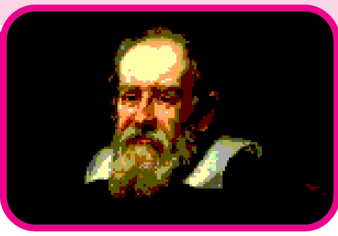
Chapter
3

LAWS OF MOTION



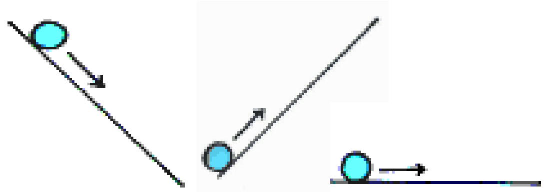
We observe the changes in motion of many objects around us. We discussed the concepts of velocity and acceleration in the chapter ‘Motion’.

Philosophers of the ancient world were very much interested in the study of motion. One question agitating their mind was, what is the natural state of an object if it is left to itself? Our commonsense tells that every moving object on earth if it is left free for some time gradually comes to rest by itself. What happens if you stop peddling your bicycle? It slows down gradually and stops finally.

We wonder to know that Aristotle, the great philosopher of that time also concluded that the natural state of an earthly object is to be at rest. He thought that the object at rest requires no explanation as any moving body naturally comes to rest.

Galileo Galilee gave birth to modern science by stating that an object in motion will remain in same motion as long as no external force is applied on it.

Galileo came up with two ingeneous thought experiments. He did his experiments on inclined planes with smooth surfaces and observed that the smoother the surface, the farther the ball travelled. He extended this argument and concluded that if the surface was perfectly smooth, the ball will travel indefinitely, until encountered by another object. (In real world such a surface of course does not exist).



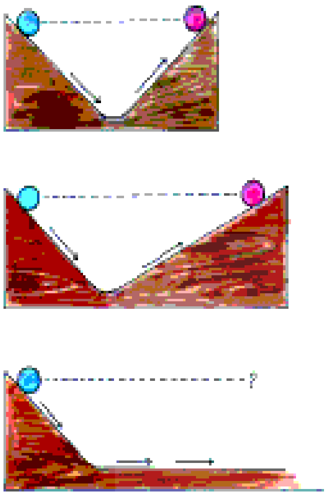
1 (a) 1 (b) 1 (c)

Fig-1 (a) downward motion (b) upward motion (c) motion on a plane surface

As shown in figure 1 (a) he observed that when a marble rolls down a slope, it picks up speed due to the force of gravity of the earth.

In figure 1 (b) when the object rolls up an inclined plane, its speed decreases. Now let us assume that a marble is moving on a level surface as shown in figure 1(c) it has no reason to speed up or slow down. So it will continue to move with constant velocity.

By this experiment, Galileo came to a conclusion which was in contrast to Aristotle's belief that the natural state of an object is 'rest'.



2 (a)

2 (b)

2 (c)

Fig-2 (a) (b) motion along inclined planes with different slopes. (c) Motion from inclined surface to plane surface

Galileo observed that, as shown in figugre 2 (a), the marble released from its initial height rolled down due to the force of gravity and then moves up the slope until it reached its initial height. Then he reduced the angle of the upward slope and did the same experiment as in figure 2 (b). The marble rolled up the same height, but it had to go farther in this instance. That means the distance travelled by it is greater. He made his observation by further reduction in the angle of the upward slope, he got the same results. To reach the same height the ball had to go farther each time.

Then a question arose in his mind, "how far must it have to move to reach the same height if it has no slope to go up"? Since it has no slope to go up as shown in figure 2(c), obviously it should keep on moving forever along the level surface at constant velocity. He concluded that the natural state of a moving object, if it is free of external influences, is uniform motion . What do you think of these experiments? Is any external force required to stop a moving object? From this experiment we can say that an object will remain in uniform motion unless a net force acts on it.

Galileo imagined a world where there is no friction. But as we learnt in class VIII this is not possible in reality because friction which affects the motion of the object plays an important role in our life. For example if there were no friction we could not be able to walk on ground, we would not be able to stop a fast moving car etc. It is very difficult to perform many physical activities without friction. Built upon ideas primarily developed by Aristotle and Galileo, Sir Isaac Newton proposed his three fundamental laws which explain the connection between force and a change in motion. These three laws are popularly called as Newton's laws of motion.

First law of motion

The first law of motion can be stated as follows: "Every object will remain at rest or in a state of uniform motion unless compelled to change its state by the action of a net force".

"Newton's first law explains what happens to an object when no net force acts on it."

It either remains at rest or moves in a straight line with constant speed (that is uniform motion). Let's discuss.

Do you know?

Galileo Galilei was born on 15 February 1564 in Pisa, Italy. Galileo has been called the "father of modern science".

In 1589, in his series of essays, he presented his theories about falling objects using an inclined plane to slow down the rate of descent.

Galileo was also a remarkable craftsman. He developed a series of telescopes whose optical performance was much better than that of other telescopes available during those days.

Around 1640, he designed the first pendulum clock. In his book 'Starry Messenger' on his astronomical discoveries, Galileo claimed to have seen mountains on the moon, the Milky Way made up of tiny stars, and four small bodies orbiting Jupiter. In his books 'Discourse on Floating Bodies' and 'Letters on the Sunspots', he disclosed his observations of sunspots.

Using his own telescopes and through his observations on Saturn and Venus, Galileo argued that all the planets must orbit the Sun and not the earth, contrary to what was believed at that time.

Activity-1

Observing the motion of a pen cap kept on thick paper ring.

Make a circular strip from a thick paper. Balance the hoop on the center of the mouth of the bottle. Now balance a pen cap on the paper hoop aligning it on the center of the bottle's mouth as shown in figure 3. Pull the paper hoop with your finger as fast as you can.

- What do you observe?
- What happens to the pen cap?

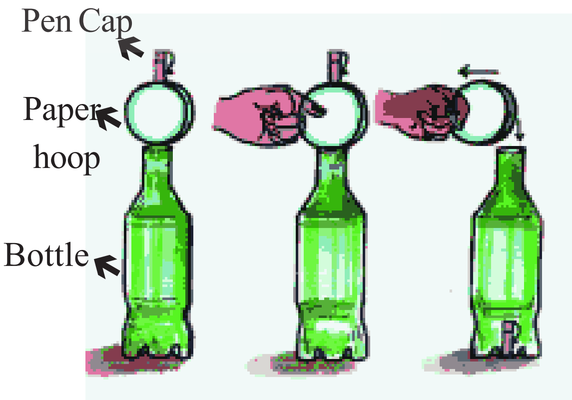


Fig-3 Fast pulling of paper hoop kept on a bottle

Activity-2

Observing the motion of the coins hit by a striker

Fig-4 Hitting the stock of coins with a striker

Make a stack of carom coins on the carom board.Give a sharp hit at the bottom of the stack with striker. You can find that the bottom coin will be removed from the stack, and the others in the stack will slide down as shown in figure 4.

- What are your observations from the above activities?
- Why does the pen cap fall inside the bottle?
- Why does the stack of carom coins fall down vertically?

To understand this, we have to discuss some more examples which we face in our daily life.

When the bus which is at rest begins to move suddenly, the person standing in the bus falls backward. Similarly when you are travelling in bus, the sudden stop of the bus makes you fall forward. Why does it happen so? These changes can be described only with the word: **Inertia.**

In simple language we can say that inertia means not accepting the change. Things tend to keep doing what they are already doing. In the first case the bus accelerated suddenly and moved forward, But the body of person tends to remain in the same state because of inertia which resulted in backward motion

In the second case when you are travelling in a bus your body is also travelling with the velocity equal to that of the bus. If the bus stops suddenly your body tends to continue in the same state of motion due to inertia. Newton's First Law of motion is also known as law of inertia.

With our day to day experiences, we all know that we must exert some force on an object to keep it moving. As far as the object is concerned the force applied by us is just one of the several forces acting on it. The other forces might be friction, air resistance or gravity. Thus it is clear that it is the net force which determines the change in motion of an object.

Let us consider a football placed at rest on the ground. The law of inertia tells us that the football will remain in the same state unless something moves it.

If you kick the ball, it will fly in the direction you kicked, with certain speed, until a force slows it down or stops it. If the ball went high, the force of gravity slows it down. If the ball rolls on the ground the force of friction make the ball slow down and stop.

If the net force acting on an object is zero, the object which is at rest remains at rest or if the object is already moving with a certain velocity it continues to move with the same velocity. Thus we can represent the first law of motion as:

If $F_{net} = 0$ then the velocity an object is either zero or constant.

Thus when the net force acting on a body is zero, we say that the body is in equilibrium.

Inertia and mass

We have learnt that inertia is the property of an object that resists changes in its state of motion. All objects have this tendency.

- Do all the bodies have the same inertia?
- What factor can decide the inertia of a body?

Which is easy for you, to push a bicycle or a car? You can observe that it is difficult to push the car. We say car has greater inertia than the bicycle. Why does the car possess more inertia than a bicycle?

Inertia is a property of matter that resists changes in its state of motion or rest. It depends on the mass of the object. The car has more inertia than a bicycle because of its mass.

Mass of an object is considered as the measure of inertia. We know that SI unit of mass is 'kg'.

Activity-3

Pushing two wooden boxes with same force

Take two rectangular wooden blocks with different masses and place them on a straight line drawn on a floor as shown in fig-5. Give the same push at the same time to both the blocks with the help of a wooden scale.

- What do you find?
- Which one goes farther? Why?
- Which block accelerates more?

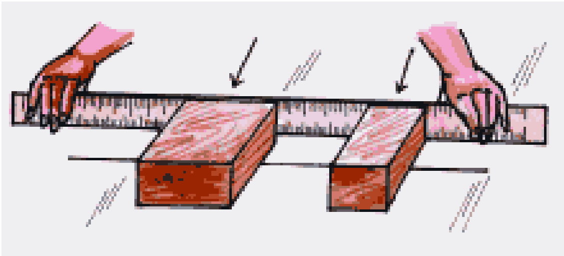


Fig-5 pushing wooden boxes with same force

Through your observations you can tell that the greater the mass of an object, the more it resists changes in its state of motion.

From the above examples we can conclude that some objects have more inertia than others. Mass is a property of an object that specifies how much inertia the object has.

Think and discuss

- You may have seen the trick where a tablecloth is jerked from a table, leaving the dishes that were on the cloth nearly in their original positions.
  - ✓ What do you need to perform this successfully? ,
  - ✓ Which cloth should we use? Is it cloth made of thick cotton or thin silk?
  - ✓ Should the dishes possess large mass or small mass?
  - ✓ Is it better to pull the cloth with a large force or pull it with a gentle and steady force?
- What is the velocity of a small object that has separated from a rocket moving in free space with velocity 10km/s?

Example 1

A body of mass 'm' is kept on the horizontal floor and it is pushed in the horizontal direction with a force of 10N continuously, so that it moves steadily.

a) Draw FBD(a diagram showing all the forces acting on the body at a point of time)

b) What is the value of friction?

Solution

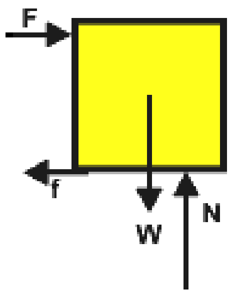


Fig-6 Free body diagram

Given that the body is moving steadily, Hence the net force on the body is zero both in horizontal and vertical directions.

Forces acting on it along horizontal direction are force of friction (f), force of push (F)

We know that $F_{net,x} = 0$

$$F + (-f) = 0$$

$$F = f$$

Hence the value of force of friction is 10N.

Second law of motion

Newton's second law explains us what happens to an object when non-zero net force acts on it.

Place a ball on the veranda and push it gently. Then the ball accelerates from rest. Thus, we can say that force is an action which produces acceleration.

A non zero net force acting on a body disturbs the state of equilibrium.

Now we are going to discuss how the acceleration of an object depends on the force applied on it and how we measure a force.

Linear momentum

Let us recall our observations form our everyday life. If a badminton ball and a cricket ball hit you with same speed, which one hurts you more? A small bullet fired from gun damages the wall only due to its high speed. We all know that a heavy truck damages more than a bicycle if both hit a wall. These can be explained by a concept called momentum which is usually denoted by the symbol 'p'.

From the above examples we can say that the momentum depends on two factors: one is mass of an object and the other is its velocity. Newton used the word "mass in motion" to represent the meaning of momentum. The momentum (p) of a body is simply defined as the product of its mass (m) and its velocity (v) : i.e.

Momentum = (mass)* x *(velocity)

$$p = mv$$

It can be stated as mass in motion. As all objects have mass, if an object is in motion, then it acquires momentum.

Momentum is a vector because velocity is a vector. Hence, the direction of momentum is in the direction of velocity.

The SI unit of momentum is kg – m/s or N-s

Activity-4

Larger the net force greater the acceleration

Gently push a block of ice on a smooth surface and observe how the object speeds up, in other words how it accelerates. Now increase the net force and observe change in its speed.

- Is the acceleration increased?

Fig-7 Different forces applied on same object

Activity-5

Larger the mass smaller the acceleration

Apply a force on an ice block. It undergoes some acceleration.

Now take a block of ice with greater mass, but apply almost the same force on the ice block which has greater mass and observe the acceleration.

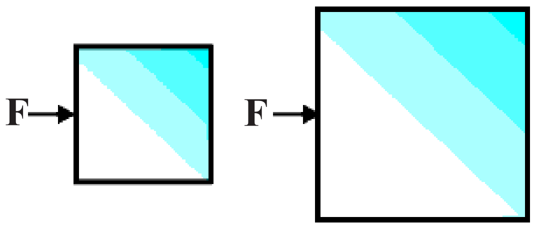


Fig-8 Same forces applied on abjects of different masses

In both the cases the object accelerates, but we can observe in the second case, it will not speed up as quickly as before.

From the above examples what have you noticed? Larger the net force greater the acceleration if the mass of the body is constant and also larger the mass lesser the acceleration if a constant net force is applied.

According to Newton's *'Principia'*: Second law states that the rate of change of momentum of an object is proportional to the net force applied on the object in the direction of net force.

Thus net force F_{net} α change in momentum / time

$$F_{net} \; \alpha \; \frac{\Delta p}{\Delta t}$$

Δp is the change in momentum of a particle or a system of particles brought by the net force in a time interval of Δt.

When a symbol of proportionality is removed, a constant is inserted in the equation.

$$F_{net} = k\frac{\Delta p}{\Delta t}$$

The SI units of momentum and time are 'kg- m/s' and's' respectively. The unit of force is so chosen that the value of constant 'k' becomes 1. So that,

$$F_{net} = \frac{\Delta p}{\Delta t}$$

We know p=mv

so that,

$\Delta p = \Delta mv$

If the mass of the body is constant during its motion then,

$\Delta p = m\Delta v$

Now we have,

$$F_{net} = m\frac{\Delta v}{\Delta t}$$

We know that $\Delta v/\Delta t = a$, is called uniform acceleration.

Then $F_{net} = ma$

The above formula says that the net force produces acceleration in a body in the direction of force.

SI units of force are $kg.m/s^2$. This unit has been named as Newton (N) and $1N = 1kg.m/s^2$.

Note:

✓ $F_{net} = \Delta p/\Delta t$ is a universal formula that can be applied for any system where as $F_{net} = ma$ can be applied only for constant mass.

✓ To solve problems by using Newton's second law, the weight of the body is taken as 'mg' vertically down. (You learn more about this in the chapter 'Gravitation')

Think and discuss

- Observe the following diagram.

Fig- 9

What is the upper limit of weight that a strong man of mass 80kg can lift as shown in figure?

- What is the momentum of ceiling fan when it is rotating?
- Is it possible to move in a curved path in the absence of a net force?
- Prove that the tension throughout the string is uniform when the mass of string is considered to be zero.

Example 2

A mat of mass 1kg and length 1m is placed on the floor. One end of the mat is pulled with a constant speed of 1m/s towards the other end till the other end comes to motion(till the mat is reversed). How much force is required to do this?

Solution

Fig-10

As shown in figure, a mat is being pulled with a constant speed of v = 1m/s, so that the mass of the part of the mat is continuously increasing. Hence here the mass is a variable.

The time required for bringing the entire mat in motion is given by

$$\Delta t = \frac{\text{distance covered by the end}}{\text{speed}}$$

$$= 2/1 = 2s$$

(Distance covered by the end=1m+1m=2m)

From Newton's second law of motion,

$$F_{net} = \frac{\Delta p}{\Delta t} = \frac{\Delta(mv)}{\Delta t}$$

Here v is constant, so we get

$$F_{net} = v \frac{\Delta m}{\Delta t}$$

Where, Δm is the change of mass in Δt time.

The change of mass in 2s is equal to entire mass of mat.

$$F_{net} = \frac{(1m/s) \times (1kg)}{2}$$

$$= \frac{1}{2} N$$

In the horizontal direction only one force is acting. Hence the required force is 1/2 N

Example 3

Atwood machine

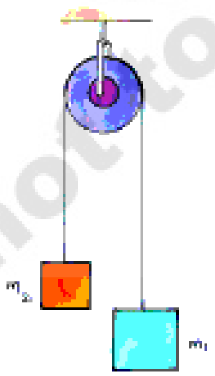


Fig-11

Atwood machine consists of two loads of masses m_1 and m_2 attached to the ends of a limp of inextensible string as shown in the figure 11. The string runs over a pulley. Find the acceleration of each load and tension in the string (m_1>m_2)

Solution

From figure 12 we know that tension of string always tries to pull the bodies up.

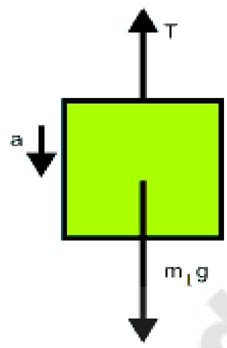


Fig-12

From the FBD of the mass m_1, there exist two forces on the load of mass m_1, one is tension of the string acting in upward direction and weight of the load (m_1g) acting in downward direction.

The net force on m_1 $F_{net} = m_1a$

$\Rightarrow$ $m_1g - T = m_1a$ ------------ (1)

Thus the net force (F_{net}) acting on mass m_1 produces an acceleration 'a' in it.

When m_1 moves down, m_2 moves up. So the magnitudes of acceleration are same.

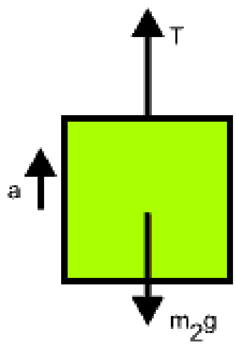


Fig-13

From the FBD of mass m_2

$F_{net} = T - m_2g = m_2a$ ------------ (2)

Solving (1) and (2) equations, we get

$$a = \frac{(m_1-m_2)g}{(m_1+m_2)}$$

and

$$T = \frac{2\,m_1m_2g}{(m_1+m_2)}$$

Third law of motion

Activity- 6

Pulling two spring balances

Let's take two spring balances of equal calibrations. Connect the two spring balances as shown in figure 14. Pull the spring balances in opposite directions as shown in figure 14.

Fig-14 Forces applied in opposite direction.

- What do you notice from the readings in the spring balances?
- Are the readings of two spring balances the same?
- Are we able to make the spring balances to show different readings by pulling them simultaneously in opposite directions? Why?

According to third law of motion, when an object exerts a force on the other object, the second object also exerts a force on the first one which is equal in magnitude but opposite in direction.

The two opposing forces are known as action and reaction pair.

Newton's third law explains what happens when one object exerts a force on another object.

If you are walking on the ground, at each step, you know that your feet exert some force on the ground. Are you thinking that the ground also exerts some force in the opposite direction on you?

Is it not surprising to hear that when you push a wall then the wall pushes you back!

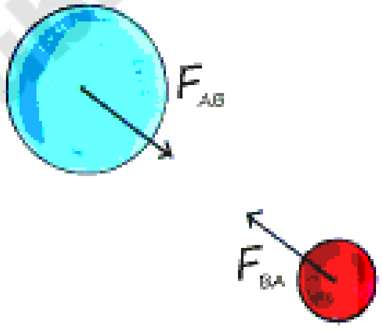


Fig-15 Action and reaction forces

If two objects interact, the force F_{AB} exerted by the object 'A' on the object 'B' is equal in magnitude and opposite in direction to the force F_{BA} exerted by object 'B' on the object 'A'.

$$F_{AB} = -F_{BA}$$

The negative sign indicates that the reaction force is acting in a direction opposite to that of action force. This states that no single isolated force exists.

Newton's first and second laws of motion apply to a single body, where as Newton's third law of motion applies to an interaction between the two bodies. Note that two forces in Newton's third law never act on the same body.

The action-reaction pair in Newton's third law always represents forces acting on two different bodies simultaneously.

Let us consider the following examples.

When birds fly, they push the air downwards with their wings, and the air pushes back the bird in opposite upward direction. Thus the force applied by the wings of bird on air and an opposite force applied by the air on wings are equal in magnitude and opposite in direction.

When a fish swims in water, the fish pushes the water back and the water pushes the fish with equal force but in opposite direction. The force applied by the water makes the fish to move forward.

A rocket accelerates by expelling gas at high velocity. The reaction force of the gas on the rocket accelerates the rocket in a direction opposite to the expelled gases. It is shown in figure-16

Fig-16 Motion of rocket

- Does the rocket exert a force on the gas expelled from it?

Activity-7

Balloon rocket

Inflate a balloon and press its neck with fingers to prevent air escaping from it.

Pass a thread through a straw and tape the balloon on the straw as shown in the figure 17.

Hold one end of the thread and ask your friend to hold the other end of the thread.

Now remove your fingers from the balloon's neck so as to release the air from the balloon.

- What happens now ?
- How would you explain this situation with Newton's third law of motion?

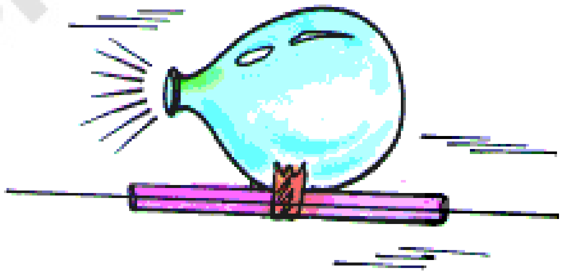


Fig-17 Balloon rocket

Inflate a balloon and tie its neck. The air within the balloon exerts force on the walls of the balloon equally in all the directions as shown in figure.18

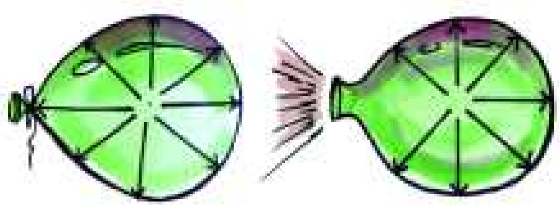


Fig-18 The forces on the inside wall of a balloon

When you release the neck of the balloon to allow air to escape from the balloon, what happens? When the air escapes there will be no force acting on the wall at the neck. But still there is a force exerted by air inside balloon which is acting in a direction opposite to the neck. Hence the balloon accelerates in that direction, on which direction the net force is acting.

Lab Activity

Aim: To show the action and reaction forces acting on two different objects.

Material required: Test tube, cork cap, Bunsen burner and laboratory stand.

Procedure

✓ Take a test tube of good quality glass and put small amount of water in it. Place a cork cap at its mouth to close it.

✓ Now suspend the test tube horizontally with the help of two strings as shown in the figure 19.

✓ Heat the test tube with a Bunsen burner until water vaporize and cork cap blows out.

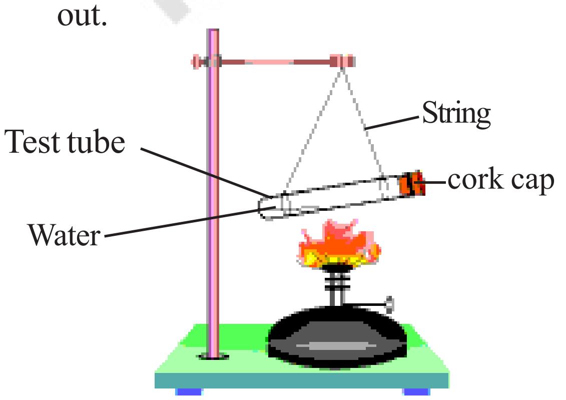


Fig-19

Observe the movement of test tube when cork cap blows out. Compare the directions of movement of test tube as well as cork cap. Observe the difference in the velocity of cork cap and that of recoiling test tube.

- What do you infer from above experiment?

Think and discuss

- The force exerted by the earth on the ball is 8N. What is the force on the earth by the ball?
- A block is placed on the horizontal surface. There are two forces acting on the block. One, the downward pull of gravity and other a normal force acting on it. Are these forces equal and opposite? Do they form action – reaction pair? Discuss with your friends.
- Why is it difficult for a fire fighter to hold a hose that ejects large amount of water at high speed?

Conservation of momentum and impulse

Let two objects with masses m_1 and m_2 travel with different velocities u_1 and u_2 respectively in the same direction along a straight line. As the velocities are different they collide with each other and the collision lasts for time 't', which is very small. During the collision the first marble exerts a force on the second marble F_{21} and the second marble exerts a force on the first marble F_{12}. Let v_1 and v_2 be the velocities of the marbles respectively after collision.

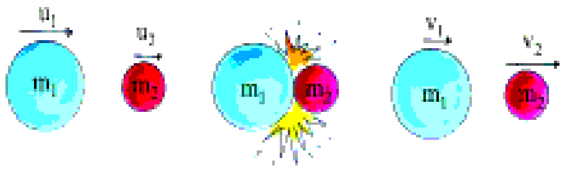


Fig-20 Conservation of momentum

What are the momenta of the marbles before and after collision? Let's know from the table.

	Marble 1	**Marble 2**
Momentum before collision	m_1u_1	m_2u_2
Momentum after collision	m_1v_1	m_2v_2
Change in momentum, Δp	$m_1v_1-m_1u_1$	$m_2v_2-m_2u_2$
Rate of change in momentum $\frac{\Delta p}{\Delta t}$	$\frac{(m_1v_1-m_1u_1)}{t}$	$\frac{(m_2v_2-m_2u_2)}{t}$

According to Newton's third law of motion, the force exerted by first marble on the second is equal to the force exerted by the second marble on the first one.

Hence $F_{12} = -F_{21}$

Hence we get,

$$\frac{(\Delta p)_1}{t} = -\frac{(\Delta p)_2}{t}$$

$$\frac{m_1v_1-m_1u_1}{t} = \frac{-(m_2v_2-m_2u_2)}{t}$$

After solving this, we get

$m_1u_1+m_2u_2 = m_1v_1+m_2v_2$

$m_1u_1+m_2u_2$ is the total momentum of the two marbles before collision and $m_1v_1+m_2v_2$ is the total momentum of the two marbles after collision.

From the above equation we observe that the total momentum is unchanged before and after collisions. We can say that the momentum is conserved. Law of conservation of momentum states in the absence of a net external force on the system, the momentum of the system remains unchanged.

A system is said to be isolated when net external force acting on it is zero.

It will be surprising if anybody says that the fall doesn't hurt, but the sudden stop at the end that hurts you. Is it true?

- Why does a pole vault jumper land on thick mats of foam?
- Is it safe to jump on sand rather than a cement floor? Why?

A softer and more cushioned landing surface provides a greater stopping distance because of the longer time taken to stop. That's why the fielder pulls back his hands while catching a fast moving cricket ball. In this situation, the fielder is trying to increase the time to decrease its velocity.

Thus, the rate of change of momentum will be less so that the force of impact of the ball on hands will be reduced.

As we expressed the second law as

$$F_{net} = \frac{\Delta p}{\Delta t}$$

It is important to minimize F_{net}, you have to maximize the stopping time.

We get $F_{net}\,\Delta t = \Delta p$

From the above equation we know that the product of net force and interaction time is called impulse of net force. Impulse is equivalent to the change in momentum that an object experiences during an interaction. Forces exerted over a limited time are called impulsive forces. Often the magnitude of an impulsive force is so large that its effect is appreciable, even though its duration is short. Let us observe following activity.

Activity-8

Dropping eggs

Take two eggs and drop them from a certain height such that one egg falls on a concrete floor and another egg falls on a cushioned pillow.

- What changes do you notice in both eggs after they are dropped? Why?

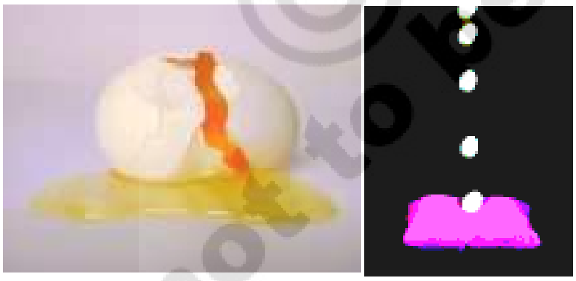


Fig-21 (a) fall of an egg on a concrete floor (b) fall of an egg on a cushioned pillow.

When we drop the egg on the concrete floor, it will break, because a large force acts on the egg for the short interval of time.

$$\Delta p = \mathbf{F}_{\mathbf{net}} \Delta t$$

When we drop the egg on a cushioned pillow it doesn't break because a smaller force acts on the egg for longer time.

$$\Delta p = F_{net}\, \mathbf{\Delta t}$$

Even if the Δp is the same in both cases, the magnitude of the net force (F_{net}) acting on the egg determines whether the egg will break or not.

Why does a fielder catch a fast moving cricket ball by pulling back his arms while catching it? If he doesn't pull his hands back what would happen? The ball definitely hurts him. When he pulls back his hands he experiences a smaller force for a longer time. The ball stops only when your hands stop. This shows the change in the momentum not only depends on the magnitude of the force but also on the time during which force is exerted on that object.

Think and discuss

- A meteorite burns in the atmosphere before it reaches the earth's surface. What happens to its momentum?
- As you throw a heavy ball upward, is there any change in the normal force on your feet?
- When a coconut falls from a tree and strikes the ground without bouncing. What happens to its momentum?
- Air bags are used in the cars for safety. Why?

Example 5

A cannon of mass m_1 = 12000 kg located on a smooth horizontal platform fires a shell of mass m_2 = 300 kg in horizontal direction with a velocity v_2 = 400m/s. Find the velocity of the cannon after it is shot.

Solution

Since the pressure of the powder gases in the bore of the cannon is an internal force so, the net external force acting on cannon during the firing is zero.

Let v_1 be the velocity of the cannon after shot. The initial momentum of system is zero.

The final momentum of the system

$= m_1v_1 + m_2v_2$

From the conservation of linear momentum, We get,

$m_1v_1 + m_2v_2 = 0$

$m_1v_1 = - m_2v_2$

$v_1 = - m_2v_2 / m_1$

Substituting the given values in the above equation, we get

$$v_1 = - \frac{(300\text{kg}) \times (400\text{m/s})}{12000\text{kg}}$$

$= -10$ m/s.

Thus the velocity of cannon is 10m/s after the shot.

Here '-' sign indicates that the canon moves in a direction opposite to the motion of the bullet.

Key words

Laws of motion, Inertia, Mass, Linear Momentum Conservation of momentum, Impulse, Impulsive force

What we have learnt

- First Law of Motion: A body continues its state of rest or of uniform motion unless a net force acts on it.
- The natural tendency of objects to resist a change in their state of rest or of uniform motion is called inertia.
- The mass of an object is a measure of inertia. SI unit of mass is Kilogram (kg).
- Second Law of Motion: The rate of change of momentum of a body is directly proportional to the net force acting on it and it takes place in the direction of net force.
- Linear momentum of a body is the product of its mass and velocity. $p = mv$
- One 'Newton' is the force which when acting on a body of mass 1 kg, produces an acceleration of 1 m/s^2

  1 newton (N) = 1kg x 1 ms^{-2}
- Third Law of Motion: If one object exerts a force on the other object, the second object exerts a force on the first one with equal magnitude but in opposite direction.
- In an isolated system, that means where there is no net force, the total momentum is conserved.

Improve your learning

1) Explain the reasons for the following. (AS_1)

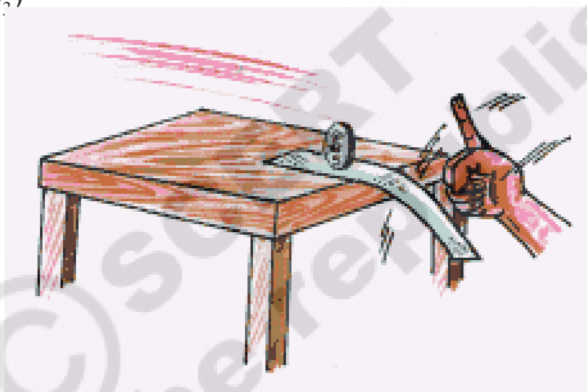
   a) When a carpet is beaten with a stick, dust comes out of it.

   b) Luggage kept on the roof of a bus is tied with a rope.

   c) A pace bowler in cricket runs in from a long distance before he bowls.

2) Two objects have masses 8 kg and 25 kg. Which one has more inertia? Why?(AS_1)

3) Keep a small rectangular shaped piece of paper on the edge of a table and place an old five rupee coin on its surface vertically as shown in the figure below. Now give a quick push to the paper with your finger. How do you explain inertia with this experiment? (AS_2)



4) If a car is traveling westwards with a constant speed of 20 m/s, what is the resultant force acting on it? (Ans:Zero)(AS_1 ,AS_7)

5) What is the momentum of a 6.0 kg bowling ball with a velocity of 2.2 m/s? (Ans: 13.2 kg m/s^2)(AS_1)

6) Two people push a car for 3 s with a combined net force of 200 N. (AS_1)

   (a) Calculate the impulse provided to the car.

   (b) If the car has a mass of 1200 kg, what will be its change in velocity?

   (Ans: (a) 600 N.s (b) 0.5 m/s)

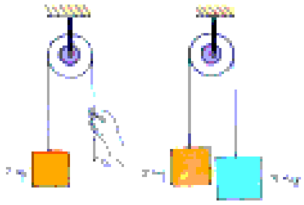
7) What force is required to produce an acceleration of 3 m/s^2 in an object of mass 0.7 kg? (Ans: 2.1 N)(AS_1)

8) A force acts for 0.2 sec on an object having mass 1.4 kg initially at rest. The force stops to act but the object moves through 4m in the next 2 sec. Find the magnitude of the force? (Ans: 14 N)(AS_1)

9) An object of mass 5 kg is moving with a velocity of 10 ms^{-1}. A force is applied so that in 20 s, it attains a velocity of 25 ms^{-1}. What is the force applied on the object?

(Ans: 5 N)(AS_1)

10) Find the acceleration of body of mass 2kg from the figures shown.



(Ans: 5m/s^2, 2m/s^2)(AS_1)

11) Take some identical marbles. Make a path or a track keeping your notebooks on either side so as to make a path in which marbles can move. Now use one marble to hit the other marbles. Take two, three marbles and make them to hit the other marbles. What can you explain from your observations? (AS_5)

12) A man of mass 30 kg uses a rope to climb which bears only 450 N. What is the maximum acceleration with which he can climb safely? (Ans: 15 m/s^2) (AS_1 ,AS_7)

13) An vehicle has a mass of 1500 kg. What must be the force between the vehicle and the road if the vehicle is to be stopped with a negative acceleration of 1.7 ms^{-2}? (Ans: 2550 N in a direction opposite to that of the vehicle) (AS_1 ,AS_7)

14) If a fly collides with the windshield of a fast-moving bus, (AS_1 ,AS_2)

(a) Is the impact force experienced, same for the fly and the bus? Why?

(b) Is the same acceleration experienced by the fly and the bus? Why?

15) A truck is moving under a hopper with a constant speed of 20m/s. Sand falls on the truck at a rate 20 kg/s. What is the force acting on the truck due to falling of sand? (Ans: 400N opposite to the motion) (AS_1 ,AS_7)

16) Two rubber bands stretched to the standard length cause an object to accelerate at 2 m/s^2. Suppose another object with twice the mass is pulled by four rubber bands stretched to the standard length. What is the acceleration of the second object? (Ans: 2 m/s^2) (AS_1)

17) Illustrate an example of each of the three laws of motion.(AS_1)

18) Two ice skaters initially at rest, push of each other. If one skater whose mass is 60 kg has a velocity of 2 m/s. What is the velocity of other skater whose mass is 40 kg?

(Ans: 30 m/s in opposite direction) (AS_1 ,AS_7)

19) A passenger in moving train tosses a coin which falls behind him. It means that the motion of the train is (AS_7)

a) Accelerated b) Uniform

c) Retarded d) circular motion

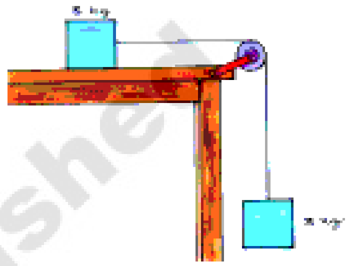
20) A horse continues to apply a force in order to move a cart with a constant speed. Explain. (AS_1)

21) A force of 5N produces an acceleration of 8 ms^{-2} on a mass m_1 and an acceleration of 24 ms^{-2} on a mass m_2. What acceleration would the same force provide if both the masses are tied together? (AS_1) (Ans: 6 m/s^2)

22) A hammer of mass 400 g, moving at 30 m s^{-1}, strikes a nail. The nail stops the hammer in a very short time of 0.01 s. What is the force of the nail on the hammer? (AS_1)
(Ans: 1200 N)

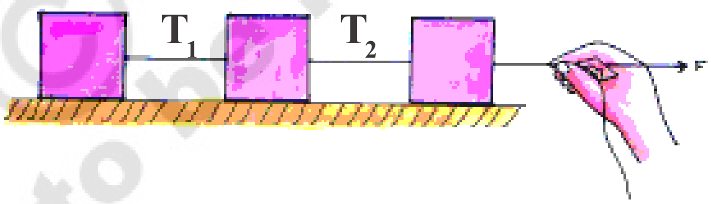
23) System is shown in figure. (AS_1)

Find the acceleration of the blocks and tension in the string. Take g=10m/s^2. (Ans: 5m/s^2, 15N)



24) Three identical blocks, each of mass 10kg, are pulled as shown on the horizontal frictionless surface. If the tension (F) in the rope is 30N. What is the acceleration of each block? And what are the tensions in the other ropes? (Neglect the masses of the ropes) (AS_1)

(Ans: a = 1m/s^2 , T_1 =10N, T_2 = 20N



25) A ball of mass 'm' moves perpendicularly to a wall with a speed v, strikes it and rebounds with the same speed in the opposite direction. What is the direction and magnitude of the average force acting on the ball due to the wall? (AS_7)

(Ans: 2mv/t away from the wall.)

26) Divya observed a horse pulling a cart. She thought that cart also pulls the horse with same force in opposite direction. As per third law of motion the cart should not move forward. But her observation of moving cart raised some questions in her mind. Can you guess what questions are raised in her mind? (AS_2)

27) How do you appreciate Galileo's thought of "any moving body continues in the state only until some external force acts on it" which is a contradiction to the Aristatile's belief of "any moving body naturally comes to rest".(AS_6)