MEC-107: Basic Engineering Mechanics

Text Books & References

LOVELY PROFESSIONAL UNIVERSITY

Text Books

1. Ferdinand P . Beer, E. Russell Johnston (2007), "Vector Mechanics for Engineers: Statics and Dynamics", McGraw-Hill InternationalEdition.
2. 2. J. L. Meriam and L. G. Kraige (2006), "Engineering Mechanics: Staticsand Dynamics (6th Edition)",Wiley Publishers

Reference

1. Irving H. Shames, (2003), "Engineering Mechanics – Statics and Dynamics", Prentice-Hallof India Private limited.
2. Russell C Hibbeler, (2009), "Engineering Mechanics: Statics and Dynamics (12thEdition)",Prentice Hall.
3. Anthony M. Bedford and Wallace Fowler (2007), "Engineering Mechanics: Statics and Dynamics (5th Edition)",Prentice Hall.

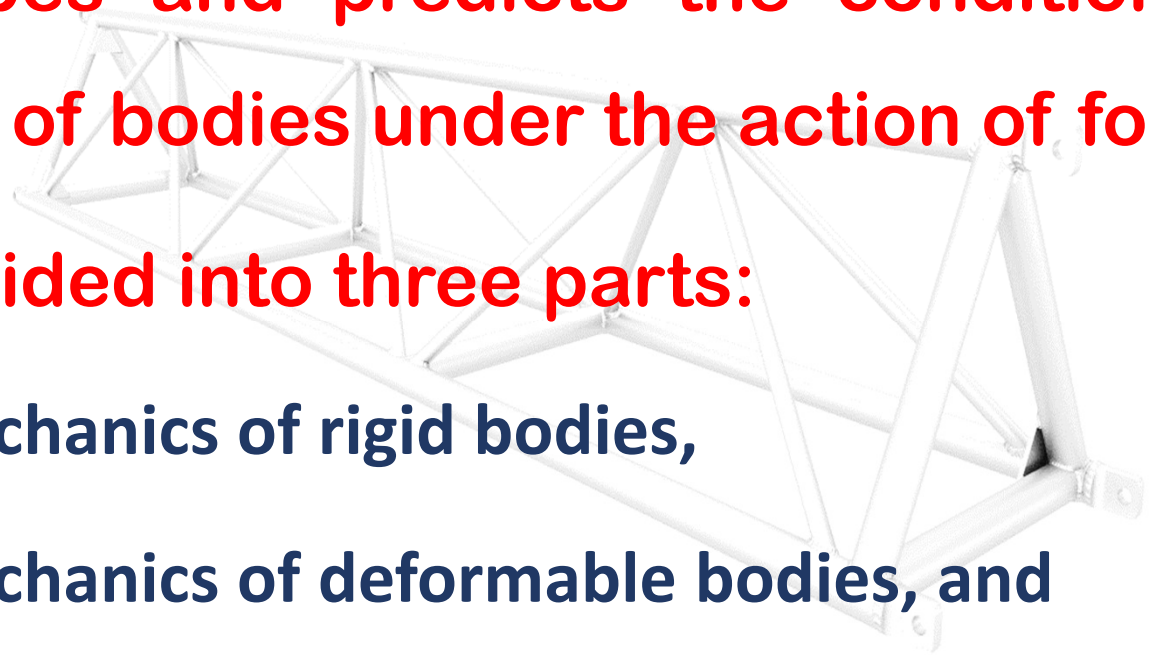
Module 1

Module	Description of Topic	Lecture Hours
1	Fundamental Principles - Coplanar forces - Resolution and Composition of forces and equilibrium of particles - Forces of a particle in space - Equivalent system of forces - Principle of transmissibility - Single equivalent force - Free body diagram - Equilibrium of rigid bodies in two dimensions and three dimension	6

WHAT IS MECHANICS?

LOVELY PROFESSIONAL UNIVERSITY

Mechanics can be defined as that science which describes and predicts the conditions of rest or motion of bodies under the action of forces.



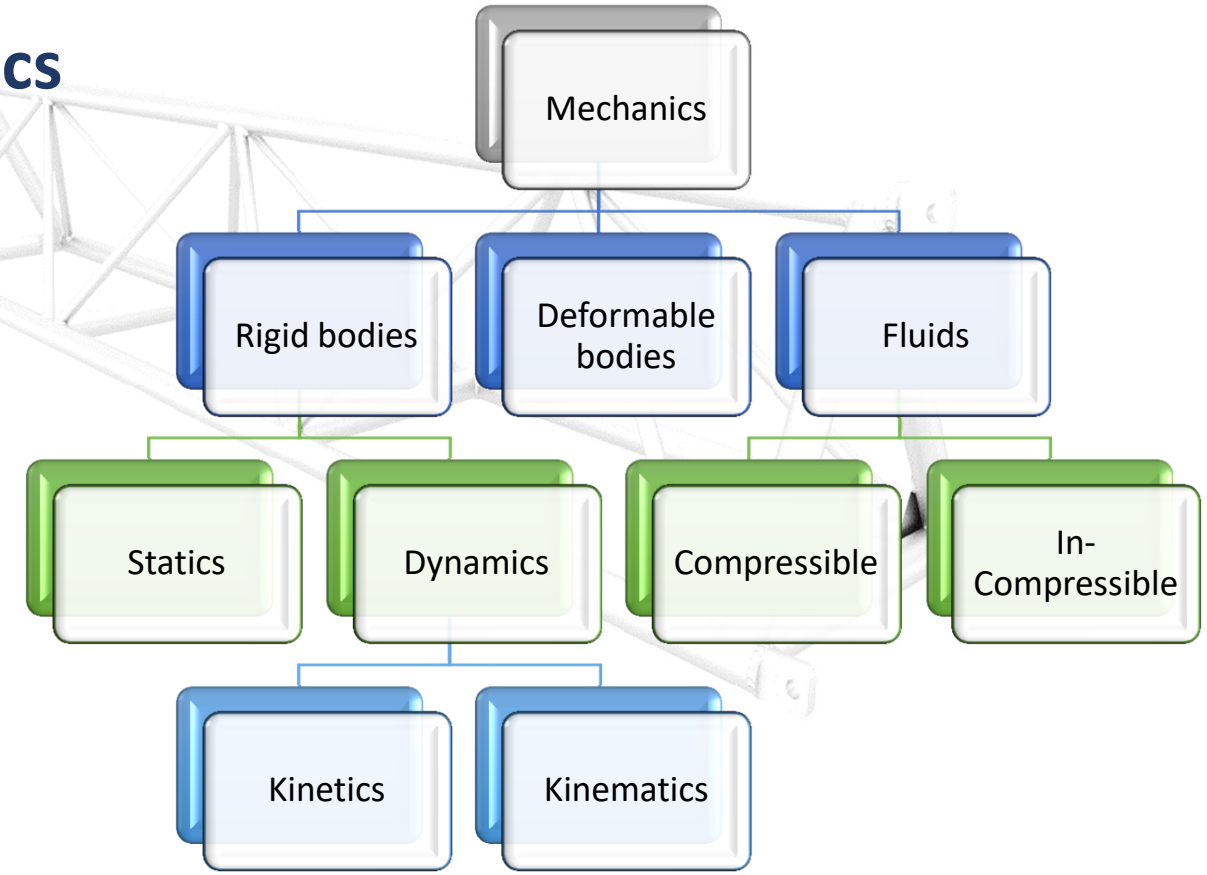
It is divided into three parts:

- Mechanics of rigid bodies,
- Mechanics of deformable bodies, and
- Mechanics of fluids.

Mechanics

The mechanics of rigid bodies is subdivided into

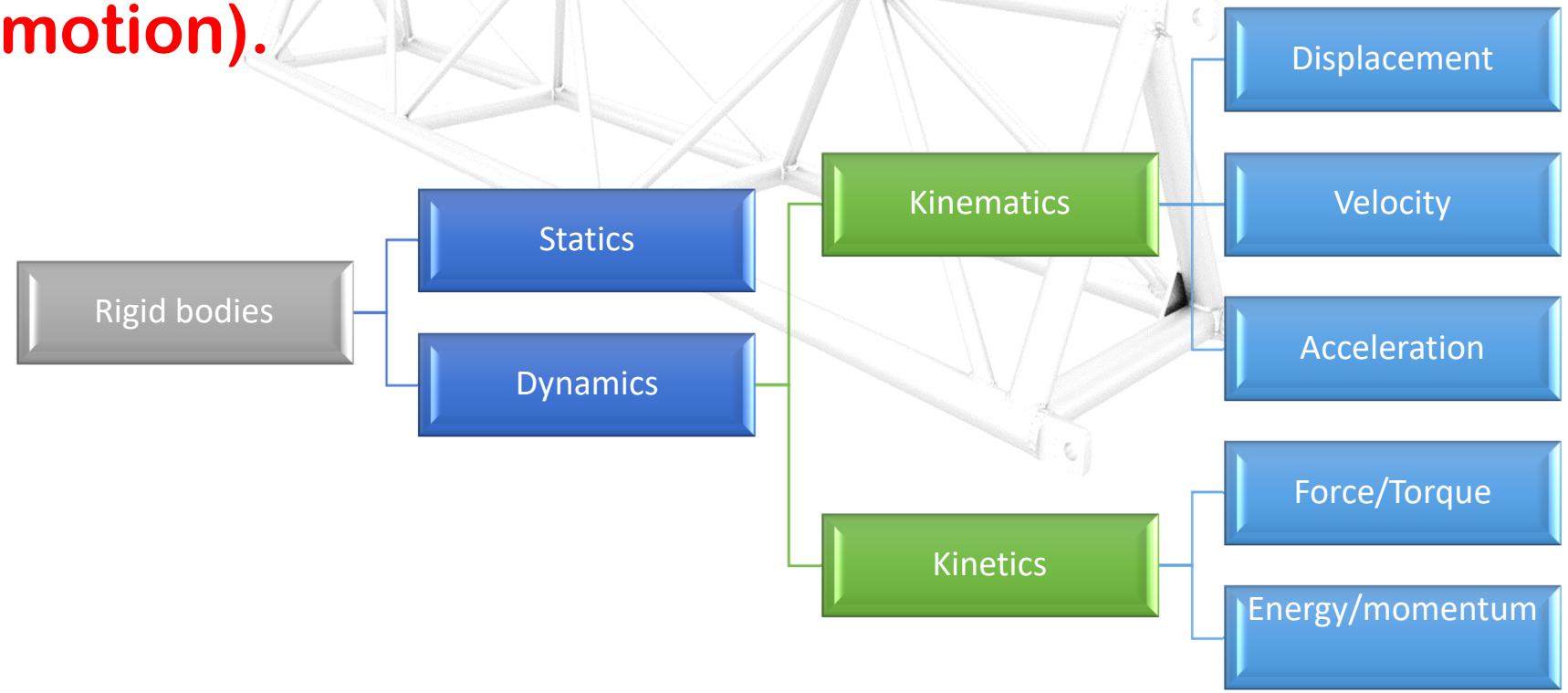
- **Statics and**
- **Dynamics**



Rigid Body Mechanics

Statics: deals with equilibrium of bodies under action of forces (bodies may be either at rest or move with a constant velocity).

Dynamics: deals with motion of bodies (accelerated motion).

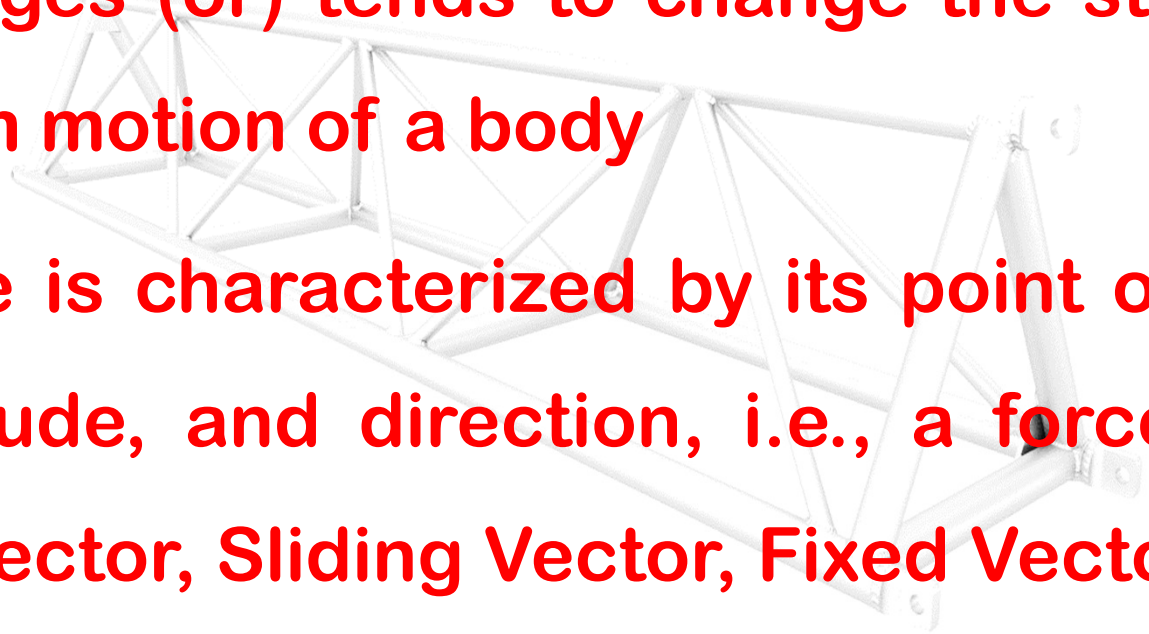


Force

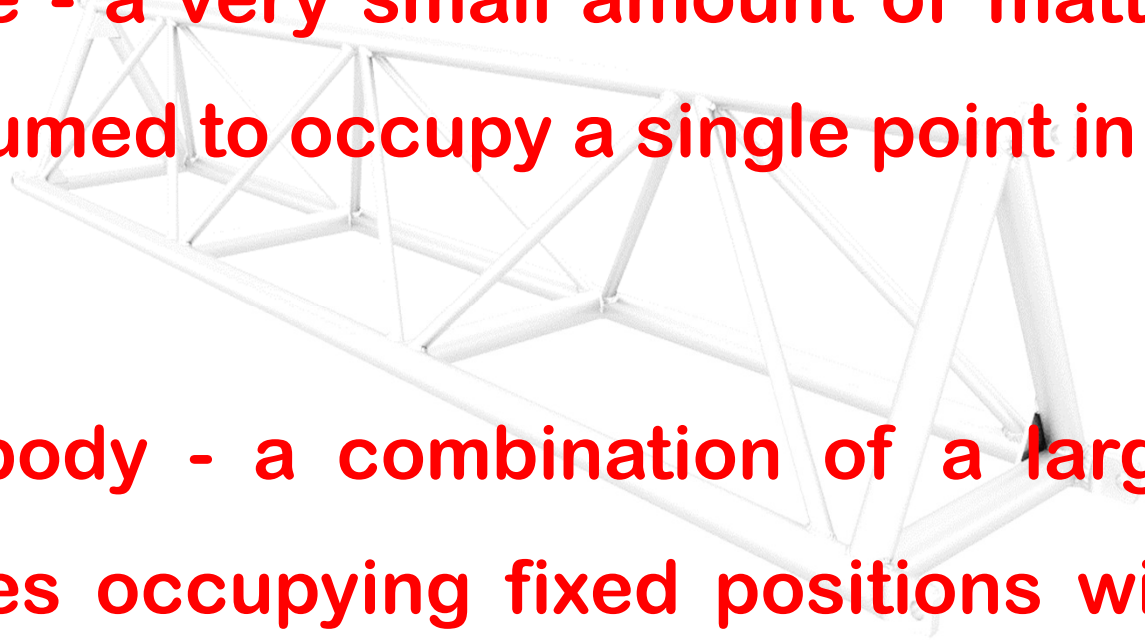
Force represents the action of one body on another.

It changes (or) tends to change the state of rest or uniform motion of a body

A force is characterized by its point of application, magnitude, and direction, i.e., a force is a vector. (Free vector, Sliding Vector, Fixed Vector)



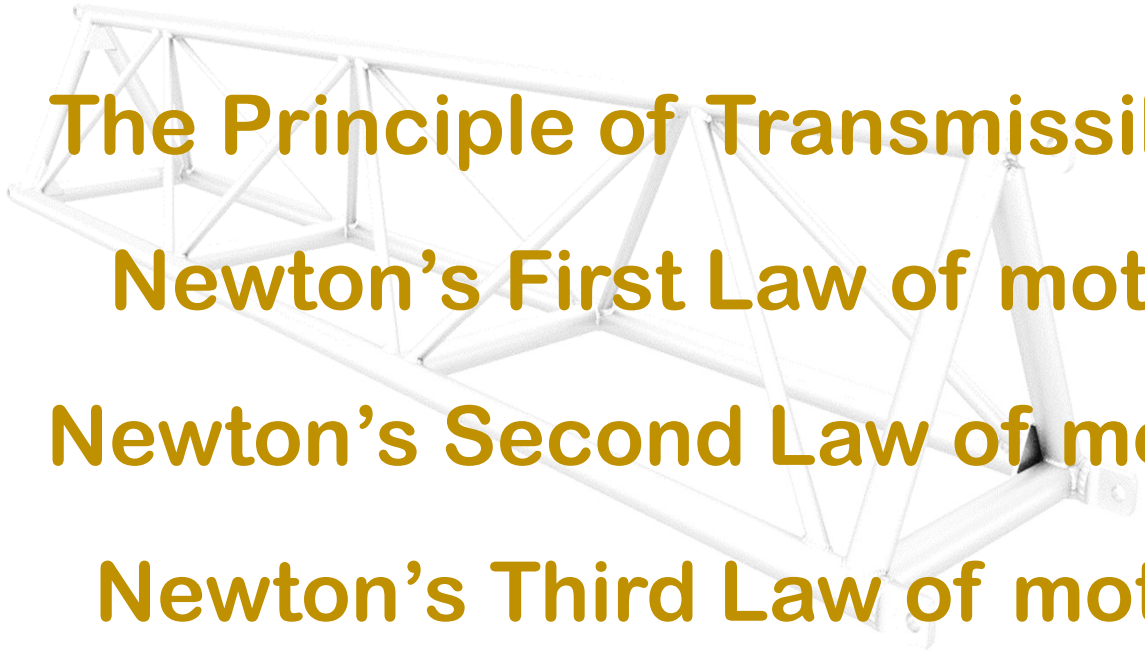
Particle & Rigid body



Particle - a very small amount of matter which may be assumed to occupy a single point in space.

Rigid body - a combination of a large number of particles occupying fixed positions with respect to each other.

SIX FUNDAMENTAL PRINCIPLES



The Parallelogram Law for the Addition of Forces.

The Principle of Transmissibility

Newton's First Law of motion

Newton's Second Law of motion

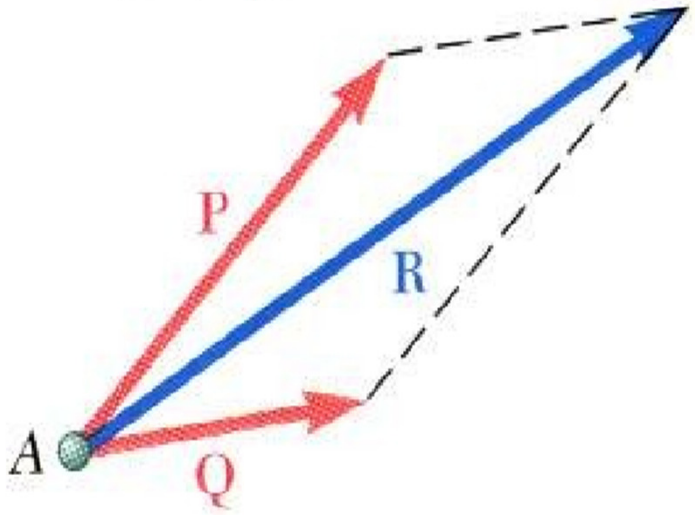
Newton's Third Law of motion

Newton's Law of Gravitation

Parallelogram Law for the Addition of Forces

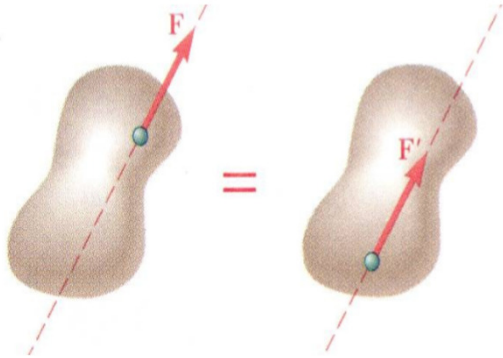
Two forces acting on a particle may be replaced by a single force, called their resultant.

It is obtained by drawing the diagonal of the parallelogram which has sides equal to the given forces.



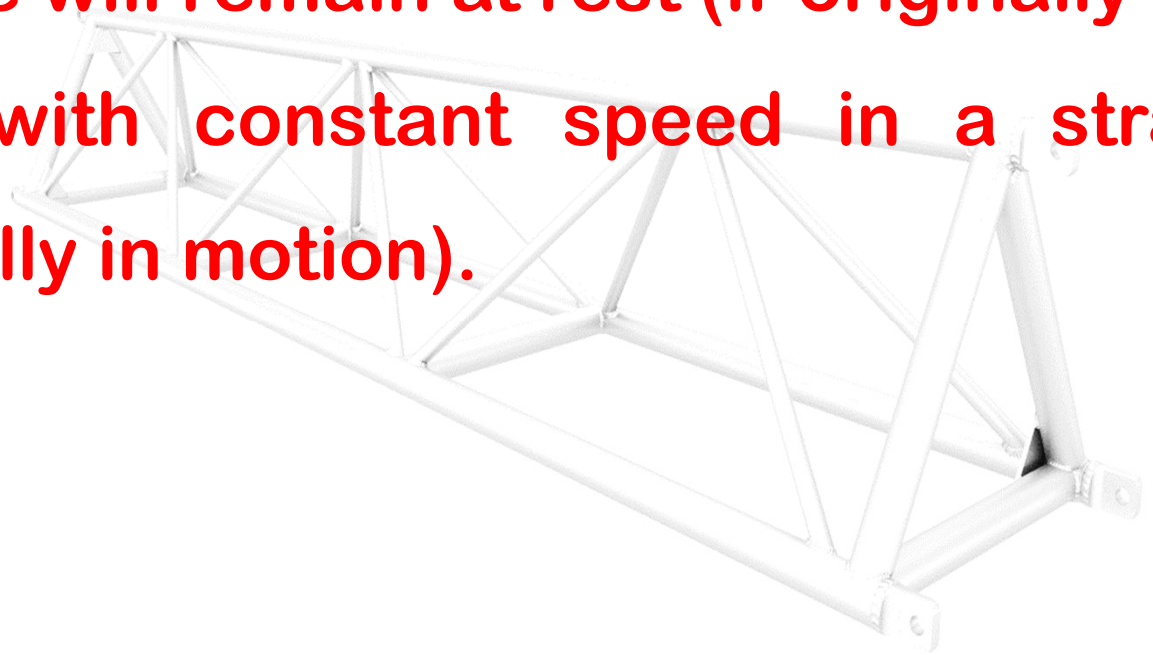
Principle of Transmissibility

The conditions of equilibrium or of motion of a rigid body will remain **unchanged** if a force acting at a given point of the rigid body is replaced by a force of the same magnitude and same direction, but acting at a different point, provided that the two forces have the same line of action.



FIRST LAW

The resultant force acting on a particle is zero, the particle will remain at rest (if originally at rest) or will move with constant speed in a straight line (if originally in motion).

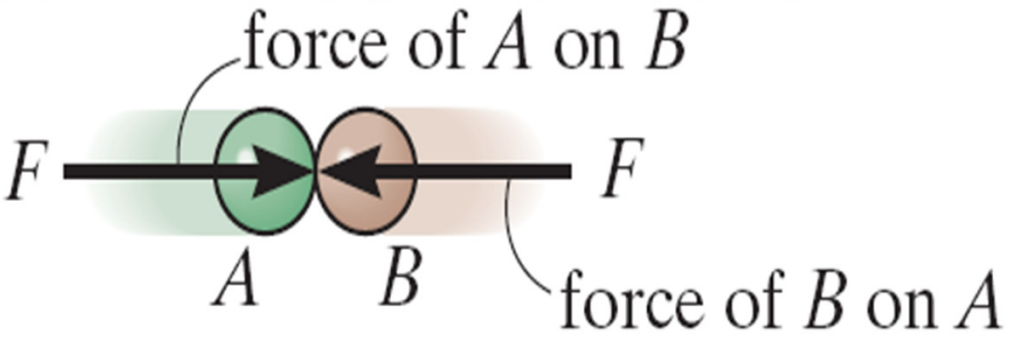


SECOND LAW

The particle will have an acceleration proportional to the magnitude of the resultant force and acceleration takes place in the direction of this resultant force. Also, acceleration is inversely proportional to mass of an object.

THIRD LAW

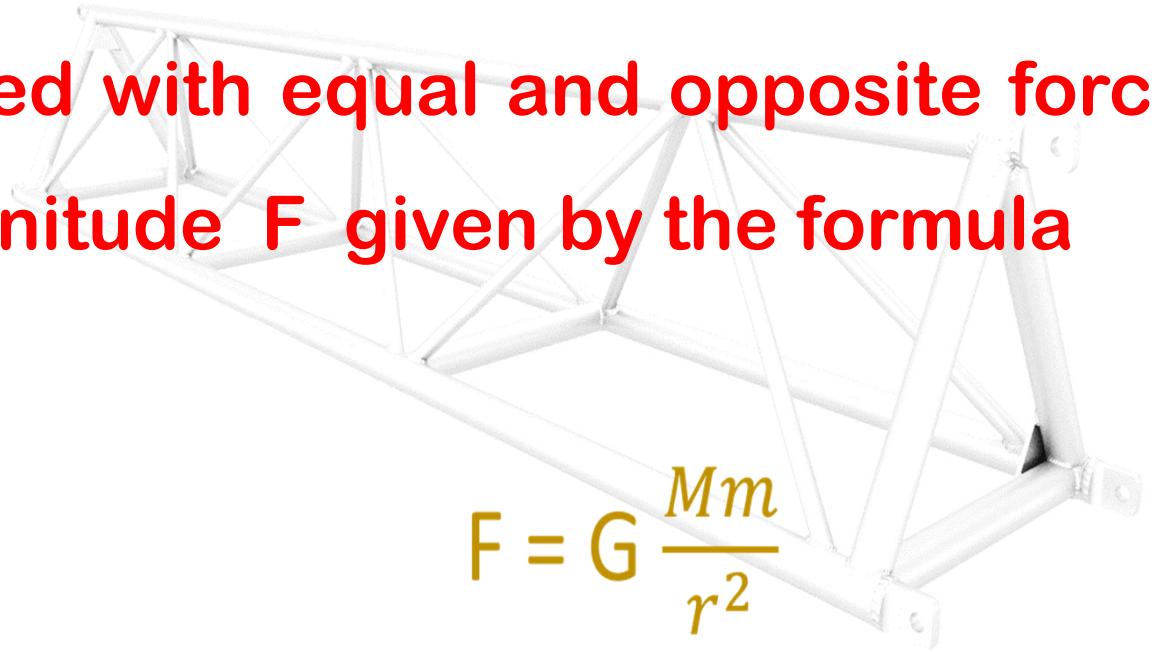
The forces of action and reaction between bodies in contact have the same magnitude, same line of action, and opposite sense



Action – reaction

Newton's Law of Gravitation

Two particles of mass M and m are mutually attracted with equal and opposite forces F and -F of magnitude F given by the formula



$$F = G\frac{Mm}{r^2}$$

Method of Problem Solution

- **Problem Statement:**

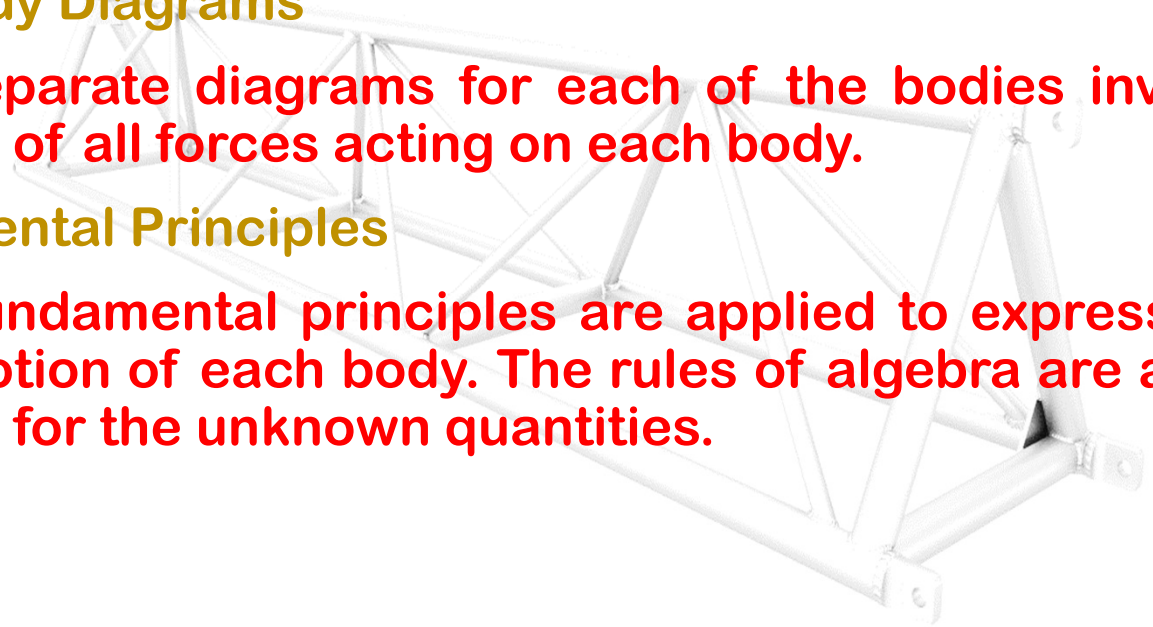
Includes given data, specification of what is to be determined, and a figure showing all quantities involved.

- **Free-Body Diagrams**

Create separate diagrams for each of the bodies involved with a clear indication of all forces acting on each body.

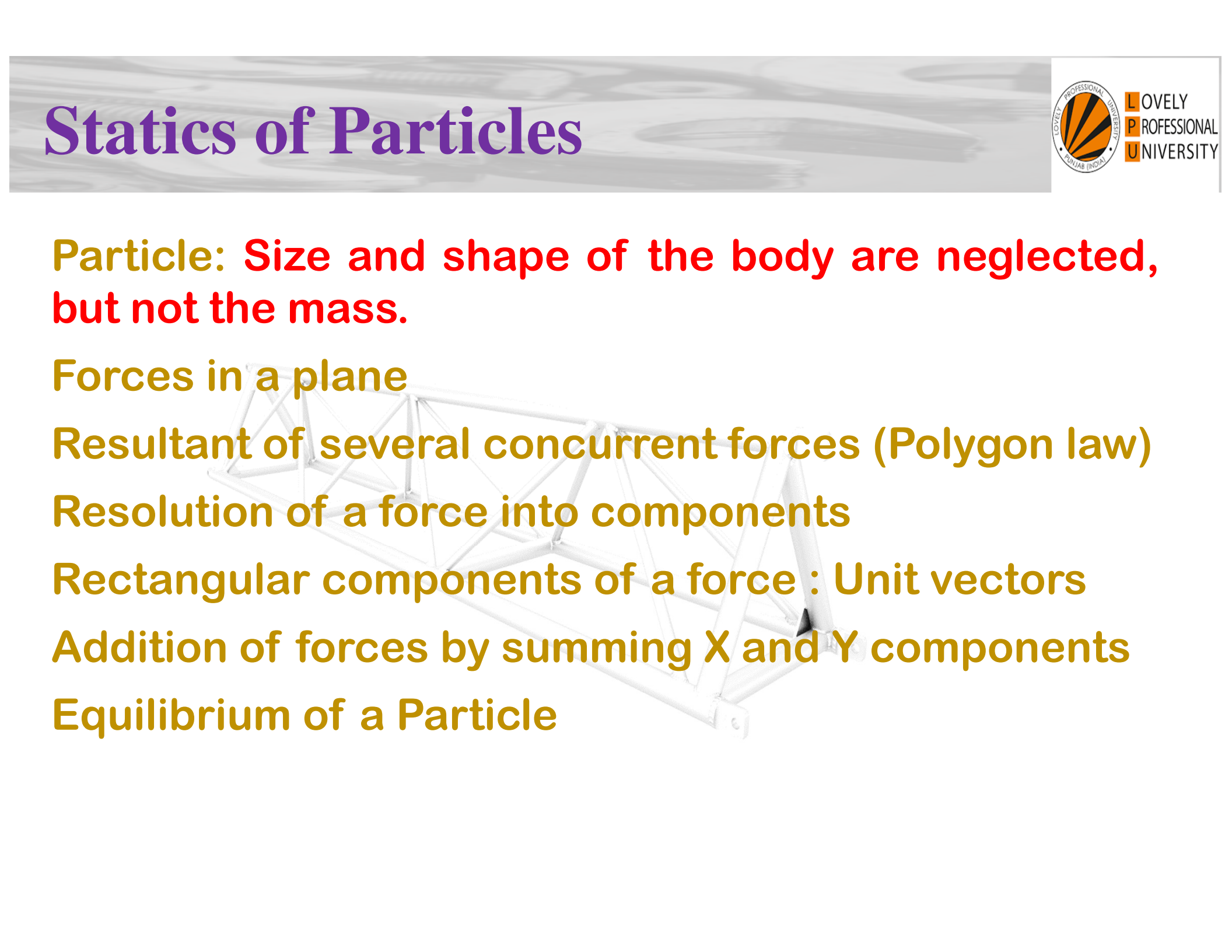
- **Fundamental Principles**

The six fundamental principles are applied to express the conditions of rest or motion of each body. The rules of algebra are applied to solve the equations for the unknown quantities.



Statics of Particles

Statics of Particles



Particle: Size and shape of the body are neglected, but not the mass.

Forces in a plane

Resultant of several concurrent forces (Polygon law)

Resolution of a force into components

Rectangular components of a force : Unit vectors

Addition of forces by summing X and Y components

Equilibrium of a Particle

Forces in a plane

A force represents the action of one body on another and is generally characterized by

- its point of application,
- its magnitude, and
- its direction

Unit: Newton (N)

1 Newton is defined as the force which gives an acceleration of 1 m/s^2 to a mass of 1 kg.

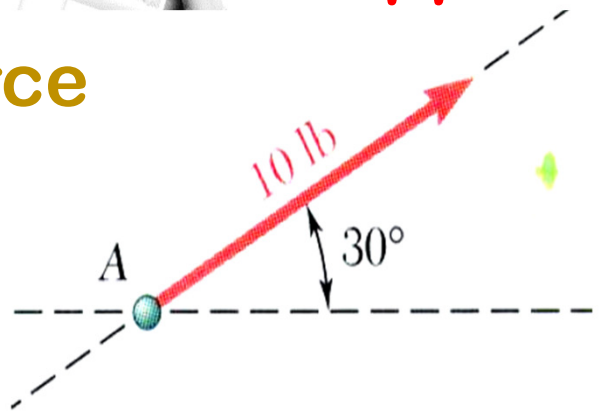
Forces

Concentrated force or a point force: it is the force acting on a very small area.

Distributed force: force distributed over a length or an area or a volume.

Line of action of force: Direction along a straight line through its point of application, in which the force tends to move a body to which it is applied.

Graphical representation of force



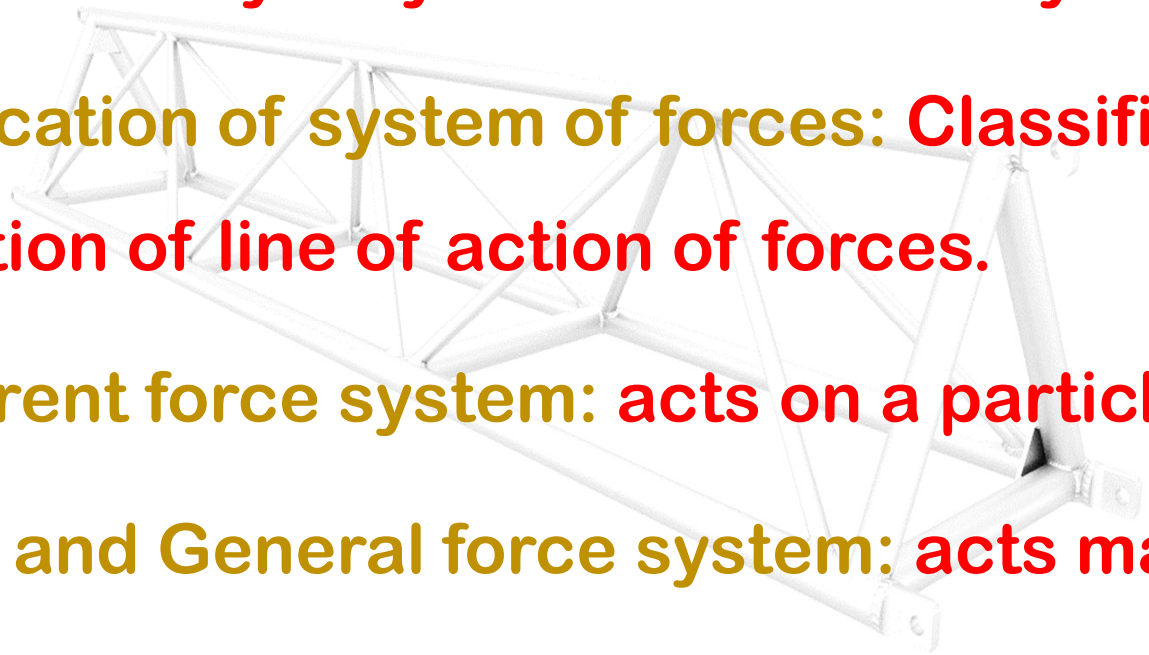
System of forces

When several forces of various magnitude and direction act upon a body they are said to form system of forces.

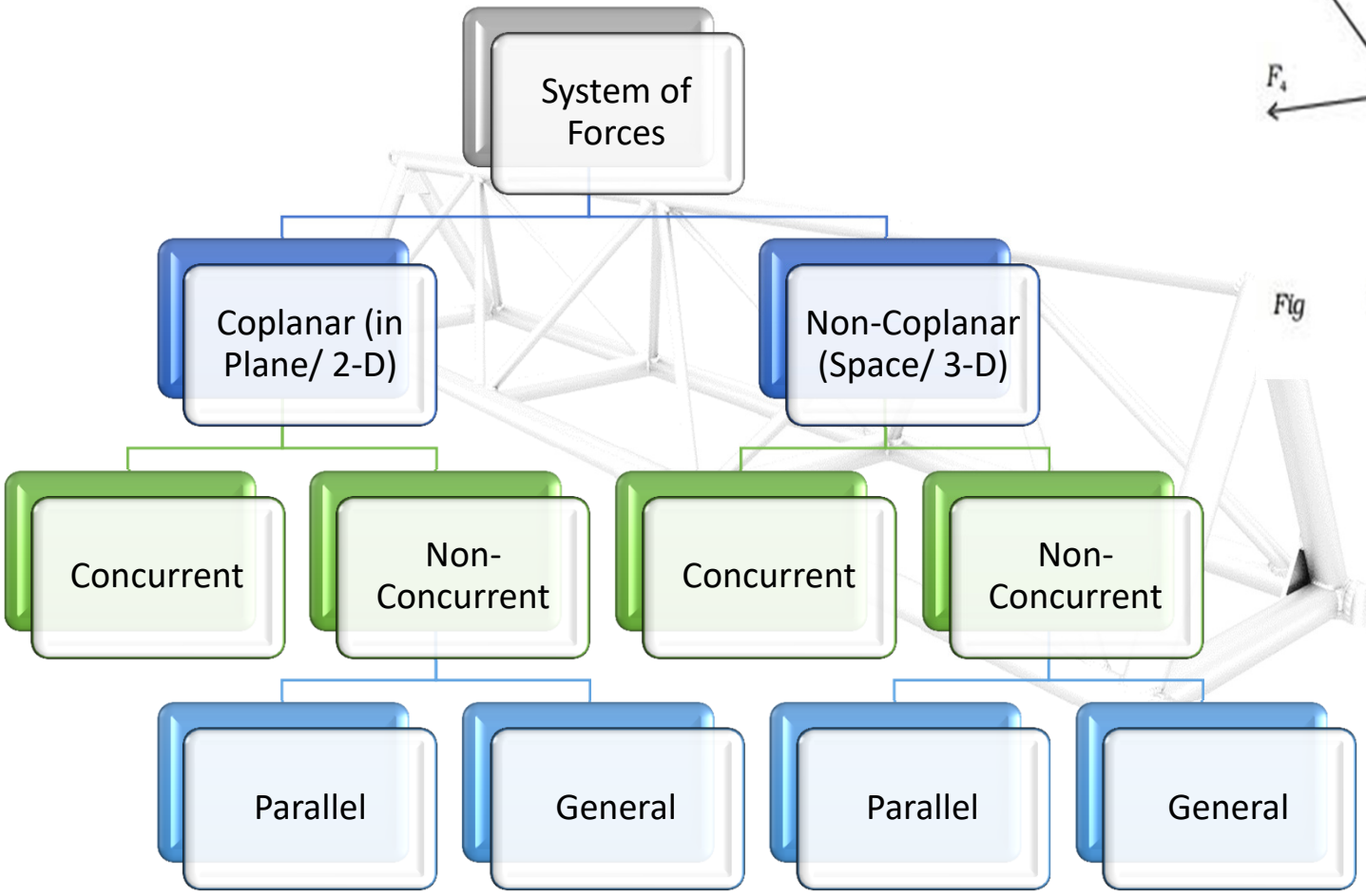
Classification of system of forces: Classified as per orientation of line of action of forces.

Concurrent force system: acts on a particle or rigid body

Parallel and General force system: acts mainly on rigid bodies



System of forces



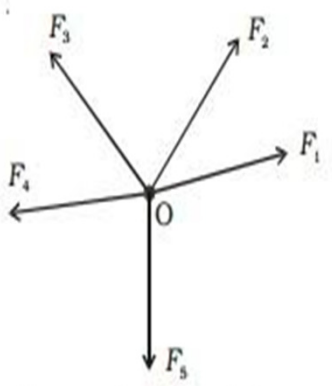


Fig Concurrent forces

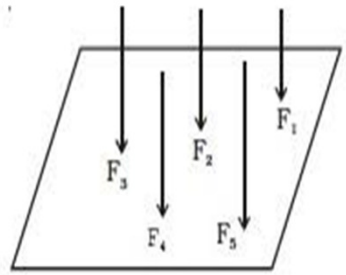
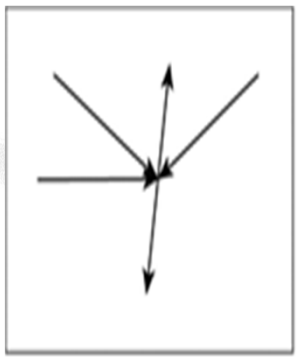
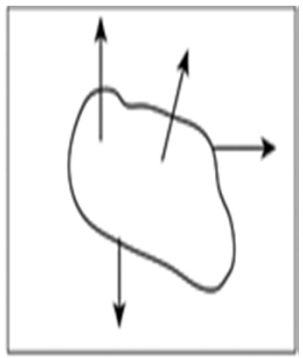


Fig Coplanar forces



Coplanar concurrent

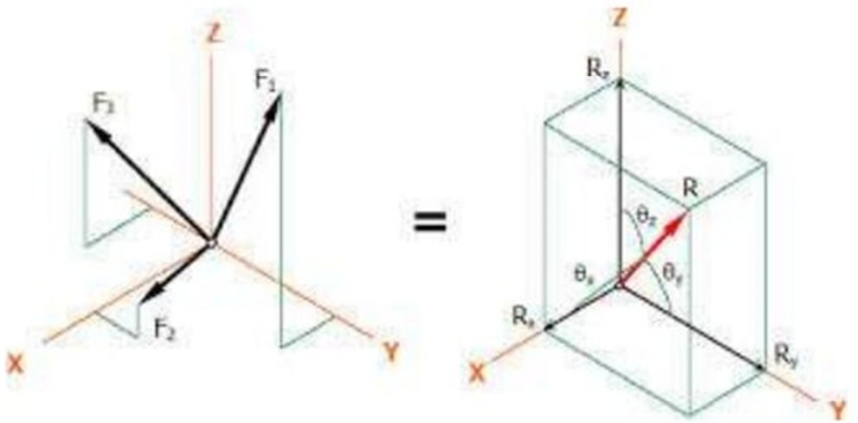


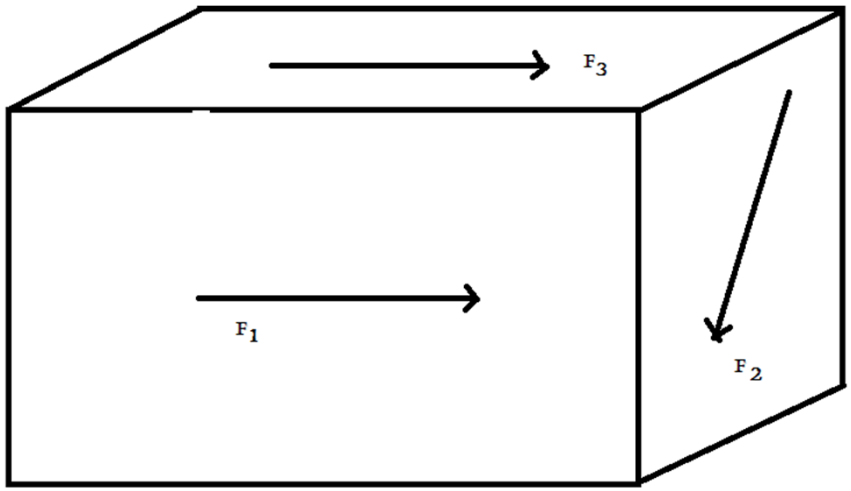
Coplanar non-concurrent

System of forces

NON-COPLANAR CONCURRENT FORCES

- *Forces whose line of action do not lie on the same plane, but they meet at one point.*





Non-coplanar non concurrent forces

Scalar & Vector

LOVELY PROFESSIONAL UNIVERSITY

Scalar

Has magnitude and no associated direction

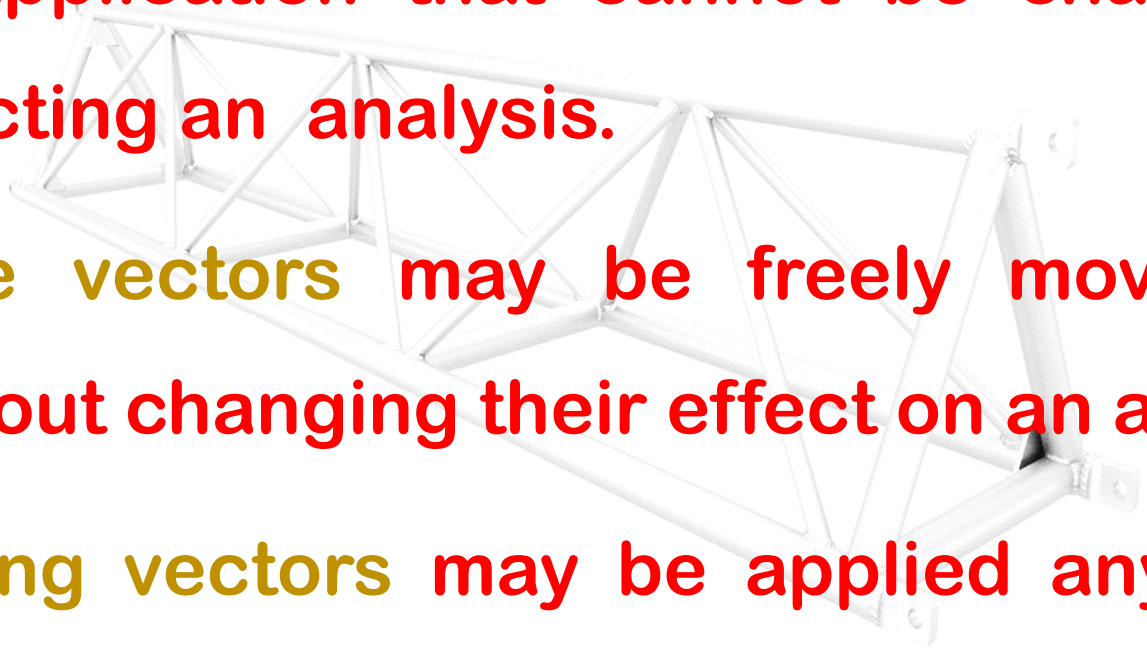
- Volume, Time, Mass, Speed, Density & Temperature.

Vector

Has magnitude and direction

- Force, Moment, Velocity & Acceleration.

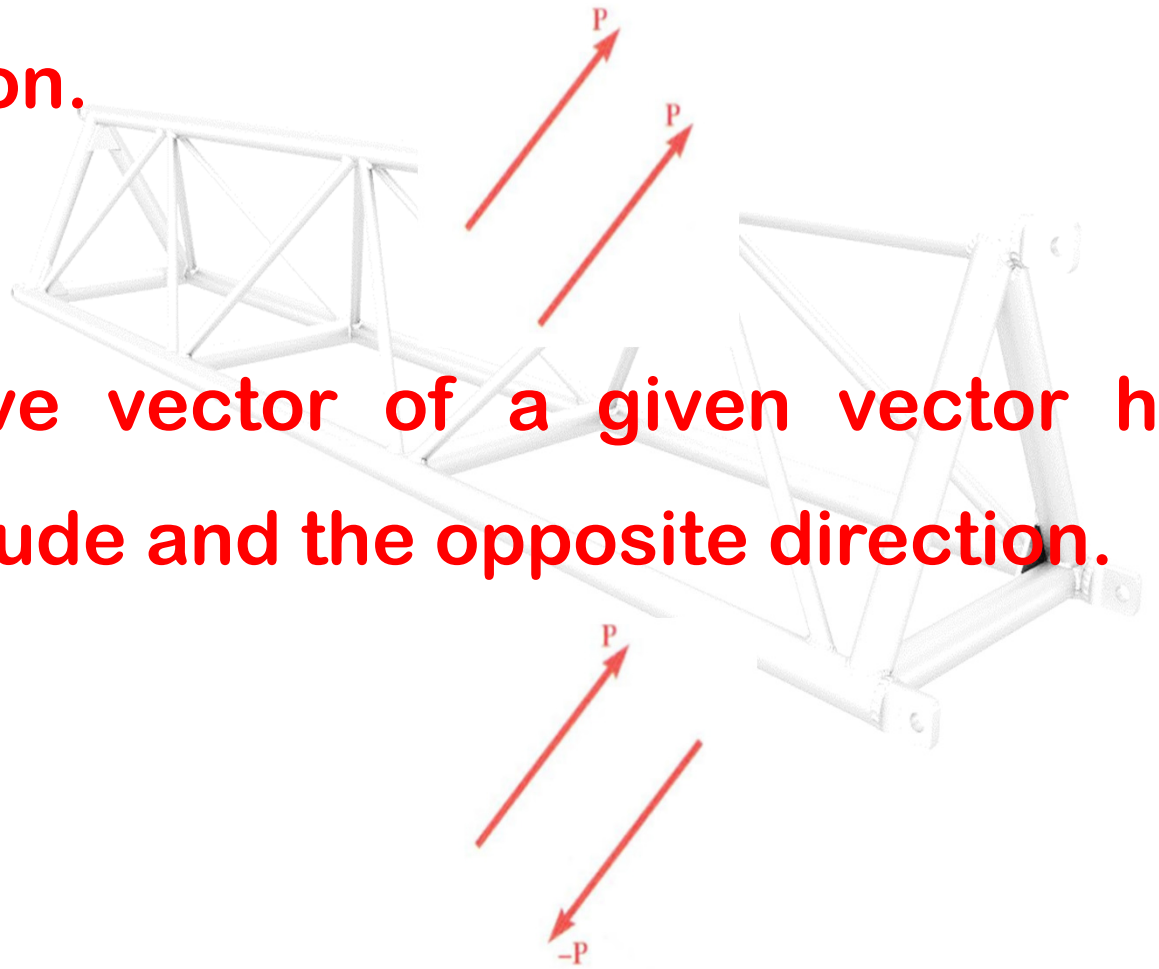
Vector classification



- Fixed or bound vectors have well defined points of application that cannot be changed without affecting an analysis.
- Free vectors may be freely moved in space without changing their effect on an analysis.
- Sliding vectors may be applied anywhere along their line of action without affecting an analysis.

Vector classification

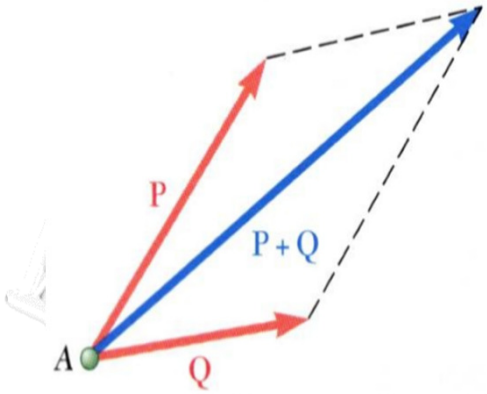
Equal vectors have the same magnitude and direction.



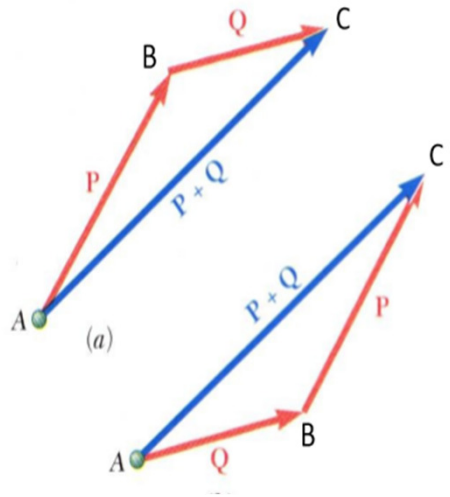
Negative vector of a given vector has the same magnitude and the opposite direction.

Addition of Vectors

- Parallelogram rule for vector addition



- Triangle rule for vector addition

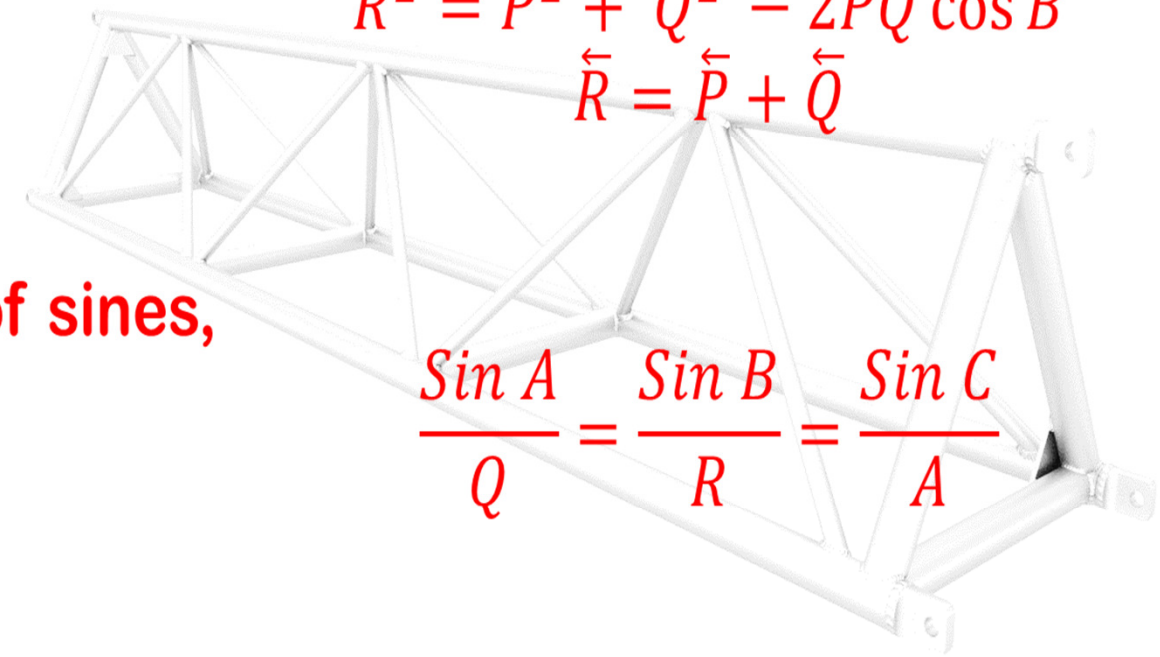


Addition of Vectors

- Law of cosines,

$$R^2 = P^2 + Q^2 - 2PQ\cos B$$

$$\overleftarrow{R} = \overleftarrow{P} + \overleftarrow{Q}$$



- Law of sines,

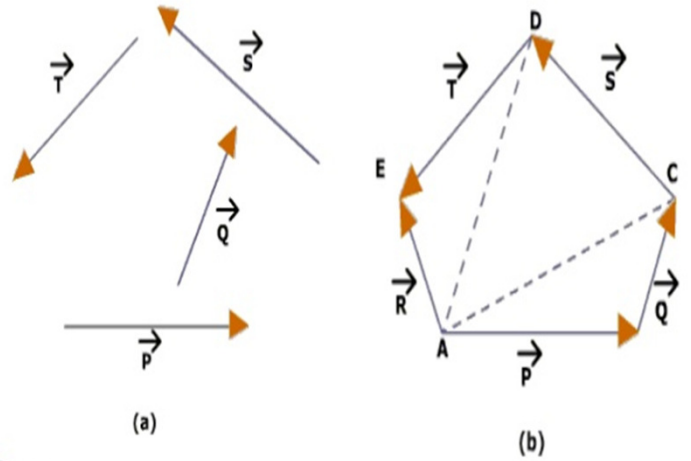
$$\frac{Sin\ A}{Q} = \frac{Sin\ B}{R} = \frac{Sin\ C}{A}$$

Addition of Vectors

Polygon Law of Forces

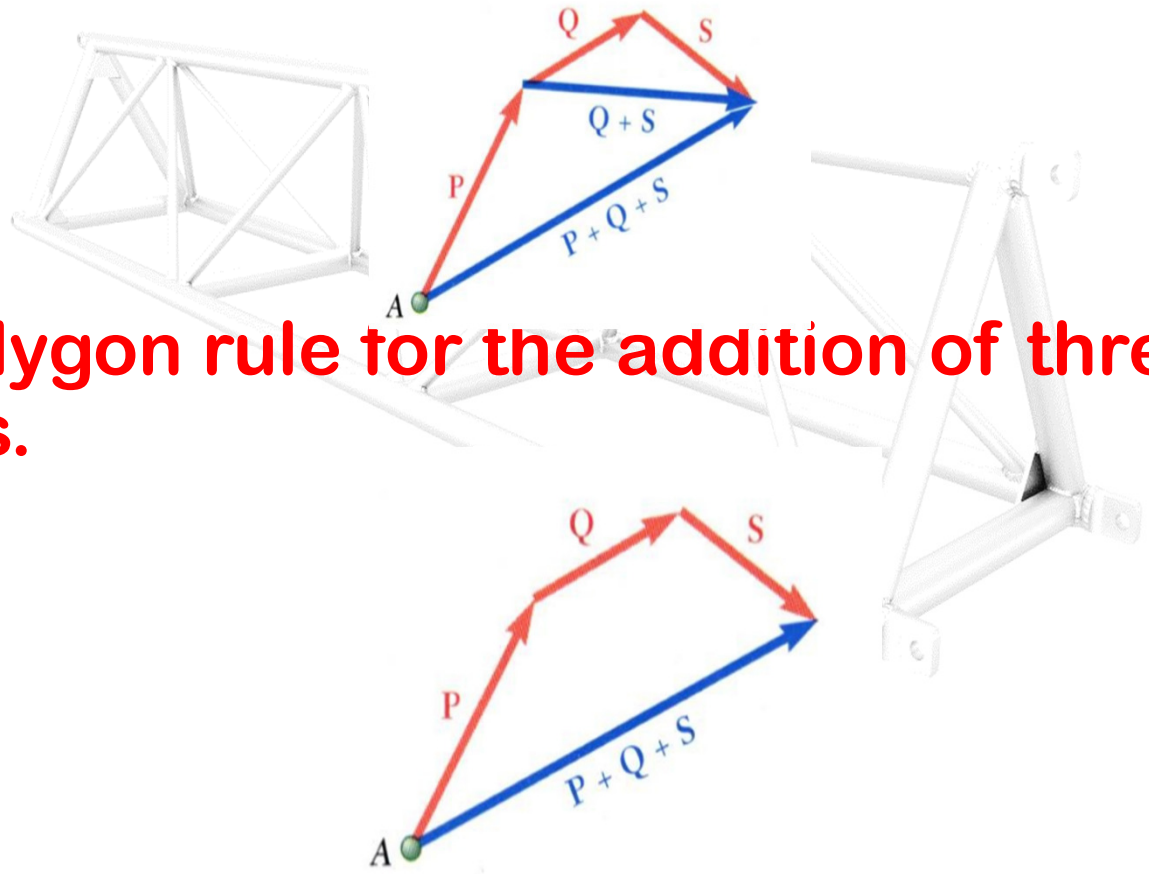
If a number of forces acting on a point be represented by the sides of a polygon taken in order then their resultant is obtained by the closing side of the polygon taken in opposite order.

Polygon Law of Forces – Graphical Method



Addition of Vectors

- Addition of three or more vectors through repeated application of the triangle rule.

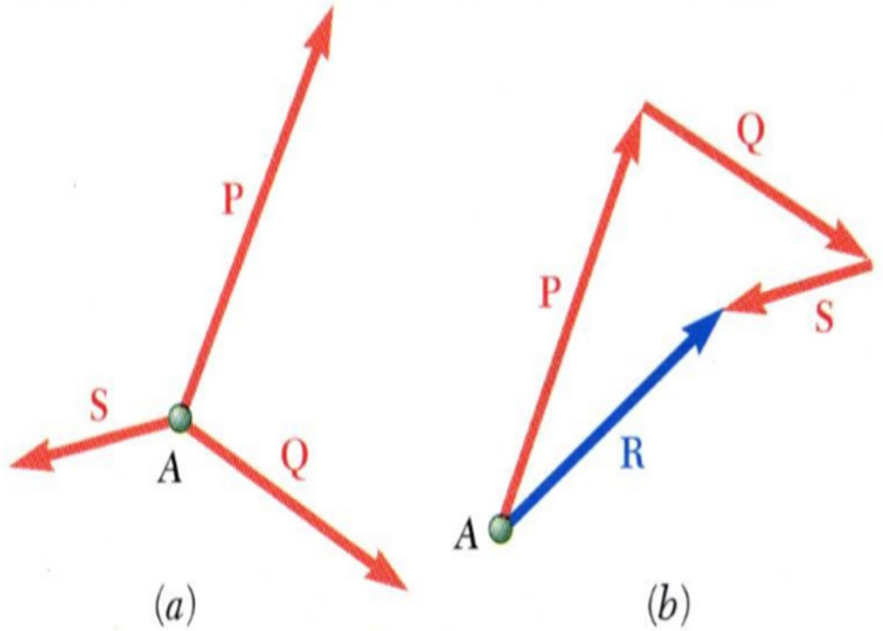


The polygon rule for the addition of three or more vectors.

Resultant of Several Concurrent Forces

Concurrent forces: set of forces which all pass through the same point.

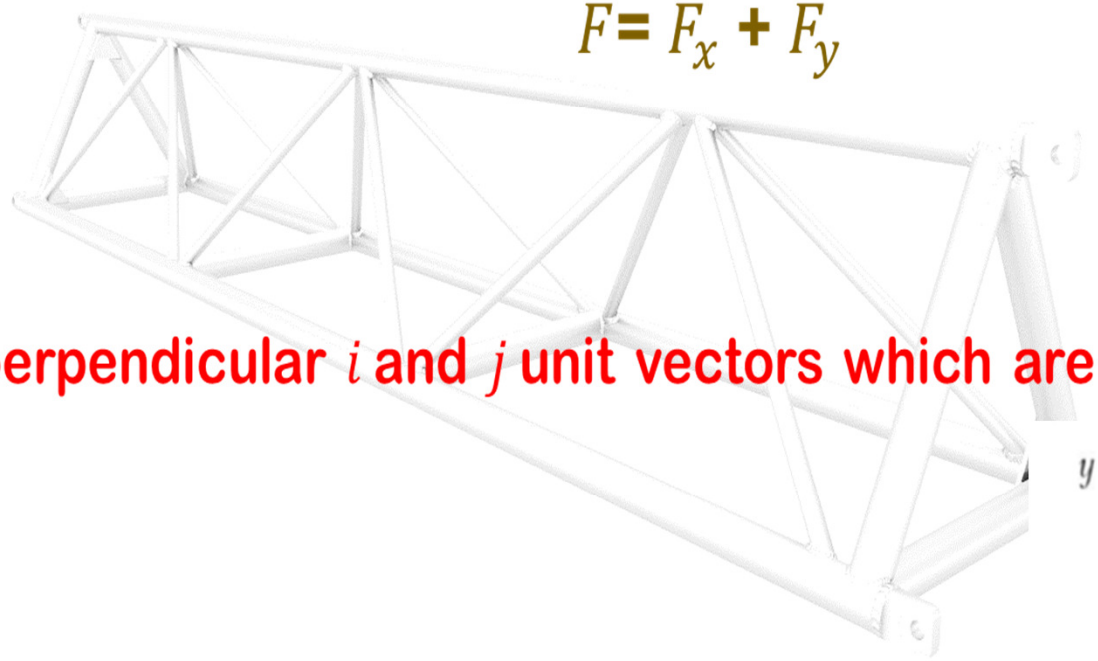
A set of concurrent forces applied to a particle may be replaced by a single resultant force which is the vector sum of the applied forces.

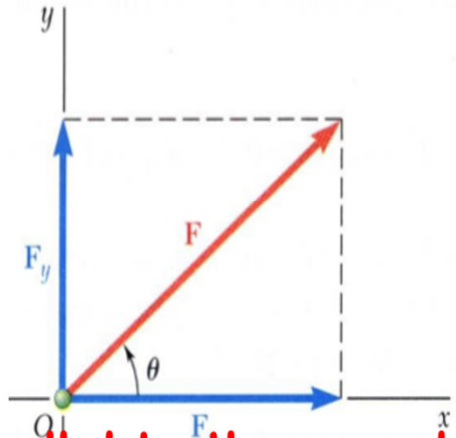


Rectangular Components of a Force:
Unit Vectors

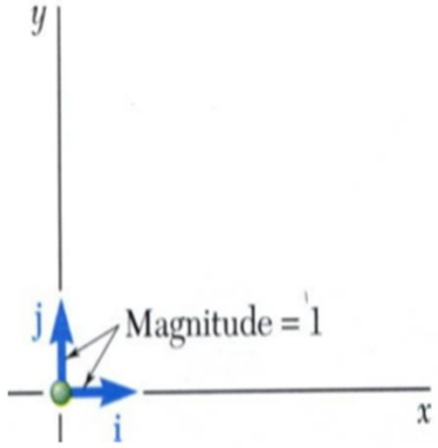
Resolve a force vector into perpendicular components so that the resulting parallelogram is a rectangle. $\overrightarrow{F_x}$ and $\overrightarrow{F_y}$ are referred to as rectangular vector components

$$\vec{F} = \overrightarrow{F_x} + \overrightarrow{F_y}$$





- Define perpendicular i and j unit vectors which are parallel to the x and y axes.



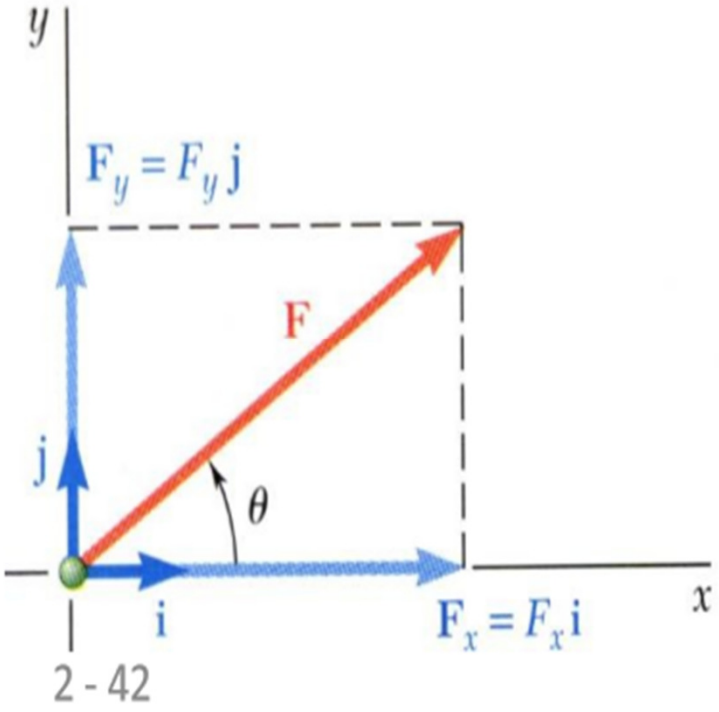
Rectangular Components of a Force:
Unit Vectors

LOVELY PROFESSIONAL UNIVERSITY

- Vector components may be expressed as products of the unit vectors with the scalar magnitudes of the vector components

$$\vec{F} = F_x\vec{i} + F_y\vec{j}$$

Fx and Fy are referred to as the scalar components of $\vec{F}$.

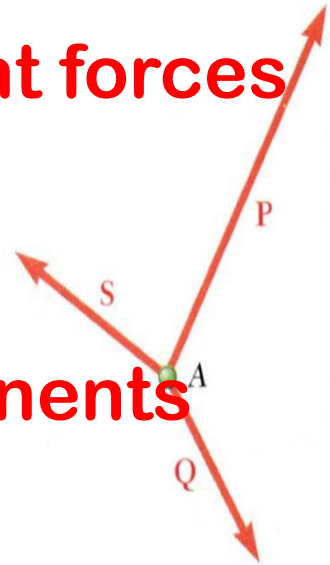


Addition of Forces by Summing Components

LOVELY PROFESSIONAL UNIVERSITY

To find the resultant of 3 or more concurrent forces

$$\vec{R} = \vec{P} + \vec{Q} + \vec{S}$$



Resolve each force into rectangular components

$$R_x\vec{i} + R_y\vec{j} = P_x\vec{i} + P_y\vec{j} + Q_x\vec{i} + Q_y\vec{j} + S_x\vec{i} + S_y\vec{j}$$

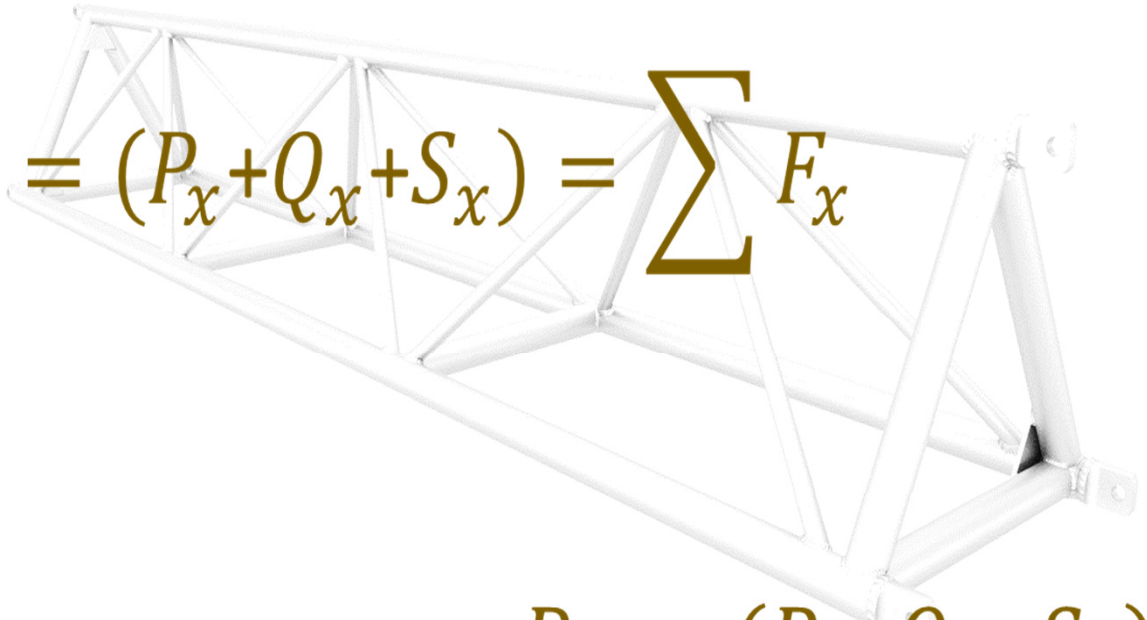
$$= (P_x + Q_x + S_x)\vec{i} + (P_y + Q_y + S_y)\vec{j}$$

The scalar components of the resultant are equal to the sum of the corresponding scalar components of the given forces

Scalar Components of resultant

LOVELY PROFESSIONAL UNIVERSITY

The scalar components of the resultant are equal to the sum of the corresponding scalar components of the given forces.



$$R_x = (P_x + Q_x + S_x) = \sum F_x$$

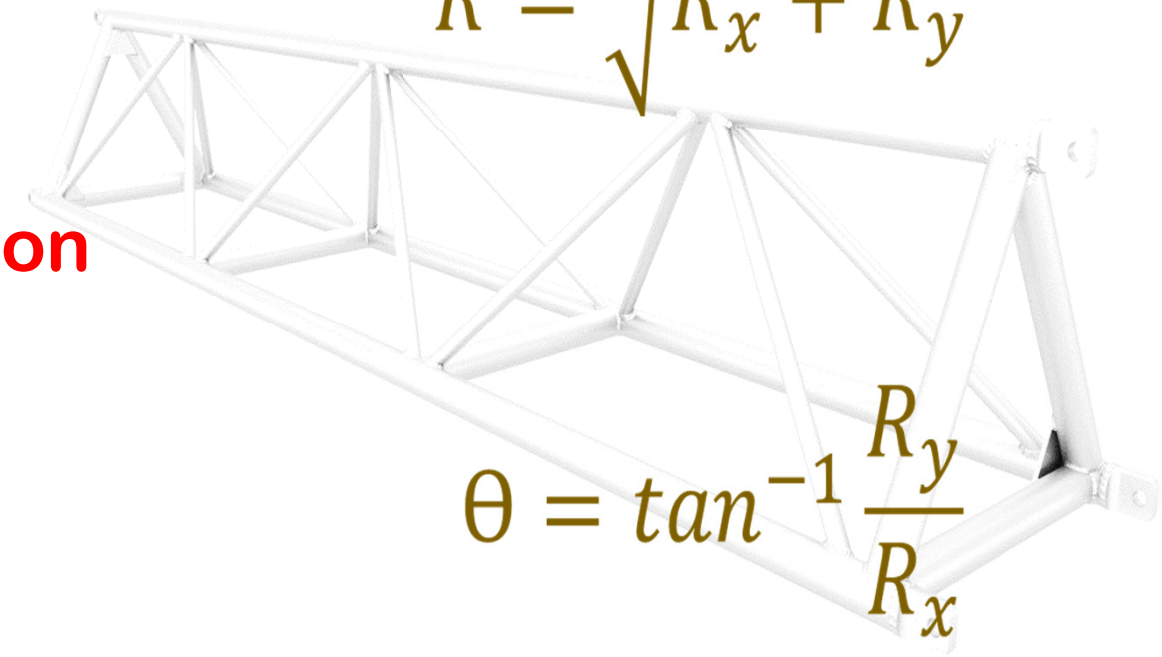
$$R_y = (P_y + Q_y + S_y) = \sum F_y$$

Magnitude and Direction of RESULTANT

LOVELY PROFESSIONAL UNIVERSITY

Magnitude

$$R = \sqrt{R_x^2 + R_y^2}$$

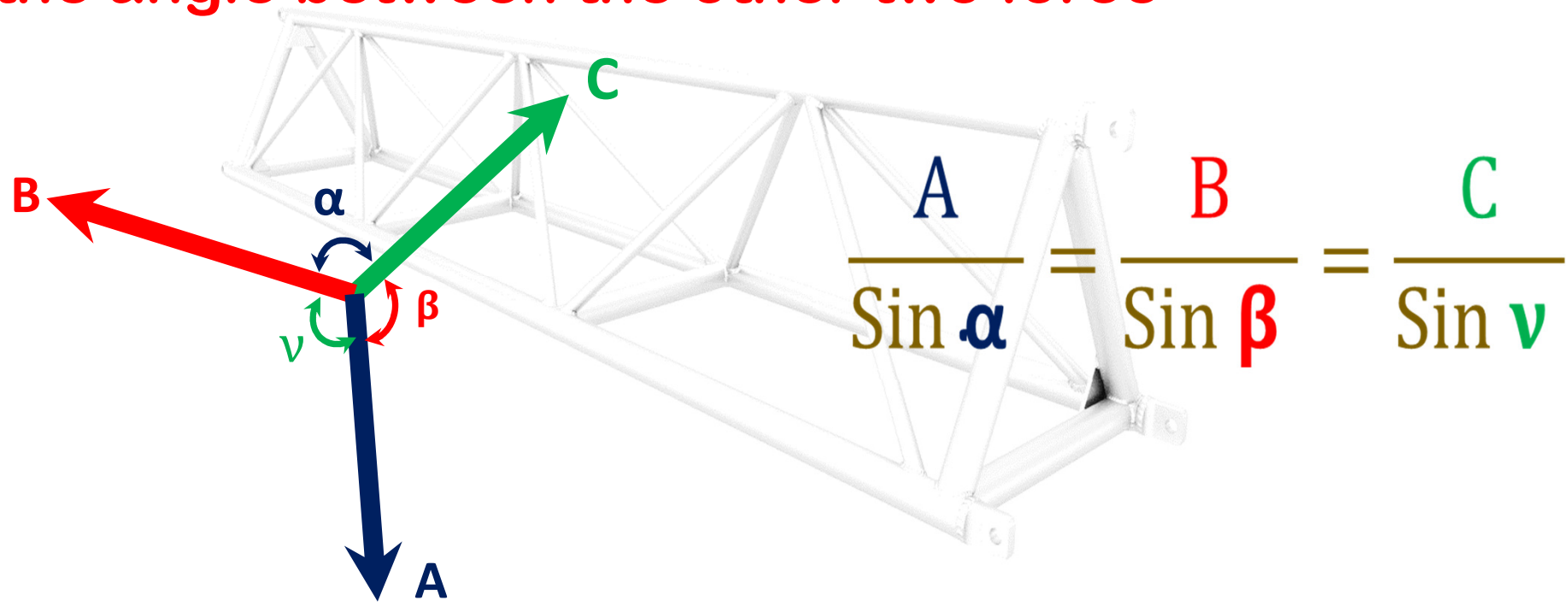


Direction

$$\theta = tan^{-1}\frac{R_y}{R_x}$$

Lami's Theorem

If the three forces acting at a point are in equilibrium, each force is proportional to the sine of the angle between the other two force



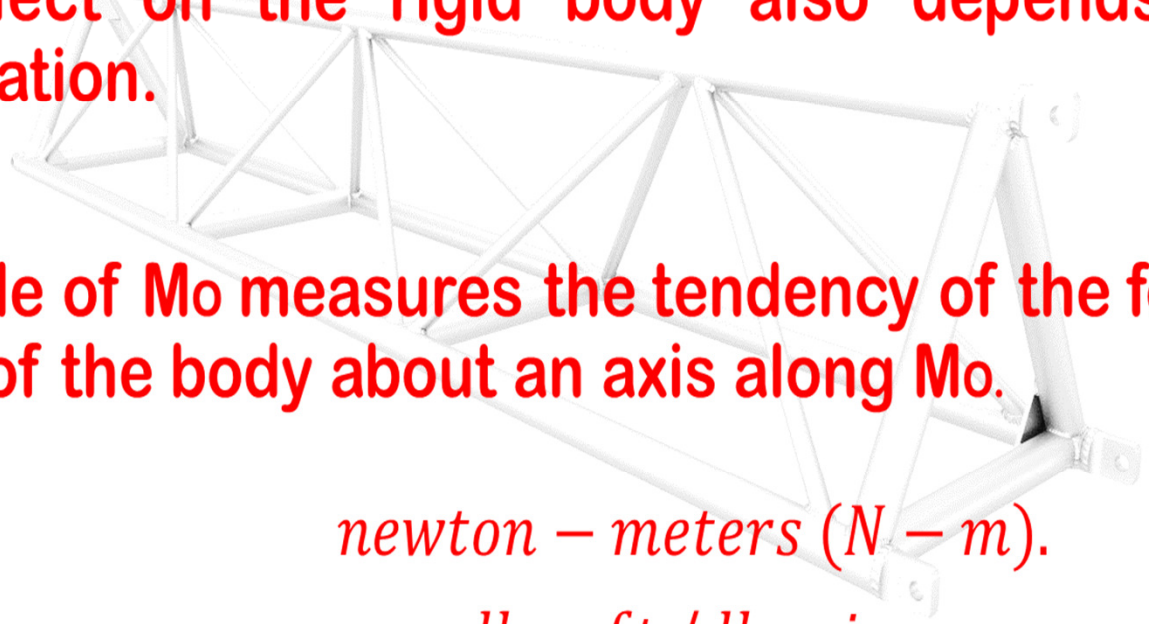
$$\frac{A}{\sin \alpha} = \frac{B}{\sin \beta} = \frac{C}{\sin \nu}$$

While using Lami's theorem, all the three forces should be either directed away or all directed towards the point of concurrence

Moment of a Force About a Point

- A force vector is defined by its magnitude and direction.

- Its effect on the rigid body also depends on it point of application.



Magnitude of M_O measures the tendency of the force to cause rotation of the body about an axis along M_O.

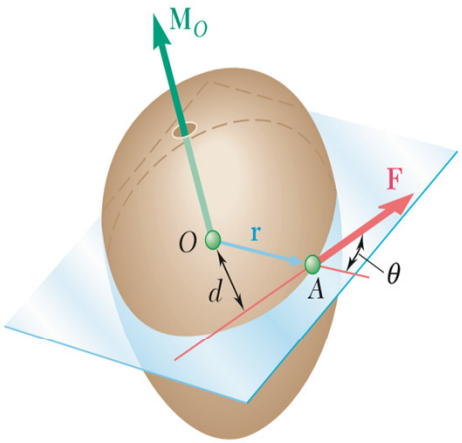
$$newton - meters\ (N - m).$$

$$lb - ft\ /\ lb - in.$$

Moment

The moment of F about O is defined a

$$M_o = r \times F$$



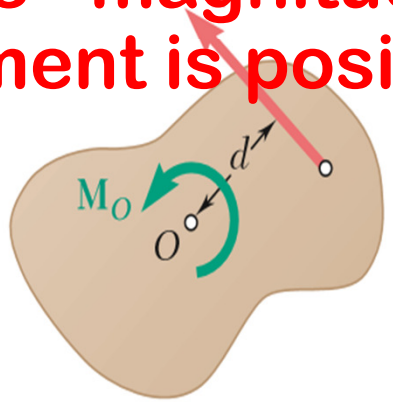
The moment vector Mo is perpendicular to the plane containing O and the force F.

The sense of the moment may be determined by the right-hand rule.

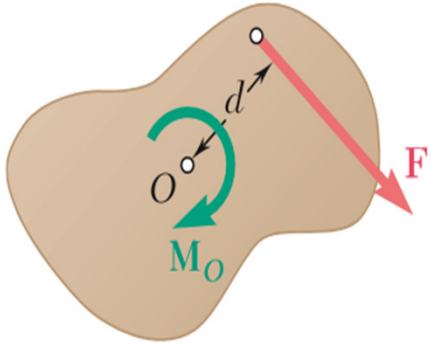
Moment in Two Dimensional System

If the force tends to rotate the structure counterclockwise, the sense of the moment vector is out of the plane of the structure and the magnitude of the moment is positive.

If the force tends to rotate the structure clockwise, the sense of the moment vector is into the plane of the structure and the magnitude of the moment



$(a)\ \mathbf{M}_O = +Fd$

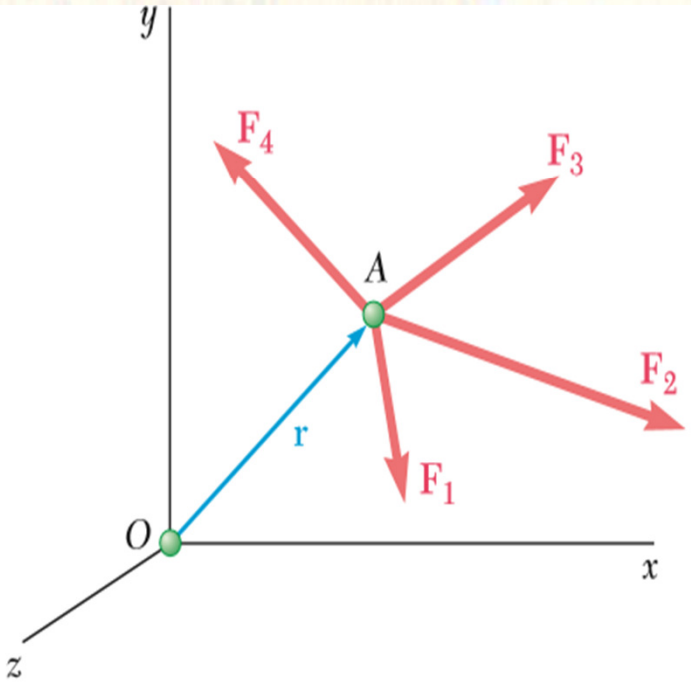


$(b)\ \mathbf{M}_O = -Fd$

Varignon's Theorem

The moment about a given point O of the resultant of several concurrent forces is equal to the sum of the moments of the various forces about the same point O.

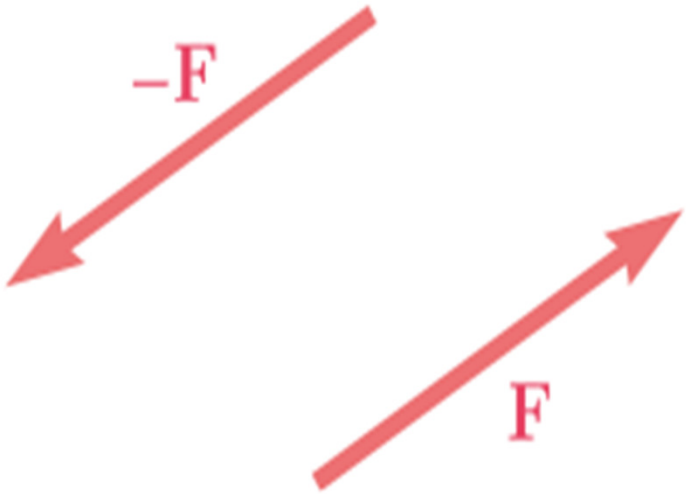
$$\mathbf{r} \times (\mathbf{F}_1 + \mathbf{F}_2 + \cdots) = \mathbf{r} \times \mathbf{F}_1 + \mathbf{r} \times \mathbf{F}_2 + \cdots$$

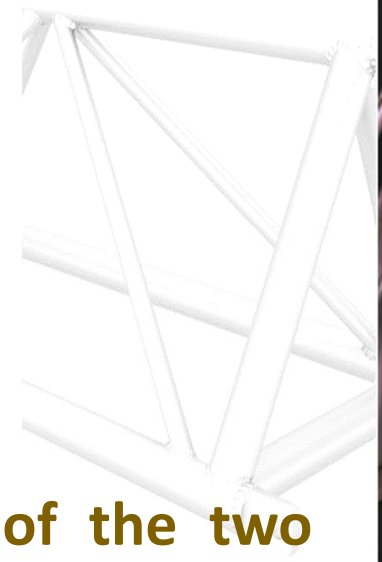


French mathematician Varignon (1654–1722) long before the introduction of vector algebra, is known as Varignon's theorem.

Couple

Two forces F and -F having the same magnitude, parallel lines of action, and opposite sense are said to





- The sum of the components of the two forces in any direction is zero.
- The sum of the moments of the two forces about a given point, however, is not zero.

4.9. ARM OF A COUPLE

The perpendicular distance (a), between the lines of action of the two equal and opposite parallel forces, is known *as arm of the couple* as shown in Fig. 4.11.

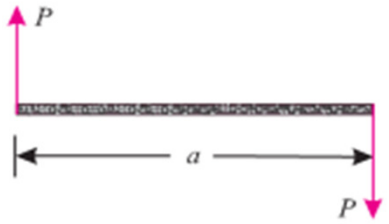


Fig. 4.11.

4.10. MOMENT OF A COUPLE

The moment of a couple is the product of the force (*i.e.*, one of the forces of the two equal and opposite parallel forces) and the arm of the couple. Mathematically:

Moment of a couple $= P \times a$

where P = Magnitude of the force, and

a = Arm of the couple.

4.11. CLASSIFICATION OF COUPLES

The couples may be, broadly, classified into the following two categories, depending upon their direction, in which the couple tends to rotate the body, on which it acts :

1. Clockwise couple, and 2. Anticlockwise couple.

4.12. CLOCKWISE COUPLE

A couple, whose tendency is to rotate the body, on which it acts, in a clockwise direction, is known as a clockwise couple as shown in Fig. 4.12 (a). Such a couple is also called positive couple.

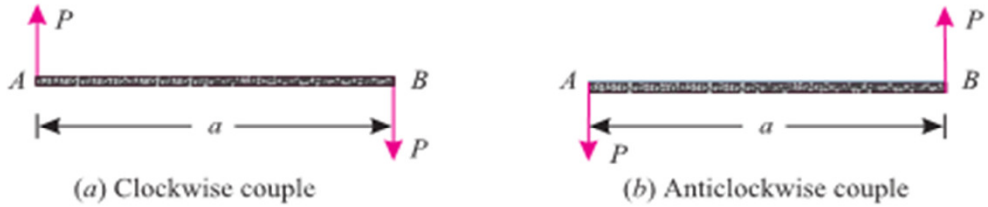


Fig. 4.12.

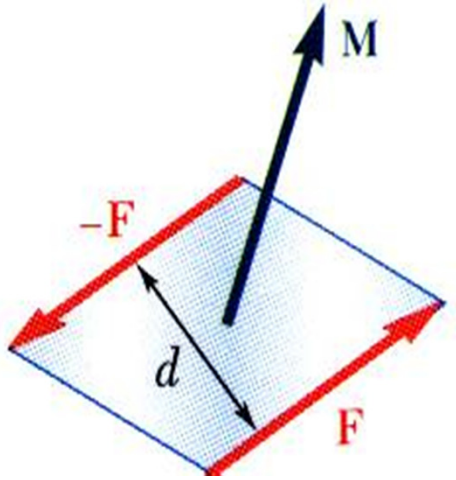
4.13. ANTICLOCKWISE COUPLE

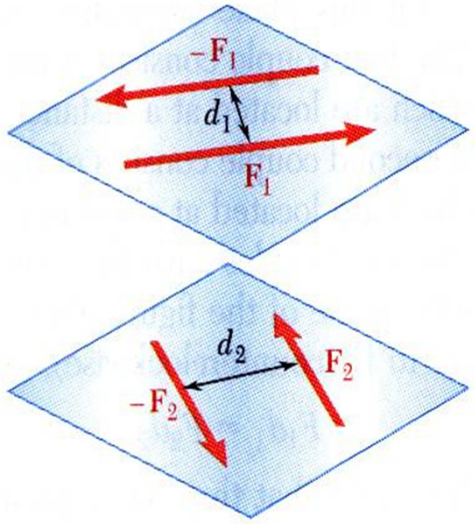
A couple, whose tendency is to rotate the body, on which it acts, in an anticlockwise direction, is known as an anticlockwise couple as shown in Fig. 4.12 (b). Such a couple is also called a negative couple.

Two couples will have equal moments if

- $F_1 d_1 = F_2 d_2$

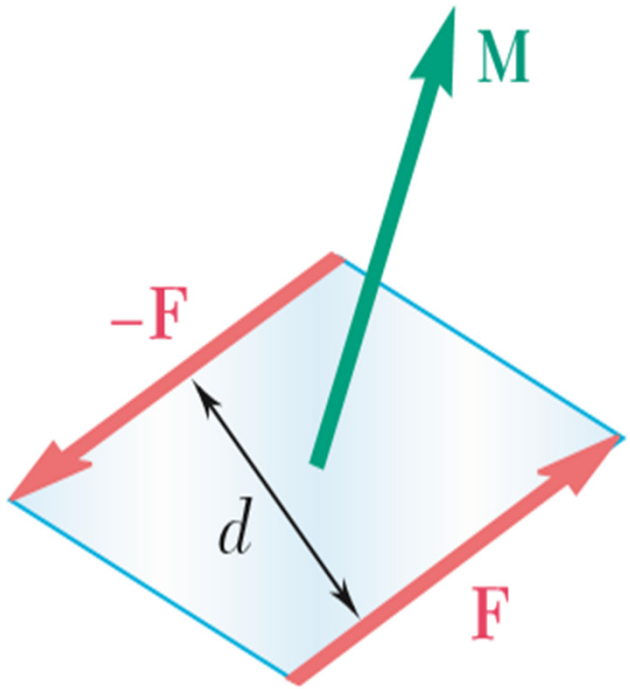
- the two couples lie in parallel planes, and
- the two couples have the same sense or the tendency to cause rotation in the same direction.





MOMENT Vector OF A COUPLE

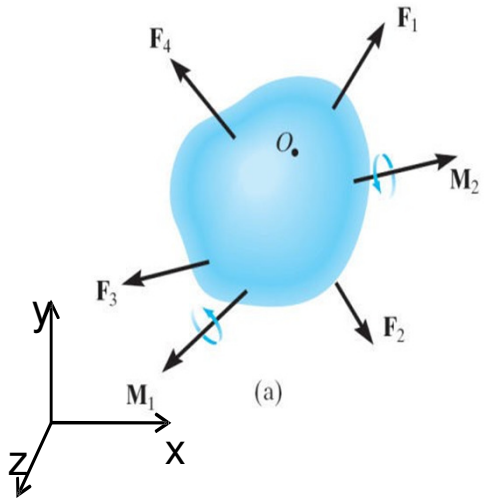
The moment vector of the couple is independent of the choice of the origin of the coordinate axes, i.e., it is a free vector that can be applied at any point with the same effect.



Rigid Body Equilibrium

A rigid body will remain in equilibrium provided

- Sum of all the external forces acting on the body is equal to zero, and
- Sum of the moments of the external forces about a point is equal to zero



$$\Sigma F_x = 0$$
$$\Sigma F_y = 0$$
$$\Sigma F_z = 0$$

$$\Sigma M_x = 0$$
$$\Sigma M_y = 0$$
$$\Sigma M_z = 0$$

LOVELY PROFESSIONAL UNIVERSITY

TUTORIAL SHEET