How Does a Leaf Fall?

Have you watched a dry leaf falling from a tree? Unless there is a strong breeze, the leaf tacks from side to side as it comes down. See the paths shown in the Figs. 17 and 18. Do you think it is as easy to measure the length of this path as that of a falling stone? Obviously not. So, how can we know the distance for the estimation of the leaf's speed? Well, if we are mainly interested in the downward motion of the leaf, we ignore the side-to-side swaying. The distance straight down divided by the time taken for the leaf to fall is taken as the average speed of the falling leaf. If you make this assumption and if the swaying motion is very small compared to the downward distance it travels, you will get a value close to the actual speed of the leaf. Can you think of an experiment to verify this assumption?

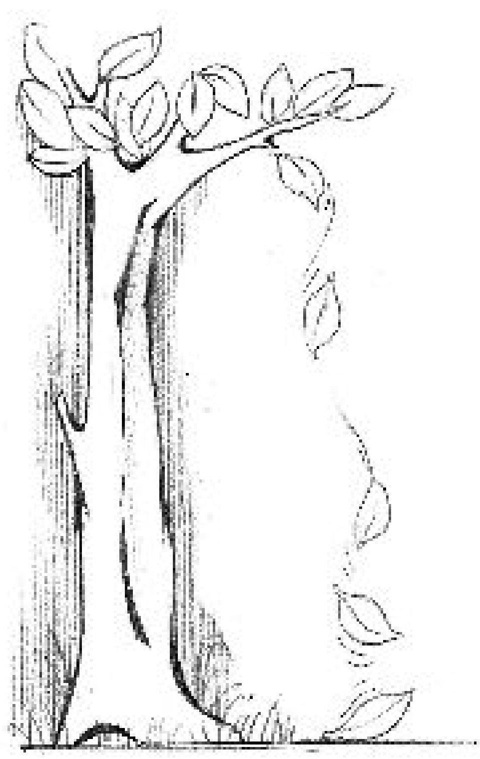


Fig. 17 No wind

Fig. 18 Windy day

Similarly, when analysing any real motion we often make the assumption that it is moving in a straight line and ignore small movements in other directions. The examples discussed further on make this assumption. While taking measurements in the activities, you can discuss the amounts of error caused by this assumption.

Uniform and Non-Uniform Motion

It is possible that while doing all the speed measurement activities at least a few of the students would have noticed that the speed does not remain the same from the beginning to the end of the activity. If no one has made such an observation, start a discussion about it with the following example.

Imagine, that we are tracking a school bus from the bus stop near your home to your school. The bus arrives at the stop and you climb in. Then, the driver puts it in gear and the bus starts moving. The bus reaches the school after some time where it stops so you can get down. If we go by the definition given earlier, we measure the distance from your home to school, and divide this distance by the time taken to reach your school to find out the average speed of the bus. But, you might have also observed that when the bus started, it moved at a slower speed, and it picked up speed only after some time. The reverse happens before the bus comes to a stop. Does this mean that during the motion from one bus stop to another, the bus has moved at different speeds at different times? In that case, what do we mean by the speed of the bus and how do we measure it?

Average and Instantaneous Speed

Suppose a bus moves straight from point A to point B in 30 seconds (Fig. 19). The distance from A to B is 300 meters. Then the average speed would be = 300 m ÷ 30 s = 300 ÷30 m/s =10 m/s.

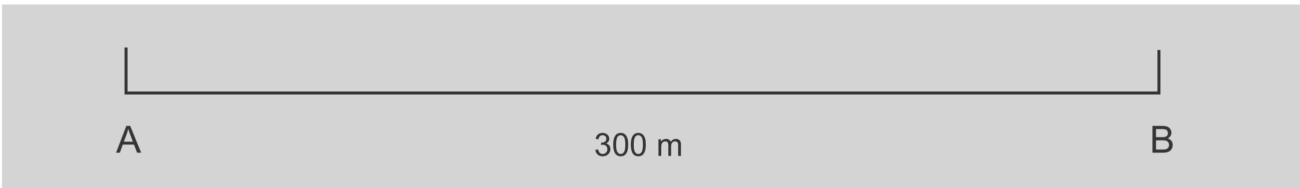


Fig. 19

Suppose we also make measurements at points between A and B (Fig. 20). We make the measurement from A to C, then C to D and so on. We then calculate the speed for each segment.

Fig. 20

We get the following values:

Table 3

Points	Distance	Time taken	Segment speed
A-C	20 m	2 s	10 m/s
C-D	60 m	6 s	10 m/s
D-E	120 m	12 s	10 m/s
E-B	100 m	10 s	10 m/s

We find that the average speed within each segment is the same as the average speed between A and B, which is 10 m/s. This is therefore an example of **Uniform Motion.** That is, the speed remains constant throughout the motion.

Alternatively, let us suppose that the following values are obtained for measurements between the same sets of points:

Table 4

Points	Distance	Time taken	Segment speed
A-C	20 m	2 s	10 m/s
C-D	60 m	10 s	6 m/s
D-E	120 m	8 s	15 m/s
E-B	100 m	10 s	10 m/s

The last column in this table too shows the average speed for each segment. But here, the distance of 60 m between the points C and D has been covered in 10 seconds (as compared to 6 s as given in Table 3). Therefore, the average speed between C and D here is 60 ÷ 10 m/s = 6 m/s. The total time taken to cover the entire 300 m between the points A and B is still 30 s (add the values in the third column of Table 4). In the very beginning, we had calculated the average speed over the entire distance between A and B (which includes the segment CD) to be 10 m/s. How can we then explain the two different speeds for this segment?

This problem arises because we had initially considered only the total time taken to cover the total distance in calculating the average speed. It only means that if the object had moved at a constant speed of 10 m/s from A to B, it would have covered the distance in 30 s. It does not tell us anything about the time taken to cover the different parts of the total distance. As we can see above, it might be that the speed was less than the average value in some parts and more than the average value in some other parts. This kind of motion where the speed keeps changing is called **Non-Uniform Motion**.

You may well ask how we can know whether the speed of a moving object will remain uniform if we further divide the segments into even smaller parts. The answer is that, of course, we cannot, unless we actually make the measurements for the smaller segments. So, the only way we can know whether a motion is uniform, is by measuring the speed of the object in motion in smaller segments along its path of motion.

What is the smallest segment that can be measured? Think of the instruments you can use to measure distance and time (rulers, measuring tapes, watches, clocks, mobile phones) and the smallest values you can read on each instrument (this is also called the 'least count' of the instrument). This is how small a segment can be. For example, if you are using a watch with a seconds hand you can measure the distances traveled every second (the least count of your watch). You can then calculate the speed during each second and use these measurements to see if motion is uniform over a longer period of time (say 15 minutes). In such a case, we call the speed measured over each second the **Instantaneous Speed**.

If we had a way of measuring a smaller time interval, say, one tenth of a second, then we would call the speed obtained by the measurement over a tenth of a second as the instantaneous speed. Later on in the module, we will discuss how to depict motion using graphs. Then we will see how distance-time graphs can be used to work out the instantaneous speed. Whichever method we use, the term 'instantaneous speed' denotes '*the average speed over the least count of the time-measurement device*'.

Calculating Averages

Children (and not only children), often make mistakes in calculating the average speed of non-uniform motion when speeds for all the segments of an entire path of motion are given. During teacher training sessions we realised that the difference between calculating the average of rates and calculating the average of simple numbers (that are not rates) is not clearly understood by many. The discussion in this section addresses this issue. One example is about exam marks and percentage marks (percentage is a rate, the amount of something per hundred) which is familiar to all students. The other example is about a purchase in a vegetable market. You can substitute this example with a different one more suited to the students' social environment, if required.

Calculate the average of the following seven numbers:

67, 55, 87, 64, 73, 42, 38.

To do this, you have to add them all and divide the sum by seven, thus getting 60.9.

But, suppose these numbers are actually Nida's marks in various subjects and her report card is as follows (Table 5):

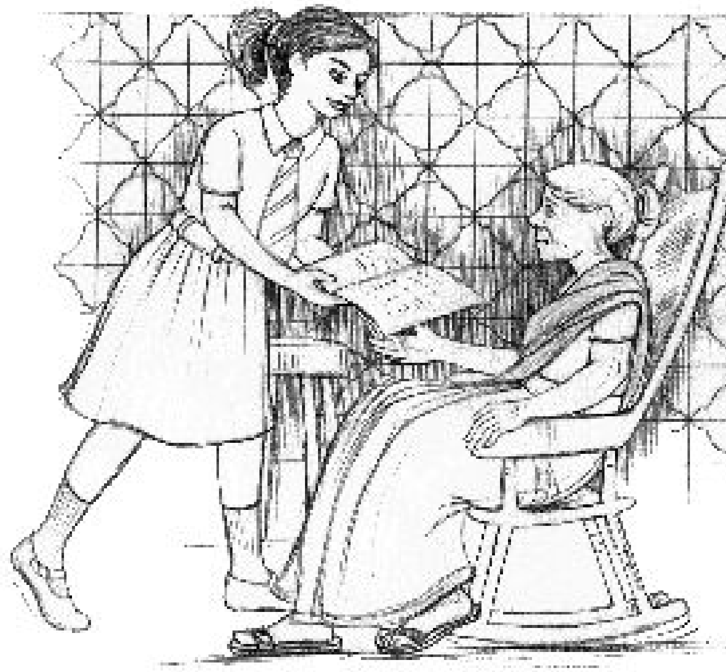


Fig. 21 *Dadima*, see my report card!

Table 5

Subject	Maximum marks	Marks obtained	Percentage
Hindi	100	67	67
English	100	55	55
Mathematics	100	87	87
Social science	100	64	64
Science	100	73	73
Craft	50	42	84
Music	50	38	76

The percentage is the number of marks which would have been obtained had the maximum marks been 100. So, it is the ratio of marks given to the student, to hundred marks (the rate of marks per hundred). The percentage is calculated by dividing the marks obtained by the maximum marks and then multiplying the ratio by 100.

Now, if we have to find the average percentage (or what is sometimes wrongly called the 'total percentage'), what do we do? Do we take an arithmetic mean of all subject percentages? If we do that for the above table we get 72.29. You should check all these calculations yourself. If this is correct, then multiplying this number by the maximum marks and dividing by 100, should give us the total marks obtained. Let us see if that happens. The total of maximum marks is 600 so if the average percentage is 72.29, then the total number of marks obtained should be $72.29 \times 600 \div 100 = 433.74$. But if we add up the total marks obtained then we get only 426. Where have we gone wrong? If you go over the calculations, you will see that we treated ratios or rates as simple numbers. For any set of ratios, the averaging has to be done by adding all the numerators and denominators separately, and then taking the ratio of the two sums. You can try this with different sets of numbers.

Your father went to the *sabzi mandi* to buy potatoes. At one place he bought 6 kg of potatoes at ₹ 6 / kg, at another he saw a different variety of potatoes and bought 2 kg at ₹ 10/kg. What was the average price he paid for the potatoes?

> If the students cannot do the above problem, solve it for them.

Fig. 22 Buying potatoes in the bazaar

Your father bought 6 kg of potatoes at ₹ 6/kg and 2 kg of potatoes at ₹ 10/kg. Now, you want to know how much, on average, he paid for the potatoes—the average rate. If you take the arithmetic mean of the two prices then the average rate, the price per kg of potatoes will be ₹ 8/kg. Your father bought 8 kg of potatoes in all. If the average price was ₹ 8/kg he should have paid a total of ₹ 64 (8 X 8). But, he actually paid (6 X 6 + 2 X 10) = ₹ 56. So, where did you go wrong in your calculations?

Let us do the calculation in another way. This time, we first total up how much we paid, ₹ 36 in the first place and ₹ 20 in the second, totalling ₹ 56. Now, divide this by the total kilograms of the potatoes bought, that is 6 kg + 2 kg = 8 kg. So we see that ₹ 56 have been paid for 8 kg of potatoes. Dividing 56 by 8 gives us an average price of ₹ 7/kg.

Coming to the estimation of average speed we should remember that speed is also a rate. Thus, the average speed cannot be arrived at by simply taking the arithmetic mean, the average of various ‘speeds’. Rather, you will have to first calculate the total time taken to cover a distance and the total distance covered, and then take the ratio of the two.

Example 10. Suppose a car covers 180 km at a uniform speed of 30 km/h, and the next 220 km at a uniform speed of 55 km/h. The average speed will then be calculated in the following way:

Total distance traveled = 180 km + 220 km = 400 km

Total time taken = (180 km ÷ 30 km/h + 220 km ÷ 55 km/h)

= (180 ÷ 30 + 220 ÷ 55) h

= (6 + 4) h = 10 h

Then, the average speed will be = (400 ÷ 10) km/h = 40 km/h

Speedometer

Vehicle drivers do not carry measuring tapes and stopwatches to measure speed. They just need to look at the watch-like dial of an instrument fitted into the dashboard (Fig. 24). This is called the speedometer. It directly shows the speed in km/h. So, how is speed measured by the speedometer? The wheels of the vehicle have sensors that count the number of rotations completed by the wheels per second. This number, together with the diameter of the wheel is used to estimate the distance covered by the vehicle in a second. The speed is shown in km/h.

Try to look at the speedometers of different vehicles like motorbikes, buses, cars, etc. Do you find any differences between them? Do you think a car's speedometer can be used in an aeroplane?

Fig. 24
A typical speedometer

Example 11. Radhika walks to Shabana's house and from there both of them cycle together to the market to buy a book. After the purchase, Radhika bids goodbye to Shabana and walks back home directly from the shop. Write down some values (with units) for the distances and time intervals involved as shown below in Table 6.

Finally, calculate Radhika's average speed for her entire trip.

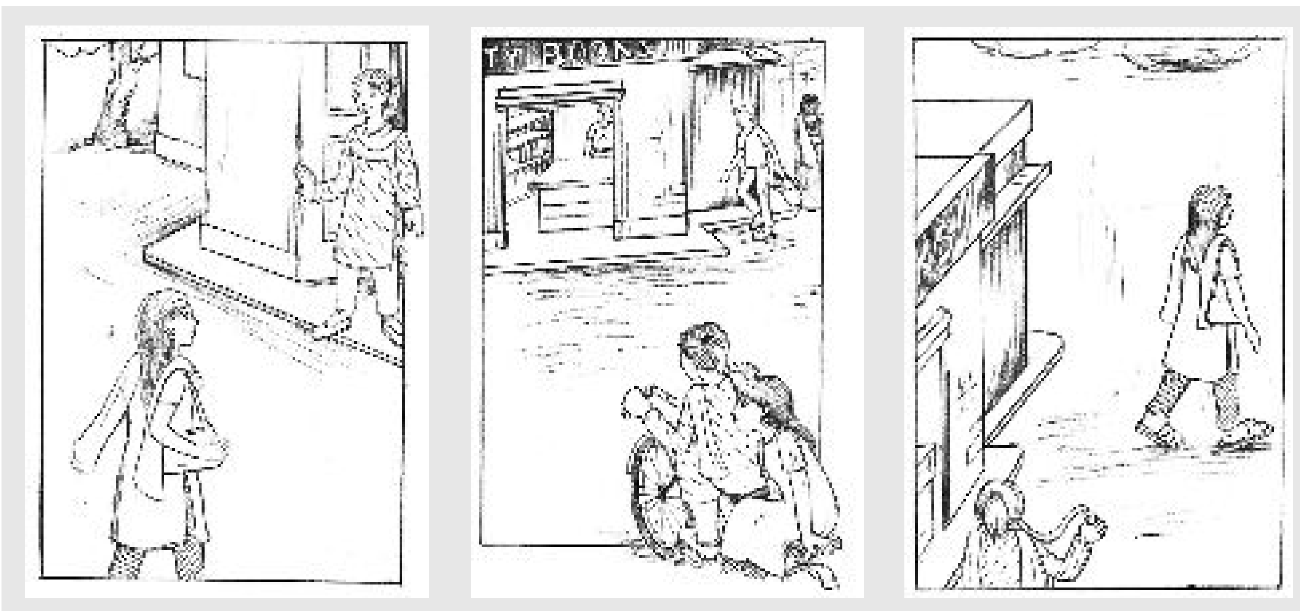


Fig. 23 A trip to the market

Table 6

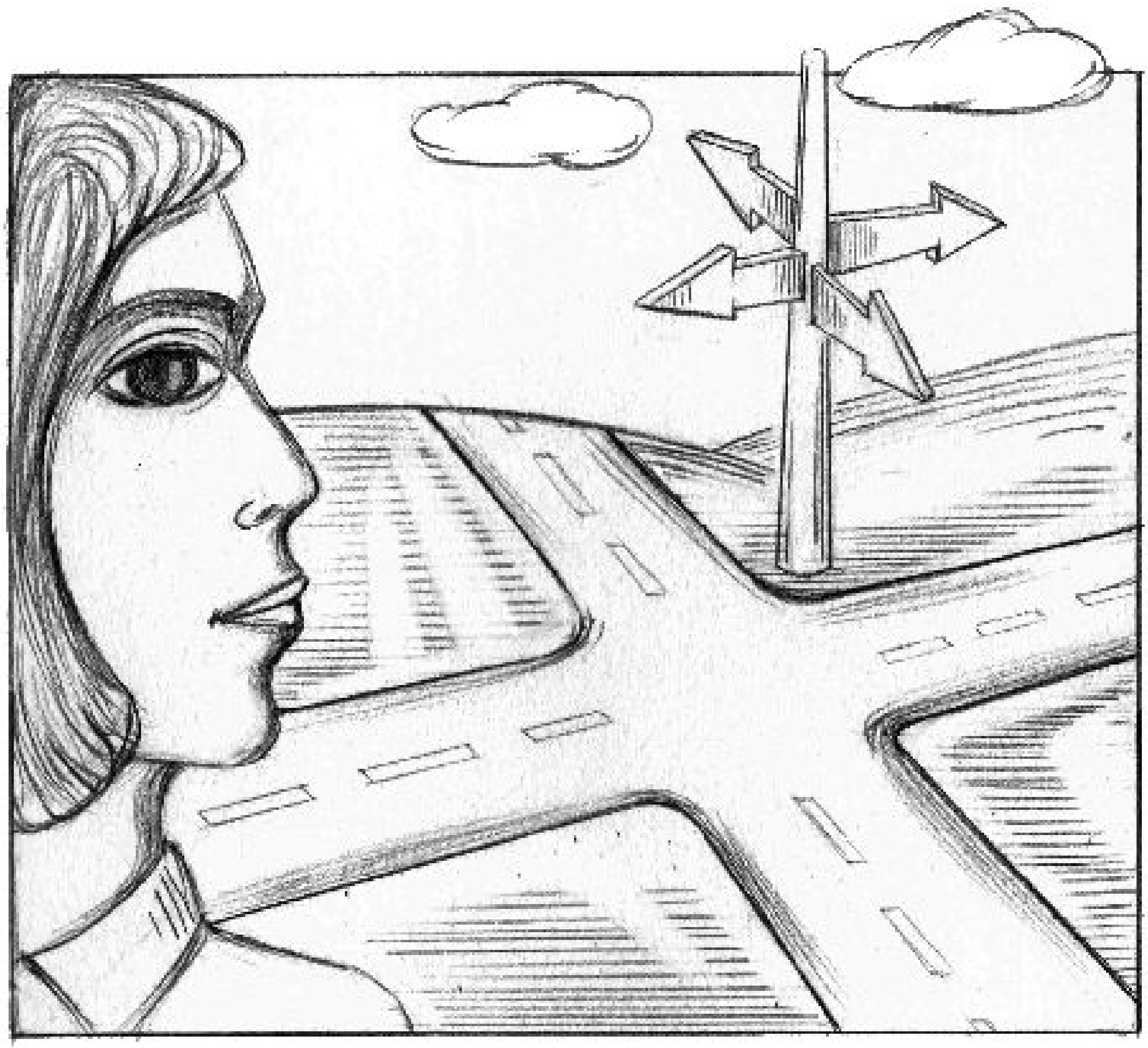
S.No.	Journey	Distance travelled	Time taken	Average Speed
1	Radhika's home to Shabana's house			
2	Shabana's house to the book shop			
3	Book shop to Radhika's home			

A popular game in villages is to roll a cycle tyre with a stick (Fig. 25). If the tyre has a diameter of 40 cm and makes 10 revolutions per second, what will be its forward speed?

Fig. 25 Sonu on a roll

Hint: In one revolution, the tyre will cover the distance equal to the perimeter of the tyre. The perimeter of a circle is roughly 3.14 times its diameter.

Crossroads



At this point, there are many ways forward. Depending on the students' background you can go to the section on graphical representation of motion on the next page, or to the discussion of acceleration in one-dimensional motion later on in the module. You can choose to start with any of the two, but we recommend that you discuss both sections. The vector treatment of motion (velocity, etc.) will be discussed in the second module of this series.

Graphical Representation

A Picture is Worth a Thousand Words

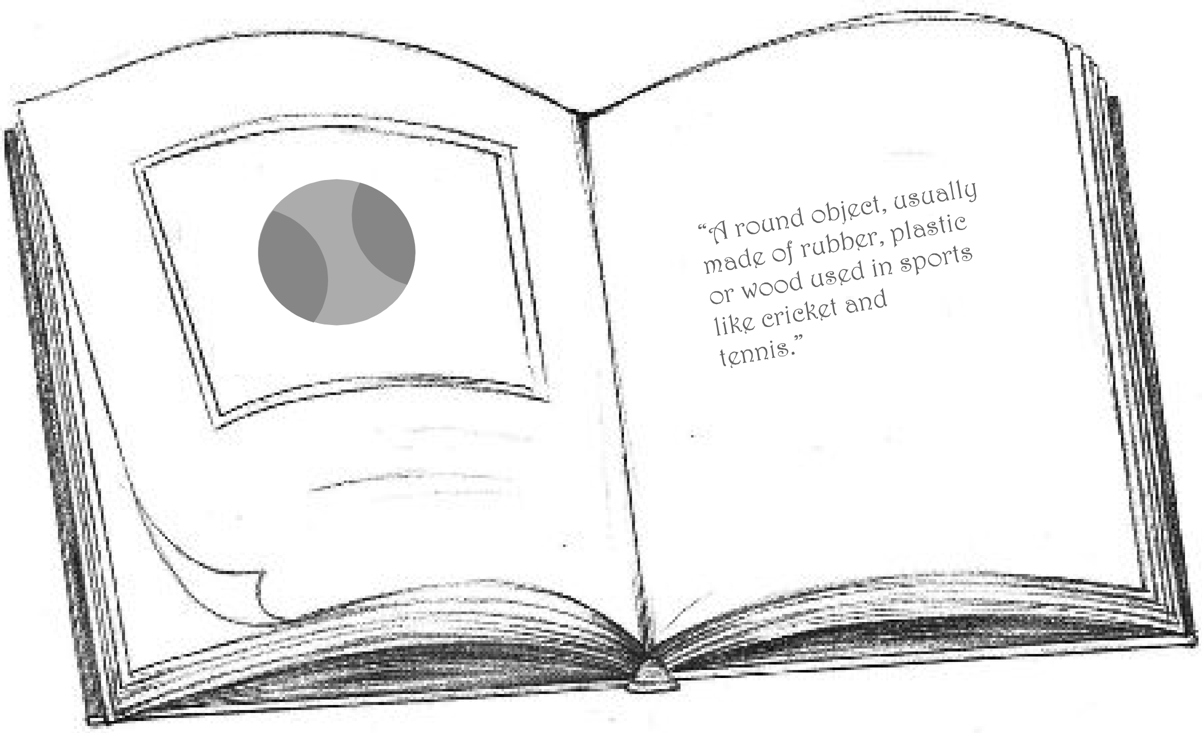


Fig. 26 'B' for ball

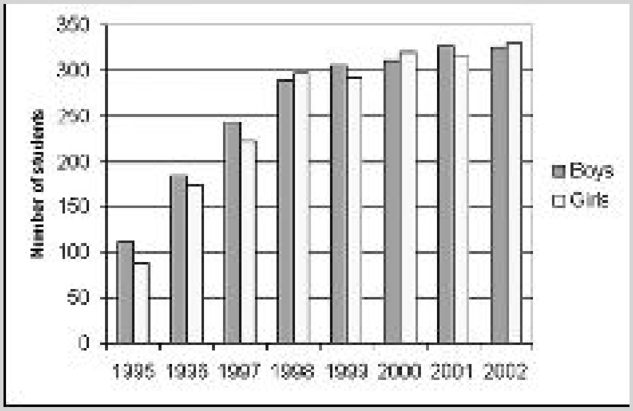
If you had to describe a ball to someone who did not know what it was, which of the above descriptions would you prefer (Fig. 26), the picture on the left or the paragraph on the right?

Pictures are often used to convey information. Graphs are pictures that show numerical data. Have you watched cricket matches on TV? Often, the run rate is shown as a graph. Why do you think it is useful to have data displayed in this form? Do you think graphs can be useful in describing motion as well?

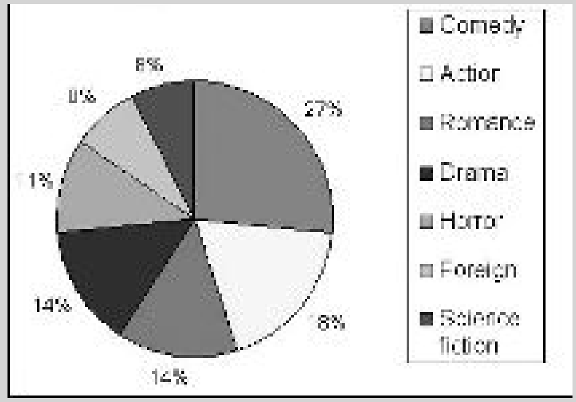
If you are reading about graphs for the first time, we recommend that you first go through Appendix 2 on graphs and then come back to this section.

Different Graphs - A Sample

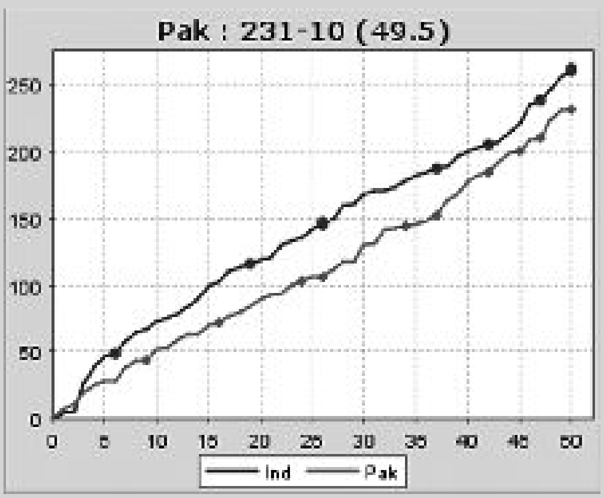
Internet use at a secondary school



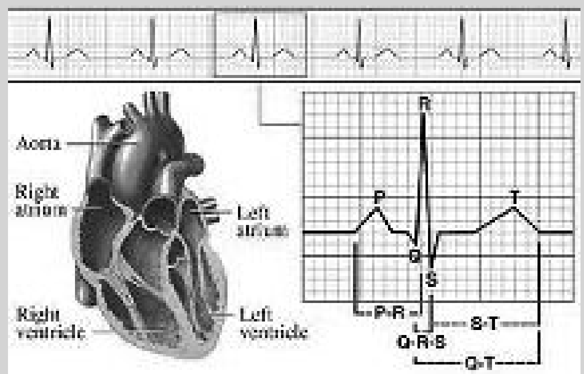
Favourite movie genres in a film class



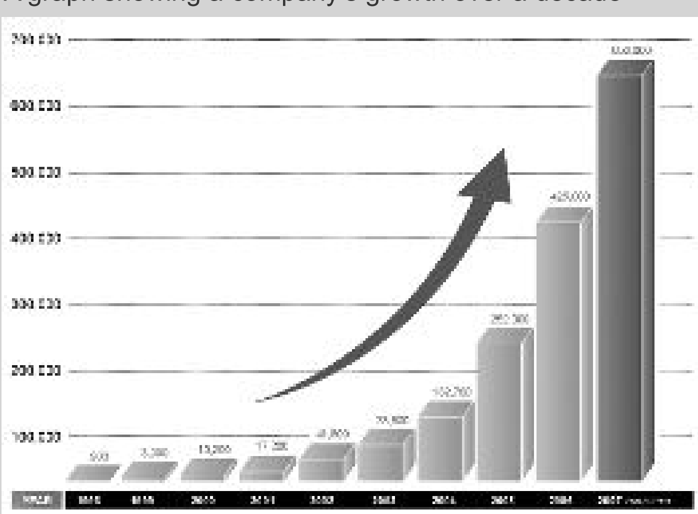
India-Pakistan cricket match score



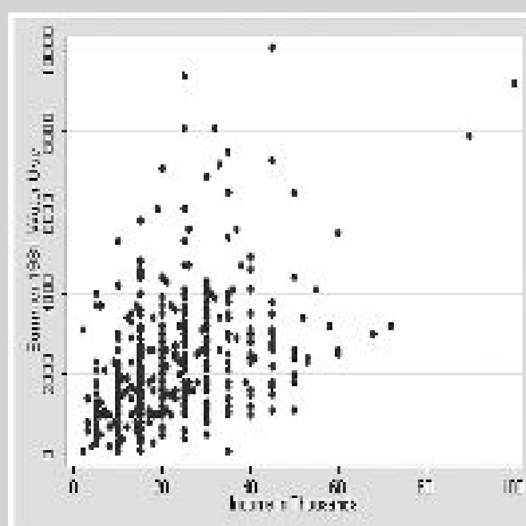
A typical electro-cardiogram (ECG)
showing electrical pulses generated by heart muscles



A graph showing a company's growth over a decade



Water usage of different income groups



Example 12. Once, my friend Ritu and I visited an old palace that had a large tiled hall. I made Ritu walk slowly in a straight line across the hall. Using a stopwatch, I kept noting down the time at which she crossed each tile. I got the data in Table 7.

What does this table tell me? If I subtract each reading for time by its preceding value, I will know how much time Ritu took to cross that particular tile (Table 8).

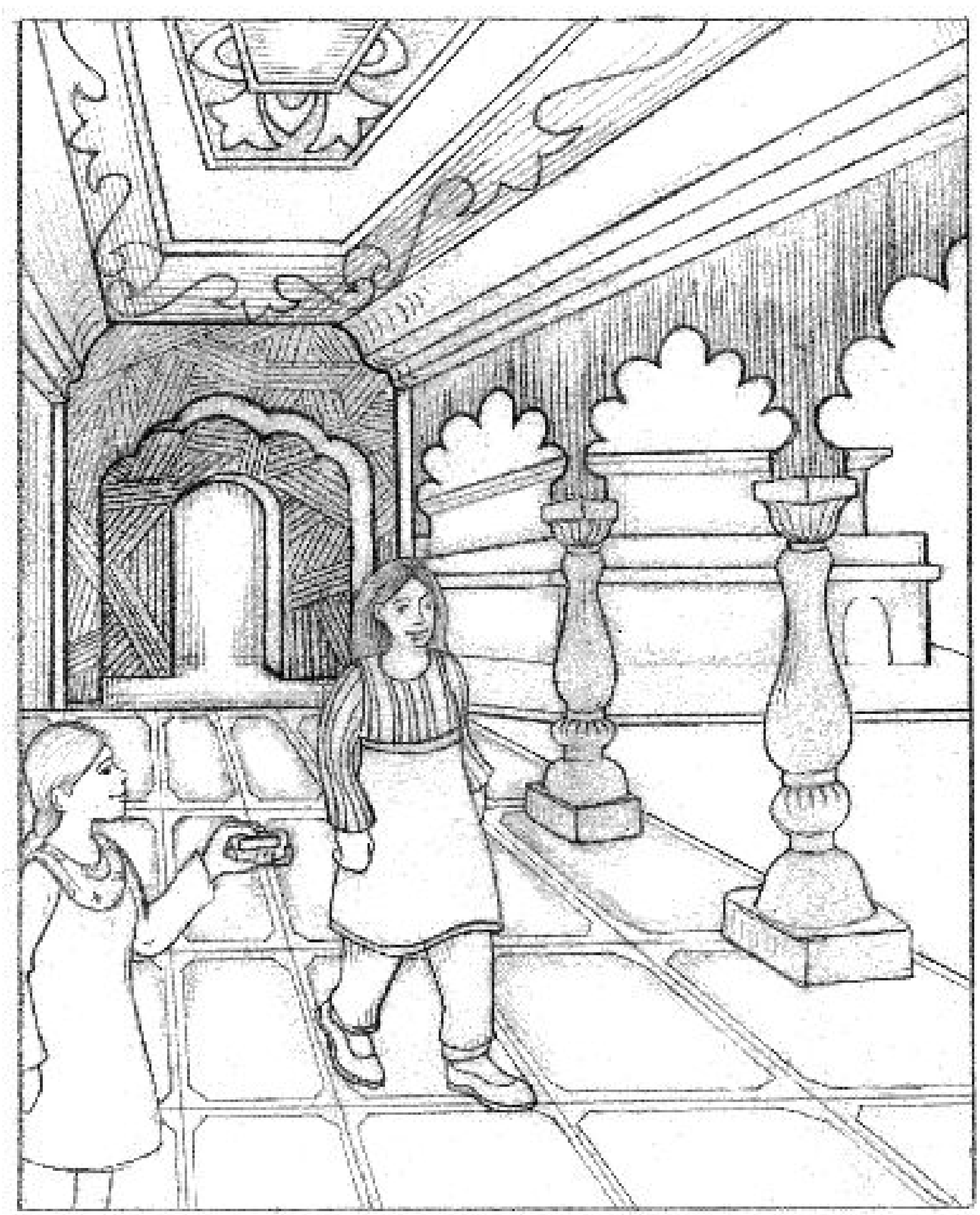


Fig. 28 Ritu and Rehana do an experiment in a palace hall

Table 7

Tile	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Distance (in m)	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Time (in s)	1.25	2.4	3.4	4.2	5.0	5.7	6.5	7.3	8.0	8.8	9.6	10.4	11.3	12.6

Calculate the average speed for crossing each tile by dividing the length of the tile by the time taken to cross it. What do the results of your calculations tell you about Ritu's motion?

Table 8

Tile	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Distance (in m)	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Time (in s)	1.25	2.4	3.4	4.2	5.0	5.7	6.5	7.3	8.0	8.8	9.6	10.4	11.3	12.6
Time for each	1.25	1.15	1.00	0.8	0.8	0.7	0.8	0.8	0.7	0.8	0.8	0.8	0.9	1.3

Now, I can also plot the data as a graph by putting the tile number on the x-axis and time on the y-axis (Fig.29).

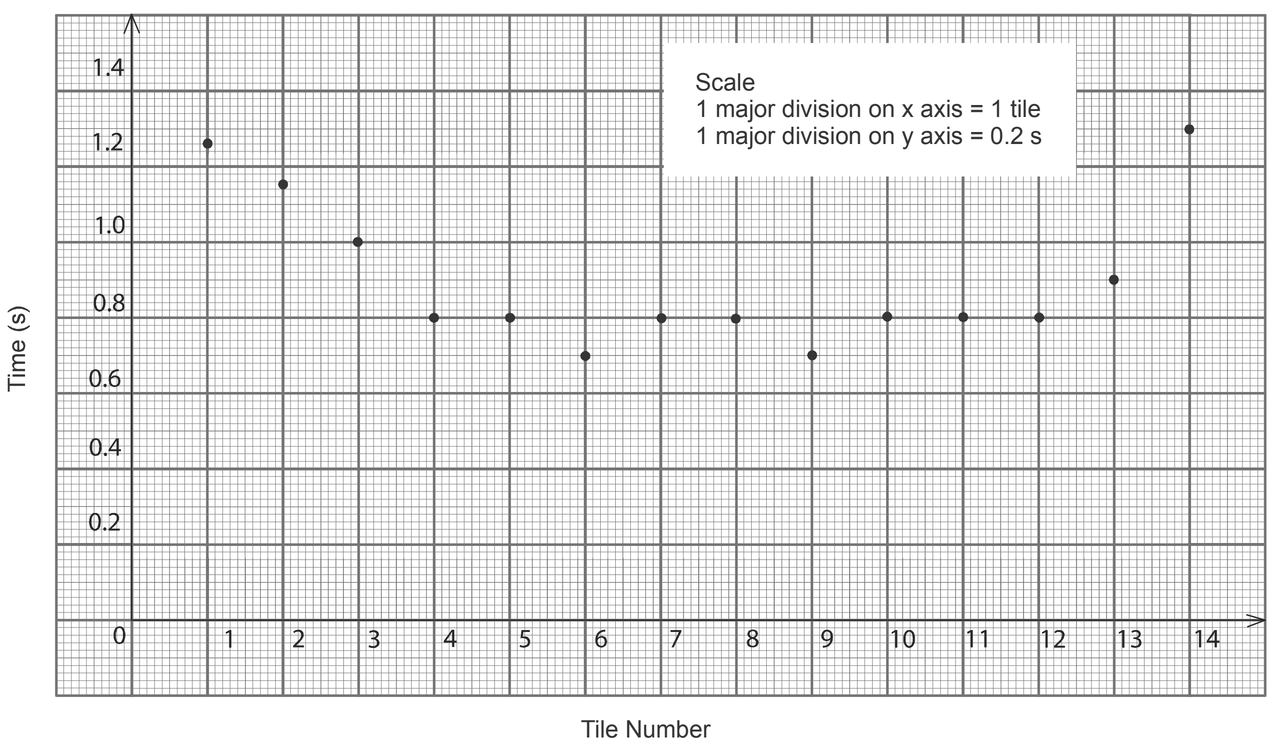


Fig. 29 Time taken to cross each tile

Since I know the length of each tile, I can also plot a time-distance graph (Fig. 30).

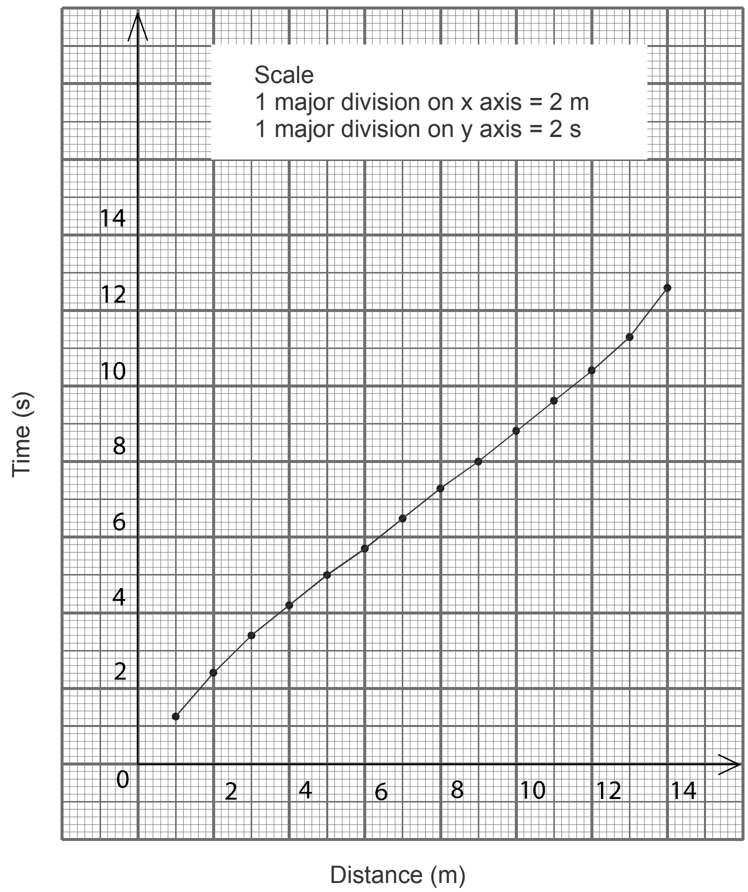


Fig. 30 Total time taken by Ritu to cross the tiles in the hall

A look at the graph straight away tells me that the points do not lie on a single straight line. That means the time taken to cross each tile is different. Had that not been the case (if the time taken to cross each tile was the same for all tiles in the hall), the plotted points would be on a straight line (why?).

A widespread confusion about the interpretation of graphs exists because students think the line of the graph is a drawing of the physical situation the graph describes. For example, looking at the time-distance graph here, some students may imagine that it shows the path actually taken by Ritu. Draw a grid of the tiled floor on paper and ask them to draw what they think is Ritu's path (Fig. 31). Then you can talk about the difference between a graph and a drawing. The actual path represents the positions in space whereas the graph points are measurements of distances between those positions (Fig. 32).

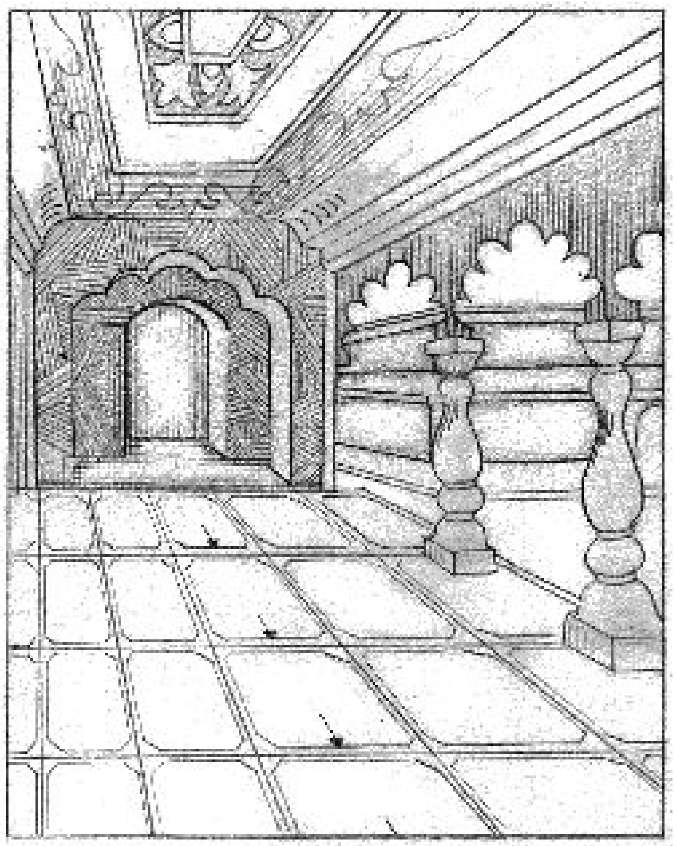


Fig. 31 Ritu's path while walking down the hall

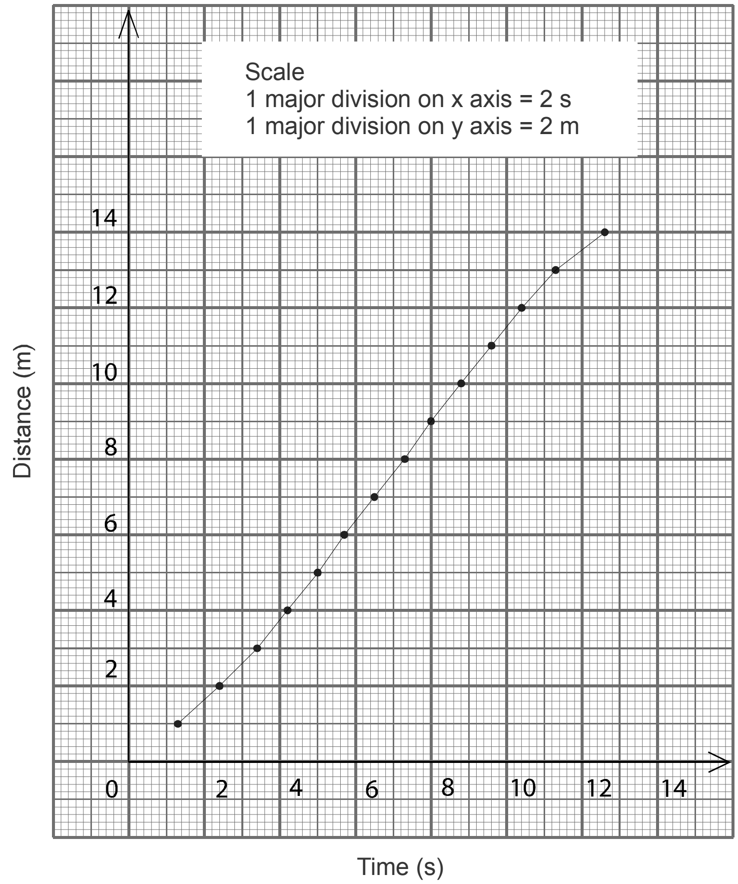


Fig. 32 Distance-time graph of Ritu's motion

Remember, graphs are pictures of numbers, not objects!

Example 13. The adjacent Fig. 33 shows several graphs. Time is plotted on the horizontal axis and distance on the vertical axis. The vertical axis shows the position with respect to the starting point. Which of the lines correspond to uniform motion?

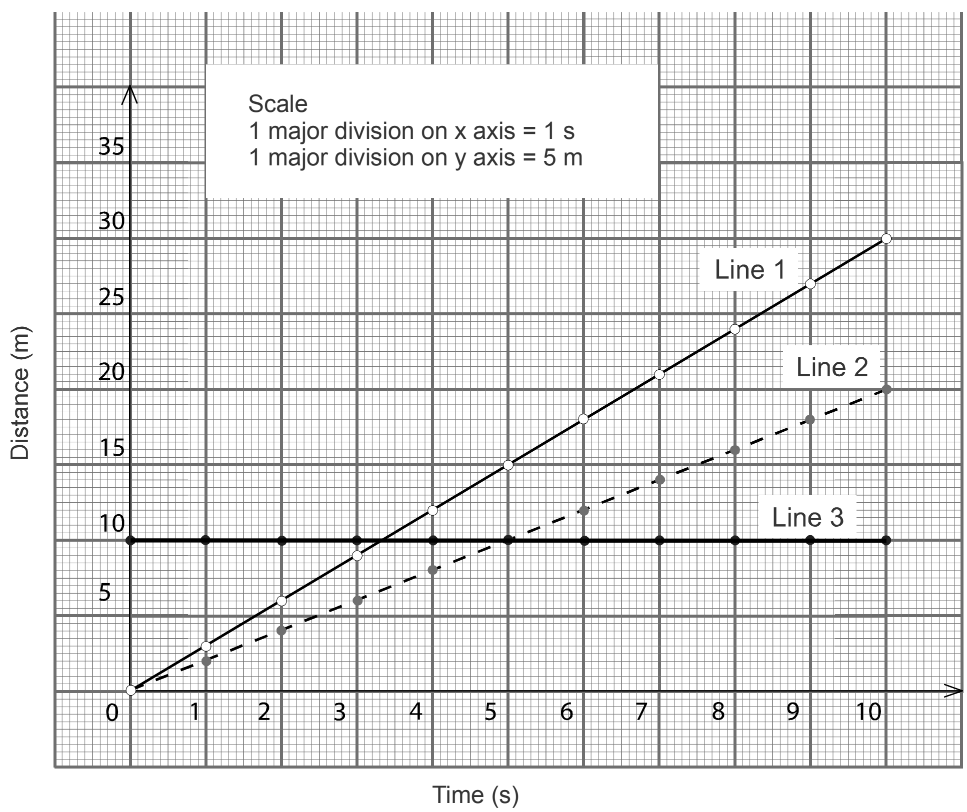


Fig. 33 Distance-time graph showing the position vs. time for three different objects

Let us see what more a distance-time graph can tell us. To begin with, let us look at the graph (Fig. 34) which shows the positions of three cars at different times.

What can we infer from looking at this graph? First, the position of car 3 is constant with time. This means that it remains at one place and is not moving (with respect to the point of reference, of course). So, a horizontal line on a distance-time graph indicates an object at rest.

Next, look at the graph for car 1. The graph for this is also a straight line but it is not horizontal; it is slanted with respect to the axes. Let us read the data points from the graph. Are you able to read the distances corresponding to 30 minutes, 60 minutes and 90 minutes? These distances are 25 km, 50 km and 75 km respectively. If you do a bit of subtraction, you will see that the car moves equal distances in equal time intervals, that is, 25 km every 30 minutes. If we calculate the average speed between any two points, it will come out to be 50 km/h (you have to convert the units for time from min to h). That means car 1 is moving at a uniform speed.

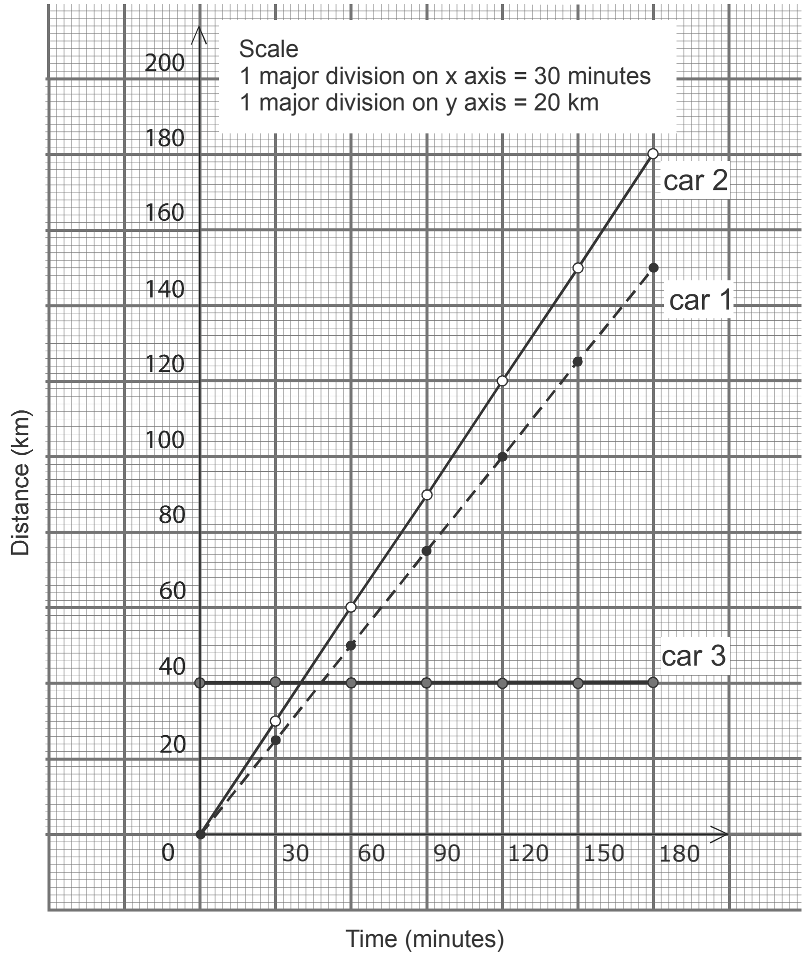


Fig. 34 Distance-time graph showing the position vs. time for three cars

If we do a similar exercise for car 2 we see that it also has a uniform motion but the speed is different from car 1, at 60 km/h. In fact, any straight line on a graph has the property that the ratio of the increment in ‘y’ values and the increment in ‘x’ values remains constant. **For a distance-time graph this means the speed is uniform.**

You also see that the line for car 2 is slanted more steeply than that for car 1. It means that the distance covered by car 2 is changing faster. In other words, it has a higher speed. So, **the more steeply slanted a line, higher the speed.** The slant of a straight line is mathematically defined as its **slope** and is calculated as shown in the following box.

The slope of any straight line is the ratio of the change in values on the y-axis to the corresponding change in values on the x-axis. That is, if a value on the x-axis is changed by 10 units and if the

$$\text{Slope of a straight line in a graph} = \frac{\text{Change in y-value}}{\text{Change in x-value}} = \frac{\triangle y}{\triangle x}$$

Here the students should come to the conclusion that if distance-time graph is a straight line, the motion must be uniform. You can plot different sets of imaginary data to confirm this.

corresponding value on the y-axis changes by 20 units, then the slope will be 20÷10 = 2. Similarly, in the case of a distance-time graph, the slope of the graph line is the ratio of the change on the distance-axis to the corresponding change in values on the time-axis. This ratio of distance and time is nothing but the average speed. Therefore, we can conclude that **the slope of a distance-time graph is the average speed** of the object whose motion we are studying.

When the distance-time graph is a horizontal line, this line is parallel to the time axis and it makes an angle of zero degrees with it. So, the slope of this horizontal line is zero and therefore, the average speed of the object that the line describes is also zero.

You may ask, when is the distance-time graph not a straight line? Going by the above argument, this will happen if for equal changes in time the distance travelled is different. In terms of speed, this means that at different times the speed is different—the speed is non-uniform. As you may have experienced, most motions that we observe are non-uniform, which is why we can easily get data to plot some of them. The first example we are going to discuss is Rashid's train journey.

Rashid traveled by train from Hoshangabad to Powarkheda. He estimated the distance the train traveled in two-minute intervals by counting the telephone poles along the railway tracks. He noted his estimates in the form of a graph (Fig. 35). This graph describes the motion of the train from the time it left Hoshangabad station until it stopped at Powarkheda station. Read from the graph the distance covered by the train in each two-minute interval and enter the numbers in a table like the one given below.

Table 9

Time taken (in minutes)	**Distance covered (in meters)**
0-2 (First 2 minutes)	100
2-4 (Next 2 minutes)	400
4-6 (.........,,.........)	
..... (.........,,.........)	
..... (.........,,.........)	
20-22 (.........,,.........)	

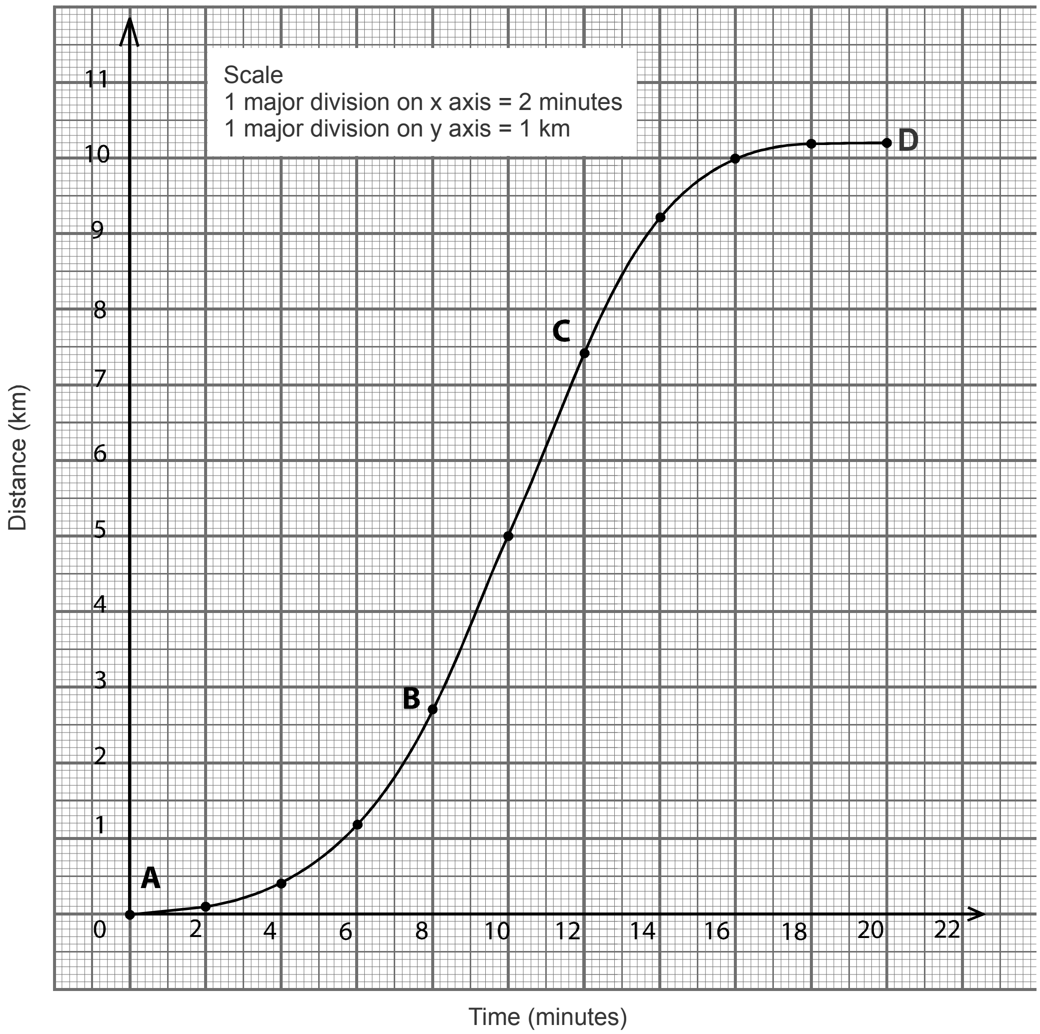


Fig. 35 Distance covered by a train traveling between Hoshangabad and Powarkheda against time taken

Did the train Rashid was traveling in cover equal distances in equal intervals of time? Which sections of the graph show the changing motion, the non-uniform motion of the train? Which sections of the graph show the uniform motion of the train? In which section of the graph is the train stationary?

Look at the sections of non-uniform and uniform motion in the graph. A curve in a graph of motion means the speed of the object is changing continuously in that section. Examine 2-minute sections of the graph. Look at the pattern of average speed in section AB of the graph. The curved line shows a gradual increase in the train's speed as it leaves Hoshangabad station. In section BC, where we have a straight line, the speed remains the same throughout that section. Further, in section CD, we find a curve again and if we analyse it in 2-minute segments, we find that the speed is not constant in that section. In fact, it shows a decreasing pattern.

1. What is the average speed of the train from t = 0 minutes to t = 6 minutes?

2. What is the average speed of the train from t = 4 minutes to t =14 minutes?

So far, we have calculated the slope as the distance traveled in a given time interval and thus estimated the average speed for that time segment. Can one also find out the instantaneous speed of motion from the graph? If you remember, instantaneous speed is the speed over the smallest measurable time interval.

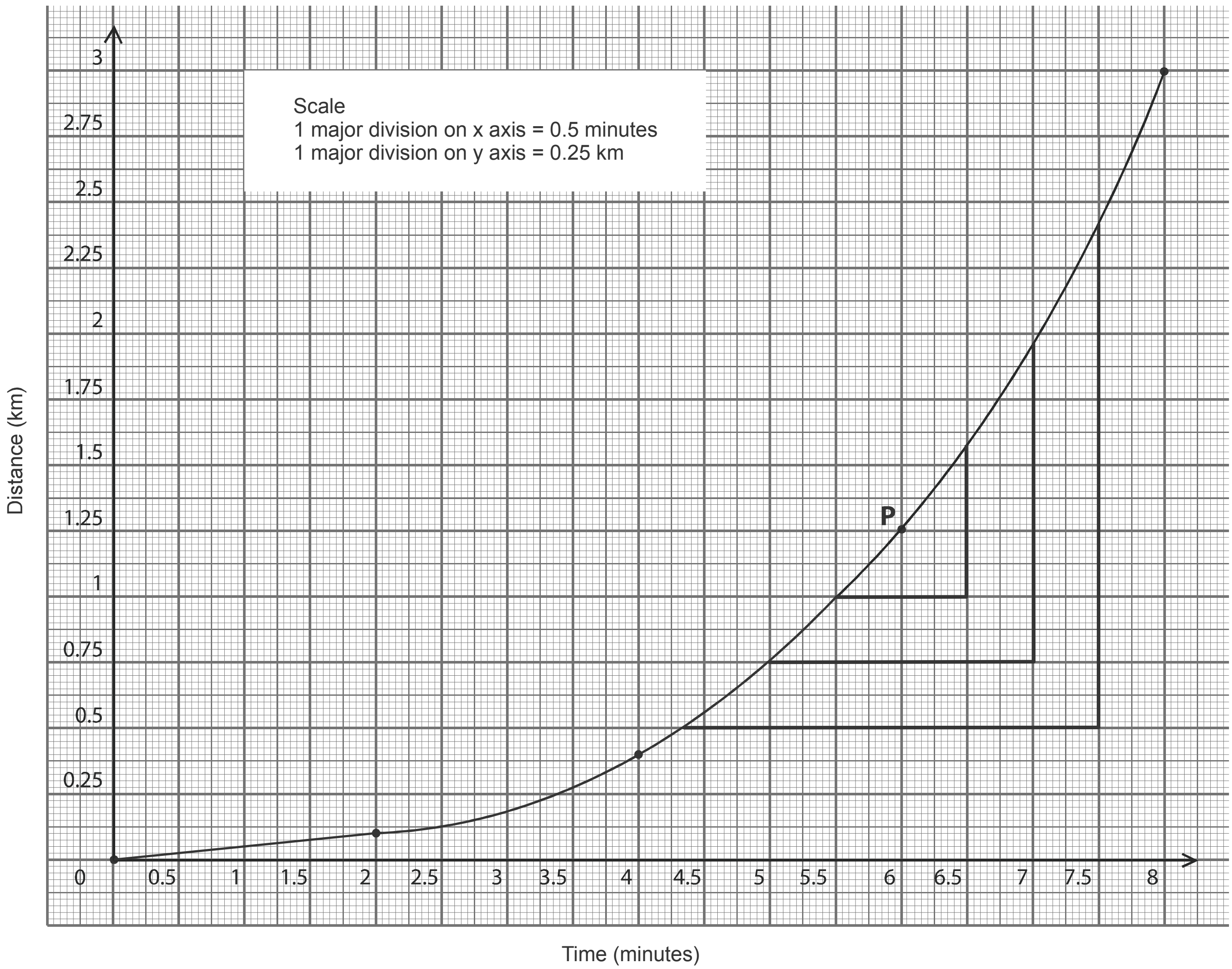


Fig. 36 Calculating the slope for a distance-time graph to find the instantaneous speed

Applying that definition here, we can reduce the time interval to a sufficiently small value and calculate the slope. Time t = 6 minutes corresponds to the point P on the graph.

Figure 36 shows three segments from one side of point P to the other, each a neighbourhood. As we go closer and closer to point P, the straight line joining the two ends of a neighbourhood starts overlapping with the curve itself. Can you safely assume that in the segment of the curve from t = 5.5 minutes to t = 6.5 minutes, the average speed is the same as the slope of the straight line joining the two graph points in this neighbourhood? We can take the slope of the straight line and call it the speed at its midpoint, the speed at t = 6 minutes, or 'the instantaneous speed' at t = 6 minutes. Thus, the instantaneous speed at a particular instant can be equated to the average speed of a particular time interval, provided:

1. The particular instant is included in that time interval.
2. The slope of the line joining the end points of the neighbourhood is obtained for a small enough part of the curve, one which is nearly a straight line segment so that it does not change appreciably when we compute it over a still smaller time interval.

If the segment length is made infinitely small (such that the segment can be taken to be almost a point), the straight line corresponding to its slope is called a 'tangent' at that point of the curve.

Now, you may like to go back and estimate Rashid's speed at t = 6, 12 and 18 minutes.

Suppose you get the distance-time graph of a rolling ball on an inclined plane similar to Fig. 37, can you say by just looking at the graph whether its speed is increasing, decreasing or constant?

Try and draw a few tangents at different points in this graph. Remember, we have just discussed that tangents can replace the straight lines joining the ends of very small neighbourhoods. Compare the slopes of these lines. The tangent passing through point A is tilted more towards the x-axis, compared with the tangent at point B, and so on. You find that the slope is increasing continuously from point A to point B to point C, and so on. It means the instantaneous speed, which is interpreted as the slope of these tangents, is also continuously increasing.

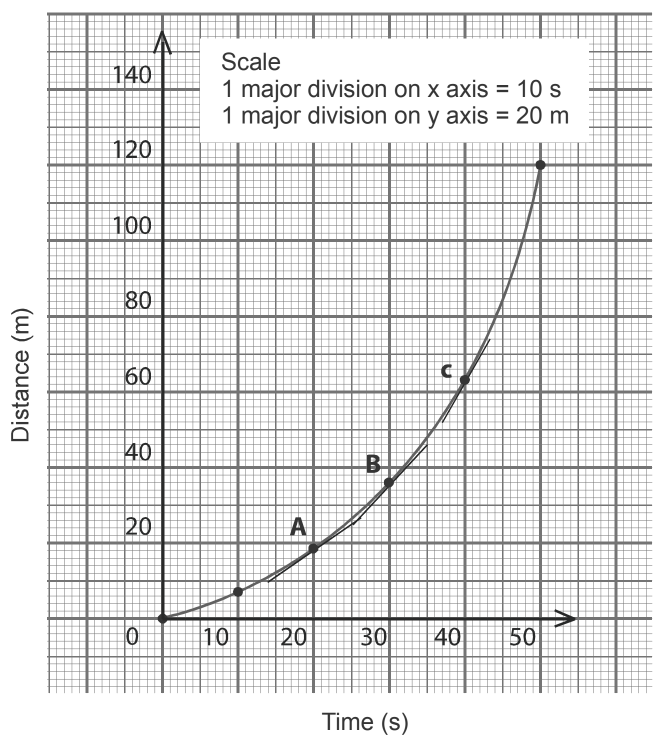


Fig. 37 Finding the slope at different points on a distance-time graph to interpret non-uniform motion

At the same time, if you draw a distance-time graph of the motion of a car as its brakes are being applied, you will find that the slopes at different points of the graph keep decreasing with time and so you can say that the speed is decreasing (Fig. 38).

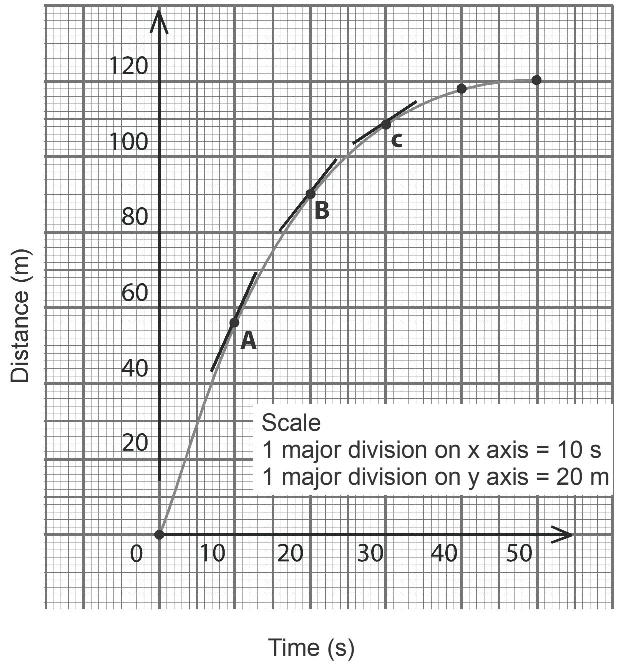


Fig. 38 Finding the slope at different points on a distance-time graph of a car after its brakes have been applied

Looking at the graphs of non-uniform motion and the effort required to extract information about the changing speeds from them, it may be better to directly plot a speed versus time graph.

In a speed-time graph, conventionally, instantaneous speed is shown on the vertical axis and time is shown on the horizontal axis. Table 10 lists data on the positions and speeds of a freely falling body at different points in time. Figs. 39 and 40 show the distance-time and the speed-time graphs, respectively, for this data.

Table 10

Data Point	Time (s)	Distance from the starting point (m)	Instantaneous speed (m/s)
1	1	5	10
2	2	20	20
3	3	45	30
4	4	80	40
5	5	125	50

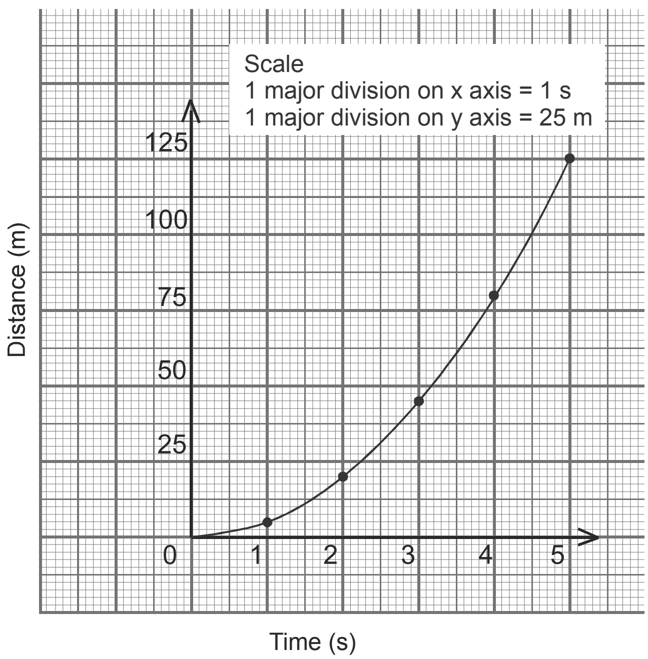


Fig. 39 Distance-time graph showing non-uniform motion

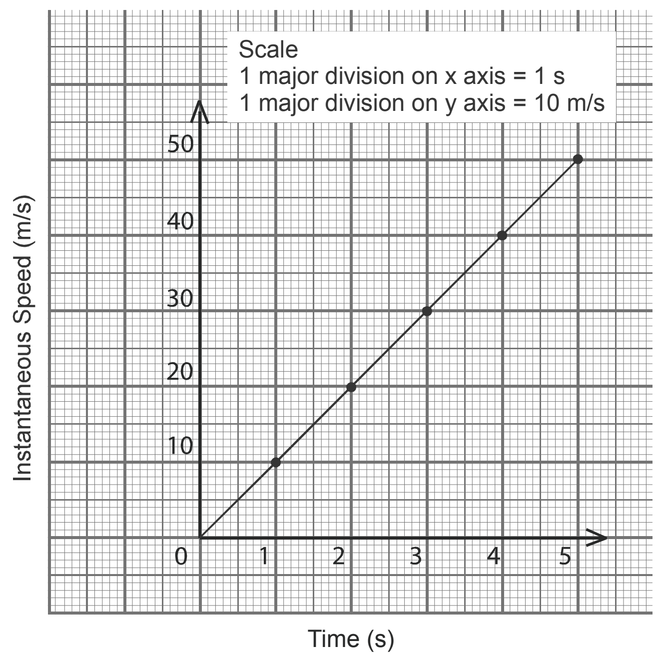


Fig. 40 Instantaneous speed-time graph showing the same non-uniform motion

If you want to further explore the graphical representation of motion, you can use the material given in Appendix 2. Showing the students two graphs with different speed-time behaviours is one way to introduce acceleration. However, if you do not want to use graphs, you can go straight to the section that begins on the following page after the discussion on average speed.

Acceleration in One-Dimensional Motion

What is the difference between a racing car and one that you normally see in everyday traffic? One difference is that the racing vehicle has a higher top speed.

Another important difference is that a racing car has a higher pick-up. What does the word ‘pick-up’ mean (remember the ad slogan “0 to 60 in 8 s”)? It tells you how fast a vehicle can increase its speed. This is one way of measuring the non-uniformity of motion. The technical term for it is ‘acceleration’.

Acceleration (for motion in a single dimension) can be defined mathematically by the following relationship:

$$\boxed{\text{Magnitude of Acceleration (a)} = \frac{\text{Final speed (v) - Initial speed (u)}}{\text{Time over which this speed change is measured (t)}}}\ ^{*}$$

Suppose a bus is moving at a speed of 30 km/h, and the speed is then increased in one minute to 50 km/h. The acceleration of the bus is calculated in the following way:

Change in speed = 50 km/h – 30 km/h = 20 km/h

Time taken for this change = 1 min

Magnitude of acceleration = 20 km/h / 1 min = 20 km/h / 1/60 h =1200 km/h^2

Note that we converted the time taken from minutes to hours. If we had not done so, the acceleration would have been 20 km/ h.min. Both the units are equally valid but conventionally, the former is used.

If the bus slows down to 10 km/h in 1 min (from the same initial speed) then its acceleration is:

Magnitude of acceleration = (10 km/h - 30 km/h) / 1 /60 h = - 20 km/h / 1/60 h = -1200 km/h^2

* ‘a’, ‘u’, ‘v’ and’t’ are standard symbols.

The acceleration is negative now. Negative acceleration is also called ‘retardation’ or ‘deceleration’. Thus, a positive value for acceleration indicates an increase in speed with time whereas a negative value means a decrease in speed with time. A higher value of deceleration means that the moving object can be stopped in a shorter time. This also means that it will come to a stop over a shorter distance.

Why must you maintain a larger distance behind a vehicle with a ‘power brake’?

At this stage it may be helpful to do an activity where accelerated motion can be observed. You can start by posing the problem of measuring the motion of a falling stone. In line with earlier measurements made by the students, they may suggest using a stopwatch and making marks on a wall to measure the speed of the stone at various points during its fall. You will find that the time taken by the stone to fall to the ground is too short to be measured accurately by a stopwatch. Someone might suggest going up on the roof and dropping the stone from there. Try all possible methods. If the measurements are difficult to make, ask the students to think whether the motion (speed) of a falling stone is uniform or not, and why. All non-uniform motion involves acceleration.

Once the students have reached the conclusion that it is not possible to measure the time of a freely falling object using ordinary stopwatches, lead the discussion onto how to get around this problem. One way is to use instruments that can measure faster. Such devices, like electronic stopwatches can measure smaller intervals of time. The other way is to somehow slow down the fall of the object. Discuss the various ways in which this can be done. One could be to make it fall in a liquid column. Another way could be to move the object down a plane inclined at some angle other than the vertical. Galileo used this method to arrive at his theory of motion and inertia. His innovation was to increase the time of fall by using an inclined plane and rolling a ball on it.

Galileo pointed out that the nature of motion in both these cases (free fall as well as motion on an inclined plane) is the same because the governing forces are similar. The forces acting on a ball rolling down an inclined plane are gravity and the friction offered by the plane. We will discuss them in detail in the second module of this series. Similarly, in a free fall, a body falls under the influence of forces due to gravity and air resistance. So, the difference between the nature of motion in both these cases is only in the magnitudes of these forces. The vertical free fall is actually a limiting case of the motion along an inclined plane and the vertical plane can be taken as an inclined plane kept at an angle of 90 degrees.

The following activity can be done either as a demonstration by the teacher or by students in groups of 4 or 5. It requires minimal equipment which can be easily procured in most schools. This is also the point where we take up an example of motion in a vertical direction, although it is still in a single dimension. This will hopefully prevent the students from thinking that motion in one dimension means only in the horizontal plane (a widely held misconception).

During this activity, you may get a chance to address a widespread confusion between speed and acceleration. Try to emphasise that these are entirely different quantities. An object may be moving at a very high speed with zero acceleration, whereas another may be moving very slowly but with a very large acceleration. For example, consider a car starting as the signal turns from red to green. Its initial speed is zero but its acceleration is large. After it has crossed the signal and reached the highway, the car’s speed is quite high but its acceleration may be close to zero.