MOTION

If you were to drive or design a scooter, a car, a truck, a train or an airplane you need to know about speed, velocity, acceleration etc. These terms helps you describe and analyze motion. You can also use these terms to analyze a cycle ride, a walk, an animal's motion, a shooting star etc. This chapter will help you to learn the scientific way to investigate and analyze the motion in a straight line.

Content

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Motion in One Dimension

The boy in the picture is riding his bicycle straight down the road. But look at the wheel and pedals of the bicycle. They are rotating around the axle. The boy turns the handle of his bicycle to the left or right to change the direction in which he is moving. So there are many different kinds of motion happening simultaneously as the boy rides his bicycle.

So there are many different kinds of motion in real life. We can sort these different motions into three simple categories:

- **One dimensional motion:** In this motion, a body moves along a straight line. A train moving along a railway track is an example of straight line motion, if you ignore the motion of its wheels or the slight curves in the track. It is also called rectilinear motion.
- **Two dimensional motion:** In this motion, a body moves on a plane and does not remain on a straight line. For example, an ant moving randomly on a plane floor.
- **Three dimensional motion:** In this motion, a body moves like a bird flying through the air.

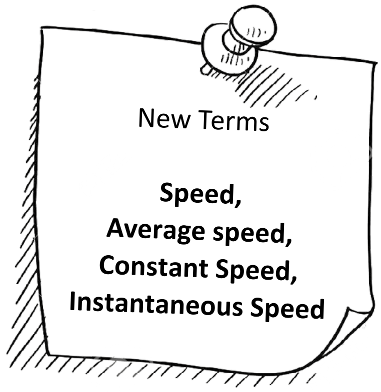
These categories help us to design simple experiments (along with control experiments) so that we can study different motions in greater detail.

In this chapter, we shall study straight line motion, which is the motion that occurs along a straight line and is also known as linear motion or motion in one dimension.

- A train moving along a railway track is an example of straight line motion, if you ignore the motion of its wheels or the slight curves in the track.
- A bus traveling on the road is also an example of linear motion, if you, again, ignore the motion of its wheels and how the driver turns the steering wheel.
- The boy riding the bicycle down the road is yet another example of motion in one dimension, if you, once again, ignore the motion of the bicycle wheels and the boy turning the handles.

We shall learn how to describe one dimensional motion using quantities such as distance, displacement, time, speed, velocity and acceleration. We shall also learn in detail what these quantities are.

1 SPEED



Some leading questions

What is speed and what does it tell us?

What is average speed and how do we calculate it?

What is the difference between average speed, constant speed and Instantaneous speed?

Activity 1

Your teacher will show you a video of a man riding a scooter. Watch the video, discuss it in class, and then answer the following questions:

1.	At what time did the man begin to ride his scooter?	
2.	At what point (kilometer) did he start his journey?	
3.	How long did the journey last?	
4.	What distance did he cover?	
5.	Did the scooter move at constant speed or did its speed change?	
6.	What was the fastest speed recorded on the speedometer?	
7.	If the man rode the scooter at this fastest speed, what distance would he have covered in an hour?	

In real life, If two objects move along the same path, with one following the other, we can easily tell which object is moving faster or slower. But this visual observations can not tell how fast or slow an object is moving.

For this, we need to be more precise in measuring speed than just saying one object is sower or faster than the other

In the case of the scooter rider, we saw two measurements of speed, both of which have different values. The first (i) was the speed indicated at any given time on the speedometer. The second (ii) was the speed at which he covered the whole journey. Both speeds (i) and (ii) are different. The first is called the instantaneous speed and the second is the average speed. Let us discus them in detail and see how we calculate the average speed.

1.1 Average speed

We have the following data about the distance and time of the journey of the man on the scooter:

Ride starts		Ride ends	
Distance (d_0)	Time (t_0)	Distance (d_1)	Time (t_1)

Usually 'd' and 't' are used to denote distance and time respectively. Here, d_0 corresponds to time t_0 and d_1 corresponds to time t_1. Delta, Δ is a Greek symbol and used to denote the difference.

Total distance covered, $\Delta d = d_1 - d_0$

$= 6-0$ km

$= 6$ km

And, time taken to cover this distance, $\Delta t = t_1 - t_0$

$= 15-0$ minutes

$= 15$ minutes

Now, to calculate the speed, we divide the total distance covered by the total time taken for the journey;

Speed, v = Total distance covered / time taken to cover this distance

$$v = \frac{\Delta d}{\Delta t}$$

$$= \frac{6 \text{ km}}{15 \text{ minute}}$$

$$= 0.4 \text{ km / minute}$$

The scooter rider covered the entire journey at a speed of 0.4 km per minute. We call this the average speed.

The average speed of an object is the distance travelled by the object per unit of time. It helps us to estimate future trends of the motion.

Let's take another example to understand what an average speed is:

The distance to a nearby town is 60km. A bus takes two hours to cover the distance. We can use the motion equation to find out that the average speed of the bus is 30km/hour. Knowing the average speed of the bus, we can now safely assume that it will take us two hours to reach the town. Of course, sometimes it may take a little more time if the bus halts many times along the route. Or it may take less time if the driver drives faster than 30km/hour.

We can calculate the average of any similar quantity, such as the average weight, height or age of students in a class.

1.2. Choosing an appropriate unit of speed

It is important to write the unit of measurement. Speed is the ratio of distance and time. So we use both the units of distance and time to write the unit of speed – kilometer/hour (km/h), kilometer/second (k/s), meter/hour (m/h), meter/minute (m/min), meter/second (m/s) and so on. The division symbol '/' is read or written as 'per', as in meters per second. We choose the unit of speed according to the context. In the case of the scooter rider, we chose km/hour and km/minute to calculate the speed. But if we want to calculate the speed of an ant, then km/hour would be too large unit. A better choice would be meter/minute. For a snail that moves even slower, cm/second could be the preferred unit. In scientific calculations, the most widely used unit is meter/second.

Note: Once you decide on a unit, use the same unit for all measurements for the convenience in calculation.

1.3. Constant speed

In the video of the scooter ride, we noted that the speed of the scooter kept changing according to the situation on the road. But suppose the rider maintained the speed of the scooter throughout the journey, not less or more, regardless of whatever obstacles that came in his way. This unchanging speed is known as constant speed. For example, the speed of the tip of the minute hand or second hand of a clock. Can you measure the speed of the minute hand of you wrist watch? Think of other examples of constant speed.

1.4. Instantaneous speed

The scooter rider travelled only 6 km during the entire journey but we saw that the speedometer sometimes showed a speed of 5 km/hour, sometimes 20 km/hour and sometimes 40 km/hour and so on. This speed, which changes frequently, is known as the instantaneous speed. It is the speed of a vehicle or object at any given moment. If you travel in a bus or car, you will see that the speedometer needle doesn't stay at the same point but keeps fluctuating. What you see is the instantaneous speed of the vehicle.

Food for thought:

1. Find out from the driver of a bus or car how many km his vehicle runs per liter of fuel. Ask him how does he calculate the average speed.
2. Is it possible for a person riding a bicycle, bullock cart or motor vehicle to maintain a constant speed?
3. Find out from your school principal what kind of data on schoolchildren (average height, weight, number etc.), he/she has to submit to the authorities. How were these averages worked out?
4. Newspapers often carry news items about drought and flood in which they give statistics of the average rainfall in the region. Similarly, in summer/winter they give average day temperatures. Try and find out how this data is collected and calculated.

To sum up

You need a set of pre-recorded data on time and distance to work out the average speed of an object. It is this average speed that we usually refer to in our day-to-day conversations. Constant speed is when the object moves at the same speed and it is difficult to achieve practically. Instantaneous speed is the speed of a moving object at any given time.

Exercise:

1. The distance to the local village market is 24.6 km. It takes four hours to reach the village by bullock cart. What is the average speed of the cart?

2. Lala is a vegetable farmer. He sells his vegetables in the city market. He sets out for the city at 5:00 am in the morning, carrying the vegetables in a basket on his head. He walks for one kilometer and rests at a square for 15 minutes. Another farmer Rama joins him there. Together, they walk another kilometer to reach the main road. A small truck, ferrying vegetable sellers from different villages, picks them up. They travel another 8.5 km in the truck and By 8:00 am, they reached in the market and set up their shops. What is the average speed of Lala for entire journey?

3. Pari and Liani walks to their school 2.9 km away their homes. Pari uses a zig-zag path to reach the school while Liani takes a straight path. The table below tabulates the time taken to reach the school by them for a week.

Time	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Taken by Pari (minute)	65	68	69	64	66	64
Taken by Lani (minute)	60	59	59	61	60	63

(i) What is the average time over the week to reach the school by them?
(ii) What is their average speed per minute and per hour?

4. The average speed of a motorcycle is 40 km/hour. Can its instantaneous speed be more or less than 40 km/hour at any time?

5. A bicyclist covers a distance of 10 km. For the first 2 km he travels with a speed of 5 km/h, next 3 km with a speed of 3 km /h and the rest 5 km he covers with a speed of 4 km/h. Find his average speed.

6. Following are the details of the distance travelled by a train in different time segments. Using this data, calculate the average speed of the train in these different time segment.

Time in seconds	Total distance travelled in Kilometer	The distance travelled in that particular time segment	Average speed in each segment
0	0	0	
10	4	4	
20	12	8	
30	29	17	
40	48	19	
50	66	18	
60	84	18	
70	100	16	
80	117	17	
90	130	13	
100	135	5	
110	155	20	

2 VELOCITY

New Terms

Observer,

Frame of reference,

Displacement,

Velocity

Some leading questions

Is it possible to describe the motion of an object without a reference point?

What is the role of the observer or reference point in describing motion?

What is the difference between distance and displacement?

Why do we need both displacement and time to describe motion?

We take motion so much for granted in our daily life that it appears absurd to even think about describing it. The moment we begin any attempt to describe it we realize what a riddle motion is. We need to solve this riddle to understand the principals behind motion that eventually helps us make meanings of quantities such as speed, velocity and acceleration.

2.1. Riddle - Motion is relative

Do you remember the scooter video? Now, just imagine if the scooter does not have a speedometer, no trees passing by, no vehicles coming from behind or in front, no houses along the roadside, not looking along side the road, and no air pressure, then would you be able to prove that the scooter is moving?

You know that the earth rotates on its axis and also revolves around the Sun at a speed of nearly 30 km/second (1,800 km/minute). We all live on this moving Earth so we, too, are moving with everything else. Then why do we say that the trees and mountains are stationary while the vehicles on the road are moving? When we describe the Earth, we don't consider its motion but assume that the land is stationary. So the land becomes our reference point to describe the different kinds of motion. The trees, mountains, roads and houses are also stationary because they don’t change their position on this stationary land. But the scooter is in motion on the road. We use the stationary objects on earth as evidence to show that the scooter is moving, even though we know that everything on earth also spins and revolves with the earth’s heavenly motions.

Try to describe whether an object is moving or stationary without reference to another object.

Motion is relative and we can describe it only in relation to another object.

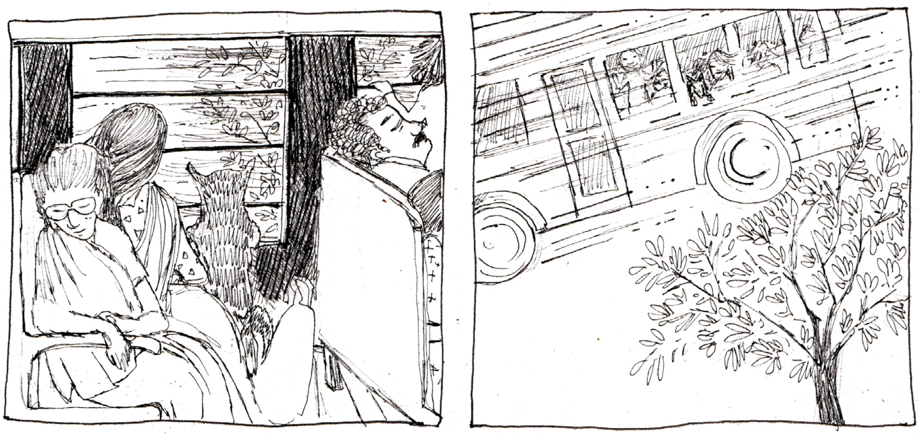
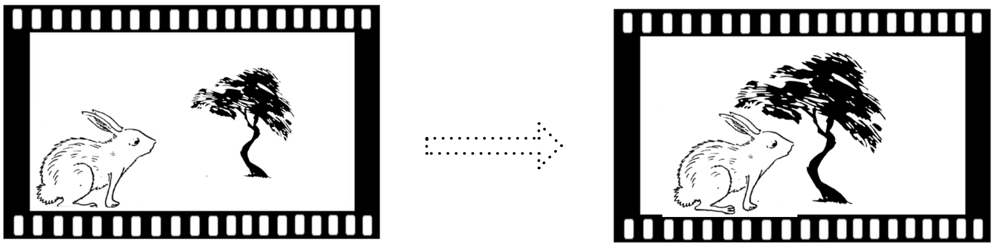
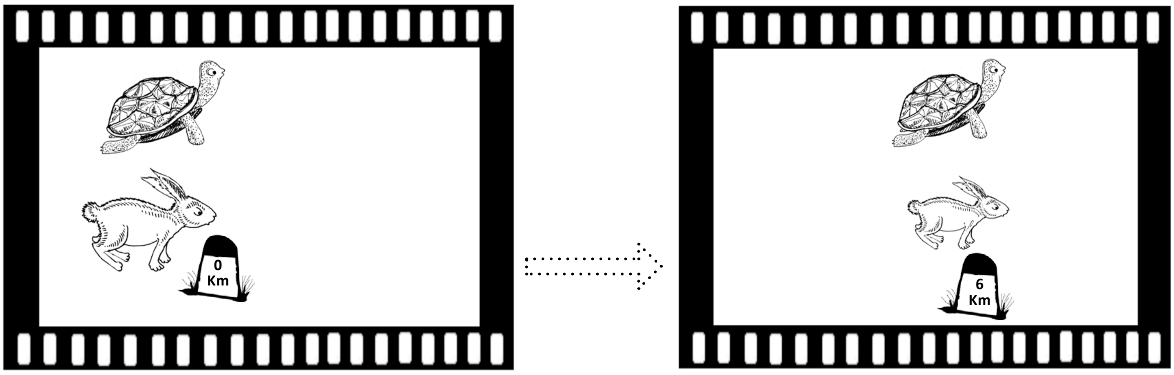


Figure: Two perspectives of relative motion: a tree seen from a moving bus and the bus seen in motion relative to the stationary tree.

Look at the picture of the rabbit given below and say whether it has moved or not. If your answer is yes, explain on what basis you have defined the rabbit's motion.



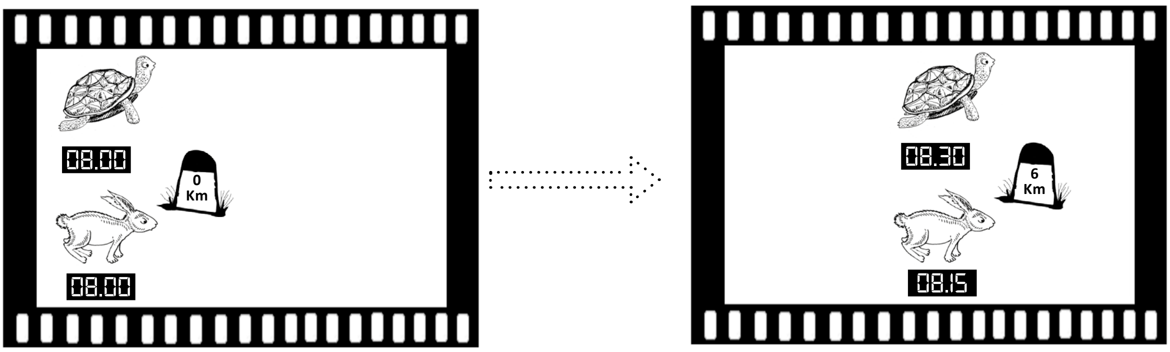
We now replace the tree with a kilometer stone to help us to find out the distance travelled. Now, consider a tortoise along with the rabbit in the picture.



Were both the tortoise and rabbit in motion? What is the reference point?

You know a tortoise moves much slower than a rabbit. Can you tell by looking at the picture which of the two moved faster and which slower? Do you need some more information to answer this questions?

Now, look at the third picture. Can you now tell who moved faster and who was slower? Did the clock help you in arriving at your decision?



You used the kilometer stone (displacement) and clock (time) to tell which is slow or fast. So we can say that when an object moves from one point to another, then it takes some time. That means to describe motion we need to know the change in position with respect to time. Further we will learn about other concepts such as velocity and acceleration, which also depend on the change in position and time.

2.2. Distance versus Displacement

Distance and displacement are important concepts to understand motion. Let us consider journey from point A to B. You can take any path to reach from point A to B. The path length covered to reach point B from A is called distance. You can also travel in a straight line to reach point B. The straight line joining from A (initial position) to B (final position) is called displacement of the object from

Point A to B. The displacement also shows the direction of the point B with respect to the point A. So, the displacement has both magnitude (a number) and direction.

A…………………………………..B

<--------------Δd-------------->

Displacement, Δd = final position - initial position = $d_B - d_A$

Distance and displacement are not equal.

Exercise: Fela starts walking from point A. He walks 500 meters to the right and comes back 200 meters.

(i) What is the total distance covered by Fela during the walk?

(ii) Show his journey by drawing in the number line given below.

0-------100--------200--------300---------400---------500

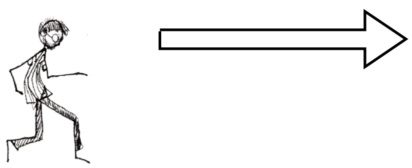
(iii) What is the displacement for Fela's journey?

(iv) Is the distance equal to the displacement?

Remember that Displacement is shown by the straight line from the Initial point to the final point of the journey.

Displacement can be positive or negative. We have stated above that displacement includes the magnitude along with the direction.

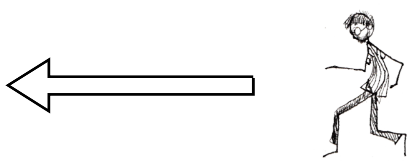
The motion in the right direction is considered to be positive direction.



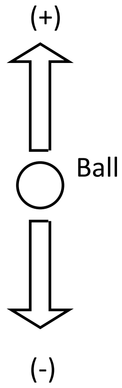
(+)

The motion in the left direction is considered to be negative direction.

(-)



The motion in the upward direction is considered to be positive direction.



The motion in the downward direction is considered to be negative direction.

Example: If Fela moves 200 meter to the right from the initial point i.e. from 0, and then moves 300 meter to the left. Please mark his movement on the path given below. Please determine the displacement during the entire journey.

-300--------- -200 ---------- -100--------0-----------100--------200--------300---------400

Example: Fela standing on the ground throws a ball vertically upward which goes to 5 meter height and he catches it back. What is the displacement of the ball and distance covered by it.

Work area

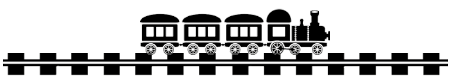
2.3. Velocity

When we say a scooter is moving at a speed of 40 km/hour there is no information about the direction of its motion. When we also inform the direction with the speed, then it called velocity. Velocity as the rate of change of displacement.

The quantity that has a direction along with magnitude is called a vector quantity.

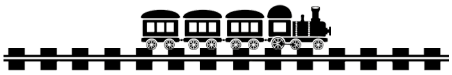
Therefore velocity is also a vector quantity. It changes if any of its components – magnitude or direction change. So if we say scooter is moving at speed of 40 km/hour towards north, we are talking about its velocity because it has speed in a specific direction.

Four diagrams of a bus or any moving object:



Train

Speedometer

Velocity constant – speed (magnitude) & direction fixed 
Velocity changes - speed changes but direction fixed 
Velocity changes – speed constant but direction changes 
Velocity changes – both speed and direction change 

Velocity can be instantaneous or average. If the instantaneous velocity of a scooter is 20 km/h (speedometer reading) northwards, then its instantaneous speed is also 20 km/h. Both are of the same magnitude (20 km/h) but instantaneous velocity has the additional information of direction. The average velocity of an object is the distance covered by the object in a unit of time in a particular direction – or its displacement in a unit of time. It can be calculated as follows:

$$\text{Average velocity} = \frac{\text{Total displacement}}{\text{Total time taken}}$$

Now, consider the motion of a boy. Let us assume that he takes 1 minute to walk 100 meters. Then he will take 15 minutes to cover the distance of 1,500 meters from A to B and back to C. His speed from A to B is 100 m/min while his velocity will be 100 m/min in the direction of the line AB. So the magnitude of velocity and speed are the same for this part of the journey.

C A B

-500 ---0---+500

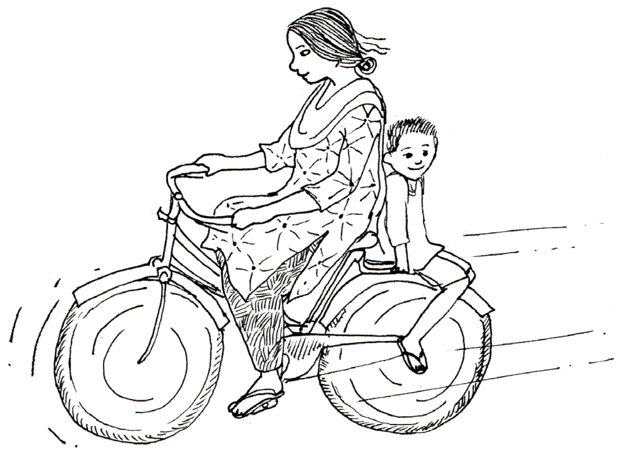
On his return journey from B to A, his speed is still 100 m/min but his displacement is zero because he comes back to its initial point A. Further, when he goes from A to C via B, the speed will be 1500 meters/15 min i.e. 100 m/min, but the velocity will be different as the displacement is 500 m leftwards,

$$\text{Velocity, } v = \frac{500 \text{ m}}{15 \text{ min}}$$

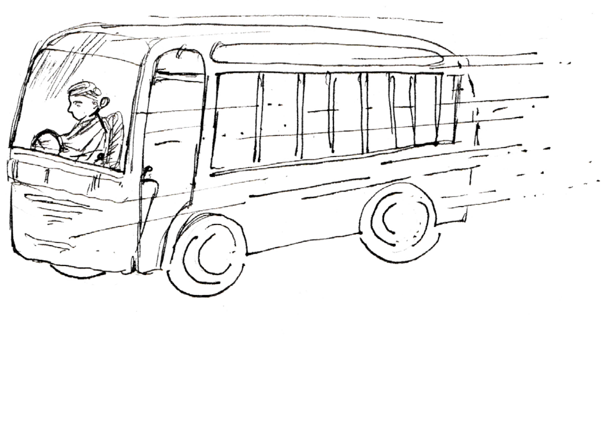
$$= 33.3 \text{ m/min}$$

Food for thought

Identify the parts of a bicycle that help you change its velocity?



Identify the parts of a bus that help in changing its velocity?



3 GRAPHS OF MOTION

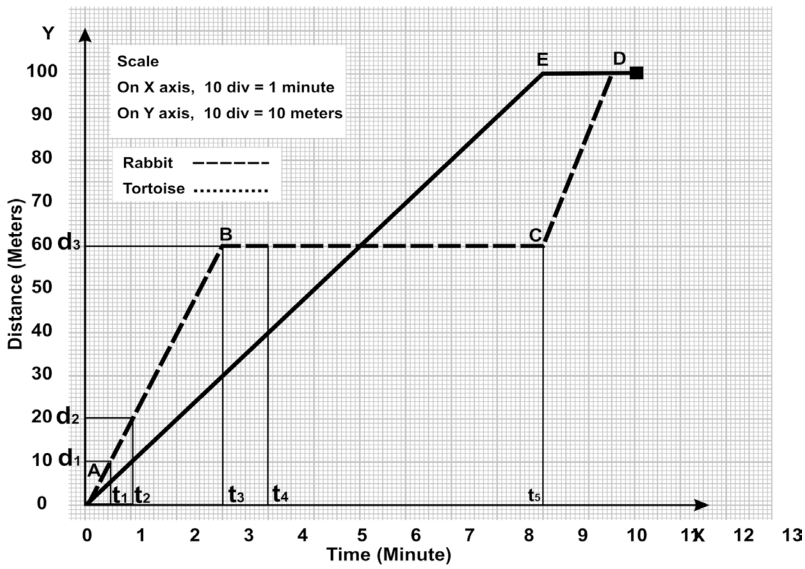
3.1. Distance-time graph

You must have heard the famous story of the race between a tortoise and a rabbit. In the story, rabbit runs faster and stay in the way while tortoise runs with slower speed but moved continuously till end point. Finally slow runner wins the race. Using the time and distance graph given below, tell your friends how both rabbit and tortoise were moving over time compare to each other. For this, you need to know how to interpret the graph.

Graph is made up of horizontal and vertical lines. You show two variables on two axis of the graph respectively. On the graph paper the thick lines are centimeter lines. The space between two centimeter lines is divided into 10 equal parts each equals to one millimeter. In the graph of motion you deal with distance-time, displacement-time, speed-time, velocity-time and acceleration-time. The relationship between these two helps you to discover the nature of motion.

The graph below depicts the story of the race between a tortoise and a rabbit.

On the line segment AB in graph distances d_1 and d_2 corresponds to times t_1 and t_2, which shows



positon is changing with respect to time. That means line segment AB in graph represents motion. Similary line segments CD and AE also represent motion. Now, you can see on the line segment BC, distance from origin d_3 corresponds to time t_3. Further, distance d_3 also corresponds to time t_4. For two different times we have same distance from the origin. So for this segment of graph, position is not changing with time and this represents the state of rest.

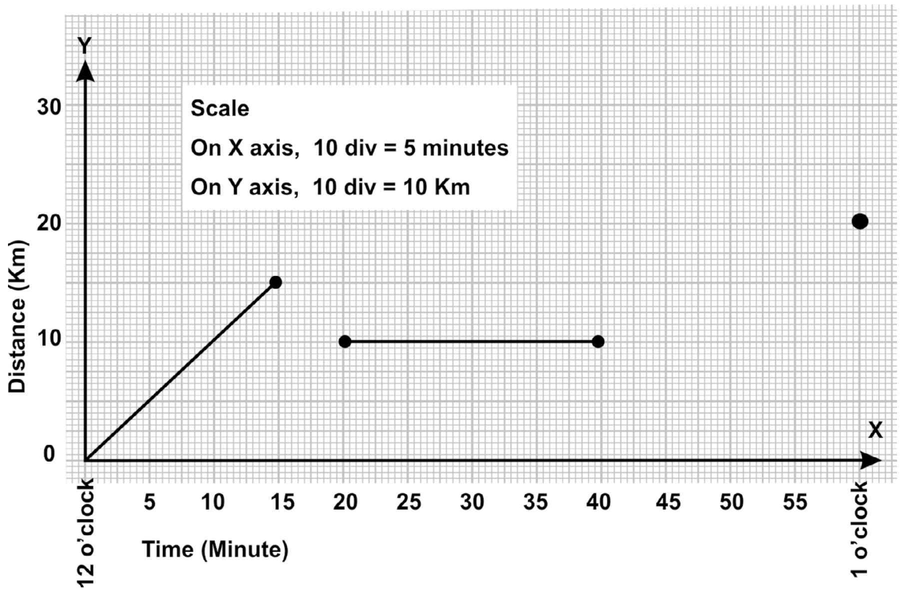
Can you figure out which curve (ABCD or AED) corresponds to rabbit' s motion and why?

Use the table given below to make another graph of the race between the tortoise and rabbit.

Note: ***Tortoise covers equal distance in every one minute. Look at the slope that shows equal distance in equal time.***

Time (Minute)	Rabbit (Meter)	Tortoise (Meter)
0	1	0
1	20	10
2	40	20
3	60	30
4	60	40
5	60	50
6	60	60
7	60	70
8	60	80
9	60	90
10	60	100
11	87	100
11.5	100	100

***Example 1*:** A goods train is going from Itarsi station to Bhopal Station. At 12:0 PM it leaves Hoshagabad and after 15 minutes at an upward track, its engine and brakes get failed and the train rolls backwards for 5 km and stop at a plane track. The driver and the train guard informs the controller. A new engine takes 20 minutes to arrive there. New engine pulls the train and helps it to cross the valley in next 20 minutes. The graph and table given below is based on this story but both are left incomplete. Can you draw the remaining portion of graph and fill in the table as well?



Title................

Time (min)	Distance (km)
12.00	0.0
12.15	......
....	10
12.40	.....

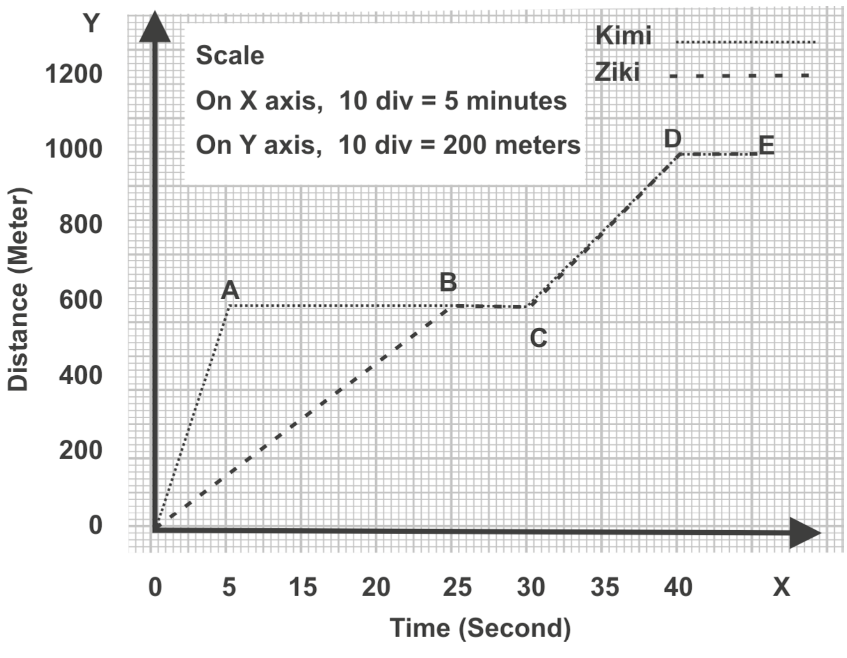
Note: ***In a position-time graph, if slope, runs horizontal for some time, parallel to the x axis, what kind of motion does it depict? Is train at rest or in motion? Explain.***

Work area

A way to choose an appropriate scale:

In the given example the train covered 20 km in one hour. The story started from Itarsi City but the part of the story that was depicted in the graph started from 12 in the afternoon. You know that in motion graphs, time is always shown on the x axis and the other variable such as distance or velocity is depicted on y axis. The starting time for the story was 12:00 PM. After that you were needed to show the passage of one hour. Also you chose 5 minute as equals to one centimeter on the graph scale. Whereas, on the y axis, you needed to show the a distance of 20 km. It was not possible to show the real distance on the graph. Therefore, you chose the scale of 1 centimeter on the graph as equal to 10 km of distance. You can also choose one centimeter equal to 5 km on the y-axis. Make a new graph using this scale also. Does the slope pattern changes from the previous graph?

Example 2: The graph given below shows the journey of two sisters Kimi and Ziki from their home to the school. Kimi takes a stop at a book shop. After a while Ziki also joins her. Then from the shop they go to the school together. Fill up the table given below using the information given in the graph.



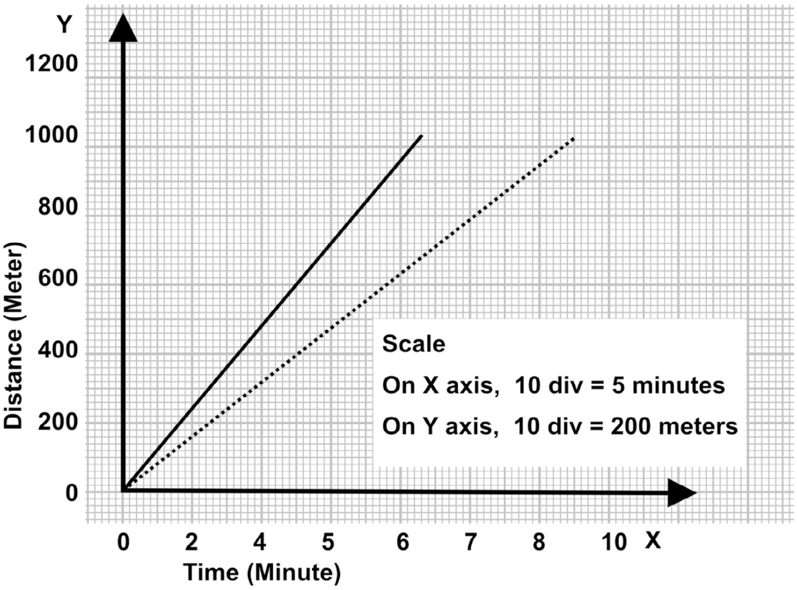
Time (sec)	Kimi (m)	Ziki (m)
0		
5		
15		
20		
25		
30		
35		
40		

Answer the following:

(i) Who does take less time to reach the shop?	
(ii) For how long Kimi stayed at the shop?	
(iii) Can you identify the part of the line depict Kimi's stay at the shop?	
(iv) What was the distance between the school and the shop, between the home and the shop?	

Observation: ***Steeper the slope, faster will be the speed. Slope is the angle made by line with x-axis. Greater the angle, higher will be the speed.***

Example 3: Vimal and Abid participate in 1000 meter race. The slope of the graph shows their run. Who ran faster, Abid or Vimal and how do you say that?

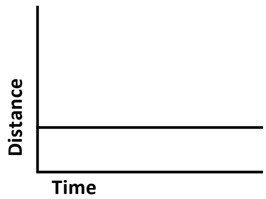


Work area

Example 4: A school bus with kids leaves the village at 10 AM. At 11 AM when it reaches the bridge, river was flooded and flowing over the bridge. It has to stop there for two hours. At 1 PM, when river flow goes down the bridge it crosses it, it takes the bus another hour to reach the school. By that time the school is already over. It begins its return journey right away. In just one hour it drops the kids to the village. Depict this story on a graph paper. (Use the graph paper given at the end of this book)

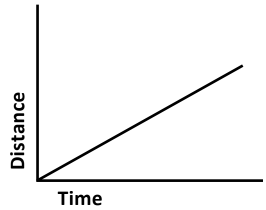
When you get a slope a plot on a graph like this then:

- Time is increasing but the object is not moving i. e. object is at rest.



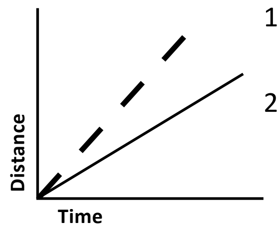
What does this slope say:

- The object covers equal distance in equal time therefore its speed is uniformally increasing i.e speed is increasing at constant rate.



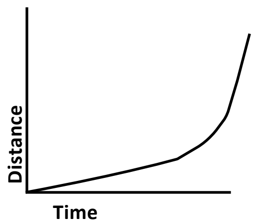
How do you compare these slopes?

- The steeper the line1 - the larger distance it covers in shorter span of time. Therefore its speed is higher.
- The less steeper line2 suggests that the object has covered lesser distance than the steeper line.



How do you interpret this curve?

- The object is covering greater distances in any next time interval. Therefore it shows changing speed.



3.2. Velocity-Time graph

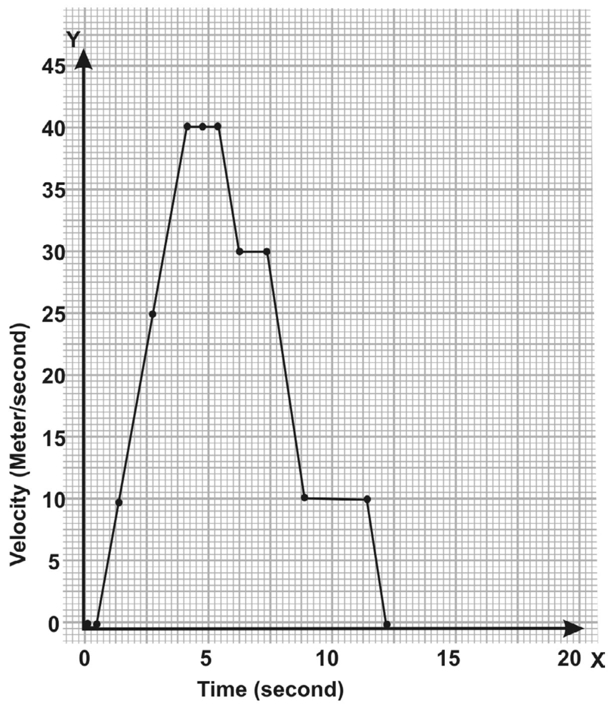
Excercise 1: Look at the following graph which shows a motorcycle ride.

(i) Mark the point(s) on the graph that shows the motorcycle is at rest.

(ii) Mark the point(s) on the graph that shows motorcycle with constant velocity.

(iii) Complete the table given below based on the graph.

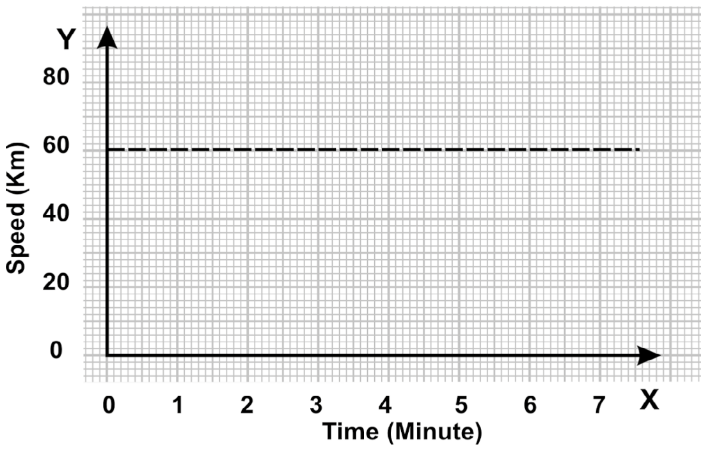
Time (sec)	Velocity (m/s)
0	
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	



Excercise 2: Police control room recieves an information that a black suspicious car is going to pass, please stop it and check it. At 12'o clock the car passes in front of the station. The police start their patrolling jeep exactly at 12'o clock but for 2 minutes they could not move the car due to some engine issues. Please answer

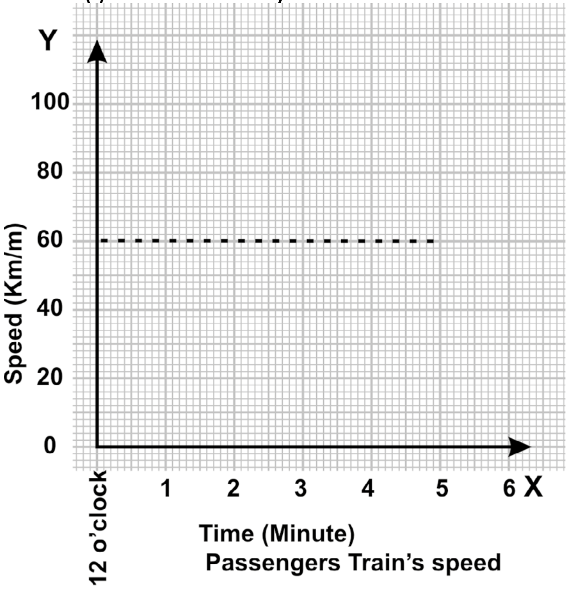
(i) If the car is moving still why the line is horizontally running parallel to the x axis?

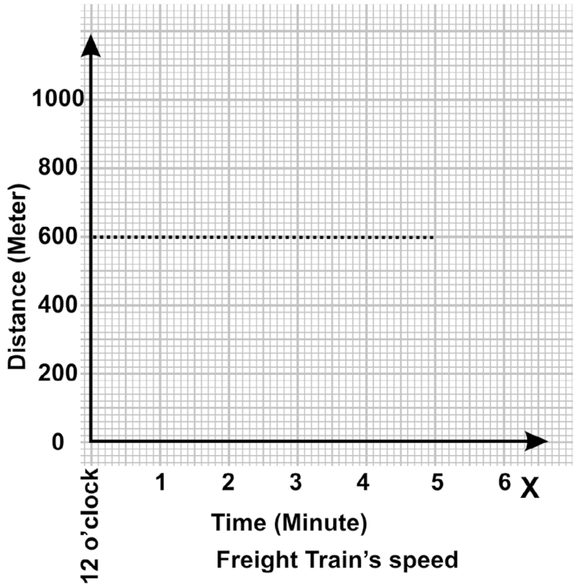
(iii) Please draw the first 5 minutes of the police jeep when it was not able to move. Draw the line on this graph.



Excercise 3: Look at the graph and answer the following:

(i) Please identify which train is in motion and which one is at rest.

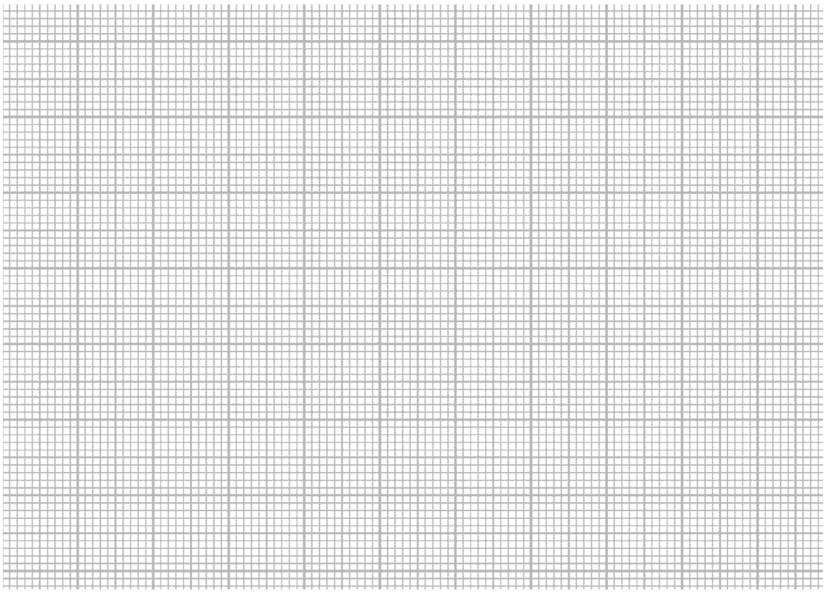




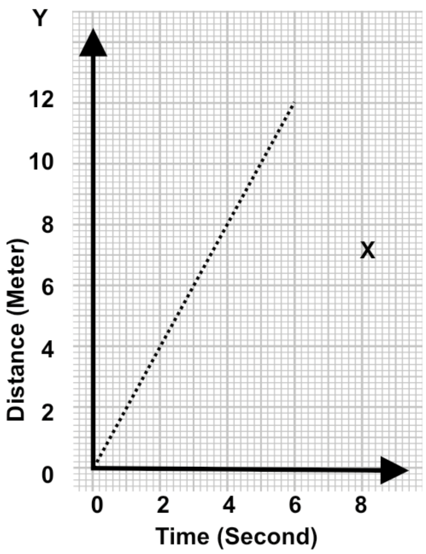
(ii) Tell us how these graph are different

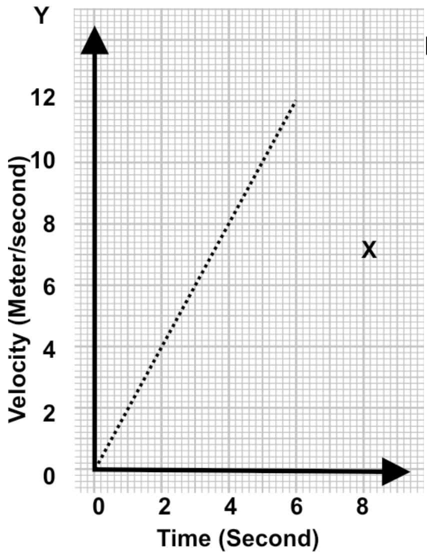
Excercise 4: Use the data given in the table below to plot the graph of two objects moving with different velocities.

Time (s)	Object 1 velocity (m/s)	Object 2 velocity (m/s)
0	0	0
1	2	1
2	4	2
3	6	3
4	8	4
5	10	5
6	12	6



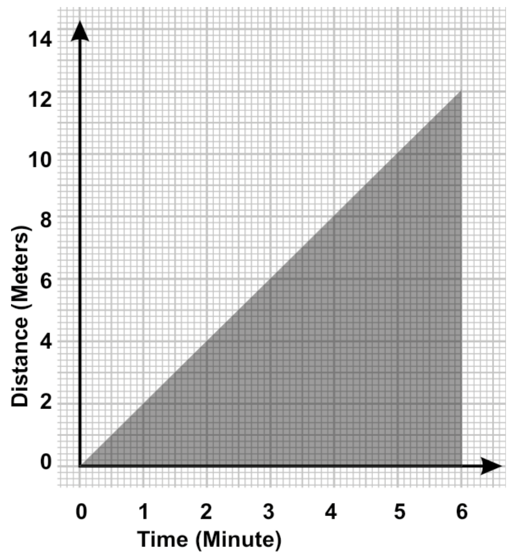
Excercise 6: Look at these graphs – do they represent same kind of motion: how do they defer from each other?





Distance-time
Velocity-time

Problem: Look at the velocity-time graph of a moving object. The area enclosed by the velocity-time curve and time axis gives you the total distance covered by the moving object. You will learn this in the equation of motion. Please fill up the blanks to get the distance for the graph given below.



Area of a triangle = ½ x a x b

= ½ x……x…….

= 36 unit

You will use this method to find the distance in section on equation of motion, where you will learn how to relate four quantities to get equations

to work out complex problems of motion.

4 HOW TO FIGURE OUT CHANGE IN VELOCITY

New Terms

Uniform motion, non-uniform motion

A leading question

How do you find out if motion is uniform or non-uniform?

We need displacement and time to describe motion. We also know that velocity can be described in units of km/hour, meter/second, meter/second etc. We need to choose the right unit according to the context.

Let us look at few problems.

A vehicle covers a distance of 1 km in a given time.

Start | Finish

Can we say whether its velocity over this 1 km stretch is uniform or non-uniform?

Remember the scooter video. We knew the distance (6km) and the time taken by the scooter to cover this distance (15 minutes). So we could calculate its average speed at 0.4 km/minute, or 24 km/hour. But could we tell whether its speed was uniform during the journey or whether it kept changing? If we had not looked at the speedometer, could we say that the instantaneous speed sometimes rose to 40km/hour and sometimes fell to 5 km/hour?

> Motion is considered to be uniform if the speed does not change with time. In non-uniform motion, the speed changes with time. The change could be irregular or it could have a regular pattern.

We need data to prove whether a motion is uniform or non-uniform. So we need to design an experiment that clearly tells us whether the motion is uniform or non-uniform.

4.1 A way to investigate motion

Suppose you run a 50-meter race. Could you estimate whether you will run from start to finish at the same speed or whether your speed will vary?

You may have also ridden a bicycle down a slope without pedaling. Did its speed increase as it rolled downhill? Did the speed keep on increasing?

To study how speed changes we need to observe it at small intervals of time, say every minute or even every second.

0min 1min 2min 3min 4min 5min 6mn 7min 8min 9min 10min

If the object covers the same distance in every equal time interval (minute), then it is moving at constant speed. So the motion is uniform.

If the object covers different distances in every equal time interval, then its motion is non-uniform.

We can also study how motion changes by studying it at equal intervals of distance (say, 100 meters).

0 km/0km 100 m 200m 300m 400m 500m 600m 700m 800m 900m 1000m

We now measure the time the object takes to cover each distance segment (100 meters). If it takes the same time to travel each segment, then its motion is uniform.

If the time the object takes to cover each successive 100 meters is different, then its motion is non-uniform.

Activity 1:

You need to organize a race for this activity. All the students in a class, including you, can participate in this running activity. Let us see whether the motion of a runner in a race is uniform or non-uniform.

Materials required: measuring tape or meter scale, stop watches, paper and pen

Choose a track that's 24 meters or 48 meters in length. Divide it into four equal segments. The 24-meter track would be marked at intervals of 6, 12, 18 and 24 meters while the 48-metre track would be marked at intervals of 12, 24, 36 and 48 meters.

Have a timekeeper with a stopwatch at each segment. Another person can blow the whistle for each runner to start. When a runner reaches the 6-meter segment, the timekeeper there stops his stopwatch. The same process is observed at each successive segment till the runner comes to the end of the 24-meter track. The time on the stopwatches at each segment are noted in the table given below (drawn for a 24-meter track):

Name of the participant	Time taken (sec) for Segment 1 (0-6 meter)	Time taken (sec) for Segment 2 (6-12 meter)	Time taken (sec) for Segment 3 (12-18 meter)	Time taken (sec) for

The average velocity equation is $\Delta V = d_1 - d_0 / t_1 - t_0$. Now fill the table given below for each segment. (It is similar to the average speed)

Name of participant	Average velocity for Segment 1	Average velocity for Segment 2	Average velocity for Segment 3	Average velocity for Segment 4

(i) Did you run the way you had estimated?

(ii) Did you take the same time to run each segment?

(iii) Did you run so that your speed kept increasing?

(iv) If you had data for only two time intervals - the beginning and the end – would your average speed give you any indication of the way your speed varied while you were running?

So, to tell whether a motion is uniform or non-uniform, we need to measure the velocity at equal time intervals. If the velocity remains the same, we can say the motion was uniform. If it varies, we can say the motion was non uniform.

Non-uniform motion is quite common, everyday examples including a bus traveling on the road, birds flying, breeze blowing, water flowing. It is difficult to find an examples of uniform motion around us.

What do you think: Suppose the motion for a particular time interval is uniform, what is the possibility of the motion becoming non-uniform if the time interval is shortened?

In principle, we can make the time interval shorter and shorter. But in reality there is a limit to what we can measure. So the time interval should always be clearly specified.

If we analyze the data of all the runners in your class, we can find out who the fastest runner is and who is fastest in each segment.

Choose four runners to form a relay team for each segment.

The running example gives you an idea about one kind of uniform motion where the change in velocity is irregular and has no pattern.

(i) What do you think of a bicycle rolling down on a slope?

(ii) Do you think it will gain speed gradually or speed gain would be erratic?

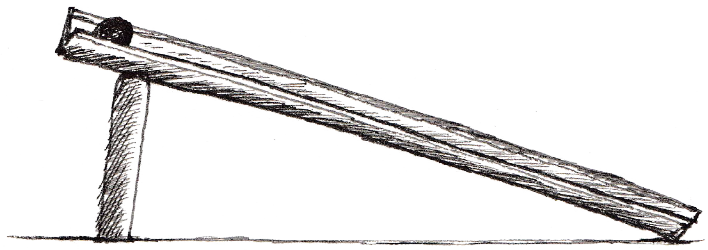
(iii) If the speed increases with the slope, and if the slope continues the speed will also keep on increasing?

(iv) Even if the slope increases there, will there be a limit to the speed?

As in the case of the running race, we will need to describe the motion of a bicycle on a slope in terms of distance covered and time elapsed. In the section non uniform and uniform motion, you have learnt that to predict the nature of motion we need to record the distance covered by an object in shorter and equal time intervals. For a cycle on a real road, it will be difficult to record data – there will be other people and vehicles on the road, it will be difficult to find the right place to sit and spot the cycle etc. Now, let’s design a control experiment.

ACTIVITY 2:

We can design an experiment that will be similar to the bicycle ride on the slope. You will be able to record data with better accuracy. We will replace road with an aluminium or wooden plate and cycle with a steel ball or a marble. We will call it inclined plane experiment.



Material Required: An aluminum angle of 160 cm length, a marble or a steel ball of 1 inch diameter, Stop watches etc.

Choose any side of the angle and mark a line across its width at every 1 or 2 cm. Choose your starting point or zero point at 0 cm mark. Now measure the rest of the length and divide it in equal 30 cm segments. You will get around 5 segments. Raise one side just enough so that if you leave the steel ball from top, it smoothly rolls down till the end. Use stop watches to record the time it takes to cover each segment. Please coordinate in your group so that everyone gets a chance to record the time. Use the following table to collect data.

Segment	Time t for 1st run (s)	Time t for 2nd run (s)	Time t for 3rd run (s)	Time t for 4th run (s)	Average time (s)	Average Speed (m/s)
0-30 cm						
30-60 cm						
60-90 cm						
90-120 cm						
120-150 cm						

Like the race you need to synchronize with your group members to record the time. Repeat the experiment many times and record data in the table as shown above. Table shows only two set of the experiments. You can extend the table in similar fashion for more sets. Now, answer the following,

(i) Was it easy to record the time?

(ii) Was the error manageable or high?

(iii) Does the speed of the ball change with time?

The ball rolls down sometimes with such a speed that it gets difficult to record the time accurately. Sometimes at the top segments one can record the time but as the ball rolls downward it gets difficult as the ball acquire higher speed. To overcome this difficulty, we can use video analysis tool described in the box below.

Video of a rolling ball with a video analysis tool

You know how difficult is to get precise data from the inclined plane experiment. To make the job easier we have recorded the entire experiment for you. We have also designed a video player for you to play this video. You know that video is made up of stills (frames). When these stills run in sequence produce the live video effect. Our inclined plan video has 30 frames in a second. It means that every frame was taken in 1/30th second of time. In this player you can play the video frame by frame. So you can get the distance rolled by the ball in every 1/30th second. You can record these data in the table given in the player itself. Once the data comes, the player also helps you to analyze the motion. All the relevent information has been provided in the video player. You can extract time versus distance data.

Use the video analyzer tool and fill up the table and answer the following:

Time (s)	Distance (cm)	Average speed (cm/s)
0		
1		
2		
3		
4		
5		

(I) Does the distance covered by the ball changes for equal time interval of time?

(ii) What can you say about the speed of the ball as it rolls downward?

(iii) Can you say something about the way it is changing?

(iv) Is the motion uniform or non-uniform?

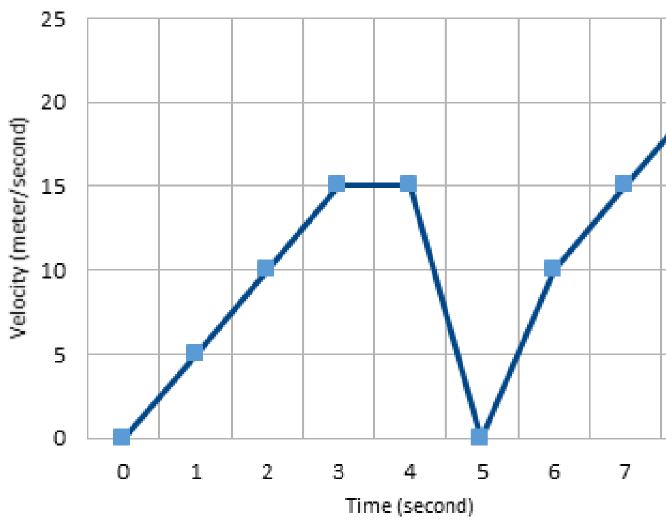
By analyzing the data, we have discovered a motion where the velocity is gradually increasing with time. A similar kind of experiment was used by the Galileo to define acceleration, which is all about how velocity changes with time. You will learn more about acceleration in the next section.

4.2 Acceleration

A bus driver slowly picks up the speed, whenever need drive quickly picks up the speed and also applies brake v to travel and why?

Whenever there is sudden change in the velocity you ma feeling is the effect of acceleration of bus. Let us explore

Given below is the velocity versus time graph of a bus. following questions:



(i) Is this a uniform motion or non-uniform motic

(ii) Is the velocity of the bus is changing every se

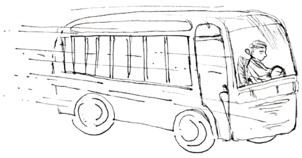
(ii) What is the velocity at 1 second and at 4 secc

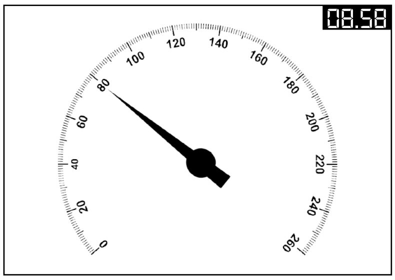
(iv) How many times the bus changed its velocity second?

In the case of non-uniform motion, We are interested in those instances in the entire story of motion, where velocity changes. When you compare the velocity changes, you get to know if the velocity change was faster or slower. Motion is accelerated if the velocity changes. In accelerated motion, if the object gains speed we call it positive acceleration or simply acceleration. In the graph, there were two instances when bus has positive acceleration, identify them in the graph. If the object loses speed we say that the object has negative acceleration or retardation. There is only one instance when the bus loses its speed from 15 to 0 meter/second speed.

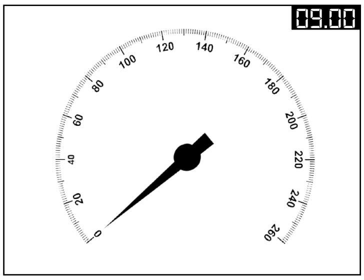
4.3 Rate of velocity change

Bus 1



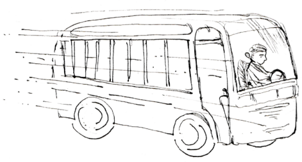


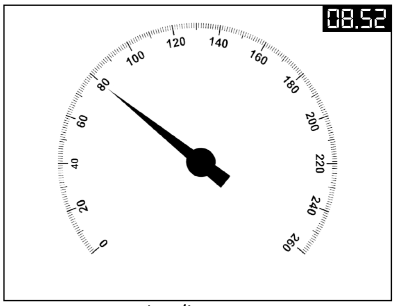
km/hour



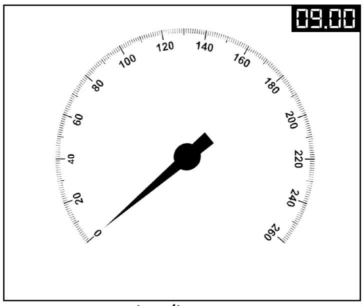
km/hour

Bus 2





km/hour



km/hour

Please answer the following:

(i) What is common in the velocity change of both the buses?

(ii)What is different in the velocity change of both the buses?

When you compare the velocity change over the time you get the rate of velocity change for a given unit of time or you get the value of average acceleration for that time interval. So,

Average acceleration = change in velocity/difference in time

$$a_{avg} = \frac{\Delta v}{\Delta t}$$

$$\text{or } a_{avg} = \frac{v_2 - v_1}{t_2 - t_1}$$

where v_1 = initial velocity, v_2 = final velocity; t_1 = time at the starting point and t_2= time at the end.

[Note: the english alphabet 'a' is used to denote acceleration. a_{avg} stands for average acceleration. Δv and Δt is change in speed and time respectively for the part of journey]

The slower the rate of velocity change or acceleration your journey will be smoother; the faster the rate of velocity change or acceleration your journey will be uncomfortable.

Example: A train is running with a speed of 60 kilometer/second. At 12:05 pm, driver applies the brakes to stop the train at the platform with a constant rate. At 12:10 the train stops at the platform. What should be the rate of change of the velocity (acceleration) so that train stops in 5 minutes? Let's calculate it.

$a = \Delta v / \Delta t$

a = (0-60) kilometer/hour / 5 minute

a = -12 km/hour/minute

This answer tells you that the speed of train must have slowed down at the rate of 12 km/hour/ minute to stop it in five minutes.

Negative sign indicates slowing or retardation of the train.

If the train slow down at constant rate then we can represent it as:

Time (minutes)	0	1	2	3	4	5
Velocity (km/ hour	60	48	36	24	12	0

4.3 Unit of the acceleration

Acceleration calculated in the above example: (-12 km/hour)/minute – look at it carefully how its unit is written. In this unit time comes twice. Remember that in acceleration we are measuring the rate of change of velocity. That is why the unit of time comes twice. First for the velocity of the object – which is expressed as kilometer/hour and second for the unit of time against which you are measuring the change in the velocity. For example, the train running with the speed of 60 kilometer/ hour, stops it in 5 minutes, so the the rate of velocity change was kilometer/hour/minute.

The standard unit of acceleration is meter/second/second, commonly written as meter/second2 (read as meter per second square). It means that you measured the velocity in meter/second and time in unit of seconds. There are other units of acceleration also; i. e. km/s2 , km/h2 etc. One unit can be converted into other with appropriate conversion factor of respective units.

Food for thought

If the motion is accelerated than we would like to know the rate of velocity change. The rate of change of velocity in per unit time is also called acceleration. Let's explore acceleration. we are interested in the velocity change. Below the steering of the bus, there are are a few pedals, they are called accelerator and brakes . There are also an accelerator and brakes on the handle of the motorcycle.

(i) What is the role of the accelerator?

ii) what is the role of the brake?

(ii) Do brakes and accelerator do the same job?

5 EQUATIONS OF MOTION

We learnt basic concepts such as speed, velocity and acceleration. These concepts help us to describe motion and get data/numbers to create a clear picture of it.

In this section we shall explore how speed, distance and acceleration are related to each other in one dimensional motion.

Let us first revisit the symbols we used in our motion analysis and their meaning.

u = initial velocity of the object in motion (also symbolized by v_1 or v_0)

v = final velocity of the object in motion (also symbolized by v_2)

t = time spent during the motion

a = acceleration of the object in motion

s = distance covered by the object in motion (also symbolized by d)

We learnt the following equations of velocity and acceleration in which we explored the relationship between three quantities (time, velocity, acceleration).

$$v = \Delta d/\Delta t$$

$$a = \Delta v/\Delta t$$

From three, we shall now explore the relationship between four quantities (time, distance, velocity and acceleration) to derive equations.

However, bear in mind that these equations hold true for motion with constant acceleration.

Problem: A scooter rider starts from rest (u = 0 meter) and attains a velocity of 6meters (v = 6 meters) in 6 seconds (t = 6 seconds).

We know that if the velocity of the scooter changes, it means it is accelerating. Let us assume that the velocity is changing at a constant rate.

We already know three quantities: time (t), initial velocity (u), final velocity (v). We now have to find out the acceleration (a) and the distance (s) covered by the rider.

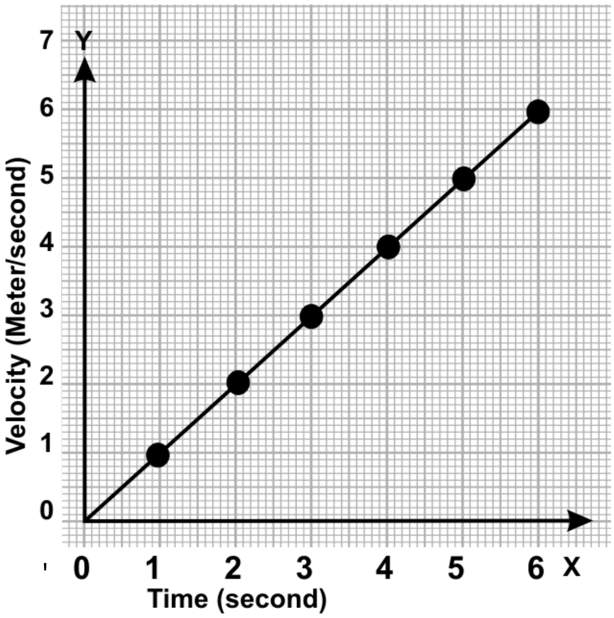
We can solve the problem in two ways – 1) numerically, by using the equations we have learnt till now, and 2) graphically, by creating graphs of the motion of the rider.

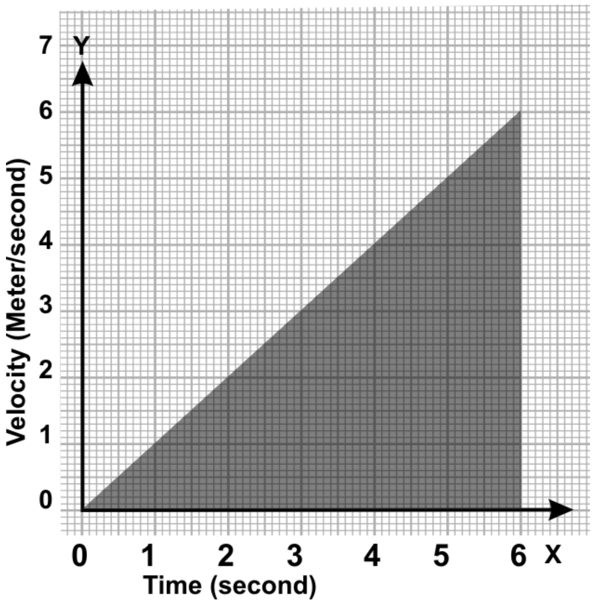
Let us begin with the numerical method to first work out the acceleration:

$$a = (v - u)/t \quad \text{................ (i)}$$

$$a = (6-0)/6 = 1 \text{ m/s}^2$$

(Since the velocity increases at a constant rate, we can find the average velocity)





v = (u + v)/2 .... (ii)

v = (0+6)/2 = 3 m/s

Once we know the average velocity, we can work out the distance using the equation that shows the relationship between distance, velocity and time

s = v t .... (iii)

s = 3 X 6 = 18 m

So the scooter rider attained a velocity of 6 meters/second in 6 seconds. Its acceleration was 1 meter/s2.. It covered a distance of 18 meters in 6 seconds.

We are already familiar with graphs so let us now verify the result by creating a graph.

Since it is a velocity time graph, we need the initial and final (terminal) velocity, and the time taken to attain the terminal velocity.

Initial velocity = 0

Terminal velocity = 6 meter/second

Time taken = 6 second

Acceleration of the scooter

The area covered by the slope (triangle) in the graph gives the distance.

area of a triangle is = (1/2) x height x base

= (1/2) x 6 x6 = 3x 6 = 18meters

So the distance covered by the scooter rider is 18 meters.

The distance calculated graphically is the same as the distance calculated numerically. We can then conclude that, in a graph, the distance covered is equal to the area between the velocity-time curve and the time axis (x-axis) while the acceleration is the slope of the speed-time curve.

Activity

A train starts from rest and attains a velocity of 4m/s in 5 seconds at constant acceleration. It travels another 5 seconds at this constant acceleration. It then decelerates at the same constant rate and stops in 6 seconds.

Plat a graph for the motion of the train and then find the following values both numerically and graphically:

i) Acceleration at which the train attains a velocity of 4 m/s.

ii) Deceleration that brings it to a stop.

iii) Total distance covered by the train.

Let us reiterate. In both the scooter and train examples, we assumed that the velocity increased at a constant rate. These are examples of motion with constant acceleration or uniformly accelerated motion. If the body does not change its velocity at a constant rate then we call it non-uniformly accelerated motion. In non-uniformly accelerated motion, the slope of the velocity-time curve changes with time. (We shall study non-uniformly accelerated motion only in the higher classes.)

First equation of motion

Let us start with the equation:

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

We can re-arrange this as:

$$v = u + a\,t \qquad \text{.............. (1)}$$

where t is the time taken to change the velocity of body from its initial velocity u to its final velocity v.

This is the first equation of motion, which relates speed, time and acceleration.

We also know the equation to find the distance if the velocity and time are known:

$$s = v\,t \qquad \text{................ (ii)}$$

We can substitute the value of v from equation (i)

$$s = [(u + v)/2] \text{ X } t$$

We can further substitute the value of v from equation (ii)

$$s = [(u + u + a\,t)/2] \text{ X } t$$

We get:

$$s = ut + (1/2)\,a\,t^2 \qquad \text{................ (2)}$$

This is the second equation of motion.

The third equation of motion relates velocity, distance, acceleration and time.

If we know the initial velocity and time and if the acceleration is constant, we can determine the distance covered by the object.

In the train example, is the acceleration constant over the whole journey? The answer is no. Then how do we find the distance if the acceleration is not constant?

Let us analyse the motion of the train. Its acceleration is constant for the first 5 seconds. Then it becomes zero for the next 5 seconds. Finally it decelerates, again at a constant rate, till it comes to a stop in the last part of the journey. So we can divide the train journey into three parts, with the acceleration in each part having some value as well as an initial and terminal velocity. For example, in the first part,

we have $u = 0$, $v = 4$ and $a = 0.2$ m/s^2.

Now find the distances for each part and add them to find the total distance covered by the train.

Compare this total distance with the result found graphically.

Let us use equations (1) and (2) to eliminate time t to get a new equation. In equation (1), t can be expressed in terms of u, v and a as:

$$t = (v – u)/a$$

If we substitute t in equation (2) we get:

$$s = u(v – u)/a + (1/2) a [(v – u)/a]^2$$

or $2 a s = 2uv - 2u^2 + v^2 + u^2 – 2uv$

or $v^2 = u^2 + 2 a s$ ------ (3)

This equation can be used to find terminal velocity if we have the initial velocity, acceleration and distance. Again, this is only applicable for motion in which the acceleration is constant.

Example: A cyclist starts from rest, accelerates at a rate of 1 m/s2 for 4 seconds. Calculate her speed after 4 seconds and how far she moves in that time.

We know the initial velocity (0 m/s, since she is at rest) and the acceleration. The first equation of motion will give us the velocity at a later time (after 4 seconds):

$$v = u + a t$$

$$v = 0 + 1 X 4$$

$$v = 4$$

The velocity at the end of 4 seconds is thus 4 m/s.

Let us find out the distance she covers in this time. The second equation of motion will be useful for this:

$$s = ut + (1/2) a t^2$$

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

$$= 8 \text{ meters}$$

Thus, at the end of 4 seconds, the cyclist would have covered a distance of 8 meters.

Exercise: A ball is thrown upwards with a velocity of 20 m/s from the edge of a 60m-high cliff. It reaches a certain height and then begins falling downwards. It passes the starting point and continues to fall to the base of the cliff. Assume that the acceleration due to gravity is equal to 10 m/s2.

(i) What is the maximum height attained by the ball?

Work area

(ii) How much time will it take to pass the starting point on its way down?

Work area

(iii) How much time will it take to reach the base of the cliff?

Work area

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