1

MOTION

CONTENTS

1.0 INTRODUCTION

In this chapter we are going to study about physical quantities like distance, displacement, speed, velocity and acceleration that are essential to describe the motion of an object which could be uniform or non-uniform. The motion of an object moving with uniform acceleration has been described algebraically with the help of three equations. Graphical method for investigating the motion has also been discussed. Every day we see a number of bodies such as cars, birds, animals etc., which are in motion. These objects move from one place to another. We can say that every object in the universe is in motion. Our earth also moves around the sun. The movement of a body or object is called motion. In the above examples, all the moving bodies change their position with time. On the other hand, we can say that a stone lying on the ground is at rest. But, the stone can also said to be in motion along with the earth around the sun. Thus, we can conclude that

'A body is said to be in motion or moving if it changes its position with respect to a stationary object taken as reference point.'

For instance, assume that we are sitting inside a moving car or a bus or a railway compartment. We constantly keep changing our position with respect to trees, poles, shops and other stationary objects with respect to the given frame of reference.

In physics, to describe the position of an object we specify its position with respect to a fixed point taken as a reference point called the origin. Thus, we can conclude that

'A body is said to be at rest if it does not change its position with respect to its given frame of reference.'

Note

- The branch of physics which deals with the study of motion of material objects is called mechanics.

From the above discussion, we can conclude that :

(a) There must be a reference point to describe the position of the given body.

(b) The position of the given body must continuously change with time and with respect to the reference point for motion to take place.

Types of Motion

There are three different types of motion namely :

(a) Linear motion

(b) Circular motion

(c) Vibratory motion

Motion can also be classified into two types, namely :

(a) Uniform motion

(b) Non-uniform motion

(a) Linear Motion

A body moving in a straight line or straight path is said to be in linear motion. It is also called as rectilinear motion.

Examples

(a) Motion of train speeding along a straight track (fig 1.1).

(b) Motion of a moving car on a straight road (fig 1.2).

(c) Motion of a ball dropped from the roof of a building.

Fig 1.1 : Motion of train speeding along a straight track.

Fig 1.2 : Motion of a moving car on a straight road.

(b) Circular Motion

A body moving around a fixed point in a circular path is said to be in circular motion. A vertical line passing through the fixed point around which the body moves is known as the axis of rotation. It is also called rotational motion.

A motion is known as circular motion when an object moves around another object in a circular orbit with a starting point.

Rotational motion is related to circular motion with a slight difference that can be best understood by following examples.

If an object rotates about its own axis, it is said to be in rotational motion and if the object also moves in an orbit then it is said to possess circular motion.

Examples

(a) Motion of earth on its axis. (Circular motion)

(b) Motion of earth around sun. (Rotational motion)

(c) Motion of an electric fan. (Rotational motion) (fig 1.3)

(d) Motion of merry-go-round. (Rotational motion) (fig 1.4)

(e) Motion of a spinning top. (Rotational motion)

Fig 1.3 : Motion of an electric fan

Fig 1.4 : Motion of merry-go-round

(c) Vibratory Motion

A body moving to and fro about a fixed point has vibratory motion. It is also called oscillatory motion.

Examples

(a) Motion of the pendulum of a wall clock (fig 1.5).

Fig 1.5 : Motion of pendulum of a wall clock

(b) Motion of a child swinging on a swing (fig 1.6).

Fig. 1.6 : Motion of a child swinging on a swing

(c) Motion of a simple pendulum (fig 1.7).

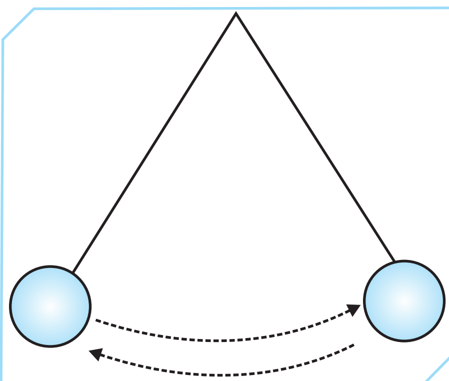


Fig. 1.7 : Motion of a simple pendulum.

(d) Motion of the string of a guitar when plucked.

Fig. 1.8 : Motion of string of a guitar when plucked.

1.1 REST AND MOTION ARE RELATIVE TERMS

A body is said to be at rest if it does not change its position with respect to its immediate surroundings, while a body is said to be in motion if it changes its position with respect to its immediate surroundings. When we say that a body or an object is in motion, then it is essential to see whether the body or object changes its position with respect to other bodies or objects around it or with respect to any fixed point. For example, when a bus moves on a road, then the bus and the passengers sitting in it change their positions with respect to a person standing by the side of the road. So, the bus and the passengers sitting in it are said to be in motion with respect to the person standing on the side of the road. However, the passengers sitting inside the bus do not change their position with respect to each other. It means that the passengers sitting in a moving bus are not in motion with respect to each other.

Let us take another example. Imagine that you are sitting in a moving train. You are in motion with respect to a farmer or a person standing in the field outside or with respect to trees outside because your position is changing with respect to them. However, you are at rest with respect to the things inside the train *i.e.,* the walls, the roofs and the fan in the train etc. Hence, we can say that an object can be in motion in relation to one object while it can be at rest in relation to another object at the same instant of time. So, rest and motion are relative terms. Let us discuss the motion along a straight line.

Motion along a Straight Line

One Dimensional Motion

If only one of the three coordinates that specifies the position of an object changes with respect to time along a straight line, then the motion of the object is called one dimensional motion. Motion of train along a straight railway track is an example of one-dimensional motion.

For example, consider a particle in one dimensional motion along the X-axis, then when the particle moves from A to B, the X coordinate changes from x_1 to x_2 (fig. 1.9). Here only one coordinate is needed to describe the motion completely.

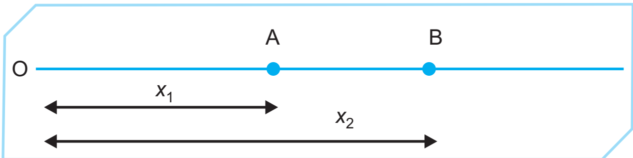


Fig 1.9 : One dimensional motion

The straight line along which one dimensional motion takes place may be taken as either along the X, Y or Z-axis.

Two Dimensional Motion

If two of the three coordinates that specify the position of an object moving in a plane change with respect to time, then the motion of that object is called two dimensional motion. Motion of a satellite revolving around the earth is an example of two dimensional motion.

For example, consider a particle moving from P(x_1, y_1) to Q (x_2, y_2) along a curved path,(fig 1.10) then the particle is said to be in two dimensional motion. Here, two coordinates are needed to describe the motion completely.

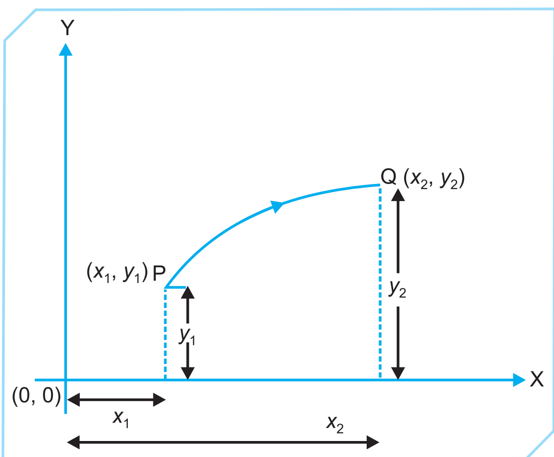


Fig 1.10 : Two dimensional motion

Three Dimensional Motion

If all the three coordinates that specify the position of an object moving in a space change with respect to time, then the motion is called three dimensional motion. Motion of a bird or a kite flying in the sky is an example of three dimensional motion.

For example, consider a particle moving from A to B. The corresponding rectangular coordinates change from (x_1, y_1, z_1) to (x_2, y_2, z_2), and the particle is said to be in three dimensional motion, as in (fig 1.11).

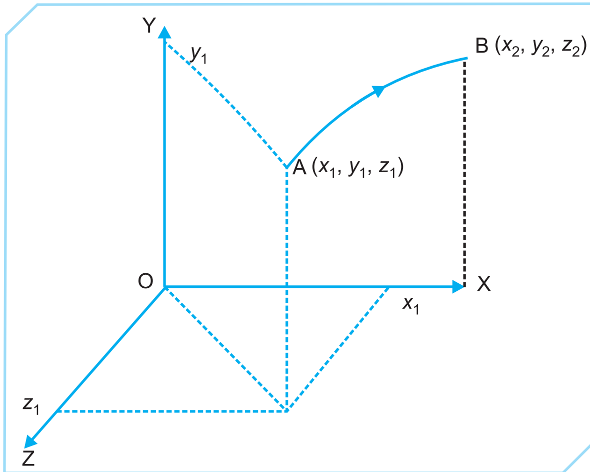


Fig 1.11 : Three dimensional motion

In order to describe the motion of an object, its position, velocity etc., need to be measured. As discussed earlier, the position of an object is measured from some fixed point known as origin or reference point. For instance, a person says that a bus is moving *i.e.*, the bus is changing its position with respect to the person. Here, the person is the reference point or origin.

In order to study the motion of bodies or objects, we need to understand about distance and displacement.

Before explaining about distance and displacement, we should know about scalar and vector quantities.

1.2 SCALAR AND VECTOR QUANTITIES

We know that physics is an experimental science which deals with a large number of physical quantities. All physical quantities fall into one of two groups namely,

(a) Scalar quantities

(b) Vector quantities

(a) Scalar Quantities

When a physical quantity has only magnitude or size and no direction, it is known as scalar quantity. For instance, when we say that mass of a body is 15 kg, it completely describes the quantity. Such quantities are called scalar quantities.

Examples of Scalar Quantities

Physical quantities such as power, volume, temperature, speed, work, energy, distance, mass, length, area, pressure etc., are scalar quantities.

Characteristics of Scalar Quantities

The following are the characteristics of scalar quantities :

(a) These are described completely only by magnitude.

(b) These can be added by simple arithmetic.

(c) These cannot be plotted on a graph as their direction is not specified.

(b) Vector Quantities

When a physical quantity has both magnitude and direction, it is known as a vector quantity. For instance, when we say that a car is moving with the speed of 30 km h^{-1} to the North, it completely describes that the quantity has both magnitude as well as direction.

Examples of Vector Quantities

Physical quantities such as displacement, acceleration, force, weight, momentum etc., are vector quantities.

Characteristics of Vector Quantities

Following are the characteristics of vector quantities :

(a) These are described completely by both magnitude and direction.

(b) These cannot be added by simple arithmetic.

(c) These can be plotted on a graph as their direction is specified.

Differences between Scalar and Vector Quantities

S. No	Characteristics	Scalar Quantities	Vector Quantities
1.	Description	These are described completely only by magnitude.	These are described completely by both magnitude as well as direction.
2.	Calculation	These can be added by simple arithmetic.	These cannot be added by simple arithmetic.
3.	Plotting graph	These cannot be plotted on a graph as their direction is not specified.	These can be plotted on a graph as their direction is specified.
4.	Examples	The physical quantities such as power, volume, temperature, speed, work, energy, distance, mass, length, area, pressure etc., are scalar quantities.	The physical quantities such as displacement, acceleration, force, weight, momentum etc., are vector quantities.

Representation of Vectors

In order to write a physical quantity in a vector form, we need to mention the direction as well as magnitude. The better way to represent a vector is a directed line segment *i.e.,* arrow mark (→) (fig 1.12). The length of the arrow tells us the magnitude of the vector. The direction of the arrow gives us the direction of the vector.

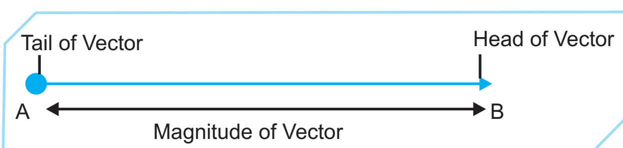


Fig 1.12 : Representation of Vectors

Graphical Representation of Vectors

The representation of vectors using line diagram is called graphical representation of vectors. We can understand the graphical representation of vectors from the following example. Let as try to represent a displacement vector of 35 m due West. We cannot draw 35 m on a normal size paper so, we choose 10 m = 1 cm in the diagram.

Therefore, 35 m = 3.5 cm in the diagram.

Let us draw the graph diagram on the paper step wise (fig 1.13).

Step 1 : Draw X-axis and Y-axis in geographic directions by dotted line.

Step 2 : Measure 3.5 cm from the origin 'O' towards West upto the point X.

Step 3 : Join 'OX' by a line and place arrow head at 'X'.

Step 4 : 'OX' represents the displacement vector of 35 m towards West.

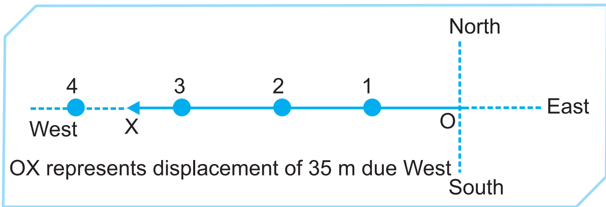


Fig 1.13 : Graphical Representation of Vectors

Now, let us draw the Graph diagram displacement vector of 5 m, 30° North-East on the paper step-by-step (fig 1.14).

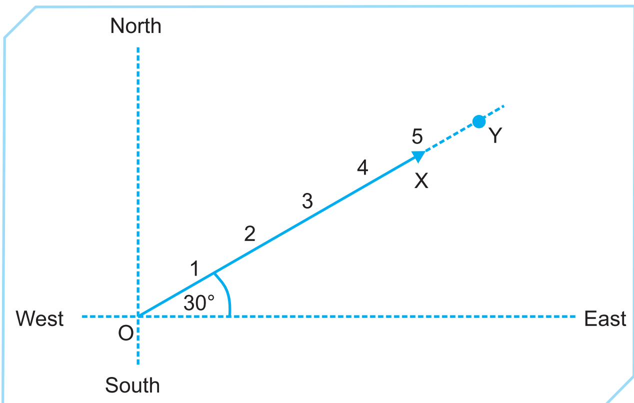


Fig. 1.14 : Graphical Representation of Vectors

Since, we cannot draw 5 m on a normal sized paper so, we choose 5 m = 5 cm in the diagram.

Step 1 : Draw X-axis and Y-axis along geographic directions by dotted line .

Step 2 : Draw OY making an angle of 30° with East.

Step 3 : Measure 5 cm from the origin 'O' towards North-East upto the point X.

Step 4 : Join 'OX' by a block line and place arrow head at 'X'.

Step 5 : 'OX' represents the displacement vector 5 m, 30° North-East.

Note

- You will study about the vectors in detail in higher classes.

TRY YOURSELF

1. Represent two forces one of 50 N due South and the other of 25 N due East acting simultaneously on a particle.
2. Draw the displacement vector of 30 m magnitude, pointing 30° South-East.
3. Draw the velocity vector of magnitude 50 m s^{-1}, pointing 45° North-West.
4. Draw the velocity vector of magnitude 40 m s^{-1}, pointing 30° South-West direction.
5. Draw the displacement vector of magnitude 5 m, pointing 30° North-East.

1.3 CONCEPT OF DISTANCE AND DISPLACEMENT

In common language, the words '*distance*' and '*displacement*' are used in the same sense. But in physics, these two words have different meanings. Let us take an example to understand the meaning of distance and displacement more clearly.

Consider a body moving from a point X to point Y along the path. The total length of the path from X to Y is called the distance moved by the body. The length of the straight line XY in direction from X to Y (fig 1.15) represented by a dotted line is called the displacement of the body.

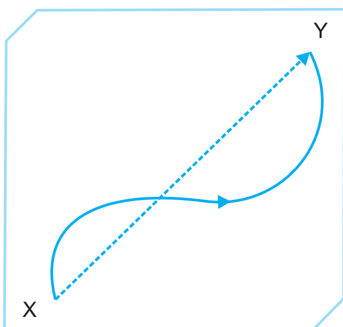


Fig 1.15 : Distance and displacement

Thus, we can conclude that when a body moves from one point to another, the distance travelled by the body is the actual length of the indirect path whereas the displacement refers to the minimum distance between the starting point and the finishing point. Hence, the shortest distance between the initial position and final position of the body along with the direction is known as its displacement.

The value of distance can never be zero or negative, during the motion of an object. The distance is represented as '*s*'. The SI unit of distance and displacement is metre (m) and C.G.S. unit is centimeter (cm).The distance travelled by the car is measured by an instrument called odometer. It records the distance in kilometres.

The value of displacement can be positive, negative or zero. The displacement is represented as $\vec{s}$.
Hence, we can write

Displacement of an object

= Final position of the object – Initial position of the object.

Since, distance has only magnitude and no specified direction, it is a scalar quantity. On the other hand, displacement has magnitude as well as direction and hence it is a vector quantity.

The total distance travelled by a body can never be zero, but the final displacement of that body can be zero if the body travels a certain distance and comes back to the position from where it has started or the initial position.

Let us explain the concept of distance and displacement with examples.

Consider a person moving along a straight road in his car. He starts his journey from his home from the point O which is a reference point (fig 1.16). He crosses a point X which is at a distance of 80 km from point O. He reaches another city at point Y at a distance of 90 km from point X and finally reaches his destination Z at the distance of 100 km from Y.

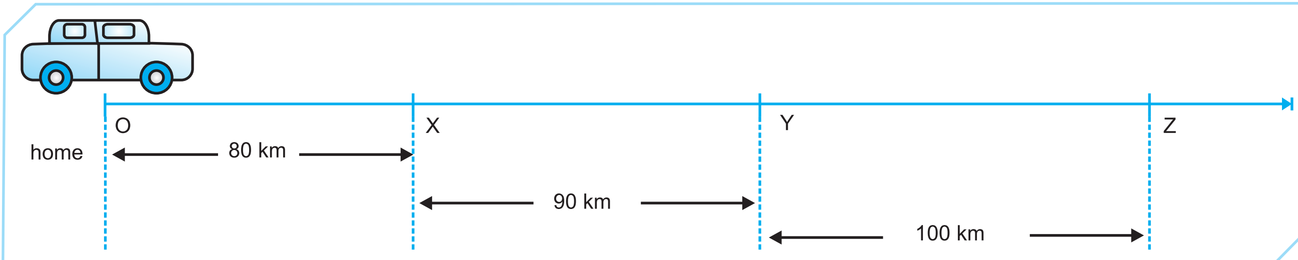


Fig 1.16 : Position of a car on a straight line path

Let us now calculate the distance travelled and displacement from O to Z.

The distance travelled by the person travelling by his car from his home at O and reaching his destination Z can be calculated as,

Distance travelled = OX + XY + YZ

= 80 + 90+ 100 = 270 km

Displacement = OX + XY + YZ

= 80 + 90 + 100 = 270 km

In this case, the magnitude of distance travelled is equal to the displacement.

Now, he returns along the same path from Z and reaches X through Y.

Let us now calculate the distance travelled and displacement from O to X through Z.

Distance travelled = OX + XY + YZ + ZY + YX

= 80 + 90 + 100 + 100 + 90

= 460 km

Displacement from O to X = OX = 80 km

In this case, the magnitude of distance is greater than displacement.

He now reaches home back at point O from the point X.

Let us now calculate the distance travelled and displacement at O through Z.

Distance travelled

= OX + XY + YZ + ZY + YX + XO

= 80 + 90 + 100 + 100 + 90 + 80

= 540 km

Displacement from O to O = zero

In this case, the final displacement is zero since, he returns to the original position.

Similarly, consider a body moving along a closed path or circular track of radius r (fig 1.17) and reaching back at starting or original point X. After one rotation, the distance travelled is equal to the circumference of the circular path *i.e.,* $2\pi r$ (circumference of track).

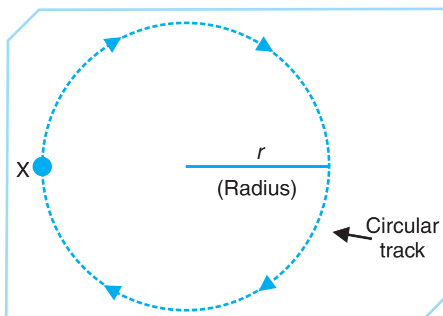


Fig 1.17 : Motion of a body along a closed or circular track

The displacement of the body during the whole journey = Final position – Initial position = zero.

This is because, its initial and the final positions are same *i.e.,* X.

On the other hand, when a body is thrown vertically upwards from a point on the ground, after some time it returns back to the same point, then the final displacement of the body is zero, but the distance travelled by the body is $2h$ where h is the maximum height attained by the body and not zero (fig 1.18).

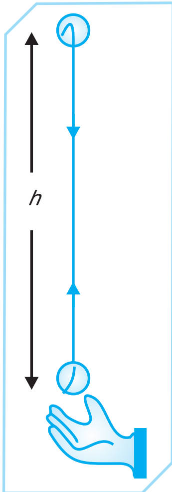


Fig 1.18 : A body thrown vertically upwards

Note

- The final displacement of a body that travels along a zig-zag path is the straight line distance between the starting point and the finishing point.

From the above discussion, we can conclude that the distance travelled by an object will be equal to the magnitude of the displacement of that object if the object continues to move in a straight line in only one direction. On the other hand, the distance travelled by an object will be greater than the magnitude of the displacement of that object, if the object moving in a straight line changes its direction of motion.

Can you now differentiate between displacement and distance?

Differences between Distance and Displacement

S. No	Distance	Displacement
1.	It is the length of the path travelled by an object in a certain amount of time.	It is the shortest distance travelled by an object in a specific direction in a certain amount of time.
2.	It is a scalar quantity and hence has only magnitude.	It is a vector quantity and hence has both magnitude and direction.
3.	It always has a positive value.	It can be positive, negative or zero.
4.	It depends on the path followed by the object.	It depends on the final and initial positions of the object.
5.	It is always more than or equal to the displacement.	Its magnitude is always less than or equal to the magnitude of distance.

SOLVED EXAMPLES

1. Sam went to the shop which is 125 m from his house. He purchased a notebook and came back to his house. Find,

   (a) The total distance travelled by Sam.

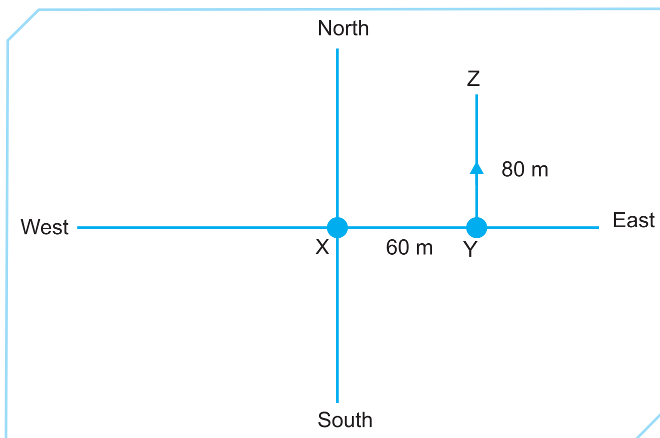
   (b) The displacement.

Solution : (a) Here, Distance = Total length travelled

Therefore, Distance = 125 + 125 = 250 m

(b) Since the initial and final position are the same, the displacement is zero.

2. Praveen went towards the east, after travelling 60 m he turned towards the north and travelled 80 m as shown in the figure.



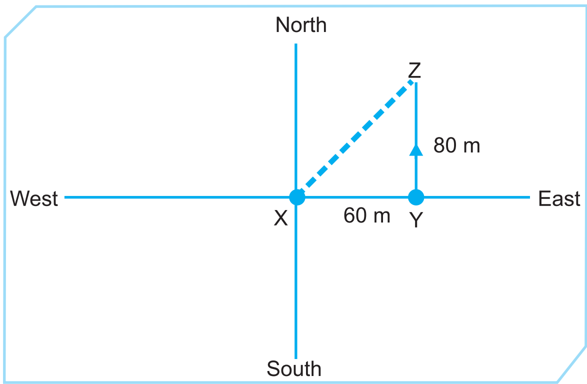
Find,

(a) The distance travelled from X to Z.

(b) The displacement from X to Z.

Solution : (a) The distance travelled from X to Z

$= XY + YZ = 60 + 80 = 140$ m



(b) Praveen's displacement is XZ which can be calculated using Pythagoras theorem,

$$XZ = \sqrt{XY^2 + YZ^2}$$

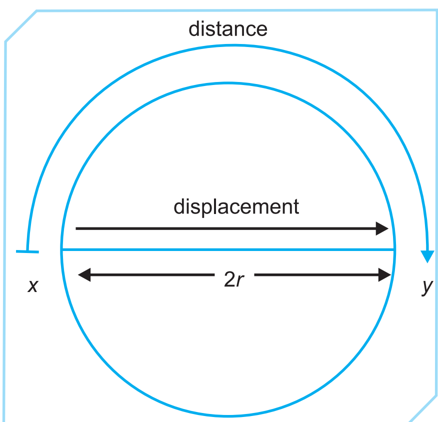
$$XZ = \sqrt{60^2 + 80^2}$$

$$= \sqrt{3600 + 6400} = \sqrt{10000}$$

$$= 100 \text{ m}$$

3. A body is moving along a circular path of radius 'r' as shown in the figure below. What is the displacement and distance of the body when it completes half a revolution?

Solution : Assume that a body starting from point 'x' moves along a circular track of radius 'r' and reaches half way at point 'y', then



$$\text{Distance travelled} = \frac{1}{2} \times 2\pi r$$

Since, circumference of circle $= 2\pi r$

So Distance travelled $= \pi r$

Displacement 'xy' $= 2r$

TRY YOURSELF

1. A particle moves 3 m towards north, then 6 m towards east and finally 3 m towards south. By drawing scale diagram, find :
   (a) The distance covered by the particle.
   (b) The displacement of the particle.
   [Ans : (a) 12 m ; (b) 6 m]
2. A body moves 10 m in one direction and then returns along the same path by 2 m. What is
   (a) The distance covered by the body.
   (b) The displacement of the body.
   [Ans : (a) 12 m ; (b) 8 m]
3. Sara travels a distance of 4 m towards west, then 3 m towards south and 6 m towards east.
   By drawing scale diagram, find:
   (a) The total distance travelled by Sara.
   (b) The displacement of Sara from her original position. **[Ans : (a) 13 m ; (b) 3.6 m]**
4. A body travels a distance of 15 m from X to Y and then moves a distance of 20 m at right angles to XY. Calculate
   (a) The total distance travelled.
   (b) The resultant displacement.
   [Ans : (a) 35 m ; (b) 25 m]
5. A body thrown vertically upwards reaches a maximum height 'h' and then returns to the ground. Calculate
   (a) The distance.
   (b) The displacement. **[Ans : (a) 2 h ; (b) zero]**

PAPER -PEN TEST : 1

1. What do you understand by the term 'reference point'?
2. Name any four physical quantities related to motion.
3. Define motion.
4. What is origin?
5. Explain three dimensional motion along a straight line with an example.
6. Define linear motion with an example.
7. When is a body said to be at rest?
8. What is mechanics?

9. Define circular motion with an example.
10. Mention the characteristics of motion.
11. Describe two dimensional motion along a straight line with an example.
12. What are the different types of motion?
13. What are the characteristics of vector quantities?
14. “Rest and motion are relative terms”. Justify.
15. Define vibratory motion with an example.
16. How can a vector be represented graphically?
17. Discuss one dimensional motion along a straight line with an example.
18. Differentiate between scalar and vector quantities.
19. What are the characteristics of scalar quantities?
20. How do you represent a vector?
21. Differentiate between distance and displacement.
22. Explain the motion of a body along a closed path.

1.4 UNIFORM AND NON-UNIFORM MOTION

Uniform Motion

Uniform motion may be circular or straight line; an object or a body is said to have uniform straight line motion, if it moves along a straight line in one direction and travels equal distances in equal intervals of time, whereas uniform circular motion may be described as the motion of a body in a circular path with constant speed. Thus, we can say that

‘An object or a body will have uniform motion, if it moves along a straight line in one direction and travels equal distance in equal intervals of time’.

For example, a car running at a constant speed of 20 m s^{-1} covers equal distance of 20 m every second. So, the motion of a car is uniform (fig 1.19). Hence, we can say that for uniform motion the distance travelled by a moving object is directly proportional to the time taken.

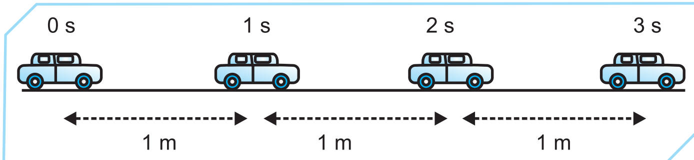


Fig 1.19 : Uniform motion

Illustration

Assume a ball travelling along a straight line covers the following distance in given interval of time having uniform motion as tabulated below :

Time (in seconds)	0	1	2	3	4	5	6	7	8	9	10
Distance covered (in metres)	0	10	20	30	40	50	60	70	80	90	100

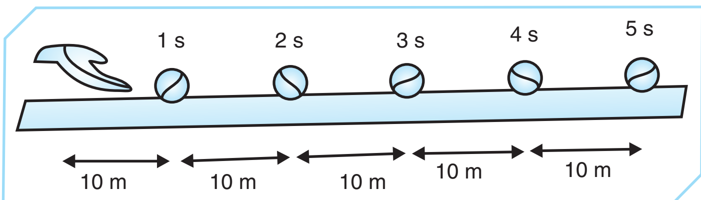


Fig 1.20 : Illustration of uniform motion

From the above table and from the (fig 1.20) we get,

The distance covered by the ball in 1^{st} second

$= 10 - 0 = 10$ m

The distance covered by the ball in 2^{nd} second

$= 20 - 10 = 10$ m

The distance covered by the ball in 3^{rd} second

$= 30 - 20 = 10$ m and so on.

Hence, we can conclude that the ball covers 10 m in each second along the straight line. So, the motion of the ball is uniform.

Examples of Uniform Motion

(a) The movement of earth around the sun (fig 1.21).
(b) A train running at a speed of 90 km h^{-1} (fig 1.22).
(c) The movement of the hands of a watch.
(d) The movement of the earth about its axis.
(e) A space ship moving at a speed of 100 km s^{-1}.

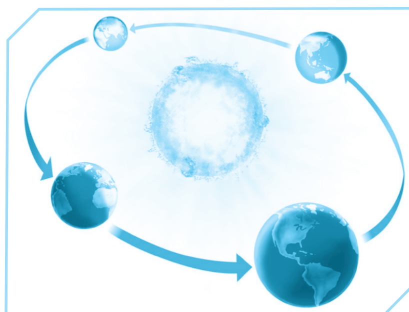


Fig 1.21 : Movement of earth around the sun

Fig 1.22 : A train running at a constant speed.

Characteristics of Uniform Motion

The following are the characteristics of uniform motion :

(a) The moving body covers equal distances in equal intervals of time, however the time intervals may be small.

(b) The graph between the distance covered and the time is a straight line.

(c) The motion is non-accelerated in nature.

Non-uniform Motion

'An object or a body will have non-uniform motion, if it travels unequal distances in equal intervals of time.'

For example, if a stone is dropped from the roof of a tall building, (fig 1.23) it covers unequal distances in equal intervals of time and hence its motion will be non-uniform. Thus, for non-uniform motion the distance travelled by a moving object is not directly proportional to the time taken.

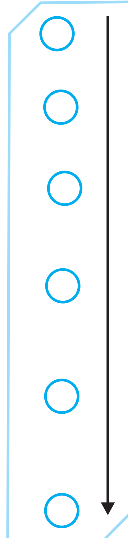


Fig 1.23 : A free falling stone due to gravity

Illustration

Assume that a ball travelling along the straight line covering the following distance in the given interval of time having non-uniform motion as tabulated below :

Time (in sec)	0	1	2	3	4	5	6
Distance covered (in m)	0	1	3	7	10	12	15

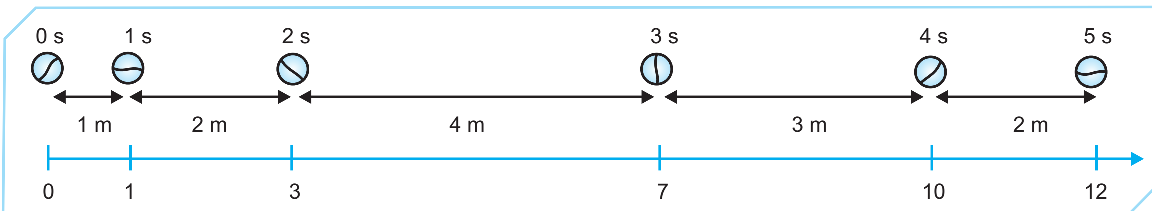


Fig 1.24 : Illustration of non-uniform motion

From the table and from the (fig 1.24) we get,

The distance covered by the ball in 1st second

= 1 – 0

= 1 m

The distance covered by the ball in 2nd second

= 3 – 1

= 2 m

The distance covered by the ball in the 3rd second

= 7 – 3

= 4 m

The distance covered by the ball in the 4th second

= 10 – 7 = 3 m and so on.

Hence, we can conclude that the ball covers different distances in each second along a straight line. So, the motion of the ball will be non-uniform.

Examples of Non-uniform Motion

(a) When brakes are applied to a speeding car.

(b) A free falling stone due to gravity.

(c) When an oscillating simple pendulum is left for some time, the oscillation stops slowly (fig 1.25).

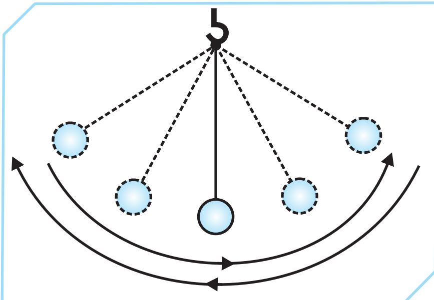


Fig 1.25 : Oscillation of a simple pendulum

(d) An aeroplane running on a runway before taking off (fig. 1.26).

Fig 1.26 : An aeroplane on the runway taking off

(e) An object thrown vertically upward (fig 1.27).

Fig 1.27 : A man throwing a ball vertically upward

Now in order to find out whether a body has uniform motion or non-uniform motion, we should draw the distance–time graph.

When a distance–time graph is drawn for uniform motion, a straight-line is formed (fig 1.28). On the other hand when a distance–time graph is drawn for non-uniform motion, a curved line is formed (fig 1.29).

Thus we can conclude that, if the distance–time graph is a straight line, then the motion will be uniform and if the distance–time graph is a curved line, then the motion will be non-uniform.

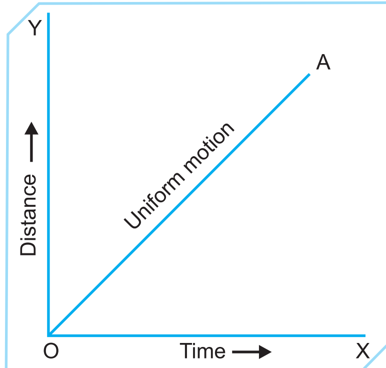


Fig 1.28 : Distance-Time graph showing uniform motion

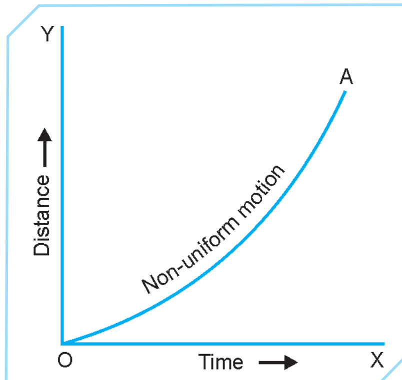


Fig 1.29 : Distance-Time graph showing non-uniform motion

Note

- The non-uniform motion is also called accelerated motion.

Characteristics of Non-uniform Motion

The following are the characteristics of non-uniform motion:

(a) The moving body does not cover equal distances in equal intervals of time.

(b) The graph between the distance covered and the time is always a curve.

(c) The motion is accelerated in nature.

Can you now differentiate between uniform motion and non-uniform motion?

Differences between Uniform Motion and Non-uniform Motion

S. No.	Uniform Motion	Non-uniform Motion
1.	The moving body covers equal distances in equal intervals of time, however the time intervals may be small.	The moving body does not cover equal distances in equal intervals of time.

2.	The graph between the distance covered and the time is a straight line.	The graph between the distance covered and the time is always a curve.
3.	The motion is non-accelerated in nature.	The motion is accelerated in nature.

Let us perform an activity to study uniform and non-uniform motion of a body.

Activity 1.1 To study uniform and non-uniform motion of a body.

PROCEDURE

The data regarding the motion of two different objects A and B are given in table below.

Time	Distance travelled by object A in m	Distance travelled by object B in m
9:30 am	10	12
9:45 am	20	19
10:00 am	30	23
10:15 am	40	35
10:30 am	50	37
10:45 am	60	41
11:00 am	70	44

State whether the motion of the objects is uniform or non-uniform.

OBSERVATION

Object A : The distance travelled in first 15 min

$$= 20 - 10 = 10 \text{ m}$$

The distance travelled in second 15 min

$$= 30 - 20 = 10 \text{ m}$$

The distance travelled in third 15 min

$$= 40 - 30 = 10 \text{ m}$$

And so on.

Object B : The distance travelled in first 15 min

$$= 19 - 12 = 7 \text{ m}$$

The distance travelled in second 15 min

$$= 23 - 19 = 4 \text{ m}$$

The distance travelled in third 15 min

$$= 35 - 23 = 12 \text{ m}$$

CONCLUSION

(a) The object A covers 10 m in each 15 min along a straight line and so it is in uniform motion.

(b) The object B covers unequal distance in each 15 min along a straight line and hence it is in non-uniform motion.

PAPER–PEN TEST : 2

1. Mention any three characteristics of non-uniform motion.
2. What is the kind of motion represented by a distance-time graph in the shape of a curved line?
3. Draw a graph to show uniform motion and non-uniform motion.
4. Differentiate between uniform and non-uniform motion.
5. What are the characteristics of uniform motion?
6. Define non-uniform motion with an example.
7. Uniform motion is also called .... motion.
8. Illustrate uniform motion.
9. What is the motion if the distance-time graph is a straight line?
10. Define uniform motion with an example.

Speed, Velocity and Acceleration

Generally, the motion of a body can be described by three terms, namely.

(a) Speed

(b) Velocity

(c) Acceleration

Let us now study these terms one by one in detail.

1.5 SPEED

We know that different objects travel different distances in different intervals of time. For a moving body, the speed is the quantity which tells us how fast or slow the body is moving. Thus, we can define speed as

'The distance travelled by the body in unit time interval.'

In other words *'The distance travelled by the body per unit time'*.

Hence,

$$\text{Speed} = \frac{\text{Distance Travelled}}{\text{Time Taken}}$$

It is denoted as 'v'.

If a body travels a distance 's' in time 't', then its speed 'v' is

$$v = \frac{s}{t}$$

Where, v is speed, and t is time taken to travel the distances s.

The speed of a running car at any instant of time can be calculated by an instrument called speedometer which is fixed in the car. Speed is a scalar quantity because it has only magnitude and has no direction.

Units of Speed

$$\text{Unit of speed} = \frac{\text{Unit of distance}}{\text{Unit of time}}$$

$$= \frac{\text{metre}}{\text{second}}$$

Therefore, the SI unit of speed is m/s or m s^{-1}. In C.G.S. system the unit of speed is cm/s or cm s^{-1}. If the distance is measured in kilometre and time in hours, then the unit of speed is km/h or km h^{-1}.

Sometimes speed is expressed in km/h or m/s. To convert km/h into m/s, we need to change km to m and hour to sec.

$$1 \text{ km h}^{-1} = \frac{1000 \text{ m}}{3600 \text{ s}} = \frac{5}{18} \text{ m s}^{-1}$$

Note

- While comparing the speeds of different bodies, we must convert all speeds into same units. The speed of moving buses, trains, aeroplanes and cars are expressed in km/h or km h^{-1}.

Types of Speed

Speed can be expressed as :

(a) Average speed

(b) Uniform speed

(c) Non-uniform speed

(d) Instantaneous speed

(a) Average Speed

While travelling in a bus, we will notice that the bus starts slowly from the starting point and then its speed increases gradually. But when the bus enters the crowded road, the speed of the bus decreases. Again after crossing the crowded roads, its speed increases. This shows that the bus is not moving with the same speed during the whole journey. In other words, we can also say that the speed of a body is not constant. Now we can define average speed as,

'The ratio of the total distance travelled by a body to the total time taken by the body.'

Hence,

$$\text{Average speed} = \frac{\text{Total Distance Travelled}}{\text{Total Time taken}}$$

The average speeds of some moving objects are tabulated below.

S. No	Moving Object	Average speed
1.	Tortoise	0.216 km h^{-1}
2.	Human Walking	7.2 km h^{-1}
3.	Bee	16 km h^{-1}
4.	Wind speed during a light breeze	32 km h^{-1}
5.	Human running [sprinter]	36 km h^{-1}
6.	Birds	18 to 54 km h^{-1}
7.	Cheetah	97.2 km h^{-1}
8.	Fast car	108 km h^{-1}
9.	Falcon	152 km h^{-1}
10.	Racing Car	216 km h^{-1}
11.	Sound in air (at 20°C)	1238.4 km h^{-1}
12.	Aeroplane	1800 km h^{-1}
13.	Light (in Vacuum)	1.08×10^9 km h^{-1}

(b) Uniform Speed

It is also called constant speed. We know that, light travels with constant speed in a medium. We can define the uniform speed as,

'A body is said to be moving with uniform speed if it covers equal distances in equal intervals of time throughout its motion'

For example, the motion of a ball on a frictionless plane surface, motion of radio signal in medium.

Let us illustrate this more clearly with an example.

Illustration

If a car travels 20 km in every half an hour, 10 km every quarter an hour and so on, we can say that the car has a uniform speed of 40 km h^{-1}. However, it is not practically possible for the speed of the body to remain constant for a long time (fig 1.30).

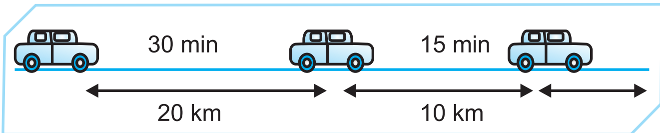


Fig 1.30 : Example showing uniform motion of car

Now, what will be the use or significance of knowing uniform speed? Let us discuss the answer. If the speed of a body is said to be constant, it helps us to find out how much distance the body will travel in a given time or how much time it will take to travel the given distance. Using the formula,

$$s = vt$$

Where 'v' is the speed, 't' is the time taken and 's' is the distance.

(c) Non-Uniform Speed

It is also called variable speed. The non-uniform speed can be defined as,

'A body is said to be moving with non-uniform speed if it covers unequal distances in the equal intervals of time'

For example, motion of a ball on a rough plane surface.

Let us illustrate this more clearly with an example.

If a car travels 30 km in 30 minutes, 25 km in next 30 minutes, 18 km in next 30 minutes, then we can say that the car possess a non-uniform motion. Thus, for non-uniform motion the distance travelled by a moving object is not directly proportional to the time taken (fig 1.31).

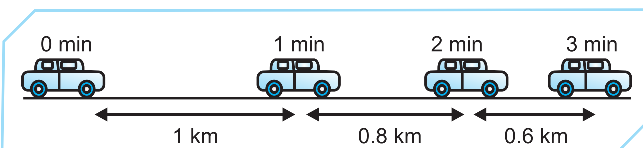


Fig 1.31 : Example showing non-uniform motion of car

Knowing the average or uniform speed of a body, we can calculate the distance moved by the body in a certain interval of time.

Note

- When a body travels with a non-uniform speed, we can calculate the instantaneous speed and the average speed of the body to describe its motion.

(d) Instantaneous Speed

If the speed of a body changes continuously with time, its speed at any instant is known as instantaneous speed. We can calculate the instantaneous speed, by finding the distance travelled by the body in a very short interval and then by dividing the distance by the time interval.

Note

- The speedometer of a vehicle measures the instantaneous speed.

Let us perform an activity to measure the distance.

Activity 1.2 To measure approximately the distance of the nearest point of lightning by taking speed of sound in air as 346 m s^{-1}

PROCEDURE

Step 1– Sit in your verandah when thunder and lightning takes place or during rainy season.

Step 2– Start a stop watch as soon as you see lightning.

Step 3– Stop the stop watch as soon as you hear thunder sound.

Step 4– Note down the time taken between lightning and thunder sound.

OBSERVATION

Let us consider the time taken between lightning and thunder sound is 4 sec.

Then,

distance of the nearest point of lightning will be

$$s = \text{Speed of sound in air} \times \text{time}$$
$$= 346 \times 4 = 1384 \text{ m}$$

We shall now try to solve some numerical problems based on the speed.

SOLVED EXAMPLES

1. A car covers a distance of 10 kilometres in 5 minutes. Calculate the speed of car in
   (a) Centimetres per second (cm s^{-1})
   (b) Metres per second (m s^{-1})

Solution :(a) In order to calculate the speed in centimetres per second we should convert the given distance of 10 kilometres into centimetres and the given time of 5 minutes into seconds.

$$\begin{aligned}\text{Distance travelled} &= 10 \text{ km}\\ &= 10 \times 1000 \text{ m}\\ &= 10 \times 1000 \times 100 \text{ cm}\\ &= 10{,}00{,}000 \text{ cm}\end{aligned}$$

$$\begin{aligned}\text{Time taken} &= 5 \text{ minutes}\\ &= 5 \times 60 \text{ s}\\ &= 300 \text{ s}\end{aligned}$$

$$\text{Speed} = \frac{\text{Distance travelled}}{\text{Time taken}}$$

$$\text{Speed} = \frac{1000000}{300}$$

$$= 3333 \text{ cm s}^{-1} \text{ [Approx]}$$

(b) In order to express the speed in metres per second we should convert the given distance of 10 kilometres into metres and the given time of 5 minutes into seconds

$$\begin{aligned}\text{Distance travelled} &= 10 \text{ km}\\ &= 10 \times 1000 \text{ m}\\ &= 10000 \text{ m}\end{aligned}$$

$$\begin{aligned}\text{Time taken} &= 5 \text{ minutes}\\ &= 5 \times 60 \text{ seconds}\\ &= 300 \text{ s}\end{aligned}$$

$$\text{Speed} = \frac{\text{Distance travelled}}{\text{Time taken}}$$

$$\text{Speed} = \frac{10000}{300} = 33 \text{ m s}^{-1} \text{ [Approx]}$$

2. The bus X travelled a distance of 100 km in 2 hours whereas another bus Y travelled a distance of 165 km in 3 hours. Which bus travelled faster?

Solution :

$$\text{Speed} = \frac{\text{Distance travelled}}{\text{Time taken}}$$

Distance travelled by Bus X = 100 km

Time taken = 2 h

$$\text{Speed of bus X} = \frac{100}{2} = 50 \text{ km h}^{-1}$$

Distance travelled by bus Y = 165 km

Time taken = 3 h

$$\text{Speed of bus Y} = \frac{165}{3} = 55 \text{ km h}^{-1}$$

Thus, bus Y travelled faster.

3. A bike travels 30 km at a uniform speed of 50 km h^{-1} and the next 30 km at a uniform speed of 40 km h^{-1}. Find the average speed of the bike.

Solution : In the first part, the bike travels a distance of 30 km at a speed of 50 km per hour,

Given,

$$\begin{aligned}\text{Speed} &= 50 \text{ km h}^{-1}\\ \text{Distance} &= 30 \text{ km}\\ \text{Time} &= ?\end{aligned}$$

$$\text{Speed} = \frac{\text{Distance travelled}}{\text{Time taken}}$$

$$\therefore \quad \text{Time} = \frac{\text{Distance}}{\text{Speed}}$$

$$\text{Time, } t_1 = \frac{30}{50} \text{ hours} = \frac{3}{5} \text{ hours}$$

For the second part, the bike travels a distance of 30 km at a speed of 40 km h^{-1},

Given,

$$\begin{aligned}\text{Speed} &= 40 \text{ km h}^{-1}\\ \text{Distance} &= 30 \text{ km}\\ \text{Time} &= ?\end{aligned}$$

$$\text{Time, } t_2 = \frac{30}{40} = \frac{3}{4} \text{ hours}$$

We can get the total time taken by the bike for the whole journey by adding the above two values t_1 and t_2, we get

$$\text{Total time taken} = \frac{3}{5} + \frac{3}{4} = \frac{12+15}{20} = \frac{27}{20} \text{ hours}$$

Total distance travelled = 30 km + 30 km = 60 km

$$\therefore \text{Average Speed} = \frac{\text{Total distance travelled}}{\text{Total time taken}}$$

$$= \frac{60 \times 20}{27}$$

$$= \frac{1200}{27} = 44.4 \text{ km h}^{-1}$$

4. On a 100 km road, a bus travels the first 30 km at a uniform speed of 30 km h^{-1}. How fast must the bus travel the next 70 km so as to average 50 km h^{-1} for the entire trip?

Solution :

$$\text{Speed} = \frac{\text{Distance travelled}}{\text{Time taken}}$$

$$\text{Total time taken} = \frac{\text{Total distance travelled}}{\text{Average Speed}}$$

$$= \frac{100}{50} = 2 \text{ hours}$$

We will now calculate the time taken by the bus to travel the first 30 km and then calculate for next 70 km.

$$\text{Speed} = 30 \text{ km h}^{-1}$$

$$\text{Distance} = 30 \text{ km}$$

$$\text{Time} = ?$$

$$\text{Speed} = \frac{\text{Distance travelled}}{\text{Time taken}}$$

$$\therefore \quad \text{Time} = \frac{\text{Distance}}{\text{Speed}}$$

$$= \frac{30}{30} = 1 \text{ hour}$$

For the second part of the bus journey, let us suppose that the speed of a bus is x km h^{-1}. So for second part of the bus journey

$$\text{Speed} = x \text{ km h}^{-1}$$

$$\text{Distance} = 70 \text{ km}$$

$$\text{Time} = ?$$

$$\text{Speed} = \frac{\text{Distance travelled}}{\text{Time taken}}$$

$$x = \frac{70}{\text{Time taken}}$$

$$\text{Time taken} = \frac{70}{x}$$

$$\text{Total time taken} = 1 + \frac{70}{x} \text{ hours}$$

We already know from the above equations the total time taken for the entire trip is 2 hours.

$$\therefore \quad 1 + \frac{70}{x} = 2$$

$$\frac{70}{x} = 2 - 1$$

$$\frac{70}{x} = 1$$

$$x = 70 \text{ km h}^{-1}$$

The bus should travel the next 70 km distance at a speed of 70 km h^{-1}.

5. A car travels at a speed of 40 km h^{-1} for 0.50 h, at 20 km h^{-1} for next 0.3 h and then at 70 km h^{-1} for next 0.67 h. What is the average speed of the car?

Solution : In this case, we need to calculate the distance travelled by the car under three different conditions of speed and time.

(i) In the first case, the car travels at a speed of 40 km h^{-1} for a time of 0.50 hours.

$$\text{Speed} = \frac{\text{Distance travelled}}{\text{Time taken}}$$

$$\text{Distance} = \text{Speed} \times \text{Time}$$

$$= 40 \times 0.50 = 20 \text{ km} \qquad \text{..........(1)}$$

(ii) In the second case, the car travels at a speed of 20 km h^{-1} for a time of 0.3 hours.

$$\text{Speed} = \frac{\text{Distance travelled}}{\text{Time taken}}$$

$$\text{Distance} = \text{Speed} \times \text{Time}$$

$$= 20 \times 0.30 = 6 \text{ km} \qquad \text{..........(2)}$$

(iii) In the third case, the car travels at a speed of 70 km h^{-1} for a time of 0.67 hours.

$$\text{Speed} = \frac{\text{Distance travelled}}{\text{Time taken}}$$

$$\text{Distance} = \text{Speed} \times \text{Time}$$

$$= 70 \times 0.67 = 46.9 \text{ km} \qquad \text{.........(3)}$$

From the equations (1), (2) and (3), we get

Total distance travelled

$$= 20 + 6 + 46.9 = 72.9 \text{ km}$$

$$\text{Total time taken} = 0.50 + 0.30 + 0.67 = 1.47 \text{ h}$$

$$\text{Average Speed} = \frac{\text{Total distance travelled}}{\text{Total time taken}}$$

$$= \frac{72.9}{1.47} = 49.6 \text{ km h}^{-1}$$

TRY YOURSELF

1. A train moving with uniform speed covers a distance of 150 m in 5 s. Calculate

(a) The speed of the train.

(b) The time it takes to cover 240 m.

[Ans : (a) 30 m s^{-1} ; (b) 8 s]

2. The speed of a car is 36 km h^{-1}. Express it in m s^{-1}.
[Ans : 10 m s^{-1}]

3. A car travels the first 30 km with a uniform speed of 60 km h^{-1} and the next 30 km with a uniform speed of 40 km h^{-1}. Calculate
   (a) The total time of journey.
   (b) The average speed of the car.
[Ans : (a) 75 min ; (b) 48 km h^{-1}]

4. A train travels 60 km h^{-1} for 0.52 h, 30 km h^{-1} for the next 0.24 h and 70 km h^{-1} for next 0.71 h. What is the average speed of the train? **[Ans: 60 km h^{-1}]**

5. A train travels for the first 30 km on a 120 km track at a uniform speed of 30 km h^{-1}. How fast must the train travel the next 90 km so as to average 60 km h^{-1} for the entire journey? **[Ans : 90 km h^{-1}]**

PAPER-PEN TEST : 3

1. When can we calculate the instantaneous speed of the body to describe its motion?
2. Illustrate non-uniform speed.
3. Define uniform speed with an example.
4. When can we calculate the average speed of the body to describe its motion?
5. Illustrate uniform speed.
6. Uniform speed is also called .... speed.
7. What is the SI unit of speed?
8. Define non-uniform speed with an example.
9. Which instrument is used to measure the instantaneous speed of a vehicle?
10. Define instantaneous speed.
11. What do you understand by the term '*average speed*'?
12. What are the different types of speed?
13. How are speeds measured in different bodies?
14. Name the instrument used to measure the speed of the vehicle at any instant of time.
15. Define speed with an example.

1.6 VELOCITY

We have already studied that how the speed of a car or any other body helps us to find out how fast a car or any other body is moving. But it does not give us any information about the direction of the body. Thus, in order to know the exact position of a moving body, we should know the speed as well as the direction of the body. This is given by the term called Velocity.

We can define velocity as

'The distance travelled by the body in a specific direction in unit time interval'

$$\text{Velocity} = \frac{\text{Distance travelled in given direction}}{\text{Time taken}}$$

If a body travels a distance '*s*' in time '*t*' in a given direction then its velocity '*v*' is given by

$$v = \frac{s}{t}$$

But, we know that distance travelled in a given direction is known as displacement. So, the velocity of a body can also be defined as,

'The displacement of the body in a specific direction in a unit interval of time'

Thus,

If a body travels with a displacement '*s*' in time '*t*' in a definite direction, then its velocity '*v*' is given by

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

$$\vec{v} = \frac{\vec{s}}{t}$$

The direction of velocity is the same as the direction of displacement of the body. Thus, the SI unit of velocity is in metre per second [m/s or m s^{-1}]. The C.G.S. unit of velocity is centimetre per second (cm/s or cm s^{-1}). But the commonly used unit of velocity is kilometer/hour [km/h or km h^{-1}].

The velocity of a body can be changed in the following ways :

(a) **By changing the speed of the body, but keeping the direction of motion of the body constant.** For instance, the velocity of a ball dropped from the top of a building changes because its speed changes. But its direction of motion is the same.

(b) **By changing both the speed as well as the direction of motion of the body.** For instance, the velocity of a car moving in a zig-zag road changes as both its speed as well as the direction of motion changes.

(c) By changing the direction of motion of the body, but keeping the speed of the body constant. For instance, the velocity of a car moving with a constant speed in a circular path changes because of continuous change in the direction of motion.

Note

- Both speed and velocity are represented by v.

Types of Velocity

The different types of velocities include

(a) Average velocity
(b) Uniform velocity
(c) Non-uniform velocity
(d) Instantaneous velocity

(a) Average Velocity

If the velocity of a body moving in a particular direction changes with time, the ratio of displacement to the time taken for the entire displacement to take place is called the average velocity.

$$\text{Average Velocity } (v_{av}) = \frac{\text{Displacement}}{\text{Total Time taken}}$$

If the velocity of the body is always changing at a uniform rate, then the average velocity is the arithmetic mean of initial and final velocity of a moving body for a given period of time.

$$\text{Average velocity} = \frac{\text{Initial Velocity + Final Velocity}}{2}$$

$$\vec{v}_{av} = \frac{u+v}{2}$$

(b) Uniform Velocity

It is also called constant velocity. Uniform velocity may be defined as

'If a body travels equal distances in equal intervals of time along a particular direction, the body is said to be moving with a uniform velocity.'

In other words, if an object travels in a specified direction in a straight line covering the same distance in each unit time, then the velocity is uniform.

If a body moves with uniform velocity v, the displacement s of the body in a time interval t is given as,

$$s = vt$$

The unit of velocity is the same as the unit of speed *i.e.*, the SI unit of velocity is m s^{-1} and the C.G.S. unit is cm s^{-1}.

Let us illustrate Uniform velocity with an example.

Consider a car starting from 0 km h^{-1} and moving at a speed of 70 km h^{-1} along a straight line. If it covers a distance of 1 km in 1 min, then the body is said to have uniform velocity (fig 1.32).

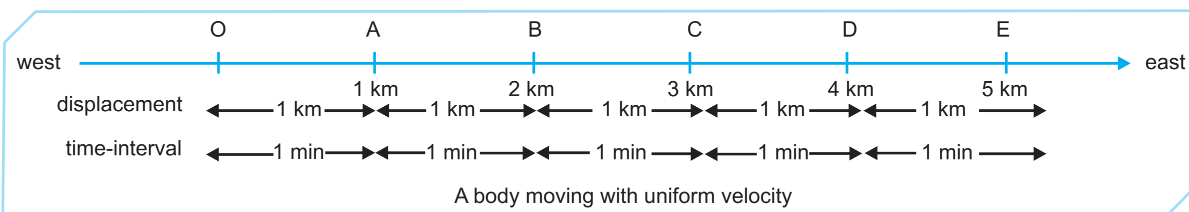


Fig 1.32 : Example of a body moving with uniform velocity

(c) Non-Uniform Velocity

It is also called variable velocity. It may be defined as,

'If a body moves unequal distances in a particular direction in equal intervals of time or if it moves equal distances in equal intervals of time, but its direction of motion is not the same, then the velocity is said to be non-uniform.'

Let us illustrate Non-uniform velocity with an example.

Consider a car starting from a point 'O' and moving on a straight road due toward east. Suppose it covers 1 m in first second, next 1.5 m in the next second and then 2 m in the third second in the same direction and so on, then the body is said to have non-uniform velocity (fig 1.33).

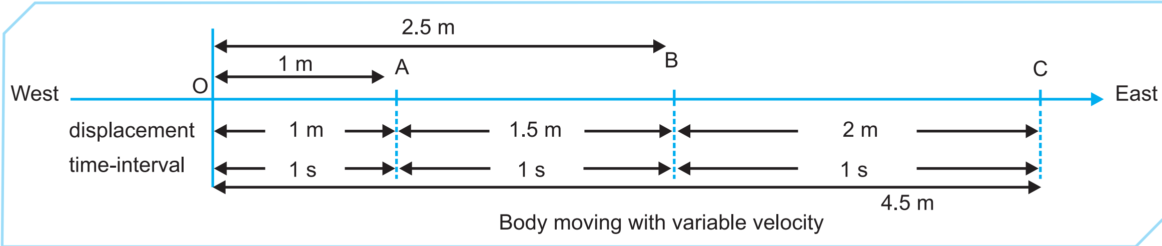


Fig 1.33 : Example of a body moving with non-uniform velocity

Now a question arises, if a man runs along a circular path with constant speed (fig 1.34), will he have uniform or non-uniform velocity?

Let us find out the answer.

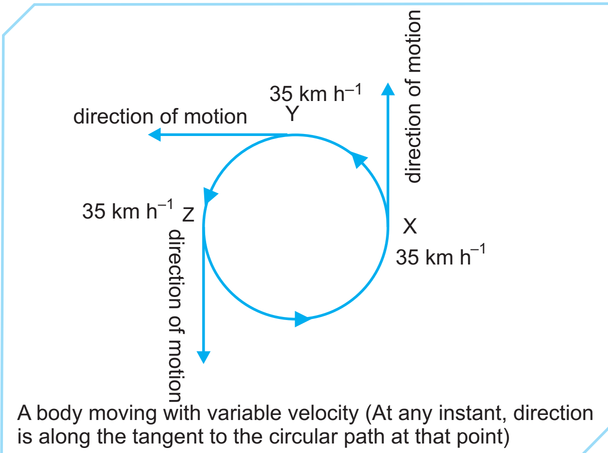


Fig 1.34 : Example of a car moving along a circular path

Consider a car moving around a circular path at constant speed of 35 km h^{-1} at every point on the path. But at every point, the direction of the moving car changes continuously. Thus, the magnitude of velocity at points X, Y, Z is the same, but the direction of motion keeps changing. Hence, the body is said to possess a non-uniform or variable velocity.

The motion of a freely falling body, motion of a body in a circular path with uniform speed and a stone thrown vertically upwards also possesses variable velocity.

Note

- The motion of a body in a circular path with uniform speed has non-uniform velocity because in circular path, the direction of motion changes continuously with time.

(d) Instantaneous Velocity

Instantaneous velocity is the velocity of an object in motion at a specific point of time. This is determined like average velocity. If an object has the same velocity over a period of time, its average and instantaneous velocities may be the same.

Let us now differentiate speed and velocity.

Differences between Speed and Velocity

S. No.	Speed	Velocity
1.	It is the distance travelled by an object per unit time.	It is the distance travelled by an object in a particular direction per unit time.
2.	Speed = $\frac{\text{Distance}}{\text{Time}}$	Velocity = $\frac{\text{Displacement}}{\text{Time}}$
3.	It tells how fast an object moves.	It tells how fast an object moves and in which direction.
4.	It is a scalar quantity.	It is a vector quantity.
5.	Speed of an object is always positive and can never be zero or negative.	Velocity of an object can be positive, negative or zero, depending on direction of motion.

Special Cases of Speed and Velocity

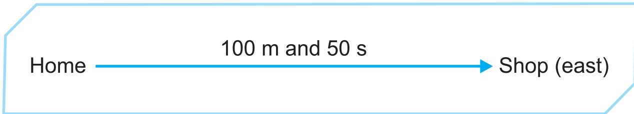
Do you know that the magnitude of speed and velocity of a moving body is equal in most cases but not always? This will become clear from the following example. Suppose a girl runs a distance of 100 m in 50 seconds while going from a shop to home in the west direction along a straight line.

Then,

$$\text{Speed} = \frac{\text{Displacement}}{\text{Total Time taken}}$$

$$= \frac{100}{50} = 2 \text{ m s}^{-1}$$

Since the girl runs in a straight line, the displacement will be equal to the magnitude of the distance travelled.



Thus,

$$\text{Velocity of the girl} = \frac{\text{Displacement}}{\text{Time}}$$

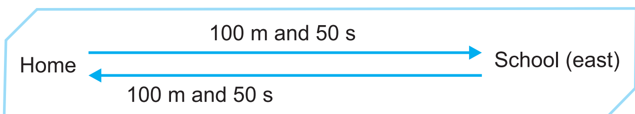
$$= \frac{100 \text{ m towards east}}{50 \text{ s}}$$

$$= 2 \text{ m s}^{-1}$$

Therefore, we can conclude that in this case, the magnitude of speed and velocity of the girl is equal.

What happens to the magnitude of the speed and velocity of a body if the body does not move in a straight line? Let us discuss.

Suppose the girl first runs a distance of 100 m in 50 seconds from her home to school towards east direction and then runs a distance of 100 m again in 50 seconds in the opposite direction from the school to home.



Then,

$$\text{Speed} = \frac{\text{Distance travelled}}{\text{Time taken}}$$

The total distance travelled by the girl is

$$100 + 100 = 200 \text{ m}$$

and the total time taken is

$$50 + 50 = 100 \text{ s.}$$

Therefore,

$$\text{Speed} = \frac{200}{100} = 2 \text{ m s}^{-1}$$

The total displacement covered will be 100 – 100 = 0 m and the total time taken is 50 + 50 = 100 s.

Thus,

$$\text{Velocity of the girl} = \frac{\text{Displacement}}{\text{Time taken}}$$

$$= \frac{0}{100} = 0 \text{ m s}^{-1}$$

Here, the magnitude of speed and velocity of the girl is not equal. This is because the girl has not moved in a straight line, with no change in direction.

Thus, from the above discussion we can conclude that the difference in the values of speed and velocity arises only when a body or object does not move in a single straight line direction and changes its direction of motion at some point of time. This also shows that the average speed of a moving body can never be zero but the average velocity of a moving body can be zero.

Let us solve the numericals based on velocity.

SOLVED NUMERICALS

1. Mira takes 20 min to cover a distance of 3.2 km on a bicycle. Calculate her velocity in
   (a) km min^{-1}
   (b) m min^{-1}
   (c) km h^{-1}

Solution : Given,

Distance covered, s = 3.2 km = 3200 m

Time taken, t = 20 min

Velocity, v = ?

For uniform velocity,

$$\text{Velocity, } v = \frac{\text{Distance}}{\text{Time taken}}$$

(a) $v = \dfrac{3.2}{20} = 0.16 \text{ km min}^{-1}$

(b) $v = \dfrac{3200}{20} = 160 \text{ m min}^{-1}$

(c) $v = \dfrac{3.2}{1/3} = 9.6 \text{ km h}^{-1}$

2. Mahesh is travelling in his car with a velocity of 45 km h^{-1}. How much distance will he cover ?
   (a) In one minute
   (b) In one second

Solution : Given,

Velocity or speed, v = 45 km h^{-1}

For uniform velocity,

$$\text{Velocity, } v = \frac{\text{Distance}}{\text{Time taken}}$$

$$s = vt$$

(a) $s = 45 \times 1$

$$= 45 \times \frac{1}{60} = 750 \text{ m or } 0.75 \text{ km}$$

(b) $s = 45 \times 1$

$$= 45 \times \frac{1}{3600} = 12.5 \text{ m}$$

$$= 0.0125 \text{ km}$$

TRY YOURSELF

1. The velocity of a bike is 18 m s^{-1}. Express it in km h^{-1}. **[Ans : 64.8 km h^{-1}]**
2. A body is moving with velocity of 10 m s^{-1}. If the motion is uniform, then what will be the velocity after 10 s? **[Ans : 10 m s^{-1}]**
3. A train is moving with a velocity of 120 km h^{-1}. How much distance will it move in 30 s? **[Ans : 1 km]**
4. An object is moving with a velocity of 5 m s^{-1} in a particular direction. Calculate the distance travelled by it in 5 sec. **[Ans : 25 m]**
5. A car travels a distance of 300 km from Kolkata to Darjeeling towards North in 5 hours. Calculate :

   (a) Speed

   (b) Velocity of the car for this trip

   [Ans : (a) 60 km h^{-1} ; (b) 60 km h^{-1} towards north]

PAPER -PEN TEST : 4

1. Define the term 'velocity' with an example.
2. Is the direction of velocity same as the direction of displacement of the body?
3. Define uniform velocity with an example.
4. What is the SI unit of velocity?
5. What is the C.G.S. unit of velocity?
6. How can the velocity of a body be changed?
7. Illustrate uniform velocity.
8. What are the different types of velocity?
9. Illustrate non-uniform velocity.
10. The constant velocity is .... velocity.
11. Define non-uniform velocity with an example.
12. If a man is running in a circular path with constant speed, will he have a uniform or non-uniform velocity?
13. Define instantaneous velocity with an example.
14. Differentiate between speed and velocity.
15. Comment : *'The magnitude of speed and velocity of a moving body is equal in most of the cases but not always.'*

1.7 ACCELERATION

Generally, the bodies do not move with constant velocities. The velocity may change either in magnitude or in direction or in both magnitude and direction. For example, the motion of a car on a busy road is said to have a variable velocity. In this case, we will consider motion in a straight line in which the velocity changes only in magnitude *i.e.,* only the speed changes without change in the direction of motion.

Thus, if the velocity of the body increases with time, then the motion is said to be accelerated and if the velocity of the body decreases with time, then the motion is said to be decelerated or retarded.

Generally, acceleration is taken as positive while, retardation is taken as negative. The change in the velocity of an object with time is expressed by a physical quantity known as acceleration. In other words, acceleration is a quantity which measures how quickly the velocity of a body or an object changes.

Let us now define acceleration.

'The rate of change of velocity of an object with respect to time is called acceleration'.

OR

'The change in velocity per unit time is called acceleration'.

Hence,

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

But, the change in velocity is the difference between final velocity and initial velocity. So,

Change in velocity = Final velocity – Initial velocity

$$\therefore \text{Acceleration} = \frac{\text{Final velocity} - \text{Initial velocity}}{\text{Time taken}}$$

Let us now try to derive an expression for acceleration.

Expression for Acceleration

Let the initial velocity of a body be 'u' and the final velocity of a body be 'v' at time, 't', then

Change in velocity = $v - u$

Time taken for change = $t - 0 = t$

∴ Acceleration of the object, a

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

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

The SI unit of acceleration is "*metre per second square*" or m/s^2 or $m\ s^{-2}$. It may also be measured in cm/s^2 or $cm\ s^{-2}$ or km/h^2 or $km\ h^{-2}$. If the motion of a body is in a straight line, the acceleration will take place in the direction of velocity. So, acceleration is a vector quantity.

Note

- If the change in velocity of an object is zero or if an object is moving with uniform velocity, then the acceleration of an object will be zero.

Types of Acceleration

There are four different types of acceleration namely,

(a) Uniform acceleration

(b) Non-uniform acceleration

(c) Positive acceleration

(d) Negative acceleration

(a) Uniform Acceleration

When a body travels in a straight line and its velocity increases by equal amount in equal intervals of time, then the body is said to have uniform acceleration. For example, when the velocity of a car increases, it is said to be accelerated. If the velocity increases at a uniform rate, then the acceleration is said to be uniform.

Examples of Uniform Acceleration

(a) The motion of a ball rolling down a smooth inclined plane (fig 1.35).

(b) The motion of a bicycle going down the slope of a road when the rider is not pedalling it (neglecting air resistance).

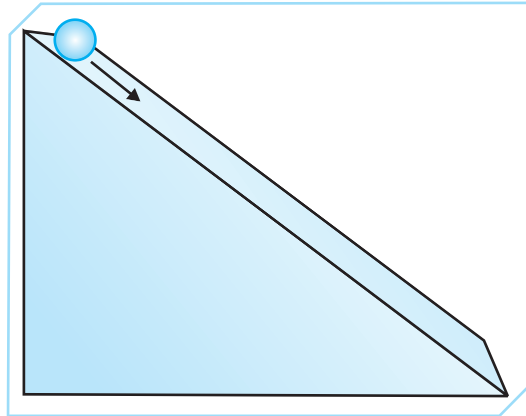


Fig 1.35 : Motion of a ball rolling down an inclined plane

(b) Non-Uniform Acceleration

If the change in velocity is not equal in equal intervals of time, then the acceleration is said to be variable or non-uniform. In other words, a body has a non-uniform acceleration if its velocity changes at a non-uniform rate.

Examples of Non-Uniform Acceleration

(a) The motion of a car on a crowded road.

(b) The motion of a bus leaving the bus stop.

(c) The motion of a train entering the platform.

(c) Positive Acceleration

When the velocity of an object increases with time in the direction of the motion of the object, then the acceleration of the body is positive. In other words, '*when the direction of the acceleration of an object is the same as that of the direction of motion of the object, then it has a positive acceleration.*'

For example, the rocket lifts off from the ground by increasing the speed towards the direction of its motion and so is said to have positive acceleration (fig 1.36).

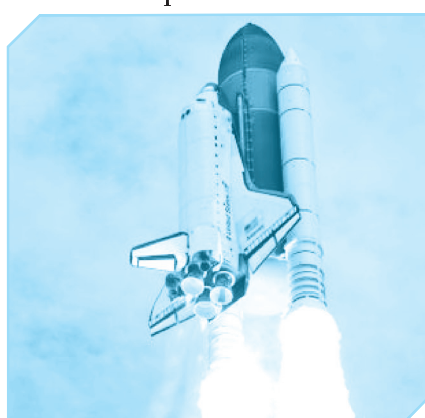


Fig 1.36 : A rocket accelerates as it lifts off from the ground showing positive acceleration

(d) Negative Acceleration

When 'the velocity of an object decreases with time, then the acceleration of the body is known as negative acceleration.' The negative acceleration is also called retardation or deceleration. In other words, acceleration with the negative sign is called retardation. The direction of negative acceleration is in the direction opposite to the direction of motion of the object. It is denoted as $-a$. For example, the speed of a parachute decreases with time and hence its acceleration is negative (fig. 1.37).

Fig 1.37 : A parachute decelerates as it falls towards the ground showing negative acceleration

If a car moving with a certain velocity is brought to rest, then the car is said to have negative acceleration.

Note

- An object will slow down if acceleration and velocity are in opposite directions. However, the object will speed up even if both the velocity and acceleration of the object are negative.

1.8 EQUATIONS OF UNIFORMLY-ACCELERATED MOTION

There are three equations of motion of bodies which travel with a uniform acceleration. These equations give relationship between initial velocity (u), final velocity (v), time taken (t), acceleration (a), and distance travelled (s) by the body. The equations relating various quantities in motion with uniform acceleration are called equations of motion.

(a) First equation of motion is $v = u + at$

(b) Second equation of motion is $s = ut + \frac{1}{2}at^2$

(c) Third equation of motion is $v^2 = u^2 + 2as$

Let us discuss these equations in detail.

First Equation of Motion

The first equation of motion gives the velocity acquired by a body in time 't'. Let us derive the first equation of motion.

Consider a body having initial velocity 'u', which is subjected to a uniform acceleration 'a' for time 't' seconds, such that the final velocity of the body becomes 'v'.

Rate of change of velocity = $\frac{v-u}{t}$

Now, from the definition of acceleration, we get

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

$$\text{Acceleration} = \frac{\text{Final velocity} - \text{Initial velocity}}{\text{Time taken}}$$

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

$$at = v - u$$

$$v = u + at$$

The first equation of motion has been derived. This first equation has four quantities in it, if any three are known the fourth can be calculated.

Second Equation of Motion

Consider a body having an initial velocity 'u' acted upon by a uniform acceleration 'a' for time 't' seconds, such that the final velocity becomes 'v' and the distance covered is 's'.

Now,

$$\text{Average velocity} = \frac{\text{Initial velocity} + \text{Final velocity}}{2}$$

$$\text{Average velocity} = \frac{u+v}{2}$$

But,

$$\text{Distance} = \text{Average velocity} \times \text{Time}$$

$$s = \frac{(u+v)}{2} \times t \qquad ....(1)$$

Substituting the value of 'v' from first equation of motion *i.e.*, $v = u + at$, we get

$$s = \frac{(2u + at)}{2} \times t$$

$$s = \left(\frac{2u}{2} + \frac{at}{2}\right) \times t$$

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

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

The second equation of motion can be used to calculate the distance travelled by a body in time 't'.

Third Equation of Motion

Consider a body having an initial velocity 'u' moving with uniform acceleration 'a' for time 't' seconds, such that the final velocity becomes 'v' and the distance covered is 's'.

From 1st equation of motion, we get

$$v = u + at \qquad ....(1)$$

From 2nd equation of motion, we get

$$s = ut + \frac{1}{2}at^2 \qquad ....(2)$$

Rearranging the 1st equation of motion, we get

$$t = \frac{v - u}{a} \qquad ....(3)$$

Substituting the value of 't' from (3) in (2) we get,

$$s = \frac{u(v-u)}{a} + \frac{1}{2}a\left(\frac{v-u}{a}\right)^2$$

$$s = \frac{uv - u^2}{a} + a\left(\frac{v^2 + u^2 - 2uv}{2a^2}\right) \qquad ....(4)$$

$$[\because (v - u)^2 = v^2 - 2vu + u^2]$$

$$s = \frac{uv - u^2}{a} + \frac{v^2 + u^2 - 2uv}{2a}$$

$$s = \frac{2uv - 2u^2 + v^2 + u^2 - 2uv}{2a}$$

$$s = \frac{v^2 - u^2}{2a}$$

$$2as = v^2 - u^2$$

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

The third equation of motion gives us the velocity acquired by the body in travelling a distance 's'.

Note

- If a body starts from rest, its initial velocity, $u = 0$
- If a body comes to rest or stops, its final velocity, $v = 0$
- If a body moves with uniform velocity, its acceleration, $a = 0$

Let us solve numericals based on equations of motion.

Numericals Based on the Equations of Motion

1. A truck attains a speed of 10 m s^{-1} in 10 s starting from rest. Calculate the acceleration of the truck.

Solution : Given,

Initial velocity, $u = 0$ m s^{-1}

Final velocity, $v = 10$ m s^{-1}

Time, $t = 10$ s

Acceleration, $a = ?$

Substituting the values in the equation $v = u + at$, we get

$$10 = 0 + a \times 10$$

$$a = \frac{10}{10} = 1 \text{ m s}^{-2}$$

2. Find the initial velocity of a bike which is stopped in 10 s by applying brakes. The retardation due to brakes is 2.5 m s^{-2}.

Solution :

Given,

Final velocity, $v = 0$ m s^{-1}

Retardation, $a = -2.5$ m s^{-2}

Time, $t = 10$ s

Initial velocity, $u = ?$

Substituting the values in the equation $v = u + at$, we get

$$0 = u + (-2.5) \times 10$$

$$0 = u - 25$$

$$u = 25 \text{ m s}^{-1}$$

3. A body starting from rest travels with uniform acceleration. If it travels 100 m in 5 s, then what is the value of acceleration?

Solution : Given,

Initial velocity, $u = 0$

Distance, $s = 100$ m

Time, $t = 5$ s

Acceleration, $a = ?$

Substituting the values in the equation, $s = ut + \frac{1}{2}at^2$, we get

$$100 = 0 \times 5 + \frac{1}{2} \times a \times 5^2$$

$$100 = \frac{25a}{2}$$

$$25a = 200$$

$$a = \frac{200}{25} = 8 \text{ m s}^{-2}$$

4. A car is moving at a uniform speed of 72 km h^{-1}. The driver sees a child at a distance of 50 m and applies brakes to stop the car just before it touches the child. Calculate the acceleration.

Solution : Given,

Initial velocity, $u = 72 \text{ km h}^{-1}$

$$= \frac{72 \times 1000}{60 \times 60} \text{ m s}^{-1}$$

$$= 20 \text{ m s}^{-1}$$

Distance, $s = 50$ m

Final velocity, $v = 0$

Acceleration, $a = ?$

Substituting the values in the equation, $v^2 = u^2 + 2as$ we get,

$$0 = 20^2 + 2 \times a \times 50$$

$$100\,a = -\,400$$

$$a = -\frac{400}{100} = -\,4 \text{ m s}^{-2}$$

TRY YOURSELF

1. A truck starts from rest and accelerates at 3 m s^{-2} for 5 s and then continues with constant velocity. Calculate the distance covered in 15 s since it starts from rest. **[Ans : 187.5 m]**
2. The velocity of an object increases at a constant rate from 20 m s^{-1} to 50 m s^{-1} in 10 s. Find the acceleration. **[Ans : 3 m s^{-2}]**
3. A body starts from rest and acquires a velocity of 10 m s^{-1} in 2 s. Find the acceleration. **[Ans : 5 m s^{-2}]**
4. A body is moving vertically upwards. Its velocity changes at a constant rate from 50 m s^{-1} to 20 ms^{-1} in 3 s. What is its acceleration? **[Ans : –10 m s^{-2}]**
5. A car has a uniform acceleration of 4 m s^{-2}. What distance will it cover in 10 s after start? **[Ans : 200 m]**

PAPER -PEN TEST : 5

1. What is meant by variable velocity? Give an example.
2. When can we say the motion is accelerated and when is it decelerated?
3. Define acceleration with an example.
4. When is acceleration taken positive and negative?
5. How do you express acceleration?
6. What will be the acceleration if the change in velocity of an object is zero or an object is moving with uniform velocity?
7. What are the different types of acceleration?
8. Derive the third equation of motion.
9. How is negative acceleration denoted?
10. What do you understand by the term 'positive acceleration'? Give an example.
11. What are the three equations of motion?
12. Differentiate uniform and non-uniform acceleration with an example for each.
13. Derive the first equation of motion.
14. What is meant by negative acceleration? Give an example.
15. Derive the second equation of motion.

1.9 GRAPHICAL REPRESENTATION OF MOTION

A graph is a straight or curved line, which shows how one quantity varies with the variation of another quantity. In other words, a graph shows the relation between two variable quantities. The quantity that does not alter with respect to change in other quantity is called the independent variable while the quantity which varies as a result of change in the other is called dependent variable. The independent quantity is shown along x-axis while the dependent quantity is shown along y-axis. Thus, we can say that a graph gives the basic information about a number of events.

Importance of Graphs

Graphs enable us to :

(a) Study complex information in a simple and understandable format.

(b) Compare and analyze data.

(c) Study the nature of physical phenomena such as motion and simple harmonic oscillation.

(d) Verify laws and principles such as Newton's Laws of motion.

How to Plot a Graph

In order to represent observations in the form of a graph, we need to follow these steps :

(a) Prepare table showing two variables. One is the independent variable while the other is the dependent variable.

(b) The independent variable is marked along x-axis while the dependent variable is marked along y-axis.

(c) Compare the range of variations and make a suitable choice of scale.

(d) Now, write the units on x-axis and y-axis.

(e) Mark the points corresponding to different observations.

Let us now discuss the various types of graphs which can be used to calculate 'speed', 'distance' and 'acceleration' of a body. In the graph, the terms 'speed' and 'velocity' are used in the same sense. We can study the nature of motion from these different types of graphs. Graphs drawn to study the nature of motion of an object is called kinematic graphs.

Kinematic Graphs

There are four types of kinematic graphs, namely

(a) Distance – time graph

(b) Displacement – time graph

(c) Velocity – time graph

(d) Acceleration – time graph

In the above two graphs, time is an independent variable and so, always shown along x-axis. The other variables such as '*velocity*', '*distance*', '*displacement*', and '*acceleration*' are dependent variables and so are always shown along y-axis.

Note

- You will study acceleration – time graph in your higher classes.

(a) Distance–Time Graph

A graph showing the change in the position of an object *i.e.,* distances covered with the change in time is called its distance-time graph.

When an object is moving with uniform velocity, the slope of the graph is always a straight line. The slope of a distance-time graph (fig 1.38) shows that the object is moving with uniform speed.

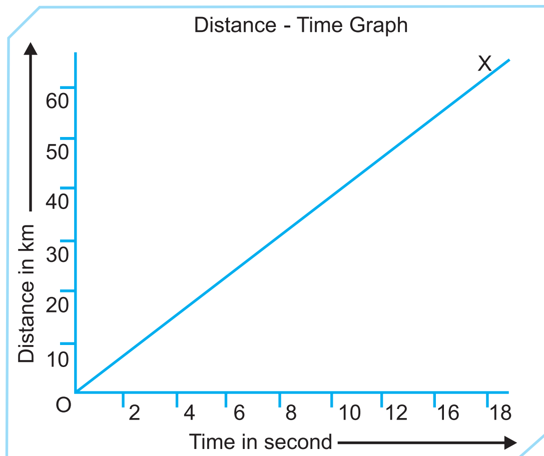


Fig 1.38 : Distance-time graph

The slope OX shows the speed of the object.

Calculation of speed using Distance-Time Graph

To calculate the speed, take two points A and B on the slope OB as shown in (fig. 1.39). Draw one line parallel to y-axis and another parallel to x-axis from B. Similarly, draw a line parallel to y-axis and another parallel to x-axis from point A.

Let the line parallel to x-axis from point B cut the y-axis at a point s_2 and the line parallel to x-axis from point A cut the y-axis at point, s_1. Let the line parallel to y-axis from point B cut the x-axis at t_2 and the line parallel to y-axis from point A cut the x-axis at t_1 (fig 1.39).

Now, BC = Distance = $s_2 - s_1$, and

AC = time = $t_2 - t_1$

We know that slope of the graph is given by the ratio of change in y-axis and change in x-axis.

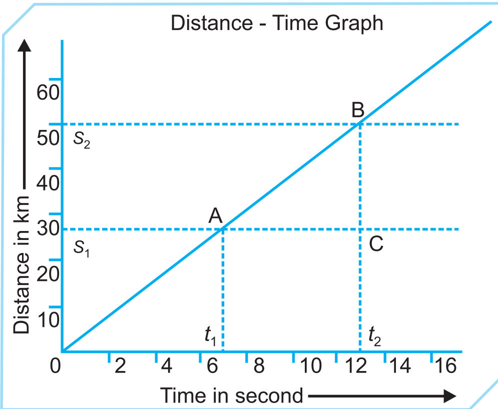


Fig 1.39 : Calculation of velocity using distance-time graph

$$\text{Slope} = \frac{\text{Change in } y\text{-axis}}{\text{Change in } x\text{-axis}}$$

$$\text{Slope AB} = \frac{\text{BC}}{\text{AC}}$$

$$v = \frac{(s_2 - s_1)}{(t_2 - t_1)}$$

Where, v = velocity,

$(s_2 - s_1)$ = interval of distance and,

$(t_2 - t_1)$ = time interval

Thus, $$\text{speed} = \frac{\text{Distance}}{\text{Time}}$$

Let us now discuss the distance-time graph for the following three cases :

Case 1 : When the body is at rest.

Case 2 : When the body is in uniform motion.

Case 3 : When the body is in non-uniform motion.

Distance–Time Graph :

(i) When the Body is at Rest

In this case the position of the object does not change with time and hence, it is said to be stationary. Thus, the distance-time graph of such a body will be a straight line parallel to x-axis or time-axis as shown in fig (1.40)

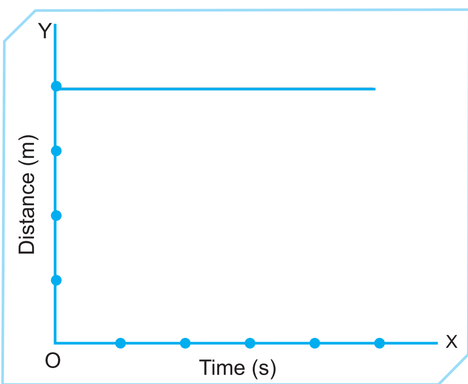


Fig 1.40 : Distance-time graph for a body at rest

(ii) When the Body is in Uniform Motion

The position of the object changes by equal amount in equal intervals of time. Thus, the distance-time graph of such a body will be a straight line inclined to x-axis or time-axis (fig 1.41).

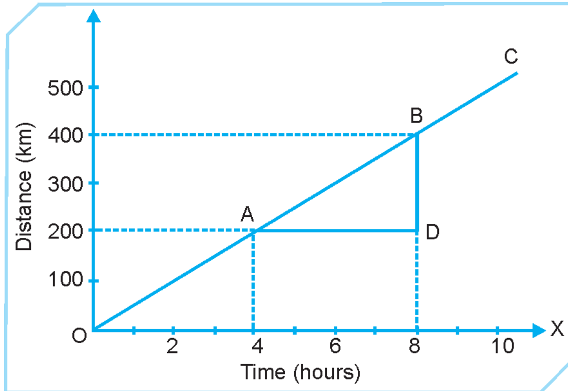
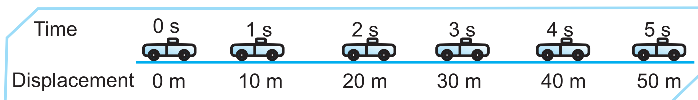


Fig 1.41 : Distance-time graph showing uniform motion

For example, a car moving on a straight path in a given direction with a uniform speed.

Time in sec	0	1	2	3	4	5
Distance in m	0	10	20	30	40	50

Consider the table above represents its distance from the starting point with time.



The distance-time graph obtained is a straight line OA inclined to the time-axis (fig. 1.42). The graph shows that the distance of a car is proportional to the time. Thus, for a body moving with uniform speed, the distance is proportional to the time. Therefore, $s \propto t$.

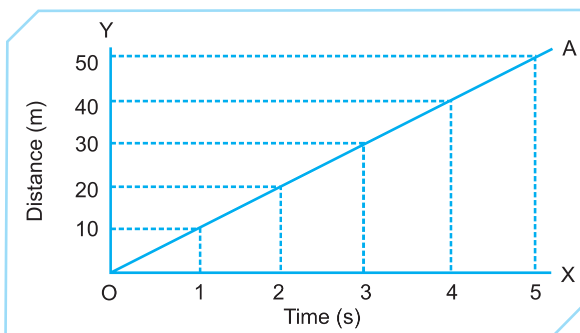


Fig 1.42 : Distance time graph

Now, let us find the speed of the car from the slope of the straight line OA. For this, we need to take two points P and Q on the line OA and draw perpendiculars PR and QS on the y-axis and PT and QV on the x-axis (fig 1.43).

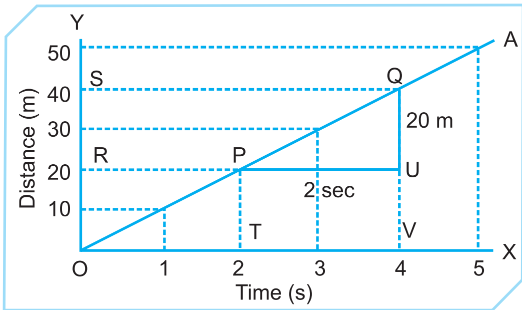


Fig 1.43 : Distance-time graph

From the graph, we get

Speed of car = Slope of the line OA

$$= \frac{QU}{UP} = \frac{SR}{VT}$$

$$= \frac{40-20}{4-2} = \frac{20\,m}{2\,s}$$

$$= 10 \text{ m s}^{-1}$$

(iii) When the Body is in Non-uniform Motion

When a graph is plotted between distance and time for an object moving with accelerated motion, *i.e.*, with increasing non-uniform speed, the slope of the graph will not be a straight line (fig. 1.44). The rising trend of slope shows the increasing trend of speed. This curved line is a parabola.

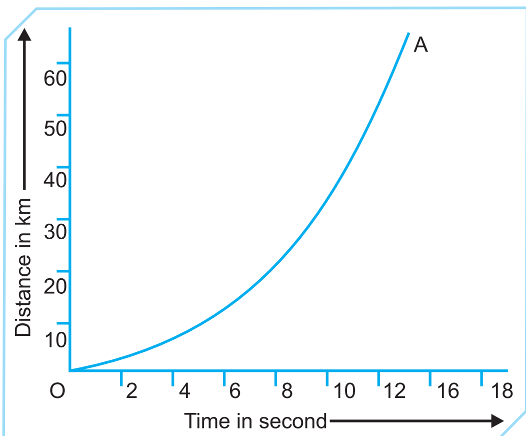


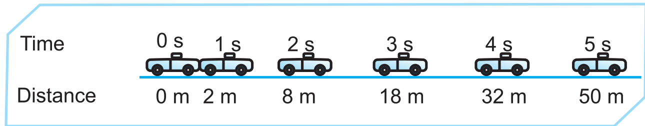
Fig 1.44 : Distance-time graph of an object in accelerated motion

For example, assume that a car is moving on a curved path in a given direction with non-uniform speed as shown in the figure given below.

Example of a car moving with a non-uniform speed

Consider the table below representing the distance from the starting point with time.

Time in sec	1	2	3	4	5
Distance in m	2	8	18	32	50



Graph is plotted between different distances at different intervals of time (fig 1.45).

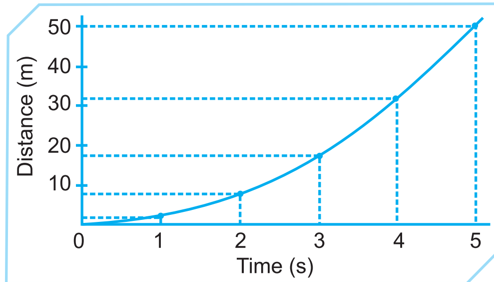


Fig. 1.45 : Distance-time graph

The speed of body at time t = 4 s or when the distance, s = 30 m (fig 1.46) is obtained by finding the slope of the tangent QS to the curve drawn at the point P corresponding to t = 4 s or s = 30 m.

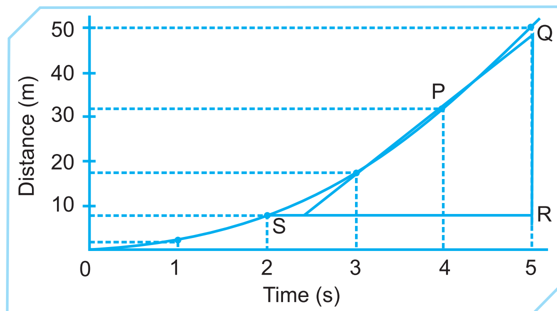


Fig 1.46 : Distance-time graph

Now let us find the speed of the car by finding the slope,

$$\text{Slope} = \frac{QR}{RS}$$

$$= \frac{50-10}{5-2} = \frac{40}{3}$$

$$= 13.33 \text{ m s}^{-1}$$

Conclusions drawn from Distance-Time Graph

From the above discussion, we can conclude that

1. If the graph is a straight line inclined to the time-axis, then the motion has uniform velocity.
2. If the graph is a curve, then the motion has non-uniform speed.
3. The slope of the straight line or the tangent to the curve at any instant gives the speed of the object at that instant.
4. The graph can never be parallel to the distance axis because it shows that the distance increases

indefinitely without any increase in time, which is impossible.

PAPER -PEN TEST : 6

1. What is meant by an independent variable?
2. Define a graph.
3. What is a dependent variable?
4. Mention the significance of a graph.
5. What is a distance-time graph? Explain.
6. How do you plot a graph?
7. Discuss the distance-time graph when the body is in uniform motion.
8. What do you understand by the term 'kinematic graph'?
9. Discuss the distance-time graph when the body is in non-uniform motion.
10. How do you calculate velocity from a distance-time graph?
11. What are the different types of kinematic graphs?
12. Discuss the distance-time graph when the body is at rest.
13. What are the conclusions obtained from the distance-time graph?

(b) Displacement – Time Graph

A graph showing the change in position of an object *i.e.,* displacement with the change in time is called its displacement-time graph. In the displacement–time graph, the time is taken on the X–axis and the displacement of the body is taken on the Y-axis.

Since velocity is the ratio of displacement and time, the slope of the displacement–time graph gives the velocity.

Let us now discuss the displacement-time graph for the following three cases :

Case 1 : When the body is at rest

Case 2 : When the body is in uniform motion

Case 3 : When the body is in non-uniform motion

Displacement – Time Graph when the Body is at Rest

If the position of the body does not change with time, then the body is said to be stationary. The displacement–time graph is a straight line parallel to the time axis (fig 1.47).

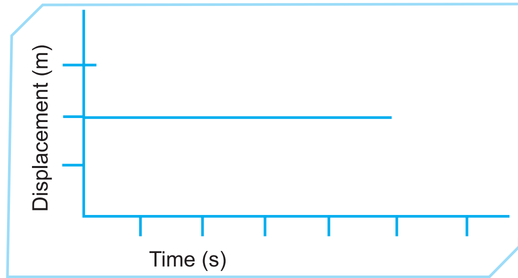


Fig 1.47 : Displacement – Time graph

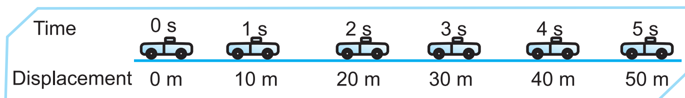
Displacement – Time Graph when the Body is in Uniform Motion

If a body is moving with uniform velocity, the displacement – time graph is a straight line inclined to the time axis. The velocity of the body can be obtained by finding the slope of the straight line.

For example, assume that a car is moving on a straight path in a given direction with a uniform speed.

Consider the table below that represents its displacement from the starting point with time.

Time in sec	0	1	2	3	4	5
Displacement in m	0	10	20	30	40	50



The displacement-time graph obtained is a straight line OA inclined to the time-axis (fig 1.48). The graph shows that the displacement of the car is proportional to the time. Thus, for a body moving with uniform speed or velocity, the displacement is proportional to the time. Therefore, $s \propto t$.

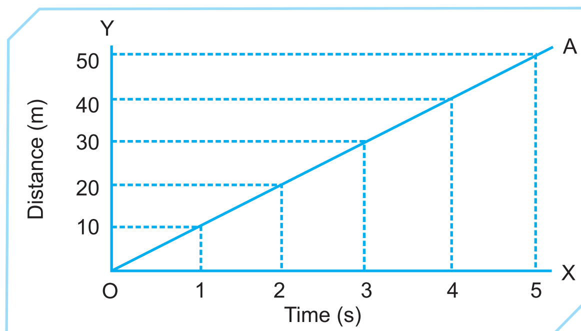


Fig 1.48 : Displacement – Time graph

Now, let us find the velocity of the car by finding the slope of the straight line OA. For this, we need to take two points P and Q on the line OA and draw perpendiculars PR and QS on the *y*-axis and PT and QV on the *x*-axis (fig 1.49).

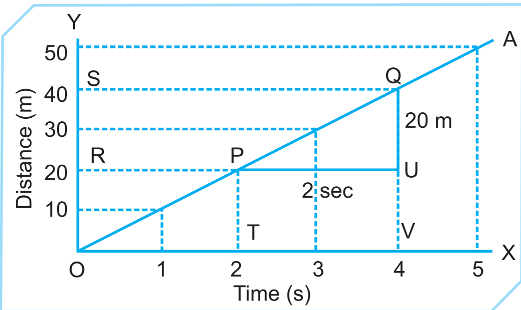


Fig 1.49 : Displacement - Time graph

From the graph, we get

Velocity of the car = Slope of the line OA

$$= \frac{QU}{UP} = \frac{SR}{VT}$$

$$= \frac{40-20}{4-2} = \frac{20}{2} = 10 \text{ m s}^{-1}$$

The displacement–time graph is a straight line OA inclined to the time axis. It shows that the displacement of car is proportional to the time and it travels equal distances in equal intervals of time in a certain direction. Thus for a body moving with uniform velocity, the displacement is proportional to the time.

Note

- The displacement-time graph can never be a straight line parallel to the displacement axis because it shows that the distance covered by the body in a certain direction is increasing without any increase in time. Thus, the velocity of the body is infinite which is impossible.

Displacement – Time Graph when the Body is in Non-uniform Motion

When a graph is plotted between distance and time for an object moving with accelerated motion, *i.e.*, with increasing non-uniform speed, the slope of the graph will not be a straight line (fig 1.50). The rising trend of the slope shows the increasing trend of velocity. The curved line is called a parabola.

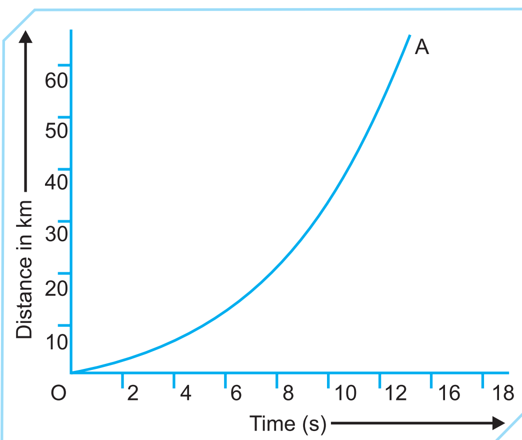
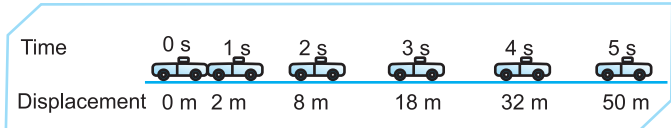


Fig 1.50 : Displacement – Time graph for non-uniform motion

For example, assume that a car is moving on a curved path in a given direction with a non-uniform speed.

Consider the table below represents its distance from the starting point with time.

Time in sec	0	1	2	3	4	5
Displacement in m	0	2	8	18	32	50



We obtain the following graph (fig 1.51) from the above table.

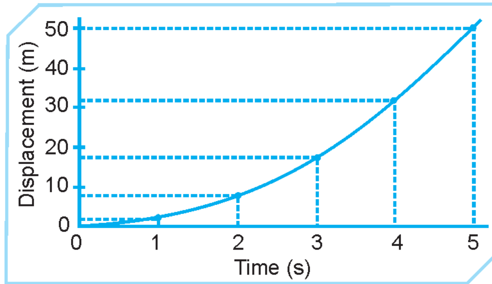


Fig 1.51 : Displacement – Time graph for non-uniform motion

The velocity of the body at time, t = 4 s or when the displacement, s = 30 m is obtained by finding the slope of the tangent QS to the curve drawn at the point P corresponding to t = 4 s or s = 30 m.

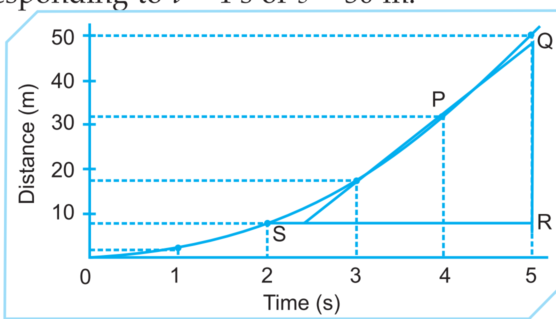


Fig 1.52 : Displacement – Time graph for non-uniform motion

Now let us find the velocity of the car by finding the slope, (fig 1.52)

$$\text{Slope} = \frac{QR}{RS} = \frac{50-10}{5-2} = \frac{40}{3}$$

$$= 13.3 \text{ m s}^{-1}$$

Note

- If the slope of the displacement–time graph is negative it means that the body is returning to its starting point.

Conclusion of Displacement-time graph

(a) From the displacement—time graph of an object, we can know the nature of motion of the object. If the graph is a straight line inclined to the time axis, the motion has uniform velocity. On the other hand, if the graph is a curve, the motion has non-uniform velocity.

(b) The slope of the straight line gives the velocity of the object at that instant.

Significance of Distance/Displacement – Time Graph

The following are the uses of distance/displacement-time graph :

(a) The position of the body at any intermediate time can be found out.

(b) The slope of the tangent gives the instantaneous velocity at that moment.

(c) The average velocity is the slope of the line passing through the initial and final position on the curve.

(d) The nature of motion can be determined.

(e) The curve is a parabola if the motion is non-uniformly accelerated.

PAPER - PEN TEST : 6

1. What is a displacement-time graph?
2. Discuss the displacement-time graph when the body is in uniform motion.
3. What does the slope in a displacement-time graph give?
4. Discuss the displacement-time graph when the body is at rest.
5. Can the displacement-time graph be a straight line? Justify your answer.
6. If the slope of the displacement–time graph is : negative, what does it mean?
7. Discuss the displacement-time graph when the body is in non-uniform motion.
8. What conclusions are obtained from the Displacement-time graph?
9. Mention the significance of the displacement-time graph.

(c) Velocity–Time Graph

The graph which shows the variation of speed of a moving object with the passage of time is called speed-time graph or velocity-time graph. The time is taken on the X-axis and the velocity is taken on the Y-axis.

Let us determine the following from the velocity-time graph.

(i) the displacement of the body in a certain time interval and

(ii) the acceleration of the body.

Determination of Displacement from Velocity – Time Graph

Since, Velocity × Time = Displacement

The area enclosed between the velocity-time graph and the x-axis gives the displacement of the body.

The area enclosed above the time axis is the positive displacement *i.e.,* the distance travelled away from the origin while the area enclosed below the time axis is negative displacement *i.e.,* the distance travelled towards the origin. The total displacement can be obtained by adding them with the proper numerical signs. The total distance travelled by the body is their arithmetic sum.

Determination of Acceleration from Velocity– Time Graph

Since acceleration is equal to the ratio of the change in velocity with time, the slope or gradient of the velocity- time graph gives the acceleration. If the slope is positive, it is an accelerated motion and if the slope is negative, the motion is decelerated or retarded.

Since velocity is a vector quantity, a positive velocity means that the body is moving in a certain direction away from its initial position and a negative velocity means that the body is moving in the opposite direction.

Let us now discuss the velocity-time graph for the following three cases:

Case 1 : When there is no acceleration of the body.

Case 2 : When the acceleration of the body is uniform.

Case 3 : When the acceleration of the body is non-uniform.

Velocity – Time Graph

(i) When there is no acceleration of the body.

If the speed of the body is constant, then there is no change in the speed with time and hence, there will be no acceleration. Thus, the velocity-time graph for a body moving with a constant speed will be a straight line parallel to the time-axis (fig 1.53).

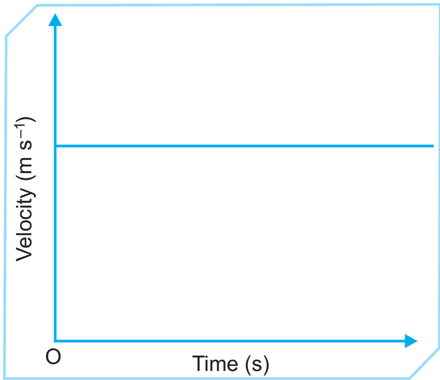


Fig 1.53 : Velocity-time graph showing constant speed

In other words, if the velocity-time graph is a straight line parallel to the time-axis, then the speed of the body is constant. Since the speed of the body is constant, there is no acceleration. However, we can find the distance travelled by the body in a given interval of time.

From (fig 1.54), we need to find the distance travelled by the body at point 'Z'. Draw a perpendicular ZY at point Z which meets the straight line graph at point Y.

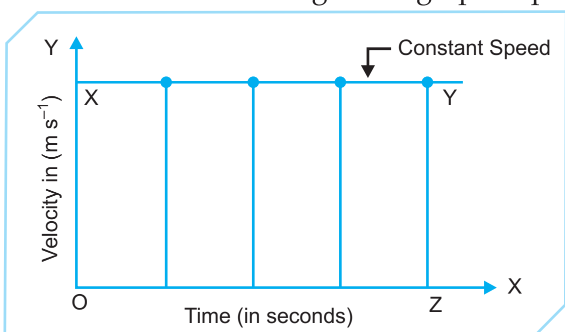


Fig 1.54 : Velocity- time graph

We know that,

$$\text{Speed} = \frac{\text{Distance travelled}}{\text{Time taken}}$$

Now,

Speed at Z = ZY

But, ZY = OX

Thus, the speed at Z = OX

Time at Z = OZ

Substituting the values in,

$$\text{speed} = \frac{\text{Distance travelled}}{\text{Time taken}}$$

We get,

Distance Travelled by the body = OX × OZ

Distance Travelled by the body = Area of rectangle OXYZ

Thus, in this graph, the area enclosed by the velocity-time curve and the time-axis gives us the distance travelled by the body.

Velocity – Time Graph

(ii) When the acceleration of the body is uniform

If the body is in motion with uniform acceleration *i.e.,* equal changes in velocity take place in equal intervals of time, then the velocity–time graph will be a straight line inclined to the time axis (fig 1.55).

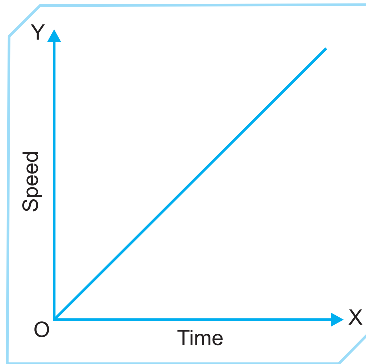


Fig 1.55 : Speed-time graph

In the above graph, we assume that the initial speed of the body is zero. However, it is possible that body has some initial speed and it then starts accelerating at a uniform rate.

Now, in order to find out the value of acceleration at a point R from the velocity-time graph of a moving body, draw a perpendicular RQ from R which touches the straight line graph at point Q (fig 1.56).

We know that,

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

The change in the speed or velocity = QR

The time taken = OR

Substituting the values, we get

$$\text{Acceleration} = \frac{QR}{OR}$$

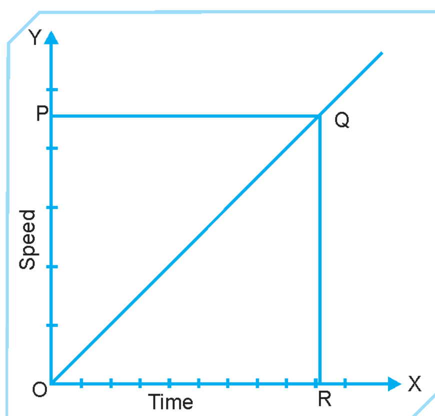


Fig 1.56 : Speed-time graph

But $\frac{QR}{OR}$ is the slope of the velocity-time graph OQ. Therefore, we can conclude that in a velocity-time graph, the acceleration is given by the slope of the graph.

Now, let us calculate the distance travelled by a moving body from velocity-time graph.

In the graph, the distance travelled by the body in time corresponding to point Q will be equal to the area of triangle OQR.

Thus,

Distance Travelled = Area of triangle OQR

$$\text{Distance Travelled} = \frac{1}{2} \text{ Area of rectangle OPQR}$$

$$= \frac{1}{2} \times OP \times OR$$

Note

- In velocity-time graph of a body, a straight line sloping upwards shows uniform acceleration. On the other hand, a straight line sloping downwards shows uniform retardation (fig 1.57)

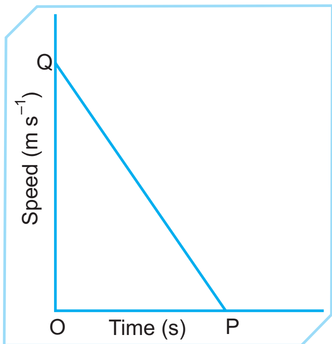


Fig 1.57 : Speed-time graph

Let us now discuss the velocity-time graph of a body whose initial speed is not zero.

The graph shows that the body has an initial speed of OA and then accelerates from A to B (fig 1.58).

Now, in order to calculate the acceleration, we need to subtract the initial speed from the final speed and then divide it by time.

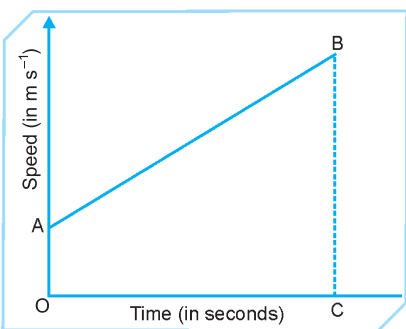


Fig. 1.58 : Speed-time graph

We know that,

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

The initial speed in the graph = OA

The final speed in the graph = BC

Time taken = OC

Hence, $$\text{Acceleration} = \frac{BC - OA}{OC}$$

Now, in this case too the distance travelled by the body in a given time is equal to the area enclosed by the velocity-time graph and the time-axis.

In the graph, the distance travelled by the body in time OC will be,

Distance travelled in time OC = Area of OABC under the velocity-time graph AB

The area OABC has two parallel sides OA and CB making it a trapezium. Thus,

Distance travelled in time OC = Area of the trapezium OABC

Area of the trapezium =

$$\frac{\text{Sum of two parallel sides} \times \text{Height}}{2}$$

Thus, substituting the values, we get

$$\text{Distance} = \frac{(OA + CB) \times OC}{2}$$

Velocity – Time Graph

(iii) When the acceleration of the body is non-uniform

When the speed of the body changes in an irregular way, then the velocity-time graph of the body can have any shape. Here, the distance travelled by the body is equal to the area enclosed by the velocity-time curve and the time axis (fig 1.59).

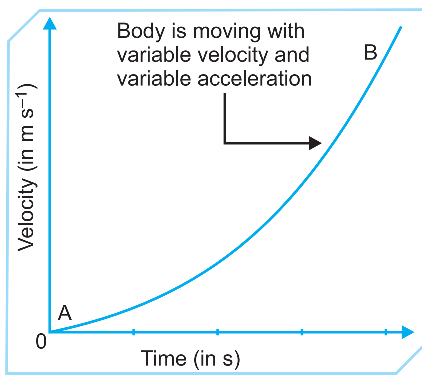


Fig 1.59 : Velocity-time graph showing non-uniform acceleration

Thus we conclude that,

(i) For motion with a uniform velocity, the velocity – time graph is a straight line parallel to the time axis. If the velocity–time graph is a straight line inclined to the time axis, the motion has a uniform acceleration. But if the graph is a curve, the motion has a non-uniform acceleration.

(ii) The slope of the straight line gives the acceleration at that instant. A positive slope means that the velocity is increasing with time while a negative slope means that the velocity is decreasing with time.

(iii) The area enclosed by the velocity–time sketch and time axis for a certain time interval gives the displacement in that interval of time.

(iv) The velocity – time graph can never be a straight line parallel to the velocity axis because it would mean that the velocity is increasing without any increase in time *i.e.*, acceleration is infinite which is impossible.

(v) If the body initially is not at rest, but moving with some uniform velocity and then accelerates on the application of force, the velocity – time sketch will not start from the origin, but from the point on the velocity axis corresponding to the initial velocity of the body.

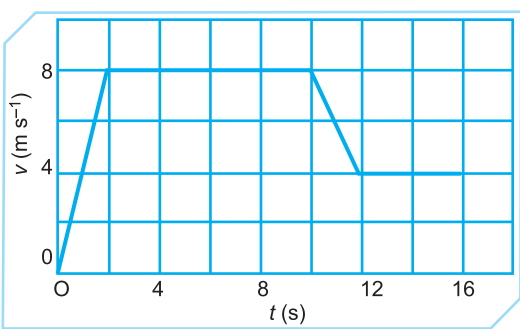
SOLVED NUMERICAL

1. Consider the motion of the object whose velocity-time graph is given in the figure below :

   (a) What is the acceleration of the object between the times t = 0 and t = 2 ?

   (b) What is the acceleration of the object between the times t = 10 and t = 12 ?

   (c) What is the net displacement of the object between the times t = 0 and t = 16 ?



Solution : (a) The v-t graph is a straight-line between t = 0 and t = 2, indicating constant acceleration during this time period. Hence,

$$a = \frac{\Delta v}{\Delta t} = \frac{8-0}{2} = 4 \text{ m s}^{-2}$$

(b) The v-t graph is a straight-line between t = 10 and t = 12, indicating constant acceleration during this time period. Hence,

$$a = \frac{\Delta v}{\Delta t} = \frac{4-8}{2} = -\ 2 \text{ m s}^{-2}$$

The negative sign indicates that the object is decelerating.

(c) The net displacement between times t = 0 and t = 16 is equal to the area under the v-t curve, evaluated between these two times. Recalling, that the area of a triangle is half of its width times its height, the number of grid-squares under the v-t curve is 25.

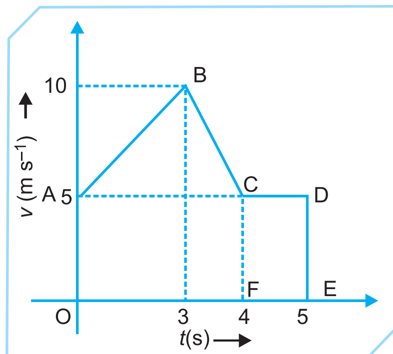
The area of each grid-square is 2 × 2 = 4 m. Hence,

The net displacement = 4 × 25 = 100 m

2. From the velocity-time graph, find

   (a) The deceleration of the body in the part BC as shown in figure below.

   (b) The total distance travelled by the body.



Solution :

From the graph, we get

Deceleration = Slope of BC

$$= \frac{10-5}{4-3} = 5 \text{ m s}^{-2}$$

Total distance travelled by the body = Area of triangle ABC + Area of rectangle OADE,

Total distance travelled by the body

$$= \left(\frac{1}{2}\times 4\times 5\right) + (5 \times 5)$$

= 35 m

TRY YOURSELF

1. The table below shows a body moving in a straight line and its displacements at various instants of time.

Time in sec	0	1	2	3	4	5	6	7
Displacement in metre	4	6	10	10	10	16	20	24

Plot the displacement-time graph and calculate the average velocity in the time interval of 1 s to 5 s.

[Ans : 2.5 m s^{-1}]

2. A bus travels with uniform velocity of 20 m s^{-1} for 5 s. The brakes are then applied and the bus is uniformly retarded and comes to rest in further 8 s. Draw a graph of velocity-time and find
   (a) The distance travelled in the first 5 s.
   (b) The distance travelled after the brakes are applied.
   (c) The total distance travelled.
   (d) The acceleration during the first 5 s and last 8 s.

   [Ans : (a) 100 m; (b) 80 m; (c) 180 m ; (d) – 2.5 m s^{-2}]

3. A ball is thrown vertically upwards with an initial velocity of 40 m s^{-1}. Draw the velocity-time graph of the motion of the ball till it returns the ground. Find:
   (a) The maximum height reached by the ball.
   (b) The total distance covered by the ball.
   (c) The net displacement.

   [Ans : (a) 80 m ; (b) 160 m ; (c) zero]

PAPER-PEN TEST : 8

1. What is a velocity-time graph?
2. How will you determine acceleration from the velocity-time graph?
3. What we can determine from the velocity-time graph?
4. Discuss the velocity-time graph when the acceleration of the body remains constant.
5. How will you determine displacement from a velocity-time graph?
6. Discuss the velocity-time graph when the acceleration of the body is uniform.
7. What does the slope of the velocity-time graph give?
8. What are the conclusions obtained from the velocity-time graph?
9. Discuss the velocity-time graph when the acceleration of the body is non-uniform.
10. Why can the velocity–time graph never be a straight line?

1.10 TO DERIVE THE EQUATIONS OF MOTION BY GRAPHICAL METHOD

We know that the three equations of motion are,

(a) The relation between initial velocity (u), final velocity (v), acceleration (a), and time (t) is known as the first equation of motion or equation for velocity-time relation. It is given by $v = u + at$

(b) The relation between the distance travelled (s), initial velocity (u), acceleration (a), and time (t) is known as the second equation of motion or equation for position-time relation. It is given by $s = ut + \frac{1}{2}at^2$

(c) The relation between initial velocity (u), final velocity (v), acceleration (a) and distance travelled (s) by the body is known as third equation of motion or equation for position velocity relation. It is given by $v^2 = u^2 + 2as$.

Let us derive the first equation of motion.

Derivation of the First Equation of Motion $v = u + at$ by Graphical Method

In the velocity–time graph of a body the initial velocity of a body is u at point P. Then , its velocity changes at a uniform rate from P to Q in time t. In other words, we can say that there is a uniform acceleration a from P to Q and after t its final velocity becomes v which is equal to QC in the graph (fig 1.60).

In the graph, the time t is represented by OC. In order to complete the figure, we need to draw the perpendicular CQ from point C and draw PR parallel to OC and also PS is the perpendicular from point Q to OS.

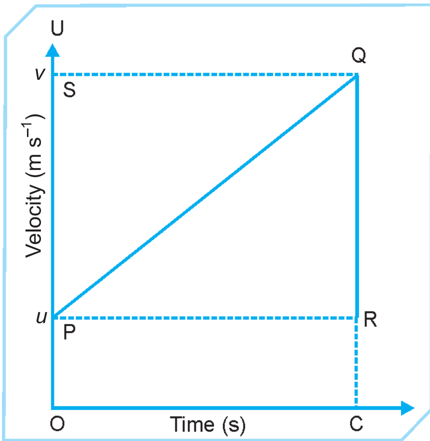


Fig 1.60 : Velocity – Time graph

Initial velocity of the body, u = OP ....(1)

Final velocity of the body, v = QC ....(2)

But from the graph QC = QR + RC

∴ v = QR + RC ....(3)

Again RC = OP

∴ v = QR + OP

From equation (1), we get

OP = u

∴ v = QR + u ....(4)

We should find out the value of QR now. We know that the slope of a velocity–time graph is equal to acceleration a.

Acceleration, a = slope of line PQ

$$a = \frac{QR}{PR}$$

But, PR = OC ='t', so substituting 't' in place of PR in the above equation we get,

$$a = \frac{QR}{t} \Rightarrow QR = at$$

Substituting the QR value in equation (4), we get

$$v = u + at$$

Hence the first equation of motion has been derived graphically.

Derivation of the Second Equation of Motion $s = ut + \frac{1}{2} at^2$ by Graphical Method

Let us consider a body travels a certain distance in time 't'. Now in velocity-time graph, the area enclosed by OPQC shows the distance travelled by the body. Thus,

Distance travelled = Area of rectangle OPRC + Area of the triangle PQR

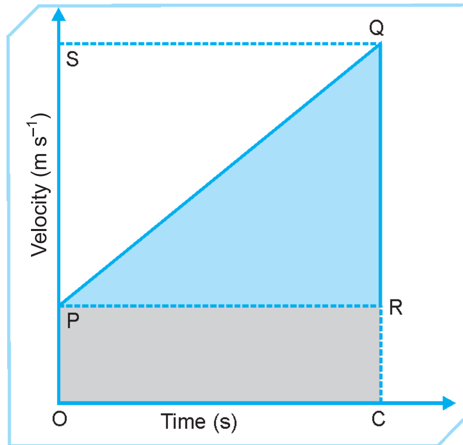


Fig 1.61 : Velocity-time graph

We will now find out the area of the rectangle OPRC and the area of the triangle PQR (fig 1.61).

(i) Area of the rectangle, OPRC = OP × OC

$= u \times t$

$= ut$

(ii) Area of the triangle PQR = $\frac{1}{2}$ × area of rectangle PSQR

$= \frac{1}{2} \times PR \times QR$

$= \frac{1}{2} \times t \times at$

$= \frac{1}{2} at^2$

Distance travelled s = Area of the rectangle OPRC + Area of the triangle PQR

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

Hence, the second equation of motion has been derived graphically.

Derivation of the Third Equation of Motion $v^2 = u^2 + 2as$ by Graphical Method

In the above derivation, the distance travelled s by a body in time t is given by the area of the figure OPQC which is a trapezium.

Similarly,

Distance travelled

$$s = \text{Area of trapezium OPQC}$$

$$s = \frac{(\text{sum of parallel sides}) \times \text{Height}}{2}$$

$$s = \frac{(OP + CQ) \times OC}{2}$$

Where, OP + CQ = $u + v$ and OC = t

Substituting these values in the above relation, we get

$$s = \frac{(u+v) \times t}{2} \qquad ....(i)$$

We now want to eliminate 't' from the above equation. This can be done by obtaining the value of 't' from the first equation of motion.

$$v = u + at$$

$$at = v - u$$

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

Substituting value of t in the equation (i) we get

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

We get,

$$2as = v^2 - u^2 \left[\because (v+u)(v-u) = v^2 - u^2\right]$$

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

The third equation of motion thus has been derived graphically.

1.11 UNIFORM CIRCULAR MOTION

The circular motion of a body having uniform or constant speed is known as uniform circular motion. At any instant the direction of motion of a body moving in a circular path is along a tangent to the position of the body on the circular path at that instant of time.

Suppose a body moves in a circular path with constant speed, its direction of motion changes continuously at every point (fig 1.62). This shows that the velocity of the body moving in a circular path changes continuously due to change in direction of its motion. It means the body moves with changing velocity in a circular path. The change in velocity of the body with time gives rise to acceleration and so, the uniform circular motion of a body is known as a case of accelerated motion.

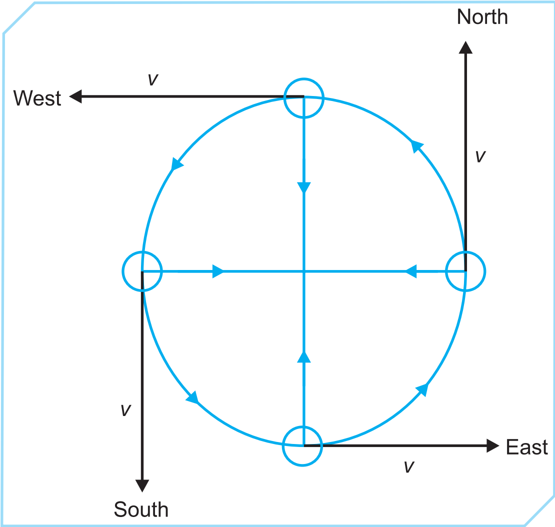


Fig 1.62 : Uniform circular motion

Let us take an example, of an athlete is running along a square or a rectangular track. Since the square track has four sides, he has to change the direction of motion four times at the four corners. Similarly, if he runs along a hexagonal track, then he has to change his direction of motion six times at the corners. If he runs along an octagonal track, then he has to change his direction of motion eight times at the corners (fig 1.63). This shows that when the number of sides of a track increases, the direction of the object also changes more and more frequently.

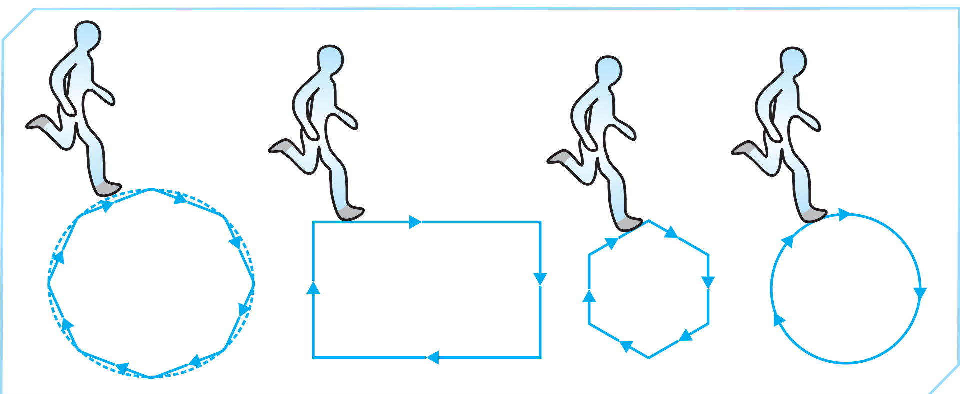


Fig 1.63 : An athlete running along a different shaped tracks

From the above discussion, we can say that when a body or an object moves along a circular path with uniform speed, then its direction of motion keeps on changing continuously. Thus, it is possible for a body to move in a circular path with uniform speed as long as it travels equal distances in equal intervals of time. However, the velocity of the body moving in a circle with uniform speed is not uniform due to the constant change in the direction of motion. The direction of velocity is along the tangent to the circle at any point in its motion.

For example, take a piece of thread and tie a small piece of stone at one end. Hold the thread by the other end and swing it (fig 1.64). We can observe that the stone moves in a circular path and the motion of the stone is a circular motion.

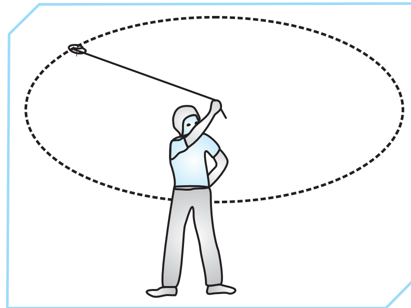


Fig 1.64 : Example of a boy swinging a piece of stone

Note

- A force is needed to make an object or a body travel in a circular path. This force is called centripetal force.

Activity 1.3 To show that the direction of motion of a body moving in a circular path is different at different positions of the circular path

PROCEDURE

Step 1– Take a piece of thread and tie a small piece of stone at one of its ends.

Step 2– Move the stone to describe a circular path with constant speed by holding the thread at the other end, as shown in figure.

Step 3– Now, let the stone go by releasing the thread.

Step 4– Can you tell the direction in which the stone moves after it is released?

Step 5– Repeat the activity for a few times by releasing the stone at different positions of the circular path.

Step 6– Check whether the direction in which the stone moves remains the same or not.

DIAGRAM

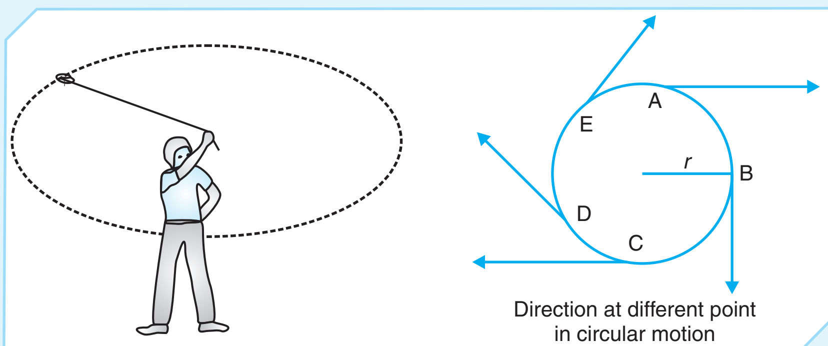


Fig 1.65 : A stone describing a circular path with a velocity of constant magnitude

OBSERVATION

(a) It will be found that the stone moves in a straight line which is tangent to the position A on the circular path.

(b) Similarly, when stone moving on circular track leaves its path, goes along straight line which is a tangent drawn at point B and so on.

CONCLUSION

Thus, we can conclude that the direction of motion of a body moving in a circular path is always along the tangent to a point on the circular path. Hence, the direction of motion of a body moving in a circular path is different at different positions of the circular path.

Other Examples of Uniform Circular Motion

Some of the examples of uniform circular motion are given below :

(i) The motion of artificial satellites in a circular orbit around the earth.

(ii) An athlete moving on a circular track with uniform speed.

(iii) The tip of seconds' hand of a watch shows uniform circular motion on the circular dial of the watch.

(iv) The earth moves around the sun in a uniform circular motion.

(v) The moon moves around the earth in uniform circular motion. (fig 1.66)

(vi) Merry-ge-round is moving on circular track. (fig 1.67)

(vii) Giant wheel is moving in circular motion (fig 1.68)

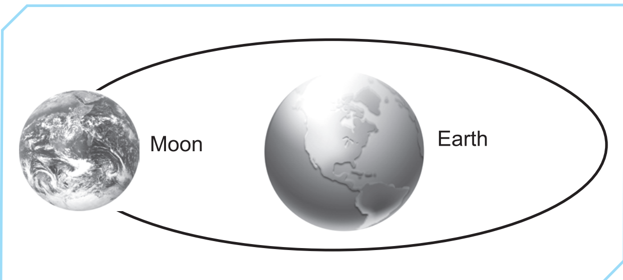


Fig 1.66 : Moon is moving around the earth in circular orbit

Fig 1.67 : Merry-go-round moving on circular track

Fig 1.68 : Giant wheel is moving in circular motion

Note

- The main difference between uniform linear motion and uniform circular motion is that in uniform linear motion, the direction of motion is fixed and so, it is not accelerated whereas in uniform circular motion, the direction of motion changes continuously and so, it is accelerated.

Calculating the Speed of a Body in Uniform Circular Motion

The speed of a body can be calculated in uniform circular motion as follows :

When a body takes a round of a circular path, then we can say that it travels a distance equal to its circumference *i.e.*, $2\pi r$ where 'r' is the radius of the circular path. Now, the speed of a moving body along a circular path is given by,

$$v = \frac{2\pi r}{t}$$

Where v is the speed, π is constant (= 22/7), r is the radius and t is the time taken for one round of circular path.

PAPER - PEN TEST : 9

1. Derive the first equation of motion by graphical method.
2. Name the graph used to derive the first equation of motion by graphical method.
3. Is it possible for a body to be accelerated without changing the magnitude of velocity?
4. Define uniform circular motion.
5. Derive the second equation of motion by graphical method.
6. Uniform circular motion is a class of ....
7. Name the graph used to derive the second equation of motion by graphical method.
8. Is it possible for a body to move in a circular path with uniform speed as long as it travels equal distances in equal intervals of time?
9. Derive the third equation of motion by graphical method.
10. Define the direction of motion of a body moving in a circular path at any instant?

11. Why is uniform circular motion called a case of accelerated motion? Explain uniform circular motion with an example.
12. Why is the velocity of the body moving in a circle with uniform speed not uniform?
13. Define centripetal force.
14. Mention any three examples of uniform circular motion.
15. How do you calculate the speed of a body from uniform circular motion?

COMPENDIUM

- If the position of an object does not change with time, it is said to be at rest.
- If the position of an object changes as time passes, it is said to be in motion.
- Reference point is a fixed point with respect to which a body is said to be at rest or in motion.
- Rest and motion are relative terms.
- Distance is the length of the actual path travelled by a body in a given time.
- Displacement is the shortest distance between the initial and final positions of the body in a known direction.
- A physical quantity which has both magnitude and direction is called a vector quantity.
- A physical quantity which has only magnitude is called a scalar quantity.
- The S.I. unit of distance and displacement is metre.
- A body is said to be in uniform motion if it travels equal distances in equal intervals of time.
- A body is said to have non-uniform motion if it travels unequal distances in equal intervals of time.
- Speed is the ratio of distance travelled to the time taken to cover that distance.
- In non-uniform motion the speed of an object is not constant.
- The S.I. unit of speed or velocity is m/s or m s^{-1}.
- The average speed (or velocity) of a body is the total distance(or displacement) travelled by it divided by the total time taken.
- Velocity is the displacement per unit time.
- Speed is a scalar quantity and velocity is a vector quantity.
- The distance-time graph is a straight line parallel to the time axis when the object is at rest.
- The slope of position-time graph is zero if the object is at rest.
- The slope of a straight line = $\frac{y_2 - y_1}{x_2 - x_1}$
- The distance-time graph is a straight line when the object is in a state of uniform motion.
- The slope of the distance-time graph gives the speed of the object.
- A more steeply inclined distance-time graph indicates greater speed.
- The nature of distance-time graph is a curve having varying slope when the object has non-uniform motion.
- If the velocity of a body remains constant, the velocity-time graph is a horizontal line parallel to the time axis.
- If the velocity of the body changes uniformly at a constant rate, the velocity-time graph is a straight line.
- If the velocity of an object changes non-uniformly, the velocity-time graph is a curve having increasing slope.
- In the velocity-time graph, the area enclosed represents the displacement.
- The slope of the velocity-time graph gives the acceleration.
- When a body travels along a circular path of constant radius with a constant speed *v* then it has uniform circular motion.
- In uniform circular motion, the velocity of a particle is not constant but its speed is constant, hence it is a class of accelerated motion.

EXERCISES (SOLVED)

NCERT IN TEXT QUESTIONS

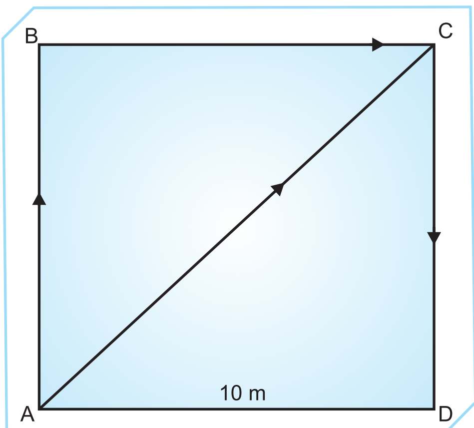
1. An object has moved through a distance. Can it have zero displacement? If yes, support your answer with an example.

   Ans : Yes, zero displacement is possible if an object has moved through a distance.

   Suppose a ball starts moving from point A and it returns to the same point A then the displacement will be zero, as displacement is the shortest distance between initial and final position and in this case both positions are same.

2. A farmer moves along the boundary of a square field of side 10 m in 40 s as shown in figure below. What will be the magnitude of displacement of the farmer at the end of 2 minutes 20 seconds from his initial position?

   Solution :



   Given, side of the square field = 10 m

   Therefore, perimeter = 10 m × 4 = 40 m

   Farmer moves along the boundary in 40 s.

   Total time of journey = 2 × 60 + 20 = 140 s

   Since in 40 s farmer moves 40 m.

   Therefore, in 1 s distance covered by farmer = $\frac{40}{40}$ m = 1 m

   Therefore, in 140 s distance covered by farmer = 140 × 1 = 140 m

   Now,

   Number of rotation to cover 140 along the boundary = $\frac{\text{Total distance}}{\text{Perimeter}}$

   $$= \frac{140 \text{ m}}{40 \text{ m}} = 3.5 \text{ rounds}$$

   Thus, after 3.5 round farmer will be at point C of the field.

   Therefore, displacement

   $$AC = \sqrt{(10)^2 + (10)^2}$$
   $$= \sqrt{100 + 100}$$
   $$= \sqrt{200} = 14.143 \text{ m}$$

   Thus, after 2 minutes 20 seconds the displacement of farmer will be equal to 14.143 m north east.

3. Which of the following is true for displacement?

   (a) It cannot be zero.

   (b) Its magnitude is greater than the distance travelled by the object.

   Ans : None of these is true for displacement.

4. Distinguish between speed and velocity.

   Ans : Speed has only magnitude while velocity has both magnitude and direction.

5. Under what condition(*s*) is the magnitude of average velocity of an object equal to its average speed?

   Ans : The magnitude of average velocity of an object will be equal to its average speed in the condition of uniform velocity.

6. What does the odometer of an automobile measure?

   Ans : In automobiles, odometer is used to measure the distance.

7. What does the path of an object look like when it is in uniform motion?

   Ans : In the case of uniform motion the path of an object will look like a straight line.

8. During an experiment, a signal from a spaceship reached the ground station in five minutes. What was the distance of the spaceship from the ground station? The signal travels at the speed of light, *i.e.,* 3×10^8 m s^{-1}.

   Solution : Here, we have speed = 3×10^8 m s^{-1}

   Time = 5 minute = 5 × 60 s = 300 seconds

We know that, distance = speed × time

$$\text{Distance} = 3 \times 10^8 \times 300$$
$$= 900 \times 10^8 \text{ m}$$
$$= 9 \times 10^{10} \text{ m}$$

9. When will you say that a body has
   (i) uniform acceleration?
   (ii) non-uniform acceleration?

   Ans : (i) A body is said to have uniform acceleration when its motion is along a straight line and its velocity changes by equal magnitude, in equal intervals of time.

   (ii) A body is said to have non-uniform acceleration when its motion is along a straight line and its velocity changes by unequal magnitudes in equal interval of time.

10. A bus decreases its speed from 80 km h^{-1} to 60 km h^{-1} in 5 s. Find the acceleration of the bus.

    Solution : Here, we have

$$u = 80 \text{ km h}^{-1}$$
$$= \frac{80 \times 1000}{60 \times 60} = 22.22 \text{ m s}^{-1}$$
$$v = 60 \text{ km h}^{-1}$$
$$= \frac{60 \times 1000}{60 \times 60} = 16.67 \text{ m s}^{-1},$$
$$t = 5 \text{ s}$$

Therefore acceleration

$$a = \frac{v - u}{t}$$
$$a = \frac{16.67 - 22.22}{5} = \frac{-5.55}{5}$$
$$= -1.11 \text{ m s}^{-2}$$

The minus sign shows that it is retardation.

11. A train starting from a railway station and moving with uniform acceleration attains a speed of 40 km h^{-1} in 10 minutes. Find its acceleration.

    Solution : Given,

    Initial velocity, $u = 0$,

    Final velocity, $v = 40 \text{ km h}^{-1} = 11.11 \text{ m s}^{-1}$

    Time (t) = 10 minutes = 60 × 10 = 600 s

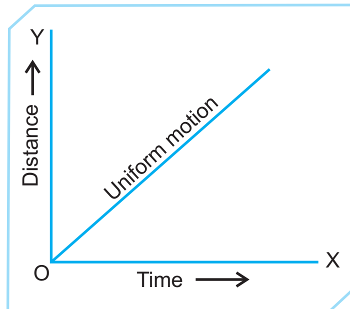
    Acceleration (a) = ?

    We know that $v = u + at$

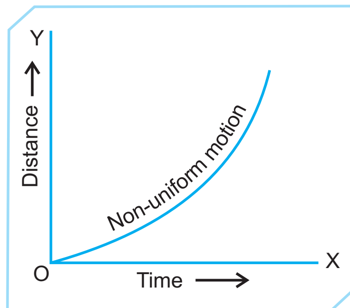
$$11.11 = 0 + a \times 600$$
$$a = \frac{11.11}{600} = 0.0185 \text{ m s}^{-2}$$

12. What is the nature of the distance-time graphs for uniform and non-uniform motion of an object?

    Ans : (a) The slope of the distance-time graph for an object in uniform motion is a straight line.



(b) The slope of the distance-time graph for an object in non-uniform motion is not a straight line.



13. What can you say about the motion of an object whose distance-time graph is a straight line parallel to the time axis?

    Ans : When the distance-time graph is a straight line parallel to time axis, it means that the distance of the object is not changing with time *i.e.*, position of the object is same at every instant of time, so the object is at rest.

14. What can you say about the motion of an object if its speed-time graph is a straight line parallel to the time axis?

    Ans : When the speed-time graph is a straight line parallel to the time axis, the object is moving with a uniform speed. So there is no acceleration.

15. What is the quantity which is measured by the area occupied below the velocity-time graph?

    Ans : The quantity of distance is measured by the area occupied below the velocity-time graph.

16. A bus starting from rest moves with a uniform acceleration of 0.1 m s^{-2} for 2 minutes. Find

(a) The speed acquired

(b) The distance travelled

Solution : Given,

Initial velocity, $u = 0$

Acceleration, $a = 0.1$ m s^{-2}

Time, t = 2 minutes = 120 seconds

(a) We know that, $v = u + at$

$$v = 0 + 0.1 \times 120$$

$$v = 12 \text{ m s}^{-1}$$

Thus, the bus will acquire a speed of 12 m s^{-1} after 2 minutes with the given acceleration.

(b) We know that,

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

$$= 0 \times 120 + \frac{1}{2} \times 0.1 \times (120)^2$$

$$= \frac{1}{2} \times 0.1 \times 14400 \text{ m} = 720 \text{ m}$$

Thus, the bus will travel a distance of 720 m in the given time of 2 minutes.

17. A train is travelling at a speed of 90 km h^{-1}. Brakes are applied so as to produce a uniform acceleration of – 0.5 m s^{-2}. Find how far the train will go before it is brought to rest.

Solution : Given,

Initial velocity, $u = 90 \text{ km h}^{-1}$

$$= \frac{90 \times 1000 \text{ m}}{60 \times 60 \text{ s}} = 25 \text{ m s}^{-1}$$

Final velocity, $v = 0$

Acceleration, $a = -0.5 \text{ m s}^{-2}$

We know that $v^2 = u^2 + 2as$

$$0 = (25)^2 + 2 \times (-0.5)\ s$$

$$0 = 625 - 1 \times s$$

$\therefore$ $s = 625$ m

Therefore, train will go 625 m before it is brought to rest.

18. A trolley, while going down an inclined plane, has an acceleration of 2 cm s^{-2}. What will be its velocity 3 s after the start?

Solution : Given,

Initial velocity, $u = 0$

Acceleration, $a = 2 \text{ cm s}^{-2} = 0.02 \text{ m s}^{-2}$

Time, $t = 3$ s

We know that $v = u + at$

Therefore $v = 0 + 0.02 \times 3$

$$v = 0.06 \text{ m s}^{-1}$$

Thus, the final velocity of the trolley will be 0.06 m s^{-1} after start.

19. A racing car has a uniform acceleration of 4 m s^{-2}. What distance will it cover in 10 s after start?

Solution : Given,

Acceleration, $a = 4 \text{ m s}^{-2}$

Initial velocity, $u = 0$

Time, $t = 10$ s

Therefore, distance covered s = ?

We know that, $s = ut + \frac{1}{2}at^2$

$$s = 0 \times 10 + \frac{1}{2} \times 4 \times (10)^2$$

$$s = \frac{1}{2} \times 4 \times 100$$

$$s = 2 \times 100 \text{ m} = 200 \text{ m}$$

Thus, the racing car will cover a distance of 200 m after start in 10 s with the given acceleration.

20. A stone is thrown vertically upwards with a velocity of 5 m s^{-1}. If the acceleration of the stone during its motion is 10 m s^{-2} in the downward direction, what will be the height attained by the stone and how much time will it take to reach there?

Solution : Given,

Initial velocity, $u = 5 \text{ m s}^{-1}$

Final velocity, $v = 0$ (Since from where stone starts falling its velocity will become zero)

Acceleration, $a = -10 \text{ m s}^{-2}$

(Since the given acceleration is in the downward direction, *i.e.*, the velocity of the stone is decreasing, the acceleration is taken as negative)

Height, *i.e.*, distance, s = ?

Time (t) taken to reach the height = ?

We know that

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

$$0 = (5)^2 + 2 \times (-10) \times s$$

$$0 = 25 - 20 \times s$$

$$20 \times s = 25$$
$$s = \frac{25}{20}$$
$$s = 1.25 \text{ m}$$

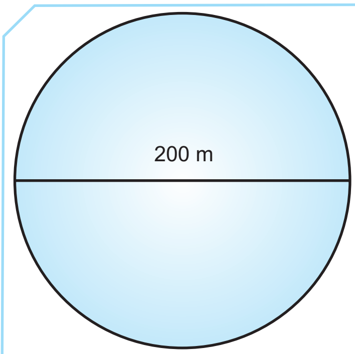
We know that

$$v = u + at$$
$$0 = 5 + (-10) \times t$$
$$0 = 5 - 10 \times t$$
$$10 \times t = 5$$
$$t = \frac{5}{10} = \frac{1}{2} \text{ s}$$
$$= 0.5 \text{ s}$$

Thus, the stone will attain a height of 1.25 m and the time taken to attain the height is 0.5 s.

NCERT EXERCISES QUESTIONS

1. An athlete completes one round of a circular track of diameter 200 m in 40 s as shown in figure below. What will be the distance covered and the displacement at the end of 2 minutes 20 s?



Circular track with diameter of 200 m

Solution : Given,

Diameter = 200 m,

Therefore, radius = $\frac{200}{2}$ = 100 m

Time of one rotation = 40 s

Time after 2 minutes 20 s = 2 × 60 s + 20 s = 140 s

$$\text{Velocity along a circular path} = \frac{\text{Circumference}}{\text{time}}$$
$$v = \frac{2\pi r}{40}$$
$$v = \frac{2 \times 3.14 \times 100}{40}$$
$$= \frac{628}{40} = 15.7 \text{ m s}^{-1}$$

(a) Distance after 140 s

We know that, distance = velocity × time

Distance = 15.7 ×140

= 2198 m

(b) Displacement after 2 minute 20 s *i.e.,* in 140 s

Since, rotation in 40 s = 1

$$\text{Rotation in } 1 \text{ s} = \frac{1}{40}$$
$$\text{Rotations in } 140 \text{ s} = \frac{1}{40} \times 140 = 3.5$$

Therefore, in 3.5 rotations athlete will be just at the opposite side of the circular track, *i.e.,* at a distance equal to the diameter of the circular track which is equal to 200 m.

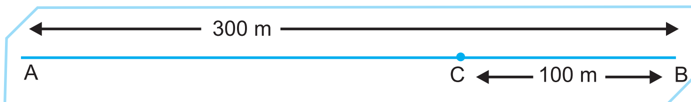
Therefore,

Distance covered in 2 m 20 s = 2198 m

And, displacement after 2 m 20 s = 200 m

2. Joseph jogs from one end A to the other end B of a straight 300 m road in 2 minutes 30 seconds and then turns around and jogs 100 m back to point C in another 1 minute as shown in figure below. What are Joseph's average speeds and velocities in jogging (a) from A to B and (b) from A to C?

Solution :



Given, distance from point A to B = 300 m

Time taken = 2 minutes 30 second

= 2 × 60 s + 30 s

= 150 s

Distance from point B to C = 100 m

Time taken = 1 minute = 60 s

Distance from A to C = 300 + 100 = 400 m

Total time taken = 2 minutes 30 s + 1 minute = 210 s

(a) Average speed and velocity from point A to B

$$\text{The average speed} = \frac{\text{Total distance}}{\text{Time taken}}$$
$$= \frac{300}{150} = 2 \text{ m s}^{-1}$$

Velocity = 2 m s^{-1} east

(b) Average speed and velocity from A to C

$$\text{The average speed} = \frac{\text{Total distance}}{\text{Time taken}}$$

$$= \frac{400}{210} = 1.90 \text{ m s}^{-1}$$

The average velocity from A to C

Displacement = 200 – 100 = 100 m

Total time = 210 s

$$\text{Average velocity} = \frac{\text{Displacement}}{\text{Total Time taken}}$$

$$= \frac{200}{210} = 0.95 \text{ m s}^{-1}$$

Therefore, the average velocity = 0.95 m s^{-1} and the average speed = 1.90 m s^{-1}.

3. Abdul, while driving to school, computes the average speed for his trip to be 20 km h^{-1}. On his return trip along the same route, there is less traffic and the average speed is 30 km h^{-1}. What is the average speed for Abdul's trip?

Solution :

Let the distance of the school = s km

Let time to reach the school in first trip = t_1

Let time to reach the school in second trip = t_2

$$\text{The average speed} = \frac{\text{Total distance}}{\text{Time taken}}$$

$$\text{Average speed in first trip} = \frac{s}{t_1}$$

$$20 = \frac{s}{t_1}$$

$$t_1 = \frac{s}{20} \text{ h}$$

$$\text{Average speed in second trip} = \frac{s}{t_2}$$

$$30 = \frac{s}{t_2}$$

$$t_2 = \frac{s}{30} \text{ h}$$

$$\text{Now total time } (t_1 + t_2) = \frac{s}{20} + \frac{s}{30}$$

$$(t_1 + t_2) = \frac{3s + 2s}{60} = \frac{5s}{60} = \frac{s}{12}$$

Average speed of both trip =

$$\frac{\text{Total distance covered}}{\text{Total time taken}}$$

$$= \frac{2s}{\frac{s}{12}} \text{ km h}^{-1} = \frac{2s \times 12}{s} \text{ km h}^{-1}$$

$$= 24 \text{ km h}^{-1}$$

Therefore, the average speed of Abdul is 24 km h^{-1}.

4. A motorboat starting from rest on a lake accelerates in a straight line at a constant rate of 3.0 m s^{-2} for 8.0 s. How far does the boat travel during this time?

Solution : Given,

Initial velocity, u = 0

Acceleration, a = 3.0 m s^{-2}

Time = 8 s

We know that,

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

$$s = 0 \times 8 + \frac{1}{2} \times 3 \times (8)^2$$

$$s = \frac{1}{2} \times 3 \times 64 \text{ m}$$

$$s = 3 \times 32 \text{ m} = 96 \text{ m}$$

Therefore, the boat travels a distance of 96 m in the given time.

5. A driver of a car travelling at 52 km h^{-1} applies the brakes and accelerates uniformly in the opposite direction. The car stops in 5 s. Another driver going at 3 km h^{-1} in another car applies his brakes slowly and stops in 10 s. On the same graph paper, plot the speed versus time graphs for the two cars. Which of the two cars travelled farther after the brakes were applied?

Solution : Given,

For first driver :

Initial velocity, u = 52 km h^{-1}

$$= \frac{52 \times 1000 \text{ m}}{60 \times 60 \text{ s}} = 14.4 \text{ m s}^{-1}$$

Time, t = 5 s

Final velocity, v = 0 (since car stops)

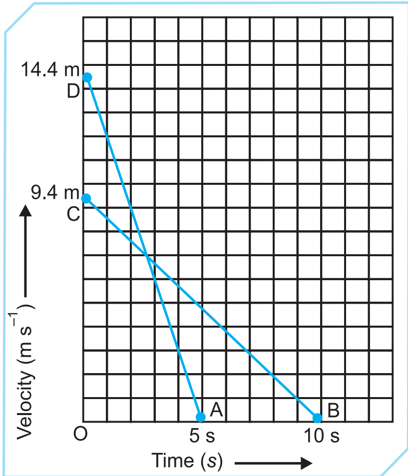
Given, for second driver

Initial velocity, u = 3 km h^{-1}

$$= \frac{300 \text{ m}}{60 \times 20 \text{ s}} = 9.4 \text{ m s}^{-1}$$

Time t = 10 s

Final velocity v = 0



The distance can be calculated by the area under the slope of the graph.

The distance covered by the 1st car = Area of triangle OAD

$$\text{Distance } s = \frac{1}{2} \times OD \times OA$$

$$s = \frac{1}{2} \times 14.4 \times 5$$

$$= 7.2 \times 5 = 36 \text{ m}$$

The distance covered by the 2nd car = Area of the triangle OBC

$$\text{Distance, } s = \frac{1}{2} \times OC \times OB$$

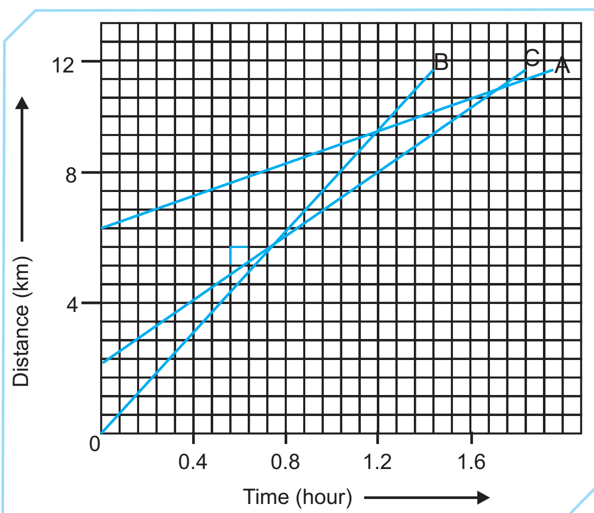
$$s = \frac{1}{2} \times 9.4 \times 10$$

$$= 4.7 \times 10$$

$$= 47 \text{ m}$$

Therefore the 2nd car travelled farther.

6. The figure below shows the distance-time graph of three objects A, B and C. Study the graph and answer the following questions :



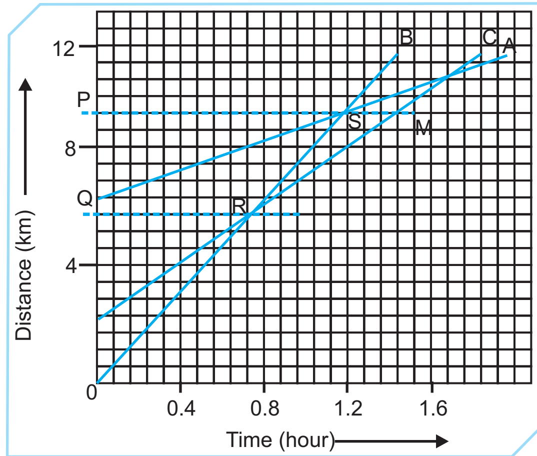
(a) Which of the three is travelling the fastest?

(b) Are all three ever at the same point on the road?

(c) How far has C travelled when B passes A?

(d) How far has B travelled by the time it passes C?

Ans :



(a) It is clear from the graph that 'B' covers more distance in less time. Therefore, 'B' is the fastest.

(b) All of them never come at the same point at the same time.

(c) According to the graph, each small division shows about 0.57 km.

'A' is passing 'B' at point 'S' which is in line with point 'P' (on the distance axis) and shows about 9.14 km.

Thus, at this point 'C' travels

$$9.14 - (0.57 \times 3.75) = 9.14 - 2.1375$$

$$= 7.0025 \text{ km} \approx 7 \text{ km}$$

Thus, when 'A' passes 'B', 'C' travels about 7 km.

(d) 'B' passes 'C' at point 'Q' at the distance axis which is 4 + 0.57 × 2.25 = 5.28 km

Therefore, 'B' travelled about 5.28 km when it passed to 'C'.

7. A ball is gently dropped from a height of 20 m. If its velocity increases uniformly at the rate of 10 m s^{-2}, with what velocity will it strike the ground? After what time will it strike the ground?

Solution : Given,

Initial velocity, $u = 0$

Distance, $s = 20$ m

Acceleration, $a = 10 \text{ m s}^{-2}$

Final velocity, v = ?

Time, t = ?

(a) Calculation of final velocity, v

From the third equation of motion, we get

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

$$v^2 = 0 + 2 \times 10 \times 20$$

$$v^2 = 400$$

$$v = 20 \text{ m s}^{-1}$$

(b) Calculation of time, t

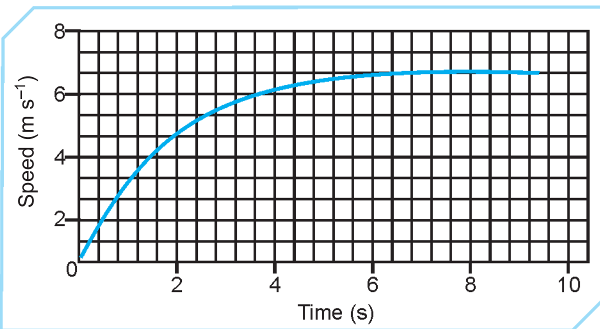
From the first equation of motion, $v = u + at$

$$20 = 0 + 10 \times t$$

$$t = \frac{20}{10} = 2 \text{ s}$$

Therefore, the ball will strike the ground at the velocity of 20 m s^{-1} after 2 seconds.

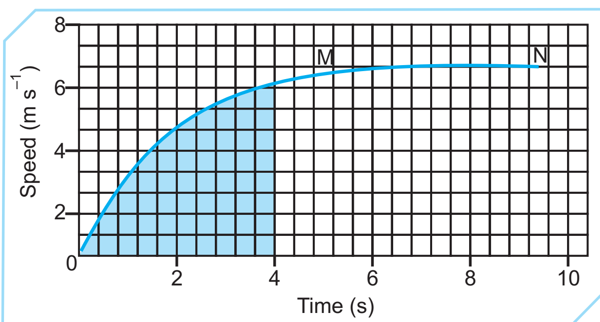
8. The speed-time graph for a car is shown in the figure below.



(a) Find how far the car travels in the first 4 seconds. Shade the area on the graph that represents the distance travelled by the car during the period.

(b) Which part of the graph represents uniform motion of the car?

Ans : The shaded area on the graph represents the distance travelled by the car during the period.



(a) Distance travelled by car in the 4 second

The area under the slope of the speed-time graph gives the distance travelled by an object.

In the given graph

56 full squares and 12 half squares come under the area slope for the time of 4 seconds.

Total number of squares = 56 + 12/2 = 62 squares

The total area of the squares will give the distance travelled by the car in 4 seconds.

On the time axis, 5 squares = 2 s

So, 1 square = $\frac{2}{5}$ s

On the speed axis, 3 squares = 2 m s^{-1}

So, 1 square = $\frac{2}{3} \text{ m s}^{-1}$

Now, the area of 1 square = $\frac{2}{5} \times \frac{2}{3} = \frac{4}{15}$ m

Therefore, the area of 62 squares = $16 \times \frac{4}{15}$ m

$$= \frac{248}{15} = 16.53 \text{ m}$$

Therefore, the car travels 16.52 m in first 4 s.

(b) Part MN of the slope of the graph is a straight line parallel to the time axis, and thus this portion of graph represents the uniform motion of car.

9. State which of the following situations are possible and give an example for each of these :

(a) An object with a constant acceleration but with zero velocity.

(b) An object moving in a certain direction with acceleration in the perpendicular direction.

Ans : (a) The term acceleration implies that the velocity of the object is changing; inspite of that, constant acceleration with zero velocity is possible. When an object is thrown in upward direction, at the maximum height the velocity of the object becomes zero but still in that condition a constant acceleration due to gravity acts.

(b) Object moving in a certain direction with acceleration in the perpendicular direction is possible; in case of circular motion. When an object moves in a circular path, its direction is along the tangent of the circle but the acceleration is towards the radius of the circle. We know that a tangent always makes a right angle with the radius; so when an object is in circular motion, the acceleration and the velocity are in mutually perpendicular directions.

10. An artificial satellite is moving in a circular orbit of radius 42250 km. Calculate its speed if it takes 24 hours to revolve around the earth.

Solution : Given,

Radius, r = 42250 km

Time, t = 24 hours

Speed = ?

$$\text{Velocity along a circular path} = \frac{2\pi r}{\text{Time}}$$

$$v = \frac{2 \times \frac{22}{7} \times 42250}{24}$$

$$= \frac{2 \times 22 \times 42250}{7 \times 24}$$

$$v = 11065.47 \text{ km h}^{-1}$$

Thus, the speed of the given satellite is 11065.47 km h^{-1}

EXEMPLAR QUESTIONS

1. A particle is moving in a circular path of radius r. The displacement after half a circle would be :

(a) Zero (b) πr

(c) $2r$ (d) $2\pi r$

2. A body is thrown vertically upward with velocity u, the greatest height h to which it will rise is,

(a) $\frac{u}{g}$ (b) $\frac{u^2}{2g}$

(c) $\frac{u^2}{g}$ (d) $\frac{u}{2g}$

3. The numerical ratio of displacement to distance for a moving object is

(a) always less than 1 (b) always equal to 1

(c) always more than 1 (d) equal or less than 1

4. If the displacement of an object is proportional to square of time, then the object moves with

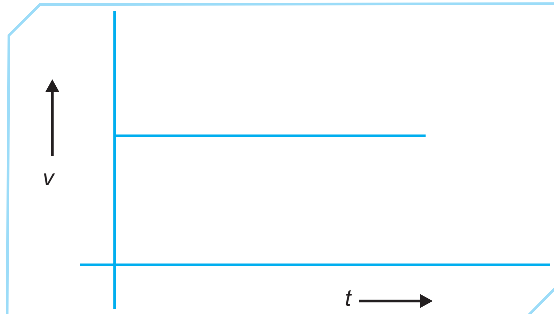
(a) uniform velocity

(b) uniform acceleration

(c) increasing acceleration

(d) decreasing acceleration

5. From the given $v - t$ graph as shown in figure below it can be inferred that the object is



(a) in uniform motion

(b) at rest

(c) in non-uniform motion

(d) moving with uniform acceleration

6. Suppose a boy is enjoying a ride on a merry-go-round which is moving with a constant speed of 10 m s^{-1}. It implies that the boy is

(a) at rest

(b) moving with no acceleration

(c) in accelerated motion

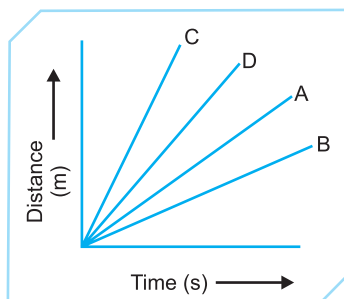
(d) moving with uniform velocity

7. Area under a v–t graph represents a physical quantity which has the unit

(a) m^2 (b) m

(c) m^3 (d) m s^{-1}

8. Four cars A, B, C and D are moving on a levelled road. Their distance versus time graph is shown in figure below. Choose the correct statement.



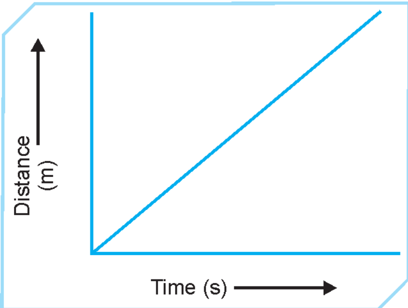
(a) Car A is faster than car D.

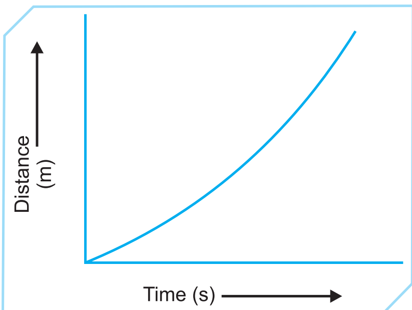
(b) Car B is the slowest.

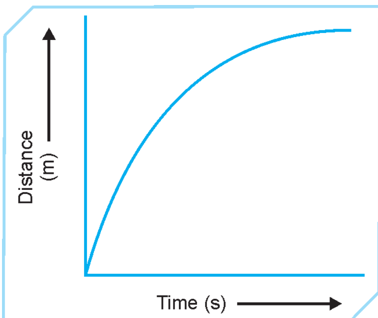
(c) Car D is faster than car C.

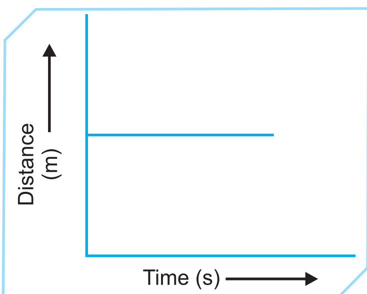
(d) Car C is the slowest.

9. Which of the following figures below represents uniform motion of a moving object correctly?

(a)


(b)


(c)


(d)


10. Slope of a velocity—time graph gives

(a) the distance (b) the displacement

(c) the acceleration (d) the speed

11. In which of the following cases of motions, the distance moved and the magnitude of displacement are equal?

(a) If the car is moving on straight road.

(b) If the car is moving in circular path.

(c) The pendulum is moving to and fro.

(d) The earth is revolving around the Sun.

ANSWERS

1. (c)	2. (b)	3. (d)	4. (b)
5. (a)	6. (c)	7. (b)	8. (b)
9. (a)	10. (c)	11. (a)	

12. The displacement of a moving object in a given interval of time is zero. Would the distance travelled by the object also be zero? Justify you answer.

Ans : No. If the displacement is zero than it is not necessary that the distance travelled will also be zero. If we are moving on a circular track whose initial and final positions are the same and which is of 10 m circumference then the displacement would be zero but the distance travelled would be 10 m.

13. A motorcyclist drives from A to B with a uniform speed of 30 km h^{-1} and returns back with a speed of 20 km h^{-1}. Find its average speed.

Solution : Let AB = s, so

$$t_1 = \frac{s}{30}$$

$$t_2 = \frac{s}{20}$$

$$\text{Total time} = t_1 + t_2 = \frac{s}{30} + \frac{s}{20}$$

$$\text{Total time} = t_1 + t_2 = \frac{5s}{60}\text{h}$$

Average speed for entire journey =

$$\frac{\text{Total distance}}{\text{Total time taken}} = \frac{2s}{\frac{5s}{60}} = 24 \text{ km h}^{-1}$$

14. How will the equations of motion for an object moving with a uniform velocity change?

Ans : When acceleration $a = 0$,

Equations of motion are $v = u$

$s = ut$

$v^2 - u^2 = 0$

15. A car starts from rest and moves along the x-axis with constant acceleration 5 m s^{-2} for 8 seconds. If it then continues with constant velocity, what distances will the car cover in 12 seconds since it started from the rest?

Solution : Given,

Initial velocity = 0

Acceleration = 5 m s^{-2}

Time = 8 sec

Distance = s_1

$$s_1 = ut + \frac{1}{2}at^2$$

$$s_1 = 0 + \frac{1}{2}(5)(8)^2 = 160 \text{ m}$$

At this point, final velocity, $v = u + at$

$$v = 0 + (5 \times 8) = 40 \text{ m s}^{-1}$$

Therefore, the distance covered in last four seconds,

$$s_2 = (40 \times 4) \text{ m} = 160 \text{ m}$$

Thus, the total distance $s = s_1 + s_2 = (160 + 160)$ m = 320 m

16. An object starting from rest travels 20 m in first 2 s and 160 m in next 4 s. What will be the velocity after 7 s from the start?

Solution :

We know that, $s_1 = ut + \frac{1}{2}at^2$

Where distance s_1 = 20 m, initial velocity = 0 m s^{-1}, time t = 2 s.

Substituting the values, we get

$$20 = 0 + \frac{1}{2}a\,(2)^2$$

$$a = 10 \text{ m s}^{-2}$$

For final velocity, $v = u + at$

Substituting the values, we get

$$v = 0 + (10 \times 2) = 20 \text{ m s}^{-1}$$

Here, v becomes the new initial velocity

Now the distance s_2

$$s_2 = vt + \frac{1}{2}at^2$$

Where distance s_2 = 160 m, v = 20 m s^{-1}, t = 4 s

Substituting the values, we get

$$s_2 = 20 \times 4 + \frac{1}{2}\,(a' \times (4)^2)$$

$$160 = 80 + \frac{1}{2}\,(a' \times 16)$$

$$a' = 10 \text{ m s}^{-2}$$

Since, the acceleration is the same

$$v' = 0 + (10 \times 7) = 70 \text{ m s}^{-1}$$

17. Obtain a relation for the distance travelled by an object moving with a uniform acceleration in the interval between 4th and 5th seconds.

Solution : We know that,

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

Distance travelled 's' in 5 sec,

$$s = u \times 5 + \frac{1}{2}a \times 5^2$$

$$s = 5u + \frac{25}{2}a$$

Distance travelled s' in 4 sec,

$$s' = u \times 4 + \frac{1}{2}a \times 4^2$$

$$s' = 4u + \frac{16}{2}a$$

Now, distance travelled in the interval between 4th and 5th second will be,

$$(s - s') = \left(u + \frac{9}{2}a\right)\text{m}$$

18. Two stones are thrown vertically upwards simultaneously with their initial velocities u_1 and u_2 respectively. Prove that the heights reached by them would be in the ratio of $u_1^2 : u_2^2$ (Assume upward acceleration is $-g$ and downward acceleration to be $+g$).

Solution : For upward motion,

$$v^2 = u^2 - 2gh$$

$$h = \frac{u^2 - v^2}{2g}$$

At highest point, $v = 0$

Therefore, $h = \frac{u^2}{2g}$

For 1st ball, $h_1 = \frac{u_1^2}{2g}$

For 2nd ball $h_2 = \frac{u_2^2}{2g}$

Thus, $\frac{h_1}{h_2} = \frac{u_1^2}{u_2^2}$

$\therefore \quad h_1 : h_2 = u_1^2 : u_2^2$

19. An electron moving with a velocity of 5×10^4 m s^{-1} enters into a uniform electric field and acquires a uniform acceleration of 10^4 m s^{-2} in the direction of its initial motion.

(i) Calculate the time in which the electron would acquire a velocity double of its initial velocity.

(ii) How much distance the electron would cover in this time?

Solution : Given,

Initial velocity $u = 5 \times 10^4$ m s^{-1}

Acceleration $a = 10^4$ m s^{-2}

(i) Final velocity

$$v = 2u \text{ (given)}$$

$$v = 2 \times 5 \times 10^4 \text{ m s}^{-1}$$

$$= 10 \times 10^4 \text{ m s}^{-1}$$

$$v = u + at$$

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

Substituting the values, we get

$$t = \left(\frac{10 \times 10^4 - 5 \times 10^4}{10^4}\right) = \frac{5 \times 10^4}{10^4}$$

$$= 5 \text{ sec}$$

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

Where initial velocity $u = 5 \times 10^4$ m s^{-1}, acceleration $a = 10^4$ m s^{-2}, time $t = 5$ sec

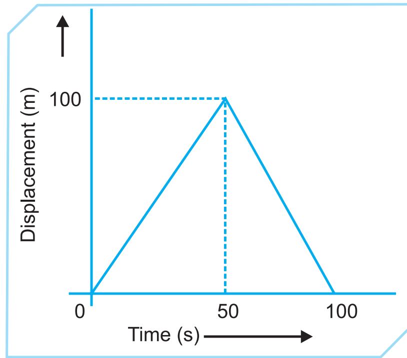
Substituting the values, we get

$$s = (5 \times 10^4) \times 5 + \frac{1}{2}(10^4) \times (5)^2$$

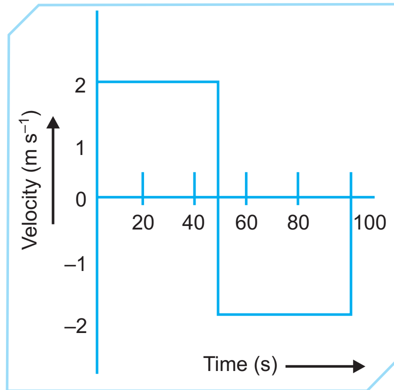
$$= 25 \times 10^4 + \frac{25}{2} \times 10^4$$

$$= 37.5 \times 10^4 \text{ m}$$

20. A girl walks along a straight path to drop a letter in the letterbox and comes back to her initial position. Her displacement–time graph is shown in the figure below. Plot a velocity–time graph for the same.



Ans : The velocity-time graph will be

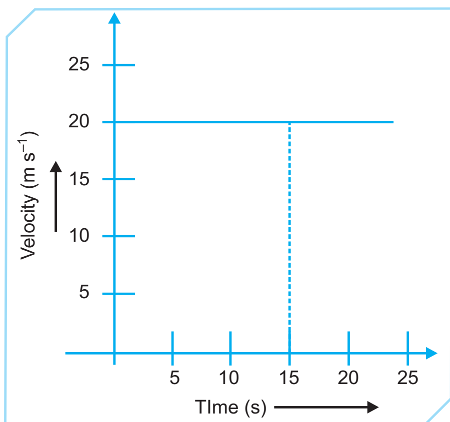


21. The velocity-time graph as shown in figure below shows the motion of a cyclist. Find

(i) its acceleration

(ii) its velocity

(iii) the distance covered by the cyclist in 15 seconds.



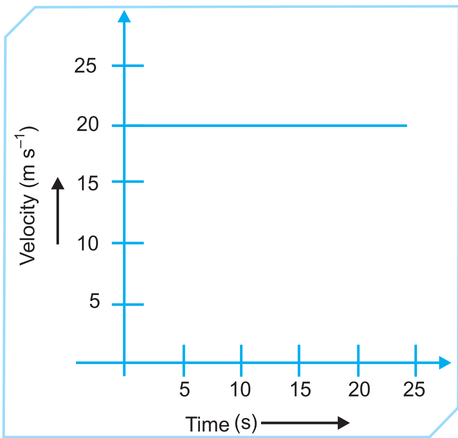
Solution :

(i) Since the velocity is not changing, acceleration is equal to zero.

(ii) Reading the graph, velocity = 20 m s^{-1}

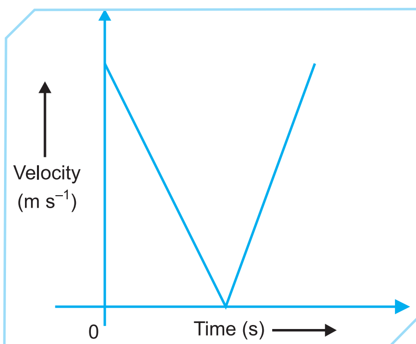
(iii) Distance covered in 15 seconds,

$$s = u \times t$$
$$= 20 \times 15$$
$$= 300 \text{ m}$$



22. Draw a velocity versus time graph of a stone thrown vertically upwards and then coming downwards after attaining the maximum height.

Ans :



23. An object is dropped from rest at a height of 150 m and simultaneously another object is dropped from rest at a height 100 m.

(a) What is the difference in their heights after 2 *s* if both the objects drop with same accelerations?

(b) How does the difference in heights vary with time?

Solution :

(a) Initial difference in height = (150 – 100) m = 50 m

Distance travelled by the first body in 2 s,

$$h_1 = 0 + \frac{1}{2}g(2)^2 = 2g$$

Where initial velocity u = 0, time t = 2 sec

Distance travelled by another body in 2 s = h_1

$$= 0 + \frac{1}{2}g(2)^2 = 2g$$

After 2 s, height at which the first body will be,

$$h_1' = 150 - 2g$$

After 2 s, height at which the second body will be,

$$h_2' = 100 - 2g$$

Thus, difference in height after 2 s = 150 – 2g – (100 – 2g)

= 50 m

= initial difference in height

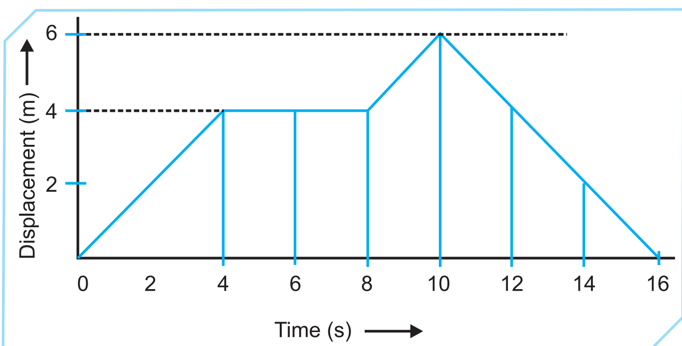
(b) The difference in heights does not vary with time.

24. Using following data draw time—displacement graph for a moving object:

Time (s)	0	2	4	6	8	10	12	14	16
Displacement (m)	0	2	4	4	4	6	4	2	0

Use this graph to find average velocity for first 4 s, for next 4 s and for last 6 s.

Solution :



Here,

Average velocity for first 4 s,

$$\text{Average velocity} = \frac{\text{Change in displacement}}{\text{Total time taken}}$$

$$v_{av} = \frac{4-4}{4-8} = 1 \text{ m s}^{-1}$$

Average velocity for next 4 s,

$$v_{av} = \frac{\text{Change in displacement}}{\text{Total time taken}}$$

$$= \frac{4-4}{4-8} = 0 \text{ m s}^{-1}$$

Average velocity for last 6 s,

$$\text{Average velocity} = \frac{\text{Change in displacement}}{\text{Total time taken}}$$

$$v_{av} = \frac{0-6}{16-10} = -1 \text{ m s}^{-1}$$

HIGHER ORDER THINKING SKILL QUESTIONS (HOTS)

1. If the speed of a moving object A is a m s^{-1} and its velocity is b m s^{-1}, what is the similarity you observe?

   Ans : Both has same unit of m s^{-1}.

2. Which object has acceleration? Object X moving with constant velocity for 5 min or object Y moving with changing velocity for 5 min.

   Ans : We know that, acceleration is the change in the velocity with time taken. Since the velocity of object X is not changing or change in velocity of the object is zero. Therefore, the object X has no acceleration. However, there is change in velocity of the object Y, so it has acceleration.

3. How is it possible for an object to move with a constant speed but with uniform acceleration?

   Ans : An object moving with a constant speed can be accelerated if its direction of motion changes.

4. What type of path does an object follow if the acceleration of the object is constant in magnitude but not in direction?

   Ans : Circular path.

5. A train travels the first 15 km at a uniform speed of 30 km/h, the next 75 km at a uniform speed of 50 km/h and the last 10 km at a uniform speed of 20 km/h. Calculate the average speed for the entire train journey.

   Ans : (a) In the first part, train travels at a speed of 30 km/h for a distance of 15 km.

$$\text{Speed} = \frac{\text{Distance}}{\text{time}}$$

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

$$t_1 = \frac{15}{30} = \frac{1}{2}h$$

(b) In the second part, train travels at a speed of 50 km/h for a distance of 75 km.

$$t_2 = \frac{75}{50} = \frac{3}{2}h$$

(c) In the third part, train travels at a speed of 20 km/h for a distance of 10 km.

$$t_3 = \frac{10}{20} = \frac{1}{2}h$$

Total distance covered = 15 + 75 + 10 = 100 km

$$\text{Total time taken} = \frac{1}{2} + \frac{3}{2} + \frac{1}{2} = \frac{5}{2}h$$

$$\text{Average speed} = \frac{\text{Total distance covered}}{\text{Total time taken}} = \frac{100}{5/2}$$

$$= 40 \text{ km/h}$$

6. Explain why, the motion of a body which is moving with constant speed in a circular path is said to be accelerated.

   Ans : The motion of a body which is moving with constant speed in a circular path is said to be accelearated because its velocity changes continously due to continuous change in the direction of motion.

MULTIPLE CHOICE QUESTIONS [MCQs]

1. A body whose position with respect to the surroundings does not change, is said to be in a state of

   (a) Rest (b) Motion
   (c) Vibration (d) Oscillation

2. In the case of a moving body

   (a) Displacement > Distance
   (b) Displacement < Distance
   (c) Displacement $\geq$ Distance
   (d) Displacement $\leq$ Distance

3. Vector quantities are those which have

   (a) Only direction.
   (b) Only magnitude.
   (c) Magnitude and direction both.
   (d) None of these.

4. What is true about scalar quantities?

   (a) Scalars quantities have direction also.
   (b) Scalars can be added arithmetically.
   (c) There are special laws to add scalars.
   (d) Scalars have special method to represent.

5. A body is said to be in motion if

   (a) Its position with respect to surrounding objects remains the same.
   (b) Its position with respect to surrounding objects keep on changing.
   (c) Both (a) and (b).
   (d) Neither (a) nor (b).

6. A distance is always
   (a) Shortest length between two points.
   (b) Path covered by an object between two points.
   (c) Product of length and time.
   (d) None of the above.
7. A displacement
   (a) Is always positive.
   (b) Is always negative.
   (c) May be positive as well as negative.
   (d) Is neither positive nor negative.
8. Examples of vector quantities are
   (a) Velocity, length and mass.
   (b) Speed, length and mass.
   (c) Time, displacement and mass.
   (d) Velocity, displacement and acceleration.
9. Which of the following is not characteristic of displacement?
   (a) It is not always positive.
   (b) It has both magnitude and direction.
   (c) It can be zero.
   (d) Its magnitude is less than or equal to the actual path length of the object.
10. The S.I. unit of displacement is
    (a) m (b) m s^{-1}
    (c) m s^{-2} (d) None of these
11. Which of the following is not a vector?
    (a) Speed (b) Velocity
    (c) Displacement (d) Acceleration
12. Time is an example of
    (a) Scalar
    (b) Vector
    (c) Scalar or vector
    (d) Neither scalar nor vector
13. In five minutes the distance between a pole and a car changes progressively. What is true about the car?
    (a) Car is at rest.
    (b) Car is in motion.
    (c) Nothing can be said with this information.
    (d) None of the above.
14. A distance
    (a) Is always positive.
    (b) Is always negative.
    (c) May be positive as well as negative.
    (d) Is neither positive nor negative.
15. When a body covers equal distance in equal intervals of time, its motion is said to be
    (a) Non-uniform (b) Uniform
    (c) Accelerated (d) Back and forth
16. The motion along a straight line is called
    (a) Vibratory (b) Stationary
    (c) Circular (d) Linear
17. A particle is travelling with a constant speed. This means that
    (a) Its position remains constant as time passes.
    (b) It covers equal distance in equal interval of time.
    (c) Its acceleration is zero.
    (d) It does not change its direction of motion.
18. The rate of change of displacement is
    (a) Speed (b) Velocity
    (c) Acceleration (d) Retardation
19. Speed is never
    (a) Zero (b) Fraction
    (c) Negative (d) Positive
20. The motion of a body covering different distances in the same intervals of time is said to be
    (a) Zig - Zag (b) Fast
    (c) Slow (d) Variable
21. The unit of velocity is
    (a) m s (b) m s^{-1}
    (c) m s^{2} (d) none of these
22. A speed
    (a) Is always positive.
    (b) Is always negative.
    (c) Can be positive as well as negative.
    (d) Is neither zero nor negative.
23. A particle moves with a uniform velocity.
    (a) The particle must be at rest.
    (b) The particle moves along a curved path.
    (c) The particle moves along a circle.
    (d) The particle moves along a straight line.

24. A quantity has value of – 6.0 m s^{-1}. It may be the
    (a) Speed of a particle
    (b) Velocity of a particle
    (c) Position of a particle
    (d) Displacement of a particle
25. In 10 minutes, a car with a speed of 60 km h^{-1} travels a distance of :
    (a) 6 km (b) 600 km
    (c) 10 km (d) 7 km
26. A particle covers equal distances in equal intervals of time, it is said to be moving with uniform
    (a) Speed (b) Velocity
    (c) Acceleration (d) Retardation
27. The SI unit of the average velocity is
    (a) m s^{-1} (b) km s^{-1}
    (c) cm s^{-1} (d) mm s^{-1}
28. Meter per second is not the unit of
    (a) Speed (b) Velocity
    (c) Displacement (d) None of them
29. A car accelerated uniformly from 18 km h^{-1} to 36 km h^{-1} in 5 s. The acceleration in m s^{-2} is
    (a) 1 (b) 2
    (c) 3 (d) 4
30. Out of energy and acceleration which is the vector?
    (a) Acceleration (b) Energy
    (c) Both (a) and (b) (d) None of these
31. The C.G.S. unit of acceleration is
    (a) m s^{-2} (b) cm s^{-2}
    (c) m s^2 (d) cm s^2
32. A train starting from a railway station and moving with a uniform acceleration, attains a speed of 40 km h^{-1} in 10 minutes. Its acceleration is
    (a) 18.5 m s^{-2} (b) 1.85 cm s^{-2}
    (c) 18.5 cm s^{-2} (d) 1.85 m s^{-2}
33. The brakes applied to a car produce a negative acceleration of 6 m s^{-2}. If the car stops after 2 seconds, the initial velocity of the car is
    (a) 6 m s^{-1} (b) 12 m s^{-1}
    (c) 24 m s^{-1} (d) zero
34. A body is moving with a uniform velocity of 10 m s^{-1}. The velocity of the body after 10 s is
    (a) 100 m s^{-1} (b) 50 m s^{-1}
    (c) 10 m s^{-1} (d) 5 m s^{-1}
35. In 12 minutes a car whose speed is 35 km h^{-1} travels a distance of
    (a) 7 km (b) 3.5 km
    (c) 14 km (d) 28 km
36. A body that is moving along a straight line at 20 m s^{-1} undergoes an acceleration of 4 m s^{-2}. After 2 s, its speed will be
    (a) 8 m s^{-2} (b) 12 m s^{-1}
    (c) 16 m s^{-2} (d) 28 m s^{-2}
37. If a car increases its speed from 20 km h^{-1} to 50 km h^{-1} in 10 secs, then its acceleration will be
    (a) 30 m s^{-1} (b) 3 m s^{-1}
    (c) 18 m s^{-1} (d) 0.83 m s^{-1}
38. When the distance travelled by an object is directly proportional to the time, it is said to travel with
    (a) zero velocity (b) constant speed
    (c) constant acceleration (d) uniform velocity
39. If a body falling freely from rest has a velocity *v* after it falls through a height *h*, then the distance it has to fall further for its velocity to become double will be
    (a) 3 h (b) 6 h
    (c) 8 h (d) 10 h
40. The velocity of bullet is reduced from 200 m s^{-1} to 100 m s^{-1} while travelling through a wooden block of thickness 10 cm. The retardation, assuming it to be uniform will be
    (a) 10×10^4 m s^{-2} (b) 1.2×10^4 m s^{-2}
    (c) 13.5×10^4 m s^{-2} (d) 15×10^4 m s^{-2}
41. If a body starts falling from height '*h*' and travels a distance of *h*/2 during the last second of motion, then the distance travelled in one sec is
    (a) $\sqrt{2}-1$ (b) $2+\sqrt{2}$
    (c) $\sqrt{2}+\sqrt{3}$ (d) $\sqrt{3}+2$
42. Area of the speed - time graph gives
    (a) Distance (b) Velocity
    (c) Speed (d) None of these

43. If an object undergoes an acceleration of 8 m s^{-2} starting from rest, then the distance travelled in 1 s is

(a) 2 m (b) 4 m

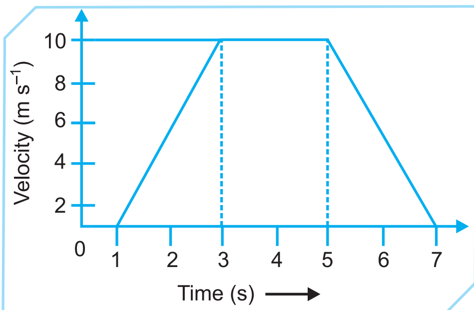
(c) 6 m (d) 8 m

44. A cyclist goes around a circular track once every 2 min. If the radius of the circular track is 105 m, then the speed of the cyclist will be

(a) 5 m s^{-1} (b) 3.5 m s^{-1}

(c) 5.5 m s^{-1} (d) 3 m s^{-1}

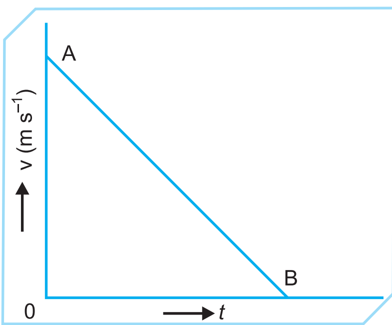
45. For the velocity-time graph shown in figure below, the distance covered by the body in the last two seconds of its motion is what fraction of the total distance covered in the seven seconds?



(a) 1/2 (b) 1/4

(c) 1/3 (d) 2/3

46. Velocity-time graph AB, in figure below shows that the body has



(a) A uniform acceleration

(b) A non-uniform retardation

(c) Uniform speed

(d) Initial velocity OA and is moving with uniform retardation

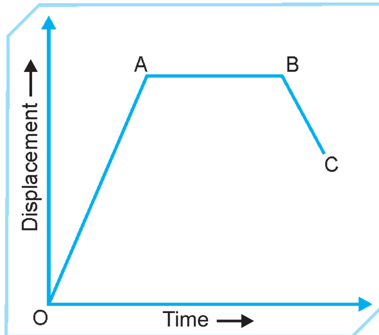
47. In figure below BC represents a body moving

(a) Backward with uniform velocity.

(b) Forward with uniform velocity.

(c) Backward with non-uniform velocity.

(d) Forward with non-uniform velocity.



48. 1 radian is equal to

(a) 57.30° (b) 5730°

(c) 1800° (d) 3600°

49. An athlete completes one round of a circular track of diameter 200 m in 40 s. What will be the displacement at the end of 2 minutes 40 s?

(a) 2200 m (b) 220 m

(c) 22 m (d) Zero

50. What will be the distance in the above question?

(a) 2512 m (b) 2500 m

(c) 2200 m (d) Zero

51. If the distance travelled by a body is directly proportional to the time, then the body is said to have

(a) Zero speed (b) Zero velocity

(c) Constant speed (d) None of these

52. An athlete runs along a circular track of diameter 28 m. The displacement of the athlete after he completes one circle is

(a) 28 m (b) 88 m

(c) 44 m (d) Zero

53. A boy is running along a circular track of radius 7 m. He completes one circle in 10 seconds. The average velocity of the boy is

(a) 4.4 m s^{-1} (b) 0.7 m s^{-1}

(c) Zero (d) 70 m s^{-1}

54. A body is moving with a uniform speed of 5 m s^{-1} in a circular path of radius 5 m. The acceleration of the body is

(a) 25 m s^{-2} (b) 15 m s^{-2}

(c) 5 m s^{-2} (d) 1 m s^{-2}

55. Unit of angular velocity is

(a) rad (b) m s^{-1}

(c) rad s^{-2} (d) rad s^{-1}

56. The bodies in circular paths of radii 1 : 2 take the same time to complete their circles. The ratio of their linear speeds is

(a) 1 : 2 (b) 2 : 1
(c) 1 : 3 (d) 3 : 1

57. In a circular path of radius 1 m, a mass of 2 kg moves with a constant speed of 10 m s^{-1}. The angular speed in radian/sec is

(a) 5 (b) 10
(c) 15 (d) 20

58. Uniform circular motion is an example of :

(a) Variable acceleration
(b) Constant acceleration
(c) a and b both
(d) None of these

59. A car travels $\left(\frac{1}{4}\right)^{th}$ of a circle with radius r. The ratio of the distance to its displacement is

(a) $1 : \frac{\pi}{2\sqrt{2}}$ (b) $\frac{\pi}{2\sqrt{2}} : 1$
(c) $2\sqrt{2} : \pi$ (d) $\pi 2\sqrt{2} : 1$

60. A velocity-time graph, in the form of a straight line having downward slope indicates

(a) Accelerated motion (b) Constant motion
(c) Retarded motion (d) None of these

61. Among the following which is not a vector quantity?

(a) Displacement (b) Distance
(c) Acceleration (d) Velocity

62. The rate of change of velocity is called

(a) Speed (b) Acceleration
(c) Displacement (d) None of these

ANSWERS

1. (a)	2. (d)	3. (c)	4. (b)	5. (b)	6. (b)	7. (b)
8. (d)	9. (a)	10. (a)	11. (a)	12. (a)	13 (b)	14. (a)
15. (b)	16. (d)	17. (b)	18. (b)	19. (c)	20. (d)	21. (b)
22. (a)	23. (d)	24. (b)	25. (c)	26. (a)	27. (a)	28. (c)
29. (a)	30. (a)	31. (b)	32. (b)	33. (b)	34. (c)	35. (a)
36. (d)	37. (d)	38. (b)	39. (a)	40. (d)	41. (b)	42. (a)
43. (b)	44. (c)	45. (b)	46. (d)	47. (a)	48. (a)	49. (d)
50. (a)	51. (c)	52. (d)	53. (c)	54. (c)	55. (d)	56. (a)
57. (b)	58. (b)	59. (c)	60. (c)	61. (b)	62. (b)	

EXERCISES (UNSOLVED)

VERY SHORT ANSWER TYPE QUESTIONS

1 Mark each

1. When is a body said to be in a state of motion?
2. When is a body said to be at rest?
3. Is it possible that the train in which you are sitting appears to move while it is at rest?
4. Under what condition will the distance covered and the displacement of a moving object have the same magnitude?
5. Give an example in which the distance travelled by a particle is larger than the magnitude of its displacement in the same time.
6. Under what condition can a body travel a certain distance and yet its net displacement is zero?
7. Does displacement of a particle depend on the actual path along which the particle moves between two points ?
8. What is the SI unit of speed?
9. Can the speed of a particle be negative?
10. Differentiate between average speed and average velocity.
11. Give an example of motion in which a body has constant speed but not constant velocity.
12. The velocity of an object is decreasing with the passage of time. What is your inference with reference to the acceleration of an object?
13. Define uniform acceleration.
14. Give the value of acceleration for a body at rest.
15. Give an example of uniformly accelerated motion.
16. Give the shape of the velocity-time graph for uniformly accelerated motion along a straight path.
17. A body moves around the sun with constant speed in a circular orbit. Is the motion of the body uniform or accelerated?

18. How will you find the magnitude of velocity from the displacement-time graph of an object?
19. Give the shape of a displacement-time graph for a non-uniform linear motion.
20. If the distance-time graph of an object is a straight line, then what can be said about the object?
21. Mention one use of a distance-time graph.
22. If the distance-time graph is parallel to the time axis, then what can you infer about the body?
23. On which axes are, distance and time taken in a distance-time graph.
24. What does the slope of the velocity-time graph represent?

SHORT ANSWER TYPE - I QUESTIONS

2 Marks each

1. (a) Define motion.
   (b) How do we perceive an object to be in motion?
2. Differentiate between displacement and distance.
3. (a) Define the displacement of a particle in linear motion.
   (b) Does it depend on the path followed ?
4. Give an example of a body moving with uniform speed and constant acceleration.
5. A particle is moving in a circular path of radius '*r*'. What will its displacement be after half a circle is completed?
6. Differentiate between speed and velocity.
7. Mention any two causes of variation in the velocity of a particle.
8. If a body is thrown vertically upwards with a velocity 'v', then what is the greatest height to which it will rise?
9. Define instantaneous velocity.
10. Give the relation between distance and time:
    (a) When a body is moving with a uniform velocity.
    (b) When a body is moving with a variable velocity.
11. When will you say that a body is in
    (a) Non-uniform acceleration
    (b) Uniform acceleration
12. (a) When is the acceleration taken as negative?
    (b) Give the SI unit of acceleration.
13. (a) Define velocity and acceleration.
    (b) Is it possible for a body to have zero velocity but constant acceleration? Justify your answer.
14. Give reason : *'The motion of satellites around planets is considered as an accelerated motion.'*
15. What is retardation ?
16. Find the kind of motion in the following:
    (a) An electron moving around the nucleus.
    (b) A car moving with constant speed turning around a curve.
17. Give two advantages of velocity-time graph.
18. Draw speed-time graph for non-uniform motion.
19. Why can the velocity-time graph never be a straight line parallel to velocity axis?
20. Assume that a girl is enjoying a ride on a merry-go-round moving with a constant speed of 10 m s^{-1}. What is the motion of the girl?

SHORT ANSWER TYPE – II QUESTIONS

3 Marks each

1. (a) Under what condition are the distance and the magnitude of the displacement equal?
   (b) Under what conditions does a body move in such a way that the magnitude of its average velocity is equal to its average speed?
   (c) How can the change in the position of an object with time be represented?
2. If the displacement of a moving object in a given interval of time is zero, will the distance travelled by the object also be zero? Justify your answer.
3. Pooja bends to touch her toes. Is the motion of her head an example of uniform motion or accelerated motion? Explain.
4. Give an example for the range of motion in each of the following case :
   (a) Acceleration is non-uniform.
   (b) Acceleration is uniform.
   (c) Acceleration is in the direction of motion.
5. Draw distance-time graph for a body
   (a) At rest
   (b) In uniform motion

6. Draw speed-time graph for a body
   (a) At rest
   (b) In uniform motion
7. Derive the first equation of motion.
8. Derive the second equation of motion.
9. Derive the third equation of motion.
10. Define Uniform circular motion.

LONG ANSWER TYPE QUESTIONS

5 Marks each

1. What decides the direction of motion of an object– Velocity or Acceleration ? Explain with an example.
2. Illustrate the graphical representation of the first equation of motion.
3. Explain the graphical representation of the third equation of motion.
4. (a) Draw a velocity-time graph for a body starting its motion with an initial velocity '*u*', uniform acceleration '*a*', and final velocity 'v' in time '*t*'.
   (b) Using the above graph, derive the second equation of motion.
5. Explain uniform circular motion with two examples.

VIVA VOCE QUESTIONS

1. Is displacement a scalar or a vector quantity?
2. What type of motion is showed by a freely falling stone?
3. What remains constant in uniform circular motion?
4. What does the slope of a speed-time graph indicate?
5. What does the slope of a distance-time graph indicate?

FILL IN THE BLANKS

1. Acceleration is the rate of change of ....
2. .... gives both the speed and the direction of motion of a body.
3. Velocity is the rate of change of ....
4. If a body moves with uniform velocity, its acceleration is ....
5. It is possible for something to accelerate but not change its speed if it moves in a ....

TRUE OR FALSE

1. Distance is a vector quantity.
2. Total distance is the product of speed and time.
3. The earth moves round the sun with uniform velocity.
4. The slope of the velocity-time graph shows displacement.
5. An object has an accelerated motion, if it travels equal distances in equal intervals of time.

ASSERTIONS AND REASONS

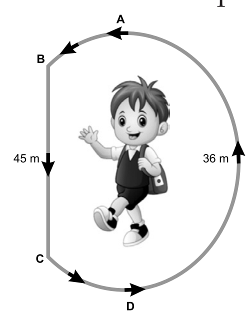
Directions : In the following questions, a statement of assertion is followed by a statement of reason. Mark the correct choice as:

(a) If both assertion and reason are true and reason is the correct explanation of assertion.
(b) If both assertion and reason are true but reason is not the correct explanation of assertion.
(c) If assertion is true but reason is false.
(d) If both assertion and reason are false.

1. **Assertion :** The displacement of the car is zero but the car travelled some distance and came back to its starting point.
   Reason : The displacement is the relative position of final and initial points.
2. **Assertion :** A fly is moving with a uniform rate. The average velocity of the fly is determined with its final and initial velocity.
   Reason : The average speed of an object obtained by dividing total distance and time taken to travel that distance.

PARAGRAPH BASED QUESTION

1. Answer question numbers (a) – (d) on the basis of your understanding of the following paragraph and the related studied concepts.



Raju goes to his teacher with the doubt of differentiating between distance and displacement. Instead of answering him directly Raju's teacher takes him along with the whole class to the school's athletic ground. Here, he marks 6 points A, B, C, D, E and F in the ground and tells the student to calculate the different lengths as given in the figure. It was found that the length of ADE is 36 m and the length of ABCD is 45 m. The teacher asks the following questions to the class students to make them understand the difference between distance and displacement.

(a) If A is both - the starting point and the destination:

(i) Calculate the distance and displacement of the boy's journey.

(ii) Calculate the speed and velocity if the boy took 27 seconds to complete the journey.

Calculate your answers in km/h.

(b) If A is the starting point and D is the destination, calculate the distance and displacement of the boy's journey.

(c) Differentiate between distance and displacement. Can both be same ?

(d) Can distance and displacement of a body moving between two points be zero ?

ANSWERS

VIVA VOCE QUESTIONS

1. Vector quantity.
2. Non-uniform motion.
3. Speed.
4. Acceleration.
5. Speed.

FILL IN THE BLANKS

1. Velocity.
2. Velocity.
3. Displacement.
4. Zero.
5. Circular path.

TRUE AND FALSE

1. False
2. True
3. False
4. False
5. False

ASSERTIONS AND REASONS

1. (a) The displacement is a vector quantity. It is the difference between final and initial position. When a car travels from one position to another and came back to its starting point. The displacement is zero for that car because the difference between final position and initial position which are at same position is zero.

Displacement = Final position – Initial position

Thus, the reason gives correct explanation for the given assertion.

2. (b) Speed and velocity are not same but similar quantities. The speed is a scalar quantity and the velocity is a vector quantity. The velocity gives the direction of an object whereas speed gives only the magnitude but not the direction.

The average velocity of the fly can be determined as it is moving at uniform rate.

One can determine average speed with total distance and time taken.

Thus, assertion and reason are correct but reason does not explain the assertion as both speed and velocity are not the same but similar quantities.

PARAGRAPH BASED QUESTION

1. (a) (i) Distance = Length of path ABCD + Length of path DEA = (45+36) m

= 81 m

Displacement = 0 m

(ii) $$\text{Speed} = \frac{\text{Distance}}{\text{Time}} = \frac{81\text{m}}{27\text{s}} = 3 \text{ m/s}$$

$$= 3\frac{\text{m}}{\text{s}} \times \frac{1\text{km}}{1000\text{m}} \times \frac{3600\text{s}}{1\text{h}}$$

= 10.8 km/h

Tip : To quickly convert m/s to km/h, multiply by $\frac{18}{5}$.

Conversely, for conversion to m/s from km/h, multiply by $\frac{5}{18}$.

$$\text{Velocity} = \frac{\text{Displacement}}{\text{Time}} = \frac{0 \text{ m}}{27 \text{ s}} = 0\text{ms}^{-1}$$

(b) Distance = 45 m

As defined earlier, displacement is the shortest possible path between two points. Also, the shortest distance between two points is always a straight line.

In the given case, the shortest path between A and D is the diameter AD of the semi-circular path AED, which is given to be 36 m.

$$\text{AD} = \frac{36}{\pi} = \frac{36}{3.14}$$

= 11.46 m

[Circumference of a full circle = $2\pi r$]

Displacement = 11.46 m

(c) Distance is defined as the actual path covered by a body between two points. It is a scalar quantity.

Displacement is defined as the shortest distance from the initial to the final position of a body. It has both magnitude and direction, hence it is a vector quantity.

Distance is equal to displacement when a body traverses some length in a straight line, because straight line is the shortest possible distance between two points.

(d) Distance of a body moving between two points can never be zero as it would physically signify a body at rest.

Displacement of a body moving between two points can be zero if the initial and final points are same.

MOCK TESTS

MOCK TEST 1

Time allowed : 1 hour 15 minutes

Maximum Marks : 35

General Instructions :

- All questions are compulsory.
- Questions 1 to 3 are of one mark questions. These are to be answered in one word or in one sentence.
- Questions 4 to 10 are of three marks questions. These are to be answered in about 50 words each.
- Questions 11 to 13 are of five marks questions. These are to be answered in about 70 words each.

1. In a given interval of time, the displacement of a moving object is zero. Would the distance travelled by the object also be zero? Comment.
2. A body goes round with the constant speed in a circular orbit. Is the motion uniform or accelerated?
3. What type of distance-time graph is obtained when an object has uniform motion?
4. When a stone is thrown vertically upwards, its velocity is continuously decreased. Why?
5. Compare rest and motion.
6. Differentiate uniform linear motion and uniform circular motion.
7. Define velocity with its SI unit.
8. Differentiate speed and velocity.
9. Compare scalar and vector quantities.
10. Define non-uniform motion. What types of graphs are obtained in uniform and non-uniform motion?
11. How is graphical representation of observations more useful and advantageous than a table?
12. Calculate the speed of the object from distance-time graph.
13. How can you calculate distance travelled by an object with the help of a speed-time graph?

MOCK TEST 2

Time allowed : 1 hour 15 minutes

Maximum Marks : 35

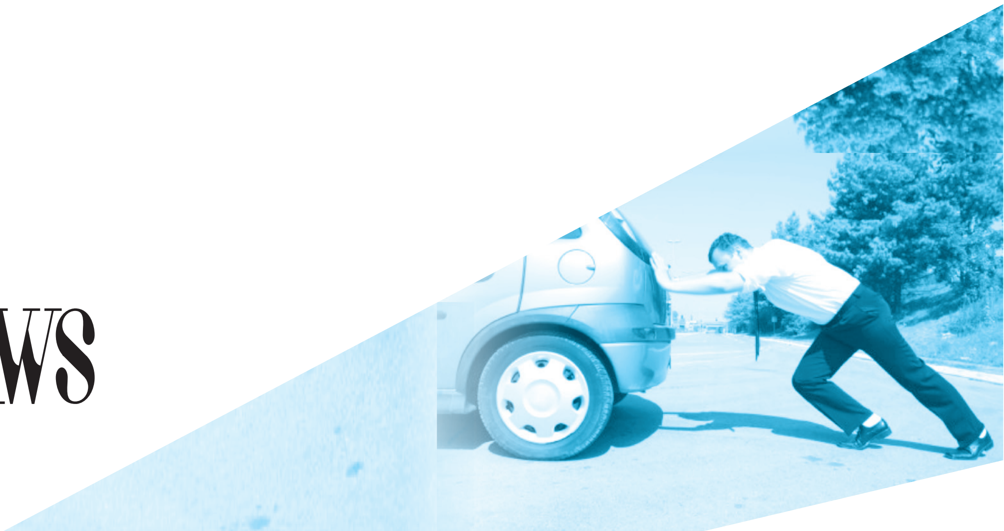
General Instructions :

- All questions are compulsory.
- Questions 1 to 3 are of one mark questions. These are to be answered in one word or in one sentence.
- Questions 4 to 10 are of three marks questions. These are to be answered in about 50 words each.
- Questions 11 to 13 are of five marks questions. These are to be answered in about 70 words each.

1. Give an example of a motion in which the acceleration is in the direction of motion.
2. Define uniform circular motion.
3. Does acceleration tell us the direction of motion?
4. At what condition, is the average speed equal to the magnitude of the average velocity?
5. How a body can have zero average velocity but not zero average speed?
6. A train starting from a railway station and moving with a uniform acceleration attains a speed of 50 km h^{-1} in 10 min. Find its acceleration.
7. State an important characteristic of uniform circular motion.
8. A body starting from rest travels with uniform acceleration. If it travels 100 m in 5 s, what is the value of acceleration?
9. Explain speed-time graph when the initial speed of the body is not zero.
10. What will be the acceleration if a bus increases its speed from 20 km h^{-1} to 50 km h^{-1} in 10 s?
11. Derive the third equation of motion by graphical method.
12. The distance between Bangalore to Mysore is 200 km. A train travels the first 100 km at a speed of 50 km h^{-1}. How fast must the train travel the next 100 km, so as to average 70 km h^{-1} for the whole journey?
13. Draw a velocity-time graph to show the motion of a car which accelerates uniformly from rest for 5 s, and then it travels at a steady velocity for 5 s.

2

FORCE AND LAWS OF MOTION



CONTENTS

2.0 INTRODUCTION

In the previous chapter, we discussed the motion of an object along a straight line in terms of velocity and acceleration. In this chapter, we will discuss the causes of motion. What causes a body to accelerate or decelerate? Do all motions require some cause? We will also discuss the relationship between the force and the state of motion of a body. Let us now discuss the concept of force. The cause of motion was a puzzle for scientists for many centuries. They knew that anything set in motion did not move forever. This observation made them conclude that

"Rest is the natural state of an object or of matter itself."

Later *Galileo Galilei* and *Sir Isaac Newton* developed a few concepts that shed light into the causes of motion.

We know from our everyday life that some effort is required to put a stationary object into motion or to stop a moving object. This can be by pushing, pulling, or hitting an object to move it or to change its state of motion. Thus a push, pull, or hit is the force that moves an object or changes its state of motion. For example, a book lying on a table is at rest and it will remain at rest unless somebody picks it up. The person picking up the book will have to make some effort. As the person moves up, the book also moves along with him. It is clear that *we require some muscular effort in the form of a push or a pull to bring a stationary body into motion or to stop a moving body*. Thus, in order to move a body, it has to be either pushed or pulled.

"The study of the causes of motion and that occur changes in motion is called dynamics."

Force

"The push or pull on a body needed to change the motion of the body is called force."

However, force cannot be seen but the effect of force on a body can be felt. Let us look at a few examples to understand the effects of force. A force is used when we stretch a rubber-band, when we kick a football, when we lift a box from the floor, when we twist a wet cloth to squeeze out water, etc.

"The direction in which a body is pushed or pulled is called the direction of force."

For instance, when we push or pull a door to open it, we need to apply a force on the door in a direction away from us or towards us, respectively. Similarly, when we pull or push the door to close it, we need to exert a force on the door in a direction towards us or away from us, respectively. Hence, we can conclude that, our everyday actions like twisting, pulling, pushing, lifting, stretching etc. all involve different forces (fig. 2.1).

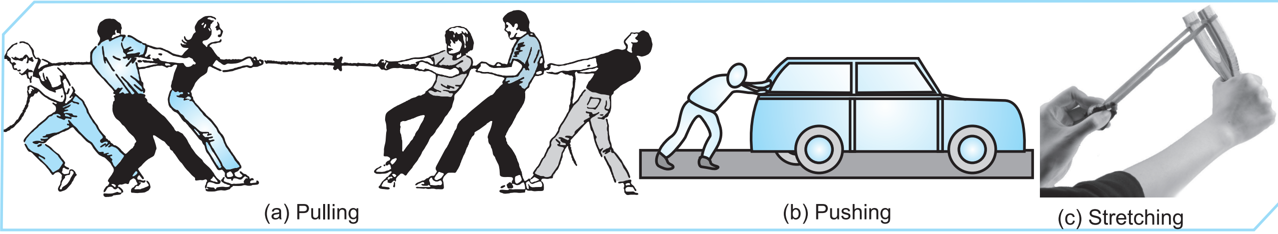


Fig. 2.1 : Example of pulling, pushing and stretching

We can now define force as, *"A physical quantity which tends to cause a motion in an object at rest or which tends to change the direction of motion or the speed of a moving object."*

Effects of Force

A force can be felt only by the effect it produces on the objects or bodies around us.

Let us discuss the different effects of force with examples.

(a) A force can move a stationary body or an object:

When a force is applied on a rigid body which is at rest but is free to move, it begins to move in the direction of the force.

Example 1 : When a football kept on the ground is kicked with our foot, it starts moving. Thus, the force exerted by our foot moves a stationary football (fig. 2.2).

Fig. 2.2 : Effect of force can move a stationary body

Example 2 : A book placed on a table moves when pushed.

Example 3 : The branches and leaves of a tree shake due to the force of wind.

(b) A force can stop a moving body or object :

A moving rigid body can be stopped by applying a force in the direction opposite to the direction of motion.

Example 1 : A fielder on the ground stops a moving ball by applying a force with his hands (fig. 2.3).

Fig. 2.3 : Effect of force can stop a moving body

Example 2 : A moving ball rolls to a stop on its own due to the force of friction.

Example 3 : A rotating top can be stopped by the force exerted by our hands.

(c) A force can change the speed of a moving body or an object :

A force can make a moving body move faster if force is applied in the direction of motion, while it can slow down a moving body if force is applied in a direction opposite to the direction of motion.

Example 1 : When someone pushes a moving bicycle from behind, the speed of the bicycle increases and it will move faster. Similarly, the speed of a bicycle decreases when someone pulls the moving bicycle from behind (fig. 2.4).

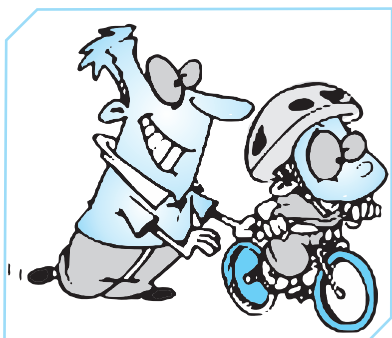


Fig. 2.4 : Effect of force can change the speed of a moving body

Example 2 : If a person pushes a moving swing in the direction of motion, it will move faster.

(d) A force can change the direction of a moving body :

When a force is applied perpendicular to the direction of motion, then it changes only the direction of motion of the moving body. If force is applied in any other direction, it changes both the speed and the direction of motion.

Example 1 : When a batsman hits the ball with his bat, the direction of the moving ball changes (fig. 2.5).

Fig. 2.5 : A force can change the direction of moving ball

Example 2 : If we blow air from our mouth on the smoke rising up from a burning incense sticks, the direction of smoke changes.

(e) A force can change the shape and size of a body :

When a force is applied on a non-rigid body which is not free to move, then it changes the shape and size of the body.

Example 1 : If we press bodies like a sponge, a balloon or a rubber-ball, their shapes change due to the force (fig. 2.6).

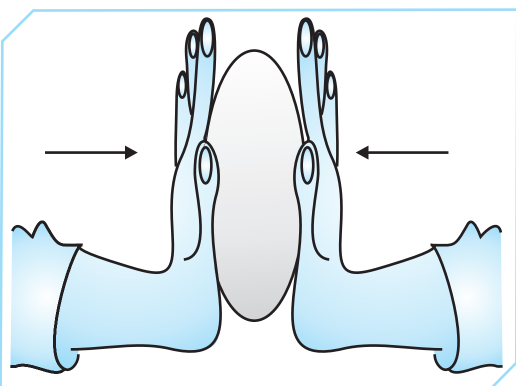


Fig. 2.6 : A spherical rubber ball becomes oblong as we apply force on it

Example 2 : If we stretch a rubber-band, its shape and size changes on stretching (fig. 2.7).

Fig. 2.7 : A rubber band changes its shape and size on application of force.

Thus, from the above discussion, we can conclude that

(a) A force can move a stationary body.
(b) A force can stop a moving body.
(c) A force can change the speed of a moving body.
(d) A force can change the direction of a moving body.
(e) A force can change the shape and size of a body.

Based on these conclusions, we can also define force as, *"an external influence which changes or tends to change the state of rest or of uniform motion of a body, changes the direction of a body or deforms a body is known as force."*

Let us now discuss the different types of forces.

2.1 BALANCED AND UNBALANCED FORCES

We shall discuss these two types of forces one by one in detail with a few examples.

Balanced Forces

When two forces of equal magnitude act in opposite directions on an object simultaneously, the object continues to be in its state of rest or of uniform motion in a straight line. Such forces acting on the object are known as balanced forces.

Let us discuss this with a few examples.

Consider a wooden block placed on a horizontal table as shown in fig. 2.8

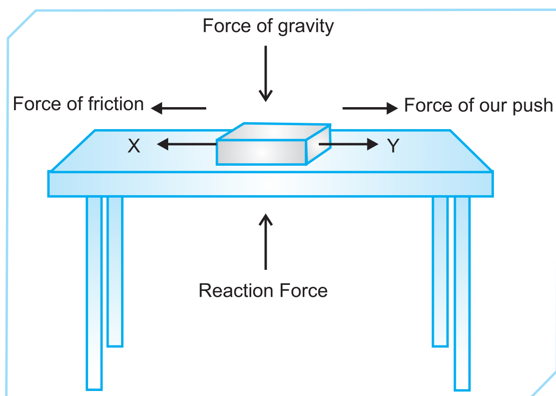


Fig. 2.8 : Balanced forces

Initially, when we don't touch the block, there are only two forces on it — the force of gravity or weight of the block and the reaction exerted by the table on the block, which acts upwards.

Now, if we push the block gently to the right without actually moving it, two or more forces start acting on the block. So, in all, there will be four forces namely,

(a) Force of our push (to the right)

(b) Force of friction that opposes our push (to the left)

(c) Force of gravity or the weight of the block (downwards)

(d) Reaction exerted by the table on the block (upwards)

Since the block remains stationary, it means that all these forces are balanced. The upward and downward forces are equal in magnitude though their directions are opposite. Similarly, the force of friction assumes a value that is equal in magnitude but opposite in direction to the push that we exert.

Now, consider two strings X and Y tied to the opposite ends of the block. If we pull the string X alone, the box will start moving to the left. But if we pull both X and Y with the same force, the block will remain stationary.

In both the above cases, the box remains stationary when the forces acting on it are balanced.

Thus, "*the forces that act on an object without changing its state of rest or of uniform motion are called balanced forces.*"

So we can say that force of gravity is balanced by the reaction force, the force of our push is balanced by the force of friction, and the pull on X is balanced by the pull on Y when they are equal. All these pairs are 'balanced forces.'

Similarly, when we push a wall, the wall does not move. The force of the push on the wall acts in the forward direction and the wall exerts an equal force on our hand in the backward direction. These two forces are equal and opposite, and hence cancel out the effect of each other. These two forces are also balanced forces.

We can observe such balanced forces in a game of tug of war (fig. 2.9). Sometimes during a game we can see that the rope does not move in any direction in spite of both teams pulling it. This happens when the forces exerted by the teams are balanced forces which are equal and opposite.

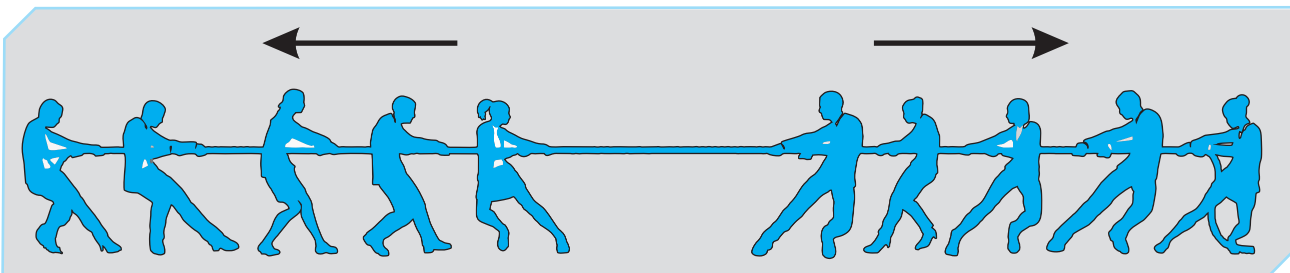


Fig. 2.9 : Balanced forces in the game of tug of war

Thus, we can conclude that if the resultant of all forces acting on a body is zero, then the forces can be called balanced forces.

Unbalanced Forces

"When two forces of unequal magnitude act in opposite directions on an object simultaneously, then the object moves in the direction of the larger force. These forces acting on the object are known as unbalanced forces".

Let us discuss this with a few examples.

Just as in the earlier example, consider a wooden block placed on a horizontal table as shown in fig. 2.10. We know that when we push the block gently, it does not move as the friction balances the push.

Now, if we increase the force with which we push the block to the right, after a certain point, the friction will not be able to balance the push and the block starts moving to the right.

We can consider the strings X and Y again. If we increase the pulling force on either string such that it exceeds the force with which the other string is pulled, the block will start moving in the direction of the greater pull.

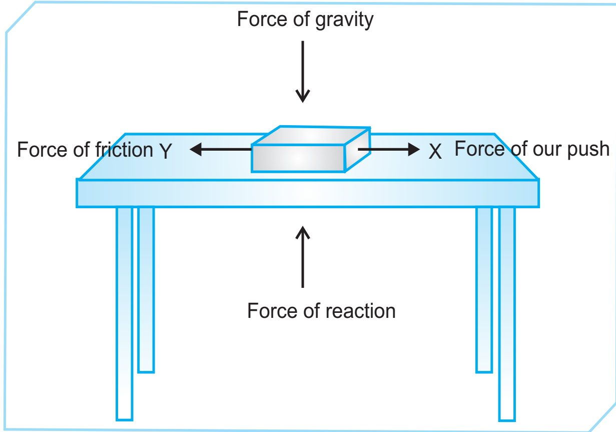


Fig. 2.10 : Unbalanced force

In both the above cases, the force of gravity is balanced by the reaction force. But the pushing force exceeds the force of friction and thus the two forces are not balanced. Similarly, the force in one string is greater than the other and hence, they are unbalanced. So the block moves in the direction of the greater force. Thus, *"the unequal forces that act on an object causing it to change its state of rest or of uniform motion are called unbalanced forces."*

When such unbalanced forces act on an object, the resultant of these forces act on the object and set it in motion.

Similarly, in fig. 2.11, when a boy drags a box on the floor, we can see that pull applied by the boy on the box will help the box to move in forward direction. On the other hand, the force of friction between the lower surface of the box and the surface of the floor will be in the opposite direction. However, the box moves in the direction of the pulling force. Hence, we can say that an unbalanced force is acting on the box.

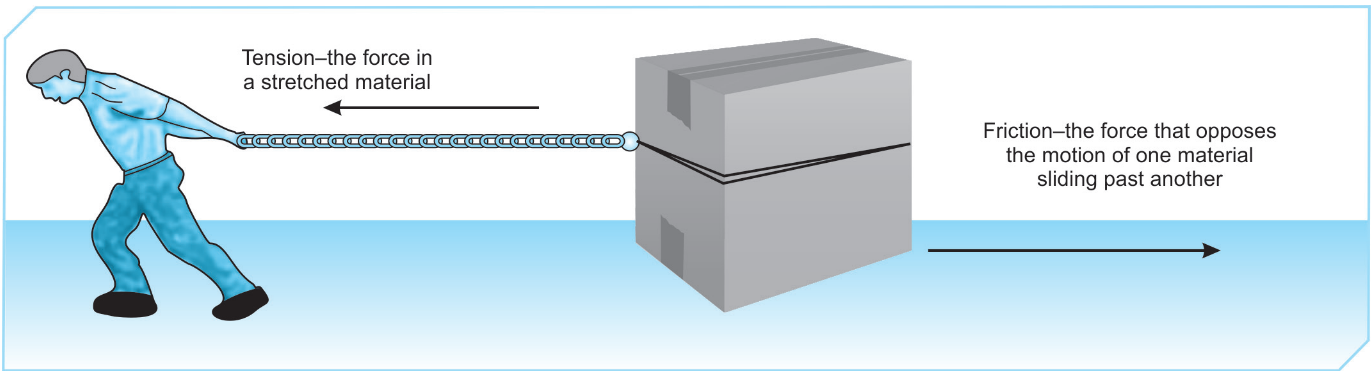


Fig. 2.11 : Two opposite forces of different magnitude acting on the block

Thus, we can conclude that if the resultant of all forces acting on a body is not zero, then the forces can be called unbalanced forces.

Let us discuss the concept of balanced and unbalanced forces more clearly with an example (fig. 2.12).

Consider some children trying to push a box on a rough floor. If one of them pushes the box with a small force, the box does not move because of friction acting in a direction opposite to the push. Friction force arises between two surfaces in contact. It balances the pushing force and therefore, the box does not move. Now, consider two children pushing the box harder, but the box still does not move. This is because the frictional force still balances the, pushing force. If the children push the box still harder, the pushing force becomes bigger than the frictional force. As a result there is an unbalanced force. So, the box starts moving.

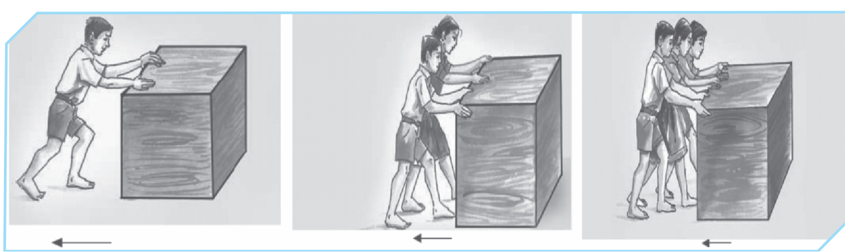


Fig. 2.12 : Effects of frictional force

Thus, from the above discussion on forces, we can also conclude that a body will continue to move with uniform speed unless acted upon by an unbalanced force. It was Galileo who found that objects move with constant speed when no forces act on them.

Note

(a) When balanced forces act on a body at rest, it remains at rest.

(b) When balanced forces act on a moving body, it continues to move in the same direction with same speed.

(c) When unbalanced forces act on a body at rest, it begins to move in the direction of the larger force.

(d) When unbalanced force acts on a moving body, its speed and/or direction change.

PAPER- PEN TEST : 1

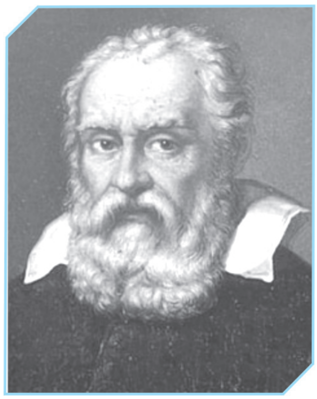
1. Define dynamics.
2. Define force.
3. What is meant by the direction of force?
4. Illustrate the direction of force with an example.
5. What are the various effects of force?
6. Give an example to show that a force can stop a moving body.
7. Give an example to show that a force can move a stationary object.
8. Give an example to show that a force can change the speed of a moving object.
9. Give an example to show that a force can change the direction of a moving object.
10. Give an example to show that a force can change the shape and size of a body.
11. What are the different types of forces?
12. Differentiate the various types of forces.
13. Explain balanced forces with an example.
14. Illustrate unbalanced forces with an example.

2.2 GALILEO'S IDEAS ON FORCE AND MOTION

Galileo, an Italian scientist made pioneering observations that laid the foundation of modern physics and astronomy. He was born on February 15, 1564 in Pisa, Italy. Galileo Galilei was a mathematics professor whose work had long-lasting implications for the study of physics. In 1583, Galileo entered the University of Pisa to study medicine. He soon became fascinated with many subjects, particularly mathematics and physics. He continued to study mathematics, supporting himself with minor teaching positions. During this time, his studies on objects in motion made him publish *'The Little Balance'* describing the hydrostatic principles of weighing small quantities.

He also conducted experiments on falling objects and published his views about motion and falling objects in his manuscript *'Du Motion (On Motion)'*.

Before Galileo, scientists believed that a force is required to keep an object moving with uniform velocity. But Galileo found that no force is required to continue the motion of a body. According to him, if a body is set in motion, it remains in motion even after the force applied on it is withdrawn. However, there should not be any force of friction opposing the motion. He verified this by performing the following experiment.



Galileo Galilei (1564-1642)

Galileo's Experiment

Galileo used inclined planes for his study of motion. He rolled a ball on an inclined plane to study the cause of motion and observed that,

(a) The velocity of the ball increases when it rolls down the inclined plane and decreases when the ball rolls up the inclined plane (fig. 2.13).

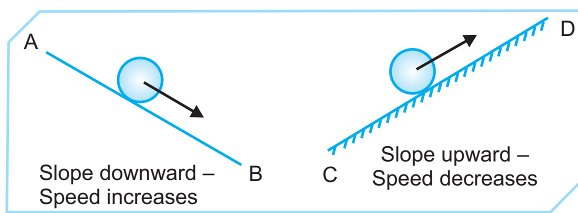


Fig. 2.13 : Velocity of the ball increases and decreases

(b) If the ball rolls between the two planes inclined equally, it will reach the same height on both the sides (fig. 2.14).

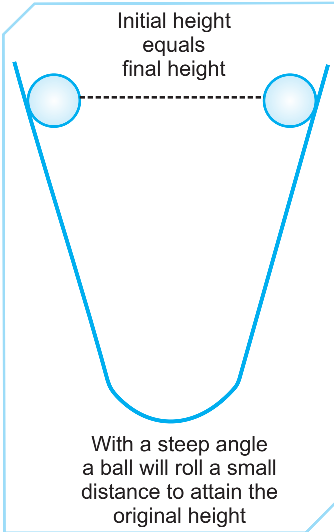


Fig. 2.14 : Ball rolls between the two planes inclined equally

If the inclination of one of the planes is decreased gradually, then the ball rolls over a larger distance in order to reach the same height (fig. 2.15).

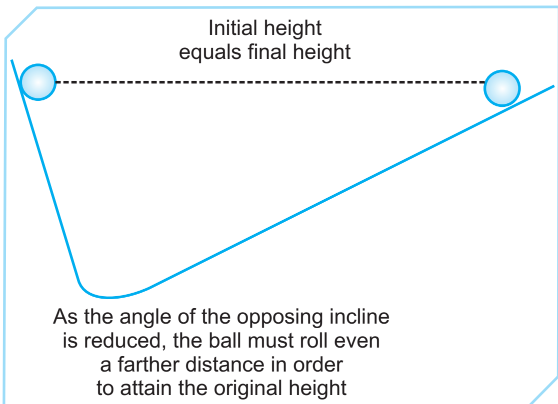


Fig. 2.15 : Ball rolls over large distances if the inclination of plane is gradually decreased

(c) If the right side plane is horizontal, then the ball continues to move indefinitely. However, the ball eventually comes to rest due to friction (fig. 2.16).

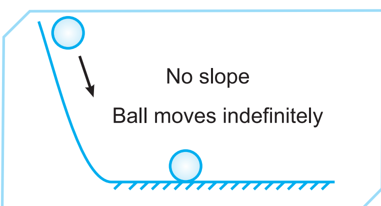


Fig. 2.16 : If the right side plane is horizontal then the ball continues to move indefinitely

(d) When the right side plane is rough, then the ball would cover only a small distance.

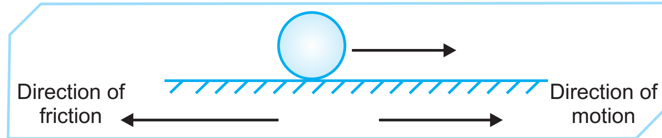


Fig. 2.17 : If the second inclined plane is rough then ball would cover less distance

We must remember that Galileo conducted his experiments under more or less ideal conditions where there was no friction.

However, in actual practice, it is extremely difficult to achieve a zero unbalanced force. This is because at the point of contact of two objects, there is always a frictional force whose direction is opposite to the direction of motion.

So, the ball stops after travelling some distance. It will never attain the same height on the inclined plane on the right hand side as on the left due to friction. The effect of force of friction can be minimized by using lubricants (grease, oil, varnishes etc.).

Let us take an example from our everyday life to explain this more clearly.

A bicycle does not stop as soon as we stop pedaling, a but moves a certain distance before it comes to rest. If the force of friction is reduced by greasing or oiling the parts of the cycle and if it moves on a smooth plane road, then it will travel for a longer distance before coming to rest. If somehow, we avoid the force of friction completely, then the cycle would remain moving forever even when the pedaling is stopped.

Thus, from the above discussion, we can conclude that in the absence of force of friction, an object in motion does not require a force to keep it moving *i.e.*, an object, if once in motion, moves with uniform velocity if no force acts on it.

Galileo's ideas on force and motion helped Newton to formulate three fundamental laws that govern the motion of objects. These laws are known as Newton's laws of motion.

Newton's Laws of Motion

Sir Isaac Newton is an English scientist whose work had influenced the course of science like none other. His findings span disciplines as diverse as astronomy, mathematics, physics, and theology. In 1868, he proposed three laws that govern the motion of bodies, which later came to be known as Newton's Laws of Motion. The first law defines the concepts of inertia and force in a qualitative manner. The second law of motion quantifies force by

Sir Isaac Newton (1643-1727)

relating it with momentum, which is measurable quantity. The third law of motion puts forth the relation between action and reaction forces.

2.3 NEWTON'S FIRST LAW OF MOTION

Statement

According to Newton's first law of motion, *"Every body continues in its state of rest or of uniform motion in a straight line unless compelled by some external force to change that state."*

Newton's first law outlines two concepts namely,

(a) Inertia

(b) Force

In order to understand Newton's first law of motion, first we need to know 'inertia'.

INERTIA

Definition of Inertia

The first part of Newton's first law, according to which an object cannot change its present state by itself, defines inertia. If the object is in the state of rest, it will remain stationary and if it is moving in some direction, it will continue to move with the same velocity in the same direction unless an external force is applied on it.

Examples of Inertia

(a) A book lying on a table remains in the same place unless it is displaced by some external agency.

(b) A ball rolling on a horizontal plane keeps on rolling unless the force of friction between the ball and the plane stops it.

Thus, *the property of an object by virtue of which it neither changes its present state nor it tends to change the present state is called the inertia.* It is the inherent property of any object.

Let us now demonstrate the property of inertia using an activity.

Demonstration of the Property of Interia

We can illustrate Newton's first law of motion or the property of inertia of a body with a simple activity described below.

Activity 2.1 Aim-To illustrate the property of inertia of a body

PROCEDURE

Step 1– Take a dry and empty glass tumbler.

Step 2– Place a square piece of thick, smooth card over the mouth of the glass tumbler.

Step 3– Now, place a coin at the centre of the card as shown in the figure below.

Step 4– Flick the card horizontally striking it hard with the finger.

Step 5– What happens to the card and the coin ?

Step 6– Note down your observation.

DIAGRAM

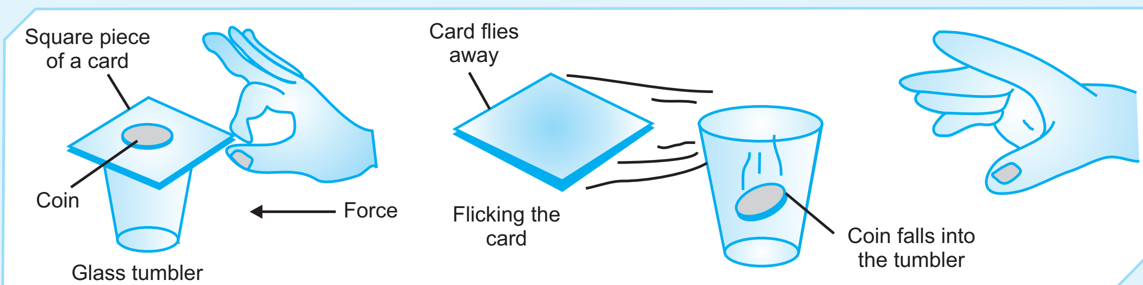


Fig. 2.18 : Experiment to illustrate the property of inertia of a body

OBSERVATION

The card flies away and the coin falls into the glass tumbler.

INFERENCE

This is because initially, both the card and the coin are at rest. When the card is flicked, the card moves. However, the coin remains at rest due to the inertia of rest. As a result, only the card flies away and the coin falls into the glass tumbler.

Note

- In activity 2.1, if we use a one-rupee coin instead of a five-rupees coin, we find that less force is required to flick the card away.

FORCE

Definition of Force

The second part of Newton's first law of motion, according to which an external cause is necessary to move a stationary object or to stop a moving object, defines force.

Let us now explain force with few examples.

Example of Force

(a) A book lying on a table moves from its place when it is pushed.

(b) A moving bicycle stops when a force is applied on its wheels by the brakes.

Thus, *force is that external cause which tends to change the state of rest or the state of motion of an object.*

Galileo was the first to establish that no force is needed to keep a body moving uniformly along a straight line. However, force is required for changing the direction or state of motion of the body. Hence, Newton's first law of motion is sometimes also called Galileo's law of inertia.

Let us now discuss the different types of inertia.

Types of Inertia

Every body has two types of inertia namely,

(a) Inertia of rest

(b) Inertia of motion

Due to inertia of rest, a body at rest tends to remain at rest while due to inertia of motion, a body in uniform motion in a straight line tends to remain in motion.

Let us now explain these two types of inertia with few examples.

Inertia of Rest

If a body is at rest, it will continue to remain at rest unless an external force is applied to change its state of rest. This property of a body is known as inertia of rest.

Examples of Inertia of Rest

(a) On shaking the branches of a tree, the fruits fall down. This is because when the stem or branches of the tree are shaken, they start moving while the fruits remain in a state of rest due to inertia of rest. Hence, the fruits get detached from the branches and fall down due to the pull of gravity (fig. 2.19).

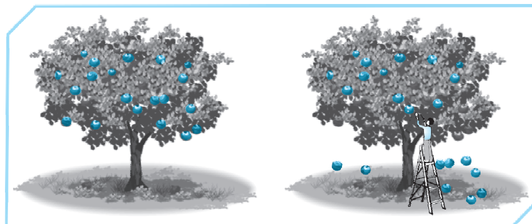


Fig. 2.19 : When the tree is shaken, it moves to and fro slightly but its fruits remain at rest due to their inertia of rest

(b) When a bus suddenly moves forward, a passenger sitting inside tends to fall backwards. This is because, when the bus starts moving, the lower part of the passenger's body which is in close contact with the bus starts moving, while the upper part of the passenger's body remains at rest. Thus, the lower part of the body moves ahead while the upper part is left behind due to the inertia of rest and passenger tends to fall backwards.

(c) When a hanging carpet is beaten with a stick, the dust particles start coming out of it. This is because, the part of the carpet where the stick strikes, moves while the dust particles on it remain in the state of rest due to inertia of rest. Thus, a part of the carpet moves ahead with the stick while the dust particles fall down due to the earth's pull.

The fact that a body will remain at rest unless acted upon by an unbalanced force can be illustrated through the following activity :

Activity 2.2 To show that a body will remain at rest unless acted upon by an unbalanced force.

PROCEDURE

Step 1 : Take a carom board.

Step 2 : Make a pile of similar coins in the centre as shown in the diagram below.

Step 3 : Now, using a striker, hit the bottom of the pile in horizontal position.

Step 4 : Note down your observation.

DIAGRAM

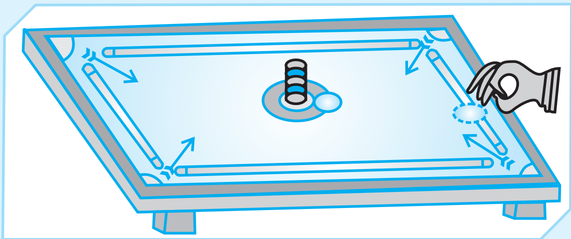


Fig. 2.20 : The carom coin at the bottom of a pile is removed when a fast moving carom coin (or striker) hits it.

OBSERVATION

On striking the bottom of a pile of carom coins with a striker, the coin at the bottom moves away while the rest of the pile of coins remains at the original position.

INFERENCE

This is because the striker exerts a force on the coin at the bottom and so it moves from the state of rest while the rest of coins remain at its place due to the inertia of rest.

Inertia of Motion

A body in a state of motion possesses inertia of motion and it continues to be in the state of motion with the same speed in the same direction in a straight line unless an external force is applied on it. This property of the body is known as inertia of motion.

Examples of Inertia of Motion

(a) When a running car stops suddenly, the passengers tend to lean forward. This is because, in a running car the whole body of the passenger is in a state of motion. So when the car stops suddenly, the lower part of the passenger's body, being in contact with the car, comes to rest while his upper part remains in the state of motion due to the inertia of motion (fig. 2.21).

Fig. 2.21 : Passenger leans forward when a running car stops suddenly.

(b) When a passenger jumps out of a moving bus, he tends to fall down. This is because, inside the bus the body of the passenger is in a state of motion with the bus. On jumping out of the moving bus, the lower part of his body comes to rest while the upper part remains in motion due to the inertia of motion.

It is interesting to note that in order to avoid falling when jumping out of moving bus, the passenger should run on the ground in the direction of motion of the bus for some distance after he jumps out of the bus.

(c) An athlete often runs before taking a long jump. This is because by running first, the athlete brings himself in the state of motion and then it becomes easier for him to take a long jump (fig. 2.22).

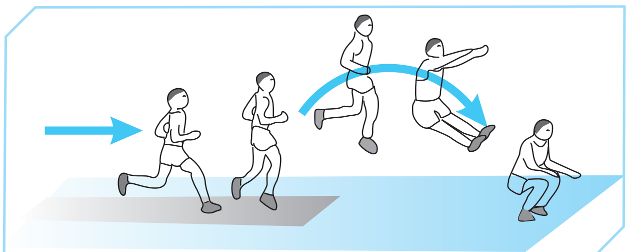


Fig. 2.22 : Athlete brings himself in the state of motion before taking a long jump due to inertia of motion.

(d) When a person in a moving train throws a ball vertically upwards, it comes back to his own hand even as the train and the passenger in it have moved forward.

This is because just when the ball was thrown, it was in a state of motion along with the person and the train. So, even while it is thrown in the air, the ball moves forward along with the train and the passenger due to inertia of motion and ends up in the person's hand.

2.4 MASS AND INERTIA

We know that inertia is an inherent property of each body by virtue of which, it has a tendency to resist

changes in its state of rest or of uniform motion. The property of inertia arises from the mass of the body. Greater the mass, greater is the inertia of the body. This means that a lighter body has less inertia than a heavier one.

In other words, when the body has more mass, it will be more difficult for it to move from rest, to stop its motion or to change the speed and the direction of motion. Hence, we can conclude that

"Mass is a measure of inertia."

Let us now relate mass and inertia with a few examples.

We know that a cricket ball is heavier than a tennis ball. When the two balls are pushed with equal force for the same amount of time, the cricket ball acquires a much smaller velocity than the tennis ball. On the other hand, if a cricket ball and a tennis ball are moving with the same velocity, then it is more difficult to stop the cricket ball which has more mass compared to the tennis ball.

Similarly, it is very difficult to set a loaded trolley, which has more mass, in motion compared to an unloaded trolley which has lesser mass. More precisely, we can say that mass is a measure of the inertia of a body. Quantitatively, inertia of a body is measured by the mass of body. The heavier the body, the greater is the force required to change its state and greater is its inertia. The reverse is also true.

PAPER–PEN TEST : 2

1. Explain Galileo's experiment to show that no force is required to continue the motion of a body.
2. Why is it extremely difficult to achieve a zero unbalanced force?
3. How can the effect of the force of friction be minimized?
4. Who proposed the three laws of motion?
5. What does the first law of motion suggest?
6. State Newton's first law of motion.
7. What are the two concepts discussed in Newton's first law of motion?
8. Define inertia.
9. Explain inertia with a few examples.
10. Demonstrate a simple experiment to illustrate Newton's first law of motion.
11. Define force.
12. Differentiate between mass and inertia.
13. How do you relate inertia and mass?
14. What are the different types of inertia?
15. Explain inertia of rest with an example.
16. Explain inertia of motion with an example.
17. When a passenger jumps out of a moving bus, he falls down. Why?
18. Note down two practical situations where we can put to use the property of inertia of rest.

Before we proceed to Newton's second law of motion it is important to know the meaning of the term *"Momentum"* of a moving body or object.

2.5 MOMENTUM

Every moving body possesses momentum. We know that, if two bodies of different masses are moving with the same velocity, then the force required to stop the heavier body is more than that required for the lighter body. For example, if we throw a cricket ball and a tennis ball with the same velocity, the force required to stop the cricket ball is more than that required for the tennis ball. Thus, we can conclude that *"force required to stop a moving body is directly proportional to its mass."*

However, if two bodies of same masses are moving with different velocities, then the force required to stop the faster body is greater than the force required to stop the slower body. Hence we can conclude that

"A force required to stop a moving body is also directly proportional to its velocity"

Thus, the force required to stop a moving body depends on the product of both mass and velocity. This gives us another term called 'momentum.'

For a body of mass 'm' moving with velocity 'v', the momentum 'p' is expressed as,

$$\text{Momentum} \propto \text{Mass}, m$$

$$\text{Momentum} \propto \text{Velocity}, v$$

Therefore, Momentum = Mass × Velocity

Thus, *"momentum of a body is equal to the product of the mass (m) and velocity ($\vec{v}$) of the body."*

Mass, we must remember, is a scalar quantity while velocity is a vector quantity. So, the product of the two must also be a vector quantity. Hence, momentum is a vector quantity which can be represented by

$$\vec{p} = m\vec{v}$$

Thus, we can conclude that the

(a) Magnitude of momentum = Mass × Magnitude of velocity

(b) Direction of momentum of a body is the same as the direction of velocity of that body.

Let us now derive the units of momentum.

Unit of Momentum

We know that,

Momentum = Mass × Velocity

Then, unit of momentum = unit of mass × unit of velocity

$$= \text{kg} \times \text{m s}^{-1}$$

Therefore, the S.I. unit of momentum is kg m s^{-1} and the C.G.S. unit of momentum is g cm s^{-1}.

If a body is at rest, then its velocity will be zero and so, its momentum will also be zero.

A body will have a large momentum if

(a) Its mass is large.

(b) Its velocity is large.

(c) Both mass and velocity are large.

Let us now discuss momentum with few examples.

Examples of Momentum

1. A karate expert can break a pile of tiles or slab of ice with a single blow of his hand. This is because he strikes the tiles with his hand very fast thereby producing an extremely large momentum (fig. 2.23).

Fig. 2.23 : The karate expert hits the pile of tiles with a single blow of hand

2. A heavy cricket ball when thrown with high speed can sometimes hurt the batsman. This is because with high speed, the cricket ball acquires a large momentum that can injure the batsman (fig. 2.24).

Fig. 2.24 : A cricket ball hit by a bat

3. A car or a bus may not be moving at high speed, but it can hurt a person in its way. This is because the large mass of a car or a bus gives a large momentum.

In fact, momentum is considered to be a measure of the quantity of motion possessed by a moving body.

Rate of Change of Momentum

If a force is applied on a moving body, the velocity of the body changes. Due to this change in velocity of the body, its momentum will also change.

Consider a body of mass 'm' having an initial velocity 'u'. Suppose a force 'F' acts on a body of mass 'm' for time 't' and changes its velocity from the initial velocity 'u' to the final velocity 'v'. Then,

$$\text{Initial momentum} = mu$$

$$\text{Final momentum} = mv$$

Change in momentum of body in t seconds

$$= \text{Final momentum} - \text{Initial momentum}$$

$$= mv - mu = m(v - u)$$

Therefore,

Rate of change of momentum

$$= \frac{\text{Change in momentum}}{\text{Time taken}} = \frac{m(v-u)}{t}$$

But, we know that acceleration, $a = \dfrac{v-u}{t}$

Substituting 'a', we get

$$\text{Rate of change of momentum} = ma$$

$$= \text{Mass} \times \text{Acceleration}$$

Thus, we can conclude that when a force acts on a body, the rate of change of momentum of the body is equal to the product of mass of the body and the acceleration produced in it due to that force. This relation holds when mass of the body is constant.

SOLVED NUMERICALS

Type – I (Calculation of Momentum)

1. What will be the momentum of a stone having a mass of 10 kg when it is thrown with a velocity of 2 m s^{-1}?

Solution : Given, mass, m = 10 kg

Velocity, v = 2 m s^{-1}

Momentum, p =?

We know that,

Momentum, p = Mass × Velocity

Substituting the values, we get

$p = 10 \times 2 = 20$ kg m s^{-1}

Thus, the momentum of the stone = 20 kg m s^{-1}.

2. Calculate the momentum of a bullet of mass 25 g when it is fired from a gun with a velocity of 100 m s^{-1}.

Solution : Given, velocity of the bullet, v = 100 m s^{-1}

Mass of the bullet, m = 25 g = 25/1000 kg = 0.025 kg

Momentum, p =?

We know that,

Momentum, p = Mass × Velocity

Substituting the values, we get

$p = 0.025 \times 100 = 2.5$ kg m s^{-1}

Thus, the momentum of the bullet = 2.5 kg m s^{-1}

3. Calculate the momentum of a bullet having mass of 25 g if it is thrown using the hand with a velocity of 0.1 m s^{-1}.

Solution : Given, velocity of the bullet, v = 0.1 m s^{-1}

Mass of the bullet, m = 25 g = 25/1000 kg = 0.025 kg

Momentum, p =?

We know that,

Momentum, p = Mass × Velocity

Substituting the values, we get

$p = 0.025 \times 0.1$ m s^{-1}

$p = 0.0025$ kg m s^{-1}

Thus, the momentum of the bullet = 0.0025 kg m s^{-1}.

4. The mass of a goods lorry is 4000 kg and the mass of goods loaded on it is 20000 kg. If the lorry is moving with a velocity of 2 m s^{-1}, what will be its momentum?

Solution : Given, velocity, v = 2 m s^{-1}

Mass of lorry = 4000 kg,

Mass of goods on the lorry = 20000 kg

Therefore, Total mass of the lorry = 4000 + 20000

= 24000 kg

Momentum, p =?

We know that,

Momentum, p = Mass × Velocity

Substituting the values, we get

$p = 24000 \times 2 = 48000$ kg m s^{-1}

Thus, the momentum of the lorry is 48000 kg m s^{-1}.

5. A car having mass of 1000 kg is moving with a velocity of 0.5 m s^{-1}. What will be its momentum?

Solution : Given, velocity of the car, v = 0.5 m s^{-1}

Mass of the car, m = 1000 kg

Momentum, p =?

We know that,

Momentum, p = Mass × Velocity

Substituting the values, we get

$p = 1000 \times 0.5 = 500$ kg m s^{-1}

Thus, the momentum of the car is 500 kg m s^{-1}.

Type – II (Calculation of Mass)

1. A vehicle is running with a velocity of 5 m s^{-1}. If the momentum of the vehicle is 5000 kg m s^{-1}, what is its mass?

Solution : Given, momentum, p = 5000 kg m s^{-1}

Velocity, v = 5 m s^{-1}

Mass, m = ?

We know that,

Momentum, p = Mass × Velocity

Substituting the values, we get

$$5000 = m \times 5$$

$$\Rightarrow \quad m = \frac{5000}{5} = 1000 \text{ kg}$$

Thus, the mass of the vehicle is 1000 kg.

2. If a stone attains a momentum of 1 kg m s^{-1} when it flies with a velocity of 2 m s^{-1}, then what is the mass of the stone?

Solution : Given , momentum, p = 1 kg m s^{-1}

Velocity, v = 2 m s^{-1}

Mass, m = ?

We know that,

Momentum, p = Mass × Velocity

Substituting the values, we get

$$1 = m \times 2$$

$$\Rightarrow \quad m = \frac{1}{2} = 0.5 \text{ kg} = 500 \text{ g}$$

Thus, mass of the stone is 0.5 kg or 500 g.

3. When a bullet is fired from a rifle its momentum becomes 20 kg m s^{-1}. If the velocity of the bullet is 1000 m s^{-1}, what will be its mass?

Solution : Given, momentum, p = 20 kg m s^{-1}

Velocity, v = 1000 m s^{-1}

Mass, m = ?

We know that,

Momentum, p = Mass × Velocity

Substituting the values, we get

$$20 = m \times 1000$$

$$\Rightarrow \quad m = \frac{20}{1000} = \frac{1}{50} \text{ kg} = 0.02 \text{ kg} = 20 \text{ g}$$

Thus, the mass of the bullet is 20 g.

4. When a missile is fired from a tank it gets a momentum of 2000 kg m s^{-1}. If the velocity of the missile is 50 m s^{-1}, what will be its mass?

Solution : Given, momentum, p = 2000 kg m s^{-1}

Velocity, v = 50 m s^{-1}

Mass, m = ?

We know that,

Momentum, p = Mass × Velocity

Substituting the values, we get

$$2000 = m \times 50$$

$$\Rightarrow \quad m = \frac{2000}{50} = 40 \text{ kg}$$

Thus, the mass of the missile is 40 kg.

5. A bird is flying with a velocity of 3 m s^{-1}. If the momentum of the bird is 3.60 kg m s^{-1}. What is its mass?

Solution : Given, momentum, p = 3.60 kg m s^{-1}

Velocity, v = 3 m s^{-1}

Mass, m = ?

We know that,

Momentum, p = Mass × Velocity

Substituting the values, we get

$$3.60 = m \times 3$$

$$\Rightarrow \quad m = \frac{3.60}{3} = 1.20 \text{ kg or } 1 \text{ kg } 200 \text{ g}$$

Thus, mass of the bird is 1 kg 200 g.

Type – III (Calculation of Velocity)

1. If the momentum of a flying brick is 50 kg m s^{-1} and its mass is 10 kg. Calculate its velocity?

Solution : Given, momentum, p = 50 kg m s^{-1}

Mass, m = 10 kg

Velocity, v =?

We know that,

Momentum, p = Mass × Velocity

Substituting the values, we get

$$50 = 10 \times v$$

$$\Rightarrow \quad v = \frac{50}{10} = 5 \text{ m s}^{-1}$$

Thus, the velocity of the brick is 5 m s^{-1}.

2. A bullet of mass 25 g when fired from a pistol gets a momentum of 50 kg m s^{-1}. Calculate the velocity of the bullet.

Solution : Given, momentum, p = 50 kg m s^{-1}

Mass, m = 25 g = 25/1000 kg = 0.025 kg

Velocity, v = ?

We know that,

Momentum, p = Mass × Velocity

Substituting the values, we get

$$50 = 0.025 \times v$$

$$\Rightarrow \quad v = \frac{50}{0.025} = 2000 \text{ m s}^{-1}$$

Thus, the velocity of the bullet is 2000 m s^{-1}.

3. A vulture when flying with a velocity 'v' attains a momentum of 20 kg m s^{-1}. If the mass of the vulture is 25 kg what is the value of 'v'?

Solution : Given, momentum, p = 20 kg m s^{-1}

Mass, m = 25 kg

Velocity, v = ?

We know that,

Momentum, p = Mass × Velocity

Substituting the values, we get

$$20 = 25 \times v$$

$$\Rightarrow \quad v = \frac{20}{25} = 0.8 \text{ m s}^{-1}$$

Thus, the velocity of the vulture is 0.8 m s^{-1}.

4. A brick after falling from a hill, collides with the ground with a momentum of 100 kg m s^{-1}. If the mass of the brick is 5 kg what was its velocity while colliding with the ground?

Solution : Given, momentum, p = 100 kg m s^{-1}

Mass, m = 5 kg

Velocity, v = ?

We know that,

Momentum, p = Mass × Velocity

Substituting the values, we get

$$100 = 5 \times v$$

$$\Rightarrow \quad v = \frac{100}{5} = 20 \text{ m s}^{-1}$$

Thus, the velocity of the brick was 20 m s^{-1}.

5. Calculate the velocity of a missile having a mass of 100 kg, if it attains a momentum of 5000 kg m s^{-1} when fired from a rocket gun?

Solution : Given, momentum, p = 5000 kg m s^{-1}

Mass, m = 100 kg

Velocity, v =?

We know that,

Momentum, p = Mass × Velocity

Substituting the values, we get

$$5000 = 100 \times v$$

$$\Rightarrow \quad v = \frac{5000}{100} = 50 \text{ m s}^{-1}$$

Thus, the velocity of the missile was 50 m s^{-1}.

TRY YOURSELF

1. Calculate the momentum of a toy truck weighing 200 g moving with a velocity of 5 m s^{-1}. **[Ans : 1 kg m s^{-1}]**
2. How much momentum will a ball of mass 10 kg transfer to the floor if it falls from a height of 80 cm? Assume its downward acceleration to be 10 m s^{-2}. **[Ans : 40 kg m s^{-1}]**
3. Calculate the momentum of a stone of mass 450 g moving with a speed of 120 km h^{-1}. **[Ans : 15 kg m s^{-1}]**
4. Find the magnitude of the momentum of a stone of mass 10 kg moving with a velocity of 5 m s^{-1}. **[Ans : 50 kg m s^{-1}]**
5. If two stones X and Y of equal masses have velocities 'v' and '$2v$' respectively, then what will be the ratio of momentum of X to that of Y? **[Ans : 1 : 2]**

PAPER-PEN TEST : 3

1. Why it is easier to stop a tennis ball than a cricket ball moving with the same speed?
2. Explain the meaning of the equation : $p = m \times v$
3. How does a karate expert break a pile of bricks with a single blow of his hand?
4. Define momentum.

5. State whether momentum is a scalar or vector quantity.
6. How momentum is expressed in vector form?
7. Derive the units of momentum.
8. When would you say that a body has a large momentum?
9. What happens to the momentum when the body is at rest?
10. What happens to the momentum when a force is applied to the moving body?
11. Derive the equation for rate of change of momentum.

Let us now discuss Newton's second law of motion with examples.

2.6 NEWTON'S SECOND LAW OF MOTION

According to this law,

"The change in momentum of a body per unit time is directly proportional to the applied force acting on the body and the change in momentum takes place in the direction of the unbalanced force on the body."

$$F \propto \frac{dp}{dt}$$

where '*dp*' is the change in momentum and '*dt*' is the time taken for this change in momentum to take place.

We know that, a force changes the velocity of the body when it is applied on it. It means that a force produces an acceleration in the body. Thus, Newton's first law of motion defines the force only qualitatively *i.e.*, it simply says that the force is the cause of acceleration.

But Newton's second law of motion gives the quantitative value of force *i.e.*, it relates the force to the acceleration and mass of the body.

When two bodies having different masses are acted upon by the same force for the same amount of time, then the lighter body attains a higher velocity as compared to the heavier one. But, the momentum will be same for both the bodies. The relation between the force and the momentum is expressed in Newton's second law of motion.

It is our common experience that if we push a tennis ball gently, a small acceleration is produced, but if the same tennis ball is pushed hard, a large acceleration is produced. Thus, the magnitude of two forces can be compared by measuring the acceleration.

In other words, if a force F_1 produces an acceleration of 5 m s^{-2} and a force F_2 produces an acceleration of 10 m s^{-2} on the same body, then we can conclude that the magnitude of force F_2 is double the magnitude of force F_1.

Similarly, if we try to produce the same velocity in a football and a tennis ball in the same time interval assuming both are initially at rest, we need to apply a large force on the football than on the tennis ball. Thus, the forces needed to produce the same acceleration in two bodies of different masses are not the same. The force is more for the body having more mass and less for the body having less mass.

In other words, if a force F is needed to produce an acceleration of 5 m s^{-2} in a body of mass 2 kg, then to produce the same acceleration of 5 m s^{-2} in a body of mass 4 kg, we need a force of magnitude 2F.

Based on the observations made on the above experiments, Newton concluded that :

(a) The acceleration produced in a body of given mass is directly proportional to the force applied on it.

$$a \propto F$$

(b) The force needed to produce a given acceleration is directly proportional to the mass of the body.

$$F \propto m$$

Thus, from the above equations,

$$F = Kma$$

where K is the proportionality constant.

Thus we conclude that, the acceleration produced in a body is directly proportional to the force acting on it and inversely proportional to the mass of the body. Hence, if the mass of a body is doubled, its acceleration will be halved and if the mass is halved then acceleration will get doubled. It also means that it will be easier to move light bodies than heavy bodies.

Let us now derive the mathematical equation for the Newton's second law of motion.

MATHEMATICAL FORMULATION OF SECOND LAW OF MOTION

Consider a body of mass 'm' moving with initial velocity 'u' (fig. 2.25).

Let a force 'F' acts on the body for time 't' so that the velocity of the body after time 't' becomes 'v'.

Initial momentum of the body $p_i = mu$

Final momentum of the body $p_f = mv$

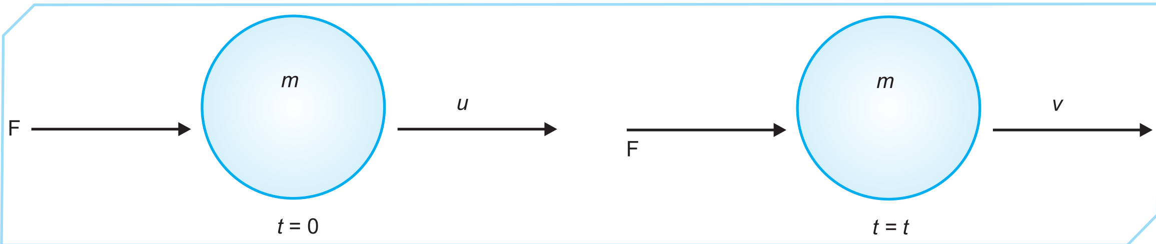


Fig. 2.25 : Initial and final momentum at time $t = 0$, $t = t$ respectively

Therefore, change in momentum of the body

= Final momentum of the body – Initial momentum of the body

$= p_f - p_i = mv - mu = m(v - u)$

Now, the time taken for this change in momentum $= (t - 0) = t$

Therefore, Rate of change of momentum

$$= \frac{\text{Change in momentum}}{\text{Time taken}}$$

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

According to Newton's second law of motion,

Force applied $\propto$ Rate of change of momentum

Hence,

$$F \propto \frac{m(v-u)}{t} \quad .... (1)$$

Equation (1) can be rewritten as,

$$F \propto ma \qquad \left[\because v = u + at \text{ or } \left(\frac{v-u}{t}\right) = a\right]$$

$$F = kma \quad .... (2)$$

where 'k' is the proportionality constant.

If F = 1 unit, m = 1 unit and a = 1 unit, then from equation (2), $k = 1$.

Therefore, $F = ma$

Thus, the force acting on a body is directly proportional to

(a) its mass 'm'.

(b) its acceleration 'a'.

Equation 2 gives the mathematical form of Newton's second law of motion.

Units of Force

We know that,

$$F = ma$$

If m = 1 unit and a = 1 unit, then

$$F = 1 \text{ unit}$$

Thus, a force is said to be a unit force if it produces unit acceleration in a body of unit mass.

The S.I. unit of force can be derived as follows.

We know that,

$$F = ma$$

S.I. unit of force = S.I. unit of mass × S.I. unit of acceleration

$= \text{kg} \times \text{m s}^{-2}$

Thus, the S.I. unit of force is kg × m s^{-2}.

1 kg × m s^{-2} is equal to 1 newton if mass is equal to 1 kg and acceleration is equal to 1 m s^{-2}.

Thus, the S.I. unit of force is newton which is denoted as N.

We can now define newton as,

"If force acting on a body of mass 1 kg produces an acceleration of 1 m s^{-2} in it, the force is said to be one newton".

C.G.S. unit of Force

We know that,

$$F = ma$$

C.G.S. unit of force = C.G.S. unit of mass × C.G.S. unit of acceleration

$= \text{g} \times \text{cm s}^{-2}$

Thus, the C.G.S. unit of force is g cm s^{-2}.

1 g cm s^{-2} is equal to 1 dyne if it can produce an acceleration of 1 cm s^{-2} in a mass of 1 g.

Let us now try to find out the relation between newton and dyne.

Relation between newton and dyne

We know,

$$1 \text{ N} = 1 \text{ kg} \times \text{m s}^{-2}$$
$$1 \text{ kg} = 1000 \text{ g} = 10^3 \text{ g}$$
$$1 \text{ m} = 100 \text{ cm} = 10^2 \text{ cm}$$

Substituting these values, we get

$$1 \text{ N} = 10^3 \text{ g} \times 10^2 \text{ cm} = 10^5 \text{ g cm s}^{-2}$$

But, $1 \text{ g cm s}^{-2} = 1$ dyne

$$\therefore \quad 1 \text{ N} = 10^5 \text{ dyne}$$

Newton's Second Law of Motion in Vector Form

We know that, force 'F' and acceleration 'a' are vector quantities whereas mass 'm' is a scalar quantity. Therefore, Newton's second law of motion can be written in vector form as

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

This relation shows that the direction of force applied on the body is same as that of the acceleration produced in the body.

Newton's first law of motion as a special case of Newton's second law of motion

We can deduce Newton's first law of motion from Newton's second law of motion as follows :

We know that,

$$F = ma$$

$$F = m\left(\frac{v-u}{t}\right) \quad \left[\because v = u + at \text{ or } \left(\frac{v-u}{t}\right) = a\right]$$

If the velocity of a body is constant, then $a = 0$

$$F = m \times 0 = 0$$

Hence, no force is required to move a body having constant or uniform velocity.

When the body is at rest, if $u = 0$, then v is also zero. This shows that the body will remain at rest if no external force is applied on the body.

Applications of Newton's Second Law of Motion

In our daily life, we find many examples when a required momentum is imparted to a body by applying a force of large magnitude for a short duration such as when hitting a cricket ball with a bat, hammering a nail, or hitting a ping-pong ball. Here, we will consider examples where, for a given change in momentum, the magnitude of force is reduced by increasing the duration of application.

1. While catching a ball, the cricketer withdraws his hands

Consider a ball of mass 'm' moving with a velocity 'u' towards a fielder, (fig. 2.26). Then,

Initial momentum = mu

When the cricketer catches the ball, $v = 0$

Hence, its final momentum = $m \times 0 = 0$

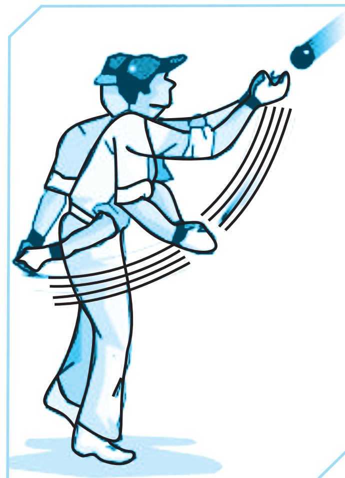


Fig. 2.26 : A cricketer drawing back his hand on catching the ball.

If the cricketer does not withdraw his hands, it takes time t_1 to stop the ball, then the force exerted by ball on the hand of the cricketer,

$$F_1 = \frac{\text{Change in momentum}}{\text{Time interval}} = \frac{0 - mu}{t_1}$$
$$= \frac{-mu}{t_1}$$

But if the cricketer withdraws his hands, it takes a longer time t_2 to stop the ball. Then, the force exerted by ball on his hands

$$F_2 = \frac{-mu}{t_2}$$

The negative sign shows that change of momentum is in a direction opposite to the initial direction of motion.

Obviously when the cricketer withdraws his hands, the ball take more time to stop as $t_2 > t_1$.

Therefore, $F_2 < F_1$ or force exerted on the hand of the cricketer is less when he withdraws his hands. Thus, the cricketer avoids the chance of injury to his hands by withdrawing his hands while catching a ball.

2. High jumpers use sand or foam to land on.

If an athlete jumps from a height on to a hard floor, his feet may hurt because they come to rest in a very short time and hence, a very large force is exerted on his feet. On the other hand, by jumping on sand or foam, the time, interval in which his feet come to rest increases and hence, the force exerted on his feet decreases. This prevents him from getting hurt (fig. 2.27).

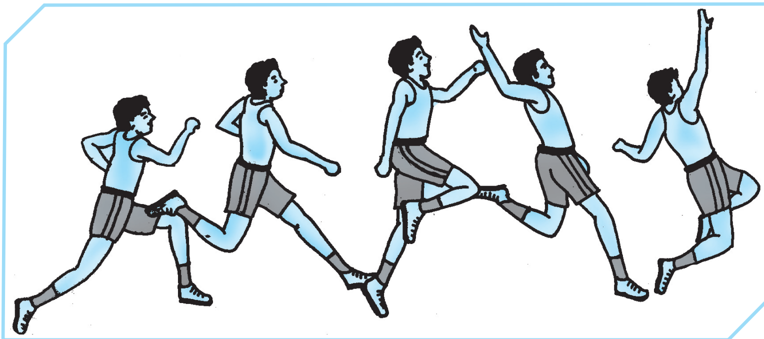


Fig. 2.27 : High jumpers are provided with either a cushion or a heap of sand

3. All cars are provided with seat belts for passengers to prevent injuries during an accident.

When a fast running car stops suddenly, the large momentum is reduced to zero in a very short time. The stretchable seat belts worn by the passengers increase the time taken to fall forward. Hence, the passengers may either not get injured at all or may get less serious injuries (fig. 2.28).

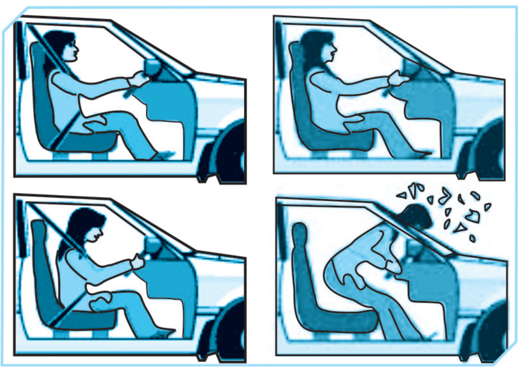


Fig. 2.28 : Seat belts prevent passengers from getting injured

Numerical Problems Based on Newton's Second Law of Motion

Type – I (Calculation of Force)

1. Calculate the force needed to speed up a car at a rate of 5 m s^{-2}, if the mass of the car is 1000 kg.

Solution : Given, acceleration, a = 5 m s^{-2}

Mass, m = 1000 kg

Force, F =?

We know that,

$$F = m \times a$$

Substituting the values, we get

$$F = 1000 \times 5 = 5000 \text{ kg m s}^{-2}$$

Therefore, the required force is 5000 kg m s^{-2} or 5000 N.

2. If the mass of a moving object is 50 kg, what force will be required to speed up the object at a rate of 2 m s^{-2} ?

Solution : Given, acceleration, a = 2 m s^{-2}

Mass, m = 50 kg,

Force, F =?

We know that,

$$F = m \times a$$

Substituting the values, we get

$$F = 50 \times 2 = 100 \text{ kg m s}^{-2}$$

Therefore, the force required to speed up the object is 100 kg m s^{-2} or 100 N.

3. What force will be needed if a vehicle having a mass of 100 kg is to be accelerated to 3 m s^{-2} ?

Solution : Given, acceleration, a = 3 m s^{-2}

Mass, m = 100 kg

Force, F =?

We know that,

$$F = m \times a$$

Substituting the values, we get

$$F = 100 \times 3 = 300 \text{ kg m s}^{-2}$$

Therefore, the required force is 300 kg m s^{-2} or 300 N.

4. A car starts from rest and rolls down a hill with constant acceleration. It travels a distance of 400 m in 20 s.

(a) Find its acceleration.

(b) Find the force acting on it if its mass is 7,000 kg.

Solution : (a) Given, Distance, s = 400 m

Initial velocity, u = 0

Time, t = 20 s

Acceleration, a = ?

We know that,

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

Substituting the values, we get

$$400 = 0 \times 20 + \frac{1}{2} \times a \times (20)^2$$

$$400 = 200\,a$$

$$a = \frac{400}{200} = 2 \text{ m s}^{-2}$$

(b) Given, Acceleration, a = 2 m s^{-2}

Mass, m = 7000 kg

Force, F = ?

$$F = m \times a$$

Substituting the values, we get

$$F = 7000 \times 2 = 14{,}000 \text{ N}$$

Type –II (Calculation of Mass)

1. We require 10 N to accelerate an object to a rate of 2 m s^{-2}. Find the mass of the object.

Solution : Given, Acceleration, a = 2 m s^{-2}

Force, F = 10 N

Mass, m = ?

We know that,

$$F = m \times a$$

Substituting the values, we get

$$10 = m \times 2$$

$$m = \frac{10}{2} \text{ kg} = 5 \text{ kg}$$

Thus, the mass of the object is 5 kg.

2. If 1000 N force is required to accelerate an object to the rate of 5 m s^{-2}, what will be the mass of the object?

Solution : Given, Acceleration, a = 5 m s^{-2}

Force, F = 1000 N

Mass, m = ?

We know that,

$$F = m \times a$$

Substituting the values, we get

$$1000 = m \times 5$$

$$m = \frac{1000}{5} \text{ kg} = 200 \text{ kg}$$

Thus, the mass of the object is 200 kg.

3. A vehicle accelerates at the rate of 10 m s^{-2} after applying a force of 50000 N. Find the mass of the vehicle.

Solution : Given, Acceleration, a = 10 m s^{-2}

Force, F = 50000 N

Mass, m = ?

We know that,

$$F = m \times a$$

Substituting the values, we get

$$50000 = m \times 10 \text{ m s}^{-2}$$

$$m = \frac{50000}{10} \text{ kg} = 5000 \text{ kg.}$$

Thus, the mass of the vehicle is 5000 kg.

Type – III (Calculation of Acceleration)

1. What will the acceleration of a vehicle having 1000 kg of mass be after applying a force of 5000 N?

Solution : Given, Mass, m = 1000 kg

Force, F = 5000 N

Acceleration, a = ?

We know that,

$$\text{Force} = \text{Mass} \times \text{Acceleration}$$

$$F = m \times a$$

Substituting the values, we get

$$5000 = 1000 \times a$$

$$a = \frac{5000}{1000} = 5 \text{ m s}^{-2}$$

Thus, the acceleration of the vehicle is 5 m s^{-2}.

What acceleration will an object of mass 2000 kg attain when a force of 1000 N is applied on it ?

Solution : Given, Mass, m = 2000 kg

Force, F = 1000 N

Acceleration, a = ?

We know that,

$$\text{Force} = \text{Mass} \times \text{Acceleration}$$

$$F = m \times a$$

Substituting the values, we get

$$1000 = 2000 \times a$$

$$a = \frac{1000}{2000} = \frac{1000}{2000} = 0.5 \text{ m s}^{-2}$$

Thus, the acceleration of the object is 0.5 m s^{-2} .

3. An object requires a force of 100 N to achieve an acceleration 'a'. If the mass of the object is 500 kg, what will be the value of 'a'?

Solution : Given, Mass, m = 500 kg

Force, F = 100 N

Acceleration, a = ?

We know that,

$$\text{Force} = \text{Mass} \times \text{Acceleration}$$

$$F = m \times a$$

Substituting the values, we get

$$100 = 500 \times a$$

$$a = \frac{100}{500} = \frac{100}{500} = 0.2 \text{ m s}^{-2}$$

Thus, acceleration required by the object is 0.2 m s^{-2}.

TRY YOURSELF

1. A force of 10 N acts upon a stone of mass 2 kg. Calculate the acceleration. **[Ans : 5 m s^{-2}]**
2. Find the acceleration produced by a force of 5 N acting on a mass of 10 kg. **[Ans : 0.5 m s^{-2}]**
3. Calculate the magnitude of a constant force acting on a body of mass 10 kg and produces an acceleration of 0.2 m s^{-2}? **[Ans : 2 N]**
4. A net force of 16 N produces an acceleration of 4 m s^{-2} in a body moving over a horizontal surface. What is the mass of the body? **[Ans : 4 kg]**
5. A man pushes a box of mass 50 kg with a force of 80 N. What will be the acceleration of the box due to this force? What will be the acceleration if the mass is halved? Assume that there is no friction. **[Ans : 1.6 m s^{-2}; 3.2 m s^{-2}]**

PAPER–PEN TEST : 4

1. Define Newton's second law of motion.
2. Justify : "Newton's first law of motion defines force only qualitatively".
3. What are the observations made by Newton's experiment performed for second law of motion?
4. Express Newton's second law of motion mathematically.
5. What are the factors on which force depends?
6. Derive the S.I. unit of force.
7. Give the relation between newton and dyne.
8. What is the C.G.S. unit of force?
9. Express Newton's second law of motion in vector form.
10. Define one newton.
11. Illustrate Newton's first law of motion as a special case of Newton's second law of motion.
12. Give a few examples that illustrate Newton's second law of motion.
13. Give an example where, for a given change in momentum, the magnitude of force is reduced by increasing the time interval.
14. High jumpers usually use sand or foam to land on. Why?
15. Give reason : "When glass vessels fall on a hard floor they break, but they do not break so easily when they fall on a carpet or on sand."

2.7 NEWTON'S THIRD LAW OF MOTION

Statement

According to Newton's third law of motion,

"To every action there is always an equal and opposite reaction."

Newton's first law and second law tells us that in order to bring a change in the state of rest or motion of an

object, a force is needed *i.e.*, a force produces a change in the velocity of the object and in the acceleration produced by a force on an object. But these two laws do not explain how the force acts on the object. This question is answered by Newton's third law.

Let us discuss this law in detail with the help of fig. 2.29.

Consider a book lying on a table. The weight of the book acts vertically downwards, but the book does not move downwards. This shows that the resultant force on the book is zero. It is possible only, if the table exerts an upward force equal to the weight of book.

In this example, we can observe that the weight of book acts in the downward direction on the table and the table exerts a force on the book in the upward direction. Thus, action and reaction act on the two different bodies.

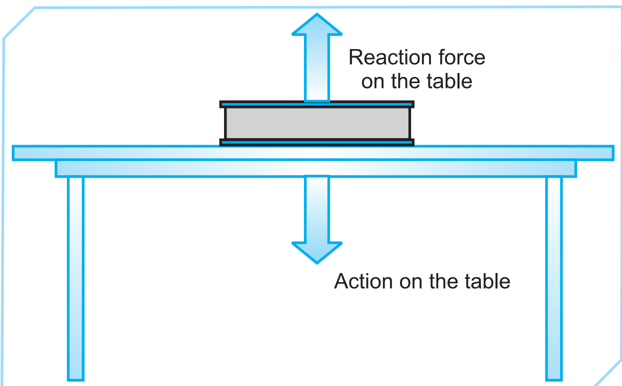


Fig. 2.29 : The book exerts action on the table and the table exert an equal and opposite reaction on the book.

Similarly, what happens when we walk on the ground ? We exert a pushing force on the ground as if to move it backwards. At the same time, the ground exerts an equal reaction, but in the forward direction, which makes us move forward. Note that the 'action' force is exerted by our feet on the ground while the 'reaction' force is exerted by the ground on our feet.

These two forces – action and reaction – always occur in pairs.

In an interaction between two bodies X and Y, the magnitude of force F_{XY} applied by the body X on the body Y is equal in magnitude to the force F_{YX} applied by the body Y on the body X. But the forces are in directions opposite to each other (fig. 2.30).

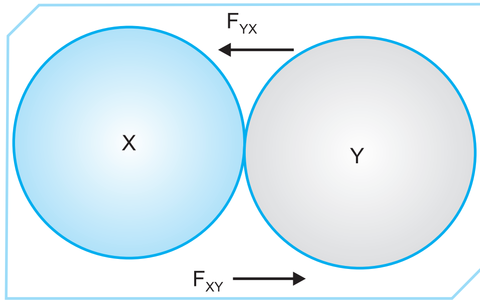


Fig. 2.30 : Interaction of two bodies X and Y

Thus, the action on a body X is equal in magnitude to the reaction on the body Y, but it is in an opposite direction. In other words, the forces F_{XY} and F_{YX} exist in pair. This is Newton's third law of motion.

We already know that the action and reaction never act on the same body, but they always act simultaneously on two different bodies.

In the (fig. 2.31), the ring of a spring balance Y is attached to a hook fixed on a wall and then the hook of another spring balance X is attached to the hook of the spring balance Y. Now, the ring of spring balance X is pulled. Then we find both the balances show the same reading. The reading on balance Y indicates the force with which balance X pulls balance Y. We can see that a corresponding reading is shown on balance X as well. This is the force with which Y pulls balance X. Interestingly, the reading on balance X will be the same as that on balance Y. This indicates that balance Y and balance X pull each other with equal but opposite forces. The pull on spring Y by the spring X is the action and the pull on spring X by spring Y is the reaction. This shows that "to every action, there is an equal and opposite reaction".

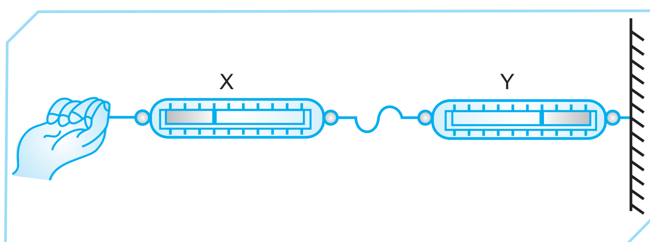


Fig. 2.31 : Experiment for demonstration of Newton's Third Law of Motion

Examples of Newton's Third Law of Motion

(a) When you exert a force (action) on a wall by pushing the palm of your hand against it, you experience a force (reaction) exerted by the wall on your palm (fig. 2.32).

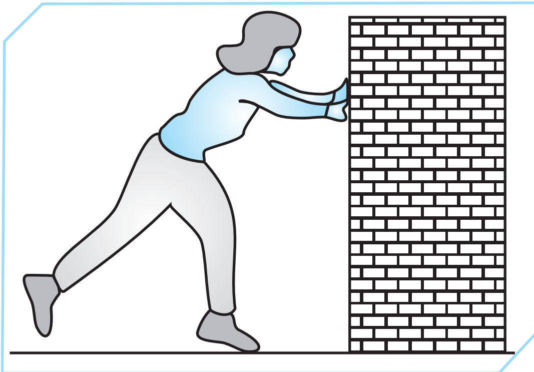


Fig. 2.32 : Diagram to show action and reaction when we exert a force on wall.

(b) A boat man pushes (action) the water backwards with his oars so that water exerts an equal and opposite force (reaction) on the boat in the forward direction, due to which the boat moves ahead (fig. 2.33).

Fig. 2.33 : Boatman pushes water backwards and water pushes boat forward.

(c) When a man fires a bullet from a gun, a force (action) is exerted on the bullet and the gun experiences a recoil (reaction) (fig. 2.34). Here, the force which sends the bullet forward is equal to the force which sends the gun backward. However, due to high mass of the gun, it moves only a little distance backward and gives a jerk to the shoulder of the shooter. This is called recoil of a gun.

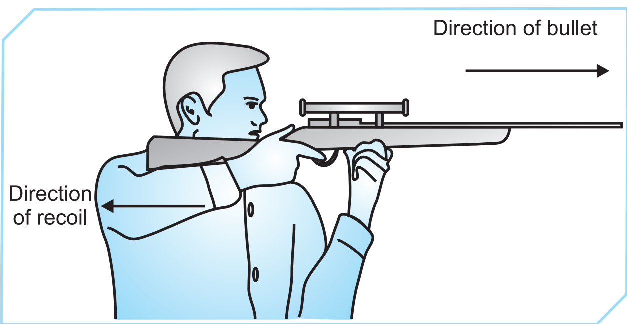


Fig. 2.34 : Diagram to show action and reaction when a bullet is fired from the gun.

(d) In a rocket motion, the rocket exerts force (action) on the gases to expel them backward. The gases exert an equal and opposite force (reaction) on the rocket due to which it moves forward (fig. 2.35).

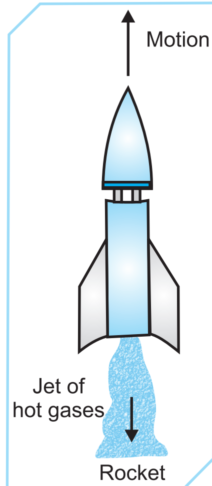


Fig. 2.35 : Diagram to show action and reaction in case of rocket

Here, the hot gases produced by the rapid burning of fuel rush out of a jet from the bottom of the rocket at a very high speed. The equal and the opposite reaction force of the plume of gases pushes the rocket in the upward direction with a great speed.

(e) When a man steps ashore from a boat, it tends to move away from the shore. The reason is that, the man needs a reaction force to step out of the boat for which he exerts a force (action) on the boat. The boat thus tends to move away from the shore (fig. 2.36).

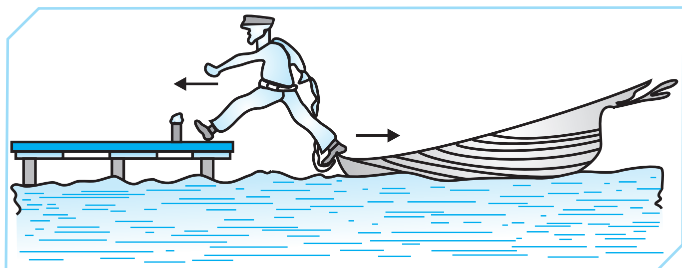


Fig. 2.36 : When a man steps ashore from a boat

(f) While catching a ball, a cricketer exerts a force (action) on the ball to stop it and the ball exerts an equal force (reaction) on his/her hands.

(g) When a boatman wants to move away from the shore, he sits in the boat and pushes the shore with his boat paddle. When boatman exerts a force (action) on the bank, the bank exerts an equal and opposite force (reaction) on the boat. So, the boat moves away from the bank.

PAPER–PEN TEST : 5

1. State and explain Newton's third law of motion.
2. What does the third law of motion signify?
3. Illustrate action and reaction forces with an example.
4. Demonstrate Newton's third law of motion.
5. Identify the action and reaction forces in the following situations :
   (a) When a man steps ashore from a boat, it tends to move away from the shore.
   (b) When a book is placed on a table.
   (c) When you exert a force on a wall.
   (d) To move a boat ahead in water.
   (e) When a man fires a bullet from a gun.
6. Explain the action and the reaction force in the working of a rocket.
7. Illustrate with an example that the action and reaction never act on the same body, but they always act simultaneously on two different bodies.

Let us now discuss the conservation of momentum.

2.8 CONSERVATION OF MOMENTUM

Statement

"When two or more bodies interact with each other, their total momentum remains constant or conserved, if no external forces are acting on them."

In other words

"The total momentum of a system remains constant if no net external unbalanced force acts on it."

This means that whenever a body gains momentum, then some other body in the system must lose an equal amount of momentum. Thus, momentum is neither created nor destroyed.

Momentum of a system, p = constant if net external force acting on it is zero *i.e.*, F = 0.

Illustration

Let a moving ball collide with stationary ball lying on the ground. After the collision, the moving ball slows down *i.e.*, its velocity decreases after colliding with the stationary ball. On the other hand, the stationary ball begins to move *i.e.*, its velocity increases after collision.

We know that,

Momentum of a body = Mass of the body × Velocity of the body

Therefore, the momentum of a moving ball decreases after collision and momentum of the stationary ball increases after collision (fig. 2.37).

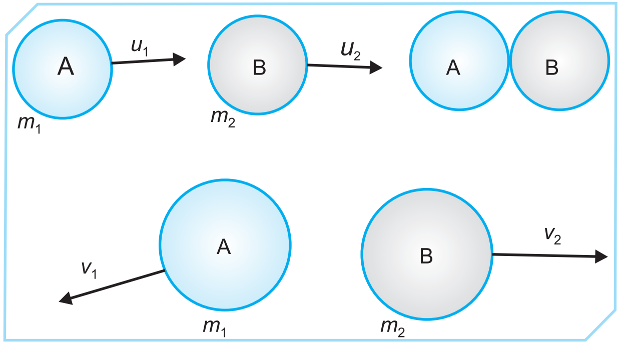


Fig. 2.37 : Conservation of momentum : $m_1u_1+m_2u_2 = m_1v_1+m_2v_2$

Thus, we conclude that when two balls collide with each other, the moving ball loses momentum and the stationary ball gains momentum. The loss of momentum of one ball is equal to the gain of momentum of the other ball. However, the total momentum of these colliding balls before and after the collision remains the same. This is the law of conservation of momentum.

Let us now prove the law of conservation of momentum.

Proof of the law of conservation of momentum

Consider a system consisting of two bodies X and Y of masses m_1 and m_2 respectively in (fig. 2.38).

Suppose two bodies are moving with velocities u_1 and u_2 and say $u_1 > u_2$.

Let these bodies collide with each other for a small interval of time 'dt'.

At the time of collision, body X exerts a force F on body Y, and body Y exerts an equal and opposite force (–F) on body X. This changes the momentum of both the bodies.

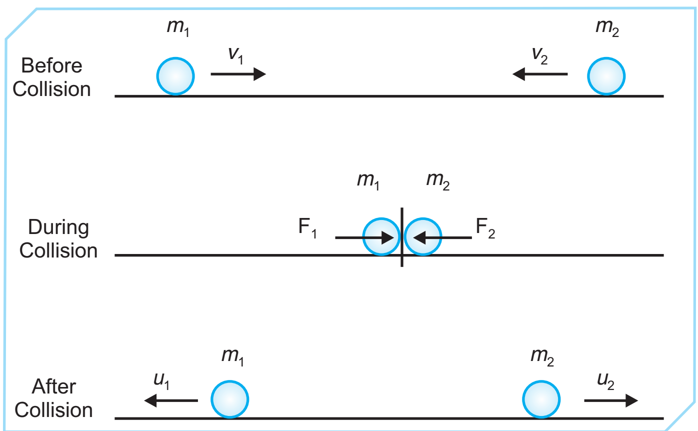


Fig. 2.38 : Total momentum of two bodies before, during and after collision.

Now, let v_1 and v_2 be the velocities of body X and Y respectively after the collision. Then

Initial momentum of body X = m_1u_1

Initial momentum of body Y = m_2u_2

Final momentum of body X = m_1v_1

Final momentum of body Y = m_2v_2

Therefore, Total momentum of the system before collision

$$= m_1u_1 + m_2u_2$$

Total momentum of the system after collision

$$= m_1v_1 + m_2v_2$$

Now,

The rate of change of momentum of a body X

$$= \frac{\text{Change in momentum of body X}}{\text{Time taken}}$$

$$= \frac{\text{Final momentum} - \text{Initial momentum}}{\text{Time taken}}$$

$$= \frac{(m_1v_1 - m_1u_1)}{dt}$$

According to Newton's second law of motion,

Force acting on body X

= Rate of change of momentum of body X

$$F = \frac{(m_1v_1 - m_1u_1)}{dt} \qquad ...(1)$$

Now,

Rate of change of momentum of body Y

$$= \frac{\text{Change in momentum of body Y}}{\text{Time taken}}$$

$$F = \frac{(m_2v_2 - m_2u_2)}{dt}$$

According to Newton's second law of motion,

Force acting on body Y

= Rate of change of momentum of body Y

$$-F = \frac{(m_2v_2 - m_2u_2)}{dt}$$

$$F = \frac{-(m_2v_2 - m_2u_2)}{dt} \qquad ...(2)$$

Equating (1) and (2), we get

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

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

Thus, total momentum of the system before collision is equal to the total momentum of the system after collision. Hence, the law of conservation of momentum is proved.

Examples of Law of Conservation of Momentum

1. Recoil of a gun

We can explain the recoil of a gun with the help of Newton's third law of motion as well as with the help of the law of conservation of momentum.

In this example, the bullet and the gun together form a system. Before firing, the gun and the bullet are at rest and therefore, momentum of the system before firing is zero.

When the bullet is fired, it leaves the gun and moves in the forward direction with a certain momentum. Since no external force acts on the system, the momentum of the system must be zero after firing. This is possible only if the gun moves backward with a momentum equal to the momentum of the bullet. That is why gun recoils or moves backward.

Recoil velocity

The velocity with which the gun moves backward after firing a bullet is known as recoil velocity.

Let us now calculate the recoil velocity of a gun (fig. 2.39).

Calculation of Recoil velocity of a gun

Let mass of the bullet = m

Velocity of the bullet after firing = v

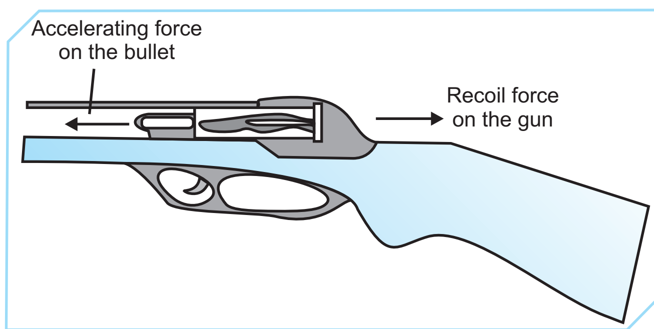


Fig. 2.39 : Recoil velocity of a gun

Mass of the gun = M

Velocity of the gun after firing = V

Since the system is at rest before firing, so the momentum of the system before firing = 0.

Thus,

Total momentum of the system after firing

= Momentum of gun + Momentum of bullet

$= M\vec{V} + m\vec{v}$

Now, according to the law of conservation of momentum,

$$M\vec{V} + m\vec{v} = 0$$

$$M\vec{V} = -m\vec{v}$$

$$\vec{V} = -\left(\frac{m}{M}\right)\vec{v}$$

The negative sign shows that the direction of velocity of the gun after firing is opposite to the direction of velocity of the bullet.

2. Rocket Propulsion

The movement of a rocket in the upward direction can also be explained with the help of the law of conservation of momentum.

Fig. 2.40 : Rocket works on the principle of conservation of momentum.

The momentum of a rocket before it is fired is zero. When the rocket is fired, gases are produced in the combustion chamber of the rocket due to the burning of fuel. These gases come out through a nozzle at the rear of the rocket with high speed. The direction of the momentum of gases coming out of the nozzle is in the downward direction. To conserve the momentum of the system, the rocket moves upward with a momentum equal to the momentum of the gases. The rocket continues to move upward as long as gases are ejected out of the rocket (fig. 2.40).

Let us perform an activity to explain Newton's third law of motion.

Activity 2.3 To illustrate the Conservation of Momentum

PROCEDURE

Step 1 : Take a big rubber balloon and inflate it fully.

Step 2 : Tie its neck using a thread.

Step 3 : Now, using adhesive tape, fix a straw on the surface of this balloon as shown in the figure.

Step 4 : Pass a thread through the straw and hold one end of the thread in your hand or fix it on the wall.

Step 5 : Ask your friend to hold the other end of the thread or fix it on a wall at some distance.

Step 6 : Now, remove the thread tied on the neck of balloon and you will notice the air escape from the mouth of the balloon.

Step 7 : Observe the direction in which the straw moves.

DIAGRAM

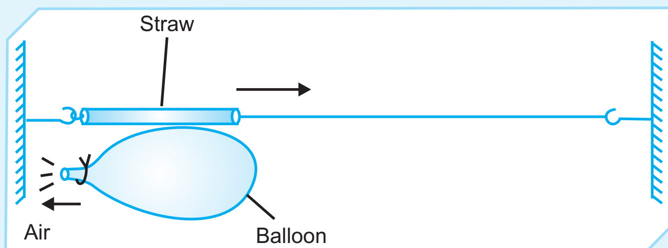


Fig. 2.41 : Straw moves in the direction opposite to that of escaping air

OBSERVATION

The straw moves in the direction opposite to that of escaping air from the balloon.

INFERENCE

The compressed air present in the balloon pushes it to the left side with a high speed as it escapes. The equal and opposite reaction of the air pushes the balloon to the right side.

Numericals Based on Conservation of Momentum

1. Find the recoil velocity of a gun having mass equal to 5 kg, if a bullet of 25 gm acquires a velocity of 500 m s^{-1} after firing from the gun.

Solution : Given, mass of bullet, m_1 = 25 gm = 0.025 kg

Velocity of bullet before firing, $u_1 = 0$

Velocity of bullet after firing, $v_1 = 500$ m s^{-1}

Mass of gun, $m_2 = 5$ kg

Velocity of gun before firing, $u_2 = 0$

Velocity of gun after firing = ?

We know that,

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

Substituting the values, we get

$$0.025 \times 0 + 5 \times 0 = 0.025 \times 500 + 5 \times v_2$$

$$\Rightarrow \quad 0 = 12.5 + 5 \times v_2$$

$$\Rightarrow \quad v_2 = \frac{-12.5}{5} = -2.5 \text{ m s}^{-1}$$

Thus, the recoil velocity of gun is equal to 2.5 m s^{-1}. Here negative (–ve) sign shows that the gun moves in the direction opposite to that of the bullet.

2. A bullet of mass 5 g is fired from a pistol of 1.5 kg. If the recoil velocity of the pistol is 1.5 m s^{-1}, find the velocity of the bullet.

Solution : Given, mass of bullet, m_1 = 5 gm

$$= \frac{5}{1000} = 0.005 \text{ kg}$$

Mass of pistol, $m_2 = 1.5$ kg

Recoil velocity of pistol, $v_2 = 1.5$ m s^{-1}

Velocity of bullet, v_1 = ?

Before firing, the bullet and the pistol are at rest. Thus,

Initial velocity of the bullet, $u_1 = 0$

and initial velocity of the pistol, $u_2 = 0$

We know that,

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

Substituting the values, we get

$$0.005 \times 0 + 1.5 \times 0 = 0.005 \times v_1 + 1.5 \times 1.5$$

$$\Rightarrow \quad 0 = 0.005 \times v_1 + 2.25$$

$$v_1 = \frac{-2.25}{0.005} = -450 \text{ m s}^{-1}$$

Thus, the velocity of bullet = 450 m s^{-1}.

Here negative sign shows that the bullet moves in the direction opposite to that of the pistol.

3. A boy of mass 50 kg runs with a velocity of 2 m s^{-1}. He jumps onto a stationary cart of mass 2 kg while running. Find the velocity at which the cart moves after the boy jumps onto it.

Solution : Given, mass of boy, $m_1 = 50$ kg

Initial velocity of the boy, $u_1 = 2$ m s^{-1}

Mass of cart, $m_2 = 2$ kg

Initial velocity of cart, $u_2 = 0$

Final velocity of cart, v_2 =?

Since, the boy jumps onto the cart, the final velocity, v_1 of the boy will be equal to that of the cart.

Therefore, $v_1 = v_2$

We know that,

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

Substituting the values, we get

$$50 \times 2 + 2 \times 0 = 50 \times v_1 + 2 \times v_2$$

$$100 = 50 \times v_2 + 2 \times v_2 \quad [\because v_1 = v_2]$$

$$100 = v_2 (50 + 2)$$

$$100 = v_2 \times 52$$

$$v_2 = \frac{100}{52} = 1.92 \text{ m s}^{-1}$$

Therefore, the velocity of the cart after the boy jumps onto it is equal to 1.92 m s^{-1}. Since velocity has positive sign, the cart will go in the same direction in which the boy was running.

4. While playing football, Kris collided and got entangled with Tom who was playing for the opposite team and running from the opposite side. Kris had a mass of 40 kg and Tom's mass was 60 kg. If Tom was running with a velocity of 3 m s^{-1} and Kris was running with a velocity of 4 m s^{-1}, find the velocity and direction of both the players after collision assuming other forces to be negligible.

Solution : Given, Mass of Kris, $m_1 = 40$ kg

Initial velocity of Kris, $u_1 = 4$ m s^{-1}

Mass of Tom, $m_2 = 60$ kg

Initial velocity of Tom, $u_2 = 3$ m s^{-1}

Final velocity and direction of both of the player after collision =?

Let the final velocity of both the players after collision be v, since they got entangled.

Assuming Kris was coming from the left and Tom was coming from the right.

Let us take the velocity of Kris as positive, and that of Tom as negative as both were running in opposite directions.

Thus, initial velocity of Kris, $u_1 = 4 \text{ m s}^{-1}$

Also initial velocity of Tom, $u_2 = -3 \text{ m s}^{-1}$

We know that,

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

Substituting the values, we get

$$40 \times 4 + 60 \times (-3) = 40 \times v + 60 \times v$$

[Since they got entangled after collision, both the player have the same velocity]

$$\Rightarrow \quad 40 \times 4 + 60 \times (-3) = 40 \times v + 60 \times v$$

$$\Rightarrow \quad 160 - 180 = v\,(40 + 60)$$

$$\Rightarrow \quad -20 = v \times 100$$

$$\Rightarrow \quad v = \frac{-20 \text{ m s}^{-1}}{100} = -0.2 \text{ m s}^{-1}$$

Thus, the velocity of both the player would become -0.2 ms^{-1}. Negative velocity shows that they would go from right to left after collision.

TRY YOURSELF

1. A body of mass 300 g kept at rest breaks into two parts due to internal forces. One part of mass 200 g is found to move at a speed of 12 m s^{-1} towards the east. What will be the velocity of the other part? **[Ans : 24 m s^{-1} towards west]**
2. A stone weighing 5 kg moves with a velocity of 10 m s^{-1} and stops after 2 s. Find the initial and the final momentum of the body. **[Ans : 50 kg m s^{-1} ; 0 kg m s^{-1}]**
3. A ball of mass 100 g moving with a speed of 30 m s^{-1} is brought to rest by a person in 0.03 s. Find the
   (a) Change in the momentum of the ball
   (b) Average force applied by the person
   [Ans : (a) -3.0 kg m s^{-1} ; (b) -100 N]
4. A stone of mass 10 g initially moves with a velocity of 50 m s^{-1}. On applying a constant force on the stone for 2 s, it acquires a velocity of 70 m s^{-1}. Calculate :
   (a) Initial momentum of the stone
   (b) Final momentum of the stone
   (c) Rate of change of momentum
   (d) Acceleration of the stone
   [Ans : (a) 0.5 kg m s^{-1}; (b) 0.7 kg m s^{-1}; (c) 0.1 kg m s^{-2}; (d) 10 m s^{-2}]
5. Two balls of masses 100 g and 200 g each are moving along the same line and direction with velocities of 2 m s^{-1} and 1 m s^{-1} respectively. They collide, and after the collision, the first ball moves at a velocity of 1.67 m s^{-1}. Determine the velocity of the second ball. **[Ans : 1.165 m s^{-1}]**

PAPER–PEN TEST : 6

1. State the law of conservation of momentum.
2. Justify : "*Momentum is neither created nor destroyed*".
3. Illustrate the conservation of momentum with an example.
4. Prove the law of conservation of momentum.
5. Explain the recoil of a gun with the help of Newton's third law of motion as well as with the help of the law of conservation of momentum.
6. Explain rocket propulsion with the help of law of conservation of momentum.

COMPENDIUM

- Force is a push or pull that acts upon an object.
- Balanced forces : The resultant of all the forces acting on a body is zero.
- Unbalanced forces : The resultant of all the forces acting on a body is not zero.
- Newton's first law of motion states that a body at rest will remain at rest and a body in motion will remain in uniform motion unless acted upon by an unbalanced force.

- The property by virtue of which an object tends to remain in the state of rest or of uniform motion unless acted upon by some force is called inertia.
- The mass of a body is a measure of inertia.
- The momentum of an object is the product of its mass and velocity and is a vector quantity that has the same direction as that of the velocity. Its S.I. unit is kg m s^{-1}.
- Newton's second law of motion states that the rate of change of momentum of a body is directly proportional to the force and takes place in the same direction as the force.
- Force is also defined as the product of mass and acceleration.
- The S.I. unit of force is kg m s^{-2}.
- The S.I. unit of force is also known as newton and represented by the symbol N.
- A force of one newton produces an acceleration of 1 m s^{-2} on an object of mass 1 kg.
- Force of friction always opposes the motion of objects.
- Two forces resulting from the interaction between two objects are called action and reaction forces respectively.
- Action and reaction forces act on two different bodies but they are equal in magnitude.
- Newton's third law : For every action there is an equal and opposite reaction; but action and reaction act on different bodies.
- Law of conservation of momentum : The sum of the momentums of two objects before collision is equal to the sum of momentums, after the collision provided there is no external unbalanced force acting on them.
- The velocity with which a gun moves in the backward direction after firing is known as the recoil velocity.

EXERCISES (SOLVED)

NCERT IN TEXT QUESTIONS

1. Which of the following has more inertia?

   (a) A rubber ball or a stone of the same size?

   (b) A bicycle or a train?

   (c) A five rupees coin or a one-rupee coin?

   Ans : (a) A stone.

   (b) A train.

   (c) A five rupees coin.

   Explanation : Inertia is associated with mass and objects having more mass have more inertia.

2. In the following example, try to identify the number of times the velocity of the ball changes :

   'A football player kicks a football to another player of his team who kicks the football towards the goal. The goalkeeper of the opposite team collects the football and kicks it towards a player of his own team'. Also identify the agent supplying the force in each case.

   Ans : The velocity of football changes four times.

   First, when a football player kicks the football to another player, second when that player kicks the football to the goalkeeper. Third when the goalkeeper stops the football. Fourth when the goalkeeper kicks the football towards a player of his own team.

   Agent supplying the force :

   First case – First player

   Second case – Second player

   Third case – Goalkeeper

   Fourth case – Goalkeeper

3. Explain why some of the leaves may get detached from a tree if we vigorously shake its branch.

   Ans : The cause of this phenomenon can be explained using Newton's first law of motion. Initially, the leaves and tree both are at rest. But when the tree is shaken vigorously, the tree moves while leaves tend to be at rest. Since they remain at rest some of the leaves may get detached from a tree if we vigorously shake its branches.

4. Why do you fall in the forward direction when a moving bus brakes to a stop and fall backwards when it accelerates from rest?

   Ans : In a moving bus, passengers are in motion along with the bus. When brakes are applied to stop a moving bus, the bus comes to rest, but because of the tendency to be in motion a person falls forward. Similarly, when a bus is accelerated

from rest, due to the tendency to be at rest, a person in the bus falls backwards.

5. If action is always equal to the reaction, explain how a horse can pull a cart.

   Ans : The horse pushes the ground in the backward direction. In reaction to this, the horse moves forward and cart moves along with the horse in the forward direction. In this case, when the horse tries to pull the cart in the forward direction, then cart pulls the horse in the backward direction, but because of the unbalanced force applied by the horse, the cart moves in forward direction.

6. Explain why is it difficult for a fireman to hold a hose which ejects large amounts of water at a high velocity.

   Ans : When a large amount of water is ejected from a hose at a high velocity, according to Newton's third law of motion, water pushes the hose in backward direction with the same force. Therefore, it is difficult for a fireman to hold a hose which ejects large amount of water at a high velocity.

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

   Solution : Given, Mass of rifle, M = 4 kg

   Initial velocity of rifle, U = 0

   Mass of bullet, m = 50 g = 50/1000 kg = 0.05 kg

   Initial velocity of bullet, u = 0

   Final velocity of bullet, v = 35 m s^{-1}

   Final velocity [Recoil velocity] of rifle, V = ?

   We know that,

   $$MU + mu = MV + mv$$

   Substituting the values, we get

   $$4 \times 0 + 0.05 \times 0 = 4 \times V + 0.05 \times 35$$

   $$0 = 4 \times V + 1.75$$

   $$V = -\frac{1.75}{4}$$

   $$= -0.4375 \text{ m s}^{-1} \approx 0.44 \text{ m s}^{-1}$$

   Here, negative sign of velocity of rifle shows that rifle moves in the opposite direction of the movement of bullet. Therefore, recoil velocity of rifle is equal to 0.44 m s^{-1}.

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

   Solution : Given, Mass of first object, m_1 = 100 g = 100/1000 kg = 0.1 kg

   Initial velocity of first object, u_1 = 2 m s^{-1}

   Final velocity of first object after collision, v_1 = 1.67 m s^{-1}

   Mass of second object, m_2 = 200 g = 200/1000 kg = 0.2 kg

   Initial velocity of second object, u_2 = 1 m s^{-1}

   Final velocity of second object after collision, v_2 = ?

   We know that,

   $$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

   Substituting the values, we get

   $$0.1 \times 2 + 0.2 \times 1 = 0.1 \times 1.67 + 0.2 \times v_2$$

   $$0.2 + 0.2 = 0.167 + 0.2\, v_2$$

   $$0.4 - 0.167 = 0.2 \times v_2$$

   $$v_2 = \frac{0.233}{0.2} = 1.165 \text{ m s}^{-1}$$

   Thus, velocity of the second object after collision will be 1.165 m s^{-1}.

NCERT EXERCISES QUESTIONS

1. An object experiences a net zero external unbalanced force. Is it possible for the object to be travelling with a non-zero velocity? If yes, state the conditions that must be placed on the magnitude and direction of the velocity. If no, provide a reason.

   Ans : When a net zero external unbalanced force is applied on the body, it is possible for the object to be travelling with a non-zero velocity. In fact, once an object comes into motion and if its motion is unopposed by any external force then the object will continue to remain in motion. It is necessary that the object should move at a constant velocity and in a particular constant direction.

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

Ans : When a carpet is beaten with a stick; the carpet moves suddenly, while dust particles trapped within the pores of carpet have the tendency to remain at rest. In order to maintain the position of rest they come out of the carpet. This is an example of Newton's first law of motion which states that any object remains in its state of rest or uniform motion unless any external force is applied on it.

3. Why is it advised to tie any luggage kept on the roof of a bus with a rope?

Ans : Luggage kept on the roof of a bus has the tendency to maintain its state of rest when bus is in rest and to maintain the state of motion when bus is in motion as Newton's first law of motion predicts.

When the bus moves from its state of rest, in order to maintain the position of rest, luggage kept over its roof may fall down. Similarly, when a moving bus comes to a state of rest or there is any sudden change in velocity because of application of brakes, luggage may fall down because of its tendency to remain in the state of motion. This is why it is advised to tie any luggage with a rope kept on the roof of a bus.

4. A batsman hits a cricket ball which then rolls on a level ground. After covering a short distance, the ball comes to rest. The ball slows to a stop because :

(a) the batsman did not hit the ball hard enough.

(b) velocity is proportional to the force exerted on the ball.

(c) there is a force on the ball opposing the motion.

(d) there is no unbalanced force on the ball, so the ball would want to come to rest.

Ans : (c) There is a force on the ball opposing the motion.

Explanation : When ball moves on the ground, the force of friction opposes its movement and after some time the ball comes to rest.

5. A truck starts from rest and rolls down a hill with a constant acceleration. It travels a distance of 400 m in 20 s. Find its acceleration. Find the force acting on it if its mass is 7 tonnes (Hint : 1 tonne = 1000 kg.)

Solution : Given, initial velocity of truck, u = 0 (Since, truck starts from rest)

Distance travelled, s = 400 m

Time, t = 20 s

Acceleration, a = ?

We know that,

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

$$400 = 0 \times 20 + \frac{1}{2} \times a \times (20)^2$$

$$400 = 0 + \frac{1}{2} \times a \times 400$$

$$a = \frac{400}{200} = 2 \text{ m s}^{-2}$$

Force acting upon truck,

Mass of truck = 7 tonnes = 7 × 1000 kg = 7000 kg

We know that,

Force, $F = m \times a$

Therefore, F = 7000 × 2 kg m s^{-2}

or F = 14000 newton.

Thus, acceleration of the truck is 2 m s^{-2} and force acting upon truck in the given condition is 14000 N.

6. A stone of 1 kg is thrown with a velocity of 20 m s^{-1} across the frozen surface of a lake and comes to rest after travelling a distance of 50 m. What is the force of friction between the stone and the ice?

Solution : Given, Mass of stone, m = 1 kg

Initial velocity, u = 20 m s^{-1}

Final velocity, v = 0 (as stone comes to rest)

Distance covered, s = 50 m

Force of friction =?

We know that,

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

$$(0)^2 = (20)^2 + 2a \times 50$$

$$a = \frac{-400}{100} = -4 \text{ m s}^{-2}$$

Now, we know that,

Force = Mass × Acceleration

Therefore, $F = 1 \times (-4)$

or $F = -4$ N

Thus, force of friction acting upon stone is –4 N. Here, negative sign shows that force is being applied in the opposite direction of the movement of the stone.

7. An engine pulls a train of 5 wagons, each of 2000 kg, along a horizontal track. If the engine exerts a force of 40000 N and the track offers a friction force of 5000 N, then calculate :

(a) the net accelerating force.

(b) the acceleration of the train.

(c) the force of wagon 1 on wagon 2.

Solution : Given, Force exerted by the engine = 40000 N

Force of friction = 5000 N

Mass of engine = 8000 kg

Total weight of wagons = 5 × 2000 = 10000 kg

(a) The net accelerating force = Force exerted by engine – Force of friction

Therefore,

Accelerating force = 40000 – 5000 = 35000 N

The net accelerating force is 35000 N

(b) The acceleration of the train

Force = Mass × Acceleration

35000 = (Mass of train) × a

35000 = 10000 × a

$$a = \frac{35000}{10000} = 3.5 \text{ m s}^{-2}$$

The acceleration of train is 3.5 m s^{-2}.

(c) The force of wagon 1 on wagon 2

Force of wagon 1 on 2 = Mass of four wagons × Acceleration

$F = 4 \times 2000 \times 3.5$

$F = 8000 \times 3.5$

$F = 28000$ N

8. An automobile 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 m s^{-2} ?

Solution : Given, Mass of the vehicle, m = 1500 kg

Acceleration, a = –1.7 m s^{-2}

Force acting between the vehicle and the road, F = ?

We know that, $F = m \times a$

Therefore, $F = 1500 \times (-1.7)$

$F = -2550$ N

Thus, force between vehicle and road is – 2550 N.

The negative sign shows that force is acting in the opposite direction to the motion of the vehicle.

9. What is the momentum of an object of mass m, moving with a velocity, v?

(a) $(mv)^2$ (b) mv^2 (c) $1/2\ mv^2$ (d) mv

Ans : (d) mv

Explanation : Given, Mass of the object = m,

Velocity of the object = v,

Momentum =?

We know that, momentum, p = Mass × Velocity

Therefore, $p = mv$

Thus, option (d) mv is correct.

10. Using a horizontal force of 200 N, we intend to move a wooden cabinet across a floor at a constant velocity. What is the friction force that will be exerted on the cabinet?

Solution : For an object to move at a constant velocity, the net unbalanced force acting on it must be zero. So, if a force of 200 N is used to move the cabinet, the opposing frictional force must also be 200 N.

11. Two objects, each of mass 1.5 kg, are moving in the same straight line but in opposite directions. The velocity of each object is 2.5 m s^{-1} before the collision, during which they stick together. What will be the velocity of the combined object after collision?

Solution : Since two objects of equal masses are moving in opposite direction with equal velocity,

therefore, the velocity of the objects after collision during which they stick together will be zero.

Explanation : Given, Mass of first object, m_1 = 1.5 kg

Mass of second object, m_2 = 1.5 kg

Initial velocity of one object, u_1 = 2.5 m s^{-1}

Initial velocity of second object, u_2 = –2.5 m s^{-1} (Since second object is moving in opposite direction)

Final velocity of both the objects, which stick after collision, v =?

We know that,

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

Substituting the values, we get

$$1.5 \times 2.5 + 1.5 \times (-2.5) = 1.5 \times v + 1.5 \times v$$

$$3.75 - 3.75 = v\,(1.5 + 1.5)$$

$$v = \frac{0}{3.00} = 0$$

Therefore, final velocity of both the objects after collision will became zero.

12. According to the third law of motion when we push on an object, the object applies an equal and opposite force on us. If the object is a massive truck parked along the roadside, it will probably not move. A student justifies this by answering that the two opposite and equal forces cancel each other. Comment on this logic and explain why the truck does not move.

    Ans : Because of the huge mass of the truck, the force of static friction is very high. The force applied by the student is unable to overcome the static friction and hence, he is unable to move the truck. In this case, the net unbalanced force in either direction is zero, which is the reason of no motion happening here. The force applied by the student and the force because of static friction cancel out each other. Hence, the logic given by the student is correct.

13. A hockey ball of mass 200 g travelling at 10 m s^{-1} is struck by a hockey stick so as to return it along its original path with a velocity at 5 m s^{-1}. Calculate the change of momentum that occurred in the motion of the hockey ball by the force applied by the hockey stick.

    Solution : Given, Mass of hockey ball,

    m = 200 g = 200/1000 kg = 0.2 kg

    Initial velocity of hockey ball, u = 10 m s^{-1}

    Final velocity of hockey ball, v = – 5 m s^{-1} (because direction becomes opposite)

    Change in momentum = ?

    We know that,

    Momentum = Mass × Velocity

    Therefore, momentum of ball before getting struck

    $= 0.2 \times 10 = 2$ kg m s^{-1}

    Momentum of ball after getting struck

    $= 0.2 \times -5 = -1$ kg m s^{-1}

    Therefore, change in momentum

    = Momentum before getting struck – Momentum after getting struck

    $= 2 - (-1)$

    $= 2 + 1 = 3$ kg m s^{-1}

    Thus, change in momentum of ball after getting struck is 3 kg m s^{-1}.

14. A bullet of mass 10 g travelling horizontally with a velocity of 150 m s^{-1} strikes a stationary wooden block and comes to rest in 0.03 s. Calculate the distance of penetration of the bullet into the block. Also, calculate the magnitude of the force exerted by the wooden block on the bullet.

    Solution : To calculate the distance of penetration of the bullet :

    Given, Mass of bullet, m = 10 g = 10/1000 kg = 0.01 kg

    Initial velocity of bullet, u = 150 m s^{-1}

    Since bullet comes to rest, thus final velocity, v = 0

    Time, t = 0.03 s

    Distance of penetration, *i.e.* distance covered, s =?

    Magnitude of force exerted by wooden block =?

    We know that,

    $$v = u + at$$

    $$\Rightarrow \quad 0 = 150 + a \times 0.03$$

    $$-150 = a \times 0.03$$

$$a = -\frac{150}{0.03} = -5000 \text{ m s}^{-2}$$

We know that,

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

$$s = 150 \times 0.03 + \frac{1}{2}(-5000) \times (0.03)^2$$

$$s = 4.5 - 2500 \times 0.0009$$

$$s = 2.25 \text{ m}$$

Therefore, penetration of bullet in wooden block is 2.25 m.

To calculate the magnitude of the force exerted by the wooden block on the bullet :

We know that,

$$\text{Force} = \text{Mass} \times \text{Acceleration}$$

$$F = 0.01 \times (-5000) = -50 \text{ N}$$

Force exerted by wooden block on bullet is –50 N. Here, negative sign shows that force is exerted in The opposite direction of bullet.

15. An object of mass 1 kg travelling in a straight line with a velocity of 10 m s^{-1} collides and sticks to, a stationary wooden block of mass 5 kg. Then they both move off together in the same straight line. Calculate the total momentum just before the impact and just after the impact. Also, calculate the velocity of the combined object.

Solution : Given, Mass of moving object, $m_1 = 1$ kg

Mass of the wooden block, $m_2 = 5$ kg

Initial velocity of object, $u_1 = 10 \text{ m s}^{-1}$

Initial velocity of wooden block, $u_2 = 0$

Final velocity of moving object and wooden block, $v = ?$

Total momentum before collision and after collision =?

We know that,

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

Substituting the values, we get

$$1 \times 10 + 5 \times 0 = 1 \times v + 5 \times v$$

$$10 = v\,(1 + 5)$$

$$10 = v \times 6$$

$$v = \frac{10}{6} = 1.67 \text{ m s}^{-1} \quad \text{.....(i)}$$

Total momentum of object and wooden block just before collision

$$m_1u_1 + m_2u_2 = 1 \times 10 + 5 \times 0 = 10 \text{ kg m s}^{-1}$$

Total momentum after collision

$$m_1v_1 + m_2v_2 = m_1v + m_2v = v(m_1+m_2)$$

(Since both the objects move with the same velocity 'v' after collision)

$$= (1 + 5) \times \frac{10}{6} \quad \text{[from (i)]}$$

$$= 6 \times \frac{10}{6} = 10 \text{ kg m s}^{-1}$$

Thus,

(a) The velocity of both the object after collision $= 1.67 \text{ m s}^{-1}$.

(b) Total momentum before collision = 10 kg m s^{-1}.

(c) Total momentum after collision = 10 kg m s^{-1}.

16. An object of mass 100 kg is accelerated uniformly from a velocity of 5 m s^{-1} to 8 m s^{-1} in 6 s. Calculate the initial and final momentum of the object. Also, find the magnitude of the force exerted on the object.

Solution : To calculate the initial and final momentum of the object :

Given , Initial velocity, $u = 5 \text{ m s}^{-1}$

Final velocity, $v = 8 \text{ m s}^{-1}$

Mass of the given object, $m = 100$ kg

Time, $t = 6$ s

Initial momentum and Final momentum =?

Magnitude of force exerted on the object =?

We know that,

Momentum, p = Mass × Velocity

Therefore, initial momentum

= Mass × Initial velocity

$= 100 \times 5 = 500 \text{ kg m s}^{-1}$

Final momentum = Mass × Final velocity

$= 100 \times 8 = 800 \text{ kg m s}^{-1}$

To find the magnitude of the force exerted on the object :

We know that,

$$v = u + at$$
$$8 = 5 + a \times 6$$
$$8 - 5 = a \times 6$$
$$a = \frac{3}{6} = 0.5 \text{ m s}^{-2}$$

Now, force exerted on object

$$= \text{Mass} \times \text{Acceleration}$$
$$= 100 \times 0.5 = 50 \text{ N}$$

17. How much momentum will a dumb-bell of mass 10 kg transfer to the floor if it falls from a height of 80 cm? Take its downward acceleration to be 10 m s^{-2}.

Solution : Given, Mass of dumb-bell = 10 kg

Distance, s = 80 cm = 80/100 = 0.8 m

Acceleration, a = 10 m s^{-2}

Initial velocity of dumb-bell, u = 0

Momentum =?

We know that,

$$v^2 = u^2 + 2as$$
$$v^2 = 0 + 2 \times 10 \times 0.8$$
$$v^2 = 16$$
$$v = \sqrt{16} = 4 \text{ m s}^{-1}$$

Now, we know that,

$$\text{Momentum} = \text{Mass} \times \text{Velocity}$$
$$= 10 \times 4 = 40 \text{ kg m s}^{-1}$$

EXEMPLAR QUESTIONS

1. Which of the following statement is not correct for an object moving along a straight path in an accelerated motion?
   (a) Its speed keeps changing.
   (b) Its velocity always changes.
   (c) It always goes away from the earth.
   (d) A force is always acting on it.
2. According to the third law of motion, action and reaction :
   (a) always act on the same body.
   (b) always act on different bodies in opposite directions.
   (c) have same magnitude and directions.
   (d) act on either body at normal to each other.
3. A goalkeeper in a game of football pulls his hands backwards after holding the ball shot at the goal. This enables the goal keeper to :
   (a) exert larger force on the ball.
   (b) reduce the force exerted by the ball on his hands.
   (c) increase the rate of change of momentum.
   (d) decrease the rate of change of momentum.
4. The inertia of an object tends to cause the object :
   (a) to increase its speed.
   (b) to decrease its speed.
   (c) to resist any change in its state of motion.
   (d) to decelerate due to friction.
5. A passenger in a moving train tosses a coin which falls behind him. It means that motion of the train is :
   (a) accelerated
   (b) uniform
   (c) retarded
   (d) along circular tracks
6. An object of mass 2 kg is sliding with a constant velocity of 4 m s^{-1} on a frictionless horizontal table. The force required to keep the object moving with the same velocity is
   (a) 32 N
   (b) 0 N
   (c) 2 N
   (d) 8 N
7. Rocket works on the principle of conservation of :
   (a) mass
   (b) energy
   (c) momentum
   (d) velocity
8. A water tanker filled up to 2/3 of its height is moving with a uniform speed. On sudden application of the brake, the water in the tank would :
   (a) move backward
   (b) move forward
   (c) be unaffected
   (d) rise upwards

ANSWERS

1. (c) 2. (b) 3. (b) 4. (c) 5. (a) 6. (b) 7. (c) 8. (b)

9. There are three solids made up of aluminium, steel and wood, of the same shape and same volume. Which of them would have highest inertia?

   Ans : Steel. As mass is the measure of inertia, for objects of same shape and size, the one having the more mass will have then highest inertia. Since steel has the greatest density and greatest mass, it has the highest inertia.

10. Two balls of the same size but of different materials, rubber and iron are kept on the smooth floor of a moving train. The brakes are applied suddenly to stop the train. Will the balls start rolling? If so, in which direction? Will they move with the same speed? Give reasons for your answer.

    Ans : Yes, the balls will start rolling in the direction in which the train was moving. When brakes are applied, the train comes to rest but due to inertia, the balls try to remain in motion. Therefore, they begin to roll. Since the masses of the balls are not the same, the inertial forces are not same on both the balls. Thus, the balls will move with different speeds.

11. Two identical bullets are fired one by a light rifle and another by a heavy rifle with the same force. Which rifle will hurt the shoulder more and why?

    Ans : The light rifle, will recoil more. This can be explained by the law of conservation of momentum or by Newton's laws of motion.

12. A horse continues to apply a force in order to move a cart with a constant speed. Explain why?

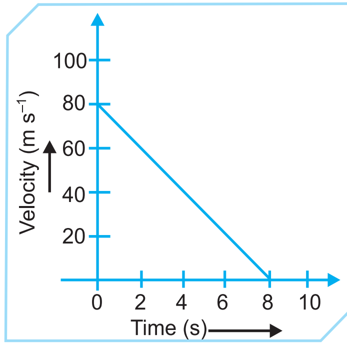
    Ans : The force applied by the horse balances the force of friction.

13. Suppose a ball of mass m is thrown vertically upward with an initial speed v, its speed decreases continuously till it becomes zero. Thereafter, the ball begins to fall downward and attains the speed v again before striking the ground. It implies that the magnitudes of initial and final momentum of the ball are same.

    Yet, it is not an example of conservation of momentum. Explain why?

    Ans : Law of conservation of momentum is applicable to isolated system (no external force is applied). In this case, the change in velocity is due to the gravitational force of earth.

14. Velocity versus time graph of a ball of mass 50 g rolling on a concrete floor is shown in figure below. Calculate the acceleration and frictional force of the floor on the ball.



Velocity –Time graph

Solution : Given, mass of ball, m = 50 g = $\frac{50}{1000}$ kg = 0.05 kg

We know that, acceleration,

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

By graph,

$$a = \frac{80-0}{8-0} = \frac{80}{8} = 10 \text{ m s}^{-2}$$

$$\text{Force (F)} = \text{Mass } (m) \times \text{Acceleration } (a)$$

$$F = 0.05 \times 10$$

$$F = 0.5 \text{ N}$$

Thus, acceleration of ball is 10 m s^{-2} and functional force applied by floor is 0.5 N.

15. A truck of mass M is moved under a force F. If the truck is then loaded with an object equal to the mass of the truck and the driving force is halved, then how does the acceleration change?

    Ans : Calculate using, F = ma

    Acceleration becomes one-fourth of the original.

16. Two friends on roller skates are standing 5 m apart facing each other. One of them throws a ball of 2 kg towards the other, who catches it. How will this activity affect the position of the two? Explain your answer.

    Ans : Separation between them will increase. Initially the momentum of both of them is zero as they are at rest. In order to conserve the momentum, the one who throws the ball would move backward. The second will experience a net force after catching the ball and therefore will move backwards, *i.e.*, in the direction of the force.

17. Water sprinkler used for grass lawns begins to rotate as soon as the water is supplied. Explain the principle on which it works.

    Ans : The working of the rotation of sprinkler is based on third law of motion. As the water comes out of the nozzle of the sprinkler, an equal and opposite reaction force comes into play. So, the sprinkler starts rotating.

18. Using second law of motion, derive the relation between force and acceleration. A bullet of 10 g strikes a sand bag at a speed of 10^3 m s^{-1} and gets embedded after travelling 5 cm. Calculate
 (a) the resistive force exerted by the sand on the bullet
 (b) the time taken by the bullet to come to rest.

Solution : According to second law of motion, force is directly proportional to rate of change of momentum.

So, $$F = \frac{dp}{dt}$$

We know that,

$$p = mv$$

So, $$F = \frac{d(mv)}{dt} = m\frac{dv}{dt}$$

$$F = ma \qquad \left[\because \frac{dv}{dt} = a\right]$$

Mass of bullet, $m = 10 \text{ g} = \frac{10}{1000} \text{ kg} = 0.01$ kg

Initial velocity of bullet, $u = 10^3$ m s^{-1}

Distance covered by bullet before coming to rest,

$$s = 5 \text{ cm} = \frac{5}{100} \text{ m}$$

(a) We know that,

$$v^2 = u^2 - 2as$$

$$0 = (10^3)^2 - 2\,a \times \frac{5}{100}$$

$$2a \times \frac{5}{100} = -(10^3)^2$$

$$a = -10^7 \text{ m s}^{-2}$$

We know that,

Force, F = Mass × Acceleration

$$= 0.01 \times 10^7 \text{ kg m s}^{-2}$$

$$= 10^5 \text{ N}$$

(b) We know that,

$$v = u + at$$

$$0 = 10^3 - 10^7 \times t$$

$$10^7\, t = 10^3$$

$$t = \frac{1}{10^4}$$

$$= 10^{-4} \text{ s}$$

19. Derive the unit of force using the second law of motion. A force of 5 N produces an acceleration of 8 m s^{-2} on a mass m_1 and an acceleration of 24 m s^{-2} on a mass m_2. What acceleration would the same force provide if both the masses are tied together?

Solution : F = ma = kg m s^{-2}

This unit is also called newton. Its symbol is N.

$$m_1 = \frac{F}{a_1} = \frac{5}{8} \text{ kg}$$

$$m_2 = \frac{F}{a_2} = \frac{5}{24} \text{ kg}$$

$$M = \left(\frac{5}{8} + \frac{5}{24}\right)\text{kg} = \left(\frac{5}{6}\right)\text{kg}$$

Acceleration produced in M,

$$a = \frac{F}{M} = \frac{5}{5/6} = 6 \text{ m s}^{-2}$$

20. What is momentum? Write its S.I. unit. Interpret force in terms of momentum.

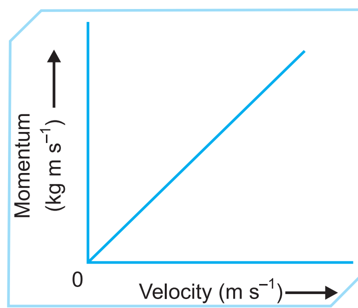
Represent the following graphically
 (a) momentum versus velocity when mass is fixed.
 (b) momentum versus mass when velocity is constant.

Ans : Momentum = Mass × Velocity

S.I. unit of momentum is kg m s^{-1}.

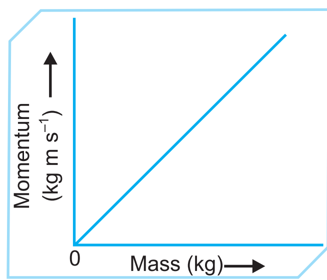
Force = Rate of change in momentum

(a)



Velocity – Momentum graph

(b)



Momentum- Mass graph

HIGHER ORDER THINKING SKILL QUESTIONS [HOTS]

1. You push on a crate with a force of 10 N to the right, and your friend pushes on the crate with a force of 25 N to the left. What happens to the motion of the crate?

   Ans : The crate accelerates to the left because there is a net force of 15 N acting to the left.

2. Comment : "*You push a heavy crate. At first it doesn't move. You push harder, and it finally starts to move, but you still have to exert some force to keep it moving at a constant velocity.*"

   Ans : At first you had to exert a large force to overcome static friction. After the crate started to move, you still had to exert a smaller force to overcome sliding friction.

3. Two crates, one heavy and one light, are at rest on a waxed floor. Which crate will need the greater force to give the same change in speed?

   Ans : The heavier crate will need more force because force is directly proportional to mass.

4. Kim sits on a rock. His weight is an action force. What is the reaction force?

   Ans : The rock supplies an upward force equal to Kim's weight.

5. For a long time, all experiments showed that a force had to be applied to keep a body in motion at constant velocity. How does our knowledge of the force of friction help us to understand, now, that this isn't true?

   Ans : The force of friction acts in the opposite direction of motion. Therefore, it is the force of friction, which must be balanced in order to keep an object in motion at a constant velocity. Without friction, an object in motion at constant velocity would remain so unless acted upon by an unbalanced force.

6. Akhtar, Kiran and Rahul were riding in a motorcar that was moving with a high velocity on an expressway, suddenly an insect hit the windshield and got stuck on the windscreen. Akhtar and Kiran started pondering over the situation. Kiran suggested that the insect suffered a greater change in momentum as compared to the change in momentum of the motorcar (because the change in the velocity of the insect was much more than that of the motorcar). Akhtar said that since the motorcar was moving with a larger velocity, it exerted a larger force on the insect. And as a result the insect died. Rahul while putting an entirely new explanation said that both the motorcar and the insect experienced the same force and a change in their momentum. Comment on these suggestions.

   Ans : We know that, according to the law of conservation of momentum, the total momentum of a system before collision is equal to the total momentum of the system after collision. In this case, since the insect experiences a greater change in its velocity so it experiences a greater change in its momentum. From this angle, Kiran's observation is correct.

   Motorcar is moving with a larger velocity and has a bigger mass; as compared to the insect. Moreover, the motorcar continues to move in the same direction even after the collision; which suggests that motorcar experiences minimal change in its momentum, while the insect experiences the maximum change in its momentum. Hence, Akhtar's observation is also correct.

   Rahul's observation is also correct; because the momentum gained by the insect is equal to the momentum lost by the motorcar. This also happens in accordance with the law of conservation of momentum.

7. You throw a ball into the air. As the ball leaves your hand, the force(s) acting on it is/are—

   Ans : Gravity and weight of the ball.

8. A student has a set of masses to use in an experiment about force :

   1 g mass, 5 g mass, 25 g mass, 100 g mass

   Which of the following masses would require the least amount of force to be lifted from the lab table?

   Ans : 1 g mass.

   We know that,

$$F = ma$$

Since force is directly proportional to the mass, the smallest mass will require the least force.

9. A student sees a motionless ball resting on a table. Describe the forces acting on the ball?

   Ans : Gravity creates a downward force that is equal to the force of the table pushing up. There are balanced forces (gravity and upward push of table) holding the ball in place.

10. Forces of 10 N down, 10 N to the right, and 5 N to the left are acting on a ball. It accelerates horizontally to the right. What other force, if any, is acting on the ball?

    Ans : There must be a force of 10 N acting upward.

11. Suppose two objects having the same weight are dropped from a tall building. One object is larger and flatter than the other. Which object hits the ground last? Why?

    Ans : Larger and flatter object hits the ground last. This is because, the flatter objects have a greater air resistance so it will hit the ground last.

12. If you double the force on an object, the object's change in speed will also double, then how are the force and acceleration related?

    Ans : They are directly proportional.

13. A net force of – 10 N acts on a wagon moving at a constant velocity to the right. What happens to the wagon?

    Ans : It has acceleration to the left so it will start slowing down.

14. Develop an example that illustrates the outcome of two forces that act in opposite directions.

    Ans : Answers will vary depends on the situation. Two forces that act in opposite direction could be balanced, or they could be unbalanced. If the two forces are balanced, there will be no net movement in either direction indicated by the force vectors. If the forces are unbalanced, there will be net movement. The outcome will vary depending on which force has the greatest magnitude and whether the force is a pulling force or a pushing force. Net movement will be in the direction of the larger force.

15. Give reason : "*An aircraft is unable to fly on the moon*".

    Ans : This is because an aircraft needs air to hold it up and to burn the fuel in the aircraft engines. Since there is no air on the moon, an aircraft cannot fly in the moon's atmosphere.

MULTIPLE CHOICE QUESTIONS [MCQs]

1. If A and B are two objects having masses 10 kg and 30 kg respectively then :
   (a) A has more inertia than B.
   (b) B has more inertia than A.
   (c) A and B have the same inertia.
   (d) none of the two have inertia.

2. First law of motion defines :
   (a) inertia
   (b) force
   (c) both inertia and force
   (d) neither inertia nor force

3. Newton's first law of motion is :
   (a) qualitative
   (b) quantitative
   (c) both qualitative and quantitative
   (d) neither qualitative nor quantitative

4. Inertia depends upon :
   (a) acceleration of the body
   (b) velocity of the body
   (c) shape of the body
   (d) mass of the body

5. Which of the following has the largest inertia?
   (a) A pin
   (b) An ink pot
   (c) Your physics book
   (d) Your body

6. When a bus starts suddenly the passengers standing on it lean backwards in the bus. This is an example of :
   (a) Newton's first law
   (b) Newton's second law
   (c) Newton's third law
   (d) none of Newton's law

7. The law which defines force is :
   (a) Newton's third law
   (b) Newton's first law

(c) Newton's second law
(d) none of these

8. Inertia of rest is the property by virtue of which the body is unable to change by itself :
(a) the state of rest only
(b) the state of uniform linear motion
(c) the direction of motion only
(d) the steady state of rest

9. An iron ball and aluminium ball has same mass
(a) inertia of iron is greater than aluminium
(b) both the balls have same inertia
(c) inertia of iron is less than that of aluminium
(d) none of these

10. Mass measure amount of ____ in a body.
(a) inertia (b) motion
(c) velocity (d) acceleration

11. Newton's second law of motion :
(a) defines force
(b) defines inertia
(c) gives measure of force
(d) none of these

12. Newton's second law of motion is :
(a) qualitative
(b) quantitative
(c) both qualitative and quantitative
(d) neither qualitative nor quantitative

13. Momentum measures the amount of _______ in a body.
(a) inertia (b) motion
(c) velocity (d) acceleration

14. Force measures the rate of change of ____ of a body.
(a) mass (b) inertia
(c) velocity (d) momentum

15. The C.G.S. unit of force is :
(a) m s^{-1} (b) s m^{-1}
(c) dyne (d) newton

16. Momentum has the same unit as :
(a) impulse (b) torque
(c) moment of force (d) couple

17. When force of 1 N acts on a mass of 1 kg, which is able to move freely, the object moves with a/an :
(a) speed of 1 m s^{-1}
(b) speed of 1 km s^{-1}
(c) acceleration of 10 m s^{-2}
(d) acceleration of 1 m s^{-2}

18. The net force acting on a body of mass of 1 kg moving with a uniform velocity of 5 m s^{-1} is :
(a) 5 N (b) 0.2 N
(c) 0 N (d) None of these

19. A body of mass 20 kg moves with an acceleration of 2 m s^{-2}. The rate of change of momentum in S.I. units is :
(a) 40 kg m s^{-2} (b) 10 kg m s^{-2}
(c) 4 kg m s^{-2} (d) 1 kg m s^{-2}

20. A body of mass M strikes against a wall with a velocity v and rebounds with the same velocity. Its change in momentum is :
(a) zero (b) Mv
(c) –Mv (d) –2 Mv

21. Gram weight is a unit of :
(a) mass (b) weight
(c) both (a) and (b) (d) neither (a) nor (b)

22. 9.8 N is equal to :
(a) 1 kg f (b) 1 kg wt
(c) both (a) and (b) (d) Neither (a) nor (b)

23. A body of mass 5 kg undergoes a change in speed from 20 m s^{-1} to 0.20 m s^{-1}. The momentum :
(a) increases by 99 kg m s^{-1}
(b) decreases by 99 kg m s^{-1}
(c) increases by 101 kg m s^{-1}
(d) decreases by 101 kg m s^{-1}

24. The combined effect of mass and velocity is taken into account by a physical quantity called :
(a) torque (b) moment of force
(c) momentum (d) all of them

25. How many dynes are equal to 1 N ?
(a) 10^8 (b) 10^4
(c) 10^5 (d) 10^3

26. Choose correct relation :
(a) $a = F/m$ (b) $Fa = m$
(c) $m = F \times a$ (d) none of these

27. If a moving ball A collides with another moving ball B, then :
(a) Momentum of A = Momentum of B

(b) (Momentum of A + Momentum of B before collision) = (Momentum of A + Momentum of B after collision)

(c) neither (a) nor (b)

(d) Both (a) and (b)

28. When a bullet is fired from a gun. The gun recoils to :

(a) conserve mass (b) conserve momentum

(c) conserve K.E. (d) none of these

29. A bullet in motion hits and gets embedded in a solid, resting on a frictionless table. What is conserved?

(a) Momentum and K.E.

(b) Momentum alone

(c) K.E. alone

(d) None of these

30. A bullet of mass 0.01 kg is fired from a gun weighing 5.0 kg. If the initial speed of the bullet is 250 m s^{-1}, calculate the speed with which the gun recoils.

(a) – 0.50 m s^{-1} (b) – 0.25 m s^{-1}

(c) + 0.05 m s^{-1} (d) + 0.25 m s^{-1}

31. Forces of action and reaction are :

(a) equal and in same direction

(b) equal and in opposite direction

(c) unequal and in same direction

(d) unequal and opposite.

32. Forces of action and reaction act :

(a) one after the other on same body

(b) simultaneously on same body

(c) one after the other on different bodies

(d) simultaneously on different bodies

33. A man is standing on a boat in still water. If he walks towards the shore the boat will :

(a) move away from the shore

(b) remain stationary

(c) move towards the shore

(d) sink

34. If the action and reaction were to act on the same body :

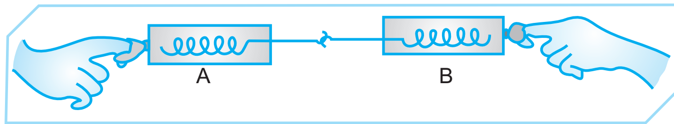
(a) the resultant would be zero

(b) the body would not move at all

(c) both (a) and (b) are correct

(d) neither (a) nor (b) is correct

35. Consider two spring balances hooked as shown in the figure below. We pull them in opposite directions. If the reading shown by A is 1.5 N, the reading shown by B will be :



(a) 1.5 N (b) 2.5 N

(c) 3.0 N (d) Zero

36. Newton is a unit used to measure :

(a) momentum

(b) force

(c) acceleration due to gravity

(d) none of these

37. A cannon after firing recoils due to :

(a) conservation of energy

(b) backward thrust of gases produced

(c) Newton's first law of motion

(d) Newton's' third law of motion

38. A diwali rocket ejects 0.05 kg of gases per second at a velocity of 400 m s^{-1}. The accelerating force on the rocket is :

(a) 20 dyne

(b) 20 newton

(c) 20 kg wt.

(d) sufficient data not given

39. The forces of action and reaction have ____ magnitude but _____ direction :

(a) same, same (b) same, opposite

(c) opposite, same (d) opposite, opposite

40. Choose correct statement :

(a) Action and reaction forces act on same object.

(b) Action and reaction forces act on different objects.

(c) both (a) and (b) are possible.

(d) Neither (a) nor B is correct.

ANSWERS

1 (b)	2 (c)	3 (a)	4 (d)	5 (d)	6 (a)	7 (b)
8 (d)	9 (b)	10 (a)	11 (c)	12 (b)	13 (b)	14 (d)
15 (c)	16 (a)	17 (d)	18 (c)	19 (a)	20 (d)	21 (b)
22 (c)	23 (b)	24 (c)	25 (c)	26 (a)	27 (b)	28 (b)
29 (b)	30 (a)	31 (b)	32 (d)	33 (a)	34 (c)	35 (a)
36 (b)	37 (d)	38 (b)	39 (b)	40 (b)		

EXERCISES (UNSOLVED)

VERY SHORT ANSWER TYPE QUESTIONS

1 Mark each

1. Mention the S.I. unit of force.
2. Which forces are responsible for change in the position of an object ?
3. What is the resultant force of a number of balanced forces?
4. Which has highest inertia? Solids made up of aluminium, steel or wood of same shape and volume ?
5. Give the relationship between force and acceleration.
6. What is the force which produces an acceleration of 1 m s^{-2} in a body of mass 1 kg ?
7. Name two factors on which acceleration depends?
8. What is the acceleration when no unbalanced force is acting on an object?
9. Mention the unit of momentum.
10. State whether momentum is a vector or scalar quantity.
11. Do action and reaction act on the same body or on different bodies?
12. Why does the sole of a shoe wear out in course of time?
13. Define friction.
14. Mention the advantage of using grease in the axle of a bicycle.
15. Give the momentum of the bullet and the gun before firing.

SHORT ANSWER TYPE - I QUESTIONS

2 Marks each

1. Define force.
2. Differentiate between balanced and unbalanced forces with an example each.
3. State Newton's first law of motion.
4. Define inertia with respect to motion.
5. State Newton's second law of motion.
6. Why it is easier to push an empty box than to push a box full of books?
7. State Newton's third law of motion.
8. What will happen if a man steps over a patch of quicksand consisting of very smooth and tiny grains of sand?
9. Why a cart pulled by a horse can be moved?
10. Define momentum.
11. Why are glasses packed with straw?
12. A ball is thrown vertically upward. What is the momentum at the highest point?
13. State the law of conservation of momentum.
14. Which has higher momentum? A bullet of mass 10 g moving with a velocity of 400 m s^{-1} or a cricket ball of mass 400 g thrown with the speed of 90 km h^{-1}.

SHORT ANSWER TYPE - II QUESTIONS

3 Marks each

1. Give reasons :
   (a) We flap wet clothes in the air before spreading them.
   (b) Dust flies off when a hanging carpet is hit with a stick.
   (c) Fruits fall off the branches when a strong wind is blown.
2. Give reasons :
   (a) You get hurt when you kick a stone.
   (b) An athlete always runs some distance before taking a jump.
   (c) It is advised to tie luggage kept on the top of a bus.
3. Prove that the rate of change of momentum is equal to mass × acceleration.
4. In high jump, the athletes are made to land on a cushion bed. Why?
5. If two balls X and Y of masses 'm' and '$2m$' are in motion with velocities '2V' and 'V' respectively, then compare:
   (a) Their inertia.
   (b) Their momentum.
   (c) Force required to stop them at the same time.
6. A lorry and a mini bus both moving with a velocity of magnitude 'v' have a headon collision and both of them come to halt after that. If the collision lasts for 1 sec, then
   (a) Which vehicle experiences the greater change in the momentum?
   (b) Which vehicle experiences the greater force of impact?
   (c) Which vehicle experiences greater accelera-tion? Justify.

LONG ANSWER TYPE QUESTIONS

5 Marks each

1. Describe an activity to illustrate the property of inertia of rest.
2. Derive Newton's second law of motion.
3. Mention any four applications of Newton's third law of motion.
4. Derive the law of conservation of momentum from Newton's third law of motion.
5. Prove the law of conservation of momentum with explanation, diagram and equation.

VIVA VOCE QUESTIONS

1. Which physical quantity corresponds to the rate of change of momentum?
2. What is the force which produces an acceleration of 1 m s^{-2} in a body of mass 1 kg?
3. Which physical principle is involved in the working of a jet aeroplane?
4. What is the unit of force?
5. What happens to the acceleration, if the mass of the body and the force acting on it are doubled?
6. State whether force is a scalar or a vector quantity?

FILL IN THE BLANKS

1. Forces that are equal in size but opposite in direction are ....
2. If gravity did not affect the path of a horizontally thrown ball, the ball would ....
3. Newton's first law of motion states that an object remains at rest unless an .... force acts on it.
4. Whenever a body is in motion, there is always .... to oppose the motion.
5. The relationship among force, mass, and acceleration is stated in ....

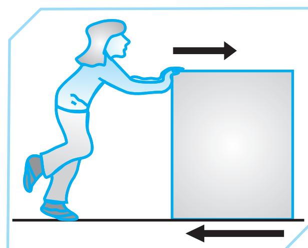
COMPLETE THE STATEMENTS FROM THE WORDS GIVEN BELOW

Contact	Balanced	Acceleration	Inertia
Gravity	Different	Acceleration	Unbalanced
Inertia	Opposite	Force	Acceleration

1. .... is the tendency of an object to resist any change in its motion.
2. A .... is a push or pull that one object exerts on another.
3. Newton's first law of motion states that an object stays in constant motion unless a(n) .... force acts on it.
4. Friction always acts in a direction .... to the direction of motion.
5. According to Newton's second law of motion, a larger force acting on an object causes a greater .... of that object.
6. When you throw a ball into the air, ... causes the ball to experience vertical acceleration.
7. Action-reaction forces always act on .... objects.
8. .... is the change in velocity divided by the change in time.
9. Speeding up, slowing down, and going around curves are examples of ....
10. If you are riding on a skateboard and it stops suddenly, your body keeps moving forward. This is because of ....
11. Forces that change an object's motion by touching the object are .... forces.
12. A spacecraft orbits the earth at a constant speed. The forces acting on it must be ....

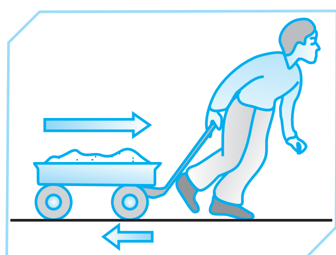
DIAGRAM BASED QUESTIONS

1. The figure below shows a girl pushing a box and the arrows represent the forces on the box, could the box in the figure be moving?



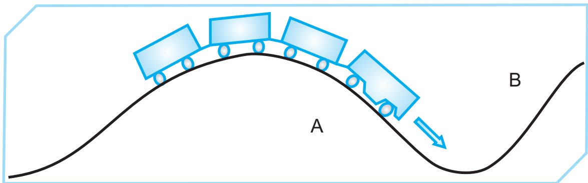
Ans : The force arrow that represents static friction that has greater magnitude than the force being applied by the girl. Therefore, the box is not moving.

2. The figure below shows a boy pulling a wagon and arrows represent the forces on the wagon. Could the wagon in the picture be moving?



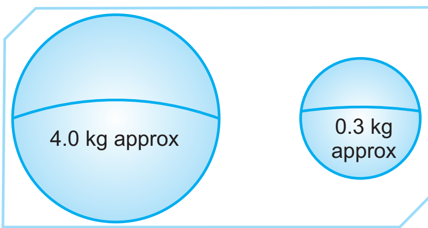
Ans : The boy is applying a greater force than that applied by static friction with the floor. Therefore, the wagon will be moving.

3. The figure below shows the motion of a train. Suppose that the train engine stops running as it passes point A. Predict the change in acceleration that will occur as more of the train passes point A.



Ans : Acceleration will increase as the train passes point A. Inertia will cause the train to continue moving in its current direction even without the engine. As more of the mass of the train begins to go down hill, the magnitude of the effect of gravity will increase. This will cause the train to go faster without taking any help from the engine. The train starts moving uphill as it reaches point B. At this point, gravity will start opposing the upward motion of the train. If the engine unable to generate more forward force, this will cause a negative change in the acceleration of the train.

4. The figure below shows two different kinds of balls. Discuss the difference in the masses of the two balls. Predict the relative amount of force that will be needed to cause the balls to move.



Ans : The ball having a mass of (approximately) 4.0 kg has a far greater mass than the ball having a mass of (approximately) 0.3 kg. All objects resist a change in motion. This resistance is called inertia. Objects with greater mass have more inertia and require more force to move. Therefore, far more force (more than 10 times) will be needed to move the ball of 4.0 kg than will be needed to move the ball of 0.3 kg.

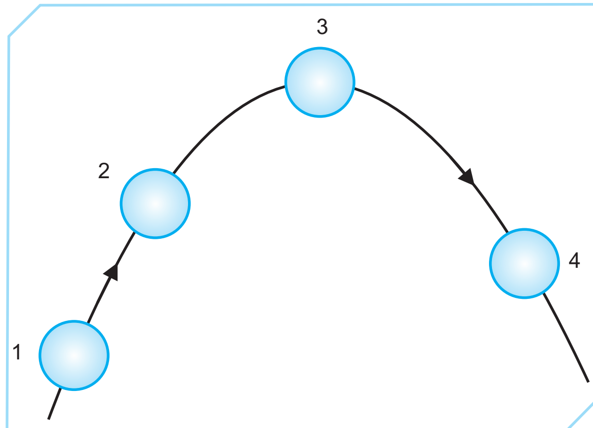
5. The figure below shows the path of a ball that was thrown up into the air. (a) At which point in the path of the ball are all the forces on the ball balanced? (b) Which of the following is not acting on the ball in the diagram?

(i) Static friction

(ii) Air resistance

(iii) Gravity

(iv) Momentum

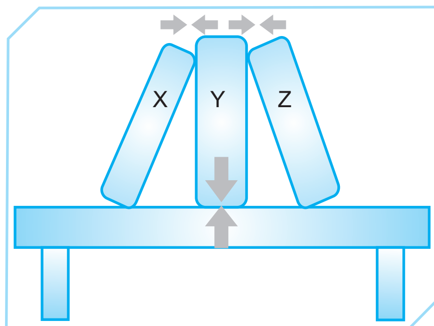


Ans :

(a) At point 3 : At the highest point of its path, the acceleration of the ball will be zero. At this point, all forces acting on the ball will be balanced.

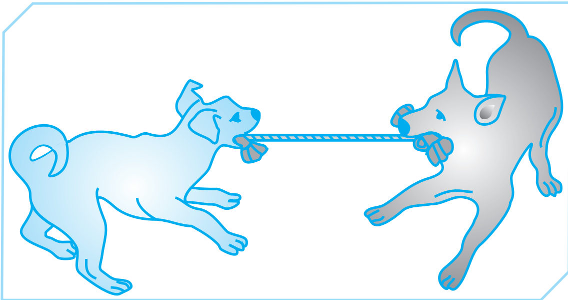
(b) Static friction : Static friction acts on objects that are not in motion. Air resistance, gravity, and momentum act on the ball while it is in motion.

6. The figure below shows three books lying on a table. How many opposing pairs of force vectors are needed to describe the forces acting on book Y?



Ans : Books X and Y are pushing each other with equal force. Books Y and Z are pushing each other with equal forces. Book Y is pushing down on the table and the table is pushing back with equal force. Therefore, three pairs of force vectors are needed.

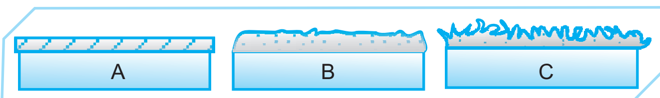
7. In the figure given below, if the black dog starts pulling a rope harder than the white dog, what will happen to the rope? If the rope moves toward the white dog, what do you know about the forces on the rope?



Ans : (a) The rope will move in the direction of the black dog.

(b) The forces on the rope are unbalanced. The white-dog-on-rope force is greater than the black-dog-on-rope force.

8. You are asked to choose a material for a floor covering. The floor must provide the greatest amount of static friction possible. Which of the sample floor coverings shown in figure below would you choose? Why?



Ans : The student should choose floor covering C. The coarser texture of C will produce the most static friction.

STATE TRUE OR FALSE

1. It is necessary to exert a balanced force to make an object move.
2. Momentum is a vector quantity.
3. Momentum is the product of mass and acceleration.
4. The forces are said to be unbalanced if even as two or more forces are acting on an object, the position of the object is not changed.
5. A moving object remains in motion due to inertia even if no external force acts.

ASSERTIONS AND REASONS

Directions : In the following questions, a statement of assertion is followed by a statement of reason. Mark the correct choice as:

(a) If both assertion and reason are true and reason is the correct explanation of assertion.

(b) If both assertion and reason are true but reason is not the correct explanation of assertion.

(c) If assertion is true but reason is false.

(d) If both assertion and reason are false.

1. **Assertion :** A boy kicks a brick which is placed in the ground, but the brick remains in the same state.

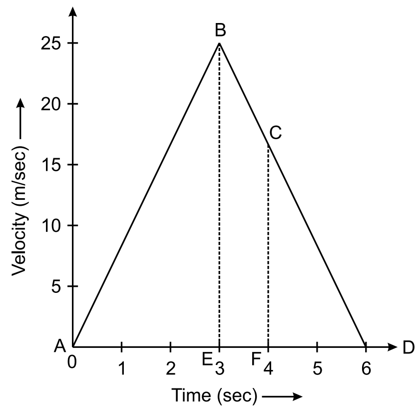
   Reason : The pushing force should be lesser than frictional force to move an object which is placed on the ground.

2. **Assertion :** The impact of the ball on the player is less when the player catches the ball without pulling his/her hands back.

   Reason : The rate of change of momentum is not proportional to the applied force.

PARAGRAPH AND TABLE BASED QUESTION

1. Study the given velocity-time graph and calculate the following:



Mohan bought a new car and wanted to test it on highways. He thought he will find out the acceleration of his car at different velocities in the first 6 seconds. He called his friend Shyam and told him to sit alongside him and note down the different speeds. Shyam prepared the following (graph 1) graph. Mohan's son, who studied in 9th class, wanted to do an experiment with the car. He had recently learned a peculiar thing about circular motion and coerced his father to take the car to a circular track and drive at constant speed.

(a) Find out the car's acceleration from A to B.

(b) Find out the car's acceleration from B to C.

(c) What peculiar thing had Mohan's son learned about circular motion in his class that he wanted to test in the track?

2. The following is the distance-time table of an object in motion:

Time in seconds	Distance in meters
0	0
1	1
2	8
3	27
4	64
5	125
6	216
7	343

(a) What conclusion can you draw about the acceleration ? Is it constant, increasing, decreasing, or zero ?

(b) What do you infer about the forces acting on the object ?

ANSWERS

VIVA VOCE QUESTIONS

1. Force.
2. 1 N.
3. Principle of conservation of momentum.
4. Newton.
5. Acceleration remains the same.
6. Vector quantity.

FILL IN THE BLANKS

1. Balanced forces
2. Travel horizontally
3. External
4. Friction
5. Newton's second law of motion

COMPLETE THE STATEMENTS FROM THE WORDS GIVEN BELOW

1. Inertia
2. Force
3. Unbalanced
4. Opposite
5. Acceleration
6. Gravity
7. Different
8. Acceleration
9. Acceleration
10. Inertia
11. Contact
12. Balanced

STATE TRUE OR FALSE

1. False 2. True 3. False 4. False 5. True

ASSERTIONS AND REASONS

1. (c) When a brick placed in the ground is kicked and it does not move, it means the frictional force acting on the object is greater than the pushing force acting on the object. But to move an object the pushing force should be greater than the frictional force. Hence, if the brick has to move then the pushing force should be greater. Thus, assertion is true but reason is false.

2. (d) When the player catches the ball without pulling his/her hands back then the impact on the player is more. This is because when the player is pulling the hands back then the rate of momentum of the ball is reduced. According to Newton's second law of motion, the rate of momentum is directly proportional to the applied unbalanced force. When the rate of the momentum is reduced the applied unbalanced force is also reduced. Thus, both assertion and reason are false.

PARAGRAPH AND TABLE BASED QUESTION

1. (a) $a = \frac{\Delta v}{\Delta t} = \frac{25-0}{3-0} = \frac{25}{3} = 8.33 \text{ m/s}^2$

(b) $a = \frac{\Delta v}{\Delta t} = \frac{25-17.5}{4-3} = \frac{7.5}{1} = 7.5 \text{ m/s}^2$

[Here, minus sign indicates retardation; velocity is decreasing]

(c) In a circular motion, the speed of an object remains same but the velocity is non – uniform. Mohan's son wanted to understand what this means.

(d) Mohan and his son felt an outward force away from the center of the track. This is the centrifugal force.

2. A careful observation of the distance - time table shows that $s \propto t^3$

It is known that

For motion with uniform velocity (zero acceleration)

$$s = ut$$

i.e., $s \propto t$

(a) For motion with uniform acceleration

$$s = ut + ½ at^2$$

i.e. $s \propto t^2$

In the present case $s \propto t^2$, we conclude in this case that acceleration must be increasing uniformly with time.

(b) As $F = ma,$

Therefore, F $\propto$ a. Hence, the force must also be increasing uniformly with time. Newton's second law of motion describes the relationship between an object's mass and the amount of force needed to accelerate it. Newton's second law is often stated as F = ma

MOCK TESTS

MOCK TEST 1

Time allowed : 1 hour 15 minutes Maximum Marks : 35

General Instructions :

- All questions are compulsory.
- Questions 1 to 3 are of one mark questions. These are to be answered in one word or in one sentence.
- Questions 4 to 10 are of three marks questions. These are to be answered in about 50 words each.
- Questions 11 to 13 are of five marks questions. These are to be answered in about 70 words each.

1. Identify the action and reaction forces when a bullet is fired from the gun.
2. Name the physical quantity which determines the rate of change of momentum.
3. Which law of motion defines force?
4. Mention any two effects of force.
5. It is difficult to balance when our body accidentally steps on a banana peel. Why?
6. Explain how a rocket works.
7. Why it is dangerous to jump out of a moving bus?
8. Describe inertia with respect to motion.
9. Why can a cart pulled by a horse be moved?
10. State and explain Newton's second law of motion.
11. Two forces, F_1 = 20 N and F_2 = 30 N are acting on an object.
    (a) What is the net force acting on the object?
    (b) What is the direction of the net force acting due to the application of these two forces?
    (c) Name the force.
12. Derive the relationship between force and momentum.
13. Describe an activity to illustrate the property of inertia of rest.

MOCK TEST 2

Time allowed : 1 hour 15 minutes Maximum Marks : 35

General Instructions :

- All questions are compulsory.
- Questions 1 to 3 are of one mark questions. These are to be answered in one word or in one sentence.
- Questions 4 to 10 are of three marks questions. These are to be answered in about 50 words each.
- Questions 11 to 13 are of five marks questions. These are to be answered in about 70 words each.

1. What will happen to the momentum of a body when the velocity is doubled?
2. Name the type of force when their resultant force acting on a body is not zero.
3. Name two factors on which acceleration depends?
4. What will happen if a man steps over a patch of quick sand consisting of very smooth and tiny grains of sand?
5. Which has higher value of momentum? A bullet of mass 10 g moving with a velocity of 400 m s^{-1} or a cricket ball of mass 400 g thrown with the speed of 90 km h^{-1}.
6. Why it is easier to push an empty box than to push a box full of books?
7. Differentiate balanced and unbalanced forces with an example each.
8. Give reasons :
    (a) You are hurt when you kick a stone.
    (b) An athlete always runs some distance before taking a jump.
    (c) It is advised to tie luggage kept on the top of the bus.
9. If two balls X and Y of masses 'm' and '$2m$' are in motion with velocities '2V' and 'V' respectively, then compare :
    (a) Their inertia
    (b) Their momentum
    (c) Force required to stop them in the same time
10. A lorry and a mini bus both moving with a velocity of magnitude 'V' have a head on collision and both of them come to halt after that. If the collision lasts for 1 sec, then
    (a) Which vehicle experiences the greater change in momentum?
    (b) Which vehicle experiences the greater force of impact?
    (c) Which vehicle experiences greater acceleration? Justify.
11. Prove the law of conservation of momentum with explanation, diagram and equation.
12. Mention any four applications of Newton's third law of motion.
13. Derive Newton's second law of motion.