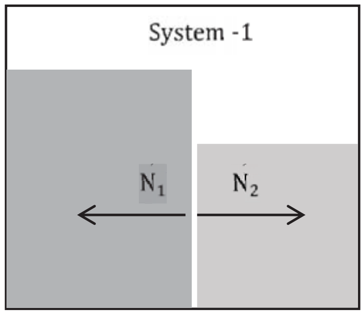
UNDERSTANDING IMPORTANT TERMS

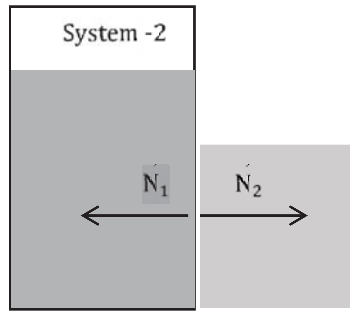
System

A system is formed when two or more objects interact with each other.

Internal and external forces

If there is an action-reaction pair within the system under consideration, it is referred to as an internal force; otherwise, it is termed an external force.





In System 1, illustrated in the provided figure, both the forces of action and reaction occur within the system. Therefore, these forces are referred to as internal forces.

In System 2, the reaction force exists outside the system. Therefore, force $\vec{N}_1$ is identified as an external force, while force $\vec{N}_2$ is disregarded as it does not act within the confines of the system.

Free-Body Diagram (FBD)

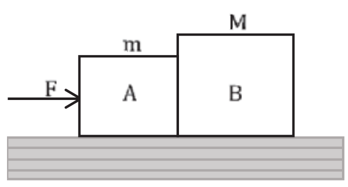
A free-body diagram (FBD) is a visual depiction of an isolated object, illustrating all external forces acting on it and highlighting its separation from the surrounding environment.

Steps for drawing the FBD

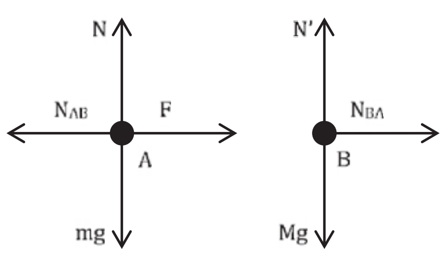
1. Isolate the free body.
2. Draw the external forces.
3. Choose the axes and resolve the forces.

> Newtonian mechanics is applied to a body treated as a point, emphasizing the use of a point representation when depicting forces in a free-body diagram (FBD). However, for visualization purposes, the body can be illustrated with a specific shape.

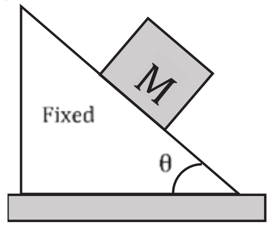
Ex. Consider two entities, A and B, with masses m and M, respectively, experiencing a force F that propels them in the positive x-axis direction. Create a free-body diagram for both objects.



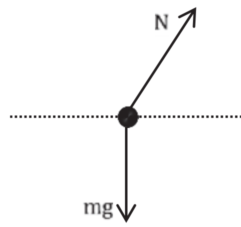
Sol. The picture shows diagrams of both blocks A and B. A has a mass of 'm', and B has a mass of 'M'.



Ex. Draw a picture representing the forces acting on a block with mass 'M' placed on a wedge fixed to the ground, as depicted in the figure.



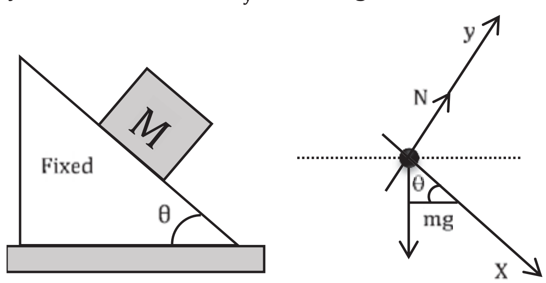
Sol. To create the free-body diagram for the provided problem, start by examining the block on the wedge and account for both its own weight and the normal reaction.



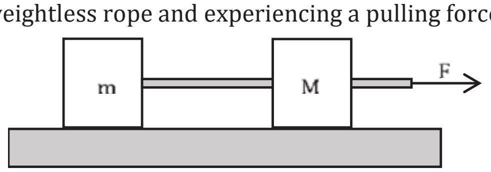
The subsequent step involves selecting the axis and resolving the forces; the x and y axes are depicted in the following diagram.

Components in the x direction $F_x = Mg\sin\theta$

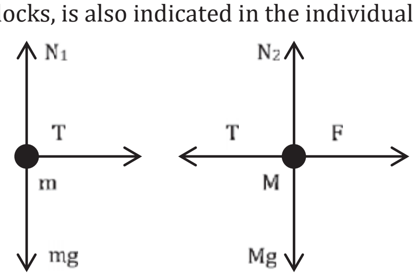
Components in the y direction $F_y = N - Mg\cos\theta$



Ex. Draw the free-body diagrams for both blocks, where one has a mass 'm' and the other has a mass 'M,' connected by a weightless rope and experiencing a pulling force 'F' applied through the rope.



Sol. Separate free-body diagrams (FBDs) have been created for each of the masses. The tension in the rope, influencing both blocks, is also indicated in the individual FBDs of the masses.



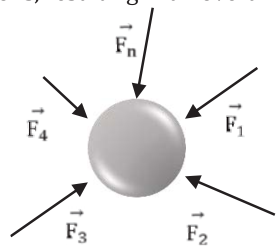
Net Force

The net force acting on a system is represented by the vector sum of all external forces acting on it.

$$\vec{F}_{net} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \cdots..\vec{F}_n$$

$$\vec{F}_{net} = \sum_{i=1}^{n} \vec{F}_i$$

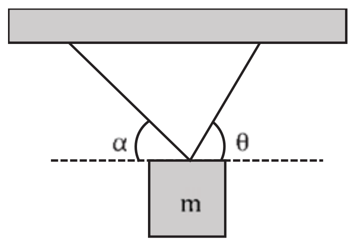
In this context, adding up all the forces yields the net force on the body, and the vector indicates the direction of the resultant force. The figure demonstrates multiple forces acting on the body with varying magnitudes and directions, resulting in an overall effect determined by the resultant force.



Equilibrium

If the net force acting on an object is zero, the object is considered to be in a state of equilibrium.
In the provided illustration, a mass 'm' is suspended from the ceiling by two connected ropes.
By definition of equilibrium

$$\sum(\vec{F}_{ext})_{sys} = \vec{0}$$
$$\sum\vec{F}_x = 0$$
$$\sum\vec{F}_y = 0$$
$$\sum\vec{F}_z = 0$$



Steps to illustrate the equilibrium

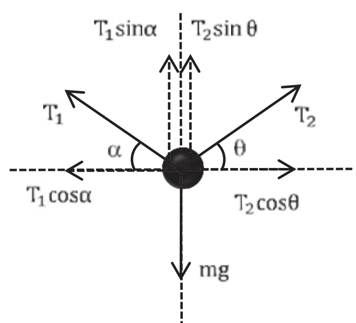
Step 1

Draw the FBD
FBD for the system of forces given in the previous figure is

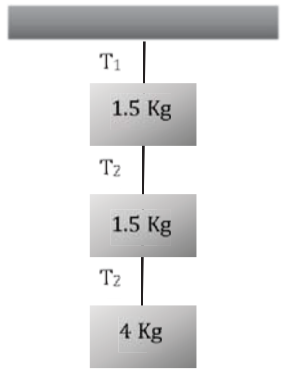
Step 2

Apply conditions of equilibrium

$$\sum\vec{F}_x = 0$$
$$T_2\cos\theta - T_1\cos\alpha = 0$$
$$\sum\vec{F}_y = 0$$
$$T_2\sin\theta + T_1\sin\alpha - mg = 0$$

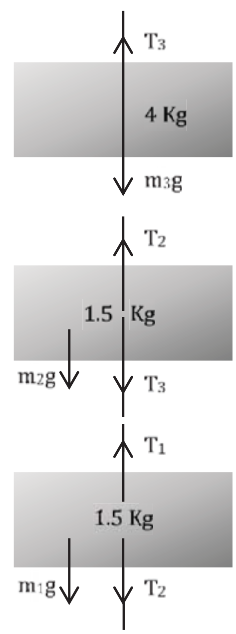


Ex. In the illustration, three blocks are hanging from a light string. What amount of force, T_1, is required to maintain balance in the system? (Assuming the acceleration due to gravity is 10 ms^{-2}.)



Sol. Commence by creating a Free Body Diagram (FBD) for each block independently. Subsequently, by employing the conditions of equilibrium, you can determine the magnitude of T_1. This pertains specifically to the lower block.

FBD can be drawn as



Applying the equilibrium equations

We get

$$T_3 = m_3 g$$
$$T_3 = 40 \text{ N}$$

By substituting the mass and gravitational acceleration values, we obtain the tension value. Likewise, the same process applies to the other two.

Applying the equilibrium equations, we get,

$$T_2 = m_2 g + T_3$$
$$T_2 = 55 \text{ N}$$

Draw a picture to show the forces on the top block, like the one next to it.

Applying the equilibrium equations, we get

$$T_1 = T_2 + m_1 g$$
$$T_2 = 70 \text{ N}$$

Hence, the value of T_1 has been calculated as 70 N

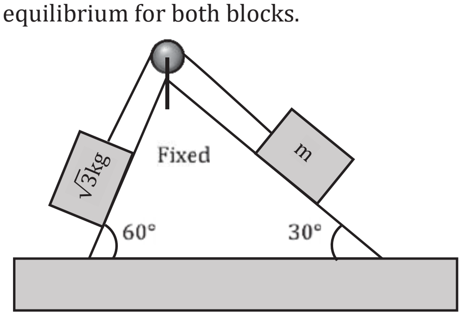
Alternative way:

Consider all three blocks as one unit. In this case, the external forces include the combined weight of the entire system pulling downward and the tension in the string pulling upward.

By balancing forces in vertical direction,

$$T_1 = m_1 g + m_2 g + m_3 g$$
$$T_1 = (1.5 + 1.5 + 4)10$$
$$T_1 = 70 \text{ N}$$

Ex. In the given figure, two blocks are linked by a string and suspended by a pulley. Determine the value of 'm' to achieve equilibrium for both blocks.



Sol. To find the mass 'm', create the Free Body Diagram (FBD) for the entire system, and then apply equilibrium conditions to the resolved force components.

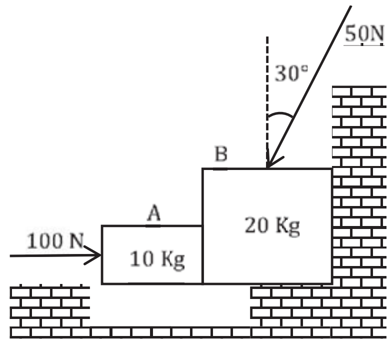
For mass m, $mg\sin 30^\circ = T$

For mass $\sqrt{3}$kg $\sqrt{3}g\sin 60^\circ = T$

From the two equations, $m = 3$ kg

The mass 'm' has been determined to be 3 kg to achieve equilibrium for the blocks.

Ex. In the given illustration, two blocks are in contact. Determine the forces applied by the surfaces (floor and wall) on the blocks, as well as the contact force between the two blocks. (Assume $g = 10\ ms^{-2}$)



Sol. To obtain the force values, create the Free Body Diagram (FBD) for the entire system, and subsequently, apply the conditions of equilibrium.

Considering block A of mass 10 kg, the FBD is shown as

$$\sum \vec{F}_x = 0 \Rightarrow N_{AB} = 100N$$
$$\sum \vec{F}_y = 0 \Rightarrow N_A = 100N$$

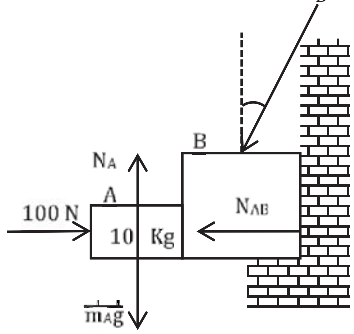
Now, considering block B of mass 20 kg,

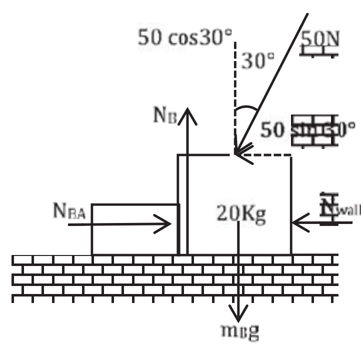
Ensuring equilibrium of forces in the horizontal direction,

$$\sum \vec{F}_x = 0$$
$$100 = N_{wall} + 25$$
$$N_{wall} = 75N$$

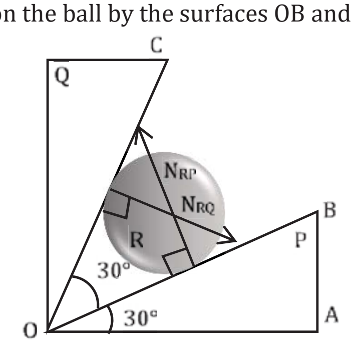
Balancing the force in the vertical direction,

$$\sum \vec{F}_y = 0$$
$$N_B = (200 + 25\sqrt{3})N$$





Ex. A 10 kg ball is positioned between two surfaces, OB and OC, as depicted in the figure. Determine the normal forces exerted on the ball by the surfaces OB and OC.



To find the values of the normal forces acting on the ball by the surfaces, create the Free Body Diagram (FBD) of the ball, and then apply the conditions of equilibrium. The provided figure illustrates the FBD of the ball.

The condition of equilibrium in the horizontal direction establishes the relationship between the normal forces.

$$\sum \vec{F}_x = 0$$

$$N_{RQ}\sin 60^\circ = N_{RP}\cos 60^\circ$$

$$\frac{\sqrt{3}}{2}N_{RQ} = \frac{N_{RP}}{2}$$

$$N_{RP} = \sqrt{3}N_{RQ} \qquad \text{... (1)}$$

Now, implementing the equilibrium condition in the vertical direction

$$\sum \vec{F}_y = 0$$

$$\frac{N_{RQ}}{2} + 100 = \frac{\sqrt{3}}{2}N_{RP}$$

$$\sqrt{3}N_{RP} = N_{RQ} + 200 \qquad \text{... (2)}$$

On Solving equation (1) and (2).

$$N_{RQ} = 100\text{N}$$

$$N_{RP} = 100\sqrt{3}\text{N}$$