Equilibrium of Forces

Physics
12

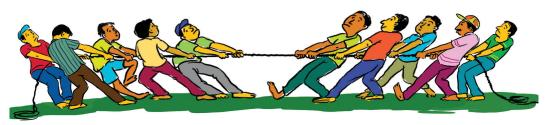## 12.1   Introduction to equilibrium of forces

Figure 12.1 – Two groups pulling a rope

In a competition of pulling a rope, two groups pull the rope in two opposite directions. When the force exerted in one direction becomes greater than the force exerted in the other direction, the rope moves in the direction of the larger force. When both groups pull with equal forces, the rope will remain at rest without moving in either direction. The sum of the two forces becomes zero. In this situation the rope is said to be in equilibrium under the action of the forces in the two directions.

Another such instance is shown in Figure 12.2. It shows an object suspended by a spring balance.

Here there are two forces acting on the object. One force is the weight of the object which arises due to the gravitational force. The other is the upward force exerted by the spring of the balance in order to keep the object from falling onto the ground. Under the action of these two forces, the object remains at rest. That is, the object is in equilibrium under the two forces.

Force exerted by
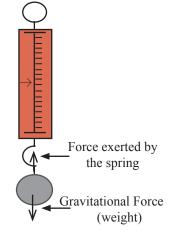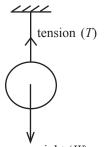the spring

Gravitational Force
(weight)

Figure 12.2 - An object
suspended by a spring balance

A sphere suspended by a string is shown in Figure 12.3. The weight of the sphere is acting vertically downwards. The sphere remains at rest as the vertically upward force applied by the string, balances the force due to its weight (The force applied by the string is called its tension). In this instance, the sphere remains in equilibrium under the downward force due the weight (W) and the upward force (T) exerted by the string.

tension (T)

weight (W)
Figure 12.3 – A sphere suspended by a string

In daily life, we come across situations where various forces act on objects quite frequently. Objects can remain in equilibrium under two, three or even many forces.

Here we will consider instances where objects remain in equilibrium under two or three forces.
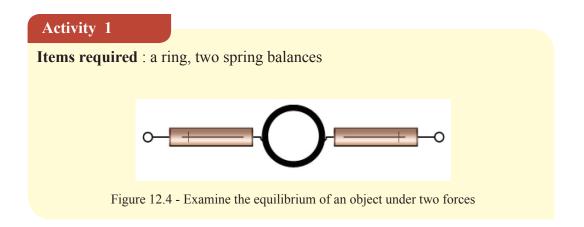
12.2   Equilibrium of a body under two forces

We learnt about the effective force or the resultant force of two collinear forces (forces acting along the same line) acting on a point, in the lesson on resultant force.

In that lesson, you have learnt that, while a certain force is acting on an object, if it is pulled by another force in the opposite direction, the magnitude of the resultant force decreases. When an object is said to be in equilibrium, what is meant is that the resultant force of the two forces acting on the object is zero.

Now let us investigate the factors required to keep an object in equilibrium under two forces acting in opposite directions along the same line.

Let us do activities 1 and 2 for this purpose.

Activity 1

Items required : a ring, two spring balances

Figure 12.4 - Examine the equilibrium of an object under two forces

- Place the ring horizontally on a table and pull it with the two balances in opposite directions as shown in Figure 12.4. By varying the extent of the pull, apply forces of varying magnitudes on the object. In each attempt, the ring must be kept at rest.

- The ring stays at rest only when it is in equilibrium under the action of the two forces in opposite directions. Every time the ring is in equilibrium, you will observe that the readings of the two spring balances are equal.

That is, at equilibrium, the two forces are equal in magnitudes.

Now try to maintain equilibrium without having the two forces along the same line. You will find that this is impossible. That is, every time the two forces are in equilibrium, they must be alligned along the same line and their directions must be opposite to one another.

Activity 2

Items required : a cubic shaped block of wood, two Newton balances, two rings to fix the balances to the wooden block

- Fix the two rings to the centers of two opposite faces of the block of wood as shown in Figure 12.5.
- Now attach the two Newton balances to the two rings and pull the block of wood along the two directions applying forces of various magnitudes.

Figure 12.5 – Pulling a block of wood in two directions

You will observe that the block of wood moves in one direction whenever there is a nonzero resultant force and that it remains stationary whenever the resultant force is zero. That is, every time the block of wood is in equilibrium, the two forces acting on it in opposite directions have equal magnitudes.

An object placed on a table is shown in Figure 12.6. Why doesn't the object fall down?

For free distribution

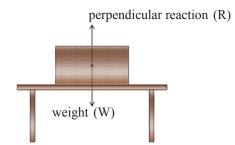perpendicular reaction (R)

weight (W)

Figure 12.6 – A book in equilibrium on a table

In this case, the weight of the object, acting vertically downwards, is balanced by the perpendicular reaction force exerted vertically upwards by the table. That is, the object is in equilibrium under the action of the two forces mentioned above and the object remains at rest.

tention (T)

weight (W)

Figure 12.7 - An object suspended by a string

If an object suspended by a string as shown in Figure 12.7 remains in equilibrium, the reason is that a force equal to the weight of the object is acting vertically upwards along the string. The force exerted upwards by the string is known as the tention of the string. As the object is held in equilibrium by two forces - its weight and the tension of the string - the object remains at rest.
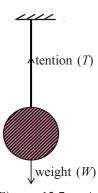
In each of the instances described above, only two forces were acting on the object. In addition, the two forces were equal in magnitude and opposite in direction. Also, their lines of action were the same. That is, for an object to remain in equilibrium, the following conditions must be satisfied.

1.   The two forces must have equal magnitudes.

2.   The two forces must act along two opposite directions.

3.   Both forces must lie along the same line of action.
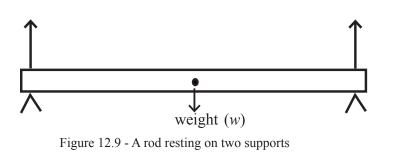
12.3 Equilibrium of a body under three coplanar parallel forces

Figure 12.8 – Bunch of banana suspended on a horizontal rod

A bunch of banana suspended on a light horizontal rod is shown in Figure 12.8. Here, the rod, the two strings used to suspend it and the string used to suspend the bunch of banana are all in the same plane. Also, all three strings are parallel. This is an example of a system in equilibrium under the action of three parallel, coplanar forces. (There are four forces acting in the system if the weight of the rod is considered. However, by a "light rod" we mean a rod whose weight is negligibly small. Therefore, we do not consider that force here.)

weight (w)

Figure 12.9 - A rod resting on two supports

A rod resting on two supports is shown in Figure 12.9. In this system of forces, the three forces, the weight of the rod and the two perpendicular reaction forces exerted on the rod are coplanar and their lines of action are parallel to one another. Under these forces, the rod is in equilibrium on the two supports.

Now, let us engage in the following activity in order to investigate the factors that affect the equilibrium of three parallel and coplanar forces.

Items required : two spring balances, a meter ruler, two rubber bands.
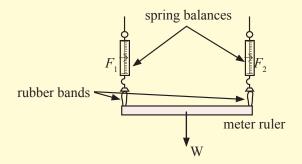

Figure 12.10 - Equilibrium of a meter rular under three coplanar parallel forces

- Measure the weight of the meter ruler. Next, suspend it at the two ends with the aid of the rubber bands and balances as shown in Figure 12.10 and keep the meter ruler in equilibrium in a horizontal position. Take measurements of the two spring balances. The system is now in equilibrium under the action of three parallel, coplanar forces.
- Investigate the relationship between the measurements of the two spring balances and the weight of the meter ruler. You will notice that the sum of the two readings of the balances is equal to the weight of the meter ruler.
- That is, the sum of the two forces exerted on the meter ruler by the two balances is equal to the weight of the meter ruler.
- See whether it is possible to push the meter ruler in a horizontal plane with a force applied normal to the meter ruler at one end of the ruler and still maintain equilibrium.
- You will understand that everytime the meter ruler is in equilibrium, the two balances and the meter ruler are in the same plane.

That is, in order for an object to maintain equilibrium under the action of three parallel forces, the following conditions must be satisfied.

  (i) The three forces must be coplanar.
  (ii) One force must have a direction opposite to the other two forces.
  (iii) The resultant of any two forces must be equal in magnitude and opposite in direction to the third force.

A child sitting on a swing is an example for a system in equilibrium under three parallel forces. The child can remain in equilibrium on the swing, since the sum of the two forces F_1 and F_2 exerted by the two ropes is equal to the weight of the child as shown in Figure 12.11.
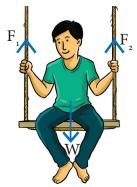

Figure 12.11 - A child sitting on a swing

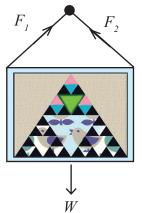## 12.4 Equilibrium of a body under three forces that are not parallel

Figure 12.12 - A framed picture hanging on the wall

A framed picture like the one shown in Figure 12.12 remains at rest because the tensions of the two strings (F_1 and F_2) and the weight of the picture (W) are in equilibrium. Although these three forces are coplanar, they are not parallel to one another as in the examples described earlier.

Let us now engage in the following activity to find out the factors necessary to maintain equilibrium in a system of three forces that are coplanar, but not parallel to one another.

Items required : a thin rectangular laminar, a string

You may use a thin sheet of metal or a piece of cardboard as the laminar. Hang your laminar from three points, one at a time as shown in Figure 12.13 and mark the verticle line that goes along the string, on the laminar each time.
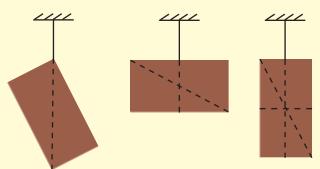

Figure 12.13 - Finding the centre of gravity of the laminar

- The point of intersection of the three lines can be considered as the center of gravity of the laminar.

  Center of gravity is the point at which the whole weight of a body may be considered to act. Therefore, the weight of the laminar acts along the verticle line that goes through its centre of gravity.

- Hang the laminar using two strings connected to it, as the framed picture shown in Figure 12.12 and keep it in equilibrium in a vertical plane.

- Mark the lines of each string on a sheet kept behind the laminar. Mark also, the vertical line passing through the center of gravity.

  All three lines marked above will lie on the same plane and they will pass through a common point.

- Now, keeping the position of one of the three forces fixed, turn the laminar to change the plane of the other forces. You will observe that, the system remains equilibrium only after readjusting the lines of action of the forces so as to have all three forces lying on the same plane.

That is, in order for a system of three non parallel forces to be in equilibrium, the three forces must be coplanar. Also, the lines of action of the three forces must meet at a common point. Furthermore, the resultant of any two of the forces should be equal to the third force in magnitude, and opposite in direction.

So far we have only discussed systems that are in equilibrium under the action of two or three forces. Equilibrium can exist under the action of more than three forces. Figure 12.14 shows a system in equilibrium under five forces.

It shows a plank of wood suspended by four strings attached to the four corners. The plank of wood maintains equilibrium since its weight acting vertically downwards is balanced by the forces of tension exerted by the four strings.
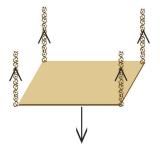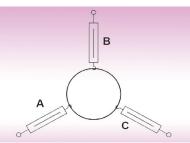

Figure 12.14 - A system in equilibrium under five forces

Miscellaneous exercises

(1) (i) An object on a horizontal plane is pulled along a certain direction with a force of 20 N. In order to bring the object to rest, what is the force that should be applied on it in the direction opposite to the 20 N force?

   (ii) What would happen if a force of 25 N is applied on the above object in the opposite direction?

(2) If several people are trying to push a car whose engine is not functioning, in what manner should each one try to exert a force on the car?

(3) If the resultant force of the two forces applied by the spring balances *B* and *C* as shown in the figure below is known, what should be done in order to bring the ring to rest?
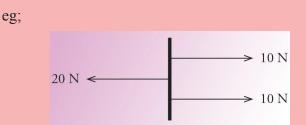

(4) A box is placed on a table. Although the gravitational attraction force is acting downwards on the box, why does it remain at rest without falling down?
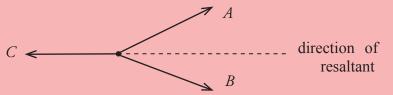
(5)   What can you say about the nature of the motion of an object on a horizontal table that is pulled in opposite directions with two unequal forces?

Summary

- If the magnitudes of two collinear forces applied on an object are equal and they have opposite directions, then the object is in equilibrium.

- An object under three parallel forces is in equilibrium if one force is equal in magnitude to the resultant of the other two forces and it is in the opposite direction.

  eg;

- If an object stays in equilibrium under three forces that are not parallel to one another, when the resultant of any two of the forces is equal in magnitude and opposite in direction to the other force.

When the resultant of the two forces A and B is applied in the dirction of the force C, the three forces will be in equilibrium.

- Even under the action of more than three forces, a system can remain in equilibrium by applying forces appropriately.

Technical terms		
Force	බලය	விசை
Equilibrium of forces	බල සමතුලිතතාව	விசைகளின் சமநிலை
Equilibrium of co-planer forces	ඒකතල බල සමතුලිතතාව	ஒரு தள விசைகளின் சமநிலை
Equilibrium of two forces	බල දෙකක සමතුලිතතාව	இரு விசைகளின் சமநிலை
Equilibrium of three forces	බල තුනක සමතුලිතතාව	மூன்று விசைகளின் சமநிலை
Equilibrium of three parallel forces	සමාන්තර බල තුනක සමතුලිතතාව	மூன்று சமாந்தர விசைகளின் சமநிலை