PHYSICS

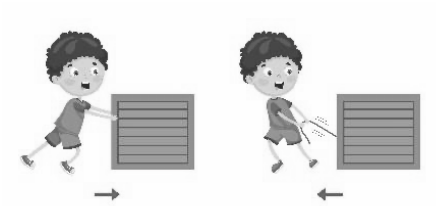
FORCE AND LAWS OF MOTION

Concepts Covered

- Introduction to force
- Types of force
- Observation of Galileo
- Newton's first law of motion
- Newton's first law of motion
- Inertia and its types, Momentum
- Newton's second law of motion
- Impulse
- Newton's third law of motion
- Law of conservation of momentum,

Forces in Nature

We observe various kinds of forces being applied in our daily activities. We press the tube to squeeze out the tooth paste or the cream. We pull or push the door in order to open or close it. This pull or push is referred to as force.



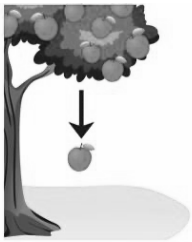
Types of Forces

(1) Non-Contact Force

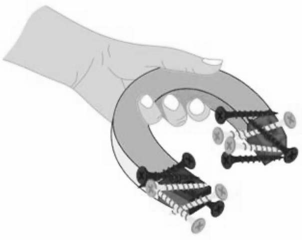
These are the forces in which contact between two objects is not necessary. The gravitational force between two bodies and the electrostatic force between two charges are two examples of non-contact forces.

(a) Gravitational Force
(b) Electrostatic Force
(c) Magnetic Force

Electrical Force



Gravitational Force



Magnetic Force

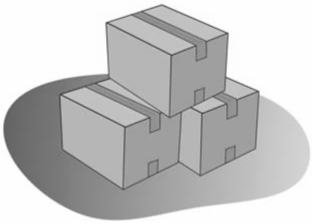
(2) Contact Forces

Some forces acts only if they have physical contact with the body. Such forces are called contact forces.

(a) Frictional force

(b) Muscular force

(c) Normal force



Normal Force

Frictional Force

Spring Force

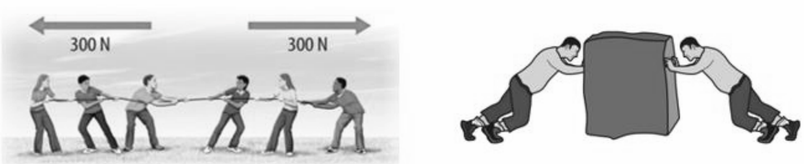
Tension Force

Air Resistance Force

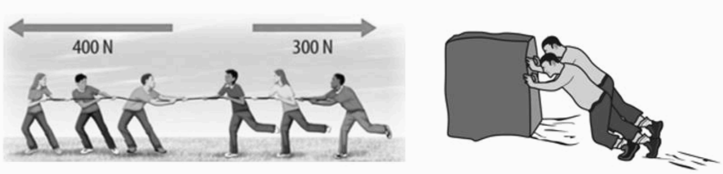
Applied Force

Balanced and Unbalanced Forces

If a set of forces acting on a body produces no acceleration in it, the forces are said to be balanced. If it produces a non-zero acceleration, the forces are said to be unbalanced. A set of unbalanced forces produces acceleration in the body.



Balanced force



Unbalanced force

DID you KNOW

The law of inertia was first formulated by Galileo Galilei for horizontal motion on Earth and was later generalized by Rene Descartes.

Observations of Galileo

It was Galileo who demonstrated the relationship between motion and force. He used two inclined smooth planes on which he rolled a ball to study the cause of motion.

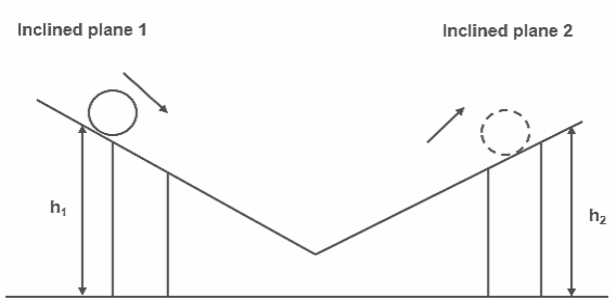
(1) The velocity of the body increases when it rolls down an inclined plane and the velocity decreases when the body rolls up the plane.

(2) If the ball rolls between two planes, inclined equally, it will attain the same height on both sides.

(3) If the inclination of the second plane is gradually decreased, the ball rolls over a large distance in order to reach the same height.

(4) When the second plane is horizontal, the ball continues to move indefinitely. But in practical the ball comes to rest due to friction.

(5) When the surface of the second plane is rough, the ball would cover less distance.



Based on the above facts, Galileo concluded that "The natural state of a body is not the state of rest. It is the tendency of the body to oppose the change in its state of motion or rest." Newton formulated laws of motion, based on Galileo's experiment.

Newton‘s First Law of Motion

"Everybody remains in a state of rest or of uniform motion along a straight line until and unless it is compelled by an external force."

Newton's first law of motion helps us to understand that

(1) an external agent or an unbalanced external force is required to accelerate a body and

(2) a body cannot change its state of rest or of uniform motion along a straight line on its own.

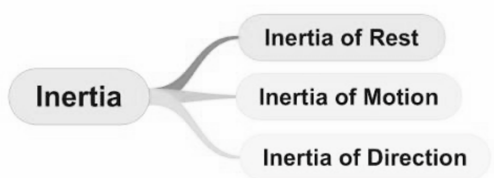
First law gives the precise definition of inertia.

An object at rest stays at rest | An object acted upon by an unbalanced force changes speed and direction | An object in motion stays in motion | An object acted upon by an unbalanced force changes speed and direction

Inertia

The tendency of a body to remain in its state of rest or of uniform motion along a straight line is called inertia.

It is due to inertia that an external, unbalanced force must be exerted on the body to change its state of rest or of uniform motion.



Inertia is of three types **–**

- Inertia of rest
- Inertia of motion
- Inertia of direction

DID you KNOW

When a train at rest starts moving suddenly, a passenger standing inside the compartment tends to fall backward.

Inertia of Rest

It is the resistance of a body to change its state of rest.

Example:

- When a bus starts suddenly, the passengers fall backwards.
- When a carpet is beaten up with a stick, the dust particles are detached.

Inertia of motion

It is a tendency of a body to continue its motion along a straight line.

Example:

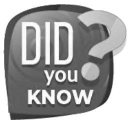
- When a running bus stops suddenly, the passengers are jerked forward.
- The passenger getting out of a moving train or bus falls in the forward direction.
- When a person jumps out of a moving bus, he should run in the direction in which the bus is moving otherwise he will fall down.
- In a train moving with a uniform speed and if a ball is thrown upwards inside the train by a passenger, then the ball comes back to his hand.

Inertia of Direction

It is the inability of a body to change its state of uniform motion along a straight line.

Example:

A passenger experiences a sideway jerk when the bus takes a sudden turn.



Newton, the father of physics, established the laws of motion in his famous book "Principia" in 1687.

- **Relation between Mass and Inertia:**

  A large force is required to move a loaded truck from rest than an unloaded truck. The force depends on the inertia of the body, thus inertia depends on the mass of the body. A body of greater mass has larger inertia. Therefore, mass is a measure of inertia. Thus, all bodies do not offer the same resistance to change their state of rest or of uniform motion.

  Larger the mass of the body, larger is the inertia.

Momentum

It is easier to stop a tennis ball than a football when both are moving with the same velocity. This is because the football has a larger mass than the tennis ball.

A bullet fired from a gun can easily get embedded in a wooden block. If the same bullet is thrown by hand, it cannot penetrate the wooden block. Here, the bullet fired from the gun has greater velocity.

Thus, mass and velocity of a body increase the impact or the effect of the force.

The product of mass and velocity defines a physical quantity called momentum.

Thus, momentum is a quantity referring to the motion of a body.

Momentum = mass × velocity

$\vec{\mathbf{P}} = \mathbf{m} \times \vec{\mathbf{v}}$

All moving bodies possess momentum. Momentum is a vector quantity. The direction of momentum is the same as that of velocity since mass is always a positive scalar quantity.

Units of Momentum

By definition, momentum = mass × velocity

∴ SI unit of momentum is $\mathbf{kgms^{-1}}$

CGS unit of momentum is $\mathbf{gcms^{-1}}$

Example:

(1) Find the linear momentum of a cricket ball of mass 250g moving with a velocity of 72km^{-1}.

Solution: $\text{m} = 250\text{g} = 25 \times 10^{-3}\ \text{kg}, \text{v} = 72\text{kmh}^{-1} = 20\text{ms}^{-1}$

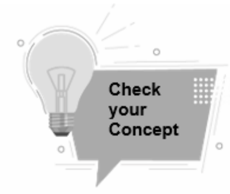
$\text{P} = \text{mv} = 25 \times 10^{-2} \times 20 = 5\text{kgms}^{-1}$

(2) Find the magnitude of momentum of a body of mass $10\ \text{kg}$ moving with a velocity of $5\ \text{m s}^{-1}$.

Solution: Given: mass $= \mathbf{10\ kg}$, velocity $= \mathbf{5\ m\ s^{-1}}$

Momentum = Mass × Velocity

$\mathbf{p = mv = 10\ kg \times 5\ m\ s^{-1} = 50\ kg\ m\ s^{-1}}$



(1) If the masses of two bodies A and B are in the ratio of 2:3 and their momentum are in the ratio of 3:2, find the ratio of their velocity.

(2) Find the magnitude of momentum of a body of mass $20\ \text{kg}$ moving with a velocity of $2.5\ \text{m s}^{-1}$.

Answer Key

(1) 9:4

(2) 50 kgms^{-1}

Newton's Second Law of Motion

When a force acts on a body, the momentum of the body changes. Larger the force, greater will be the change in momentum. This is summarized in Newton's second law of motion.

"The rate of change of momentum is directly proportional to the net force acting on the body and changes takes place in the direction of the net force."

i.e., $\mathbf{F} \propto \frac{\Delta \mathbf{p}}{\Delta \mathbf{t}}$

Derivation of $\text{F} = \text{ma}$

Consider a body having an initial momentum $\vec{\mathbf{p}}_1$. Let its momentum change to $\vec{\mathbf{p}_2}$ when a net force $\vec{\mathbf{F}}$ acts on it during a time $\Delta \mathbf{t}$.

Rate of change of momentum $= \frac{\vec{p_2} - \vec{p_1}}{\Delta t}$

But $\vec{\mathbf{p}}_2 = \mathbf{m}\vec{\mathbf{v}}$ ($\vec{\mathbf{v}}$ is the final velocity) and $\vec{\mathbf{p}_1} = \mathbf{m}\vec{\mathbf{u}}$ ($\vec{\mathbf{u}}$ is the initial velocity)

∴ Rate of change of momentum $= \frac{\mathbf{mv - mu}}{\Delta \mathbf{t}} = \mathbf{m}\left(\frac{\vec{\mathbf{v}} - \vec{\mathbf{u}}}{\Delta \mathbf{t}}\right) = \mathbf{m}\frac{\Delta \mathbf{v}}{\Delta \mathbf{t}}$

Here, $\Delta \vec{\mathbf{v}}$ is the change in velocity

From Newton's second law of motion $\mathbf{F} \propto \frac{\mathbf{m}\Delta \vec{\mathbf{v}}}{\Delta \mathbf{t}}$

$\Rightarrow \mathbf{F} \propto \mathbf{ma} \left(\because \vec{\mathbf{a}} = \frac{\Delta \mathbf{v}}{\Delta \mathbf{t}}\right.$ is the acceleration of body)

$\mathbf{F = kma}$

Unit of force is chosen in such a way that it produces unit acceleration on unit mass. Then the constant of proportionality $\mathbf{k = 1}$.

∴ $\mathbf{F = ma}$

Thus, Newton's second law of motion establishes that an unbalanced external force is required to accelerate a body.

Force is a vector quantity.

Units of force

Force have two types of units, namely, absolute unit and gravitational unit.

Newton $(\mathbf{N})$:

It is the absolute unit of force in the SI system.

$\mathbf{1\ N = 1\ kg \times 1\ m\ s^{-2}}$

1 newton is that force which acts on a mass of $\mathbf{1\ kg}$ and produces an acceleration of $\mathbf{1\ m\ s^{-2}}$.

Dyne is an absolute unit of force in CGS system.

1 dyne $= \mathbf{1\ g \times 1\ cm\ s^{-2}}$

Relation between newton and dyne

$\mathbf{1\ N = 1\ kg \times 1\ m\ s^{-2} = (1000\ g) \times (100\ cm\ s^{-2})}$

Kilogram weight $(\mathbf{kg_{wt}})$ or kilogram force $(\mathbf{kg_f})$

It is a gravitational unit of force in SI system.

$\mathbf{1\ kg_{wt} = 9.8\ N}$

Gram weight $(\mathbf{g_{wt}})$ or gram force $(\mathbf{g_f})$

It is the gravitational unit of force in CGS system.

$\mathbf{1\ g_{wt} = 980}$ dynes

DID you KNOW

Newton's laws continue to give an accurate account of nature, except for very small bodies such as electrons and for bodies moving close to the speed of light.

Example:

(A) A person falling on a cemented floor gets injured but a person falling on a heap of sand is not injured.

(B) The vehicles are fitted with shockers (i.e. springs).

Example:

(1) Calculate the force required to produce an acceleration of 10 m/s^2 in a body of mass 2.4 kg.

Solution: We know that force = mass × acceleration

= 2.4 kg × 10 m/s^2 = 24 N

(2) A force of 20N causes an acceleration of 5 $\mathbf{m\ s^{-2}}$ in a body. Calculate the mass of the body.

Solution: Let the mass of the body is m.

We know that force = mass × acceleration

20 = m × 5

m = 4 kg.

Check your Concept

1. A constant force acts on a body of mass $\mathbf{10\ kg}$ and produces in it an acceleration of $\mathbf{0.2\ m\ s^{-2}}$. Calculate the magnitude of force acting on the body.

2. A force of 24 N is acting on a body of mass 2 kg. Calculate the acceleration produced in the body.

Answer Key

(1) 2N

(2) 12 $\mathbf{m\ s^{-2}}$

Impulsive Force and Impulse

When a sharp knock is given at a door, the moving finger has momentum. Once the door is struck, the momentum of the finger is reduced to zero in a very short interval of time.

As a result, the force imparted on the door is very large. Similarly, when a ball is struck, its momentum changes in a very short interval of time.

This large force acting for a short interval of time is called impulsive force.

The product of force and time during which the force acts is called impulse.

Impulse $=$ force $\times$ time

∴ Impulse = mass × acceleration × time = $\mathbf{ma \times t = \frac{m(v-u)}{t} \times t = mv - mu}$

Thus, impulse can be defined as change in the momentum. Like momentum, impulse is a vector quantity.

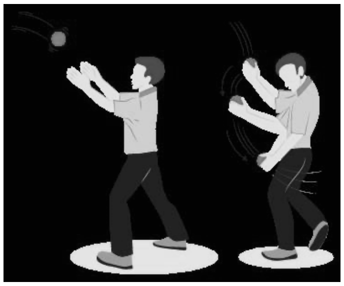
Unit of Impulse

Impulse = force × time

∴ unit of impulse in the SI system is $\mathbf{Ns}$ or kg m s $^{-1}$ and in CGS system it is dyne second or $\mathbf{gcms^{-1}}$.

Example:

- While catching a cricket ball, a player moves his hands backwards.



A collapsed star, known as a neutron star, has the strongest magnetic force of any object in the universe.

- An athlete taking a long jump or a high jump bends his knees before landing. By doing so, he increases the time of fall. This decreases the rate of change of momentum and this greatly reduces the impact of fall.

- A blacksmith holds the rod in an anvil while striking it with a hammer, thereby decreasing the time of contact, and increasing the impulsive force.

The smaller the radius of the circle, the more force required to achieve circular motion.

Example:

(1) A force acts for 0.4 s on a body of mass 5 kg initially at rest. The force then ceases to act and the body moves through 4 m in the next one second. Calculate the magnitude of force.

Solution: When the force ceases to act, the body will move with a constant velocity.

Since it moves a distance of $\mathbf{4\ m}$ in $\mathbf{1\ s}$, therefore, its uniform velocity = $\mathbf{4\ m/s}$.

Now, initial velocity, $\mathbf{u = 0}$, Final velocity, $\mathbf{v = 4\ m/s}$

Time interval, $\mathbf{\Delta t = 0.4\ s}$

∴ Acceleration, a = $\mathbf{\frac{v-u}{\Delta t} = \frac{4-0}{0.4} = 10\ m/s^2}$

Force, $\mathbf{F = 5 \times 10 = 50\ N}$

(2) A car moving at a speed of $36\ \mathrm{km\ h^{-1}}$ is brought to rest while covering a distance of $100\ \mathrm{m}$. If the mass of the car is $400\ \mathrm{kg}$, find the retarding force on the car and the time taken by the car to stop.

Solution: Since the car is brought to rest its final velocity, $v = 0$

Initial velocity of the car, u = 36 kmh^{-1} = 36 × $\frac{5}{18}$ = 10 ms^{-1}.

Distance traveled by the car, $\mathbf{s = 100\ m}$

Mass of the car, $\mathbf{m = 400\ kg}$

Force = mass × acceleration (from Newton's second law)

To find the acceleration, we use equation of motion $\mathbf{v^2 = u^2 + 2}$ as

$\mathbf{0 = 100 + 200a}$

$\mathbf{a = \frac{-100}{200} = -0.5\ m\ s^{-2}}$

Acceleration is negative because the final velocity ($= \mathbf{0}$) is less than the initial velocity ($= \mathbf{36\ km\ h^{-1}}$)

$\mathbf{F = m \times a}$

$\mathbf{= 400 \times -0.5 = -200\ N}$

Here, the negative sign represents a retarding force.

Check your Concept

(1) A motorcycle is moving with a velocity of 100 m/s and it takes 5 s to stop it after the brakes are applied. Calculate the force exerted by the brakes on the motorcycle if its mass along with the rider is 200 kg.

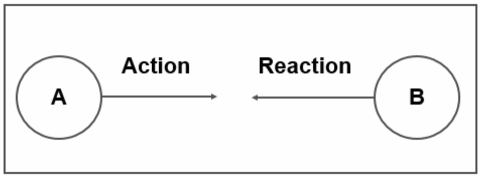
(2) A cricket ball of mass $100\ \mathrm{g}$ is moving with a velocity of $10\ \mathrm{m\ s^{-1}}$ and is hit by a bat so that it turns back and moves with a velocity of $40\ \mathrm{m\ s^{-1}}$. Find the impulse and the force, if the force acts for $0.01\ s$.

Answer Key

(1) 4000 N

(2) 3 kgms^{-1}, $\mathbf{300\ N}$

Newton's Third Law of Motion



For every action, there is an equal and opposite reaction.

Consider two bodies A and B colliding. A exerts a force on **B** and this is called an action. According to Newton's third law, B exerts an equal force on A but in the opposite direction. This is known as a reaction.

Every action is accompanied by a reaction.

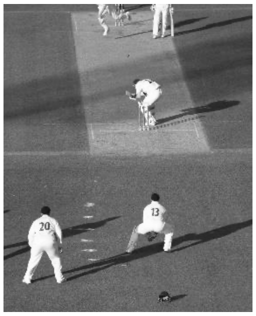
Thus, we find that forces always exist in pairs; in other words, a single isolated force cannot exist.

Action and reaction do not act on the same body. It involves two bodies. Hence, they do not cancel each other.

Example:

- Gravitational force between the Sun and the planets.
- Rocket Propulsion.

Applications of Newton's Third Law of Motion

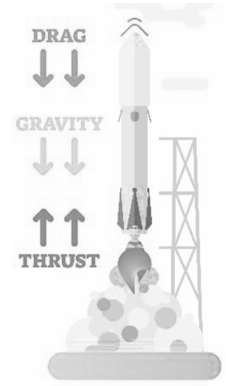


- In order to bowl a bouncer, a fast bowler has to pitch the ball very hard on the ground. The ground exerts an equal and opposite force on the ball (reaction) and this bounces the ball at the desired height.

DID you KNOW

The force of gravity pulling the ball down is equal to the drag force of the air pushing it upwards.

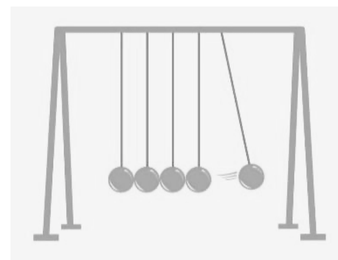
- When the fuel of a rocket is ignited, huge amounts of gases escape with high velocity through the opening at the rear end. The force on the gases forms action. The burnt gases in turn exert a force, equal in magnitude but opposite in direction, on the rocket. This is the reaction force (acceleration of the rocket keeps on increasing as the mass is constantly reduced due to the burning of the fuel).



A typical rocket produces more than a million pounds of thrust that allows it to carry more than 6,000 pounds at speeds topping 22,000 miles per hour. This is equivalent to the power generated by 13 Hoover Dams, carrying the weight of eight horses, and traveling at speeds 15 times faster than a speeding bullet!

Law of Conservation of Momentum

Newton demonstrated, using the equipment shown in the figure, that if an external force acting on a system is zero, the total momentum of the system remains constant. The total momentum of the system of balls is the same before and after the collision.



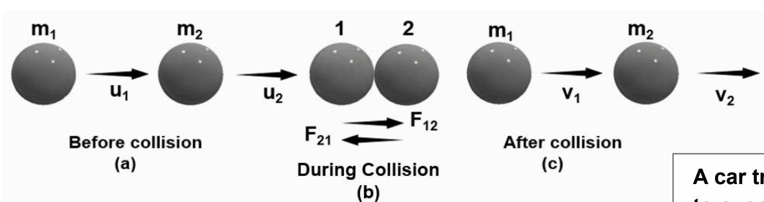
Verification of Law of Conservation of Momentum

Consider two bodies 1 and 2 of masses $\mathbf{M_1}$ and $\mathbf{M_2}$ and let $\mathbf{u_1}$ and $\mathbf{u_2}$ be their initial velocities, respectively. Let the two bodies collide with the collision lasting for t seconds, during the time of which their velocities change.

Let $\mathbf{v_1}$ and $\mathbf{v_2}$ be their velocities after the collision.

From the second law of motion, we have,

Rate of change of momentum of $\mathbf{body\ 1}, \vec{\mathbf{F_1}} = \frac{\Delta \vec{p_1}}{t}$



A car travelling at 80 kph (50 mph) uses half its fuel to overcome wind resistance.

Rate of change of momentum of $\mathbf{body\ 2}, \vec{\mathbf{F_2}} = \frac{\Delta \vec{p_2}}{t}$

From Newton's third law, $\vec{\mathbf{F_2}} = -\vec{\mathbf{F_1}}$

The force exerted by A on B is equal and opposite to the force exerted by B on A.

$$\frac{\Delta \mathbf{p_2}}{\mathbf{t}} = -\frac{\Delta \mathbf{p_1}}{\mathbf{t}}$$

$$\overrightarrow{\Delta \mathbf{p_1}} = \mathbf{M_1 v_1 - M_1 u_1}$$

Similarly, $\Delta \vec{\mathbf{p_2}} = \mathbf{M_2 v_2 - M_2 u_2}$

$$\mathbf{M_2 v_2 - M_2 u_2 = -(M_1 v_1 - M_1 u_1)}$$

$$\mathbf{(M_1 u_1 + M_2 u_2) = (M_1 v_1 + M_2 v_2)}$$

Total momentum before the collision = total momentum after the collision.

Example:

(1) A bullet of mass 10 gm moving with a velocity 250 m/s gets embedded into a wooden block of mass 990 gm suspended by string. Calculate velocity acquired by the combined system.

Solution: Mass of the bullet, $\mathbf{m_1 = 10gm} = \frac{10}{1000}\ \mathbf{kg = 0.01\ kg}$

Velocity of the bullet, $\mathbf{u_1 = 250\ m/s}$

Momentum of the bullet $= \mathbf{m_1 u_1 = 0.01 \times 250\ kg - m/s = 2.5\ kg - m/s}$

Now, the bullet gets embedded into a wooden block of mass $\mathbf{990gm}$.

The mass of the block and bullet $= \mathbf{990 + 10 = 1000\ gm = 1\ kg}$

Let the velocity of the combined system $= \mathbf{v}$

Momentum of the combined system $= \mathbf{1 \times v\ kg - m/s = 1\ v\ kg - m/s}$

Now, applying the law of conservation of momentum, $\mathbf{m_1 u_1} = (\mathbf{m_1 + m_2})\mathrm{v}$

or $\mathbf{2.5 = 1 \times v}$

$\therefore \mathbf{v = 2.5\ m/s}$

(2) A bomb of mass $6\ \mathrm{kg}$ initially at rest explodes into two fragments of masses of $4\ \mathrm{kg}$ and $2\ \mathrm{kg}$, respectively. If the greater mass moves with a velocity of $5\ \mathrm{m\ s^{-1}}$, find the velocity of the $2\ \mathrm{kg}$ mass.

Solution: Given: $\mathbf{M_1 = 4\ kg}$

$\mathbf{M_2 = 2\ kg}$

Since the bomb is initially at rest, $\mathbf{u = 0}$

$\mathbf{v_1 = 5\ m\ s^{-1}}$, $\mathbf{v_2} = ?$

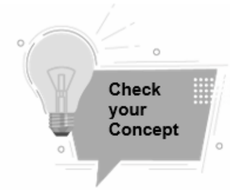
Using the law of conservation of momentum

$\mathbf{m_1 u_1 + m_2 u_2 = m_1 v_1 + m_2 v_2}$

$\mathbf{0 = 4 \times 5 + 2 \times v_2 = 20 + 2 \times v_2}$

$\mathbf{v_2 = \dfrac{-20}{2} = -10\ m\ s^{-1}}$

$\mathbf{2\ kg}$ mass moves in the direction opposite to $\mathbf{4\ kg}$ mass since $\mathbf{v_2}$ is negative.



(1) From a rifle of mass $4\ \mathrm{kg}$, a bullet of mass $50\ \mathrm{g}$ is fired with an initial velocity of $35\ \mathrm{m\ s^{-1}}$. Calculate the initial recoil velocity of the rifle.

(2) Two objects of masses $100\ \mathrm{g}$ and $200\ \mathrm{g}$ are moving along the same line and direction with velocities of $2\ \mathrm{ms^{-1}}$ and $1\ \mathrm{ms^{-1}}$, respectively. They collide and after the collision, the first object moves at a velocity of $1.67\ \mathrm{ms^{-1}}$. Determine the velocity of the second object.

Answer Key

(1) $\mathbf{v = -1.5\ m/sec}$

(2) $\mathbf{v = +4.65\ m/sec}$

Solved Examples

(1) Give few examples of Newton's third law of motion.

Answer: (i) Jet aeroplanes and rockets work on the principle of the third law of motion. In this case, the hot gases come out of a nozzle with great force, i.e., action and the rocket moves with high speed upwards as a reaction.

(ii) If we fill a balloon with air and hold it with its mouth downwards, then when releasing the balloon, the air rushes out vertically downwards (action). The balloon moves vertically upwards (reaction).

(2) Why does an athlete puts some sands or cushion on the ground while high jumping?

Answer: When a high jumper falls on a soft landing site (such as a cushion or a heap of sand), then the jumper takes a longer time to come to stop. The rate of change of momentum of an athlete is less due to which a smaller stopping force acts on the athlete. And the athlete does not get hurt. Thus, the cushion or sand, being soft, reduces the athlete's momentum more gently. If however, a high jumping athlete falls from a height on to hard ground, then his momentum will be reduced to zero in a very short time. The rate of change of momentum will be large due to which a large opposing force will act on the athlete. This can cause serious injuries to the athlete.

(3) What is the acceleration produced by a force of 10 Newton exerted on an object of mass $3\ \mathbf{kg}$?

Solution: In this problem, force, $\mathbf{F} = \mathbf{10\ N}$

Mass, $\mathbf{m} = \mathbf{3\ kg}$

We know that $\mathbf{F} = \mathbf{m} \times \mathbf{a}$,

Putting the given values, we have

$\mathbf{10 = 3 \times a \Rightarrow a = \frac{10}{3}\ m/s^2}$

(4) A man throws a ball of mass $0.5\ \mathbf{kg}$ vertically upwards with a velocity of $10\ \mathbf{m/s}$. What will be its initial momentum? What would be its momentum at the highest point of its reach?

Solution: Here, $\mathbf{m = 0.5\ kg, u = 10\ m/s}$

Initial momentum of the ball $= \mathbf{mu = 0.5 \times 10 = 5\ kg\ m/s}$

At the highest point, velocity of ball is zero,

So momentum of the ball $= \mathbf{0 \times 5 \times 0 = 0}$

(5) Which would require a greater force-accelerating a $3\ \mathbf{kg}$ mass at $5\ \mathbf{ms^{-2}}$ or a $2\ \mathbf{kg}$ mass at $2\ \mathbf{ms^{-2}}$?

Solution: Here, $\mathbf{m_1 = 3\ kg, a_1 = 5\ ms^{-2}, m_2 = 2\ kg, a_2 = 2\ ms^{-2}}$

$\mathbf{F_1 = m_1 a_1 = 3 \times 5 = 15\ N}$

$\mathbf{F_2 = m_2 a_2 = 2 \times 2 = 4\ N}$

$\mathbf{F_1 > F_2}$

Thus, accelerating a $\mathbf{3\ kg}$ mass at $\mathbf{5\ ms^{-2}}$ acceleration would require a greater force.

(6) Give reason for the following:

When a hanging carpet is beaten with a stick, the dust particles start coming out of it.

Answer: When a hanging carpet is beaten with a stick, the dust particles come out of it because the force of the stick makes the carpet move to-and-fro slightly but the dust particles tend to remain at rest (or stationary) due to their inertia and hence get separated from the carpet.

(7) Explain why, it is dangerous to jump out of a moving bus.

Answer: It is dangerous to jump out of a moving bus because the person who jumps is moving with the same speed as that of the bus and would tend to remain in motion (due to inertia) even after falling to the ground; thus, he may get hurt due to the resistance of the stationary ground.

(8) Why are road accidents at high speeds much worse than road accidents at low speeds?

Answer: It is a common observation that road accidents due to vehicles travelling at high speeds are much worse than those with vehicles at low speeds. This is because the momentum of vehicles running at greater speeds is very high and causes a lot of damage to the vehicles and injures the passengers during the collision.

(9) Find the acceleration produced by a force of $5.2\ \mathrm{N}$ acting on a mass of $10\ \mathrm{kg}$.

Solution: We know that: Force = mass × acceleration

$\mathbf{F} = \mathbf{m} \times \mathbf{a}$

Here, mass, $\mathbf{m} = \mathbf{10\ kg}$

force, $\mathbf{F} = \mathbf{5.2\ N}$

Putting these values in the above formula, we get:

$\mathbf{5.2\ N} = \mathbf{10} \times$ acceleration

$\Rightarrow$ acceleration $= \dfrac{\mathbf{5.2}}{\mathbf{10}}$

$\Rightarrow$ acceleration $= \mathbf{0.52\ m/s^2}$

(10) A girl weighing $25\ \mathrm{kg}$ stands on the floor. She exerts a downward force of $250\ \mathrm{N}$ on the floor. What force does the floor exerted on her?

Answer: According to Newton's third law of motion, the floor exerts a force of $\mathbf{250\ N}$ on her in the upward direction.

(2) A body of mass $10\ \mathrm{kg}$ is moving with a speed of $5\ \mathrm{ms}^{-1}$. Calculate the distance travelled by the body before coming to rest when a constant retarding force of $20\ \mathrm{N}$ is applied on it.

Solution: $\mathbf{F} = -\mathbf{20\ N}$

(-ve sign shows that it is retarding force)

$\mathbf{m} = \mathbf{10\ kg}, \mathbf{u} = \mathbf{5\ ms^{-1}}, \mathbf{v} = \mathbf{0}, \mathbf{t} =\ ?$

Step-1: Using relation $\mathbf{F} =$ ma, we have $\mathbf{a} = \frac{\mathbf{F}}{\mathbf{m}}$

$= \dfrac{-\mathbf{20}}{\mathbf{10}} = -\mathbf{2ms^{-2}}$ i.e. retardation

Step-2: Using $\mathbf{v} = \mathbf{u} +$ at, we get

or $\mathbf{0} = \mathbf{5} - \mathbf{2t}$ or $\mathbf{2t} = \mathbf{5}$

$\therefore \mathbf{t} = \mathbf{2.5\ s}$

Step-3: $\mathbf{S} = \mathbf{ut} + \frac{1}{2}$ at ^{2}

$= 5 \times 2.5 + \dfrac{1}{2}(-2) \times (2.5)^2 = 6.25\ \mathbf{m}$

(3) A body of mass $4\ \mathrm{kg}$ is moving with a velocity of $2\ \mathrm{ms}^{-1}$. Now a force is applied on the body so that its velocity changes to $3\ \mathrm{ms}^{-1}$ in $25\ \mathrm{s}$. Calculate the direction and magnitude of the force acting on the body.

Solution: Here, $\mathbf{m} = \mathbf{4\ kg}, \mathbf{u} = \mathbf{2\ ms^{-1}}, \mathbf{v} = \mathbf{3\ ms^{-1}}, \mathbf{t} = \mathbf{25\ s}$

$$\mathbf{F} = \mathbf{ma} = \mathbf{m}\left(\frac{\mathbf{v}-\mathbf{u}}{\mathbf{t}}\right) = 4 \times \frac{(3-2)}{25} = \frac{4}{25} = 0.16\ \mathbf{N}$$

The direction of force is along the direction of motion.

(4) A child is standing in the middle of the road when a driver of a scooter moving with velocity 20 ms^{-1} sees him. He applies breaks to save the child and brings his scooter to rest in $4s$. Calculate the retarding force on the scooter; given, mass of scooter is $100\ \mathrm{kg}$ and that of a drive is $60\ \mathrm{kg}$.

Solution: Here, $\mathbf{m} = \mathbf{100} + \mathbf{60} = \mathbf{160\ kg}$

$\mathbf{u} = \mathbf{20\ ms^{-1}}, \mathbf{v} = \mathbf{0}, \mathbf{t} = \mathbf{4\ s}, \mathbf{F} = ?$

Step - 1: Using $\mathbf{v} = \mathbf{u} +$ at, we get

or $\mathbf{a} = \frac{\mathbf{v}-\mathbf{u}}{\mathbf{t}} = \frac{\mathbf{0}-\mathbf{10}}{\mathbf{4}} = -\frac{\mathbf{20}}{\mathbf{4}} = -\mathbf{5\ ms^{-2}}$

Negative sign shows that it is retardation.

Step $-\mathbf{2}$: Retarding force, $\mathbf{F} = \mathbf{ma} = -\mathbf{160} \times \mathbf{5} = -\mathbf{800\ N}$

(5) A force of $20\ \mathrm{N}$ produces an acceleration of $4\ \mathrm{ms}^{-2}$ in a body of mass m_1 and $5\ \mathrm{ms}^{-2}$ in a body of mass m_2. What will be the acceleration produced by the same force when both the bodies are tied together?

Solution: $\mathbf{F} = \mathbf{20\ N}$,

$$\mathbf{a_1} = \mathbf{4\ ms^{-2}} \therefore \mathbf{m_1} = \frac{\mathbf{F}}{\mathbf{a_1}} = \frac{\mathbf{20}}{\mathbf{4}} = \mathbf{5\ kg}$$

$a_2 = 5\ ms^{-2}\ \therefore m_2 = \frac{F}{a_2} = \frac{20}{5} = 4\ kg$

Now, $F = (m_1 + m_2)a$

$\therefore\ a = \frac{F}{m_1 + m_2} = \frac{20}{9} = 2.22\ ms^{-2}$

(6) A machine gun has a mass of $20\ kg$. It fires $35\ g$ bullets at the rate of 4 bullets per second, with a speed of $400\ ms^{-1}$. What force must be applied to the gun to keep it in position?

Solution: $V = \frac{mv}{M} = \frac{35\times10^{-3}\times400}{20} = 0.7\ ms^{-1}$

Change in velocity of gun $= 0.7\ ms^{-1}$

$t = \frac{1}{4}s$

$\therefore\ a = \frac{0.7}{1/4} = 2.8\ ms^{-2}$

Hence, $F = ma = 56\ N$

(7) A rubber ball of mass $200\ g$ falls from a height of $1\ m$ and rebounds to a height of $20\ cm$. Find the impulse and the average force between the ball and the ground, if time during which they are in contact was $0.1\ s$.

Solution: Velocity of ball just striking the ground

$v = \sqrt{2gh} = \sqrt{2\times9.8\times1} = 4.43\ ms^{-1}$

Velocity of the ball just rebounding

$v_1 = \sqrt{2gh} = \sqrt{2\times9.8\times0.2} = 1.97\ ms^{-1}$

Impulse, $Ft = mv_1 - (-mv) = m(v + v_1) = 0.2\times6.40 = 1.280Ns$ and $F = \frac{1.280}{0.1} = 12.8\ N$

(8) A constant retarding force of $50\ N$ is applied to a body of mass $10\ kg$ moving initially with a speed of $15\ m/s$. How long does the body take to stop?

Solution: We know $F = \frac{mv-mu}{t}$

Given $F = -50\ N$

Initial momentum,

$mu = 10\times15 = 150\ kg.m/s$

Final momentum, $mv = 20\times0 = 0$

Time, $t = ?$

Putting the values in (i) equation

$\Rightarrow -50 = \frac{0-150}{t}$

$\Rightarrow t = 3$ second

(9) A ball of mass 30 gm is initially moving with a velocity of $100\ m/s$. On applying a constant force on the ball for $0.5\ s$, it acquires a velocity of 150 m/s. Calculate the following :

(i) Initial momentum of the ball

(ii) Final momentum of the ball

(iii) Rate of change of momentum

Solution: Given, $m = 30gm = \frac{30}{1000}\ kg = 0.03\ kg$

Initial velocity, $u = 100\ m/s$

Time interval, $t = 0.5\ s$

Final velocity, $v = 150\ m/s$

(i) Initial momentum of the ball = mass × initial velocity

or $P_1 = mu = 0.03\ kg\times100\ m/s = 3\ kg\ - ms^{-1}$

(ii) Final momentum of the ball = mass × final velocity

or $P_2 = mv = 0.03\ kg\times150\ m/s = 4.5\ kg - ms^{-1}$

(iii) Rate of change of momentum $= \frac{\text{Final momentum - Initial momentum}}{\text{Time}}$

or $\frac{\Delta P}{\Delta t} = \frac{4.5 - 3}{0.5} = \frac{1.5}{0.5} = 3.0\ \text{kg} - \text{ms}^{-1} = 3.0\ \text{N}$

(10) Deduce Newton's first law from the second law.

Solution: According to second law, $\mathbf{F = ma}$

If $\mathbf{F = 0, a = 0}$ since $\mathbf{m \neq 0}$,

But $\mathbf{a} = \frac{\mathbf{v-u}}{\mathbf{t}}$

or, $\mathbf{v - u = 0}$

$\mathbf{So, v = u}$ for whatever time $\mathbf{t}$ is taken.

This means that the object will continue moving with uniform velocity, u throughout the time, t. If u is zero then $\mathbf{v}$ will also be Zero. That is, the object will remain at rest.

Solved Examples

FILL IN THE BLANKS

(1) 9.8N =______kgf.

(2) The net force acting on a body of mass of 1 kg moving with a uniform velocity of 5 ms^{-1} is ________.

(3) The law which defines force is______.

(4) Relation between force and momentum is ________.

(5) Mass measures amount of ________ in a body.

(6) If a boy of mass 50kg moves with velocity of 20m/s, then his momentum is _______.

(7) During collision _______of body remains constant.

(8) Equation of impulse is _________.

(9) When a running car stops suddenly, the passengers are jerked________.

(10) Newton's first law of motion is also called Galileo's law of__________.

TRUE OR FALSE

(1) All forces exist in pairs.

(2) Impulse and momentum have similar units.

(3) Mass of a body is a measure of its inertia.

(4) If two bodies of different masses move with the same momentum, the heavier body will have the greater velocity.

(5) If the same force is applied on two bodies of different masses for the same time, the change produced in the momentum of the two bodies are also same.

(6) The first law of motion is also known as Galileo's law of inertia.

(7) Motion of a rocket can be explained on the basis of Newton's third law.

(8) Action and reaction are equal in magnitude but act on bodies in opposite directions.

(9) Action and reaction act on the same body.

(10) If the same force is applied on two bodies of different masses, larger acceleration will be produced in heavier body.

OBJECTIVE TYPE QUESTIONS

(1) Mass measures amount of __________in a body.

(A) inertia (B) motion

(C) velocity (D) acceleration

(2) If no external force acts on a body, it will

(A) move with more speed. (B) change its shape.

(C) break its shape. (D) either remain in its state of rest or in uniform motion.

(3) When a running motorbike accelerate suddenly, the pillion rider has a tendency to fall backward. This is an example of:

(A) Newton’s first law of motion. (B) Newton’s second low of motion.

(C) Newton’s third law of motion. (D) Newton’s law of gravitational of motion.

(4) How many dynes are equal to 1 N?

(A) 10^6 (B) 10^4

(C) 10^5 (D) 10^3

(5) The net force acting on a body of mass of 1 kg moving with a uniform velocity of 5 ms^{-1} is -

(A) 5 N (B) 0.2 N

(C) 0 N (D) None of these

(6) A body of mass 6 kg undergoes a change in speed from 30 m/s to 0.30 m/s. The momentum-

(A) increases by 99 kgm/s. (B) decreases by 99 kgm/s.

(C) increases by 101 kgm/s. (D) decreases by 101 kgm/s.

(7) The forces of action and reaction have ________ magnitude but _______ direction.

(A) same, same (B) same, opposite

(C) opposite, same (D) opposite, opposite

(9) Action-reaction force:

(A) Act on same body (B) Act on different bodies

(C) Act along different lines (D) Act in same direction

(10) Impulse has same unit as that of:

(A) Force (B) Pressure

(C) Momentum (D) Momentum of force

Solved Examples

(I) FILL IN THE BLANKS

(1) 1

(2) 0

(3) Second law of Motion

(4) $F = \frac{p}{t}$

(5) Inertia

(6) 1000

(7) Momentum

(8) Force × Time

(9) Forward

(10) inertia

(II) TRUE OR FALSE

(1) True
(2) True
(3) True
(4) False
(5) True
(6) True
(7) True
(8) True
(9) False
(10) False

(III) OBJECTIVE TYPE QUESTIONS

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
(A)	(D)	(A)	(C)	(C)	(B)	(B)	(B)	(A)	(C)