a Closed pair: When the elements of a pair are held together mechanically, it is known as a closed pair. The contact between the two can only be broken only by the destruction of at least one of the members. All the lower pairs and some of the higher pairs are closed pairs.

b) Unclosed pair: When two links of a pair are in contact either due to force of gravity or some spring action, they constitute an unclosed pair. In this the links are not held together mechanically. Ex.: Cam and follower pair.

iii Kinematic pairs according to nature of relative motion.

a Sliding pair: If two links have a sliding motion relative to each other, they form a sliding pair. A rectangular rod in a rectangular hole in a prism is an example of a sliding pair.

b) Turning Pair: When on link has a turning or revolving motion relative to the other, they constitute a turning pair or revolving pair.

c Rolling pair: When the links of a pair have a rolling motion relative to each other, they form a rolling pair. A rolling wheel on a flat surface, ball ad roller bearings, etc. are some of the examples for a Rolling pair.

d) Screw pair Helical Pair: if two mating links have a turning as well as sliding motion between them, they form a screw pair. This is achieved by cutting matching threads on the two links.

The lead screw and the nut of a lathe is a screw Pair

e Spherical pair: When one link in the form of a sphere turns inside a fixed link, it is a spherical pair. The ball and socket joint is a spherical pair.

1.2 Degrees of Freedom:

An unconstrained rigid body moving in space can describe the following independent motions.

1. Translational Motions along any three mutually perpendicular axes x, y and z,

2. Rotational motions along these axes.

Thus a rigid body possesses six degrees of freedom. The connection of a link with another imposes certain constraints on their relative motion. The number of restraints can never be zero joint is disconnected) or six (joint becomes solid).

Degrees of freedom of a pair is defined as the number of independent relative motions, both translational and rotational, a pair can have.

Degrees of freedom = 6 – no. of restraints.

To find the number of degrees of freedom for a plane mechanism we have an equation known as **Grubler's equation and is given by $F = 3(n - 1) - 2j_1 - j_2$**

F = Mobility or number of degrees of freedom

n = Number of links including frame.

j1 = Joints with single (one degree of freedom.

J2 = Joints with two degrees of freedom.

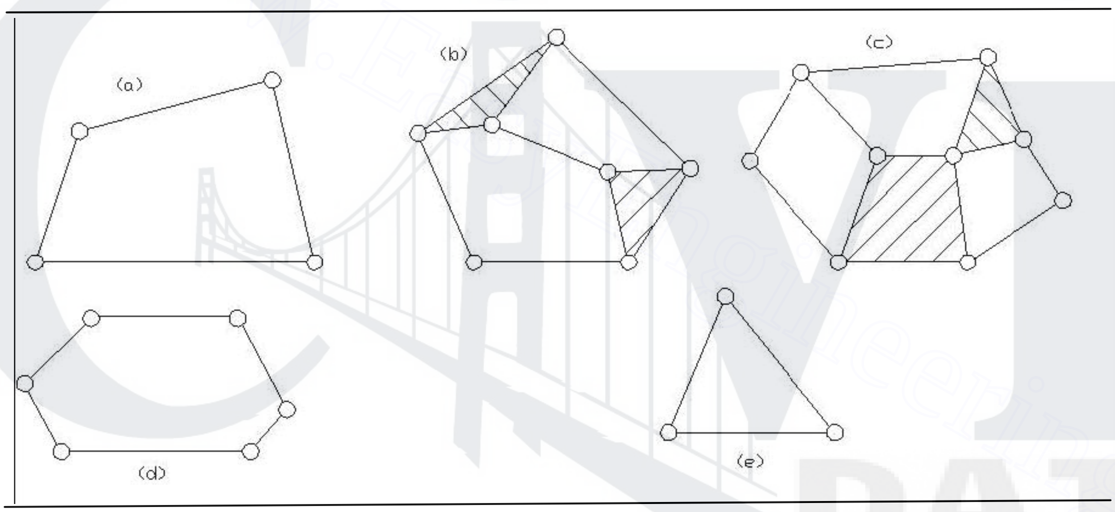
If F > 0, results in a mechanism with 'F' degrees of freedom.

F = 0, results in a statically determinate structure.

F < 0, results in a statically indeterminate structure.

1.2.1Kinematic Chain:

A Kinematic chain is an assembly of links in which the relative motions of the links is possible and the motion of each relative to the others is definite (fig. a, b, and c.)



In case, the motion of a link results in indefinite motions of other links, it is a non-kinematic chain. However, some authors prefer to call all chains having relative motions of the links as kinematic chains.

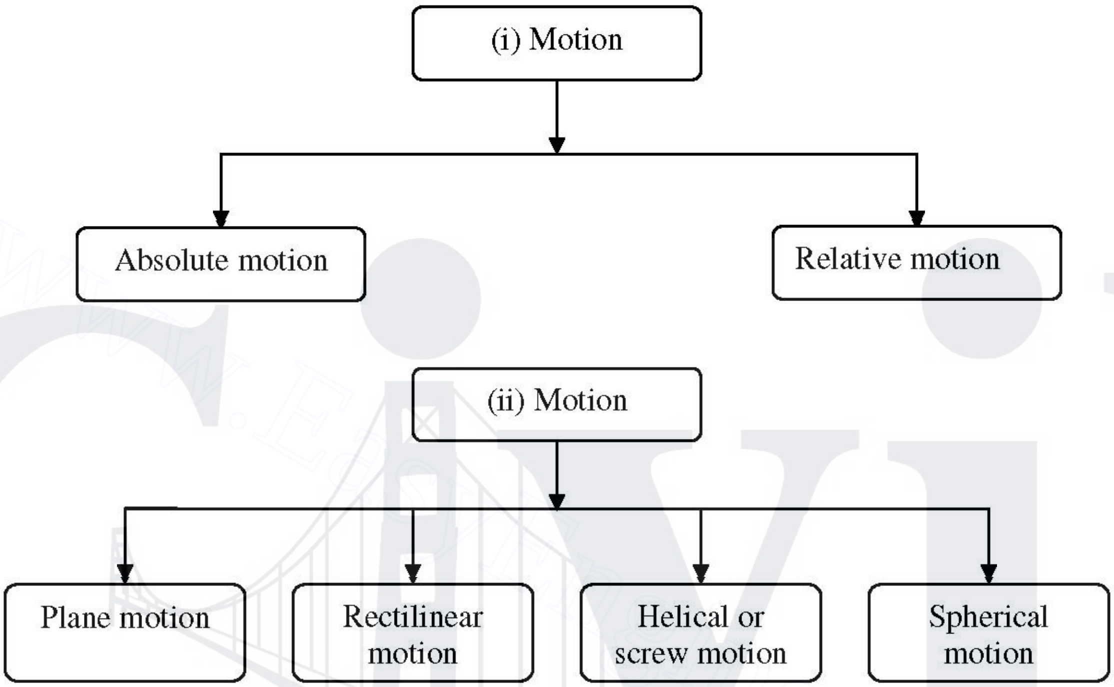
1.2.2Linkage, Mechanism and structure:

A linkage is obtained if one of the links of kinematic chain is fixed to the ground. If motion of each link results in definite motion of the others, the linkage is known as mechanism. If one of the links of a redundant chain is fixed, it is known as a structure.

To obtain constrained or definite motions of some of the links of a linkage, it is necessary to know how many inputs are needed. In some mechanisms, only one input is necessary that determines the motion of other links and are said to have one degree of freedom. In other mechanisms, two inputs may be necessary to get a constrained motion of the other links and are said to have two degrees of freedom and so on.

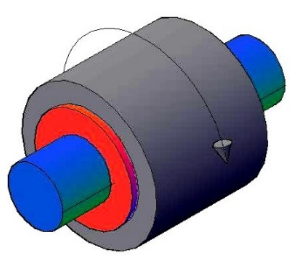
The degree of freedom of a structure is zero or less. A structure with negative degrees of freedom is known as a **Superstructure.**

- **Motionand itstypes:**

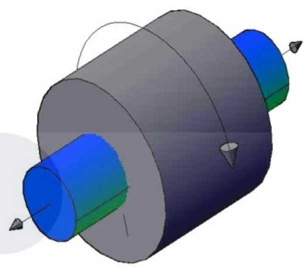


- **The threemain typesof constrainedmotion in kinematic pairare,**

1.**Completely constrained motion** : If the motion between a pair of links is limited to a definite direction, then it is completely constrained motion. E.g.: Motion of a shaft or rod with collars at each end in a hole as shown in fig.



2. Incompletely Constrained motion : If the motion between a pair of links is not confined to a definite direction, then it is incompletely constrained motion. E.g.: A spherical ball or circular shaft in a circular hole may either rotate or slide in the hole as shown in fig.



3. Successfully constrained motion or Partially constrained motion: If the motion in a definite direction is not brought about by itself but by some other means, then it is known as successfully constrained motion. E.g.: Foot step Bearing

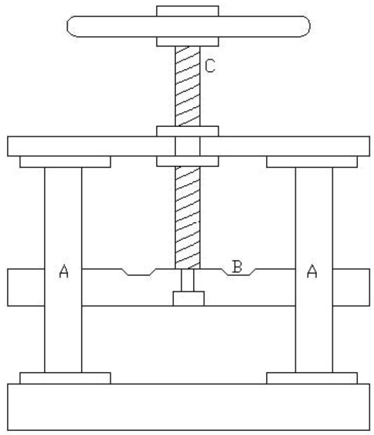
- **Machine**:

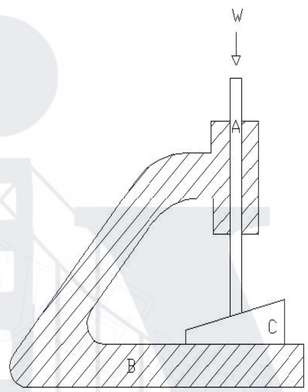
It is a combination of resistant bodies with successfully constrained motion which is used to transmit or transform motion to do some useful work. E.g.: Lathe, Shaper, Steam Engine, etc.

- ***Kinematic chain with three lower pairs***

It is impossible to have a kinematic chain consisting of three turning pairs only. But it is possible to have a chain which consists of three sliding pairs or which consists of a turning, sliding and a screw pair.

The figure shows a kinematic chain with three sliding pairs. It consists of a frame B, wedge C and a sliding rod A. So the three sliding pairs are, one between the wedge C and the frame B, second between wedge C and sliding rod A and the frame B.





This figure shows the mechanism of a fly press. The element B forms a sliding with A and turning pair with screw rod C which in turn forms a screw pair with A. When link A is fixed, the required fly press mechanism is obtained.

1.3.Kutzbach criterion, Grashoff's law
Kutzbach criterion:

- **Fundamental Equation for 2-D Mechanisms:** $M = 3(L - 1) - 2J_1 - J_2$
  Can we intuitively derive Kutzbach's modification of Grubler's equation? Consider a rigid link constrained to move in a plane. How many degrees of freedom does the link have? 3: translation in x and y directions, rotation about z -axis

- If you pin one end of the link to the plane, how many degrees of freedom does it now have?
- Add a second link to the picture so that you have one link pinned to the plane and one free to move in the plane. How many degrees of freedom exist between the two links? 4 is the correct answer
- Pin the second link to the free end of the first link. How many degrees of freedom do you now have?

- How many degrees of freedom do you have each time you introduce a moving link? How many degrees of freedom do you take away when you add a simple joint? How many degrees of freedom would you take away by adding a half joint? Do the different terms in equation make sense in light of this knowledge?

1.3.1 Grashoff's law:

- **Grashoff 4-bar linkage:** A linkage that contains one or more links capable of undergoing a full rotation. A linkage is Grashoff if: S + L < P + Q where: S = shortest link length, L = longest, P, Q = intermediate length links. Both joints of the shortest link are capable of 3 60 degrees of rotation in a Grashoff linkages. This gives us 4 possible linkages: crank-rocker input rotates 360), rocker -crank-rocker coupler rotates 360), rocker -crank follower; double crank all links rotate 360). Note that these mechanisms are si mply the possible inversions (section 2.11, Figure 2-16 of a Grashoff mechanism.
- **Non Grashoff 4 bar:** No link can rotate 360 if: S + L > P + Q

Let's examine why the Grashoff condition works:

- Consider a linkage with the shortest and longest sides joined together. Examine the linkage when the shortest side is parallel to the longest side 2 positions possible, folded over on the long side and extended away from the long side. How long do P and Q have to be to allow the linkage to achieve these positions?
- Consider a linkage where the long and short sides are not joined. Can you figure out the required lengths for P and Q in this type of mechanism

1.4 Kinematic Inversions of 4-bar chain and slider crank chains:

- ***<u>Types of Kinematic Chain:</u>*** 1) Four bar chain 2) Single slider chain 3) Double Slider chain
- **<u>Four bar Chain:</u>**

The chain has four links and it looks like a cycle frame and hence it is also called *quadric cycle chain*. It is shown in the figure. In this type of chain all four pairs will be turning pairs.