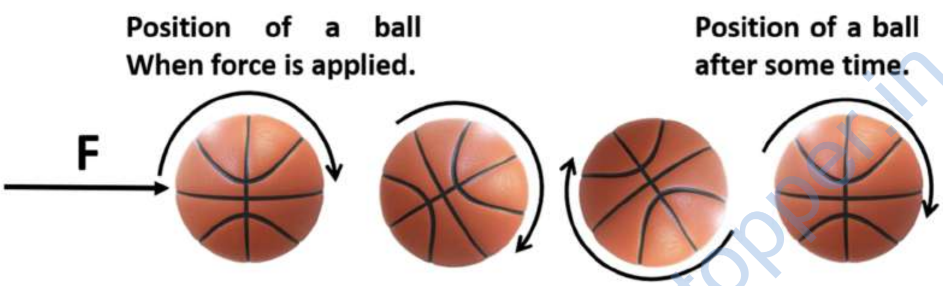
Chapter – 9

Force and Laws of Motion

Balanced and Unbalanced Forces

Force: The external push or pull applied on an object causes the movement in the object. This external push or pull is called force.

Example: When force F is applied on the ball, it comes into motion.

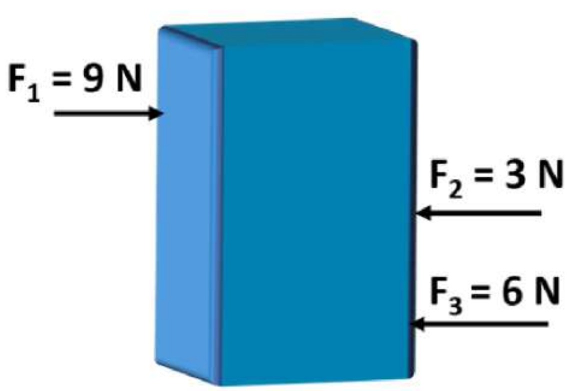


Balanced Forces: When two forces of equal magnitudes but opposite in directions are applied on an object, such that the resultant of applied forces become zero. The forces applied are called balanced forces.

Unbalanced Forces: When the resultant of applied forces is non – zero, the forces are called unbalanced forces.

Tip: Remember that the object changes its state of motion only when the unbalanced external force is applied on it.

Example: Does this object change its state of motion?



Solution: Net force $F = F_1 - F_2 - F_3$

$F = 9\text{ N} - 3\text{ N} - 6\text{ N} = 0\text{ N}$

The net force is zero. The forces are balanced. So, the object does not change its state of motion.

First Law of Motion

Study of Force and Motion:

Aristotle's Statement: According to Aristotle, the natural state of an object is at rest.

He explained, if we push or pull an object it comes into motion and after some time it comes into its natural state that is rest.

Galileo's Statement: According to Galileo, an unbalanced force is required to change the motion of an object, but no net force is necessary to sustain the uniform motion of the object.

Galileo did experiments with inclined planks. Galileo considered one inclined plank followed by a horizontal plank as shown.

Galileo explains if we consider there is no friction, the ball will never stop and will always be in motion on the horizontal plane.

Newton's First Law of Motion: According to this law, an object remains in a state of rest or of uniform motion in a straight line unless acted on by a non-zero net force.

Inertia: The tendency of an object to resist its change of state is called inertia.

Newton's first law of motion is based on this property of inertia. That's why the first law of motion is also known as the law of inertia.

The inertia of an object is measured by its mass.

Tip: Remember according to the first law of motion when a non-zero force is applied on an object the velocity of the object gets changed.

Example: What happens with the person standing in a bus, when the driver suddenly applies the brakes?

Solution: When the bus is moving, the person standing in it is also in motion along with the bus. But when the driver applies the brake, the bus comes in a state of rest.

Due to the first law of motion, the legs of the person who are in contact with the bus come in rest while the rest part of his body tries to maintain the inertia of motion. Because of this, a forward force is exerted on him and the passenger falls forward.

Example: A person applies an equal force of 1N on rock and stone, the stone moves but the rock does not move. This happens because the mass of rock is more than the mass of stone. So, the rock required greater force to come in motion. Here the force required to change the state of motion is dependent on the mass of a body.

Therefore, the rock has more inertia (Property of a body to resist the change in motion) as compared to the small stone.

The inertia of an object is measured by its mass.

Hence, the heavier body has greater inertia as compared to the lighter body.

Second Law of Motion

Momentum: The Momentum is the product of the mass of a body and the velocity by which it is moving.

Momentum is denoted by P and P = mv.

The SI unit of momentum is $kgms^{-1}$.

Newton's Second Law of Motion: The second law of motion states that the rate of change of momentum of an object is proportional to the applied unbalanced force in the direction of the force.

Mathematically:

$$Force \propto \frac{Change\ in\ momentum}{Time}$$

If a body has mass m moving with the initial speed u and when an external force F is applied on a body, the body accelerates with an acceleration a and the final velocity of an object becomes v.

$$F = \frac{mv - mu}{t}$$

And,

$$F = ma$$

Example: Why does a fielder in the game of cricket pull his hands backwards with a moving ball to catch the fast-moving cricket ball?

Solution: Fielder pulls his hands backwards to increase the time during which the fast-moving ball comes to rest.

According to the second law of motion.

$$F = \frac{m(v - u)}{t}$$

Force is inversely proportional to the time for which force is applied.

So, the increase in time decreases the impact of force and the player does not hurt himself while catching.

Example: Karan riding a bicycle and the bicycle is moving with a velocity of 10 km/h. When Karan applied the brakes, the bicycle stops after 12 s. If the mass of Karan along with bicycle is 150 kg. Calculate the force exerted by the brakes on the bicycle.

Solution: It is given that the bicycle moving with a speed of 10 km/h which means u = 10 km/h and it stops after 12 s which means final velocity v = 0.

Mass, m = 150 kg {Given}

Using the second law of motion.

$$F = \frac{m(v-u)}{t}$$

$$F = \frac{150(0-10)}{12}$$

$$F = \frac{-150 \times 10}{12}$$

$$F = -125\ N$$

Tip: While answering the theoretical questions based on the second law of motion, recall that the force increased when time decreased and the change in momentum increased.

Third Law of Motion

Newton's Third Law of Motion: "Every action has an equal and opposite reaction".

Whenever one object exerts a force on a second object, the second object exerts an equal and opposite force on the first.

If the action force is F_1 and the reaction force is F_2.

Mathematically, the third law of motion can be written as

$F_1 = - F_2$

Tip: Remember the action and reaction always act on two different bodies.

Example: A boy playing with a ball, when he threw the ball on the wall, the ball bounce back towards him and if he threw the ball with more force, the ball also comes back with more force. More the force ball applies on the wall, the wall also applies more force on the ball. This happens because of the third law of motion, the harder the ball threw towards the wall, the harder it bounced back.

Example: 1) Does the action and reaction always act on the same body?

2) Does the acceleration produce by the action force and the reaction force is always equal in magnitude?

Solution: 1) No, the action and reaction always act on a different body.

When a man fires a bullet, according to the third law of motion, the gun exerts a forward force (action) on the bullet and the bullet exerts an equal and opposite force (reaction) on the gun that is called recoil force.

2) Consider the above scenario.

So, the magnitude of both forces is equal.

And,

We know, $F = ma$

$$a = \frac{F}{m}$$

Here, the force exerted is equal on both gun and bullet.

And, the acceleration is inversely proportional to the mass of an object.

Therefore, the object has a greater mass, producing less acceleration.

In this case, the gun has a much greater mass than the bullet, so the acceleration of the gun is less than the acceleration of the bullet.

No, the acceleration produced by the action force and the reaction force is always equal in magnitude.

Conservation of Momentum

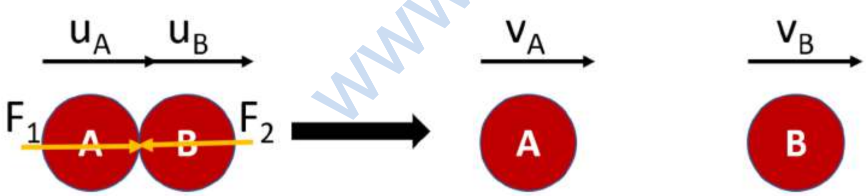
Conservation of Momentum: According to the law of conservation of momentum initial momentum of a system is always equal to the final momentum of a system provided no external unbalanced forces are acting.

Derivation:

Consider two balls A and B having mass m_A and m_B**,** respectively are moving in the same direction along a straight line with an initial speed of u_A and u_B respectively. Here, the speed of ball A is greater than the speed of ball B that is $u_A > u_B$.

So, after some time ball A reaches closer to ball B and they collide with each other.

During collision ball A exerts a force F_1 on ball B and ball B exert a force F_2 on ball A for a time interval of t.



After the collision, both balls A and B start moving with changed velocity v_A and v_B respectively. As the force applied during collision accelerates the balls.

So, using the third law of motion

Force on ball B applied by ball A is equal and opposite to the force applied by ball B on ball A.

$F_1 = -F_2$ -------eq^n 1

Now, using the second law of motion

$$Force \propto \frac{Change\ in\ momentum}{Time}$$

$$F_1 = \frac{m_A v_A - m_A u_A}{t}$$

Similarly,

$$F_2 = \frac{m_B v_B - m_B u_B}{t}$$

The time interval of force applied is the same for F_1 and F_2 because both balls A and B are in contact with each other for the same time interval during the collision.

By substituting these values of F_1 and F_2 in eq^n 1.

We get,

$$m_A v_A - m_A u_A = -(m_B v_B - m_B u_B)$$

After simplification,

$$m_A v_A - m_A u_A = -m_B v_B + m_B u_B$$

By rearranging, the equation

$$m_A v_A + m_B v_B = m_A u_A + m_B u_B$$

Final momentum = Initial momentum