

Module 2 Laws of Motion - Part 2

This module is designed to help you to:

- explain Newton's third law of motion and facilitate its comprehension to students with respect to its application;
- describe the law of conservation of linear momentum as a consequence of Newton's third law of motion;
- apply the concept of frame of reference and discuss Newton's laws of motion in inertial and non-inertial frames of reference;
- use free body diagrams to solve problems related to equilibrium of particles, forces, and motion of particle/system of particles;
- analyse different types of forces in mechanics with respect to their nature and effects.

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5.2.1 Introduction

Suppose you are sitting on a chair with your feet on the floor. You lift your feet from the floor and try to rise from the chair. You will not be able to do so. Either you have to press the floor with your feet or press the chair with your hands in order to be able to rise from your seat. Have you wondered why it is like that? Newton's third law of motion is at work and this law of Newton is perhaps the most widely celebrated law as it is used in virtually everything that we do in our daily lives. The concept of action and reaction forces and their role in the principle of conservation of linear momentum, all emanate from Newton's third law of motion. The free body diagram, which happens to be a very useful component of popular techniques undertaken for solving a variety of problems in all branches of mechanics, takes into account the concept of the third law of motion.

5.2.2 Newton's third law of motion

This law states: **To every action, there is always an equal and opposite reaction.** Here action and reaction essentially refer to two forces. Action and reaction act simultaneously on two different objects and in opposite directions, but as they act on different bodies they cannot produce equilibrium.

Activity 5.2.1: To observe and discuss that action/reaction act on different bodies and that they always come in pairs.

Let us take two Footballs, Football (1) of mass m_1 and Football (2) of mass m_2 .

Football (1) is rolled towards a stationary Football (2). After the collision how the two footballs move will depend on their masses and on the velocity of Football (1) before collision.

Let us consider three cases [Fig.5.2.1 (a),(b),(c)].

Case 1: Football (1) is heavier than Football (2), which is stationary. The heavier body is being rolled towards the lighter body.

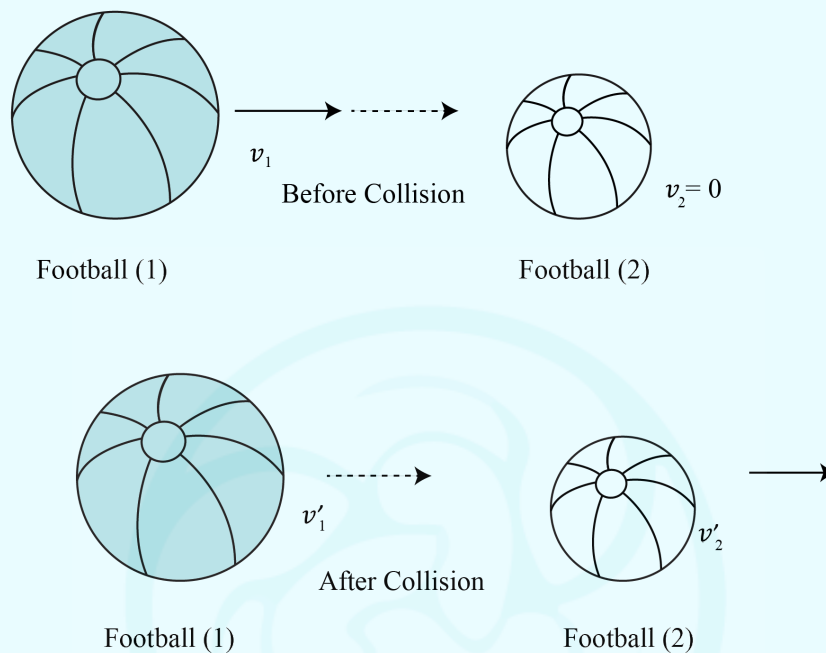


Fig. 5.2.1(a): $v'_1 < v_1$ and $v'_2 > 0$

Case 2: Both Footballs have the same mass and Football (1) is rolled towards the stationary Football (2).

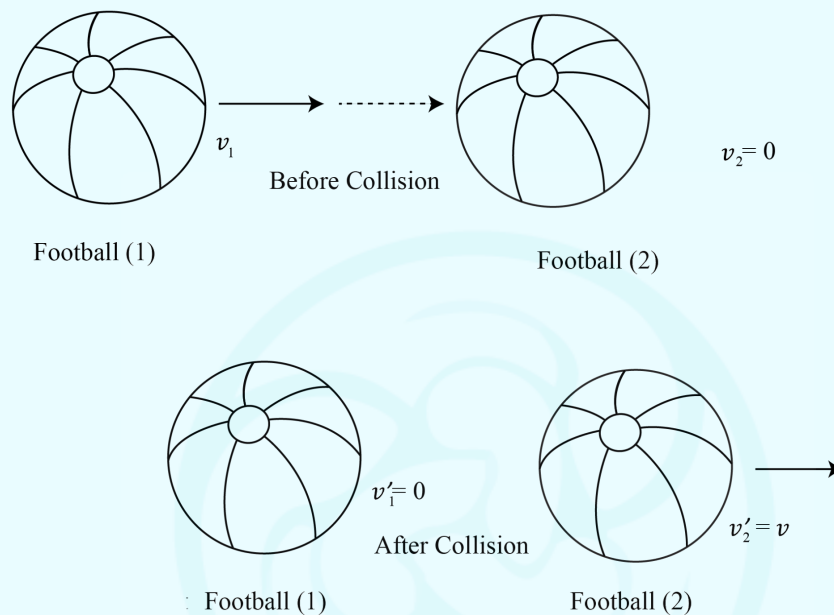


Fig. 5.2.1(b) $v_1' = 0$, $v_2' = v_1$ (These can be obtained analytically by applying the theory of elastic collisions, which you will study at a later stage).

Case 3: Football (1) is lighter than Football (2), that is stationary. The lighter body is rolled towards the heavier body.

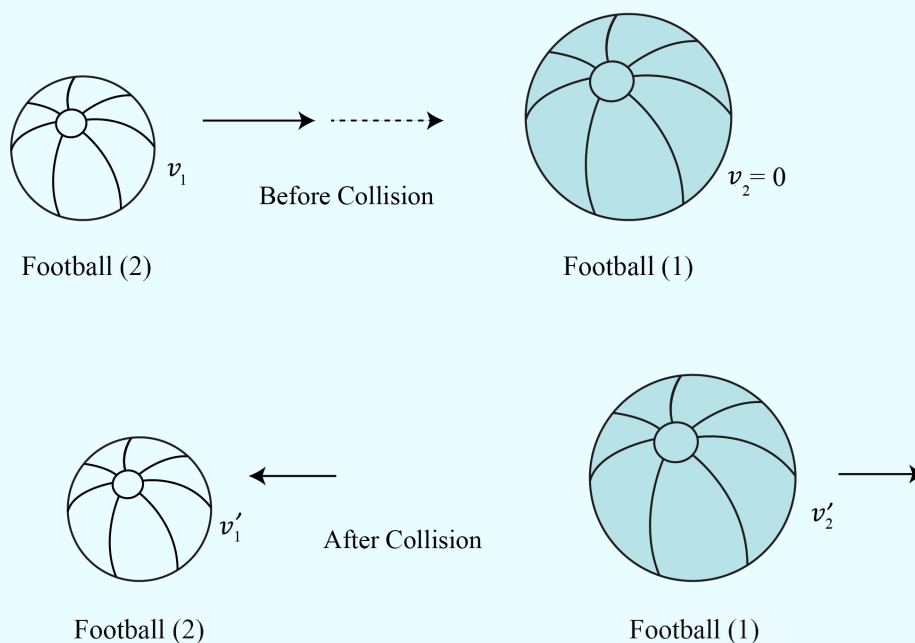


Fig.5.2.1(c): $v_2' > 0$ (Football (1) moves opposite to the direction of its approach to Football (2). Specific values of the respective velocities can be obtained analytically after studying the theory of collision).

While presenting the cases 1, 2 and 3, we have presumed that there is no friction between the balls and the surface on which they are rolling. However, you may try this activity with two footballs of different masses, and make an attempt to verify the above results at least qualitatively.

Discuss these cases in the context of Newton's second and third laws of motion. Since force is a vector quantity, make sure that you have duly taken into account its direction. The second law relates external force to acceleration, but it remains silent about the origin of this force. The external force on a body arises either by way of contact (like push, pull, etc.) or action at a distance (like gravitation, statical electricity and so on).

With reference to what we have studied so far, the following points need elaboration:

- The terms action and reaction stand for simultaneous mutual forces between a pair of bodies, and these do not account for any external force.

- Action and reaction do not act on the same body, but always act on different bodies. Like when a book of mass m lies on a table, a force mg gets applied in the vertically downward direction on the table by the body as the action Force, and its reaction, also equal to mg , gets applied in the vertically upward direction on the book by the table.
- These forces always occur in pairs.
- If we consider a system of two bodies as a whole, the action and reaction are internal forces of the system. Being equal and opposite, they add up vectorially to zero, but it should not be misconstrued that they produce equilibrium. In order to be in equilibrium under the influence of two forces, these should be equal and opposite, but more importantly, they should be acting on the same body, which is NOT the case with an action-reaction pair. Internal forces in a body or system of particles thus cancel away in pairs. This concept will be of importance when we study the motion of a system of particles in a later chapter. At any instant, where there is action, there is an equal and opposite reaction. You cannot have action in isolation. No isolated single force exists in this universe. You may make a list of examples where you can identify action-reaction force pairs.

Let '1' and '2' be two particles of masses m_1 and m_2 (Fig. 5.2.2).

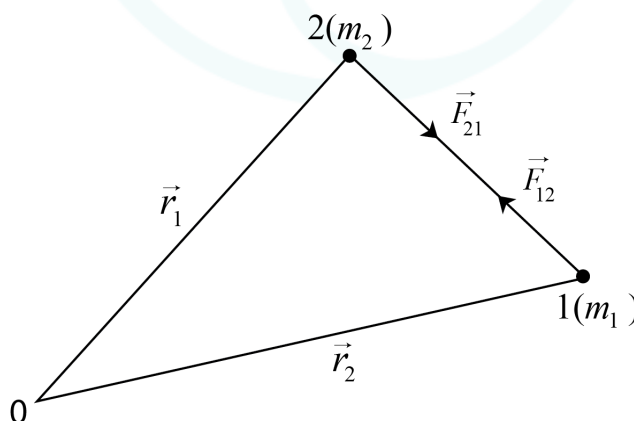


Fig. 5.2.2 Force acting between two particles are equal and opposite

They are moving under the influence of their mutual action and reaction, no external force is acting on the system. $\vec{F}_{12}$ is the force acting on body (1) due to body (2) and $\vec{F}_{21}$ is the force acting on body (2) due to

body (1). then we have from Newton's second law of motion (with symbols having their usual meanings) that,

$$\vec{F}_{12} = m_1 \frac{d^2 \vec{r}_1}{dt^2} = m_1 \frac{d}{dt} \left(\frac{d\vec{r}_1}{dt} \right) = m_1 \frac{d}{dt} (\vec{v}_1) = \frac{d}{dt} (m_1 \vec{v}_1) \quad (5.2.1)$$

$$\vec{F}_{21} = m_2 \frac{d^2 \vec{r}_2}{dt^2} = m_2 \frac{d}{dt} \left(\frac{d\vec{r}_2}{dt} \right) = m_2 \frac{d}{dt} (\vec{v}_2) = \frac{d}{dt} (m_2 \vec{v}_2) \quad (5.2.2)$$

From Newton's third law, we have,

$$\vec{F}_{12} = -\vec{F}_{21} \quad (5.2.3)$$

$$\frac{d}{dt} (m_1 \vec{v}_1) = -\frac{d}{dt} (m_2 \vec{v}_2) \quad (5.2.4)$$

$$\frac{d}{dt} (m_1 \vec{v}_1 + m_2 \vec{v}_2) = 0 \quad (5.2.5)$$

Eq. (5.2.5) provides the background of the principle of conservation of linear momentum, which we shall state now.

5.2.3 Conservation of linear momentum

For a single particle, we find that if no external force acts on it, then from Newton's second law of motion, its rate of change of linear momentum is zero, and **so the linear momentum of a particle remains conserved, if no external force acts on it.** It is the most fundamental statement of the principle. It takes the generalized form for a many particle system moving under their mutual action and reaction forces. However, here we shall introduce it for a two-particle system following Eqn (5.2.5). Since, the RHS of the equation is zero, we have,

$$m_1 \vec{v}_1 + m_2 \vec{v}_2 = \text{a constant vector.} \quad (5.2.6)$$

So, the principle can be stated as: **the total linear momentum of an isolated system of two interacting particles is conserved.**

Examples of such two particle (or, body) systems are the Sun and the earth, the Earth and Moon, rifle and the bullet and so on. Let us consider the example of a rifle and bullet.

When a bullet of mass m is fired with a velocity $\vec{v}$ from a rifle of mass M , the initial total momentum of the system (bullet and rifle) before the explosion of the gun powder is zero. It is an internal phenomenon, no

external force acts on the system, and so the final total momentum would be zero, which means that the rifle will have a momentum in a direction opposite to that of the bullet. If the velocity of the rifle is $\vec{V}$, then we have

$$MV + m\vec{v} = 0 \Rightarrow \vec{V} = -\frac{m\vec{v}}{M} \quad (5.2.7)$$

The negative sign indicates the rifle moves in the reverse direction. It is said that the rifle recoils, and the positive value of $\vec{V}$ is called the velocity of recoil.

Collisions are events that provide a suitable illustration of the principle. In case of an elastic collision, the linear momentum is conserved and the kinetic energy is also conserved, whereas in case of inelastic collisions, kinetic Energy is not conserved but total energy and linear momentum are conserved. We shall study further details about them in a later chapter.

Now that we have covered the three laws of motion, it will be worthwhile to talk a bit critically about the notion of the observer, and we shall do that by having a brief discussion about frame of reference.

5.2.4 Frame of Reference (FoR) - Whenever an event is described, among other things space and time need to be specified - like a meeting will be held at the first floor of your school building at 10 AM on the second Saturday of this month. In order to fix this event in space and time, we need to describe a three-dimensional coordinate system (x, y, z) attached to an observer. This observer has to record the time also, and so he/she should be having a clock. But the clock from the point of view of an observer is not ideally a single clock, but a hypothetical set of synchronized clocks and this along with the three space coordinates constitutes a frame of reference.

The description of space and time gets provided by the four numbers (x, y, z, t) in their respective prescribed units. It can easily be understood that these numbers will vary from one FoR to another.

Physicists, including Sir Isaac Newton had thought of attaching the absolute frame of reference with the distant stars. However, the search for an absolute FoR turned out to be futile. It was thus felt that an FoR be visualized as moving with respect to other FoRs.

- (a) Inertial frame of reference - A frame of reference at rest or moving with a constant velocity with respect to another frame of reference, are together inertial frames of reference with respect to one

another. Laws of Newtonian mechanics retain the same form in inertial frames of reference. Two athletes moving with uniform speed with respect to each other are inertial with respect to each other.

(b) Non- inertial frame of reference - A frame of reference that is accelerating is non-inertial. Our earth happens to be a non-inertial frame of reference because it is accelerating due to its rotation about its axis, as well as round the Sun. The laws of Newtonian Mechanics do not retain their usual form in a non-inertial frame. There we have to postulate the existence of a force (called pseudo force or inertial force) to make the laws tenable. We shall study this through the example of centrifugal force in the next module.

So far, we had considered examples involving invariant mass. How to go about with the application of Newton's second law of motion when mass does not remain invariant.

Newton's laws of motion when the mass is not invariant: The examples of such cases are like - A falling raindrop gathers mass and thereby its mass keeps changing during its fall; a conveyor belt also keeps gathering mass; a rocket continuously sheds its mass as it moves upward. Let us look into the last case through a numerical example.

Example 5.2.1 A rocket burns 0.2 kg of fuel per second, as a result of which a gas gets ejected with a velocity of 750 m/s. What is the force exerted by the gas on the rocket?

Solution

According to Newton's second law of motion, with symbols having their usual meanings, we have

$$\vec{F} = \frac{d}{dt}(m\vec{v}) = \vec{v} \frac{dm}{dt}$$

The process of differentiation needs to be perused carefully. Here, for a change v is constant, m is varying with time, and thus we have considered the time derivative of mass, not the velocity.

Now, $\frac{dm}{dt} = -0.2 \text{ kg/s}$.

The negative sign appears because mass is decreasing with time.

So, the reqd force = $-750(0.2) \hat{n} \text{ (m/s)(kg/s)} = -150 \hat{n} \text{ kg m/s}^2$

Here $\hat{n}$ is the unit vector in the direction of the velocity. So, the force is 150 N in the direction opposite to that of the velocity, as is always the case which one must have observed.

Activity 5.2.2: A block is kept on the floor of a truck which is

- (a) at rest
- (b) moving with uniform linear velocity
- (c) moving with constant acceleration

What is the effect on the block in the three cases and why? Discuss the result of the activity in the light of Newton's laws of motion. The student should be introduced to the manner in which Newton's laws of motion are to be applied. Concepts of frame of reference, inertial and non-inertial frames should be taken into consideration.

5.2.5 Equilibrium of a particle

A particle is said to be in equilibrium if the net external force on the particle is zero. Note that force is a vector quantity and therefore while adding two or more forces; we must follow the law of addition of vectors [Fig. 5.2.3 (a)]. If two forces $\vec{F}_1$ and $\vec{F}_2$ acts on a particle, equilibrium requires

$$\vec{F}_1 = -\vec{F}_2$$


Fig. 5.2.3(a) *Equilibrium of two forces*

i.e the two forces on a particle must be equal and opposite.

Equilibrium under three concurrent forces $\vec{F}_1$, $\vec{F}_2$ and $\vec{F}_3$ requires that the vector sum of the three forces is zero [Fig. 5.2.3 (b)].

$\vec{F}_1 + \vec{F}_2 + \vec{F}_3 = 0$, which happens when the forces can be represented in magnitude, direction and position by the three sides of a triangle taken in order.

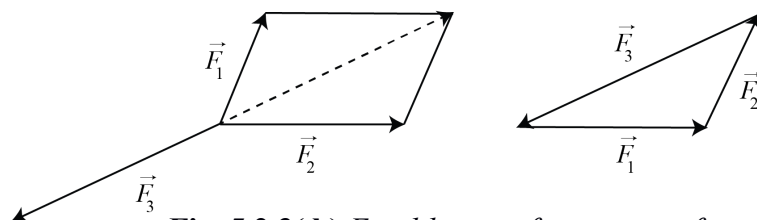


Fig. 5.2.3(b) *Equilibrium of concurrent forces*

If the forces are not concurrent, then they should be parallel to one another, such that the resultant of two is equal and opposite to the third.

We shall now study examples of equilibrium of forces using free-body diagrams.

Solving problems in mechanics: use of Free Body Diagram (FBD)

The state of motion of a point object is determined by the resultant of all forces acting on it. These forces may have different origins. These may be the forces at a distance like gravity or the force on a piece of iron exerted by a magnet held at a certain distance. These forces may be contact forces like tension in a string or the buoyant force on a floating body. However, while dealing with the problems involving the equilibrium of a body, we only need to consider the forces acting on it and need not worry about the source of a force. In a crowded queue for purchasing tickets at a metro station, if you feel a push from behind you just blame the person standing immediately behind you but he may helplessly argue that the push is coming from far behind, but for you he is the source for the push. We apply similar principles in drawing the free body diagram (FBD). Let us look at a few examples.

In Fig 5.2.4 (a), the system of two masses is suspended from rigid support with the help of massless strings and the whole system is stationary. If we look at the equilibrium of mass M_1 we know there are three forces acting on it. We should focus our attention on these three forces. We can write down the equation for the equilibrium of the mass M_1 and balancing all the forces acting on it as shown in Fig.5.2.4 (a) as

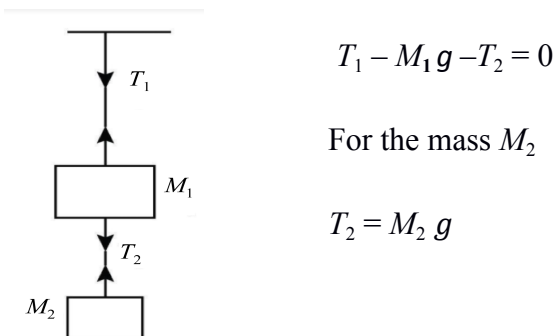


Fig. 5.2.4 (a) system of two masses is suspended from rigid support

On the other hand, suppose a block is stationary on a rough inclined plane [Fig. 5.2.4(b)]. The forces under consideration will be the weight of the body mg and the normal reaction N . However, for the equilibrium of the

body a component of the weight, $mg \sin \theta$, will act in the downward direction along the inclined plane and the normal reaction perpendicular to the surface of the plane would be $N = mg \cos \theta$.

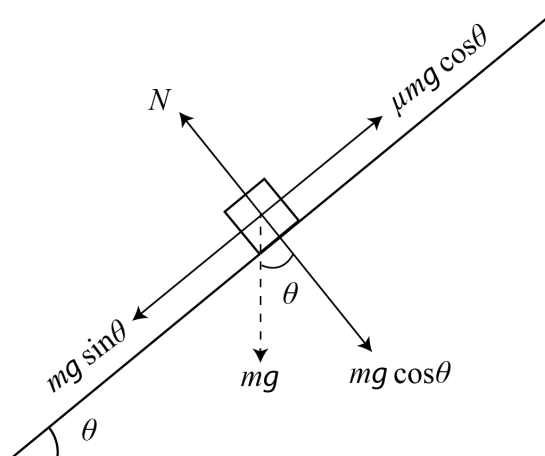


Fig. 5.2.4 (b) Forces on a block resting on an inclined plane

Equilibrium condition needs to be fulfilled for directions perpendicular and parallel to the plane. For the former case $N = mg \cos \theta$ and for the latter, $mg \sin \theta = \mu mg \cos \theta$, leading to $\mu = \tan \theta$, where μ is the coefficient of static friction between the body and the surface.

To handle a typical problem in mechanics systematically, we should use the following steps:

- (i) Draw a diagram showing schematically the various parts of the assembly of bodies, the links, supports, etc.
- (ii) Choose a convenient part of the assembly as one system.
- (iii) Draw a separate diagram that shows this system and all the forces on the system by the remaining part of the assembly. Include also the forces on the system by other agencies. Do not include the force on the environment by the system.

A diagram of this type is known as a Free Body Diagram (FBD).

Note this does not imply that the system under consideration is without a net force.

- (i) In a free body diagram, include information about forces (their magnitudes and directions) that are either given or you know for sure (e.g. the direction of tension in a string is along its length). The rest should be treated as unknown to be determined using laws of motion and other due considerations.

(ii) If necessary, follow the same procedure for another choice of the system. In doing so, employ Newton's third law. That is, if, in the free-body diagram of A, the force on A due to B is shown as $\vec{F}$, then in the free-body diagram of B, the force on B due to A should be shown as $-\vec{F}$.

(iii) The practice of drawing free body diagrams is of great help in solving problems in mechanics. It allows us to clearly define our system and consider all forces on the system due to objects that are not part of the system itself.

Let us look at an example. Three masses are suspended as shown in Fig. 5.2.5 This type of arrangement is popularly known as a connected system.

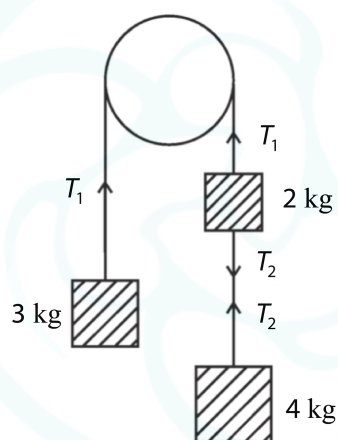


Fig. 5.2.5 A connected system of three mass

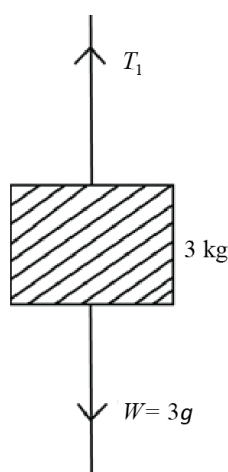
Important points

1. The pulley is assumed to be massless/light. This is because it ensures that no energy is lost from the system due to the rotational motion of the pulley. [Please note this is an approximation].
2. There is no friction. This assumption is also an approximation to simplify the problem. Otherwise, we need to take different tension on different parts of the string on either side of the pulley. But this would involve equations of rotational motion of the pulley.
3. The direction of the tension in a string should ensure that it exerts a pull on a body.

Let us work out the problem shown in Fig. 5.2.5 with the help of free body diagrams. We have first drawn the direction of tension in different strings. The 2 kg mass can 'see' the tension T_1 in the upward direction, its

weight 2 kg wt in the downward direction and T_2 the tension of the second string acting downward. This mass does not ‘see’ what agencies are responsible for these pulls. We also look at these forces only while finding out the motion of the 2 kg mass. This problem can be done with two approaches as the whole thing is taking place in a conservative field i.e. the field of gravity. ($g = 9.8 \text{ m s}^{-2}$).

Force approach



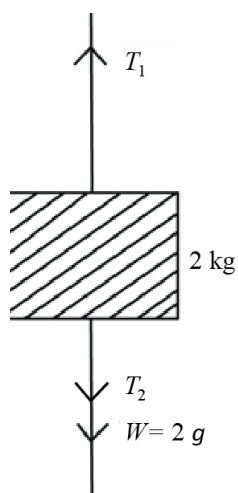
FBD for 3 kg mass Fig 5.2.6(a).

$$T_1 - 3g = 3a$$

or,

$$T_1 = 3a + 3g \quad (5.2.8)$$

Fig. 5.2.6(a) FBD for 3 kg mass



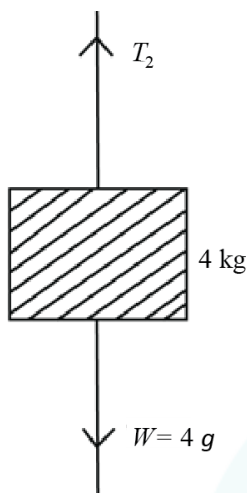
FBD for 2 kg mass Fig 5.2.6(b)

$$T_2 + 2g = 2a + T_1$$

or,

$$T_2 + 2g - T_1 = 2a \quad (5.2.9)$$

Fig. 5.2.6(b) FBD for 2 kg mass



FBD for 4 kg mass Fig 5.2.6(c)

$$4g = 4a + T_2$$

or

$$4g - T_2 = 4a$$

(5.2.10)

Fig. 5.2.6(c) FBD for 4 kg mass

Adding equations (5.2.8), (5.2.9) and (5.2.), we get

$$3g = 9a$$

$$a = g/3 \text{ m s}^{-2}$$

Energy approach

Start from the mass-pulley system being held at rest and then released. After the system has moved by a vertical distance h (3 kg mass has gone up and 2 kg and 4 kg masses have come down). The velocity is given by

$$v^2 = 2ah$$

$$\text{Gain of PE by 3 kg mass} = 3gh$$

$$\text{Gain of KE by 3 kg mass} = \frac{1}{2} \cdot 3 \cdot 2ah = 3ah$$

$$\text{Loss of PE by 2 kg mass} = 2gh$$

$$\text{Gain of KE by 2 kg mass} = \frac{1}{2} \cdot 2 \cdot 2ah = 2ah$$

$$\text{Loss of PE by 4 kg mass} = 4gh$$

$$\text{Gain of KE by 4 kg mass} = \frac{1}{2} \cdot 4 \cdot 2ah = 4ah$$

In this conservative system, total gain will be equal to total loss

$$3gh + 3ah + 2ah + 4ah = 2gh + 4gh$$

$$9ah = 3gh$$

$$a = \frac{g}{3}$$

Using this value of a , T_1 and T_2 can be found out like this

$$T_1 - 3g = 3 \cdot \frac{g}{3}$$

$$T_1 = 4g$$

$$4g - T_2 = 4 \cdot \frac{g}{3}$$

$$T_2 = \frac{8}{3}g$$

So, it can be seen that both the approaches produce the same results.

Now let us look at the problem below (Fig 5.2.7). The mass on the inclined plane is 3 kg and the other mass is 2 kg.

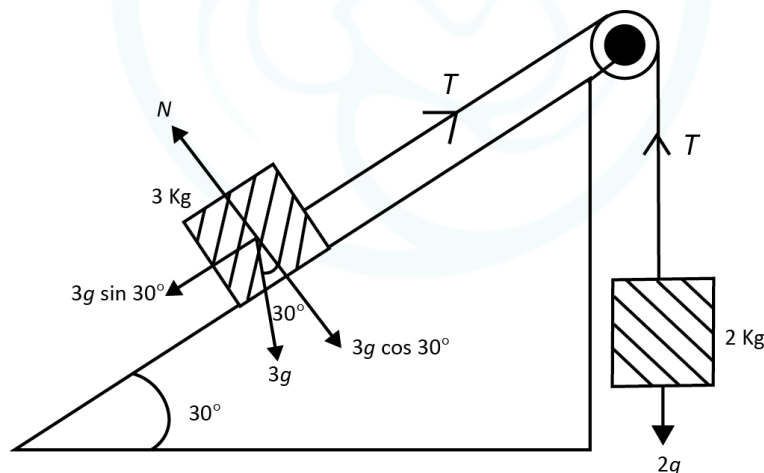


Fig. 5.2.7 3 kg mass goes down along the inclined plane and the 2 kg mass moves up to an inclined plane

Let us assume the 3 kg mass goes down along the inclined plane and the 2 kg mass moves up. We can write down the equation using a free body diagram. Let T is the tension on the string.

FBD equation for 3 kg mass

$$3g \sin 30^\circ - T = 3a$$

FBD equation for 2 kg mass

$$T - 2g = 2a$$

Adding the two equations we have

$$1.5g - 2g = 5a$$

$$a = \frac{-0.5}{5}g$$

$$\therefore a = -0.1g$$

Example 5.2.2 A horizontal force of 12 N is applied on the combination of the three blocks placed on a smooth plane surface as shown in Fig.5.2.8. Find the acceleration of the system and force at the interfaces of 1 kg and 2 kg mass and that of 2 kg mass and 3 kg mass.

Now if the same force is applied to the same set of blocks arranged in a reverse order, how will the acceleration of the system and force at the interfaces change?

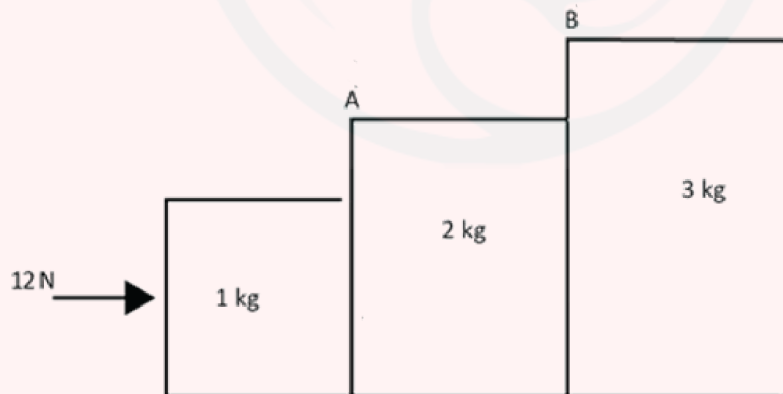


Fig. 5.2.8

Solution: Force at the interface between 1 kg and 2 kg masses is taken as F_A and that of 2 kg and 3 kg masses is taken as F_B (Fig. 5.2.9).

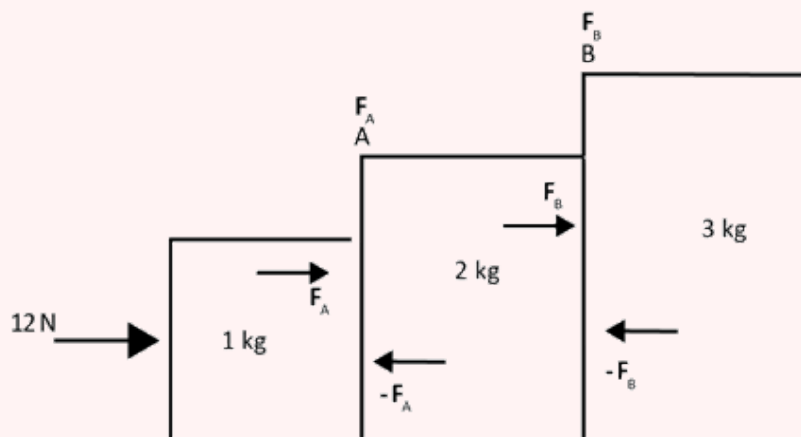


Fig. 5.2.9

F_A acts on 2 kg block

– F_A (equal and opposite) acts on 1 kg block

F_B is the force from 2 kg block to 3 kg block

– F_B is the force (equal and opposite) exerted by a 3 kg block on 2 kg block.

We want to find the forces acting at the interface of A and B. If the common acceleration is a

$$12 - F_A = 1 \times a$$

$$\text{or, } F_A = 12 - a$$

$$F_A - F_B = 2 \times a$$

$$\text{or, } 12 - a - F_B = 2a$$

$$\text{or, } F_B = 12 - 3a$$

$$F_B = 3 \times a = 3a$$

Comparing the values of F_B we have

$$12 - 3a = 3a$$

$$6a = 12 \Rightarrow a = 2 \text{ m s}^{-2}$$

$$F_A = 12 - 2 = 10 \text{ N}$$

$$F_B = 3 \times 2 = 6 \text{ N}$$

Now the same force is applied to the same set of blocks arranged in reverse order Fig. 5.2.10. Let us see the forces at the interfaces.

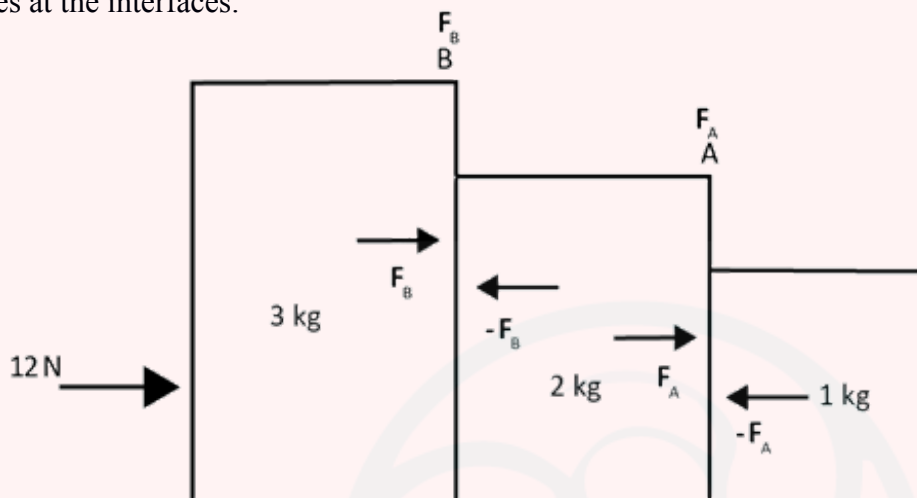


Fig. 5.2.10

$$12 - F_B = 3 \times a$$

$$\text{or, } F_B = 12 - 3a$$

$$F_B - F_A = 2 \times a = 2a,$$

$$F_A = 1 \times a = a$$

Substituting for F_A and F_B we get

$$a = 2 \text{ m s}^{-2}, \quad F_B = 6 \text{ N}, \quad F_A = 2 \text{ N}$$

So, in the first case, the force F_A at the interface of 1 kg and 2 kg blocks was 10 N whereas in the second case, it is equal to 2 N. In the first case F_B , the force between the 2 kg and 3 kg block was 6 N while in the second case this remains the same for this problem.

Note: Following similar problems can be discussed with students.

A force of 12 N has been applied to the three blocks 3 kg, 1 kg, and 2 kg kept on a smooth floor as shown in Fig. 5.2.11 Find the acceleration of the system and force at the interfaces of 3 kg mass with 1 kg mass and of 1 kg mass with 2 kg mass.

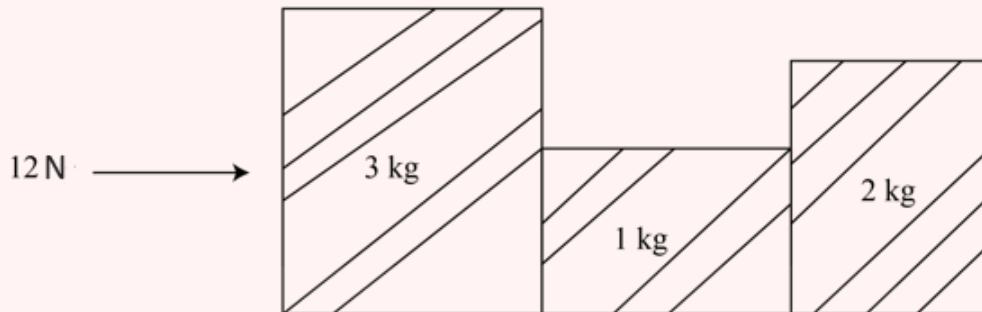


Fig. 5.2.11

Example 5.2.2 A mass of 6 kg is suspended by a rope of length 2 m from the ceiling. A force of 50 N in the horizontal direction is applied at the midpoint P of the rope, as shown in [Fig. 5.2.12 (a)]. What is the angle the rope makes with the vertical in equilibrium? (Take $g = 10 \text{ m s}^{-2}$). Neglect the mass of the rope.

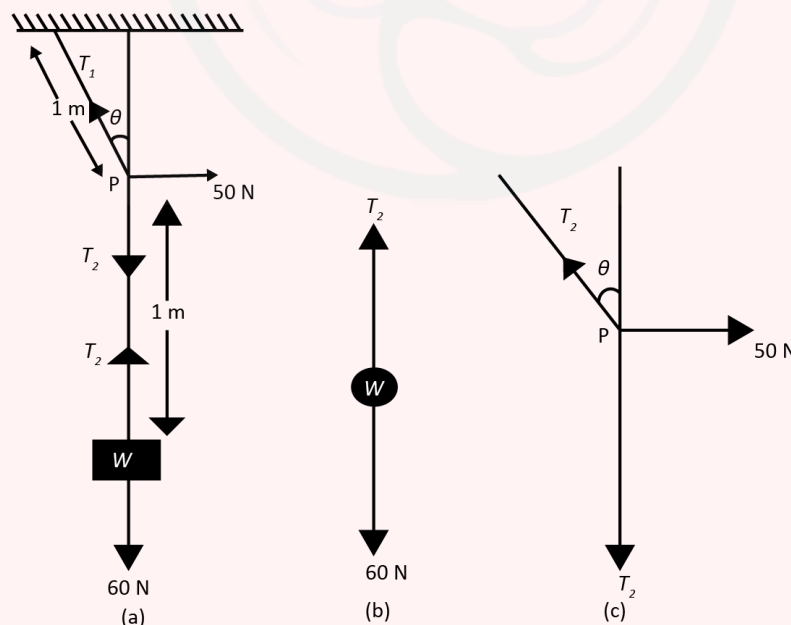


Fig. 5.2.12 (a,b,c)

Solution: Fig. 5.2.12 (b) is the free-body diagram of W and Fig. 5.2.12 (c) is the free-body diagram of point P. Consider the equilibrium of the weight W . Clearly, $T_2 = 6 \times 10 = 60$ N. Consider the equilibrium of the point P under the action of three forces - the tensions T_1 and T_2 , and the horizontal force 50 N. The horizontal and vertical components of the resultant force must vanish separately [Fig. 5.2.12(d)].

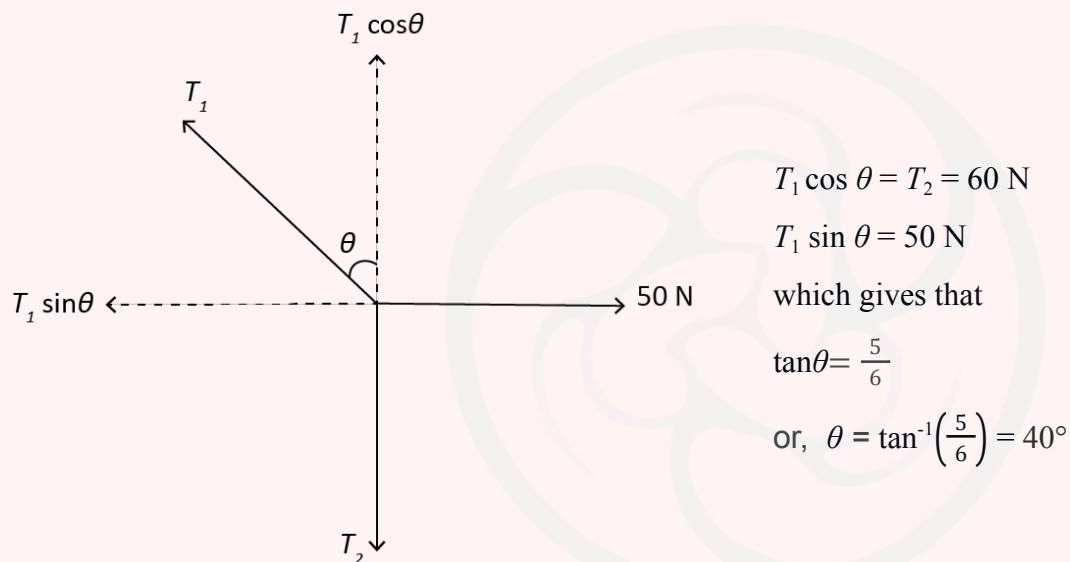


Fig. 5.2.12(d)

Note that the answer does not depend on the length of the rope (assumed massless) nor on the point at which the horizontal force is applied.



Let Us Reflect

Q.5.2.1 A block of mass 25 kg is raised by a 50 kg man in two different ways as shown in Fig. 5.2.13. What is the action on the floor by the man in the two cases? If the floor yields to a normal force of 700 N, which mode should the man adopt to lift the block without the floor yielding?

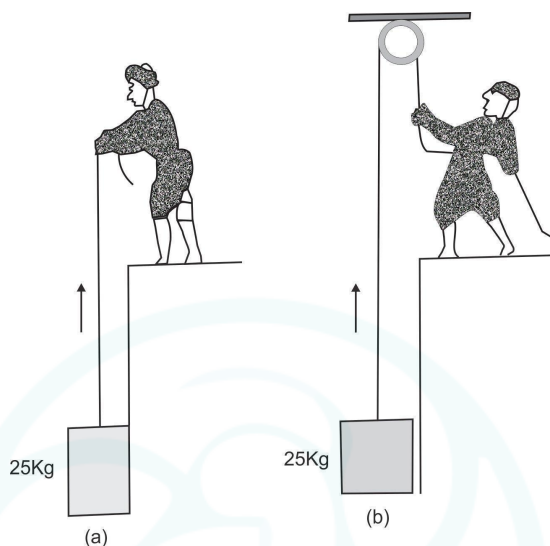


Fig. 5.2.13

Q.5.2.2 A monkey of mass 40 kg climbs on a rope, as shown in Fig 5.2.14, which can stand a maximum tension of 600 N. In which of the following cases will the rope break: when the monkey

- (a) Climbs up with an acceleration of 6 m s^{-2}
 - (b) Climbs down with an acceleration of 6 m s^{-2}
 - (c) Climbs up with a uniform speed of 5 m s^{-1}
 - (d) Falls down the rope nearly freely under gravity?
- (ignore the mass of the rope.)

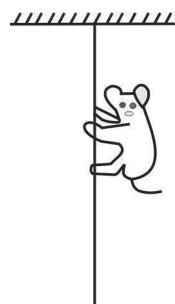


Fig 5.2.14

Q.5.2.3 Two bodies A and B of mass 5 kg and 10 kg in contact with each other rest on a table against a rigid wall (Fig. 5.2.15).

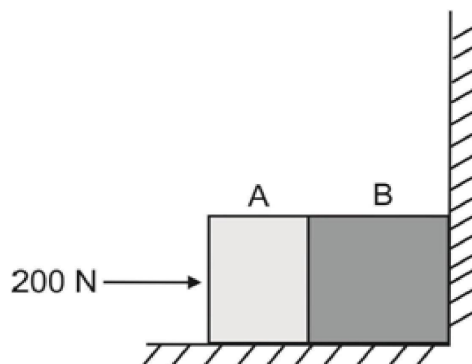


Fig. 5.2.15

The coefficient of friction between the bodies and the table is 0.15. A force of 200 N is applied horizontally to A. What are (a) the reaction of the wall (b) the action-reaction forces between A and B? What happens when the wall is removed? Does the answer to (b) change, when the bodies are in motion? Ignore the difference between μ_s and μ_k .

Q.5.2.4 Design three problems in Mechanics that can be solved using laws of motion and Free Body Diagram.



Answers

A.5.2.1 Consider the forces on the man in equilibrium: his weight, force due to the rope and normal force due to the floor.

(a) 750 N (b) 250 N; mode (b) should be adopted.

A.5.2.2 (a) $T - 400 = 240$, $T = 640$ N

(b) $400 - T = 240$, $T = 160$ N

(c) $T = 400 \text{ N}$

(d) $T = 0$

The rope will break in case (a).

A.5.2.3 We assume perfect contact between bodies A and B and the rigid wall. In that case, the self-adjusting normal force on B by the wall (reaction) equals 200 N. There is no impending motion and no friction. The action-reaction forces between A and B are also 200 N. When the wall is removed, kinetic friction comes into play.

$$\text{Acceleration of A + B} = [200 - (150 \times 0.15)] / 15 = 11.8 \text{ m s}^{-2}$$

$$\text{Friction on A} = 0.15 \times 50 = 7.5 \text{ N}$$

$$200 - 7.5 - F_{AB} = 5 \times 11.8$$

$$F_{AB} = 133.5 \text{ N; opposite to motion .}$$

$$F_{BA} = 133.5 \text{ N; in the direction of motion.}$$

A.5.2.4 Teacher can facilitate students to design the problems.

5.2.6 Common forces in mechanics

In mechanics, we encounter several kinds of forces.

- The gravitational force is all pervasive and acts on all objects. It is a non-contact force. All other forces common in mechanics are contact forces.
- The different terms like friction, normal reaction, tension, air resistance, viscous drag, thrust, buoyancy, weight, centripetal force, all stand for force in different contexts. For clarity, every force and its equivalent terms encountered in mechanics should be reduced to the phrase force on A by B.
- Contact force: Friction, tension, restoring force in spring.
- Non-contact forces (force at a distance): gravitational force, electromagnetic force.

Activity 5.2.3: Give examples from your daily life involving the presence of contact and non-contact forces.

- **Tension:** It is a type of contact force whose direction is always directed away from the body causing it. With the help of a string, one can apply a pull on a body attached to it but no push can be applied on a body with the help of a string. For example, when a small mass tied to a string is suspended from the ceiling of a room then the tension force acting on the small mass will be upward so as to pull it upward and the tension force on the ceiling will be downward so as to pull it downward.
- **Direction of force:** Normal direction- is direction that is at a right angle (90°) to the surface or area being considered. Tangential direction- a direction that is parallel or along the surface or area being considered.

5.2.7 Summary

- **Newton's third law of motion:**

To every action, there is always an equal and opposite reaction. In simple terms, the law can be stated thus: Forces in nature always occur in pairs. Force on body A by body B is equal and opposite to the force exerted on body B by body A. Action and reaction forces are simultaneous forces. There is no cause-effect relationship between action and reaction. Any of the two mutually opposite and equal forces can be called action and reaction forces. Action and reaction act on different bodies so they cannot be cancelled out. The internal action and reaction forces between different parts of a body do, however, sum to zero.

- **Law of conservation of momentum**

The total momentum of an isolated system of particles is conserved. The law follows from the second and the third law of motion.

- In order to study any kind of motion, it is important to define the frame of reference in which the motion is taking place. There are two types of frames of reference: (a) Inertial frame of reference (this is a non-accelerating frame of reference); (b) Non-inertial frame of reference (this is an

accelerating frame of reference). The frame of reference fixes the origin and the coordinates relative to which the motion is taking place. Without a frame of reference, motion has no meaning. Typically, all of Newton's laws of motion are valid only in an inertial frame of reference.

- A particle is said to be in equilibrium if the net external force on the particle is zero.
- Free Body Diagram (FBD) is an important tool to solve problems in Physics and Engineering involving the motion of bodies subjected to various forces. FBD helps in visualizing the forces applied to a body and calculating the resulting reactions in many problems in mechanics. The important concept here is to draw a free body diagram to show the magnitude and direction of all the forces acting on it and being exerted by it.
- FBD also helps in developing an understanding of the concept of the body in equilibrium. Thus, if all the forces acting on the body or being exerted by it are balanced, then the body is in equilibrium and is either at rest or in uniform motion. If all the forces acting on the body or being exerted by it are unbalanced, then the body is not in equilibrium and is experiencing accelerated or decelerated motion.

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