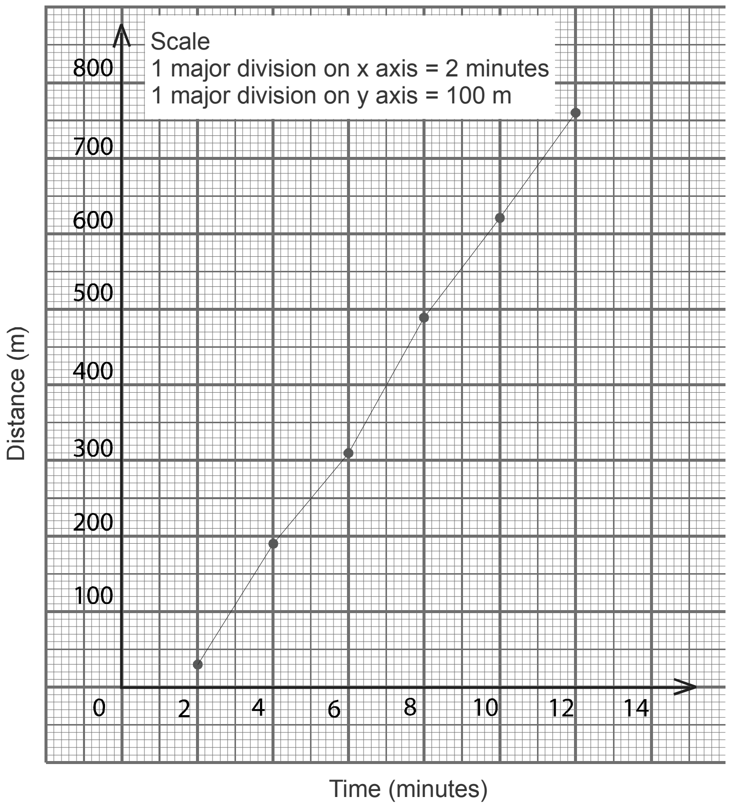


Fig. 7 Distance covered by Munni vs. Time taken

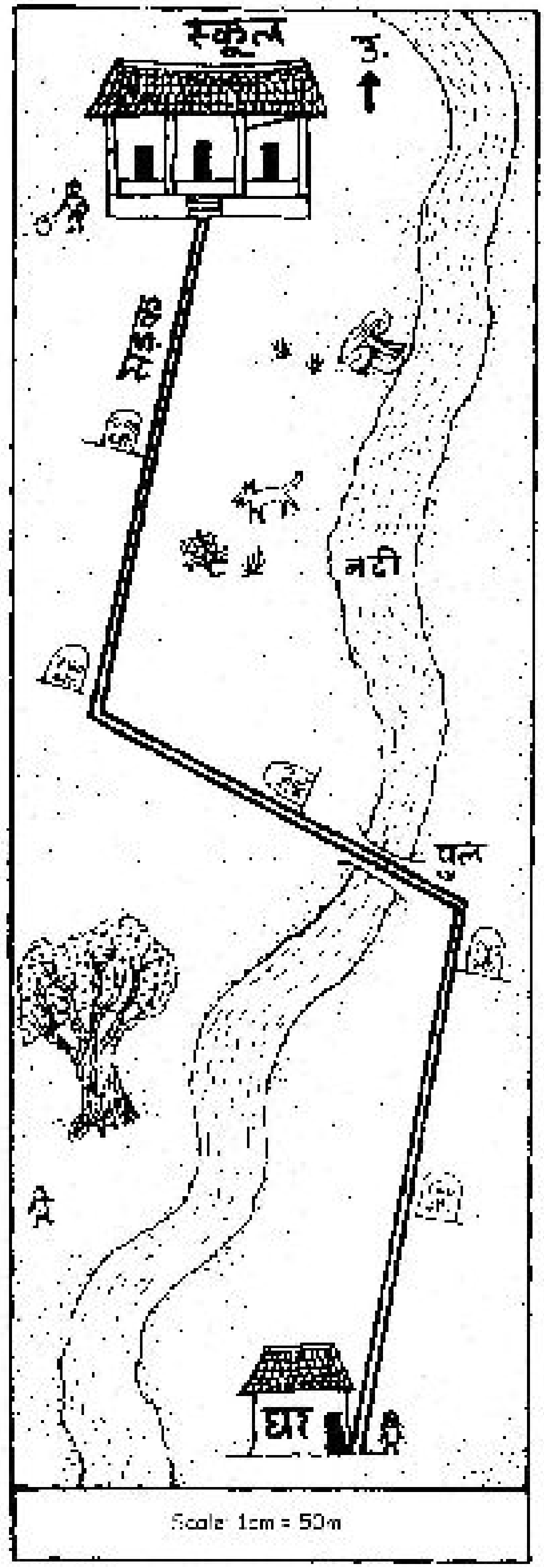


Fig. 8 Map of the route taken by Munni from her house to school

Questions 3 and 4 on the previous page are designed to test whether the students can extract information from graphs. If they find it difficult to answer these questions, the exercises given previously should be done again.

B: Graphs of Motion

This section is a continuation of the discussion on graphs in the main text.

We have seen that the slope of a distance-time graph can give us the speed of the object in motion. We also plotted speed-time graphs. Can we get any information from the slope of a speed-time graph as well? We shall again look at the data in the table on Page 47 which gave the positions and speeds at various points in time of a body in free fall.

Table 4

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

The two graphs we drew there were like this:

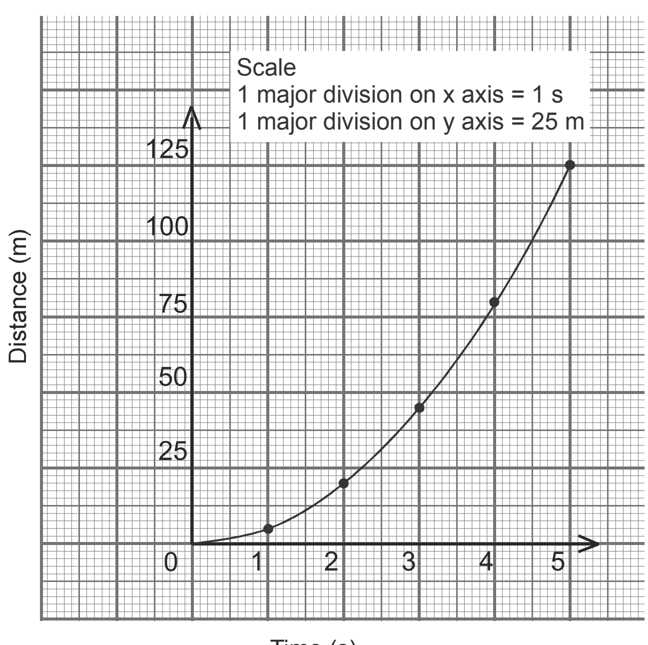


Fig. 9 Distance-time graph for a given motion

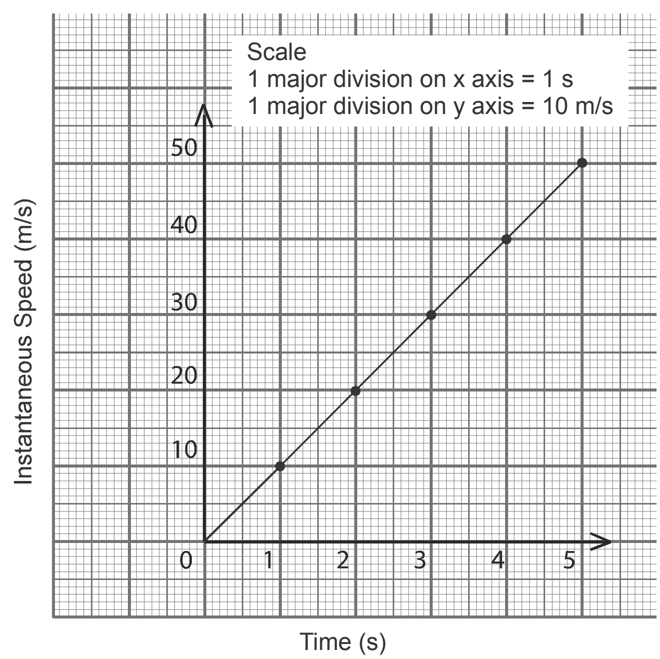


Fig. 10 Instantaneous speed vs. Time for the same motion

The slope of the speed-time graph corresponds to the ratio of the change in speed to the corresponding change in time. This, by definition, is the acceleration. Therefore, the slope of the speed-time graph gives the acceleration!

Find out the slope of the speed-time graph and check to see if it is the same as the acceleration calculated from data in the table.

The next example is designed to illustrate a few points that have not yet been covered. For one thing, the data is explicitly stated to be artificial and is used as an abstract illustration of a theory. This theory, nonetheless, is still applicable to real life situations. This method is one way of extracting underlying principles. Then the distance-time and speed-time graphs are given together to help establish the correlation between them. Also, the speed-time graph is an example of a graph that does not start from the origin, that is, the value of y is not zero at x = 0.

Following the same line of argument, we can deduce that if the speed-time graph is a straight line, the acceleration must be uniform. There is one difference however. Unlike speed, acceleration can take on negative values. The table below shows the data for distance and speed of a motion with negative acceleration and figures that follow show the corresponding distance-time and speed-time graphs.

Table 5

Time (s)	Distance (m)	Instantaneous Speed (m/s)
0	0	10
10	95	9
20	180	8
30	255	7
40	320	6
50	375	5
60	420	4
70	455	3
80	480	2
90	495	1
100	500	0

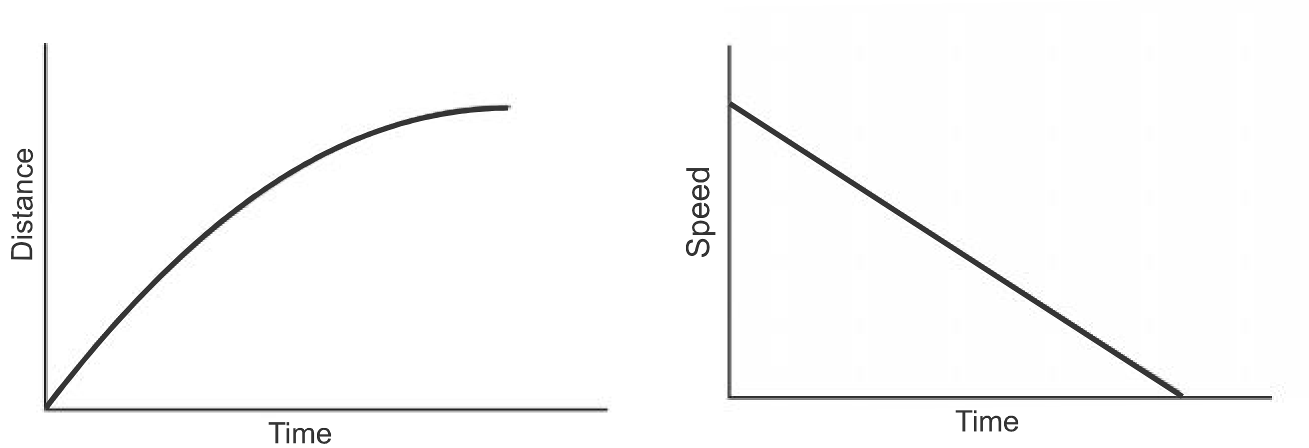


Fig.11 Graphs for motion with negative acceleration

You may note that no units are given because this is imaginary data for illustrating the concept. You can try plotting the data to see if your graphs look similar to the ones here. Let us see what the graphs tell us:

1. The distance at time t = 0, is 0. This means that we are taking the position at time t = 0 to be the reference point.
2. The speed is not zero at the beginning although the distance is zero (see point 1).
3. The speed decreases with time till it reaches zero, the distance increases with time as long as the speed is not zero.

If the speed remains zero after this time, the graphs would look like the following:

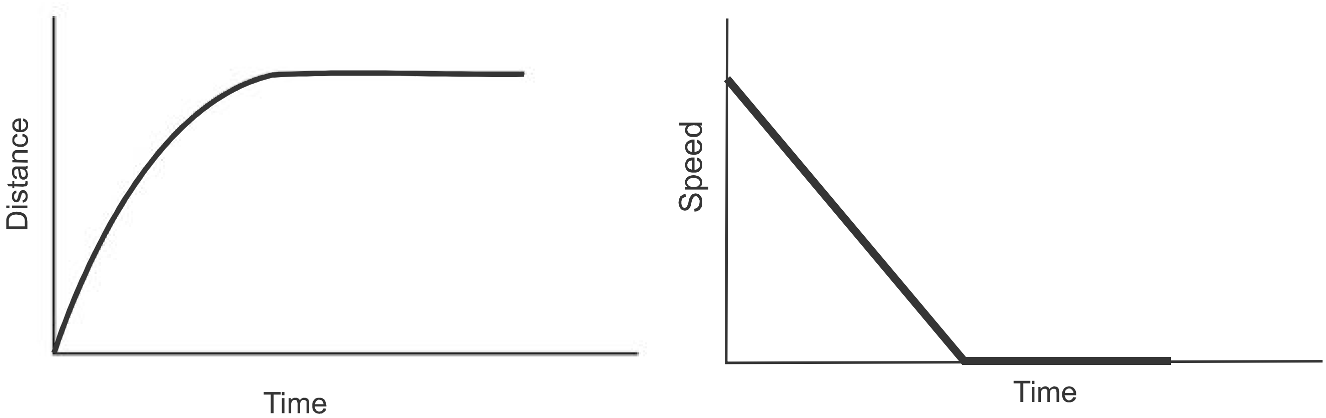


Fig.12

As you can see, once the speed becomes zero, the distance covered does not increase.

Given below are some more examples of distance-time and corresponding speed-time graphs. What can you say about the motions being depicted?

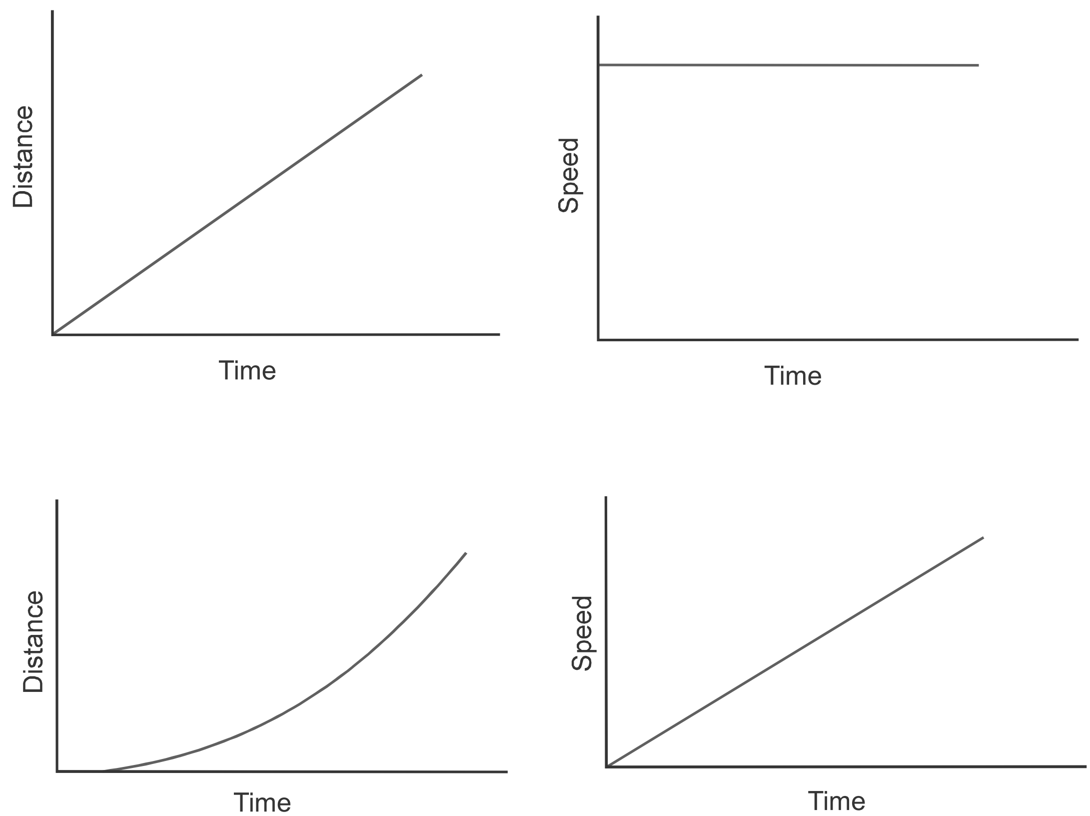


Fig.13 Distance-time graphs along with the corresponding speed-time graphs

News Item

If you are wondering whether distance-time graphs exist only in textbooks, take a look below at a news item from 2009.

ALLAHABAD: In its continuous tryst to amalgamate modern technologies, the Allahabad division of North Central Railway is switching over to computerised charting of the movement of trains. This will ensure better and safer movement of trains running in the Allahabad division which extends from Mughalsarai to Ghaziabad near New Delhi. The computerised charting of trains is a mission critical 24x7 real time system designed to manage traffic control operations and maintain the punctuality of trains through better decision-making. Control charts, basically the time-distance graphs of the trains' motion, used by section controllers are presently manually made and interpreted. In a step towards full automation of train operations, the process of chart making and its analysis are being fully computerised. The application deals with charting the running of trains and forecasting paths for new trains automatically and efficiently. While making the computerised charting, the mail/ express trains are shown with red lines, goods trains are shown with green lines while the passenger trains are depicted with blue lines. No sooner than a train passes a particular station, the section controller gets the information through the concerned station master. He records the movement of the train on a graph known as the master chart. The distance (in kms) is shown on the x-axis while the time is depicted on the y-axis. The x-axis has the details of the various stations in a particular section. The section controller regularly updates the graph as the train surges along the railway track and records the arrival time at the different stations in his section.

When you are next stuck at a railway station waiting for a train, request the station master to show you the train control chart.

If you have access to a computer, learn how to plot graphs on it.

Measurement: Limitations and Errors

This appendix is addressed to teachers. Therefore, the treatment is at a slightly higher level than that elsewhere. However, understanding this topic is essential to be able to guide students while they perform activities given in the main text, and to also address any questions that they may come up with while taking measurements.

We have taken measurements at several places in this module. We have also talked about the various precautions to be taken while measuring any quantity. But despite this, have you noticed that we do not get exactly the same value when we repeat a reading, even when we do our best to keep all the conditions of the experiments the same? This is a very common practical problem, and students can not appreciate it until they have taken some measurements by themselves. This is why we insist that you give every child in your class the opportunity to take measurements. Measurement is an important skill, but many times it remains implicit and we overlook many conceptual issues related to measurement. In this section we will try to deal with some of these conceptual questions.

To start with, one such issue is whether you can measure any length you like using a ruler, or any duration of time with a stopwatch. Then there is that baffling observation we discussed in the above paragraph—why are all the readings of a quantity taken under similar circumstances not exactly the same? After all, the length, or the time measured have some definite values! Do they not? So, which of the different readings is to be taken as the correct one, which one is the most accurate and are there readings which should not be used at all? These are some critical questions related to measurement. We will start by discussing questions related to the limitations of measurements, and then we will move on to discuss possible sources of inaccuracies in an experiment.

Limitations of Measurements:

Measuring with an instrument is constrained by two major kinds of limitations: the limitations of the instrument itself, and the limitations while handling the instrument. Let us now try to understand this in detail.

Every measuring instrument has a lower limit of values it can read; it cannot measure any value that is smaller than this lower limit. An ordinary 15 cm ruler cannot measure lengths of less than 1 mm. Your wristwatch can only measure times equal to or more than one second. The minimum value which an instrument can measure with accuracy is called the 'Least Count' of the instrument. If the smallest markings on your ruler are at a distance of 1 cm, its least count is 1 cm. If the distance between any line or marking on your ruler and the one immediately following it is 1 mm, its least count is 1 mm, and if you have to measure a length less than 1 mm, you can't use this ruler. This is a limitation of the instrument that we had mentioned earlier. Ask children in your class to draw a line of 3.41 cm so they understand the problems in drawing a line of exactly that length.

Now, it may be that the actual accuracy of a measurement is less than the best possible with that measuring device. A good example is time measurement using a stopwatch, as described earlier on. The stopwatch we used has a least count of 1 centi-second (a 100th part of a second). But the least time anyone needs to just switch it on and off is between 15 to 20 centi-seconds. Therefore, you cannot measure a time less than or close to these values with accuracy.

Accuracy in an Experiment:

Even if we measure a time period that falls within the limits of a measuring instrument and its handling, we might not get accurate results. This can happen because of several other errors that are possible during an experiment. These errors possible in any measurement are generally classified into two major categories: **systematic errors** and **random errors**.

Systematic Errors:

Systematic errors are those errors which occur due to a faulty experimental setup or faulty measuring instruments.

a) Systematic errors due to a faulty experimental setup:

   Suppose in the inclined plane activity, the plank is placed such that the ball does not roll straight down and instead rolls towards one side. In that case, we will be measuring the time for a different distance while assuming that it is the time taken for the ball to cross the segments we have marked, and our results will reflect this error. Thus, we need to identify possible systematic errors beforehand and rectify them in advance. Like in this case, you would have to adjust the plank such that the ball rolls straight down.

b) Systematic errors due to a faulty instrument:

   If a measuring instrument is not calibrated correctly then the readings you take with it will be incorrect. This problem may become evident when a measured value differs from the actual value by a fixed proportion of the latter. For example, if all the inch divisions on a ruler are marked incorrectly and each one is 5% shorter than the actual length of 1 inch, then a measured value of 4 inches will differ from the actual length by 5% of 4 inches. Similarly, a measured value of 6 inches will differ from the actual length by 5% of 6 inches.

Such an error may occur not only because of incorrect calibration. It is also possible that the instrument being used is deformed—if a wooden meter ruler is bent slightly then it will consistently measure incorrectly.

Another kind of systematic error that can occur is a zero-setting error—arising because of incorrect measurement with respect to the reference point, or the ‘zero’ of the instrument. For example, if you measure the length of a thread with one end held at the '1 cm' mark of the ruler and the other at the '10 cm' mark, then its length is not 10 cm. The length of the thread in this case is the difference between the two points: 10 cm – 1cm = 9 cm. This is a mistake students often make. In this case, each measurement of a given length will be incorrect by a constant value—1 cm. This also means that if you take one measurement with the '0 cm' mark as the reference point, and others with some other reference points, like in the example above, then the distance will have to be calculated according to the reference point in each instance.

Systematic errors are not always easy to spot, but they can be removed if we look for possible sources of such errors in advance. Then the necessary changes can be made in the experimental setup, or the equipment being used. To have confidence in the readings taken during any experiment, one has to ensure calibration of all the instruments being used.

Random Errors:

Random errors are those errors which occur by chance. Every time data is noted, it is impossible to exactly replicate the conditions they are noted in. This reflects in the data in the form of variations in readings.

Consider the same inclined plane experiment. It is difficult to mark the exact instant of time when the ball crosses from one segment to the next one because of the minimum reaction times of the handlers noting the crossing of the ball and pressing the buttons on the stopwatch. Only by increasing the number of readings and taking the average of those readings can this error be minimized. A basic understanding of statistics tells us that the average of these readings gets closer to the actual value as the number of readings increases. So, if you take 8-10 readings, you are likely to get an average value very close to the actual value. None of these readings are more accurate than the others. Only the average value of all the readings will give the most accurate value.

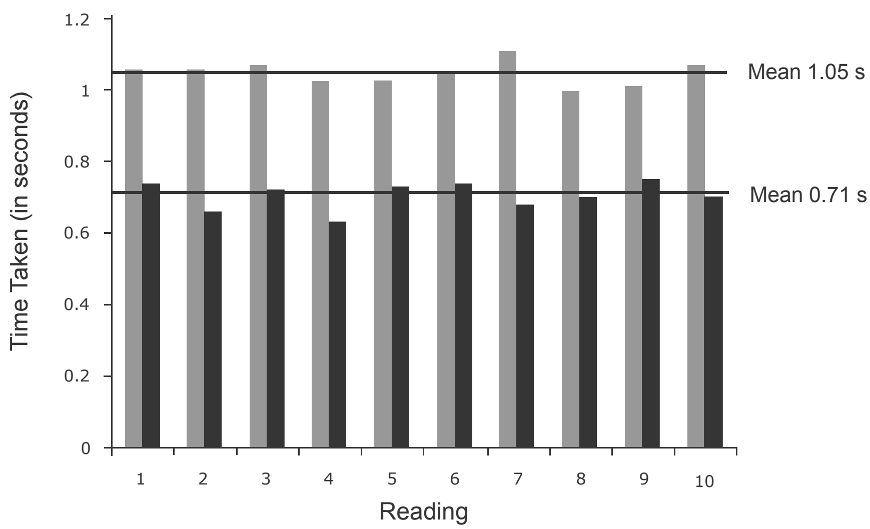
The following table contains the sample data taken for the inclined plane experiment. The data shows the time taken by the ball to cross the two segments of 45 cm each (R1, R2, etc. represent the different readings):

Table 1

	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
Segment 1	1.06	1.06	1.07	1.03	1.03	1.05	1.11	1.00	1.01	1.07
Segment 2	0.74	0.66	0.72	0.63	0.73	0.74	0.68	0.70	0.75	0.70

Assuming that the observers have carefully recorded this data knowing how to use the instruments correctly and their limitations, you can see that the values are not the same in all the readings for either segment. If we plot this data, we see that the deviation from the mean is in both directions—there are values greater as well as lesser than the mean.

The grey bars in the graph show the time taken to cross segment 1 and the black bars show the time taken by the ball to cross segment 2. The mean time for the ball to cross segment 1 turns out to be 1.05 seconds and that to cross segment 2 comes to 0.71 seconds. If you draw two horizontal lines representing the two means for both segments, you can see that the deviation of the data from the average value is on both sides, above and below the lines.



However, even with our best efforts, this deviation of the data, the difference in the time cannot be avoided completely and we can minimize it only by repeating the experiment 8-10 times. So, even if we repeat the experiment several times, we cannot get rid of this error completely. Some error will always be there. Now, if you want to know how close your experimental value is to the theoretical value, that is, if you want to quantify this error while doing a verification experiment, you can calculate the 'percentage error' in your experiment—a commonly used method to describe the experimental error. It is nothing but a ratio of the difference between the actual and the expected or standard value, to the expected value.

The numerical form of percentage error is:

$$\% \text{ error} = \frac{(\text{Actual Measurement} - \text{Expected Value}) \text{ X } 100}{\text{Expected Value}}$$

If you don't know the theoretical or expected value in advance, you cannot know the magnitude of this error. But you could design an experiment to calculate 'the acceleration due to gravity', for which the theoretical value is 9.8 m/s^2. This is called a verification experiment. In that case, if your experimental value comes out to be 9.6 m/s^2, your percent error will be –

$$\% \text{ error} = (9.6 - 9.8) \times 100 \div 9.8$$

$$= 2\,\% \text{ approximately}$$

If you get a high percentage error (say more than 10%), you should revise your entire experiment starting from its design to the recording of observations.

When doing an experiment for which the expected answer is not known, we need to check the range of readings we get. If the range is about 10 % of the average reading, we need to revise the experiment while looking out for sources of error.

$$\% \text{ error} = \frac{(\text{Maximum Value} - \text{Average Value}) \times 100}{\text{Average Value}}$$

Thus, we see that in spite of working within the limits of the measuring instrument and with all the necessary precautions, we cannot get rid of all errors. The point, that there is always a variation in the readings, should be reinforced when you discuss issues related to measurement in your class. You may like to do some more measurement activities and then discuss conceptual matters by referring to the data you have collected. One of these activities could be to measure the length of a table. You can discuss the basic precautions that need to be taken while measuring length, and then ask the students to measure the length of the table as accurately as possible. Once everybody is done with taking the measurements, discuss the variation in the data as well as other issues related to errors and accuracy in measurement.

Appendix 4

Suggestions for Projects

The following projects are meant to give students the opportunity to design their own experiments for solving a given problem.

Measuring Average Speed:

You can ask students to design experiments for estimating the average speeds for some of the following objects in motion. It is possible that they will find that some of the speeds cannot actually be measured with locally available equipment. However, it will still be a good exercise to find out which speeds cannot be measured locally and why this should be so. (Assume all these motions are along straight lines.) Also discuss what the errors in the proposed methods could be and how they can be minimised.

1. A cricket ball thrown from the outfield to the wicket-keeper
2. The wind
3. A cloud
4. A raindrop
5. A hand moving back and forth as fast as possible between two fixed points
6. The tip of a swinging cricket bat
7. A person while walking on level ground, climbing up stairs and going down stairs
8. A camera shutter opening and closing
9. The tip of the growing nail
10. A bird flying
11. Water flowing down a drain
12. The centre of a vibrating guitar string

Measuring Acceleration:

1. In the inclined plane experiment that you did, think of the ways you can calculate the acceleration of the rolling ball.
2. Assuming that the brakes of a cycle provide uniform deceleration, can you design ways to measure that deceleration.

Measuring the Average Speed for Running a Distance of 20 Meters:

To measure the time for running this distance, the activity should be performed in an open ground to provide sufficient space for running. Ask one of the students in the group to run up a 20 meters long straight path. The student noting the time taken for the other to run this distance should be standing at the finishing line. He/she will tell the runner when to start running and will start the stopwatch at the same time and will stop the timer exactly when the runner crosses the finish line. Note down the readings in the following table:

Table 1

S.No.	Name	Total Distance (m)	Time Taken (s)	Average Speed (m/s)
1		20		
2		20		
3		20		
4		20		
5		20		

This activity, in contrast to the other activities in the module, is to be done in an open ground. It can be used as a refreshing change if the students show signs of tiring of classroom work. Once the data has been taken, a discussion on possible errors and how to improve the accuracy of the experiment can be conducted.

Finding the Speed of a Rolling Marble:

To measure the time of a rolling marble, ask the students to form teams of 3-4 members. Let one student in each team roll the marble a definite distance away, say 2 meters. To note the time taken, use the same procedure as mentioned in the last activity. An inclined plane can be used instead of a flat ground for rolling the marble. Ask the students to calculate the speed of the rolling marble on their own and to also tabulate the data for the other team members.

Measuring the Time for Blinking an Eyelid

An interesting activity of measuring the time for blinking an eyelid can be performed in which the students can be asked to blink their eyelids 20 times continuously at a normal rate. During the repeated blinking by one of the students, ask another to note the time taken for this blinking using a stopwatch. Perform this activity involving all the group members, i.e., all the students in the group can blink their eyelids one by one to compare the fastness or slowness of blinking.

This activity is somewhat different from the previous activities and doesn't give the sense of speed. In this activity, instead of measuring distance, the number of times the eyelid blinks during a given time is being counted. The number of blinks per unit time is known as the frequency of blinking. The concept of frequency can also give the sense of fastness or slowness of an object executing periodic motion.

Measuring the Time for Chopping Clay

This may be another interesting activity brings in the idea of frequency once again. Roll some clay (plasticine) into a cylinder of roughly 20 cm length and 1 cm diameter and ask one of the students to chop the roll with a knife, say 20 cuts. This can be repeated by all the students of the group, i.e., one by one all the students can chop the roll. To get the respective frequencies of chopping, ask the students to count the number of pieces of the roll and divide it by the observed time to estimate their frequency of chopping. As they finish this exercise, they could be asked to take an average of their time readings for each case.

Appendix 5

Problem Set

Conceptual Questions

1. Discuss why trains coming from the opposite direction appear to be moving very fast and why a train that is overtaking your train seems to be moving very slowly.

2. It was raining heavily one day while Amit was cycling to school and so he had his umbrella open. When he cycled past some people waiting for a bus, Amit was surprised to see that they were all holding their umbrellas upright while he himself was holding his umbrella tilted well forward. He wondered why this should be so. Can you think of an answer for his question?

3. If your younger sister asks you to estimate the average speed of a bird flying overhead, what would be your answer? How would you check whether your estimate is correct?

4. If you are asked to measure the instantaneous speed of any object, for example, the instantaneous speed of a bullet as it leaves the barrel of a rifle, explain how you would do this. What are the factors you would need to know in order to measure this speed? Can you think of more than one way of doing this?

5. An owl sat on a tall tree holding a stone in its beak. After some time the stone slipped from its beak and fell down. Here are a few statements describing the motion of that stone. Tick the correct statement(s).

   a. The stone starts falling with zero speed. ( )

   b. The stone will fall in a straight line. ( )

   c. The stone falls with a constant speed till it reaches the ground. ( )

   d. Its speed keeps on increasing continuously from the beginning till it reaches the ground. ( )

   e. The speed acquires its maximum value just before striking the ground. ( )

6. If a brick falls accidentally from the 4th floor of a construction site, what will be its acceleration when it starts to fall? What will be its acceleration just before it reaches the ground? Will the time taken by the brick to cross the windows of each floor be the same (assume that the windows are identical)? Will any of your answers be different if the brick were to fall from the 10th floor?

7. Three different types of inclined planes are shown in Fig.1. In which case will the acceleration be uniform and in which will it change? If the acceleration is changing, do you expect it to increase or decrease?

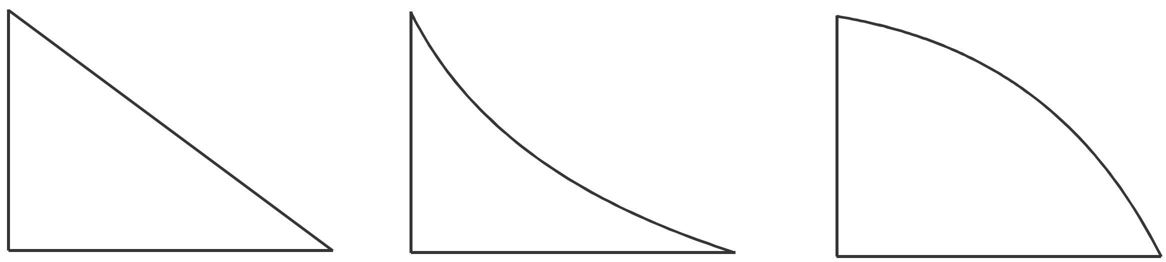


Fig. 1 Inclined planes with different slopes

8. The following position-time graph (Fig. 2) depicts the motion of a cart. Answer the following questions on the basis of the information given in the graph:

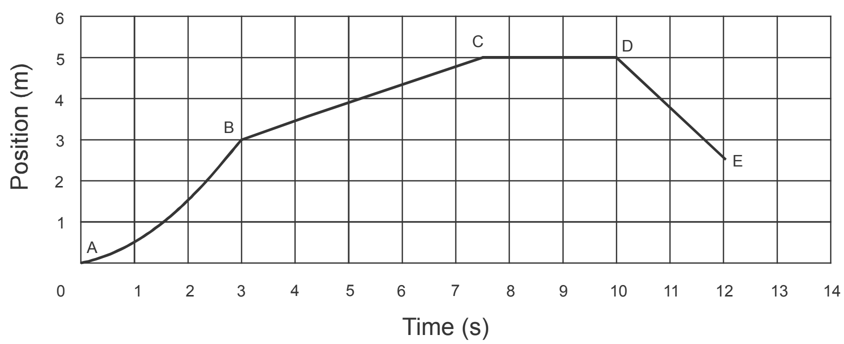


Fig. 2 Position-time graph of a cart in motion

a. During which interval was the cart at rest?

i. AB ii. BC

iii. CD iv. DE

b. During which interval was the cart moving towards the original position?

i. AB ii. BC

iii. CD iv. DE

c. During which of these two intervals, BC and DE, was the cart traveling faster?

i. DE ii. BC

9. A helicopter is flying east with a uniform speed of 50 km/h. Which graph(s) correctly represent the motion of the helicopter (Fig. 3)?

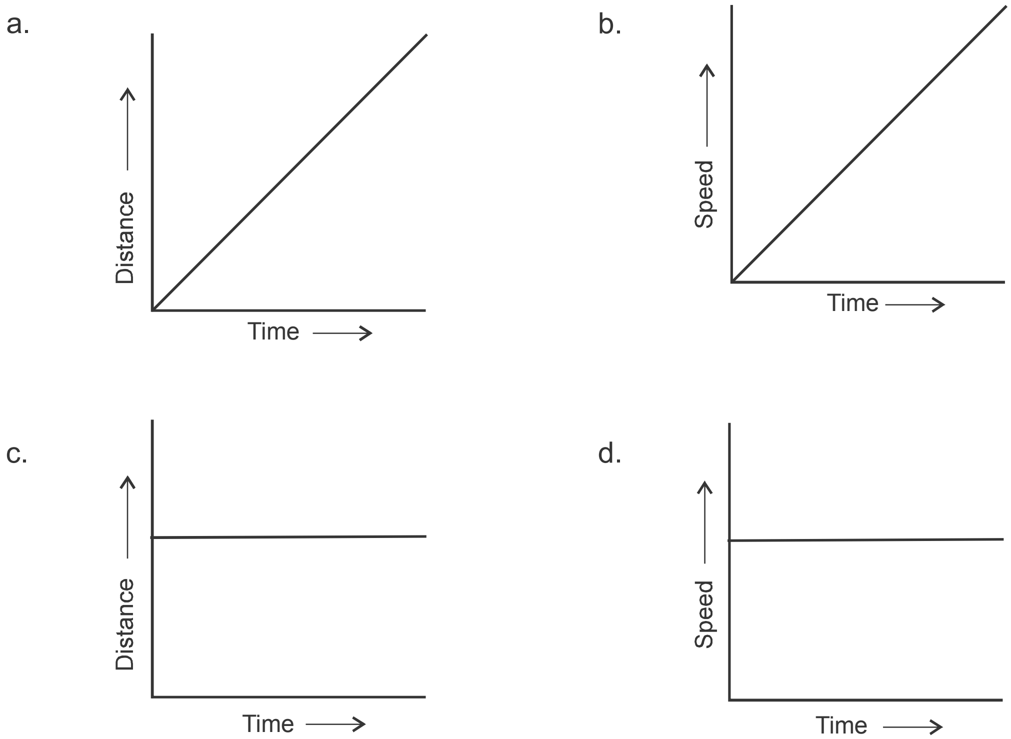


Fig. 3 Distance-time and speed-time graphs for the helicopter

10. This is a very old story. You may have heard it many times before. It is the story of the race between a rabbit and a tortoise. The two have a bet on who will win the race. The rabbit takes off swiftly while the tortoise begins with a slow and steady pace. The rabbit initially runs far ahead of the tortoise. But then, he decides to rest under a tree for a while and falls asleep. The tortoise, meanwhile, continues to forge ahead steadily. When the rabbit wakes up, he runs to the finishing post. But, alas! when he reaches the finish line he finds that the tortoise has already won the race.

    Illustrate the race between the rabbit and the tortoise in the form of a graph.

11. The winner of the 2012 Olympic gold medal in the men's 400 m hurdle race took 47.63 s while the gold medallist in the women's 400 m hurdle race took 52.70 s.

    Runners are supposed to clear ten hurdles in the 400 m hurdle race. Assuming that the hurdles are evenly spaced around the track, draw the speed-time graph of an athlete participating in the 400 m hurdle race. Will the graph be different for a 400 m race with no hurdles? What about a 400 m relay race?

12. Fig. 4 shows the distance-time graph for Ramesh's (black circles) and Hamid's (white squares) journeys. Write a story about this journey on the basis of the graph.

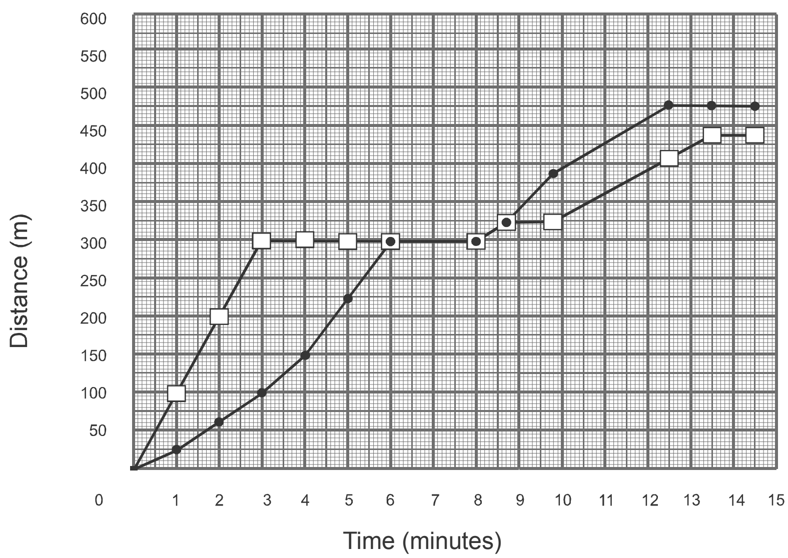


Fig. 4 Distance-time graph depicting Ramesh's and Hamid's motion

13. If you ride a bicycle, you may have noticed that you don't have any problem pedalling with uniform motion when the road is straight and level. But when you climb uphill, your speed decreases. On the other hand, when you go downhill your speed increases and the bicycle moves really fast. Fig. 5 shows the graph of a bicycle trip taken by Kamala. Look at the graph and say which of the following statements are true:

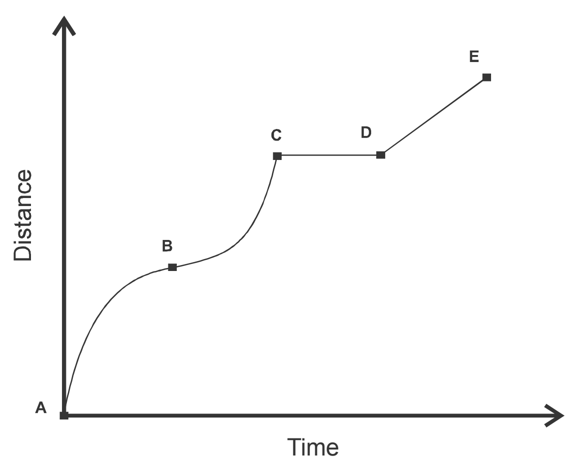


Fig. 5 Graph showing the details of Kamala's cycle ride

a. Kamala cycled up a slope, then went down a slope, then stopped and rested for some time. She then cycled on a level road. ( )

b. Kamala cycled uphill continuously. ( )

c. Kamala first went downhill, then on a level road, then climbed uphill and finally rested. ( )

d. Kamala first cycled uphill, then stopped and rested for some time because she was tired, then cycled on a level road and finally rode downhill. ( )

e. None of these. ( )

14. Can a motorbike moving initially at 80 km/h and a car moving initially at 40 km/h be made to accelerate by an equal amount?

15. The speed of a moving object is zero at some point of time in its path. Which of the following statement(s) is/are correct?

    a. The acceleration at that point will be zero. ( )

    b. If the acceleration remains zero for next 10 seconds after that point, the speed will also be zero in that interval. ( )

    c. If the speed is zero for next 10 seconds after that point, the acceleration will also be zero in that interval. ( )

16. A ball is thrown vertically upwards from the edge of a cliff and it is noticed that it lands on the ground below the cliff. If it were to be thrown downwards from the same place with the same speed, would its speed just before landing be greater, lesser or the same as before?

Numerical Problems

17. A 500 m long train is moving with a uniform speed of 10 m/s. Calculate the time taken by the train to cross (i) a 250 m long bridge, (ii) an electric pole.

18. Two cars travel along the same road in the same direction from the same starting point. However, one car starts at 10 AM and maintains a speed of 40 km/h, while the other car starts 1 hour later and maintains a speed of 60 km/h. How many hours will it take for the second car to overtake the first car? How far would it have traveled by then?

19. Shreya walked at a speed of 6 km/h for 1 km and 8 km/h for the next 1 km. If she had to cover the same distance in the same amount of time but maintain a uniform speed throughout the journey, at what speed would she have to walk? Is it the same as the average of the two speeds?

20. What is your average speed in each of these cases?

    a. You run 100 m at a speed of 5 m/s and then you walk 100 m at a speed of 1 m/s.

    b. You run for 100 s at a speed of 5 m/s and then you walk for 100 s at a speed of 1 m/s.

21. The following table shows four positions of an object as it traveled at a constant speed.

Table 1

Position (cm)	**Time (s)**
0	0
3	9
5	15
7	21

    a. How fast was it traveling in the 20^{th} second?

    b. What was the position of the object after 18 seconds?

22. A bus increases its speed from 60 km/h to 70 km/h in 5 seconds while a cyclist goes from rest to 10 km/h in the same period of time. Which of the two undergoes greater acceleration?

23. Kamal and Sona decided to visit Ramu's sweet shop after school. When they were about to leave school, the teacher called Sona. So, Kamal left for the sweet shop alone. After a short while, Sona came running and caught up with Kamal. They then went together to Ramu's shop and ate *jalebis* there. The entire episode is shown in the form of a graph using different symbols for showing how Kamal and Sona travelled (Fig. 6).

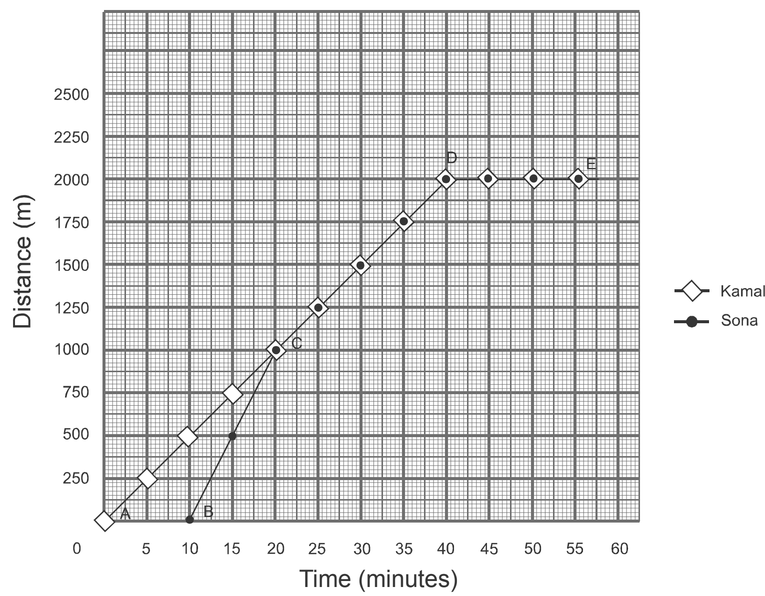


Fig. 6 Distance-time graph for Kamal and Sona's trip to Ramu's sweet shop

Look at the graph and answer the following questions:

a. What was Kamal's average speed till he reached the sweetshop?

b. How long was Sona detained by her teacher?

c. How much time did Sona take to catch up with Kamal?

d. What was Sona's average speed while she was running?

e. How far from the school did Sona finally catch up with Kamal?

f. What is the distance between the school and Ramu's shop?

g. How far did they walk together?

h. For how much time did they walk together?

24. You may have read the story of the flying turtle. Two swans held the ends of a stick firmly in their beaks and the turtle hung on to the stick with its teeth. The swans flew carrying the turtle along. As they were flying 180 metres above a lake, the beautiful scene below overwhelmed the turtle. He couldn't contain his excitement and exclaimed “Wow!” The remaining story of the turtle's flight is given in table 2.

a. Draw a graph depicting the turtle's motion.

b. What does the graph look like?

Table 2

Time (s)	Distance fallen by the turtle (m)
0	0
1	5
2	20
3	45
4	80
5	125
6	180

c. Can you say, on the basis of this graph, whether the motion of the turtle was uniform or non-uniform?

d. How long did it take for the turtle to fall into the lake from the height of 180 metres?

e. What was the average speed of the turtle during its fall?

f. Can you say what the turtle's speed at t = 2 s was?

25. A careful analysis of the motion of a moving object yielded some information which is plotted in the graph below (Fig. 7). Now answer the following questions:

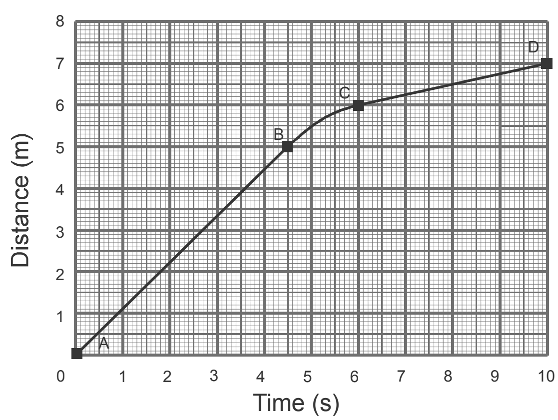


Fig. 7 Distance-time graph showing an object in motion

a. When was the speed the greatest? What was the value of the speed at that time?

b. At what moment or in which time interval was the speed least? What was the speed at that time?

c. What was the speed at t = 1 s?

d. What was the speed at $t = 8$ s?

e. How far did the object move from time $t = 7$ s to $t = 9.5$ s?

f. What was the average speed between $t = 4$ s and $t = 7$ s?

26. A loaded truck left the warehouse with the meter reading 12345 km. When it got back after three days the reading was 13245 km. What was the average speed of the truck during this period?

27. A cyclist starting from rest accelerates at the rate of 1 m/s^2 for 4 seconds. What will be her speed after 4 seconds? What distance would she have covered by then?

28. A bullet is fired from a rifle which has a 1 m long barrel. The bullet leaves the barrel with a uniform speed of 500 m/s and enters a concrete wall. The bullet penetrates 5 cm into the wall before it comes to rest.

    a. How much time would the bullet have spent in the barrel assuming the acceleration in the barrel is constant?

    b. Find the deceleration in the bullet's speed once it hits the concrete wall.

29. An object starts moving with an initial speed of 3 m/s and it experiences a uniform acceleration of 1 m/s^2 in the same direction.

    a. Find the distance travelled by it in the first two seconds.

    b. How much time would it take to reach a speed of 7 m/s?

    c. How much distance would it have covered before reaching a speed of 7 m/s?

30. Note: This problem involves some algebraic calculations and it is suggested that this problem should not be given to the students unless they have a good command over algebra.

    Two objects A and B start from rest and move for an equal amount of time in a straight line. Object A has acceleration 'a' for the first half of the total time and '2a' for the second half. Object B has an acceleration of '2a' for the first half and 'a' for the second half. Which object will cover a greater distance? Calculate the distances travelled by both the objects and their final speeds.

31. A superfast train was traveling at 72 km/h when the driver noticed a buffalo caught in the tracks and braked immediately in order to save its life. If the brakes cause a deceleration of 1 m/s^2 and the buffalo was at a distance of 250 m from the train when the driver saw it, would the buffalo survive?

32. Clouds are generally found at a height of 1500 m above the ground. Falling from this height, what would be the speed of raindrops when they reach the ground?

    Actually, raindrops face a lot of air resistance in-between and are slowed down quite a bit. Otherwise it would not have been safe to walk outside during a rainstorm.

33. Due to a small leakage in a pipe, drops of water fall at equal time intervals on the floor 9 meters below. The first drop strikes the floor at the same instant the fourth drop begins to fall. How far would the second and third drops have fallen when the first one strikes the floor?

34. A ball is thrown upwards with a speed of 20 m/s from the edge of a 60 m high cliff. After some time, it starts falling down. It passes through the starting point and continues to fall further to the base of the cliff.

    a. What is the maximum height attained by the ball?

    b. How much time will it take to pass its starting point on the way down?

    c. How much time will it take to reach the base of the cliff?

    Assume that the acceleration due to gravity is roughly equal to 10 m/s^2.

Answer Sheet

Conceptual Questions

1. Hint: Think in terms of the 'point of reference'.
2. The point of reference is different for Amit as compared to the people standing still. So, the perceived motion of the raindrops by these two groups will be different with respect to both the magnitude as well as the direction of the raindrops.
3. Hint: To measure the average speed of an object, you will have to mark a distance and note down the time taken in covering that distance.
4. Hint: If the bullet is fired horizontally, its speed in that direction will not change even after it leaves the barrel. Apply equations of motion.
5. Hint: All freely falling bodies fall with a constant acceleration (acceleration due to gravity) irrespective of the height from where they start falling. In any accelerated motion, the speed increases continuously and so the time taken to cover the same distance will keep on decreasing.
6. Hint: Same as question 5.
7. Hint: The slope of an inclined plane will govern the acceleration of the rolling ball. Higher the slope, greater the value of acceleration.
8. Hint: The slope of a line in a distance-time graph depicts speed. A steeper slope means greater speed. A horizontal line in a distance-time graph means that the distance covered is not changing with time, that is, the object is at rest.
9. The speed-time graph of a uniform motion will be a horizontal line. Since the distance will increase linearly with time, the distance-time graph will be a straight line with some slope.

14. Yes. Acceleration is the rate of change of speed. It should not be confused with the speed itself.
15. b and c
16. The speed would remain the same in both the cases. In the first case, when the ball is thrown upwards, its speed keeps on decreasing till it comes to rest. Then it comes back and by the time it passes through the same point, it attains the same speed. The rest of the story will be the same in both the cases.

Numerical Problems

17. Train length = 500 m,

Speed of the train = 10 m/s

First case:

The distance traveled by the train to cross the bridge = 500 m + 250 m = 750 m

Suppose the time taken by the train to cross the bridge is 't' seconds.

As average speed = Distance traveled ÷ Time taken

10 m/s = 750 m/ t

t = 75 s Ans

Second case:

The distance traveled by the train to cross an electric pole will be the same as the length of the train because the width of a typical electric pole is negligible in comparison to the length of the train. The pole can therefore be treated as a point.

Here again, if the time taken to cross the pole is assumed to be 't' seconds:

Using, average speed = Distance traveled ÷ Time taken

10 m/s = 500 m/ t

t = 50 s Ans

18. The speed of the first car = 40 km/h

The speed of the second car = 60 km/h

Suppose the second car overtakes the first car after 't' hours. By this time, the first car would have traveled for (t+1) hours and the distances traveled by the two cars will be the same.

Using, average speed = distance traveled/time taken, and equating the distances traveled by the two cars, we can say:

40 km/h X (t+1) = 60 km/h X t

t = 2 h

This means that after two hours of travel, the second car will overtake the first car. Ans

The distance traveled by the cars will be 60 km/h X t = 120 km. Ans

19. Total distance traveled by Shreya = 1 km + 1 km = 2 km

Suppose the time taken by her to cover the first half is t_1 hours.

Applying the equation: average speed = distance travelled ÷ time taken,

$$6 \text{ km/h} = (1 \div t_1) \text{ km/h}$$

$$t_1 = \tfrac{1}{6} \text{ h}$$

Similarly, if the time taken to cover the second half is t_2 hours

Applying the equation: average speed = distance traveled ÷ time taken,

$$8 \text{ km/h} = (1 \div t_2) \text{ km/h}$$

$$t_2 = \tfrac{1}{8} \text{ h}$$

Total time taken by her = $t_1 + t_2$ = $(\tfrac{1}{6} + \tfrac{1}{8})$ h = 7 / 24 h

If she has to travel the same 2 km walk in $\tfrac{7}{24}$ h but with a uniform speed, her speed will be:

$$\begin{aligned} \text{Speed} &= 2 \text{ km} \div (\tfrac{7}{24})\text{h} \\ &= \tfrac{48}{7} \text{ km/h Ans} \\ &< 7 \text{ km/h (arithmetic mean of the two speeds)} \end{aligned}$$

Ans

20. a. Average Speed = Distance traveled ÷ Time taken

Total distance traveled = 100 m + 100m = 200 m

Time taken to cross the first segment = Distance traveled ÷ Average speed

= (100 m) ÷ (5 m/s)

= 20 s

Time taken to cross the second segment = Distance traveled ÷ Average speed

= (100 m) ÷ (1 m/s)

= 100 s

Total time taken = 20 s + 100 s = 120 s

Average speed = 200 m ÷ 120 s = 1. 67 m/s — Ans

b. Average Speed = Distance traveled $\div$ Time taken

Total time taken = 100 s + 100 s = 200 s

Distance traveled during the first 100 s = Time taken X Average speed

= (100 s) X (5 m/s)

= 500 m

Distance traveled during the second 100 s = Time taken X Average speed

= (100 s) X (1 m/s)

= 100 m

Total distance traveled = 500 m + 100 m = 600 m

Average speed = 600 m $\div$ 200 s = 3 m/s Ans

21. Since the speed is constant, it will remain same for the 20th second as well.

Speed for the first interval = Change in position $\div$ Time taken

= (3 – 0) cm $\div$ 9 s

= ⅓ cm/s

= 0.33 cm/s

Speed in the 20th second = 0.33 cm/s Ans

After 18 seconds, the distance traveled = speed X time

= ⅓ cm/s X 18 s

= 6 cm Ans

22. Acceleration of the car = Change in speed $\div$ Time taken

= (70 – 60) km/h $\div$ 5 s

= 10 km/h $\div$ 5 s

= (10 X 1000) $\div$ (5 X 3600) m/s^2

= $\frac{5}{9}$ m/s^2 Ans

Acceleration of the cycle = Change in speed ÷ Time taken

= (10 – 0) km/h ÷ 5 s

= 10 km/h ÷ 5 s

= (10 X 1000) ÷ (5X3600) m/s^2

= $\frac{5}{9}\ m/s^2$ Ans

23. a. The distance traveled by Kamal in 40 minutes is 2000 meters. So, her speed is (2000 ÷ 40) m/minute = 50 m/minute.

    b. Sona started after 10 minutes (point B in the graph).

    c. Sona joined Kamal at point C, which corresponds to t = 20 minutes. So, the time taken by Sona to catch up with Kamal is (20–10) minutes = 10 minutes.

    d. Sona ran between point B and C. The distance traveled by her is 1000 m in 10 minutes. So her average speed would be 1000 m/ 10 minutes = 100 m/minute.

    e. 1000 m. (Refer to point C in the graph).

    f. 2000 m. (Refer to point D in the graph).

    g. The distance covered together is the distance between point C and point D as read on the y-axis of the graph = (2000 –1000) m = 1000 m.

    h. The time they traveled together is the time interval between point C and point D as read on the x-axis of the graph = (40–20) minutes = 20 minutes.

24. a. Distance-time graph.

    b. A curved line with an increasing slope.

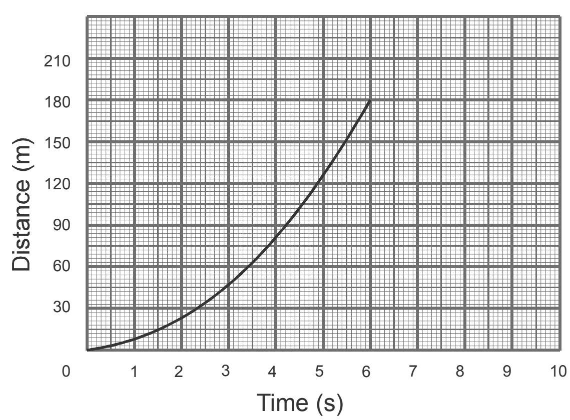
    c. Since the slope of the curve is not constant, the motion of the turtle cannot be uniform.

    d. 6 seconds.

    e. Total distance traveled = 180 m

       Total time taken = 6 s

       Average speed = 180 m ÷ 6 s = 30 m/s



Distance-time graph showing the turtle's position at different times after it lets go of the stick

f. 20 m/s (Read the slope of the curve in the distance-time graph at $t = 2$ s. Alternatively, apply equations of motion to find out the speed at $t = 2$ s.)

25. a. In segment AB, Speed = 5 m ÷ 4.5 s = 1.11 m/s

b. In segment CD, Speed = 1 m ÷ 4 s = 0.25 m/s

c. 1.11 m/s

d. 0.25 m/s

e. Position at $t = 7$ s, is 6.25 m and position at $t = 9.5$ s, is 6.75 m.

Hence, the distance traveled = (6.75 – 6.25) m = 0.5 m

f. Average speed = Total distance covered ÷ Time taken

= (6.25 – 4.5) m ÷ (7 – 4)s

= 1.75m ÷ 3s

= 0.58 m/s Ans

26. The total distance traveled by the truck = (13,245 – 12,345) km = 900 km

The time taken to cover this distance = 3 days

Average speed = Total distance traveled ÷ Time taken = (900 ÷ 3) km/day = 300 km/day

27. Given, $u = 0$ m/s, $a = 1\ m/s^2$ and $t = 4$ s

Applying the first equation of motion, $v = u + at$

$= 0\ m/s + (1\ m/s^2 \times 4\ s)$

$= 4$ m/s Ans

Applying the second equation of motion, $s = ut + \frac{1}{2}at^2$

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

$= 8$ m Ans

28. a. $u = 0$ m/s, $v = 500$ m/s, $s = 1$ m, acceleration is constant (say 'a')

Suppose the time taken by the bullet in the barrel, which is to be calculated, is 't'.

Applying the first equation of motion, $v = a\,t = 500$ m/s

Applying the second equation of motion, $s = ut + ½\,at^2$

$1 = 0 \text{ X } t + ½\,at \text{ X } t$

$= ½ \text{ X } 500 \text{ m/s X } t$

$= 250 \text{ m/s X } t$

ð $t = 4$ milliseconds Ans

(1000 milliseconds = 1 second)

b. Given, $u = 500$ m/s, $v = 0$ m/s and $s = 5$ cm $= 0.05$ m

Applying third equation of motion, $v^2 = u^2 + 2\,a\,s$

$0 \text{ m/s}^2 = (500 \text{ m/s})^2 + 2 \text{ X } a \text{ X } 0.05 \text{ m}$

ð $a = -25{,}00{,}000 \text{ m/s}^2$ (Too much!) Ans

Since a concrete wall will stop the bullet, it will decelerate. Therefore, the negative value of 'a' is justified.

29. $u = 3$ m/s, $a = 1 \text{ m/s}^2$

a. 8 m (Apply the second equation of motion) Ans

b. 4 s (Apply the first equation of motion) Ans

c. 20 m (Apply the third equation of motion) Ans

30. Second case. (Hint: For simplicity, assume the total time of travel is 2t and apply the equations of motion for each half.)

31. Speed of the train = 72 km/h = 20 m/s

Deceleration = 1 m/s^2

To save the buffalo's life, the driver should be able to stop the train before 250 m.

Suppose the train travels distance 's' before it comes to a stop.

Applying the third equation of motion, $v^2 = u^2 + 2\,a\,X\,s$

$$0 = 20^2 + 2\,X\,(-1)\,X\,s$$

$$ð \quad s = 200\text{ m}$$

The train will stop at 200 m and the buffalo will be safe. Ans

32. $s = 1500\text{ m}$, $u = 0$, $a = 10\text{ m/s}^2$

Applying the third equation of motion, $v^2 = u^2 + 2as$

$$v^2 = 2\,X 10\,X\,1500$$

$$v^2 = 30000$$

$$v = 173.2\text{ m/s}$$ Ans

33. Suppose the time interval between any two consequent drops is 't'. So, the first drop would have traveled for time '3t' while the second and third drops would have traveled for times '2t' and 't' times, respectively.

Applying the second equation of motion for the motion of the first drop,

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

$$9 = 0 + \tfrac{1}{2}g\,(3t)^2$$

$$t^2 = 2\,/g \qquad \ldots\ldots\ldots\ldots(1)$$

For the second drop:

Suppose the distance covered is h_2.

Applying the second equation of motion,

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

$$h_2 = 0 + \tfrac{1}{2}g\,(2t)^2$$

$$h_2 = 2gt^2$$

Putting in the value of t^2 from equation (1) above:

$$h_2 = 2g\,X\,(2/g)$$

$$h_2 = 4\text{ m}$$

Similarly, for the third drop:

Suppose the distance covered is h_3.

Applying second equation of motion, $s = ut + ½at^2$

$$h_3 = 0 + ½g(t)^2$$

$$h_3 = ½gt^2$$

Putting in the value of t^2 from equation (1):

$$h_3 = ½g \text{ X } (2/g)$$

$$h_3 = 1 \text{ m}$$

The second and third drops will be 4 m and 1 m below the drip point respectively when the first drop reaches the ground. Ans

34. If we assume the vertically upward direction as positive and take 'a' to be approximately 10 m/s^2, then:

$u = 20$ m/s, $v = 0$, $a = –10$ m/s^2

a. Suppose the maximum height attained by the ball is 'h'.

Applying third equation of motion, $v^2 = u^2 + 2as$

$$0 = (20 \text{ m/s})^2 + 2 \text{ X } (–10 \text{ m/s}^2) \text{ X } h$$

$$ð \quad h = 20 \text{ m}$$ Ans

b. In the case when motion is linear but back and forth along a line, the distance traveled by the object is measured as the shortest distance between the starting point and the end point. This is because of the vector nature of various related physical quantities and the relationship between them which will be discussed in detail in the second part of this series.

In this case, when the object is passing through its original position, the shortest distance between the starting point and the end point will be zero which means, $s = 0$.

$u = 20$ m/s and, $a = –10$ m/s^2 (acceleration and the direction of motion at the start are in the opposite direction. So gravitational acceleration will actually be decelerating the motion.)

Now, applying second equation of motion, $s = ut + ½at^2$

$$0 = 20 \text{ m/s X } t + ½(–10 \text{ m/s}^2) \text{ X } t^2$$

$$0 = 20t – 5t^2$$

$$0 = 5t(4 - t)$$

ð $t = 0\,s$ or $4\,s$

Since $t = 0$ corresponds to the starting time, the ball will pass through the same position after 4 seconds. Ans

c. The total time taken by the ball to reach the ground can be calculated in two parts:

1. Time taken by the ball in coming to its starting position, and

2. Time taken by the ball to go further and reach the ground.

We have already calculated the time taken by the ball to come to its original position and that is 4 s.

Suppose the ball takes 't' seconds more to reach the ground,

Applying second equation of motion, $s = ut + \frac{1}{2}at^2$

ð $60\,m = 20\,m/s \times t + \frac{1}{2} \times (10\,m/s^2) \times t^2$

Re-arranging quantities on either side of the equation:

$$5t^2 + 20t - 60 = 0$$

$$t^2 + 4t - 12 = 0$$

$$t^2 + 6t - 2t - 12 = 0$$

$$t(t+6) - 2(t+6) = 0$$

$$(t+6)(t-2) = 0$$

ð Either $t - 2 = 0$ or $t + 6 = 0$

ð $t = 2\,s$ or $t = -6\,s$

Since $t = -6$ s represents a meaningless quantity, $t = 2$ s will be the time taken by the ball to reach the ground after crossing the starting position.

Therefore, the ball will reach the ground in $4+2 = 6$ seconds. Ans

Index

This module was conceptualised and written mainly by Rama Chari, Himanshu Srivastava and Pragya Shrivastava, with preliminary inputs from Pallavi Sukhtantar and Vikram Chourey.

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Eklavya is a non-government registered society working in the fields of education and people's science since its inception in 1982. Its main aim is to develop educational practices and materials related to a child's environment that are based on play, activities and creative learning.

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Motion and Force

Part 1 - Motion

Force and Motion is considered one of the fundamental topics in science and is therefore taught in middle and high schools. However, the topic is treated in a perfunctory manner, forgetting that the current understanding of motion, and the development of concepts like speed and acceleration took place over a period of two thousand years.

We have tried to tackle these difficult concepts in the modules on Force and Motion. In this, the first module, we have concentrated on describing motion in a scientific manner. The module is primarily aimed at teachers. It presents a sequence of activities worked out on the basis of detailed discussions with subject experts and feedback from teacher-training sessions that lead to an understanding of Motion.

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