E-CONTENT OF APPLIED MECHANICS FOR THE STUDENTS OF MECHANICAL ENGINEERING

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CHAPTER-1

INTRODUCTION

1.1 CONCEPT OF ENGINEERING MECHANICS

Mechanics: It is the physical science concerned with the behavior of bodies that are acted upon by forces.

Statics: It is the study which deals with the condition of bodies in equilibrium subjected to external forces.

In other words, when the force system acting on a body is balanced, the system has no external effect on the body, the body is said to be in equilibrium.

Dynamics: It is the branch of mechanics in which the forces and their effects on the bodies in motion.

Dynamics is sub-divided into two parts:

(1) Kinematics and (2) Kinetics

Kinematics: It deals with the geometry of motion of bodies without considering external forces.

Kinetics: It deals with the motion of bodies with the application of external forces.

Rigid Body: A body is said to be rigid if it retain its shape and size even if the external forces are applied on it. It is called a rigid body.

1.2 SOME BASIC TERMS USED IN MECHANICS

The followings are the basic terms which are used in mechanics:

Mass: The quantity of the matter possessed by a body is called mass. The mass of a body cannot change unless the body is damaged and part of it is physically separated.

Length: It is a concept to measure linear distances.

Time: Time is the measure of succession of events. The successive event selected is the rotation of earth about its own axis and this is called a day.

Space: Any geometric region in which the study of a body has been done is called space.

Displacement: It is defined as the distance moved by a body or particle in the specified direction.

Velocity: The rate of change of displacement with respect to time is defined as velocity.

Acceleration: It is the rate of change of velocity with respect to time.

Momentum: The product of mass and velocity is called momentum. Thus

Momentum = Mass × Velocity

Particle: It can be defined as an object which has only mass and no size. Such a body cannot exist theoretically.

When we deal with the problems involving distances considerably larger compared to the size of the body, the body may be treated as particle.

1.3 LAWS OF MECHANICS

The following are the fundamental laws of mechanics:

(i) Newton's first law

(ii) Newton's second law

(iii) Newton's third law

(i) Newton's first law: It states that everybody continues in its state of rest or of uniform motion in a straight line unless it is compelled by external agency acting on it.

(ii) Newton's second law: It states that the rate of change of momentum of a body is directly proportional to the impressed force and it takes place in the direction of the force acting on it.

According to this law,

Force = rate of change of momentum. But momentum = mass × velocity

As mass do not change,

Force = mass × rate of change of velocity

i.e., Force = mass × acceleration

$F = m \times a$

(iii) Newton's third law: It states that for every action there is an equal and opposite reaction.

1.4 UNITS AND DIMENSIONS OF QUANTITIES

1.4.1 Units: Measurements are always made in comparison with certain standards.

For example, when we say that cloth piece is 2.5 meter long, the measurement of length is with respect to a scale on which graduations are marked. In turn, the graduation of the scale must have been made according to a national or an international standard. The standard so chosen for the measurement of length is called the unit of length. In this example, 'meter' is the unit of length.

Similarly, for the measurement of time, weight, current, speed etc, different units are used.

Each physical quantity is measured for the purpose of analysis, study, comparison, experimentation/results, design etc. with the help of measuring units by comparison.

There are four systems of units used for the measurement of physical quantities. viz. **FPS** (Foot – Pound – Second) system**, CGS** (Centimeter – Gram – Second) system**, MKS** (Meter - Kilogram – Second) system **and SI** (System international d'units – the French name). The SI system of units is said to be an absolute system.

S.I Units (International System of Units)

The fundamental units of the system are meter (m) for length, kilogram (kg) for mass and second (s) for time.

The unit for force is Newton (N). One Newton is the amount of force required to induce an acceleration of 1 m/sec^2 on one kg mass. Weight of a body (in N) = Mass of the body (in kg) × Acceleration due to gravity (in m/sec^2).

1.4.2 Dimensions

The branch of mathematics dealing with dimensions of quantities is called dimensional analysis. There are two systems of dimensional analysis viz.

Absolute system (MLT system)

A system of units defined on the basis of length, time and mass is referred to as an absolute system.

According to SI system of units, three basic unit's meter, second and kilogram are used. In MLT system, M refers to Mass, L refers to Length and T refers to Time.

Gravitational system (FLT system)

A system of units defined on the basis of length, time and force is referred to as a gravitational system.

In this system, force is measured in a gravitational field. Thus, its magnitude depends upon the location where the measurement is made. FLT system refers to the Force-Length-Time system.

Scalar Quantity: A quantity is said to be scalar if it is completely defined by its magnitude alone. Examples of scalar quantities are:

Area, length, Mass, Moment of inertia, Energy, Power, Volume and Work

Vector Quantity: A quantity is said to be vector if it is completely defined only when its magnitude as well as direction are specified. Examples of vector quantities include:

Force, Moment, Momentum, Displacement, Velocity and Acceleration

CHAPTER- 2

LAWS OF FORCES

2.1 DEFINITION OF FORCE

Force is an external agent capable of changing the state of rest or motion of a particular body. It has a magnitude and a direction. The direction towards which the force is applied is known as the direction of the force, and the application of force is the point where force is applied.

2.2 CHARACTERISTICS OF A FORCE

A Force has following basic characteristics

i) Magnitude

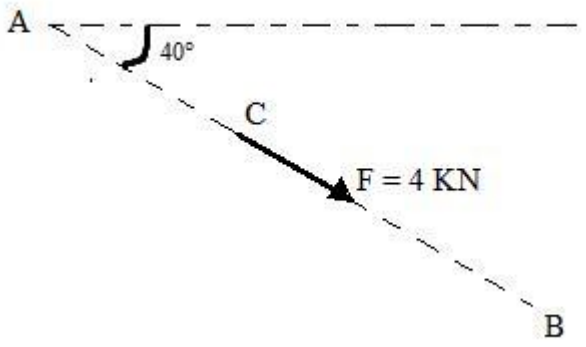
ii) Direction

iii) Point of application

iv) Line of action

Force is represented as a vector. i.e. an arrow with its magnitude.

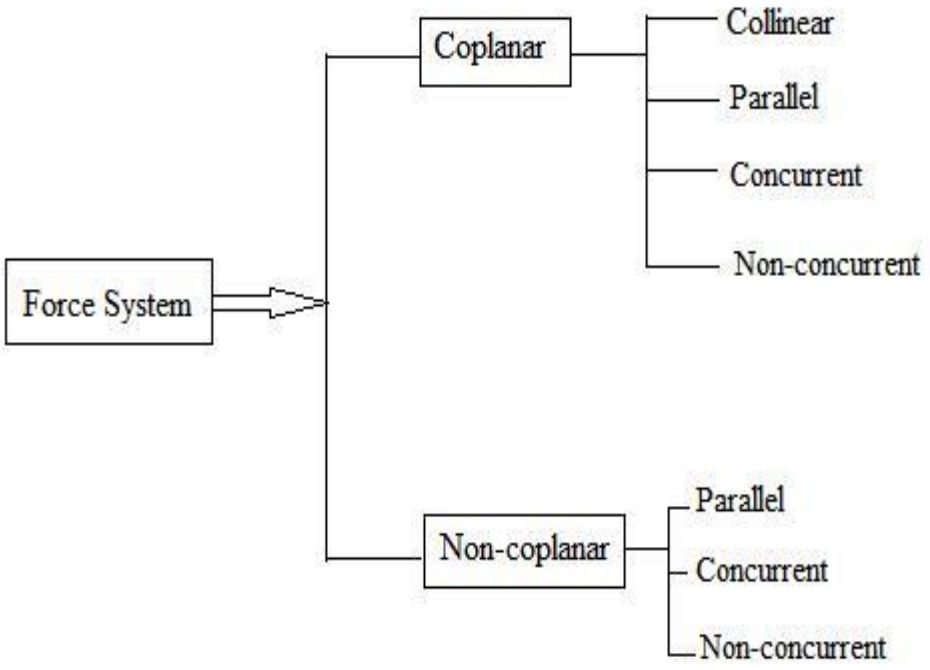
For e.g. The force shown in Fig. is represented by magnitude of 4KN, direction is 40° with the horizontal in fourth quadrant, point of application is C and line of action is AB.



Characteristics of a force

2.3 DIFFERENT FORCE SYSTEMS

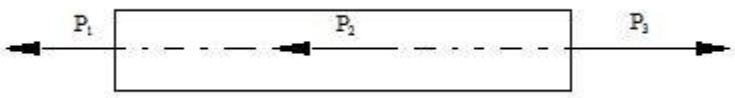
A mechanics problem having more than one force acting on it is known as a ‘force system’



Force System

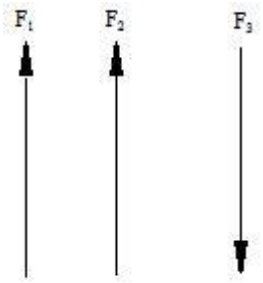
2.3.1 Collinear Force System

When the lines of action of all the forces of a system act along the same line, this force system is called collinear force system.



Collinear Force System

2.3.2 Parallel Forces



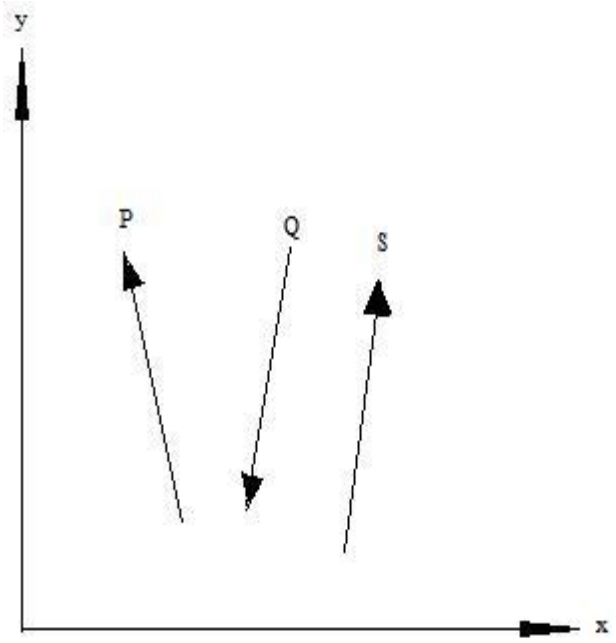
Parallel Force System

2.3.3 Coplanar Force System

When the lines of action of a set of forces lie in a single plane is called coplanar force system.

2.3.4 Non-Coplanar Force System

When the line of action of all the forces do not lie in one plane, is called Non-coplanar force system



2.3.5 Concurrent Force System

The forces when extended pass through a single point and the point is called point of concurrency. The lines of actions of all forces meet at the point of concurrency. Concurrent forces may or may not be coplanar.

2.3.6 Non-concurrent Force System

When the forces of a system do not meet at a common point of concurrency, this type of force system is called non-concurrent force system. Parallel forces are the example of this type of force system. Non-concurrent forces may be coplanar or non-coplanar.

2.3.7 Coplanar and concurrent force system

A force system in which all the forces lie in a single plane and meet at one point, For example, forces acting at a joint of a roof truss

2.3.8 Coplanar and non-concurrent force system

These forces do not meet at a common point; however, they lie in a single plane, for example, forces acting on a beam as shown in Fig.2.7:

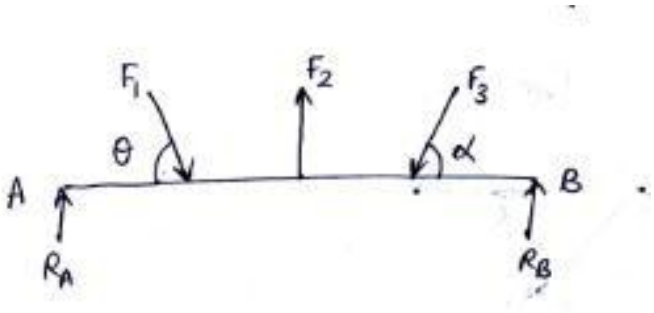


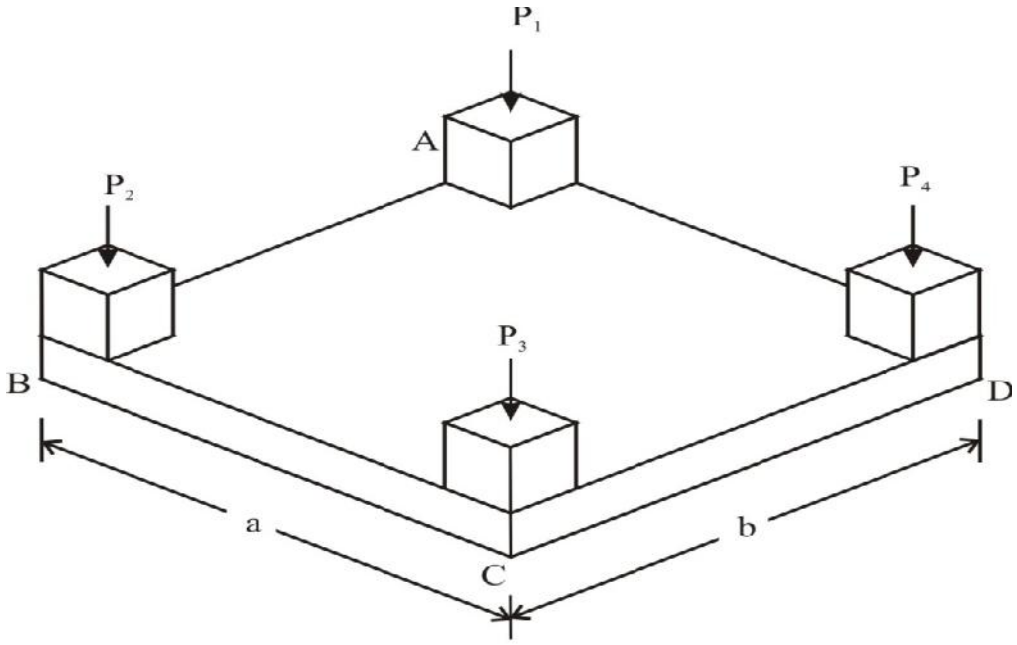
Fig.2.7 Coplanar non-concurrent force system

2.3.9 Non-coplanar and concurrent force system

In this system, the forces lie in different planes but pass through a single point. Example is forces acting at the top end of an electrical pole

2.3.10 Non-coplanar and non-concurrent force system

The forces which do not lie in a single plane and do not pass through a single point are known as non-coplanar and non-concurrent forces.



Non- Coplanar and non-Concurrent force system

PRINCIPLE OF TRANSMISSIBILITY OF FORCES

The principle of transmissibility states that the point of application of a force can be moved anywhere along its line of action without changing the external reaction forces on a rigid body.

PRINCIPLE OF SUPERPOSITION OF FORCES

This principle states that the combined effect of force system acting on a particle or a rigid body is the sum of effects of individual forces

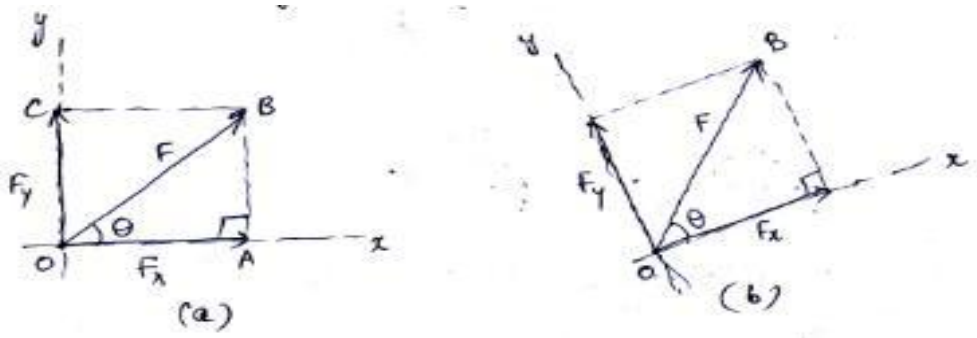
RESOLUTION OF A FORCE INTO COMPONENTS

A given force *F* can be resolved into (or replaced by) two forces, which together produces the same effects that of force *F*. These forces are called the components of the force *F*. This process of replacing a force into its components is known as resolution of a force into components. A force can be resolved into two

components, which are either perpendicular to each other or inclined to each other. If the two components are perpendicular to one another, then they are known as rectangular components and when the components are inclined to each other, they are called as inclined components. The resolution of force into components is illustrated as follows.

Resolution of a Force into Rectangular Components

Consider a force *F* acting on a particle O inclined at an angle Θ as shown in Fig.4.1 (a). Let *x* and *y* axes can be the two axes passing through O perpendicular to each other. These two axes are called rectangular axes or coordinate axes. They may be horizontal and vertical or inclined as shown in Fig. 4.1(b).



Resolution of force into rectangular components

The force *F* can now be resolved into two components F_x and F_y along the *x* and *y* axes and hence, the components are called rectangular components. Further, the polygon constructed with these two components as adjacent sides will form a rectangle OABC and, therefore, the components are known as rectangular components.

From the right angled triangle OAB, the trigonometrically functions can be used to resolve the force as follows:

$\text{Cos } \Theta = [\{OA\} \setminus \{OB\}]$

Therefore,

$OA = OB \times \text{Cos } \Theta$

Or

F_x = OA = F Cos Θ (……1)

Therefore,

AB = OB × sin Θ

F_y = OC = AB = F sin Θ (…….……2)

Therefore, the two rectangular components of the force F are:

$F_x = F$ cos Θ and $F_y = F$ sin Θ

The conventional coordinate directions are used for the sign conventions of the components of the force. That is, the components along the coordinate directions are considered as positive components and the one in the opposite direction as negative components.

TRIANGLE LAW OF FORCES

It states that if two forces acting at a point are represented in magnitude and direction by the two adjacent sides of a triangle taken in order, then the closing side of the triangle taken in the reversed order represents the resultant of the forces in magnitude and direction.

PARALLELOGRAM LAW OF FORCES

It states that if two forces acting at a point are represented in magnitude and direction by the two adjacent sides of a parallelogram, then their resultant is represented in magnitude and direction by the diagonal passing through the point.

FREE BODY DIAGRAM

A free body diagram is a sketch of a body, a portion of a body, or two or more bodies completely isolated or free from all other bodies, showing the forces exerted by all other bodies on the one being considered.

1. It is a diagram or sketch of a body.
2. The body is shown completely separated from all other bodies.
3. The action on the body of each body removed in the isolating process is shown as a force or forces on the diagram.

EQUILIBRIUM OF FORCES

Equilibrium is defined as the condition of a body, which is subjected to a force system whose resultant force is equal to zero. It means the effect of the given force system is zero and the particle or rigid body is said to be in equilibrium.

For example, a particle subjected to two forces will be in equilibrium when the two forces are equal in magnitude, opposite in direction and act along the same line of action as shown in Figure.

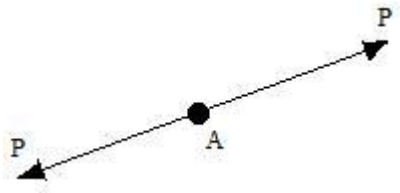
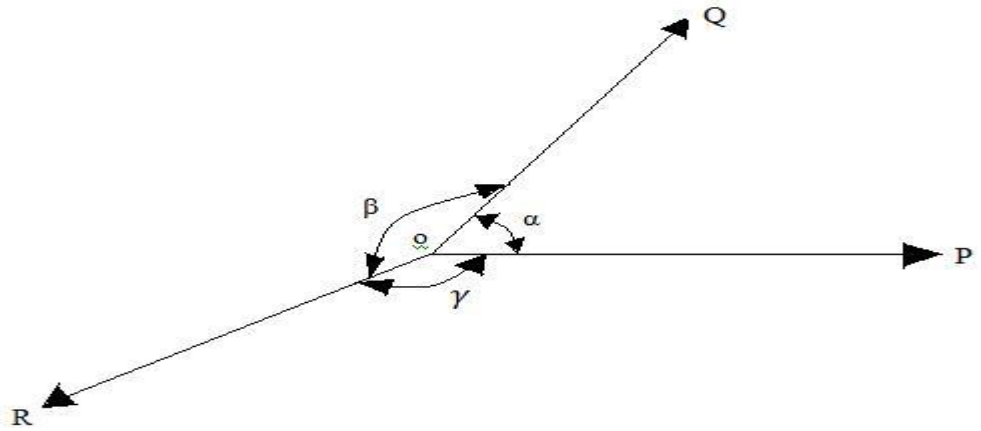


Fig. 5.1 Equilibrium of forces

LAMI'S THEOREM

It states that," If three forces acting at a point are in equilibrium each force will be proportional to the sine of the angle between the other two forces."

Suppose the three forces P, Q and R are acting at a point O and they are in equilibrium as shown.



CHAPTER- 3

MOMENT OF A FORCE

Moment is the measure of the capacity or ability of the force to produce twisting or turning effect about an axis. The axis is perpendicular to the plane containing the line of action of the force.

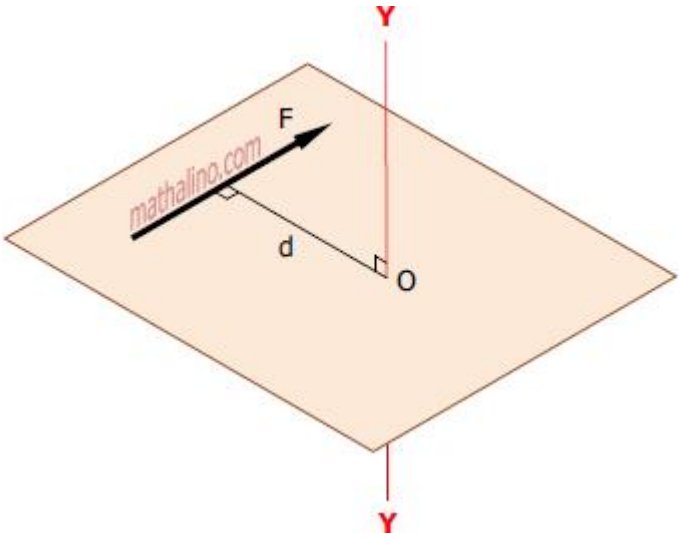
The magnitude of moment is equal to the product of the force and the perpendicular distance from the axis to the line of action of the force.

MOMENT CENTER

The intersection of the plane and the axis is commonly called the moment center.

MOMENT ARM

The perpendicular distance from the moment center to the line of action of the force is called moment arm.



From the figure above, O is the moment center and d is the moment arm. The moment M of force F about point O is equal to the product of F and d.

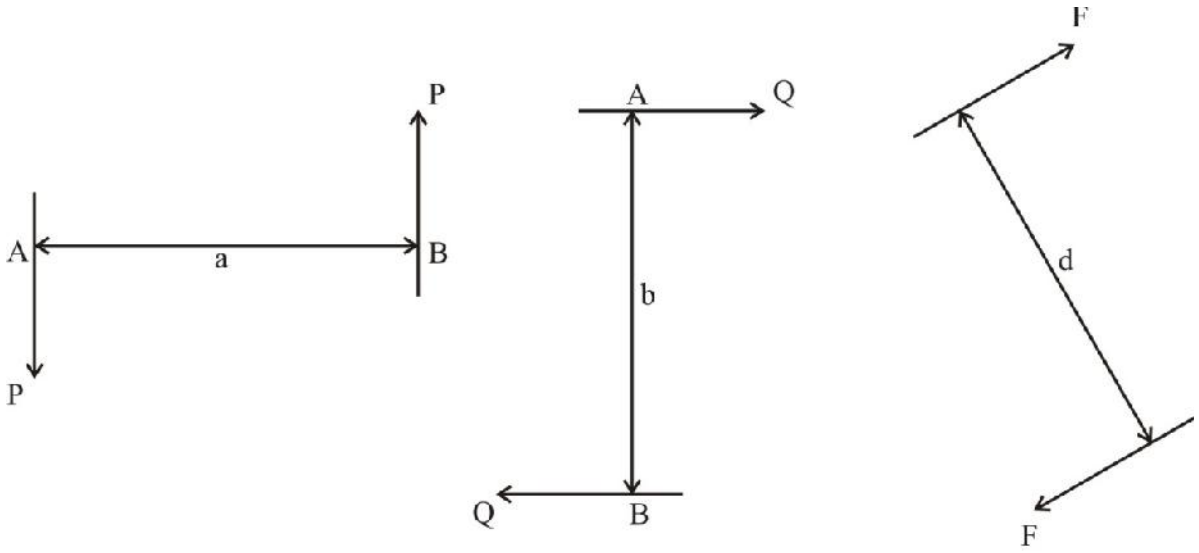
$$M=Fxd$$

VARIGNON'S THEOREM

Varignon's theorem states that the moment at any point of the force acting on a body is equal to the moment of the resultant at that particular point.

COUPLE

A system of two equal parallel forces acting in opposite directions is said to form a couple. Fig. shows a couple formed by horizontal, vertical and inclined forces.



COUPLE SYSTEM

Couple is a system of forces whose magnitude of the resultant is zero. Couple is composed of two equal forces that are parallel to each other and acting in opposite direction

PLANE OF THE COUPLE

The plane in which the two forces forming a couple lie is called the plane of the couple.

ARM OF THE COUPLE

The distance between their lines of action is called the arm of the couple.

Any couple acting on a rigid body produces only rotation to the body. This rotation is measured by the moment of the couple, which is product of magnitude of the force and the distance between the two forces.

CHARACTERISTICS OF A COUPLE

A couple is completely defined by following elements:

i) The magnitude of its moment

ii) The plane in which it acts defined by the direction of the normal to the plane.

iii) The direction of rotation in the plane that is the sense of the couple.

Moment of a couple is a vector quantity having the direction normal to the plane in which it acts.

CHAPTER- 4

FRICTION

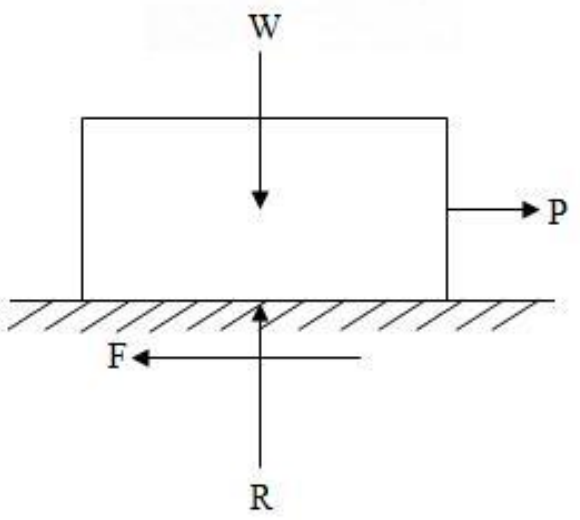
Friction depends upon the nature of the surface in contact. Friction acts parallel to the surface of contact. In other words, friction opposes motion.

- Friction is an important force in many aspects of everyday life.
- If there is too much friction, loss of energy, wear and tear of materials in contact occurs.
- If there is less friction or no friction, this would result in ‘slipping’ all around.

  For example oil in the engine of car is meant to minimize friction between moving parts in contact to reduce excessive friction for reducing loss of energy and material.

We need the friction between the tires on the road surface, to let the wheels roll.

When one body moves relative to the other, the tangential forces will always be developed along the surfaces of contact. These tangential forces are called frictional forces.



$F = \mu R$ where μ is the coefficient of friction

TYPES OF FRICTION

1. Static Friction
2. Sliding Friction
3. Rolling Friction
4. Fluid Friction

STATIC FRICTION

Static friction is defined as the frictional force that acts between the surfaces when they are at rest with respect to each other.

SLIDING FRICTION

Sliding friction is defined as the resistance that is created between any two objects when they are sliding against each other.

ROLLING FRICTION

Rolling friction is defined as the force which resists the motion of a ball or wheel and is the weakest types of friction.

FLUID FRICTION

Fluid friction is defined as the friction that exists between the layers of the fluid when they are moving relative to each other.

LIMITING FRICTION

Limiting friction is the maximum value of static friction that comes into play when the body is just at the point of sliding over the surface of another body.

COEFFICIENT OF FRICTION

Coefficient of friction (COF) is a dimensionless number that is defined as the ratio between friction force and normal force

The value of the coefficient of friction is given by μ

LAWS OF FRICTION

1. The force of friction always acts in a direction opposite to that in which body tends to move.

2. Till the limiting value is reached, the magnitude of friction is exactly equal to the force which tends to move the body.

3. The magnitude of the limiting friction bears a constant ratio to the normal reaction between the two surfaces of contact and this ratio is called coefficient of friction.

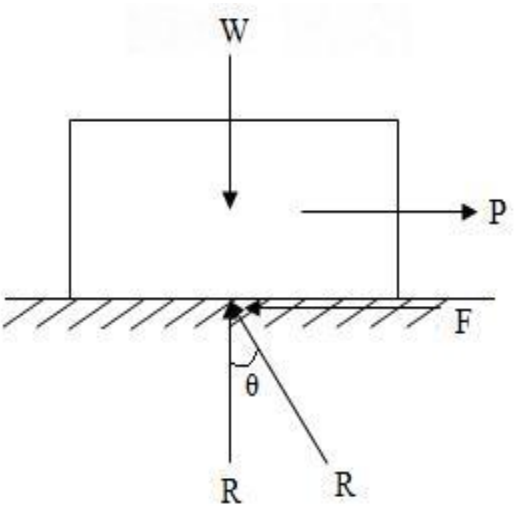
4. The force of friction depends upon the roughness/smoothness of the surfaces.

5. The force of friction is independent of the area of contact between the two surfaces.

6. After the body starts moving, the dynamic friction comes into play, the magnitude of which is less than that of limiting friction and it bears a constant ratio with normal force. This ratio is called coefficient of dynamic friction.

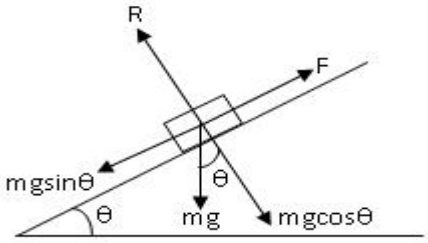
ANGLE OF FRICTION

Consider the block resting on the horizontal rough surface. Let R' be the resultant reaction (resultant of the normal reaction R and friction F). The angle Θ between the resultant reaction and the normal to the surface is called the angle of friction.



ANGLE OF REPOSE

Angle of repose is defined as the minimum angle made by an inclined plane with the horizontal such that an object placed on the inclined surface just begins to slide.



ADVANTAGES OF FRICTION

1. It becomes easy to walk on a road due to friction.
2. We cannot fix nail in the wood or wall if there is no friction. It is friction which holds the nail.

DISADVANTAGES OF FRICTION

1. The main disadvantage of friction is that it produces heat in various parts of machines due to which some useful energy is wasted as heat energy.
2. Due to friction, noise is also produced in machines.
3. Due to friction, engines of automobiles consume more fuel.

METHODS OF REDUCING FRICTION

1. USE OF LUBRICANTS

The parts of machines which are moving over one another must be properly lubricated by using oils and lubricants of suitable viscosity.

2. USE OF GREASE

By proper greasing between the sliding parts of machine reduces the friction.

3. USE OF BALL BEARING

In machines where possible, sliding friction can be replaced by rolling friction by using ball bearings.

4. DESIGN MODIFICATION

Friction can be reduced by changing the design of fast moving objects.

CHAPTER-5

CENTRE OF GRAVITY

A point from which the weight of a body or system may be considered to act is known as the centre of gravity.

CENTROID

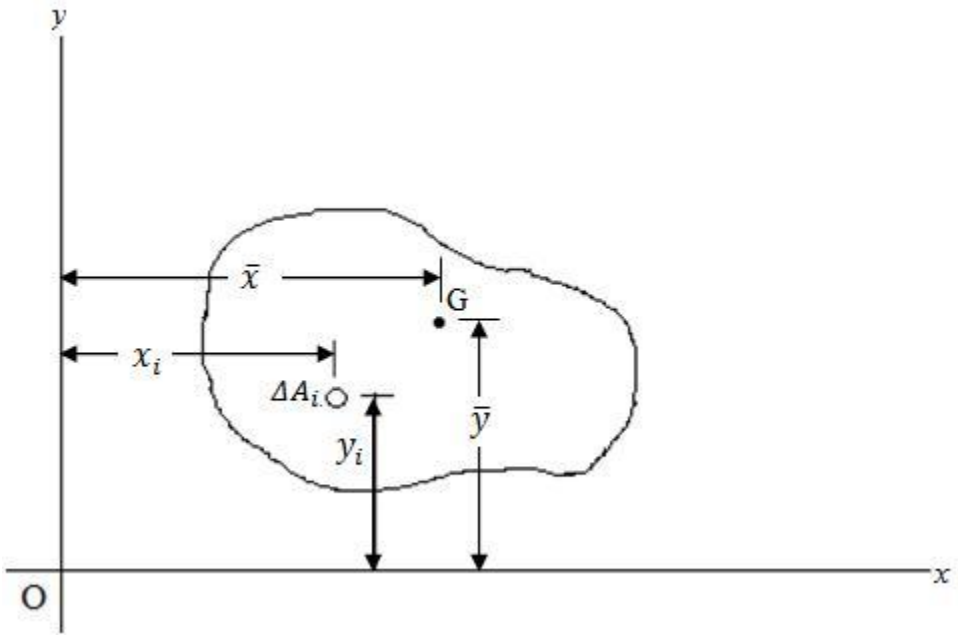
The centroid may be defined as that point through which the total area of the given figure may be imagined to be acting.

DIFFERENCE BETWEEN CENTRE OF GRAVITY AND CENTROID

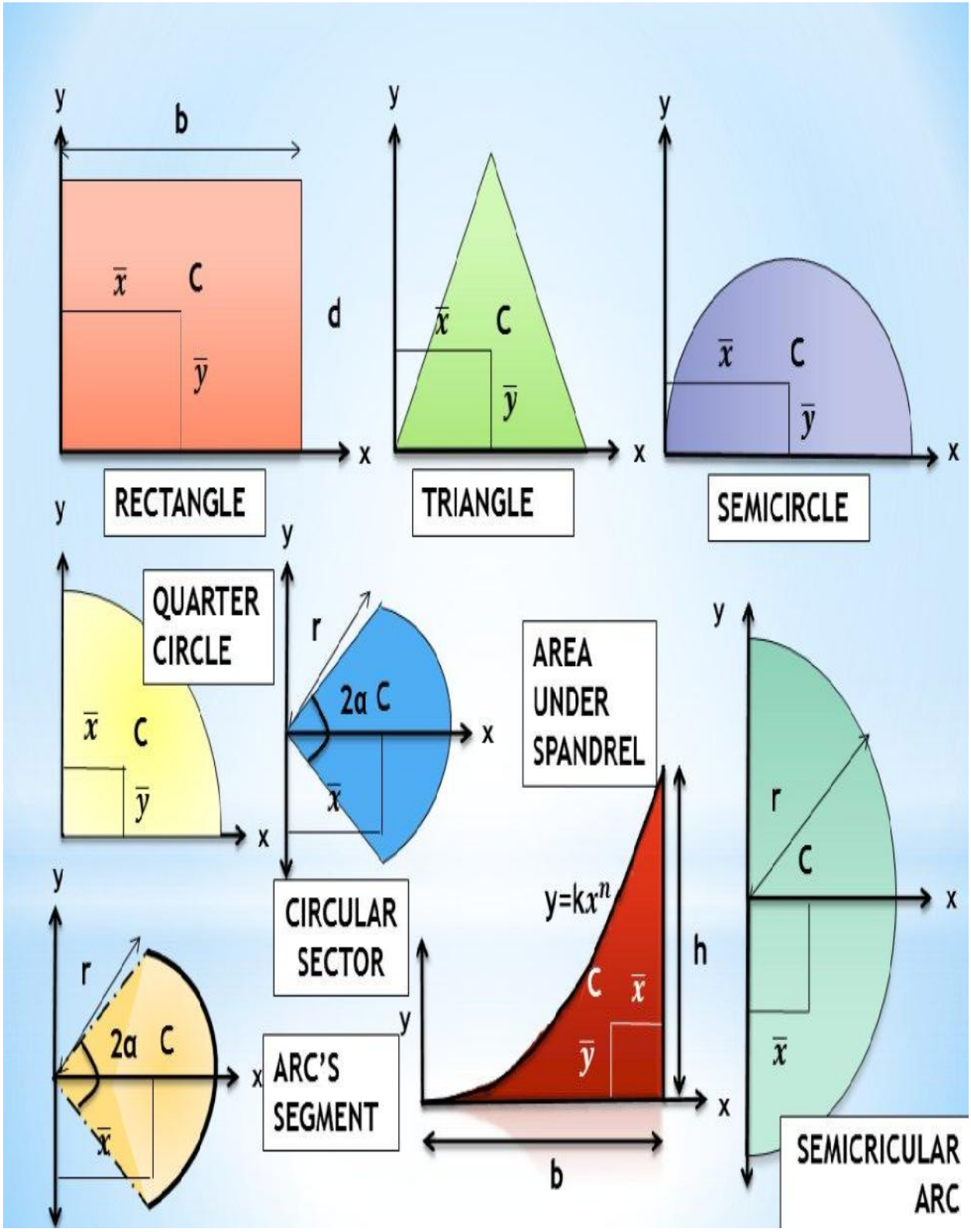
The difference between centre of gravity and centroid is that the centre of gravity applies to the bodies with mass and weight, while the centroid refers to the plane areas, lines and volumes of the body**.**

POSITION OF THE CENTROID

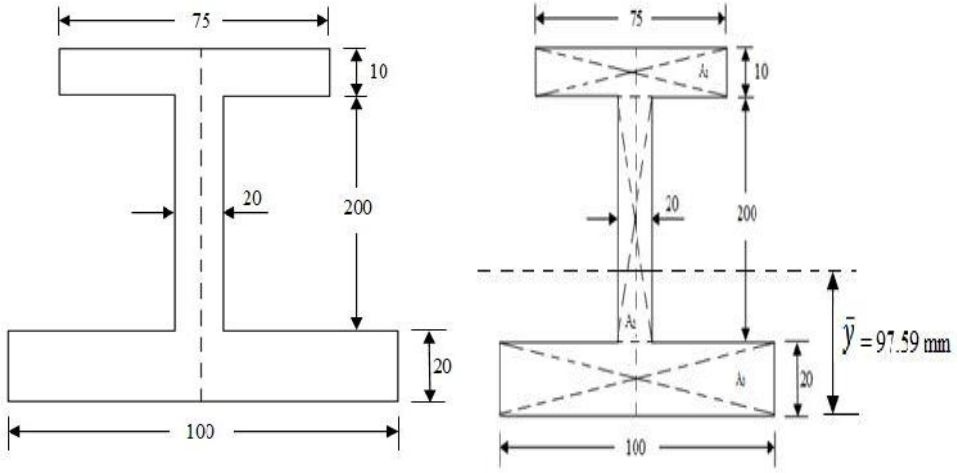
The position of the centroid of a plane area is defined analytically with reference to the coordinate axes as shown in Fig.



THE POSITION OF CENTROID OF DIFFERENT GEOMETRICAL FIGURES IS SHOWN IN FIGURE



Example: Find the position of the centroid of I-section as shown in Figure.



Sol: First, divide the figure into standard areas means rectangles.

I-section is symmetrical about y-axis.

A_1 = area of the top flange

A_2 = area of the web

A_3 = area of the bottom flange

Rectangles	Area (mm^2)	Centroidal distance y_i from x axis	$A_i y_i$ (mm^3)
A_1	75×10 = 750	20+200+5 = 225	168750
A_2	200×20 = 4000	20+100 = 120	480000
A_3	100×20 = 2000	= 5	10000
	$\sum A_i = 6750$		$\sum A_i y_i = 678750$

$$\bar{y} = \frac{\sum A_i y_i}{\sum A_i} = \frac{658750}{6750} = 97.59 \text{ mm}$$

CHAPTER-6

SIMPLE MACHINES

A machine is any device that does work. Machines make our lives easier because they reduce the amount of energy, power, and time we need to get one thing done by magnifying our input force.

Simple machine can:

- transfer a force from one place to another
- change the direction of a force
- increase the magnitude of a force
- increase the distance or speed of a force

COMPOUND MACHINES

Compound machines combine many simple machines such as levers, pulleys, and gears to get work done.
Compound machine is a device which may consists of number of simple machines.
Compound machines do heavy work with less efforts and greater speed.
For example
In a crane, gears are used to drive the rope drum and pulleys are used to lift the load. Thus, a crane consists of two simple machines or mechanisms i.e. gears and pulleys. Hence, it is a compound machine.

IMPORTANT DEFINITIONS

WORK

It is said to be done when an applied force causes an object to move in the direction of the force.

ENERGY

It is the ability to cause change; can change the speed, direction, shape, or temperature of an object.

EFFORT

It may be defined as, the force which is applied so as to overcome the resistance or to lift the load. It is denoted by P.

Magnitude of effort (P) is small as compared to the load (W).

LOAD

The weight to be lifted or the resistive force to be overcome with the help of a machine is called as load (W).

VELOCITY RATIO (V.R.)

It is defined as the ratio of distance traveled by the effort (P) to the distance traveled by the load (W)

V. R. Z Distance travelled by effort (P) / distance traveled by the load (W)

Velocity ratio will be always more than one and for a given machine, it remains constant.

MECHANICAL ADVANTAGE

It is defined as the ratio of load to be lifted to the effort applied.

M. A. = Load to be lifted (W) / Effort Applied (W)

EFFICIENCY OF A MACHINE

The efficiency of a machine is the ratio of the output work to the input work.

The relation between these terms is,

Efficiency=Mechanical advantage / Velocity ratio×100%

REVERSIBLE MACHINE

A machine which is capable of doing work in the reverse direction even after the removal of effort is called Reversible machine.

For reversible machine efficiency will be greater than 50%

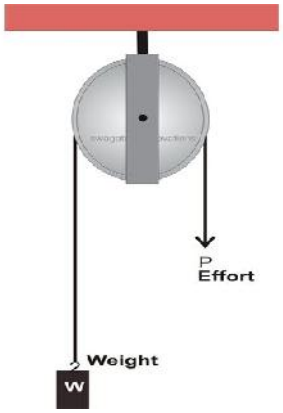
NON - REVERSIBLE MACHINE

A machine which is not capable of doing work in the reverse direction is called Non - Reversible machine. It is also called self- locking machine

For non-reversible machine efficiency will be less than 50%

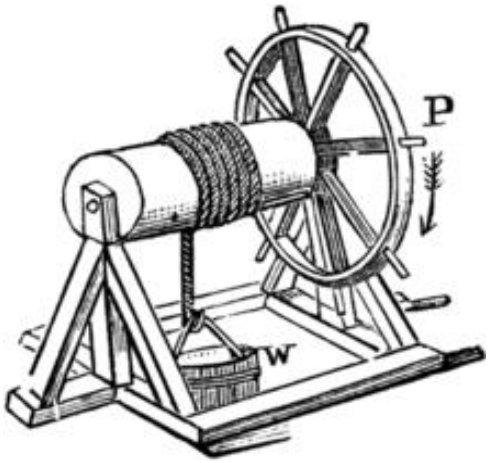
PULLEY

A simple pulley basically consists of two components, the wheel and the string; the wheel may be made up of wood or metal and includes a grove cut along its circumferential periphery. The string is allowed to slide or pass through this groove with a load that is to be lifted fixed at one of its ends and an effort applied at the other end in order to lift the load. The pulley wheel is supported over a rigid frame about its central axis.



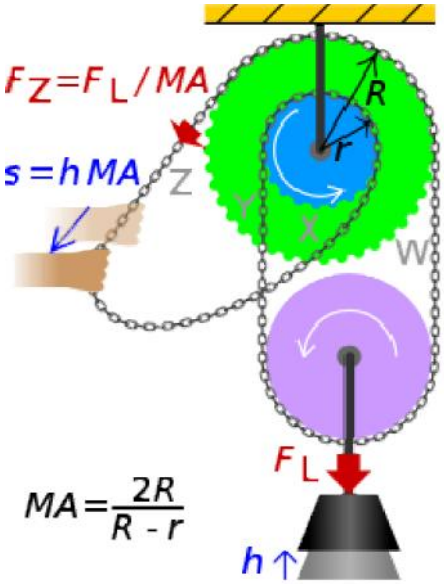
WHEEL AND AXLE

The wheel and axle is a machine consisting of a wheel attached to a smaller axle so that these two parts rotate together in which a force is transferred from one to the other.



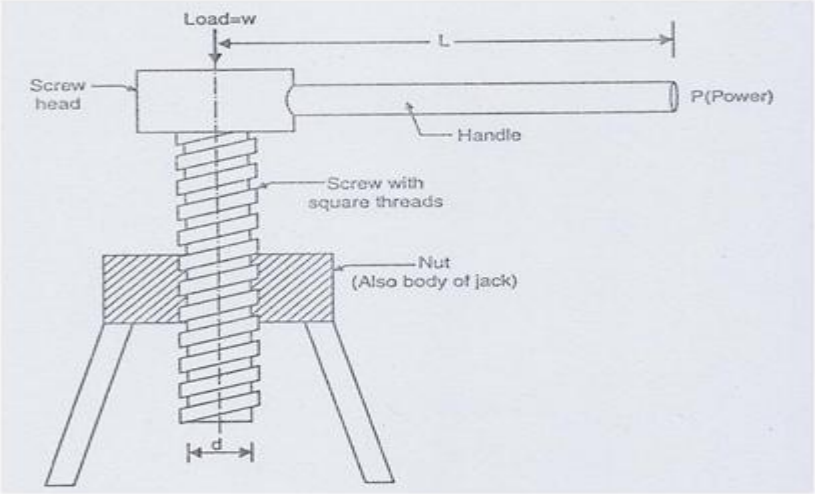
WESTON DIFFERENTIAL PULLEY

It is used to manually lift very heavy objects like car engines. It is operated by pulling upon the slack section of a continuous chain that wraps around pulleys.



SCREW-JACK

A Screw-jack is a device used for lifting heavy weights or loads with the help of a small effort applied at its handle.



WORM AND WORM WHEEL

A **worm drive** is a gear arrangement in which a **worm** meshes with a **worm gear**

A worm gear is a gear consisting of a shaft with a spiral thread that engages with and drives a toothed wheel. It changes the rotational movement by 90 degrees, and the plane of movement also changes due to the position of the worm on the worm wheel. They are typically comprised of a steel worm and a brass wheel.