1. Laws of Motion

- Motion
- Acceleration
- Distance and displacement
- Newton's laws of motion and related equations.

Motion of an object

Can you tell?

In which of the following examples can you sense motion? How will you explain presence and absence of motion?

1. The flight of a bird
2. A stationary train
3. Leaves flying through air
4. A stone lying on a hill

We see the motion of several objects every day. Sometimes we cannot see the motion of an object directly, as in the case of a breeze. Can you list other examples of motion, besides those given here?

Think about it.

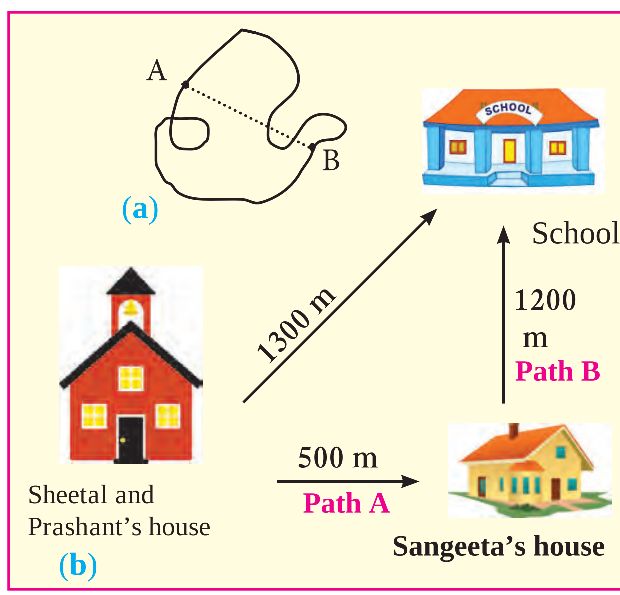
1. You are travelling in a bus. Is the person sitting next to you in motion?
2. What do you take into consideration to decide if an object is moving or not?

You have learnt that motion is a relative concept. If the position of an object is changing with respect to its surroundings, then it is said to be in motion. Otherwise, it is said to be at rest.

Displacement and distance

Let's try this

1. Measure the distance between points A and B in different ways as shown in figure 1.1(a)
2. Now measure the distance along the dotted line. Which distance is correct according to you and why?



1.1 Location of the school and houses

Think about it.

A. Sheetal first went to her friend Sangeeta's house on her way to school (see figure 1.1b).

B. Prashant went straight from home to school. Both are walking with the same speed. Who will take less time to reach the school and why?

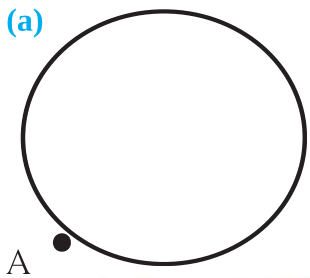
In the above example, is there a difference between the actual distance and the distance travelled? What is it?

'Distance' is the length of the actual path travelled by an object in motion while going from one point to another, whereas displacement is the minimum distance between the starting and finishing points.

Use your brain power!

1. Every morning, Swaralee walks round the edge of a circular field having a radius of 100 m. As shown in figure 1.2 (a), if she starts from the point A and takes one round, how much distance has she walked and what is her displacement?
2. If a car, starting from point P, goes to point Q (see figure 1.2 b) and then returns to point P, how much distance has it travelled and what is its displacement?

(a)



(b)

1.2 Distance and displacement

Even if the displacement of an object is zero, the actual distance traversed by it may not be zero.

Speed and velocity

Can you recall?

1. What are vectors and scalars?
2. Which of the quantities distance, speed, velocity, time and displacement are scalars and which are vectors?

$$\text{Speed} = \frac{\text{Total distance travelled}}{\text{Time required}}$$

The distance travelled in one direction by an object in unit time is called its velocity. Here, unit time can be one second, one minute, one hour, etc. If large units are used, one year can also be used as a unit of time.

The displacement that occurs in unit time is called velocity.

$$\text{Velocity} = \frac{\text{Displacement}}{\text{Time}}$$

Always remember

1. The units of speed and velocity are the same. In the SI system, the unit is m/s while in the CGS system, it is cm/s.
2. Speed is related to distance while velocity is related to the displacement.
3. If the motion is along a straight line, the values of speed and velocity are the same, otherwise they can be different.

   Velocity is the displacement that occurs in unit time.

In the first example (on page 1), the straight line distance between the houses of Sheetal and Sangeeta is 500 m and that between Sangeeta's house and school is 1200 m. Also, the straight line distance between Sheetal's house and school is 1300 m. Suppose Sheetal takes 5 minutes to reach Sangeeta's house and then 24 minutes to reach school from there, Then,

Sheetal's speed along path A $= \dfrac{\text{Distance}}{\text{Time}} = \dfrac{500\text{ m}}{5\text{ minute}} = 100\text{ m/minute}$

Sheetal's speed along path B $= \dfrac{\text{Distance}}{\text{Time}} = \dfrac{1200\text{ m}}{24\text{ minute}} = 50\text{ m/minute}$

Sheetal's average speed $= \dfrac{\text{Total distance}}{\text{Total time}} \quad \dfrac{1700\text{ m}}{29\text{ minute}} = 58.6\text{ m/minute}$

Sheetal's velocity $= \dfrac{\text{Displacement}}{\text{Time}} = \dfrac{1300\text{ m}}{29\text{ minute}}$

Sheetal's velocity = 44.83 m/minute

Effect of speed and direction on velocity

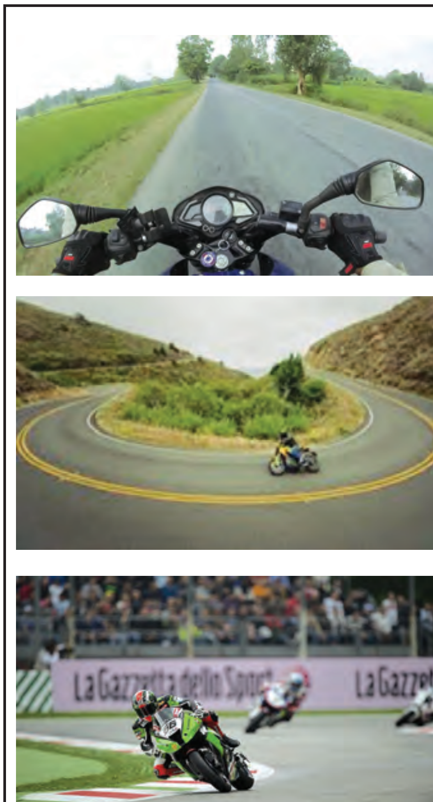
Sachin is travelling on a motorbike. Explain what will happen in the following events during Sachin's ride (see figure 1.3).

1. What will be the effect on the velocity of the motorcycle if its speed increases or decreases, but its direction remains unchanged?
2. In case of a turning on the road, will the velocity and speed be same?

   If Sachin changes the direction of the motorcycle, keeping its speed constant, what will be the effect on the velocity?
3. If, on a turning, Sachin changes the direction as well as the speed of the motorcycle, what will be the effect on its velocity?

   It is clear from the above that velocity depends on speed as well as direction and that velocity changes by

1. changing the speed while keeping the direction same
2. changing the direction while keeping the speed same
3. changing the speed as well as the direction.



1.3 Effect on velocity

Always remember

The first scientist to measure speed as the distance /time was Galileo. The speed of sound in dry air is 343.2 m/s while the speed of light is about 3×10^8 m/s. The speed of revolution of the earth around the sun is about 29770 m/s.

Uniform and non-uniform linear motion

Amar, Akbar and Anthony are travelling in different cars with different velocities. The distances covered by them during different time intervals are given in the following table.

Time in the clock	Distance covered by Amar in km	Distance covered by Akbar in km	Distance covered by Anthony in km
5.00	0	0	0
5.30	20	18	14
6.00	40	36	28
6.30	60	42	42
7.00	80	70	56
7.30	100	95	70
8.00	120	120	84

Use your brain power !

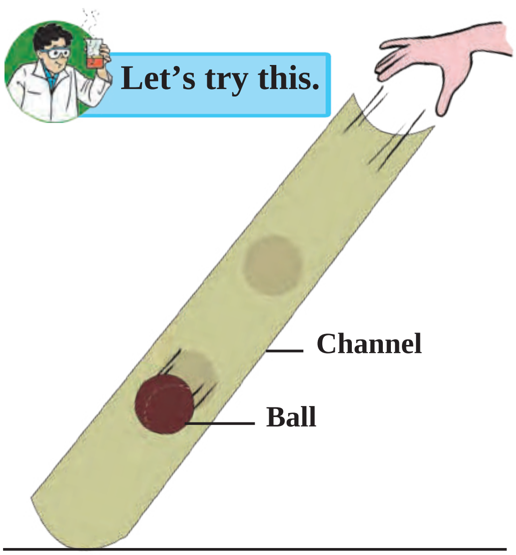
1. What is the time interval between the notings of distances made by Amar, Akbar and Anthony?
2. Who has covered equal distances in equal time intervals?
3. Are all the distances covered by Akbar in the fixed time intervals the same?
4. Considering the distances covered by Amar, Akbar and Anthony in fixed time intervals, what can you say about their speeds?

If an object covers equal distances in equal time intervals, it is said to be moving with uniform speed.

If an object covers unequal distances in equal time intervals, it is said to be moving with non-uniform speed. For example, the motion of a vehicle being driven through heavy traffic.

Acceleration

Let's try this.



1.4 Change in velocity

1. Take a 1m long plastic tube and cut it lengthwise into two halves.
2. Take one of the channel shaped pieces. Place one of its ends on the ground and hold the other at some height from the ground as shown in figure 1.4.
3. Take a small ball and release it from the upper end of the channel.
4. Observe the velocity of the ball as it rolls down along the channel.
5. Is its velocity the same at all points?
6. Observe how the velocity changes as it moves from the top, through the middle and to the bottom.

You must have all played on a slide in a park. You know that while sliding down, the velocity is less at the top, it increases in the middle and becomes zero towards the end. The rate of change of velocity is called acceleration

$$\text{Acceleration} = \frac{\text{Change in velocity}}{\text{Time.}}$$

If the initial velocity is ‘u’ and in time ‘t’ it changes to the final velocity ‘v’,

$$\text{Acceleration} = a = \frac{\text{Final velocity} - \text{Initial velocity}}{\text{Time}} \quad \therefore a = \frac{(v-u)}{t}$$

If the velocity of an object changes during a certain time period, then it is said to have accelerated motion. An object in motion can have two types of acceleration.

Use your brain power!

1. If the velocity changes by equal amounts in equal time intervals, the object is said to be in uniform acceleration.
2. If the velocity changes by unequal amounts in equal time intervals, the object is say to be non-uniform acceleration.

1. When an object is at rest in the beginning of its motion, what is its initial velocity?
2. When an object comes to rest at the end of its motion, what is its final velocity?

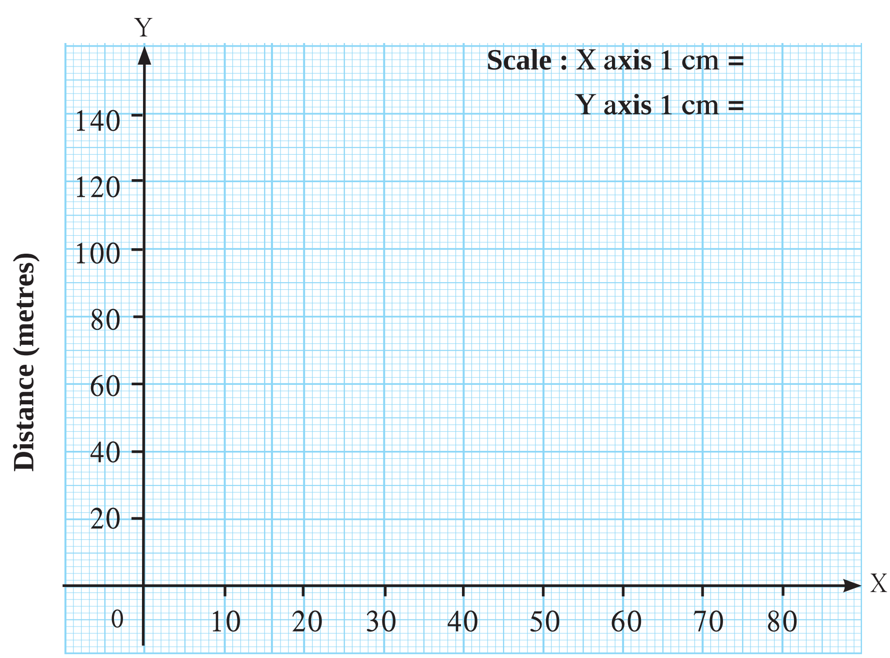
Positive, negative and zero acceleration

An object can have positive or negative acceleration. When the velocity of an object increases, the acceleration is positive. In this case, the acceleration is in the direction of velocity. When the velocity of an object decreases with time, it has negative acceleration. Negative acceleration is also called deceleration. Its direction is opposite to the direction of velocity. If the velocity of the object does not change with time, it has zero acceleration.

Distance-time graph for uniform motion

The following table shows the distances covered by a car in fixed time intervals. Draw a graph of distance against time taking ‘time’ along the X-axis and ‘distance’ along the Y-axis in figure 1.5.

Time (seconds)	Distance (metres)
0	0
10	15
20	30
30	45
40	60
50	75
60	90
70	105



1.5 Distance - time graph

An object in uniform motion covers equal distances in equal time intervals. Thus, the graph between distance and time is a straight line.

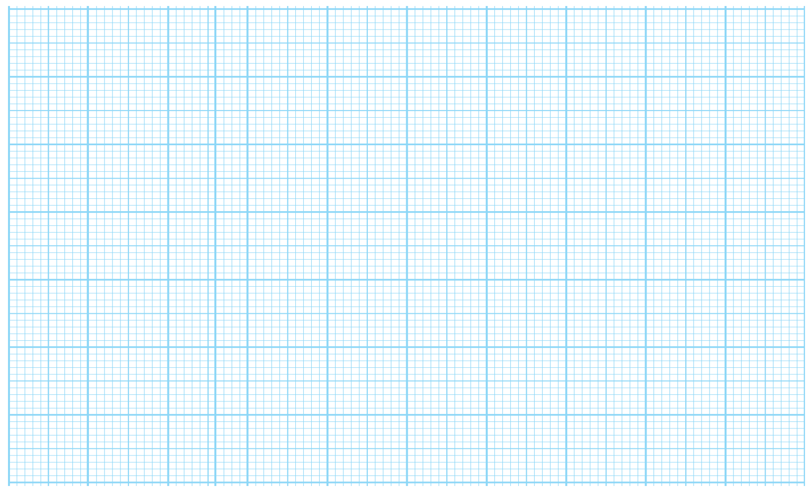
Use your brain power !

In the distance-time graph above, what does the slope of the straight line indicate?

Distance-time graph for non-uniform motion

The following table shows the distances covered by a bus in equal time intervals Draw a graph of distance against time taking the time along the X-axis and distance along the Y-axis in figure 1.6. Does the graph show a direct proportionality between distance and time?

Time (second)	Distance (metre)
0	0
5	7
10	12
15	20
20	30
25	41
30	50
35	58



1.6 Distance - time graph

Here, the distance changes non-uniformly with time. Thus, the bus is having non-uniform motion.

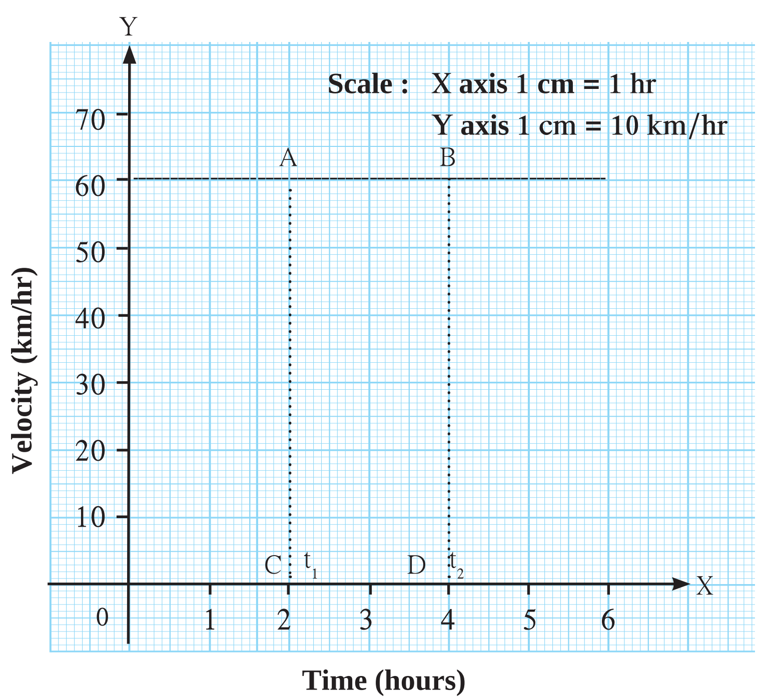
Use your brain power !

What difference do you see in the distance-time graphs for uniform and non-uniform motion?

Velocity-time graph for uniform velocity

A train is moving with a uniform velocity of 60 km/hour for 5 hours. The velocity-time graph for this uniform motion is shown in figure 1.7.

1. With the help of the graph, how will you determine the distance covered by the train between 2 and 4 hours?
2. Is there a relation between the distance covered by the train between 2 and 4 hours and the area of a particular quadrangle in the graph? What is the acceleration of the train?

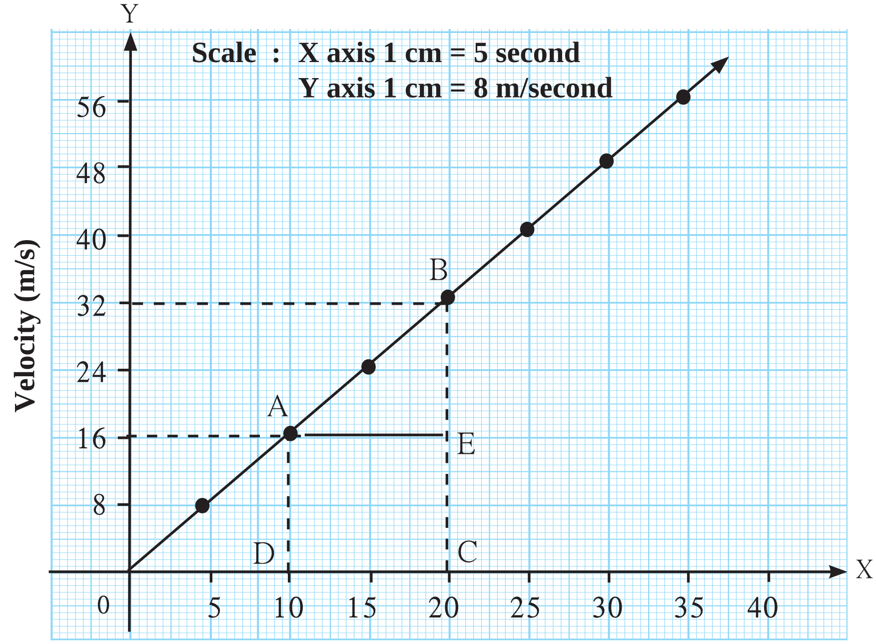


1.7 Velocity - time graph

Velocity-time graph for uniform acceleration

The changes in the velocity of a car in specific time intervals are given in the following table.

Time (seconds)	Velocity (m/s)
0	0
5	8
10	16
15	24
20	32
25	40
30	48
35	56



1.8 **Velocity - time graph**

The velocity-time graph in figure 1.8 shows that,

1. The velocity changes by equal amounts in equal time intervals. Thus, this is uniform acceleration in accelerated motion. How much does the velocity change every 5 minutes?
2. For all uniformly accelerated motions, the velocity-time graph is a straight line.
3. For non-uniformly accelerated motions, the velocity-time graph may have any shape depending on how the acceleration changes with time.

From the graph in figure 1.8, we can determine the distance covered by the car between the 10^{th} and the 20^{th} seconds as we did in the case of the train in the previous example. The difference is that the velocity of the car is not constant (unlike that of the train) but is continuously changing because of uniform acceleration. In such a case, we have to use the average velocity of the car in the given time interval to determine the distance covered in that interval.

From the graph, the average velocity of the car = $\frac{32+16}{2} = 24$ m/s

Multiplying this by the time interval, i.e. 10 seconds gives us the distance covered by the car. Distance covered = 24 m/s x 10 s = 240 m

Check that, similar to the example of the train, the distance covered is given by the area of quadrangle ABCD.

$$\mathbf{A}(\square\ ABCD) = \mathbf{A}(\square\ AECD) + \mathbf{A}(\triangle\ ABE)$$

Equations of motion using graphical method

Newton studied motion of an object and gave a set of three equations of motion. These relate the displacement, velocity, acceleration and time of an object moving along a straight line.

Suppose an object is in motion along a straight line with initial velocity 'u'. It attains a final velocity 'v' in time 't' due to acceleration 'a' its desplacement is 's'. The three equations of motion can be written as

$v = u + at$ This is the relation between velocity and time.

$s = ut + \frac{1}{2}at^2$ This is the relation between displacement and time.

$v^2 = u^2 + 2as$ This is the relation between displacement and velocity.

Let us try to obtain these equations by the graphical method.

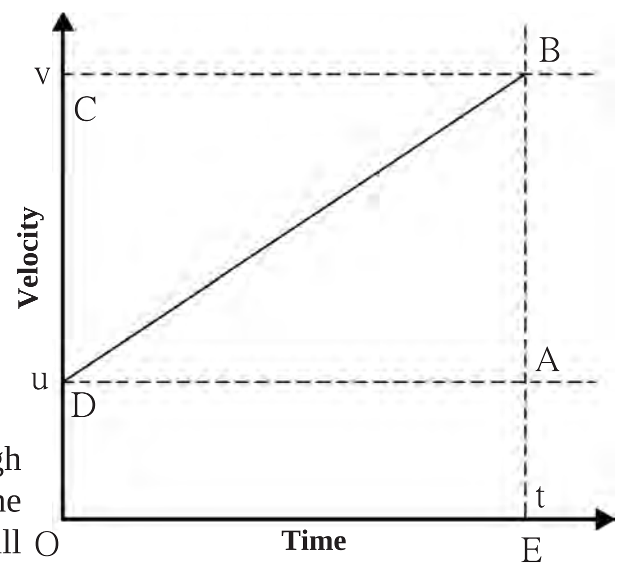
Equation describing the relation between velocity and time

Figure 1.9 shows the change in velocity with time of a uniformly accelerated object. The object starts from the point D in the graph with velocity u. Its velocity keeps increasing and after time t, it reaches the point B on the graph.

The initial velocity of the object = u = OD

The final velocity of the object = v = OC

Time = t = OE



1.9 **Velocity - time graph**

$$\text{Acceleration } (a) = \frac{\text{Change in velocity}}{\text{Time}}$$

$$= \frac{(\text{Final velocity} - \text{Initial velocity})}{\text{Time}}$$

$$= \frac{(OC - OD)}{t}$$

$\therefore$ CD = at …… (i) (OC - OD = CD)

Draw a line parallel to Y axis passing through B. This will cross the X axis in E. Draw a line parallel to X-axis passing through D. This will cross the line BE at A.

From the graph…. BE = AB + AE

$\therefore$ v = CD + OD .....(AB = CD and AE = OD)

$\therefore$ v = at + u …………(from i)

$\therefore$ v = u + at

This is the first equation of motion.

Equation describing the relation between displacement and time

Let us suppose that an object in uniform acceleration 'a' and it has covered the distance 's' within time 't'. From the graph in figure 1.9, the distance covered by the object during time 't' is given by the area of quadrangle DOEB.

$\therefore$ s = area of quadrangle DOEB

= area (rectangle DOEA) + area of triangle (DAB)

$\therefore$ $s = (AE \times OE) + (\frac{1}{2} \times [AB \times DA])$

But, AE = u, OE = t and (OE = DA = t)
AB = at ---(AB = CD) --- from (i)

$$\therefore\ s = u \times t + \frac{1}{2} \times at \times t$$

$\therefore$ Newton's second equation of motion is $s = ut + \frac{1}{2}at^2$

Equation describing the relation between displacement and velocity

We have seen that from the graph in figure 1.9 we can determine the distance covered by the object in time t from the area of the quadrangle DOEB. DOEB is a trapezium. So we can use the formula for its area.

$\therefore$ s = area of trapezium DOEB

$\therefore$ s = $\frac{1}{2}$ × sum of lengths of parallel sides × distance between the parallel sides

$\therefore\ s = \frac{1}{2} \times (OD + BE) \times OE$ But, $OD = u$, $BE = v$ and $OE = t$

$$\therefore\ s = \frac{1}{2} \times (u + v) \times t \quad \text{------ (ii)}$$

$$\text{But, } a = \frac{(v-u)}{t}$$

$$\therefore\ t = \frac{(v-u)}{a} \quad \text{---------------(iii)}$$

$$\therefore\ s = \frac{1}{2} \times (u + v) \times \frac{(v-u)}{a}$$

$$\therefore\ s = \frac{(v+u)(v-u)}{2a}$$

$$\therefore\ 2as = (v+u)(v-u) = v^2 - u^2$$

$$\therefore\ v^2 = u^2 + 2as$$

this is Newton's third equation of motion.

Always remember

The velocity of an accelerated object changes with time. Change in the velocity can be due to a change in direction or magnitude of the velocity or both.

Uniform circular motion

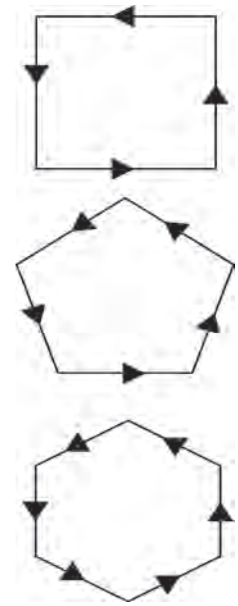
Let's try this

Observe the tip of the second hand of a clock. What can you say about its velocity and speed?

The speed of the tip of a clock is constant, but the direction of its displacement and therefore, its velocity is constantly changing. As the tip is moving along a circular path, its motion is called uniform circular motion. Can you give more examples of such motion?

Try out and think about it

1. Draw a rectangular path as shown figure 1.10
2. Place the tip of your pencil on the middle of any side of the square path and trace the path.
3. Note how many times you have to change the direction while tracing the complete path.
4. Now repeat this action for a pentagonal, hexagonal, octagonal path and note the number of times you have to change direction.
5. If you increase the number of sides of the polygon and make it infinite, how many times will you have to change the direction? What will be the shape of the path?
   This shows that as we increase the number of sides, we have to keep changing direction more and more times. And when we increase the number of sides to infinity, the polygon becomes a circle.



1.10 Changes in direction

When an object is moving with a constant speed along a circular path, the change in velocity is only due to the change in direction. Hence, it is accelerated motion. When an object moves with constant speed along a circular path, the motion is called uniform circular motion, e.g. the motion of a stone in a sling or that of any point on a bicycle wheel when they are in uniform motion.

If an object, moving along a circular path of radius 'r', takes time 't' to come back to its starting position, its speed can be determined using the formula given below :

$$\text{Speed} = \frac{\text{Circumference}}{\text{Time}}$$

$$v = \frac{2\pi r}{t}$$ r =radius of the circle

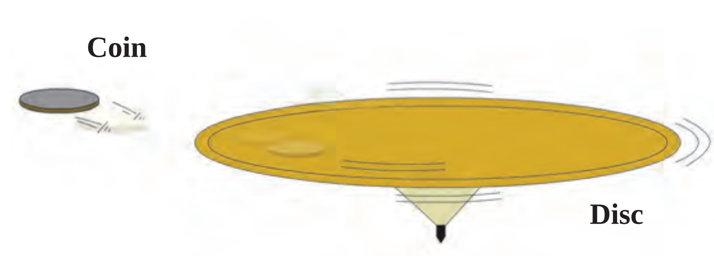
Research

Find out more examples of circular motion in day to day life.

Determining the direction of velocity in uniform circular motion.

Let's try this

Take a circular disc and put a five rupee coin at a point along its edge. Make it move around its axis by putting a pin through it. When the disc is moved at higher speed, the coin will be thrown off as shown in figure 1.11. Note the direction in which it is thrown off. Repeat the action placing the coin at different points along the edge of the circle and observe the direction in which the coin is thrown off.



1.11 The coin and the disc

The coin will be thrown off in the direction of the tangent which is perpendicular to the radius of disc. Thus, the direction in which it gets thrown off depends on its position at the moment of getting thrown off. It means that, as the coin moves along a circular path the direction of its motion is changing at every point.

Solved examples

Example 1: An athlete is running on a circular track. He runs a distance of 400 m in 25 s before returning to his original position. What is his average speed and velocity?

Given : Total distance travelled = 400 m

Total displacement = 0, as he returns to his original position.

Total time = 25 seconds.

Average speed = ?, Average velocity = ?

$$\text{Average speed} = \frac{\text{Total distance covered}}{\text{Total time taken}} = \frac{400}{25} = 16 \text{ m/s}$$

$$\text{Average velocity} = \frac{\text{Total displacement}}{\text{Total time taken}} = \frac{0}{25} = 0 \text{ m/s}$$

Example 2: An aeroplane taxies on the runway for 30 s with an acceleration of 3.2 m/s^2 before taking off. How much distance would it have covered on the runway?

Given : a= 3.2 m/s^2, t = 30 s, u = o , s = ?

$$s = ut + \frac{1}{2}at^2 = 0 \times 30 + \frac{1}{2} \times 3.2 \times 30^2 = 1440 \text{ m.}$$

Example 3: A kangaroo can jump 2.5 m vertically. What must be the initial velocity of the kangaroo?

Given :

$a = 9.8 \ m/s^2$

$s = 2.5$ m

$v = 0$

$u = ?$

$v^2 = u^2 + 2as$

$(0)^2 = u^2 + 2 \times (-9.8)(2.5)$ Negative sign is used as the acceleration is in the direction opposite to that of velocity.

$0 = u^2 - 49$

$u^2 = 49$

$u = 7 \ m/s$

Example 4 : A motorboat starts from rest and moves with uniform acceleration. If it attains the velocity of 15 m/s in 5 s, calculate the acceleration and the distance travelled in that time.

Given :

Initial velocity, u = 0,

final velocity, v = 15 m/s, time, t = 5 s.

Acceleration = a = ?

From the first equation of motion

$$a = \frac{v-u}{t} = \frac{15-0}{5} = 3 \ m/s^2$$

From the second equation of motion, the distance covered will be

$$s = ut + \frac{1}{2} at^2$$

$$s = 0 \times 5 + \frac{1}{2} 3 \times 5^2$$

$$= 0 + \frac{75}{2} = 37.5 \text{ m}$$

Newton's laws of motion

What could be the reason for the following?

1. A static object does not move without the application of a force.
2. The force which is sufficient to lift a book from a table is not sufficient to lift the table.
3. Fruits on a tree fall down when its branches are shaken.
4. An electric fan keeps on rotating for some time even after it is switched off.

If we look for reasons for the above, we realize that objects have some inertia. We have learnt that inertia is related to the mass of the object. Newton's first law of motion describes this very property and is therefore also called the law of inertia.

Newton's first law of motion

Let's try this

Fill a glass with sand. Keep a piece of cardboard on it. Keep a five rupee coin on the cardboard. Now strike the cardboard hard using your fingers. Observe what happens.

Balanced and unbalanced force

You must have played tug-of-war. So long as the forces applied by both the sides are equal, i.e. balanced, the centre of the rope is static in spite of the applied forces. On the other hand, when the applied forces become unequal, i.e. unbalanced, a net force gets applied in the direction of the greater force and the centre of the rope shifts in that direction.

'An object continues to remain at rest or in a state of uniform motion along a straight line unless an external unbalanced force acts on it.'

When an object is at rest or in uniform motion along a straight line, it does not mean that no force is acting on it. Actually there are a number of forces acting on it, but they cancel one another so that the net force is zero. Newton's first law explains the phenomenon of inertia, i.e. the inability of an object to change its state of motion on its own. It also explains the unbalanced forces which cause a change in the state of an object at rest or in uniform motion.

All instances of inertia are examples of Newton's first law of Motion.

Newton's second law of motion

Let's try this

A. 1. Ask your friend to drop one plastic and one rubber ball from the same height.

2. You catch the balls. Which ball was easier to catch and why?

B. 1. Ask your friend to throw a ball towards you at slow speed. Try to catch it.

2. Now ask your friend to throw the same ball at high speed towards you. Try to catch it. Which ball could you catch with greater ease? Why?

The effect of one object striking another object depends both on the mass of the former object and its velocity. This means that the effect of the force depends on a property related to both mass and velocity of the striking object. This property was termed 'momentum' by Newton.

> Momentum has magnitude as well as direction. Its direction is the same as that of velocity. In SI system, the unit of momentum is kg m/s, while in CGS system, it is g cm/s.
> If an unbalanced force applied on an object causes a change in the velocity of the object, then it also causes a change in its momentum. The force necessary to cause a change in the momentum of an object depends upon the rate of change of momentum.

Momentum (P) : Momentum is the product of mass and velocity of an object. P = m v. Momentum is a vector quantity.

'The rate of change of momentum is proportional to the applied force and the change of momentum occurs in the direction of the force.'

Suppose an object of mass m has an initial velocity u. When a force F is applied in the direction of its velocity for time t, its velocity becomes v.

$\therefore$ The initial momentum of the object = mu,

Its final momentum after time t = mv

$$\therefore \text{ Rate of change of momentum} = \frac{\text{Change in momentum}}{\text{Time}}$$

$$\therefore \text{ Rate of change of momentum} = \frac{mv - mu}{t} = \frac{m(v-u)}{t} = ma$$

According to Newton's second law of motion, the rate of change of momentum is proportional to the applied force.

$\therefore$ ma α F

$\therefore$ F = k ma (k = Constant of proportionality and its value is 1).

$F = m \times a$

Consider two objects having different masses which are initially at rest. The initial momentum for both is zero. Suppose a force 'F' acts for time 't' on both objects. The lighter object starts moving faster than the heavier object. However, from the above formula, we know that the rate of change of momentum i.e. 'F' in both objects is same and the total change in their momentum will also be same i.e. 'Ft'. Thus, if the same force is applied on different objects, the change in momentum is the same.

In SI system, the unit of force is newton.
Newton (N) : The force necessary to cause an acceleration of 1 m/s^2 in an object of mass 1 kg is called 1 newton.
$1 \text{ N} = 1 \text{ kg} \times 1 \text{ m/s}^2$
In CGS system the unit of force is a dyne.
Dyne: The force necessary to cause an acceleration of 1 cm/s^2 in an object of mass 1 gm is called 1 dyne.
$1 \text{ dyne} = 1 \text{ g} \times 1 \text{ cm/s}^2$

Use your brain power !

Why is there a thick bed of sand for a high jumper to fall on after his jump?

Newton's third law of motion

Let's try this

1. Take a plastic boat and make a hole at its rear end.
2. Inflate a balloon and fix it on the hole in the boat. Release the boat in water. What happens to the boat as the air in the balloon escapes slowly? Why?

We have learnt about force and its effect on an object through Newton's first and second laws of motion.

'However, in nature force cannot act alone.' Force is a reciprocal action between two objects. Forces are always applied in pairs. When one object applies a force on another object, the latter object also simultaneously applies a force on the former object. The forces between two objects are always equal and opposite. This idea is expressed in Newton's third law of motion. The force applied by the first object is called action force while the force applied by the second object on the first is called reaction force.

'Every action force has an equal and opposite reaction force which acts simultaneously.'

1. Action and reaction are terms that express force.
2. These forces act in pairs. One force cannot exist by itself.
3. Action and reaction forces act simultaneously.
4. Action and reaction forces act on different objects. They do not act on the same object and hence cannot cancel each other's effect.

Use your brain power !

1. While hitting a ball with a bat, the speed of the bat decreases.
2. A gun recoils i.e. moves backwards when a bullet is fired.
3. Mechanism of firing of a rocket.

How will you explain these with the help of Newton's third law of motion?

Law of conservation of momentum

Suppose an object A has mass m_1 and its initial velocity is u_1. An object B has mass m_2 and initial velocity u_2.

According to the formula for momentum, the initial momentum of A is $m_1 u_1$ and that of B is m_2u_2 .

Suppose these two objects collide. Let the force on A due to B be F_1. This force will cause acceleration in A and its velocity will become v_1.

$\therefore$ Momentum of A after collision = $m_1 v_1$

According to Newton's third law of motion, A also exerts an equal force on B but in the opposite direction. This will cause a change in the momentum of B. If its velocity after collision is v_2,

The momentum of B after collision = m_2v_2. If F_2 is the force that acts on object B,

$$F_2 = -F_1$$

$$\therefore m_2 a_2 = - m_1 a_1 \text{............} \because F= ma$$

$$\therefore m_2 \times \frac{(v_2-u_2)}{t} = - m_1 \times \frac{(v_1-u_1)}{t} \text{ ....} \quad \because a = \frac{(v-u)}{t}$$

$$\therefore m_2 (v_2 - u_2)= - m_1 (v_1-u_1)$$

$$\therefore m_2 v_2 - m_2 u_2 = - m_1 v_1+ m_1 u_1$$

$$\therefore (m_2 v_2 + m_1 v_1)= (m_1 u_1+m_2 u_2)$$

The magnitude of total final momentum = the magnitude of total initial momentum.

Thus, if no external force is acting on two objects, then their total initial momentum is equal to their total final momentum. This statement is true for any number of objects.

'When no external force acts on two interacting objects, their total momentum remains constant. It does not change.'

This is a corollary to Newton's third law of motion. The momentum is unchanged after the collision. The momentum gets redistributed between the colliding objects. The momentum of one of the objects decreases while that of the other increases. Thus, we can also state this corollary as follows.

'When two objects collide, the total momentum before collision is equal to the total momentum after collision.'

In order to understand this principle, let us consider the example of a bullet fired from a gun. When a bullet of mass m_1 is fired from a gun of mass m_2, its velocity becomes v_1, and its momentum becomes $m_1 v_1$. Before firing the bullet, both the gun and the bullet are at rest and hence the total initial momentum is zero. According to the above law, the total final momentum also has to be zero. Thus, the forward moving bullet causes the gun to move backward after firing. This backward motion of the gun is called its **recoil**. The velocity of recoil, v_2 , is such that,

$$m_1 v_1 + m_2 v_2 = 0 \text{ or } v_2 = - \frac{m_1}{m_2} \times v_1$$

As the mass of the gun is much higher than the mass of the bullet, the velocity of the gun is much smaller than the velocity of the bullet. The magnitude of the momentum of the bullet and that of the gun are equal and their directions are opposite. Thus, the total momentum is constant. Total momentum is also constant during the launch of a rocket.

Solved examples

Example 1: The mass of a cannon is 500 kg and it recoils with a speed of 0.25 m/s. What is the momentum of the cannon?

Given : mass of the cannon = 500 kg, recoil speed = 0.25 m/s   Momentum = ?

Momentum = m × v = 500 x 0.25 = 125 kg m/s

Example 2: 2 balls have masses of 50 gm and 100 gm respectively and they are moving along the same line in the same direction with velocities of 3 m/s and 1.5 m/s respectively. They collide with each other and after the collision, the first ball moves with a velocity of 2.5 m/s. Calculate the velocity of the other ball after collision.

Given :

The mass of first ball = m_1 = 50 g = 0.05 kg, mass of the second ball = m_2 = 100 g = 0.1 kg

Initial velocity of the first ball = u_1 = 3 m/s, Initial velocity of the second ball = u_2 = 1.5 m/s

Final velocity of the first ball = v_1 = 2.5 m/s ,Final velocity of the second ball = v_2 = ?

According to the law of conservation of momentum, total initial momentum = Total final momentum.

$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$

$(0.05 \times 3) + (0.1 \times 1.5) = (0.05 \times 2.5) + (0.1 \times v_2)$

$\therefore\ (0.15)+(0.15) = 0.125 + 0.1v_2$

$\therefore\ 0.3 = 0.125 + 0.1\ v_2$

$\therefore\ 0.1v_2 = 0.3 - 0.125 \quad \therefore v_2 = \dfrac{0.175}{0.1} = 1.75$ m/s

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Exercises

1. Match the first column with appropriate entries in the second and third columns and remake the table.

S. No.	Column 1	Column 2	Column 3
1	Negative acceleration	The velocity of the object remains constant	A car, initially at rest reaches a velocity of 50 km/hr in 10 seconds
2	Positive acceleration	The velocity of the object decreases	A vehicle is moving with a velocity of 25 m/s
3	Zero acceleration	The velocity of the object increases	A vehicle moving with the velocity of 10 m/s, stops after 5 seconds.

2. Clarify the differences

A. Distance and displacement

B. Uniform and non-uniform motion.

3. Complete the following table.

u (m/s)	a (m/s^2)	t (sec)	v = u + at (m/s)
2	4	3	–
–	5	2	20

u (m/s)	a (m/s^2)	t (sec)	$s = ut + \frac{1}{2}at^2$ (m)
5	12	3	–
7	–	4	92

u (m/s)	a (m/s^2)	s (m)	$v^2 = u^2 + 2as$ $(m/s)^2$
4	3	–	8
–	5	8.4	10

4. Complete the sentences and explain them.

a. The minimum distance between the start and finish points of the motion of an object is called the ……….. of the object.

b. Deceleration is -------- acceleration

c. When an object is in uniform circular motion, its ……… changes at every point.

d. During collision ……….. remains constant.

e. The working of a rocket depends on Newton's …….. law of motion.

5. Give scientific reasons.

a. When an object falls freely to the ground, its acceleration is uniform.

b. Even though the magnitudes of action force and reaction force are equal and their directions are opposite, their effects do not get cancelled.

c. It is easier to stop a tennis ball as compared to a cricket ball, when both are travelling with the same velocity.

d. The velocity of an object at rest is considered to be uniform.

6. Take 5 examples from your surroundings and give explanation based on Newtons laws of motion.

7. Solve the following examples.

a) An object moves 18 m in the first 3 s, 22 m in the next 3 s and 14 m in the last 3 s. What is its average speed? **(Ans: 6 m/s)**

b) An object of mass 16 kg is moving with an acceleration of 3 m/s^2 . Calculate the applied force. If the same force is applied on an object of mass 24 kg, how much will be the acceleration? **(Ans: 48 N, 2 m/s^2)**

c) A bullet having a mass of 10 g and moving with a speed of 1.5 m/s, penetrates a thick wooden plank of mass 900 g. The plank was initially at rest. The bullet gets embedded in the plank and both move together. Determine their velocity. **(Ans: 0.15 m/s)**

d) A person swims 100 m in the first 40 s, 80 m in the next 40 s and 45 m in the last 20 s. What is the average speed? **(Ans: 2.25 m/s^2)**

Project:

Obtain information about commonly used gadgets or devices which are based on the principles of Newton's laws of motion.

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