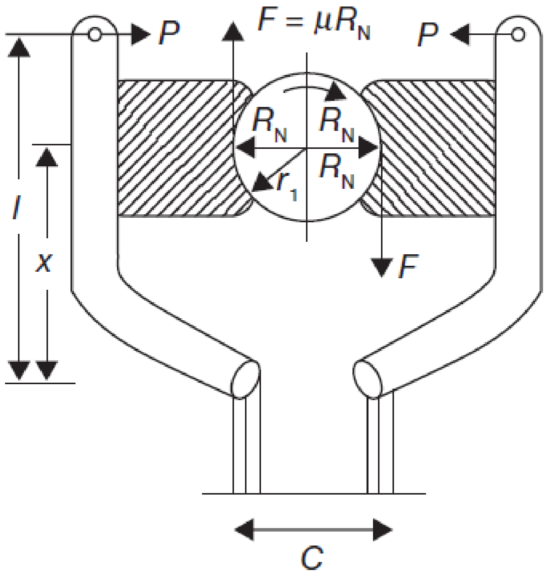
1. *Block or shoe brake.*
2. *Band brake.*
3. *Band and block brake.*
4. *Internal expanding shoe brake.*

Block or Shoe Brake

In this brake, a shoe or block is pressed against the drum. The force can be increased by using a lever. The brake lining for friction is made of softer materials so that it can be replaced easily after wearing.

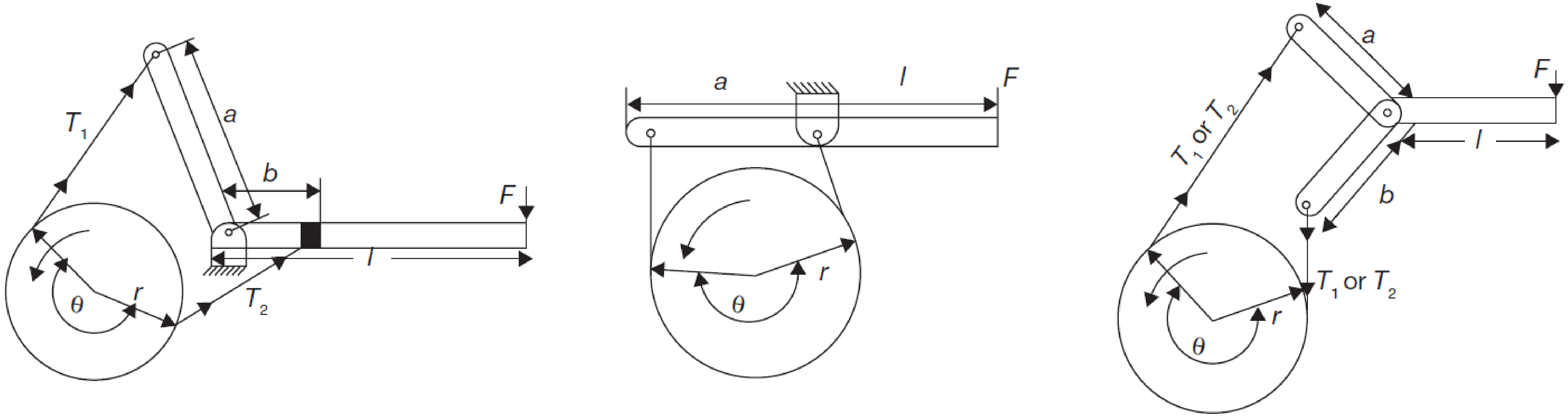






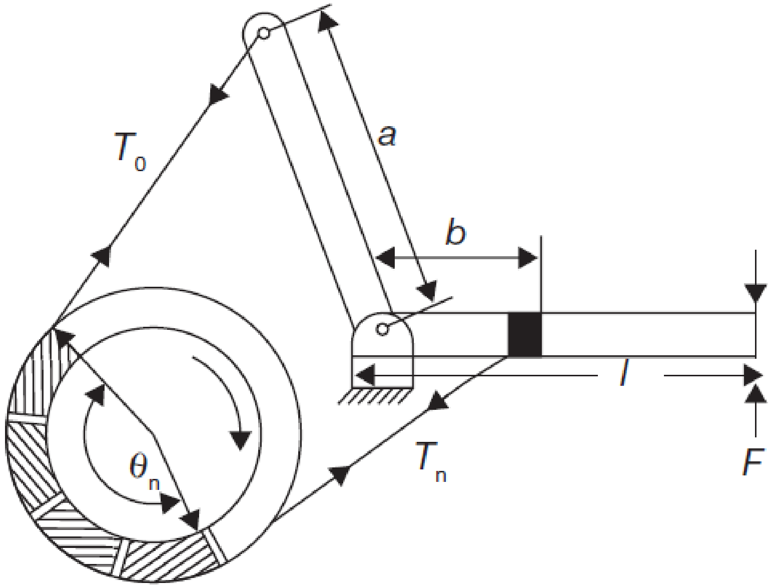
Band Brake

Band brake consists of a band in the form of belt, rope or steel band. When force is applied at the free end of the lever, the brand is pressed against the external surface of the drum.



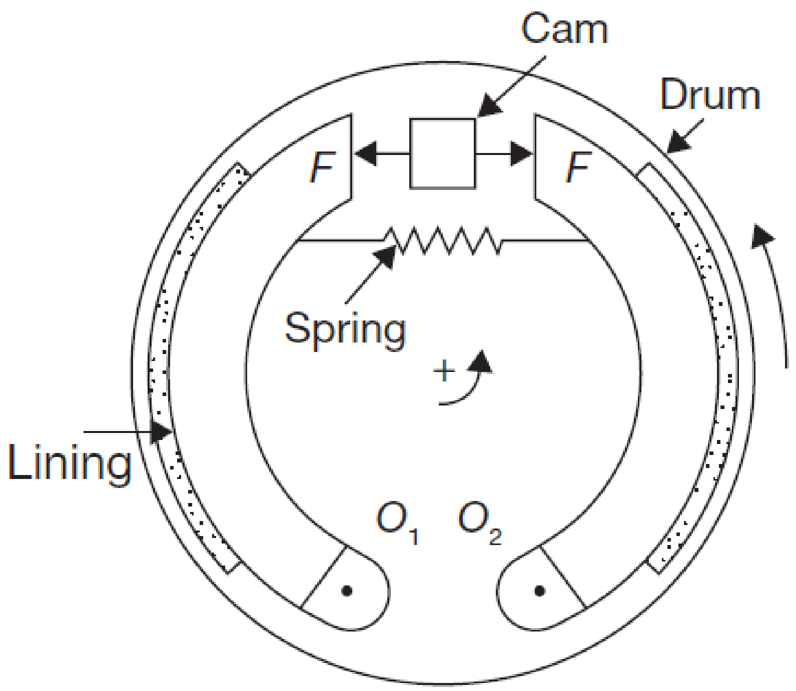
Band and Block Brake

This is a combination of band and block brake. A number of blocks are mounted on the drum and inside the band and brake is applied by pressing the blocks against the drum with the help of the band. To increase the effectiveness of brake blocks are used under the band since blocks have a higher coefficient of friction.



Internal Expanding Shoe Brake

Internal expanding shoe brake has two semicircular shoes which are lined with friction materials. The outer diameter of the shoe is less than the inner diameter of the drum so that the drum can rotate freely. When the brake is applied, the shoes expand and press the inner surface of the drum and resist the motion. It is used in an automobile. It is self-energizing and good heat dissipative. A hydraulic pressure is generated in piston-cylinder arrangement. This hydraulic force is applied equally to both the shoes in the direction. For counterclockwise rotation of the drum, the left shoe is primary leading shoe while the right shoe is secondary or trailing shoe.



BASIC MECHANICAL ENGINEERING

Robotics

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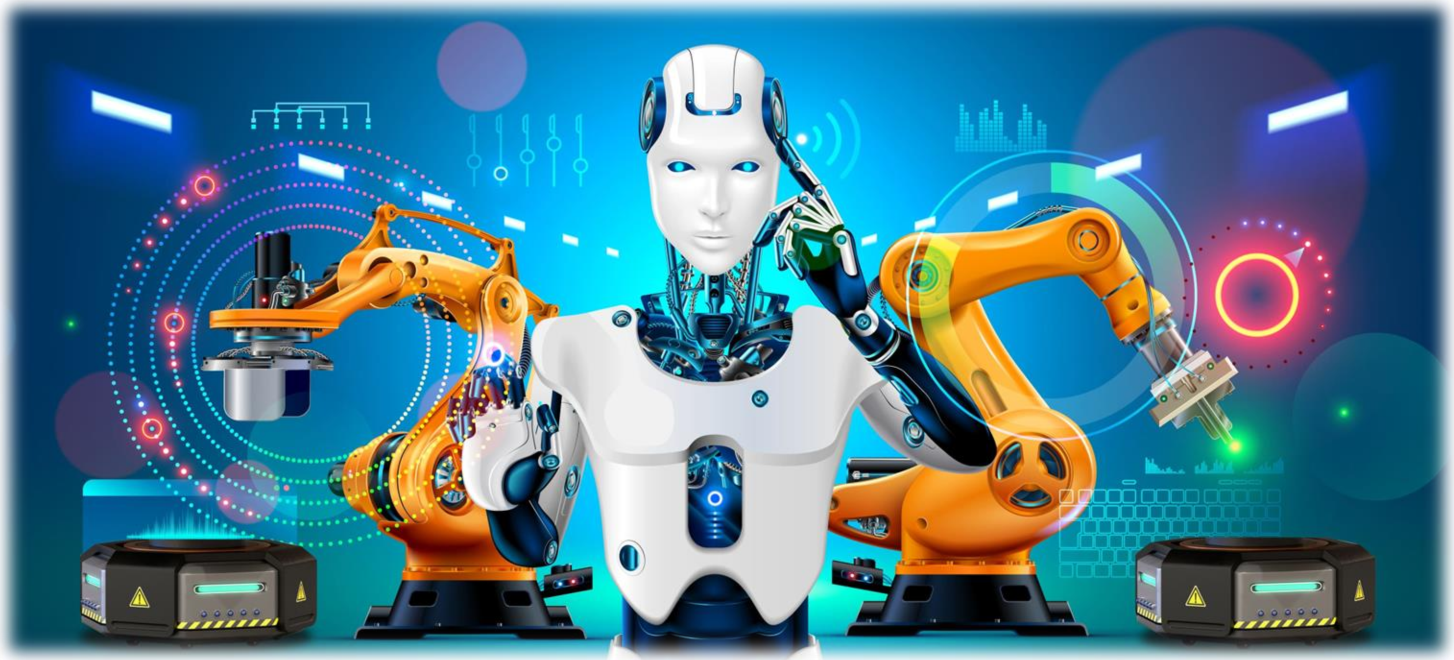
Robotics

Robotics is the study, design, construction, operation, and use of robots and computer systems. It's an interdisciplinary field that includes mechanical engineering, electrical engineering, and computer science.

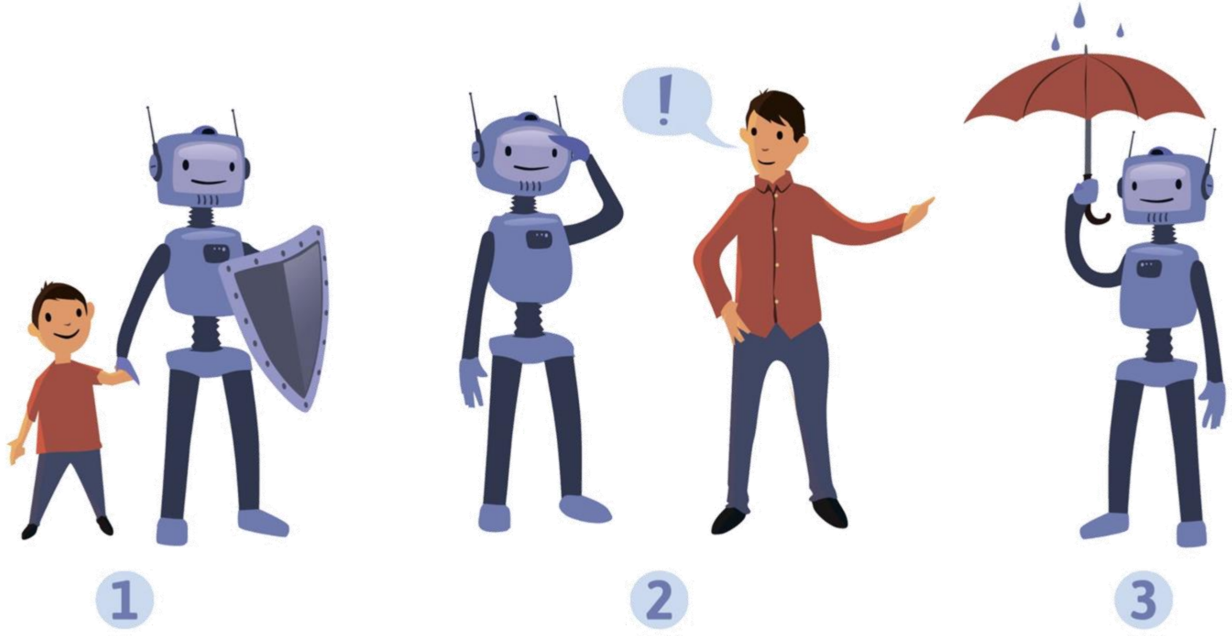


Three Laws of Robotics

The First Law: A robot may not injure a human being or, through inaction, allow a human being to come to harm.

The Second Law: A robot must obey the orders given it by human beings except where such orders would conflict with the First Law.

The Third Law: A robot must protect its own existence as long as such protection does not conflict with the First or Second Law.

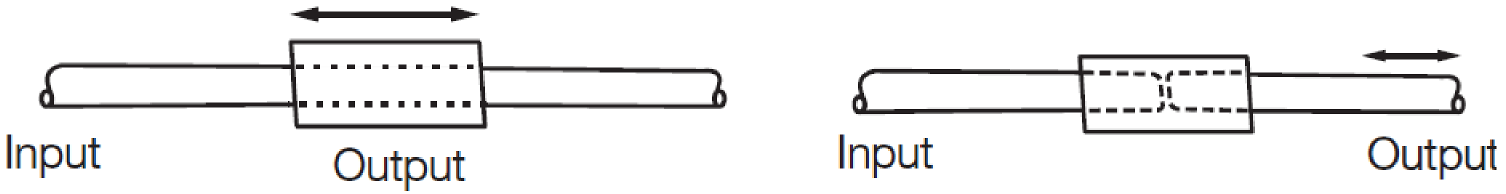


Robot Anatomy

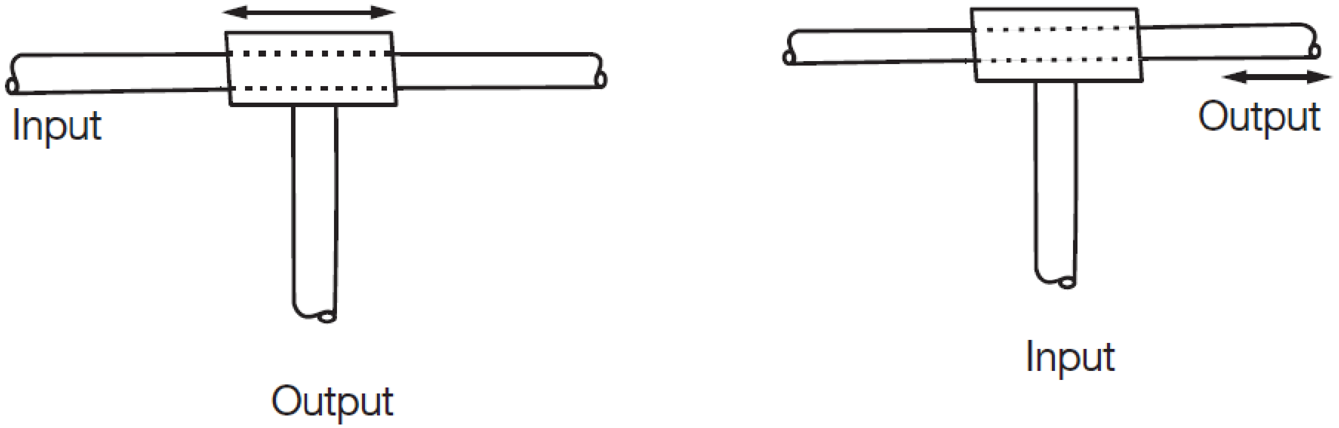
Joints and Links: The joints used in an industrial robot are very similar to the joints in a human body; it provides relative motion between two parts of the body. Each joint provides the robot with a degree of freedom (d.o.f.) of the motion. In nearly all cases, only one d.o.f. is associated with a joint. Two links are connected to each joint, one which we call the input link and another is called the output link.

Nearly all industrial robots have mechanical joints that can be classified into one of five types.

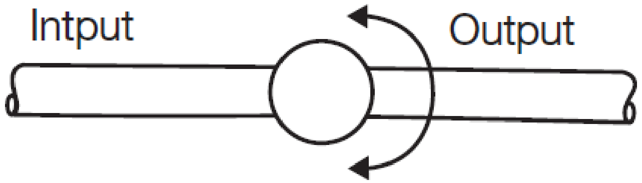
Linear Joint: In this joint, the relative movement between the input link and the output link is a linear sliding motion, with the axes of the two links being parallel. We refer to this as type L-joint.



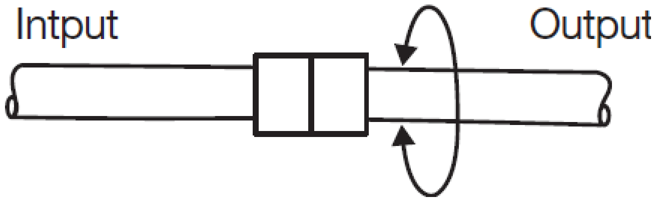
Orthogonal Joint: This is also a linear sliding motion, but the input and output links are perpendicular to each other during the movement. This is a type O-joint.



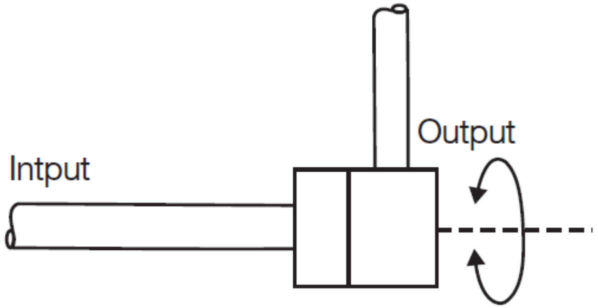
Rotational Joint: This type of joint provides a rotational relative motion of the joints, with the axes of the input and output link. This is a type R-joint.



Twisting Joint: This joint also involves a rotary motion, but the axis of rotation is parallel to the axes of the two links. We called this as type-T joint.



Revolving Joint: In this type of joint, the axis of the input link is parallel to the axis of rotation of the joint, and the axis of the output link is perpendicular to the axis of rotation. We refer to this as a type V-joint.

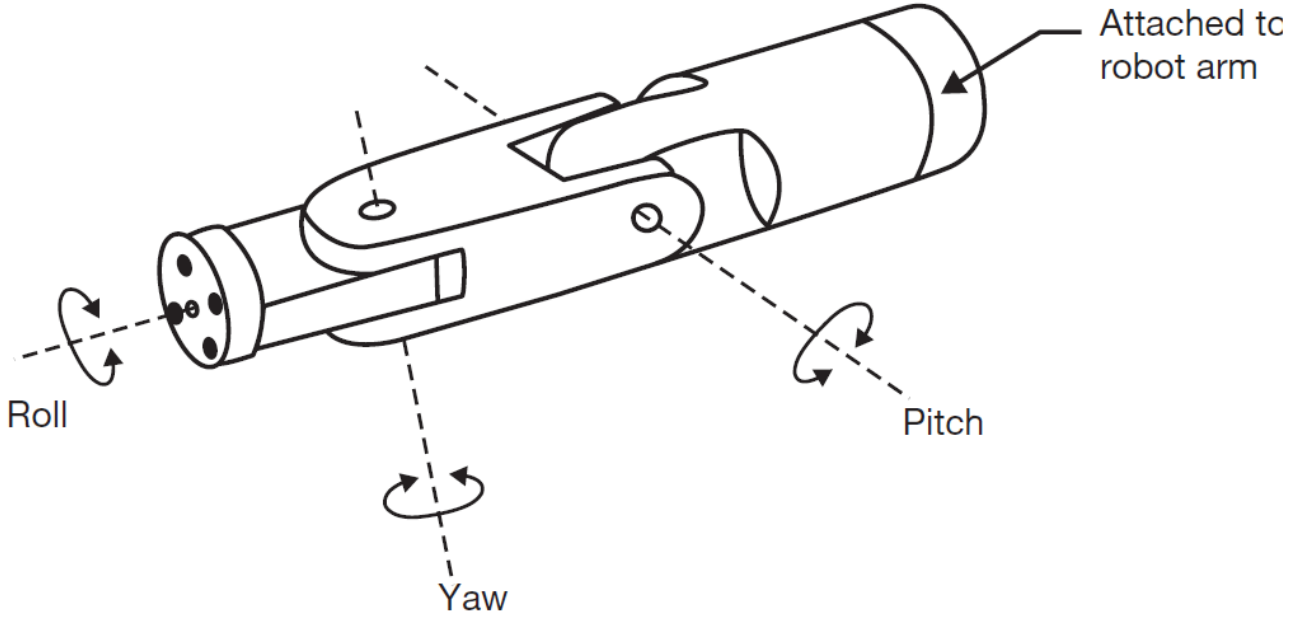


Three Degree of Freedom for Robot's Wrist

Roll: This degree of freedom (d.o.f.) can be accomplished by a T-type joint to rotate the object about the arm axis.

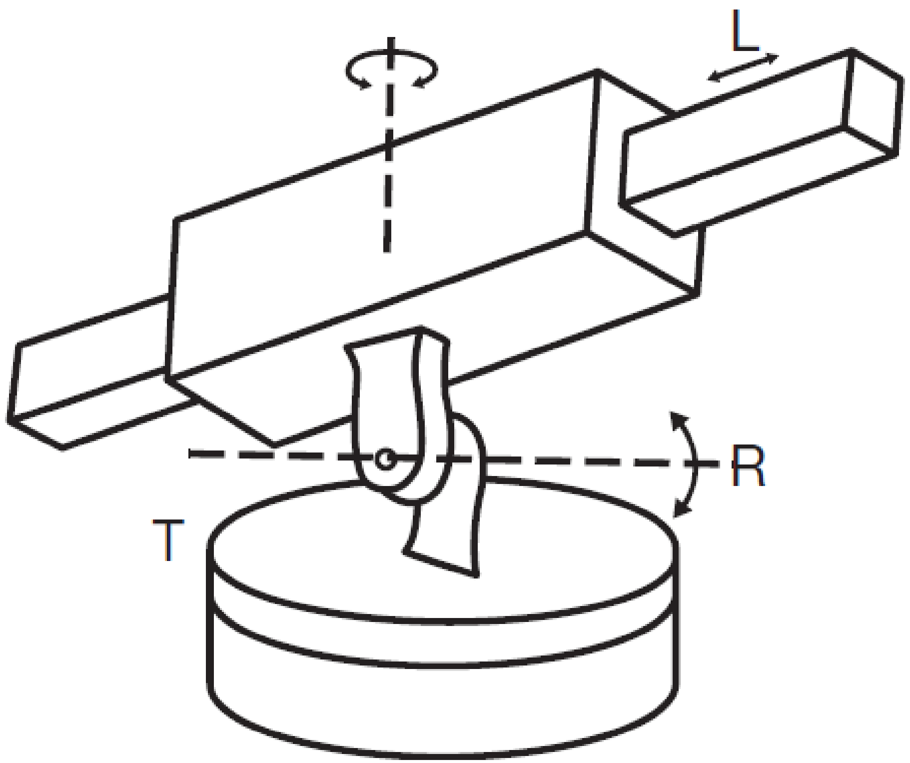
Pitch: This involves the up and down rotation of the object, typically done by means of a type R-joint.

Yaw: This involves right-to-left rotation of the object, also accomplished typically using an R-type joint.



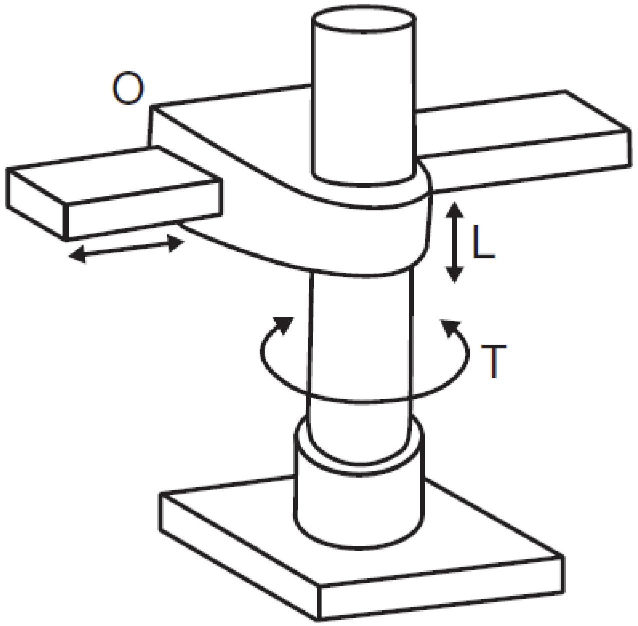
Robot Configurations

Polar Configuration: This configuration has a TRL notation. A sliding arm is actuated relative to the body, which can rotate about both a vertical axis (type T-joint) and horizontal axis (type R-joint).



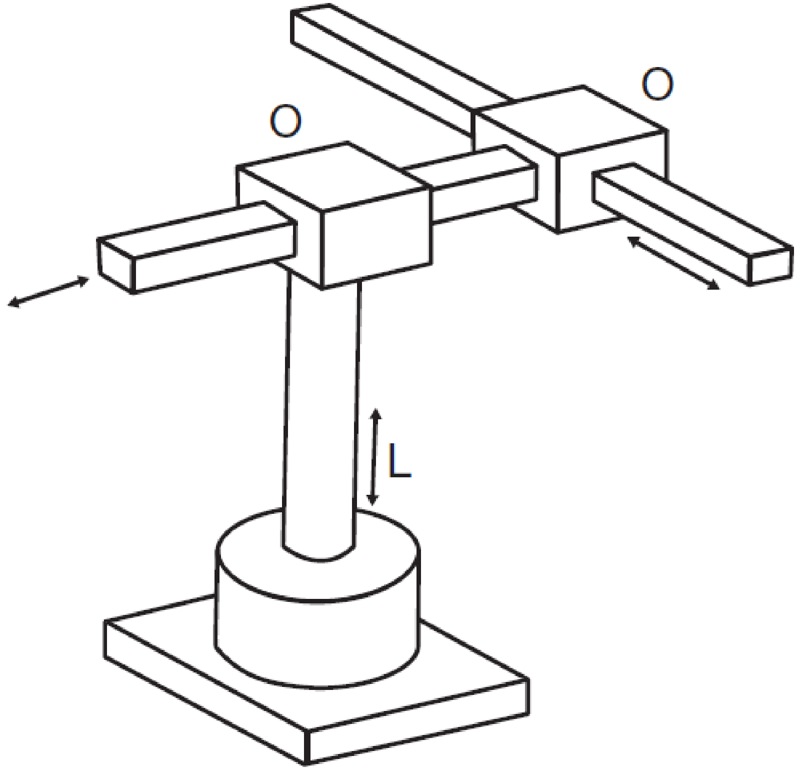
Robot Configurations

Cylindrical Configuration: This robot configuration consists of a vertical column, relative to which an arm assembly can be moved up and down. The end-of-arm can be moved in and out relative to the axis of the column. This configuration can be realized structurally in several ways. Example TLO, LVL.



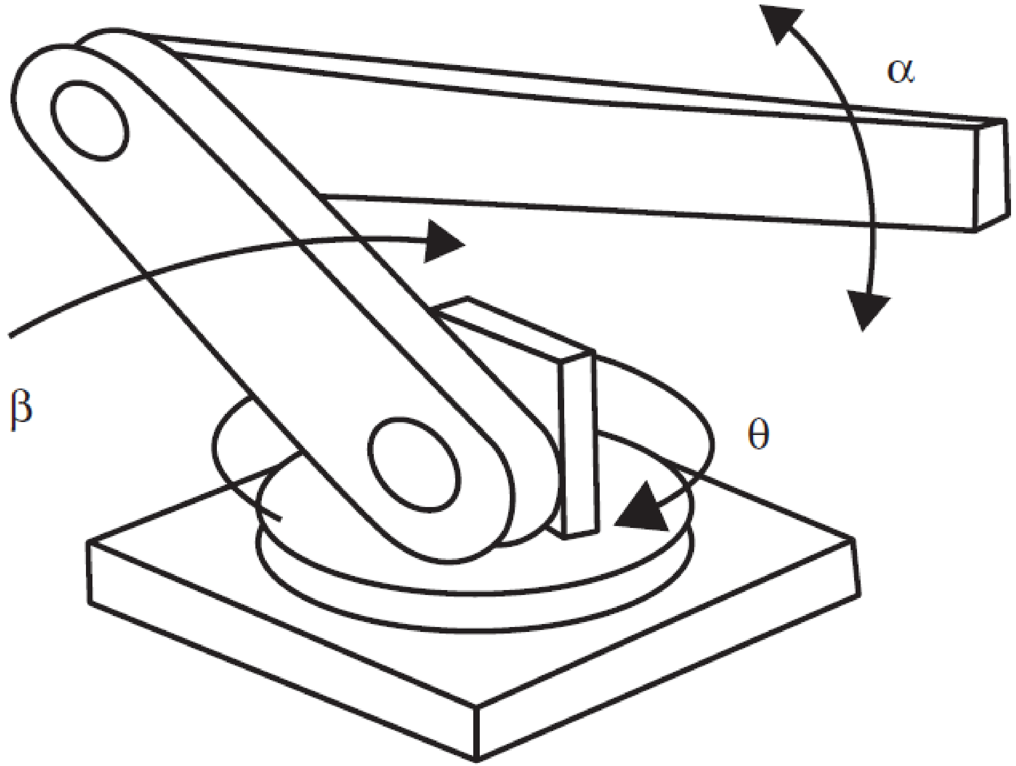
Robot Configurations

Cartesian Coordinate Robot: Other names for this configuration include rectilinear robot and x-y-z robot. It is composed of three sliding joints two of which are orthogonal. The sketch in the shows a LOO rotation. Another possible rotation is OLO.



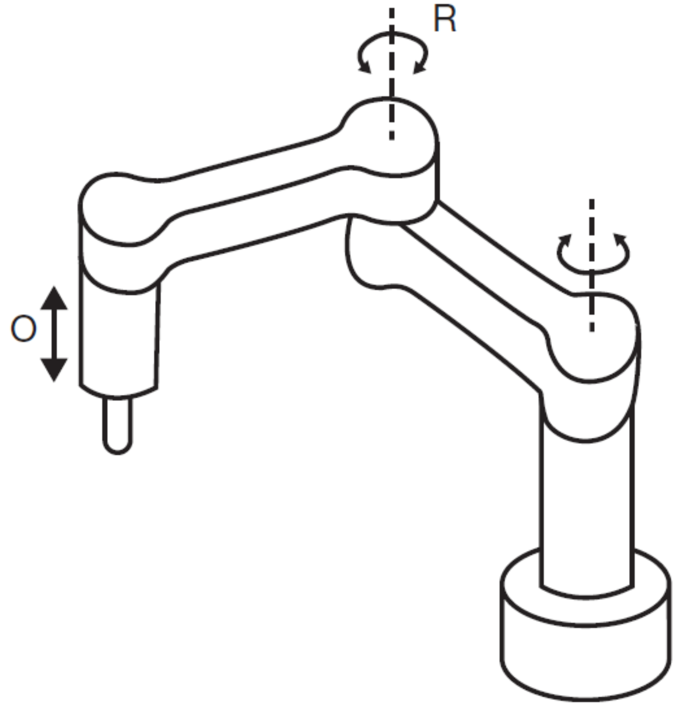
Robot Configurations

Jointed-arm-robot: This robot has a human arm. Its arm has a shoulder joint and an elbow joint and the arm can be swiveled about the base. Possible configurations for this type include TRR and VVR type.



Robot Configurations

SCARA (Selective Compliance Assembly Robot Arm): This is similar to the jointed arm robot except that the shoulder and elbow rotational axes are vertical but compliant in the horizontal direction.



Applications of Robots

A. Material handling applications.

▶▶ Machine loading.

▶▶ Machine unloading.

▶▶ Machine loading and unloading.

Machine loading and unloading include the processes: die casting, plastic molding, metal machining, forging, press working, and heat treating.

B. Processing Operations.

Spot welding, Continuous arc welding, spray painting, drilling, grinding, wire brushing, water jet cutting, laser cutting, and riveting.

C. Assembly and inspection.