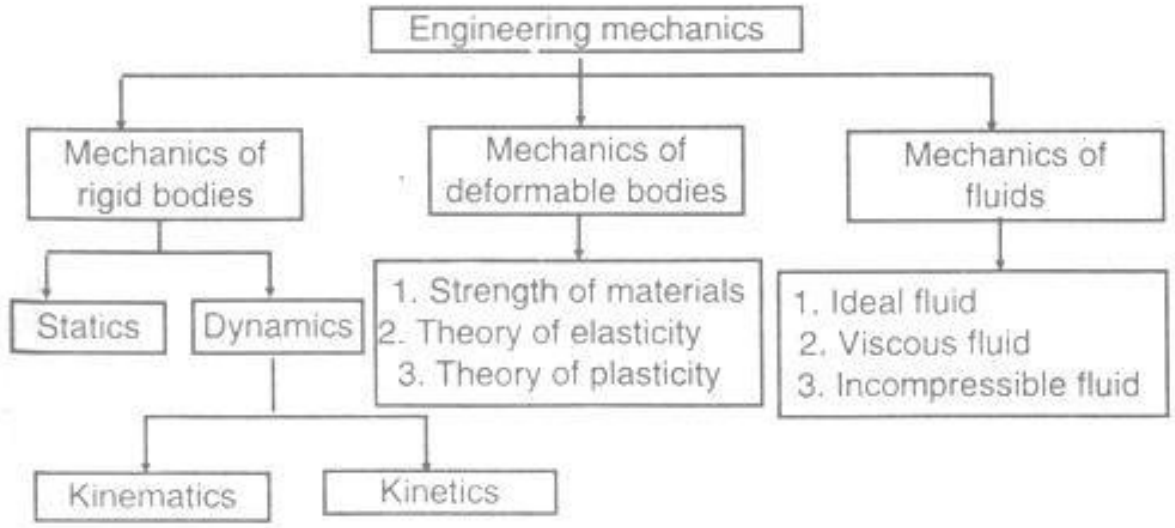
Unit 1. ENGINEERING MECHANICS

Mechanics : Mechanics is a branch of physical science which deals with the objects which are at rest or in motion under the action of various forces acting on them.

Engineering mechanics : The subject which deals with the study of applications of the principles of newtonion mechanics is called engineering mechanics or applied mechanics.



Mechanics of rigid bodies :

It is the branch of science which deals with the study of bodies that do not undergo any deformation under the application of forces.

It can be classified into two types :

1. **Statics** – branch of mechanics which deals with the study of behavior of bodies in the state of rest.
2. **Dynamics** – branch of mechanics which deals with the study of behavior of bodies in the state of motion.

It is further classified into two types:

1. **Kinetics** - the force causing the motion are not considered.
2. **Kinematics** – the force causing the motion are mainly considered.

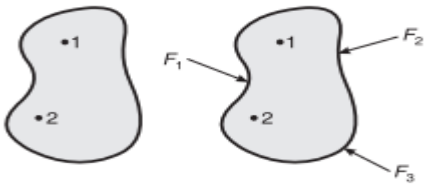
Idealisations of mechanics :

Particle : A body of infinitely small volume whose mass can be neglected, is called a particle.

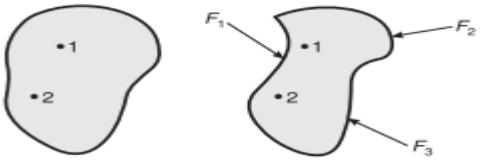
Ex- in the study of movement of the earth in celestial sphere, earth is treated as a particle.

Continuum : A continuous distribution of molecules in a body without intermolecular space is called the continuum.

Rigid body : A rigid body is one in which the positions of the constituent particles do not change under the application of external forces, such as the position of particles 1 and 2 in Figure.



Deformable body : A deformable body is one in which the positions of constituent particles change under the application of external forces, such as the positions of particles 1 and 2 in Figure.



Point force : A force which is applied at a point on an object is called as point force.

Space : It is a geometric region occupied by bodies whose positions are described by linear and angular measurements relative to coordinate system.

Time : It is a measure of the succession of events and is a basic quantity in dynamics.

Mass : It is a measure of the inertia of a body, which is its resistance to a change of velocity.

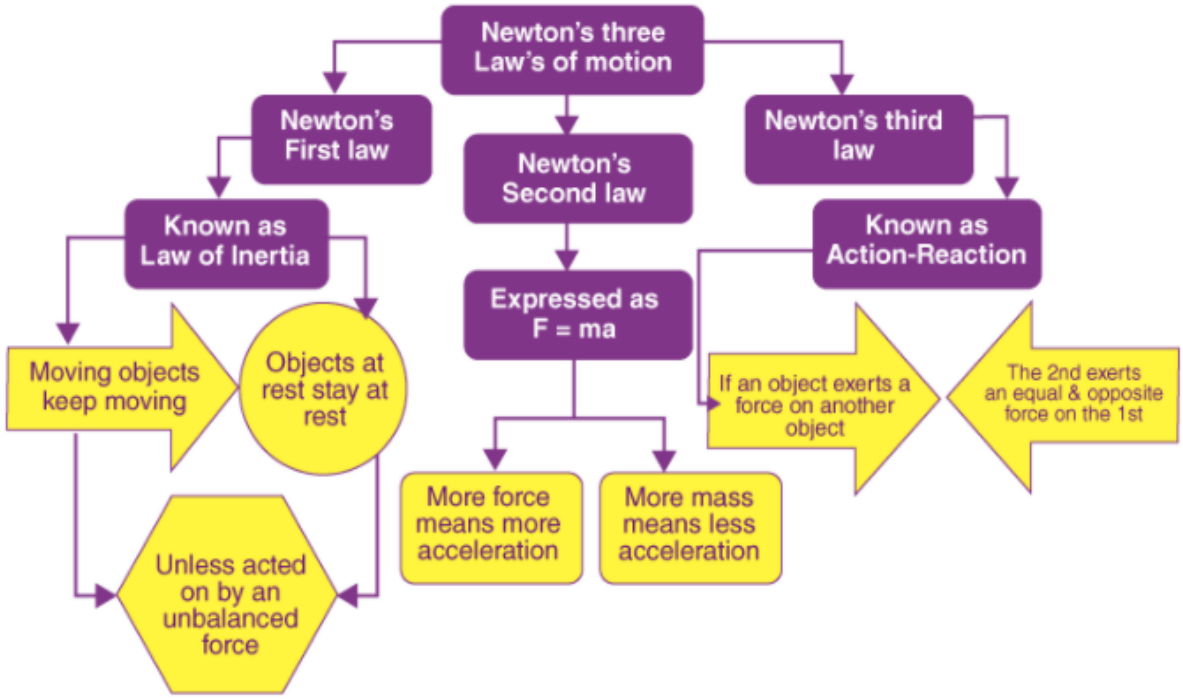
It is denoted by kilogram(Kg).

Acceleration : a measurement of how quickly an object is changing speed.

Scalar quantity : A physical quantity which has only magnitude, is called scalar quantity. For example, time, mass, density, volume, distance, and so forth.

Vector quantity : A physical quantity which has a direction in addition to magnitude, is known as vector quantity. For example, force, displacement, velocity, acceleration, and so forth.

Newton's laws of motion :



First law : Every object in a state of uniform motion tends to remain in that state motion unless an external force is applied to it.

This law is also called "law of inertia".

Inertia: the tendency of an object to resist changes in its state of motion

Second law : The change of motion is proportional to the natural force impressed and is made in a direction of the straight line in which the force is impressed.

It can be stated as :

$f \propto (dP/dt)$

$\Rightarrow f \propto (\frac{mv-mu}{t})$

$\Rightarrow f \propto m(v-u)/t$

$\Rightarrow f \propto ma$

$\Rightarrow f = kma$

In the equation, k is the constant of proportionality, and it is equal to 1 when the values are taken in SI unit. Hence, the final expression will be,

$$F = ma$$

where ***F*** is the applied force, *m* is the mass and ***a*** is the acceleration.

Third law : For every action, there is an equal and opposite reaction .

Force : Force is the action of one body on another. A force tends to move the body in the direction of its action. The action of a force is characterized by its magnitude, by the direction of its action and by its points of application.

SI unit of force is Newton (N).

SI units : SI stands for system internationale d' units or international system of units.

As in MKS systems, in SI system also the fundamental units are metre for length, kilogramme for mass and second for time.

The units of all other quantities may be expressed in terms of these basic units.

Quantity	Dimensional Symbol	SI UNIT	
		Unit	Symbol
Mass	M	Kilogram	Kg
Length	L	Meter	M
Time	T	Second	s
Force	F	Newton	N

Basic Unit

Characteristics or elements of a force :

I. **Magnitude :** The length of the vector represents the magnitude of force, as shown in Figure .

II. **Direction :** The direction of a force can be represented by an arrowhead.
III. **Line of action :** It is the line along which the force acts.
IV. **Point of application** : It is the point at which the force acts.

Classification of forces :

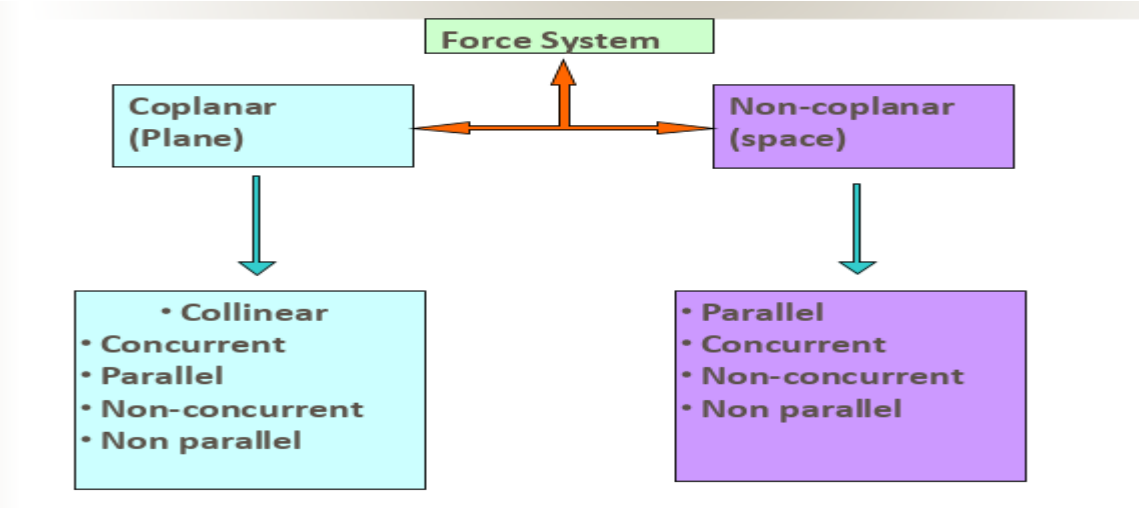
a) Concentrated force or point force
b) Distributed forces – distributed over an area or length throughout
c) Body force – distributed throughout the volume. Eg – gravity force

a) External force
b) Internal force

a) Contact force
b) Non-contact force

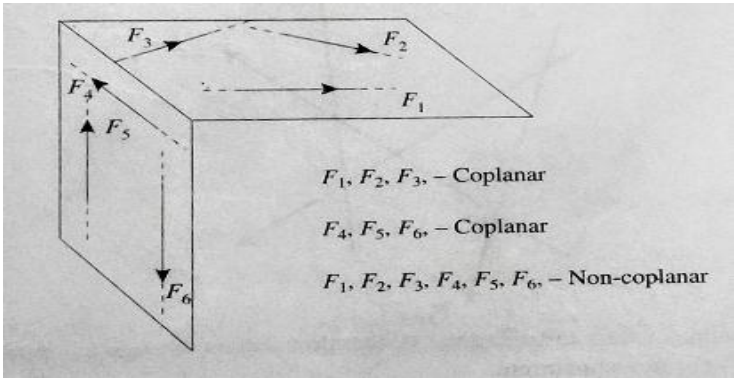
a) Uniformly distributed force or load (UDL)
b) Uniformly varying force (UVL) or trapezoidal force

Classification of force systems :

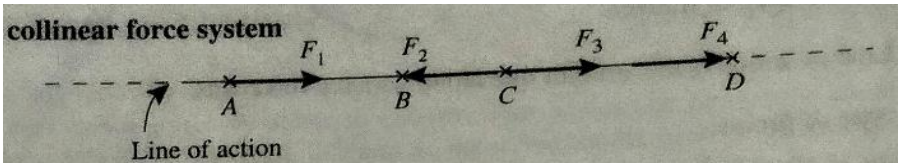


1. **(a) Coplanar force system –** if the line of action of all forces of the system lie in the same plane then the system is said to be coplanar.

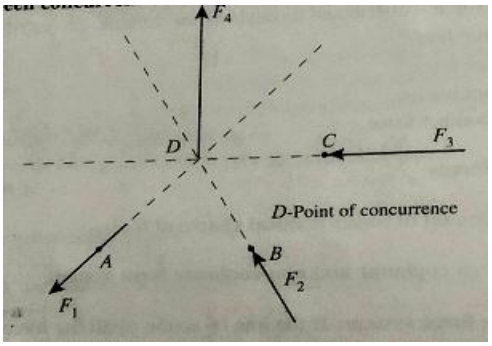
   (b) Non-coplanar force system – if the line of action of all the forces of the system do not lie in the same plane then the system is said to be non-coplanar.



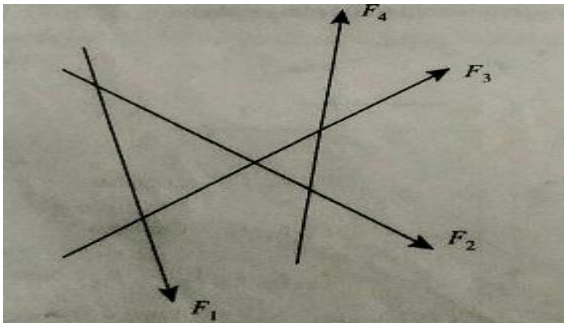
2. **Collinear force system –** if the forces forming a system have common line of action then system is said to be collinear.



3. **(a) Concurrent force system –** if the line of action of forces forming the system pass through a common point then the system is said to be concurrent.

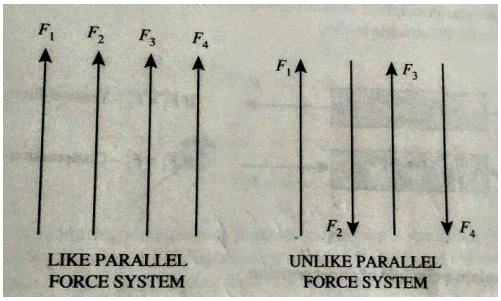


   (b) Non-concurrent force system – if the line of action of forces forming the system do not pass through a common point then the system is said to be non-concurrent.



4. **Parallel force system –** a special case of non-concurrent force system in which line of action of forces forming the system are parallel is called parallel force system. They are classified into two types:

   (a) Like parallel force system
   (b) Unlike parallel force system



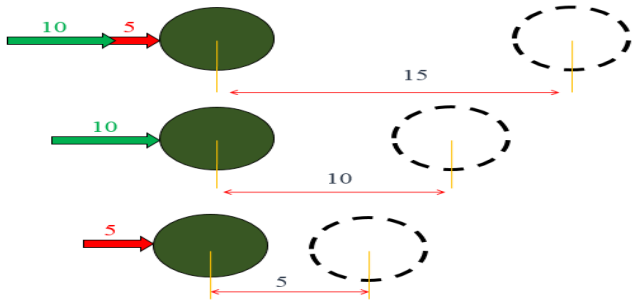
Basic principles of mechanics :

1. Principle of physical independence of forces

The external effect produced by a force on a body is independent of the presence of other forces on the same body simultaneously. This principle is called the principle of physical independence of forces.

2. Principle of superposition of forces

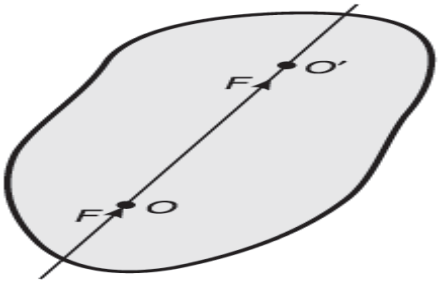
It states that – the net effect of forces applied in any sequence on a body is given by the algebraic sum of effect of individual forces on body.



3. Principle of transmissibility of forces

It states that – the force can be transmitted from one point to another point along the same line of action such that the effect produced by the force on a body remains unchanged.

Let us consider a rigid body subjected t a force of F at point O as shown in figure. According to the principle, the force F can be transmitted to a new point O' along the same line of action such that the net effect remains unchanged.



Moment of a force

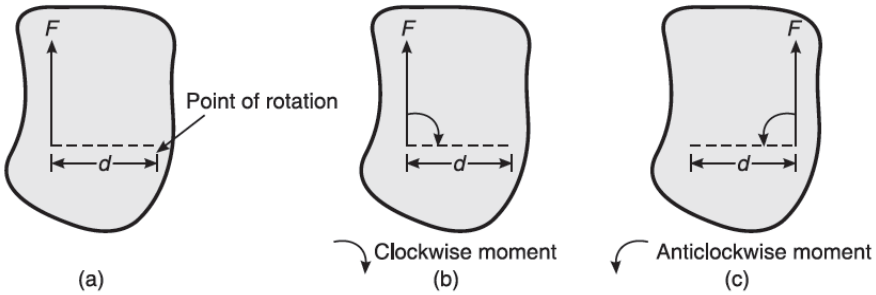
The turning effect produced by a force on a body is known as the **moment of the force**.
The plane of force in which the rotation of the object takes place is called the **plane of rotation.**
The point of intersection of the axis of rotaton with the plane of rotation is called **moment center**.
The perpendicular distance between the line of action, the force and the moment centre is called the **moment arm**.

The magnitude of the moment is given by the product of the magnitude of the force and the perpendicular distance between the line of action of the force and the point or axis of rotation.
i.e., **M = Fd** and unit is Nm

Types of moments :

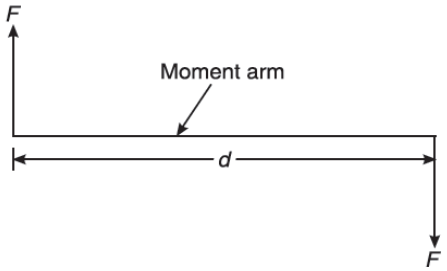
1. If the tendency of a force is to rotate the body in the clockwise direction, it is said to be a **clockwise moment** and is taken positive, as shown in Fig(b).

2. If the tendency of a force is to rotate the body in the anticlockwise direction, it is said to be **anticlockwise moment** and is taken negative as shown in Fig(c).



Moment of a couple

The system of two equal opposite forces having parallel lines of action is known as a **couple.**
it is given by, **M= Fd**



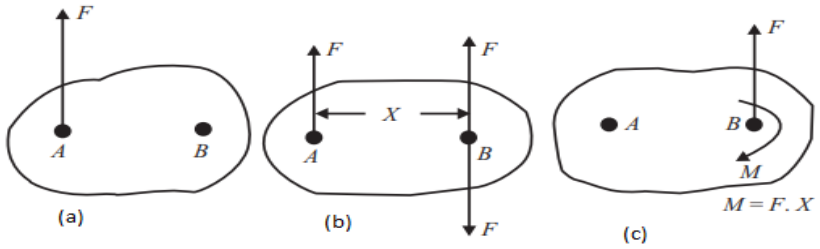
The plane in which the force forming the couple are present is called the **plane of couple**.
The perpendicular distance between the two forces forming couple is called **arm of couple**.
The product of any one of the forces forming the couple and arm of couple is called the **moment of the couple**.

Characteristics of a couple :

- A couple can produce only rotating effect and no translator motion.
- The algebraic sum of the forces forming a couple is zero.
- The moment of a couple about any point is constant.
- For a couple of certain moment there are infinite combinations of magnitude of force and arm of couple.
- Couple can be balanced by only another couple of same moment but of opposite direction.

Equivalent force couple system

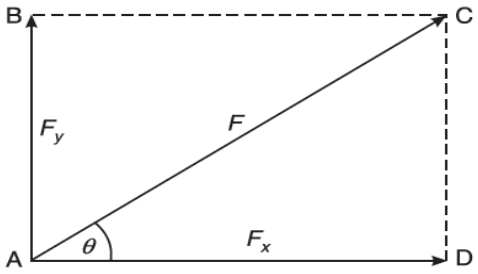
Forces with the same magnitude acting in the same direction and acting along the same line of action is called equivalent force.



F is the force acting on a body at A. it is possible to show that F at A can be resolved into a force at B and a moment M=F.X at B. where, X is the perpendicular distance from the line of action of F acting through the point A. by applying equal and opposite forces F at B the system of forces is not disturbed. Hence, the system of force in fig(b) is same as the system of force in fig(a). now the force at A and downward force at B forms a rotational effect. i.e., moment of a couple M=Fx at B therefore F at B is replaced by force F at A.

Resolution of a force

The process of splitting of a force into its two rectangular components (horizontal and vertical) is known as **resolution of the force**.
In the figure, *F* is the force which makes an angle θ with the horizontal axis, and has been resolved into two components, namely *Fx* and *Fy*, along the *x*-axis and *y*-axis respectively.



In Δ CAD,

$$\cos\theta = \frac{F_x}{F} \quad \Rightarrow \quad F_x = F\cos\theta$$

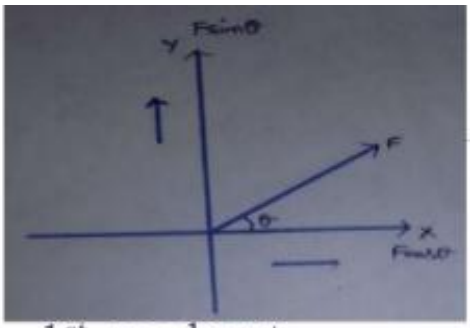
$$\sin\theta = \frac{F_y}{F} \quad \Rightarrow \quad F_y = F\sin\theta$$

If on other hand, θ is the angle made by force F with the vertical axis, the

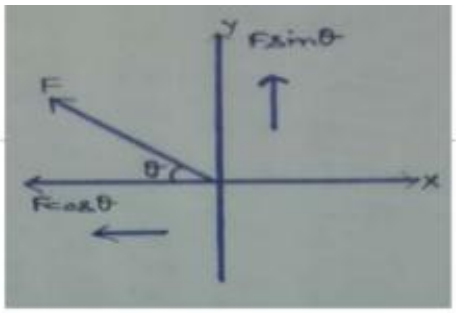
$$F_y = F\cos\theta\,; \quad F_x = F\sin\theta$$

- The single force which is going to be replaced by two or more forces is called the **resultant force**. The force which are going to replace the single force are called **components of resultant**.
- In engineering mechanics, normally a given force will be resolved into two components which are mutually perpendicular to each other. Those two mutually perpendicular components are called **rectangular components or resolved parts**.

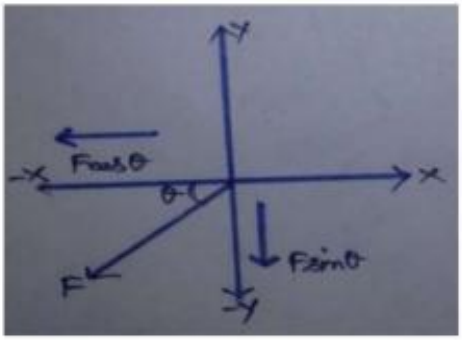
Note : quadrants and sign convention



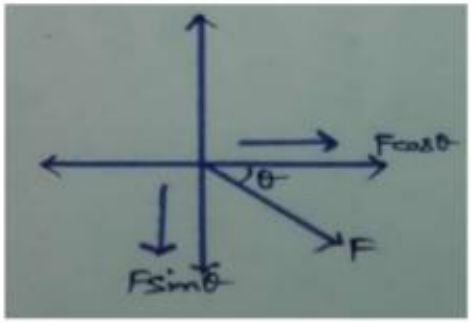
1st quadrant



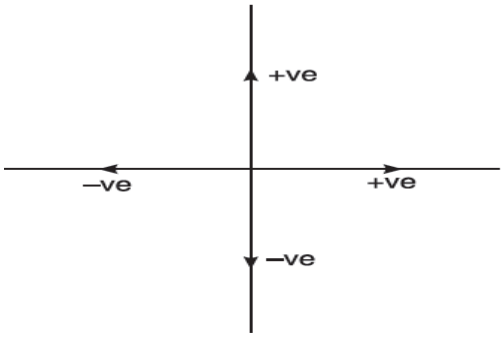
2nd quadrant



3rd quadrant



4th quadrant



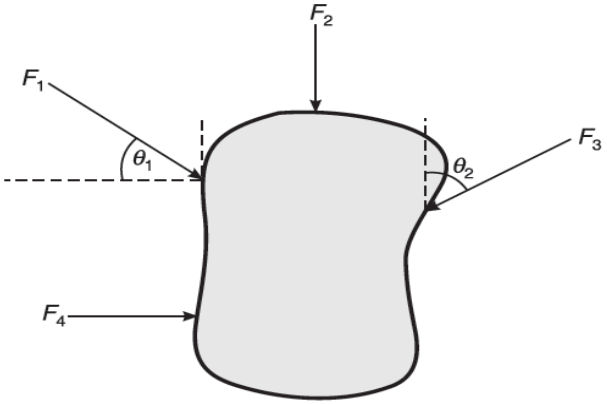
Positive and negative convention of forces.

Composition of forces

It is the process of combining a number of forces into a single force such that the net effect produced by the single force is equal to the algebraic sum of the effects produced by the individual forces. The single force in this case is called the **resultant force** which produces the same effect on the body as that produced by the individual forces acting together. Or

It is a process of determining the magnitude, direction and point of application of the resultant force of a given system of forces.

For eg, in fig- the body acted upon by number of forces.



ΣF_x = algebraic sum of the components of the forces along the x-axis

i.e. $\Sigma F_x = F_4 + F_1 \cos \theta_1 - F_3 \sin \theta_2$

and ΣF_y = algebraic sum of the components of the forces along the y-axis

i.e. $\Sigma F_y = -F_2 - F_1 \sin \theta_1 - F_3 \cos \theta_2$

$\therefore$ The magnitude of the resultant,

$$R = \sqrt{\Sigma F_x^2 + \Sigma F_y^2}$$

and the direction of the resultant,

$$\theta = \tan^{-1}\left(\frac{\Sigma F_y}{\Sigma F_x}\right)$$