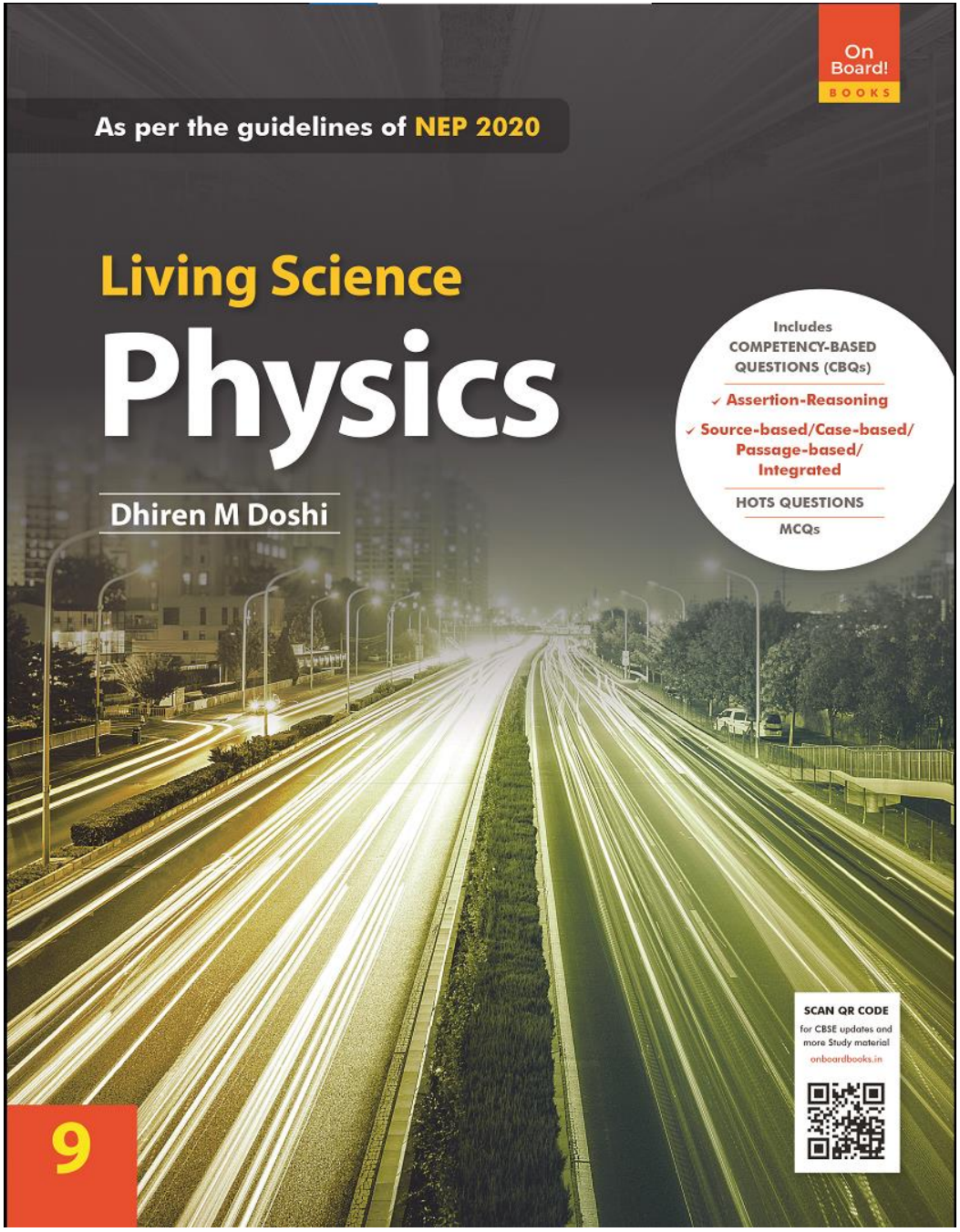


CBSE
Living Science
Physics

Class 9

Chapter-2 Force and Laws of Motion

LEARNING OBJECTIVES

Force

- ❖Effects of force
- ❖Balanced and unbalanced forces
- ❖ Motion without Force: Galileo's Experiment

Laws of Motion

- ❖ Newton's First Law of Motion
- ❖Inertia and Mass
- ❖ Types of Inertia

Momentum and Newton's Second Law of Motion

- ❖ Impulse

Newton's Third Law of Motion

- ❖ Law of Conservation of Momentum
- ❖ Application of law of conservation of momentum

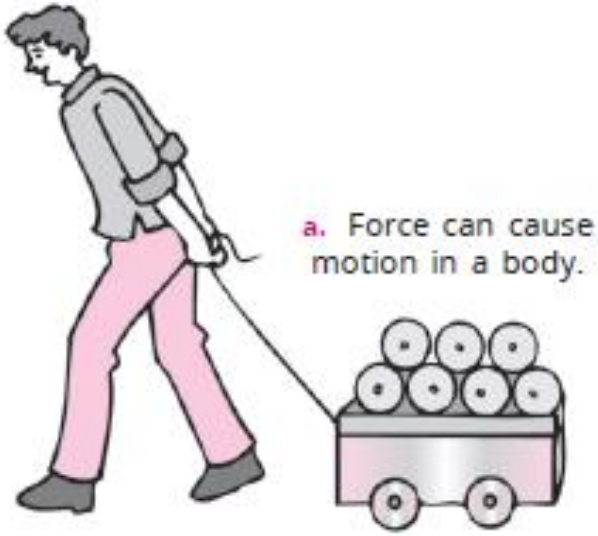
Dynamics and Force of Motion

The study of causes of motion or changes in motion is called dynamics.

Force is a push or a pull acting on a body which changes or tends to change the state of rest or of uniform motion, or the direction of motion, or the shape and size of a body.

Effects of Force

A force cannot be seen, tasted or felt. It can be seen or felt only by the effects which it can produce on various bodies (or objects) around us. A force often produces the following five effects on an object (or a body).



a. Force can cause motion in a body.

c. Force can bring a moving body to rest.

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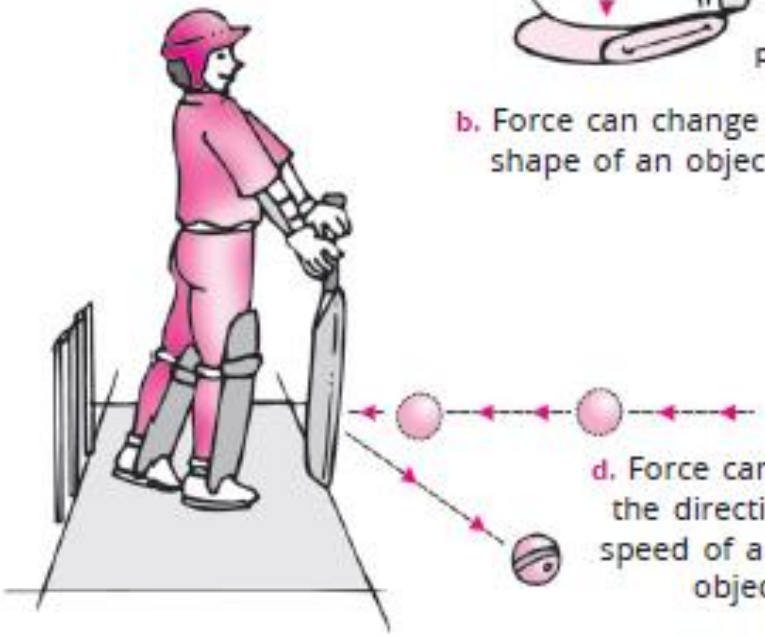
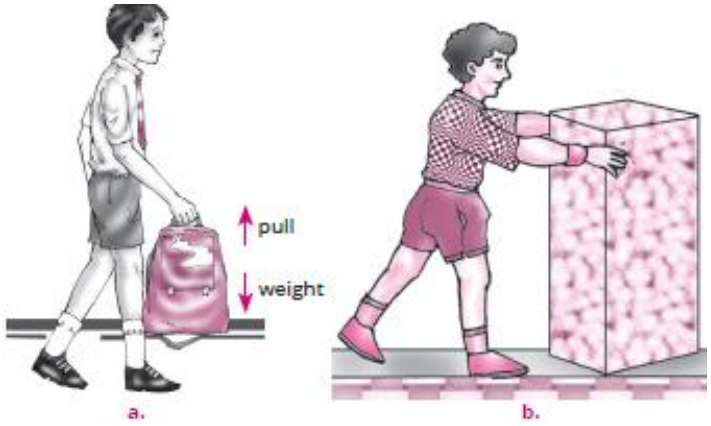
b. Force can change the shape of an object.



d. Force can change the direction and speed of a moving object.

Balanced and unbalanced forces

When a number of forces acting simultaneously on a body do not bring about any change in its state of rest or of uniform motion along a straight line, then these forces are said to be balanced forces.



1. A boy holding a school bag in his hand: The downward force due to the weight of the school bag is balanced by the force of pull applied by the hand in the upward direction by the boy.

2. A boy trying to push a heavy box along a rough surface : The pushing force applied by the boy is balanced by the large force of friction opposing the motion of the box.

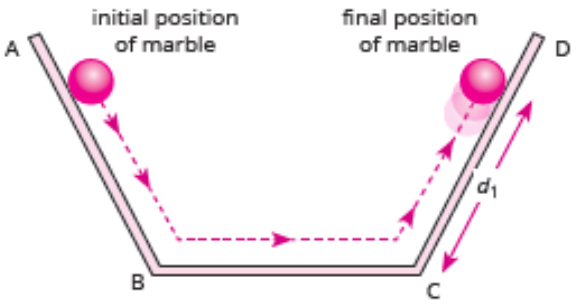
When a number of forces acting simultaneously on a body bring about a change in its state of rest or of uniform motion along a straight line, then these forces are said to be unbalanced forces.

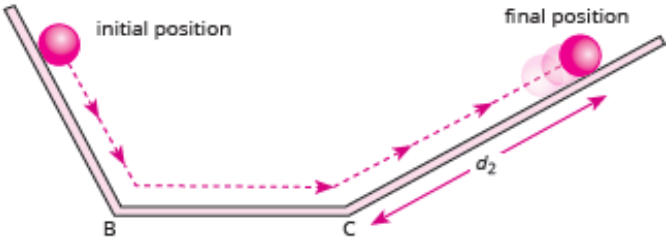
A toy car moves towards left when unbalanced forces are acting (F_1 > F_2) on it.

Refer to Table 2.1 for Comparison between balanced and unbalanced forces

Motion without Force: Galileo's Experiment

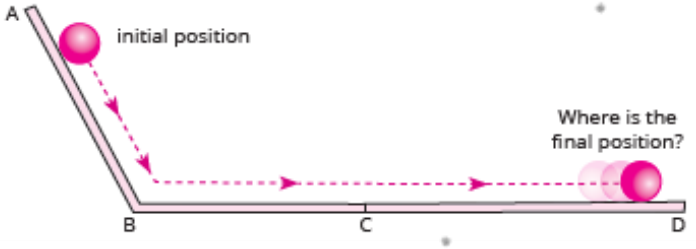
a. When the two inclined planes had equal inclinations, the marble rolled down from one side attained the same height on the other side.





b. When the inclination of one of the planes was decreased, the marble rolled down from the more inclined plane attained the same height on the other plane but covered a longer distance on the less inclined plane.

c. When the inclination of one of the planes was reduced to zero, the marble rolled down from the more inclined plane continued to move on the horizontal plane.



According to Galileo's law of inertia, **'When no unbalanced force is exerted on a body, it stays at rest or moves in a straight line with constant speed, i.e. it will remain unaccelerated.'**

Newton's Laws of Motion

Newton's first law of motion gives a precise definition of 'inertia' and 'force'. Newton's second law of motion establishes the relationship between force and momentum, whereas Newton's third law of motion establishes the relationship between the 'action' and 'reaction' forces

Newton's First Law of Motion

Newton's first law of motion states that 'A body continues to be in its state of rest or of uniform motion in a straight line unless it is compelled by some external applied force to change that state.'

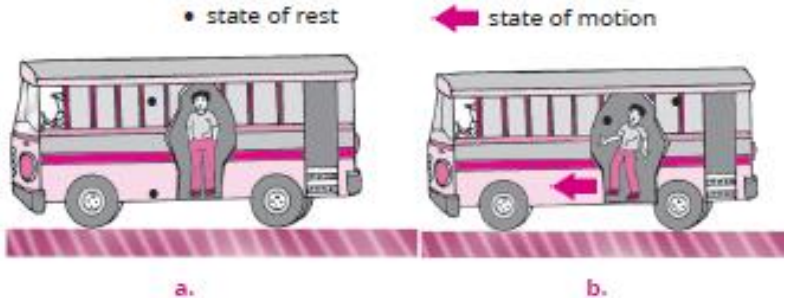
Inertia

Newton's first law defines inertia and is rightly called **the law of inertia.** The inherent property of a body by virtue of which it resists any change in its state of rest or of uniform motion in a straight line on its own is called its **inertia.**

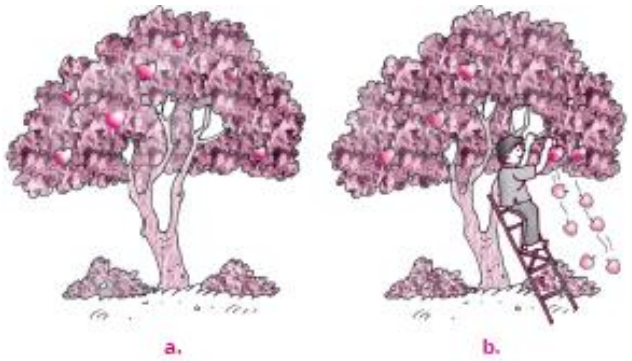
Mass and Inertia: Mass is a measure of the inertia of a body. Quantitatively, the inertia of a body is measured by its mass. The heavier a body, the greater is the force required to change its state and the greater is its inertia. The reverse is also true.

Types of Inertia

Inertia of rest : A body at rest remains at rest and cannot start moving on its own due to the inertia of rest.



A passenger tends to fall backwards when the bus starts suddenly. This is due to inertia of rest of the upper part of the passenger's body.

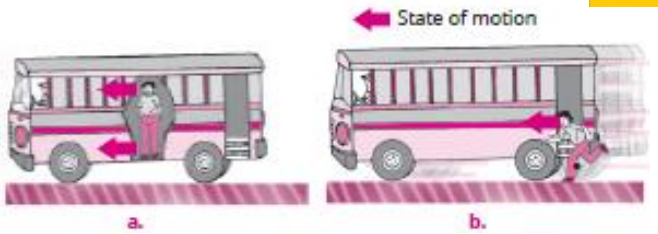


Fruits fall down when the branches of a tree are shaken. This is due to inertia of rest of the fruits.

Inertia of motion: A body in uniform motion can neither get accelerated nor retarded on its own. It also cannot come to rest on its own. This is said to be inertia of motion of a body.

A passenger tends to fall forward when the bus stops suddenly. This is due to inertia of motion of the upper part of the passenger's body.

A passenger jumping out of a moving bus may fall forward. This is due to inertia of motion of the upper part of the passenger's body.



Inertia of direction: A body moving along a straight line will continue to move along the same direction unless some external force changes its direction of motion.

When a car takes a sharp turn, the person sitting inside tends to fall outwards. As the car turns, the person tries to resist the change in direction due to inertia of direction.

Momentum and Newton's Second Law of Motion

The momentum of a body of mass *m* travelling with velocity *v* is defined as the product of its mass and velocity.

Thus, momentum $p = mv$

The SI unit of momentum is kilogram metre per second which is written as kg m s^{-1} or kg m/s.

According to Newton's second law of motion, 'The rate of change of momentum of a body is directly proportional to the applied unbalanced force in the direction of force.'

Rate of change of momentum

$= m(v-u)/t = ma$ Since $(v-u)/t = a$

According to Newton's Second Law of motion

$F \propto$ rate of change of momentum

$\therefore F \propto m \times a$

$F = k \times m \times a$

$F = m a$ (if $k = 1$)

One newton is that force which when acting on a mass of 1 kg produces in it an acceleration of 1 m/s^2 in its own direction.

Applications of Newton's second law of motion

- A karate player breaks a pile of tiles or a slab of ice in a single blow
- In cricket, a fielder moves his arms backwards in the direction of the ball while taking a catch.
- When a car goes out of control, the driver would prefer to hit something soft (say haystack) than something hard (say a concrete wall)
- Athletes performing in a high jump athletic event are made to fall either on a cushioned bed or on a sand bed
- China and glassware are packed with soft material while transportation
- Springs are present in car seats
- Athletes are advised to stop slowly after finishing a race

By a single blow, a karate player is able to break a pile of tiles or a slab of ice

By pulling arms back with the ball, a fielder is able to catch the ball without injuring himself.

Impulse

Impulse of a force is a measure of total effect of the force applied for a short time. It is given by the product of force and the time for which the force acts on the body, i.e.

Impulse = Force $\times$ Time

$I = F \times t$

From Newton's second law of motion,

Force, F = Change in momentum / Time taken

= Change in momentum/ t

or $F \times t$ = Change in momentum

or Impulse = Change in momentum $[I = F \times t]$

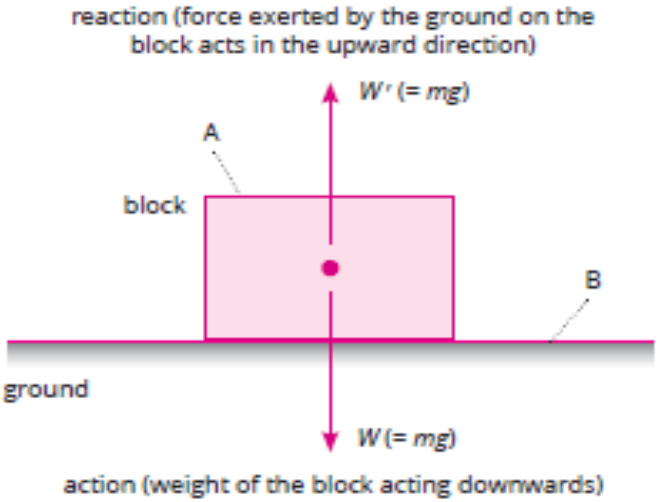
So, impulse is also defined as the change in momentum of a body.

So, the SI unit of impulse is newton second (N s), or kilogram metre per second (kg m/s).

Newton's Third Law Of Motion

According to Newton's third law of motion, 'To every action, there is an equal and opposite reaction; action and reaction forces act on different bodies.'

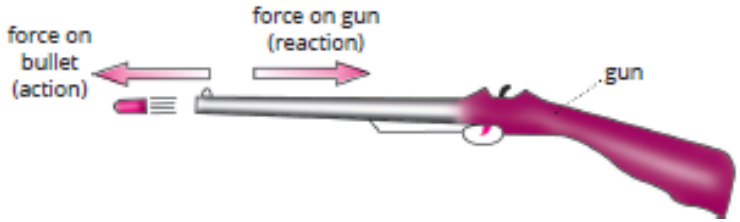
In other words, whenever two bodies interact with each other, the force exerted by the first body on the second (called action) is equal and opposite to that exerted by the second body on the first (called reaction).



Action and reaction act on different bodies.

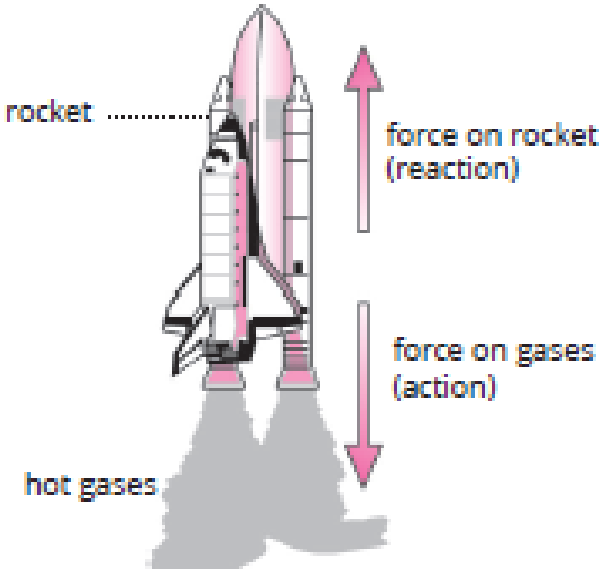
Examples to illustrate Newton's third law of motion

1. A gun recoils when a shot is fired from it

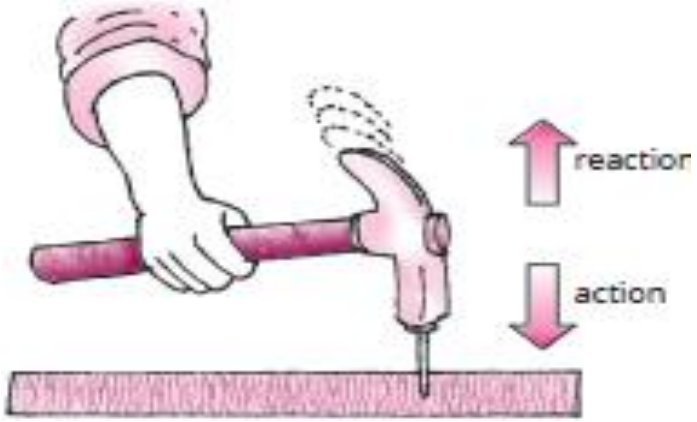


2. A person swimming

3. The flying of jet aeroplanes and rockets



Action and reaction in the case of a



4. Boatman ties his boat before allowing the passengers to disembark:

Action and reaction when a man steps out of a boat

5. We feel pain in the hand when we hammer a nail into a wooden plank

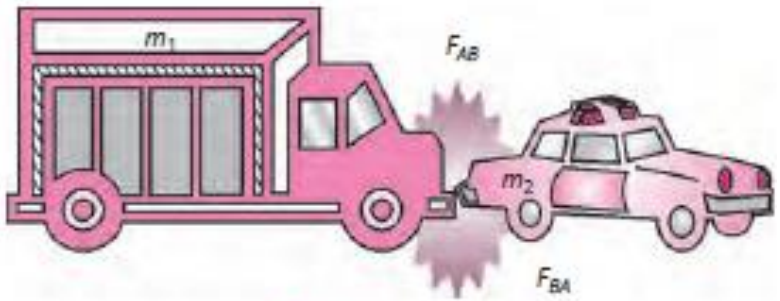
Action and reaction when you hammer a nail into a wooden plank

Law of Conservation of Momentum

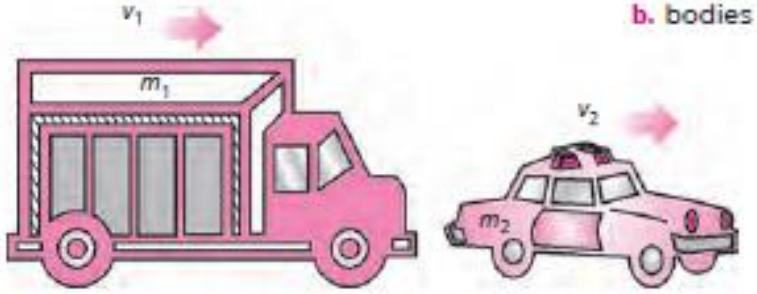
When two moving bodies collide with each other, they exert forces of action and reaction on each other. These forces change the momentum of each of the two bodies which had collided. It has been found by observation and experimentation that though the momentum of each body changes, the total momentum of the two bodies together remains the same.

According to **the law of conservation of linear momentum,** in the absence of an external force the total momentum of all the bodies of a system remains constant (conserved).

a. bodies before collision



b. bodies at collision



c. bodies after collision

Initial momentum of the system = $m_1u_1 + m_2u_2$

Now, let body A collide with body B and after collision, their velocities be v_1 and v_2 respectively. So, final momentum of the system = $m_1v_1 + m_2v_2$

Body A exerts a force of action F_{AB} on body B. Body B exerts a force of reaction F_{BA} on body A.

F_{AB} = Rate of change of momentum of body A $= m_1 (v_1 - u_1)/ t$

F_{BA} = Rate of change of momentum of body B = $m_2 (v_2 - u_2) /t$

Since action = – reaction (Newton's third law of motion)

$\therefore \quad F_{AB} = - F_{BA}$

$$m_1 (v_1 - u_1)/ t = m_2 (v_2 - u_2) /t$$

or $$m_1v_1 - m_1u_1 = - m_2v_2 + m_2u_2$$

Or $$m_1v_1 + m_2v_2 = m_1u_1 + m_2u_2$$

$\therefore$ Momentum of the system after collision = Momentum of the system before collision

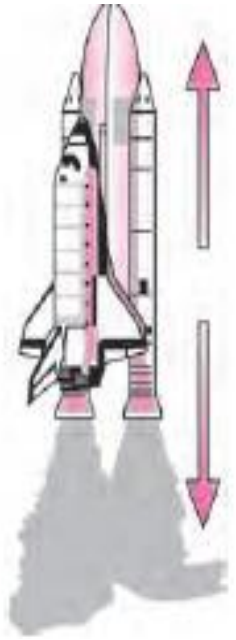
Application of the law of conservation

Man and boat: When a man in a boat near a river bank is at rest, the total momentum of the boat and the man is zero. When the man jumps from the boat, the boat slightly moves away from the shore. This is because on jumping from the boat, the man gains velocity.

According to the law of conservation of momentum, the momentum of the system (man and boat) after the man jumps should remain zero. To conserve momentum, the momentum of the boat should be equal and opposite to that of the man. This is possible only if the boat moves in the opposite direction. Hence, the boat is pushed behind.

Motion of rockets: Before the rocket is fired, the total momentum of the system is zero since the rocket is in a state of rest. When the rocket is fired, chemical fuels inside the rocket are burnt and a blast of hot gases is released with a very high velocity.

According to the law of conservation of momentum, the total momentum of rocket and exhaust gases should remain zero after the firing of the rocket. As the hot gases gain momentum to the rear on leaving the rocket, the rocket acquires equal momentum in the upward (i.e. opposite) direction because the total momentum is conserved.



All the cases in which actions and reactions are involved are examples of law of conservation of momentum.

Note: For more examples refer to the book p 82-84.

SUMMARY

1. Force: Force is a push or pull acting on a body which changes or tends to change the state of rest or of uniform motion, or the direction of motion, or the shape and size of the body.

2. Newton: The SIunit of force is newton (N). One newton is the force which acts on a body of mass 1 kg producing an acceleration of 1 m/s2 in it.

3. Balanced forces: When a number of forces acting simultaneously on a body do not bring about any change in its state of rest or of uniform motion in a straight line, then the forces acting on the body are said to be balanced forces.

4. Unbalanced forces: When a number of forces acting simultaneously on a body bring about a change in its state of rest or of uniform motion in a straight line, the set of forces acting on the body are said to be unbalanced forces.

5. Galileo's law of inertia: When no unbalanced force is exerted on a body, it stays at rest or it moves in a straight line with constant speed.

6. Newton's first law of motion: It states that 'Abody continues to be in its state of rest or of uniform motion in a straight line unless it is compelled by some external force to change that state.'

7. Inertia: The inherent property of a body by virtue of which it resists any change in its state of rest or of uniform motion in a straight line is called inertia.

8. Kinds of inertia: a. inertia of rest **b.** inertia of motion **c.** inertia of direction

9. Mass: Mass of a body is a measure of inertia of the body.

10. Momentum: The momentum of a body of mass *m* moving with a velocity *v* is defined as the product of its mass and velocity.

11. Newton's second law of motion: It states that 'The rate of change of momentum of a body is directly proportional to the net external force applied on it and the change in momentum takes place in the direction in which the force is applied.'

12. Impulsive forces: The forces which act on bodies for short time are called impulsive forces.

13. Impulse: It is a measure of total effect of the force applied for a short time. It is given by the product of force and time for which the force acts on the body.

14. Newton's third law of motion: It states that 'To every action there is an equal and opposite reaction; action and reaction forces act on different bodies.'

15. Law of conservation of momentum: The sum of momenta of two objects before collision is equal to the sum of momenta after the collision provided there is no external unbalanced force acting on them.