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RRB - JE

MECHANICAL

Railway Recruitment Board

Volume - 1

Engineering Mechanics

SIERRA INNOVATIONS

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SYSTEM OF FORCES

THEORY

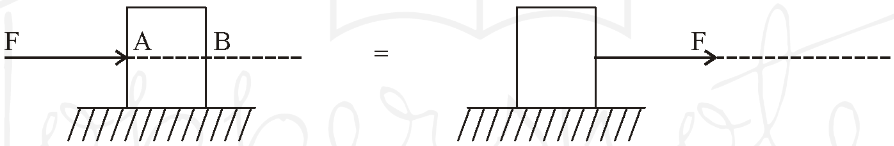
2.1 DEFINITIONS

Force - It is something that have either displacement or deformation effect on the body

Line of action of force - It is the direction of effect on the body. It is also the direction of force

2.2 LAW OF TRANSMISSIBILITY OF FORCE

Along the line of action if force is shifted, effect of force will remain same



2.3 SYSTEM OF FORCES

When multiple forces act on the body in different direction, at different point and of different magnitude, it is called system of forces

It can be of two types:

(a) Coplanar Forces (2D Forces)

(b) Non Coplanar forces (3D Forces)

System of Forces

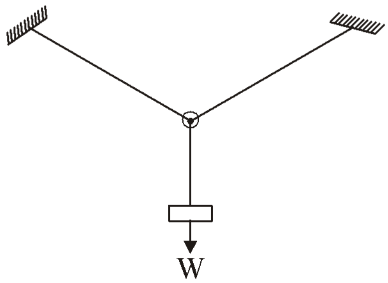
Coplaner forces [Single Plane-2D]

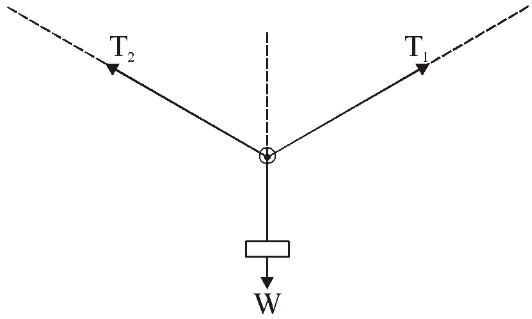
→ Concurrent forces
→ Non Concurrent forces
→ Parallel forces
→ Collinear forces

Non-Coplaner forces [3D forces]

→ Concurrent forces
→ Non Concurrent forces
→ Parallel forces
→ Collinear forces

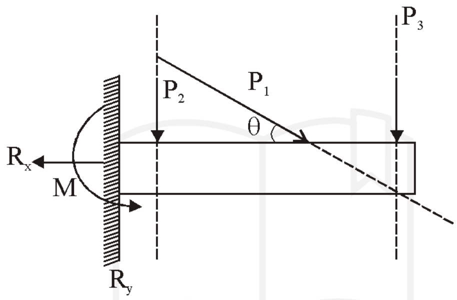
Concurrent Forces : If the line of action of all the force meet at a single point, then it is called concurrent for system.



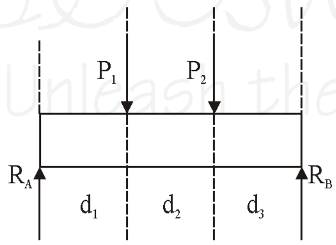


T_1, T_2 & W are Meeting at 'O'

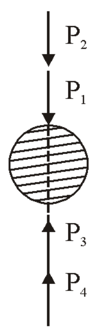
Non concurrent forces : If the line of action of all forces do not meet at a single point, then it is called non-concurrent force system.



Parallel Forces : if the line of action of all forces do not meet anywhere, then it is called parallel force system.



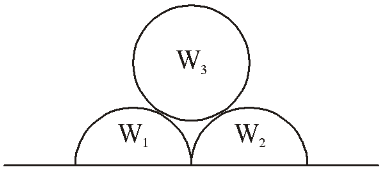
Collinear Forces : If all the forces are having same line of action, then is is called collinear force system.



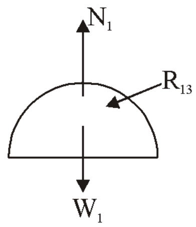
2.4 Free Body Diagram

It is the diagram representing all the external forces acting on a body or the system of bodies.

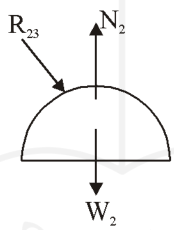
Example 1



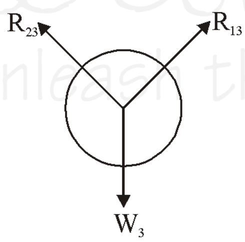
F.B.D. For W_1



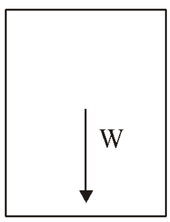
F.B.D. For W_2

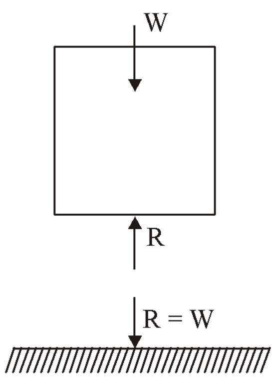


F.B.D. For W_3



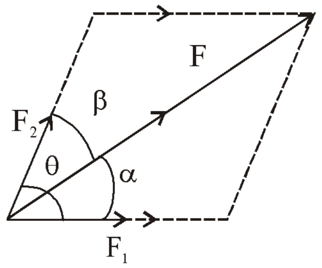
Example 2





2.5 LAW OF FORCES

2.5.1 *Law of Parallelogram*



$$F = \sqrt{F_1^2 + F_2^2 + 2F_1F_2\cos\theta}$$

$$\tan\alpha = \frac{F_2\sin\theta}{F_1 + F_2\cos\theta}$$

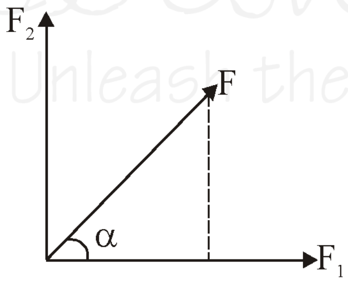
Case–I

$\theta = 0$ $\Rightarrow$ Collinear force

$$F = F_1 + F_2$$

Case–II

$\theta = 90^o$ $\Rightarrow$ Perpendicular force



$$F = \sqrt{F_1^2 + F_2^2}$$

$$\tan\alpha = \frac{F_2}{F_1}$$

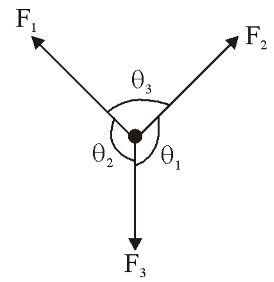
Case–III

$\theta = 180^o$ $\Rightarrow$ Collinear force

$$F = F_1 - F_2 \quad [F_1 > F_2]$$

$$F = F_2 - F_1 \quad [F_2 > F_1]$$

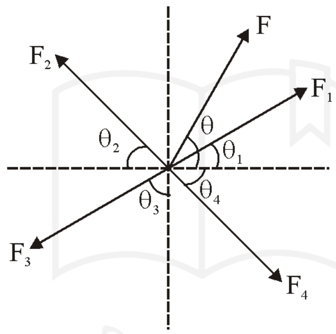
2.5.2 *Lami's Theorem (Sine Rule)*



For three concurrent forces to be in equilibrium

$$\Rightarrow \qquad \frac{F_1}{\sin\theta_1} = \frac{F_2}{\sin\theta_2} = \frac{F_3}{\sin\theta_3}$$

2.5.3 *Component of Forces*



In this method forces are resolved along two perpendicular axes.

$$F_x = F_1\cos\theta_1 - F_2\cos\theta_2 - F_3\sin\theta_3 + F_4\cos\theta_4$$

$$F_y = F_1\sin\theta_1 + F_2\sin\theta_2 - F_3\sin\theta_3 - F_4\sin\theta_4$$

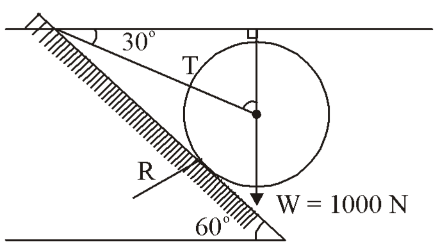
For resultant force

$$F = \sqrt{(\Sigma F_x)^2 + (\Sigma F_y)^2}$$

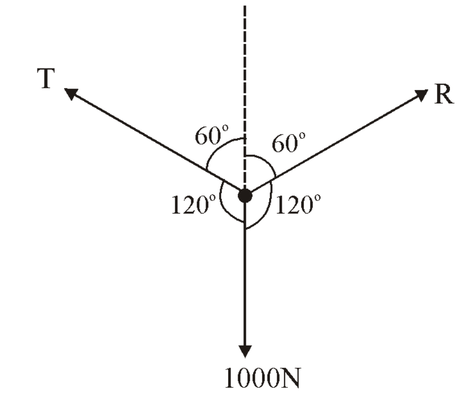
$$\tan\theta = \frac{F_y}{F_x}$$

Example 3

Determine reaction by inclined plane on the sphere



Solution:

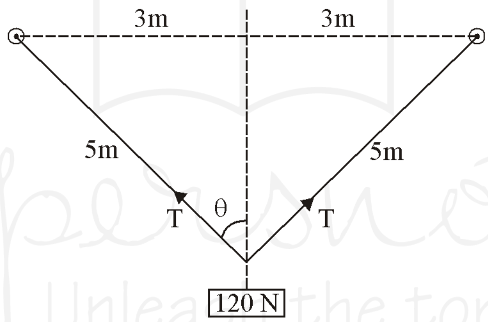


$$\frac{T}{\sin 120^o} = \frac{R}{\sin 120^o} = \frac{1000}{\sin 120^0}$$

$$T = R = 1000N$$

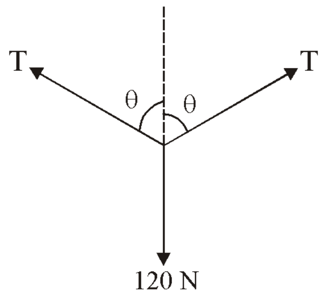
Example 4

A string of length 10m supporting a weight of 120 N as shown in fig.



Determine Tension in string

Solution:



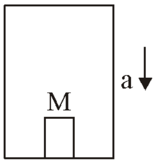
$$2T \cos\theta = 120$$

$$T = \frac{120 \times 5}{2 \times 4}$$

$$T = 75 \text{ N}$$

Example 5

With what acceleration 'a' should the box of figure descend so that the block of mass m exerts a force Mg/4 on the floor of the box?



Solution:

The block is at rest with respect to the box which is accelerated with respect to the ground. Hence, the acceleration of the block with respect to the ground is 'a' downward. The force on the block are

(i) Mg downward (by the earth) and

(ii) N upward (by the floor).

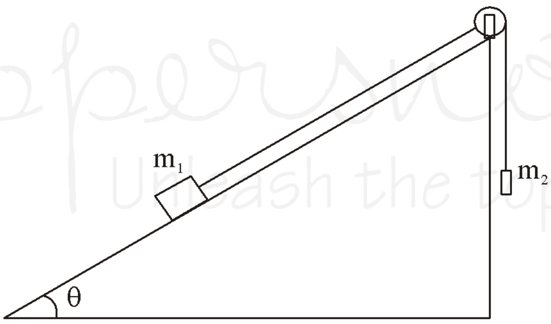
The equation of motion of the block is, therefore,

$$Mg - N = Ma.$$

If N = Mg/4, the above equation gives a = 3g/4. The block and hence the box should descend with an acceleration 3g/4.

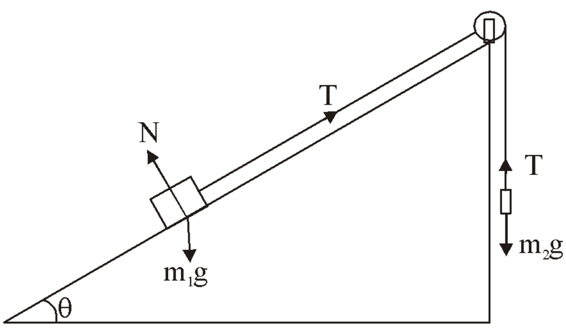
Example 6

Two bodies of masses m_1 and m_2 are connected by a light string going over a smooth light pulley at the end of an incline. The mass m_1 lies on the incline and m_2 hangs vertically. The system is at rest. Find the angle of the incline and the force exerted by the incline on the body of mass m_1.



Solution:

Figure shows the situation with the forces on m_1 and m_2 shown. Take the body of mass m_2 as the system. The forces acting on it are



(i) m_2g vertically downward (by the earth),

(ii) T vertically upward (by the string).

As the system is at rest, these forces should add to zero.

This gives $T = m_2g$. ...(i)

Next, consider the body of mass m_1 as the system. The forces acting on this system are

(i) m_1g vertically downward (by the earth),

(ii) T along the string up the incline (by the string)

(iii) N normal to the incline (by the incline).

As the string and the pulley are all light and smooth, the tension in the string is uniform everywhere. Hence, same T is used for the equations of m_1 and m_2. As the system is in equilibrium, these forces should add to zero.

Taking components parallel to the incline,

$$T = m_1g\cos\left(\frac{\pi}{2} - \theta\right) = m_1g\sin\theta. \quad \text{...(ii)}$$

Taking components along the normal to the incline,

$$N = m_1g\cos\theta \quad \text{...(iii)}$$

Eliminating T from (i) and (ii),

$$m_2g = m_1g\sin\theta$$

or, $$\sin\theta = m_2/m_1$$

giving $$\theta = \sin^{-1}(m_2/m_1).$$

From (iii) $$N = m_1g\sqrt{1-(m_2/m_1)^2}$$

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