1.3 DESCRIBING MOTION IN A STRAIGHT LINE

In the previous section, you have come across many examples of motion. You have learnt that to describe the motion of an object we must know its **position** at different points of **time**. The **position** of an object is always taken with respect to some **reference point.** The **straight line motion of a particle** is the easiest to describe and we begin this section with it. Straight line motion can be purely **vertical** (as that of a **falling ball**), purely **horizontal** (as that of a **cyclist on a straight road**) or **slanted** (as that of a **wheelchair on a ramp**). Before reading further, you may like to jot down a few examples of straight line motion around you. Use the margin!

There are many ways of describing motion: Through **words**, **pictures**, **graphs** and **mathematical equations.** In this section, we shall be using the first three ways for describing the position, distance, displacement, speed, velocity and acceleration of objects moving along a straight line.

1.3.1 Position, Distance and Displacement

Study Fig. 1.4. It shows a ball rolling straight on a surface in the direction of the brown arrow. What is its position? We can use the following definition to answer this question:

The **POSITION** of an object moving **along a straight line** is uniquely defined by **its coordinate with respect to some point of reference.** This point is often taken to be the **origin** (the point *O* in Fig. 1.4). The position in straight line motion is fully specified by **1 coordinate**. This is why it is also called **ONE-DIMENSIONAL motion.**

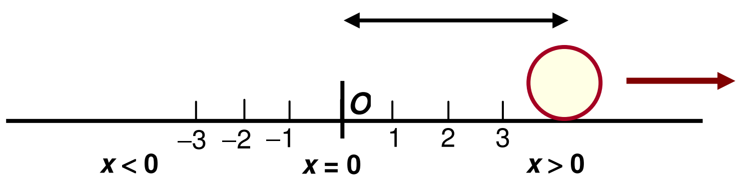


Fig. 1.4: The position of an object in straight line motion is defined by 1 coordinate. The positive direction ($x > 0$) of the axis is the direction of increasing numbers (coordinates). It is to the right in Fig. 1.4. The opposite direction is the negative direction.

For a given problem, the origin can be chosen at any convenient point. Usually, the position of the object at time $t = 0$ is chosen as the origin. Let us now define the words **distance** and **displacement**.

DISTANCE AND DISPLACEMENT

The DISTANCE travelled by an object in a given time interval is THE TOTAL LENGTH OF THE ACTUAL PATH it covers during that time.

***DISPLACEMENT* of an object in a given time interval from t_i to t_f *refers to* its *CHANGE IN THE POSITION* during that time. It includes the direction of motion.**

Displacement = final position of the object (at time t_f) – initial position of the object (at time t_i).

You have learnt that **the position of a moving object is a function of time.** Let us now explain how to describe how its position changes with time.

1.3.2 Average Speed and Average Velocity

Study the position-time graph of a bus moving on a straight road (Fig. 1 .5).

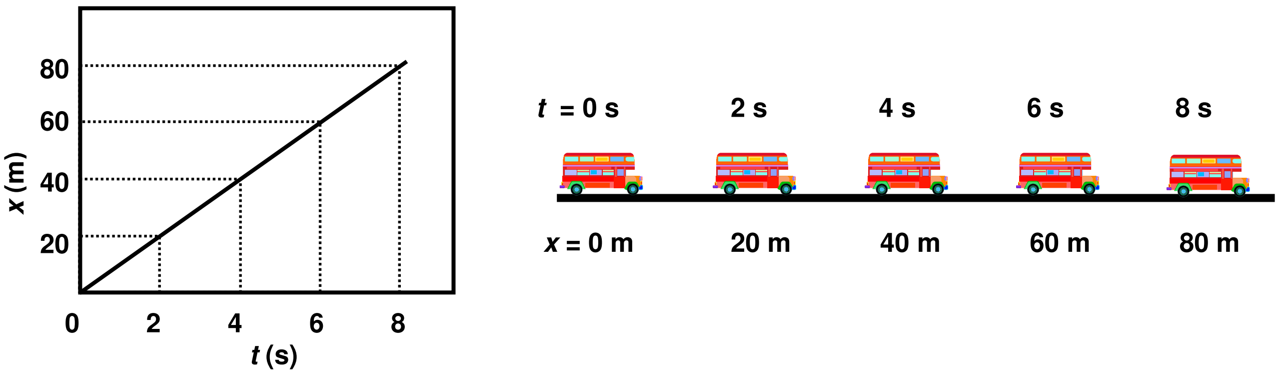


Fig. 1.5: The graph showing the positions of a moving bus at different instants of time with respect to the point x = 0, which is the origin.

Suppose you want to know: **How fast is the bus moving?** You can find the answer to this question by calculating the distance travelled by the bus in 1 second or in 1 hour. Try doing so!

You know the word "*speed*" very well as you use it in your daily life. You know that the speed of an aeroplane is much more than the speed of a train. The speed of a bus is much more than the speed of a cyclist. A fast moving object has *high speed*; a slow moving object has *low speed*. In Fig. 1.5, the bus moves 80 m in 8 s. So it moves 10 m in 1 second or 36 km in 1 hour. This brings us to the concept of **average speed**. You may ask: How do we define **AVERAGE SPEED** in physics?

There is another term you need to know and that is **AVERAGE VELOCITY**. Let us define these terms.

AVERAGE SPEED AND AVERAGE VELOCITY

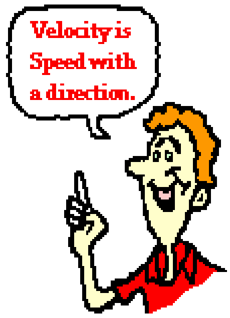
***SPEED* of an object is defined as the *DISTANCE TRAVELLED BY IT IN UNIT TIME*.**

$$\textit{AVERAGE SPEED} = \frac{\textit{TOTAL DISTANCE TRAVELLED}}{\textit{TOTAL TIME TAKEN}}$$

***VELOCITY* of an object is defined as the *CHANGE IN ITS POSITION IN UNIT TIME*. It includes the *DIRECTION* of motion.**

$$\textit{AVERAGE VELOCITY} = \frac{\textit{DISPLACEMENT}}{\textit{TIME INTERVAL}}$$

The SI unit of speed and velocity is metres per second written as ms^{-1}.



ALWAYS WRITE THE <u>DIRECTION</u> OF THE <u>VELOCITY</u> OF AN OBJECT.

You have learnt so far that an object that **changes** its **position with time** has a **non-zero velocity**. When we talk about the change in position of an object, we have to include the **direction** of motion. If the velocity of an object is to be increased, its **change in position from the initial position**, that is, its **displacement** should be increased with time. This object should never change direction and return to where it started from!

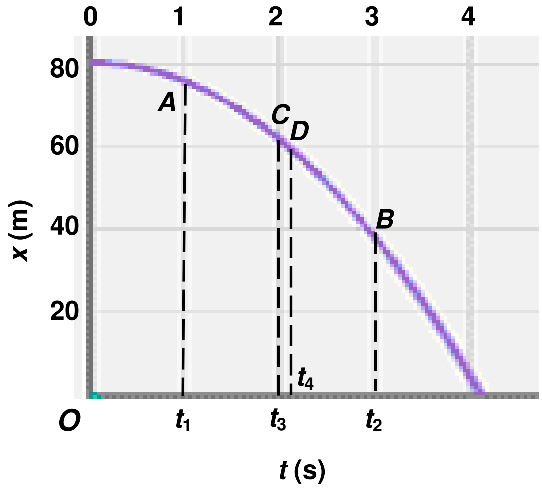
Now think of this situation: Suppose you are travelling in a train. Do you always move at the same speed or with the same velocity? The train stops at different stations. Sometimes it moves fast and at other times it slows down. *So its speed and velocity change at every instant of time*. The average velocity does not tell us how fast an object moves at any given instant. To describe this kind of motion, we use words like **instantaneous velocity** and **instantaneous speed**.

INSTANTANEOUS VELOCITY AND SPEED

INSTANTANEOUS VELOCITY IS VELOCITY AT EACH INSTANT OF TIME.

INSTANTANEOUS SPEED IS SPEED AT EACH INSTANT OF TIME.

The speedometer of a car or a bus tells us its instantaneous speed. You will learn how to find the instantaneous speed and instantaneous velocity.



Time (s)	Position (m)
0	80
1	75
2	60
3	35
4	0

Fig. 1.8: Non-uniform motion

Study Fig. 1.8. Draw straight lines joining the points *A* and *B* on the curve with the origin. What is the change in the position of the ball between the times t_1 (= 1 s) and t_2 (= 3 s)? What is the average speed of the ball? What is its average velocity? Remember that **the direction of the velocity is in the same direction as that of the change in position.**

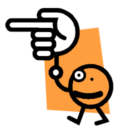
NOTE

The instantaneous speed of an object with non-constant speed at a point can be found from the slope of a line tangent to its path given by the curve $x(t)$.

Now take two points *C* and *D* on the curve closer to each other. Draw the straight lines *OC* and *OD*. Calculate the change in position, the average speed and the average velocity between the times t_3 (= 2 s) and t_4 (= 2.1 s). What is the direction of velocity in this case?

What happens to the change in position, average speed and average velocity as you bring the point *D* closer and closer to *C*? Do you notice that as *D* gets closer to *C*, the time interval $t_4 - t_3$ becomes very small? We get closer to the instant of time t_3. The values of average speed and average velocity also get closer to the values of instantaneous speed and instantaneous velocity.

THE DIRECTION OF INSTANTANEOUS VELOCITY IS ALONG THE TANGENT TO THE CURVE AT THE POINT C IN THE DIRECTION OF THE CHANGE IN POSITION.



How do we describe the change in the speed and velocity of any object with time? For this, we need to introduce the concept of **ACCELERATION**.

Recall that the velocity of an object tells us how its displacement changes with time. In the same way, the **acceleration** of an object tells us how its speed or velocity **CHANGES WITH TIME**. Just as we defined average speed/average velocity and instantaneous speed/instantaneous velocity, we shall define **AVERAGE ACCELERATION AND INSTANTANEOUS ACCELERATION**.

AVERAGE ACCELERATION

The AVERAGE ACCELERATION of an object is defined as the net change in its velocity per unit time:

$$\textit{AVERAGE ACCELERATION} = \frac{\textit{CHANGE IN VELOCITY}}{\textit{TIME INTERVAL}}$$

The SI unit of acceleration is m / s /s and is written as ms $^{-2}$. You must always write the *DIRECTION* of acceleration.

Quite often we wish to know the acceleration of an object at a given instant of time. Then we need to define its ***instantaneous acceleration***. We shall give its precise definition in the next section after you have learnt the mathematics needed. For the moment, you can understand ***INSTANTANEOUS ACCELERATION as acceleration at any given instant of time.***

You may have heard sports commentators saying that a person is accelerating if he or she is moving fast. **But acceleration has nothing to do with going fast**. An object could be moving very fast (at a high **CONSTANT** velocity), and still not be accelerating. **ACCELERATED MOTION MEANS THAT THE OBJECT'S VELOCITY IS CHANGING.** If its velocity does not change with time, then the object is not accelerating. When an object slows down, it is said to be **DECELERATING**.
For example, when a car or bus starts, it has a finite acceleration as its velocity changes from 0 to some value in a given time. But when it moves with a constant speed/velocity, its acceleration is zero.

CONSTANT VELOCITY **MEANS** ***ZERO ACCELERATION*.**

CONSTANT ACCELERATION **MEANS THAT THE** ***CHANGE IN VELOCITY*** **IS** ***CONSTANT*.**