Unit 2

Force and Motion

Learning Objectives

After studying this unit, students will be able to:

- ❖ define distance and displacement.
- ❖ differentiate distance and displacement.
- ❖ define speed, velocity and acceleration.
- ❖ differentiate speed and velocity.
- ❖ draw and explain distance - time and velocity - time graphs.
- ❖ measure and calculate the speed of moving objects.
- ❖ know the day to day uses of centre of gravity and stability.

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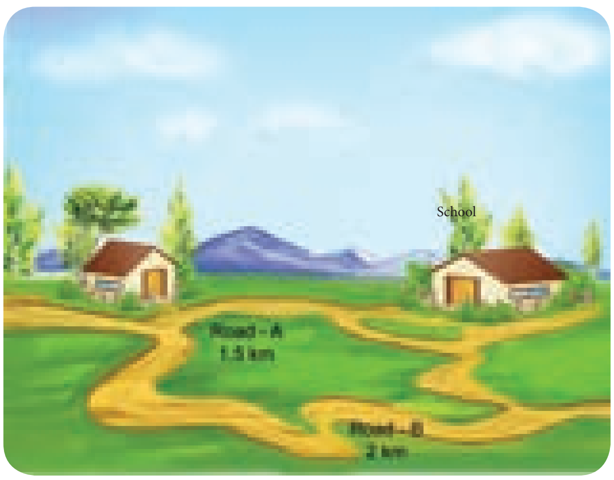
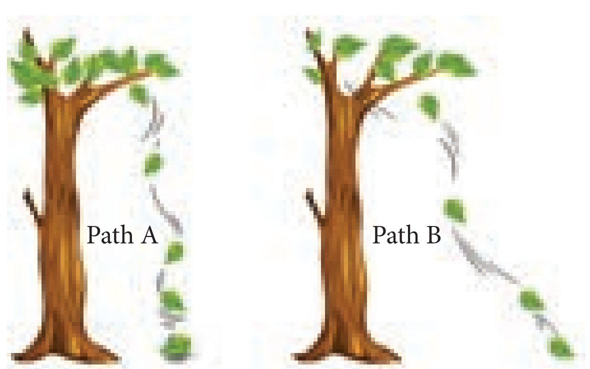
Introduction

Look at the picture given below. Kavitha can reach her school in two ways, as shown in the picture. Can you tell, by choosing which path she could reach the school early?



In the picture given below, you can see leaf falling from a tree. In which path the leaf will reach the ground first?

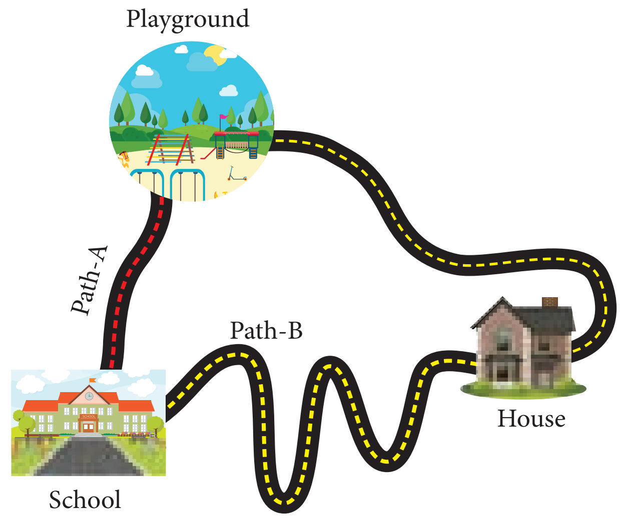


Path of the leaf, when there is no wind.

Path of the leaf when there is wind.

Uma and Priya are friends studying in the same school. After school hours, they go to the nearby playground, play games and return back home. One day Uma told that she would reach the playground after visiting her grandmother's house. The paths which they took to reach the playground is shown here.

Take a twine and measure the length of the two paths (A and B). Which is the longest path among the two?



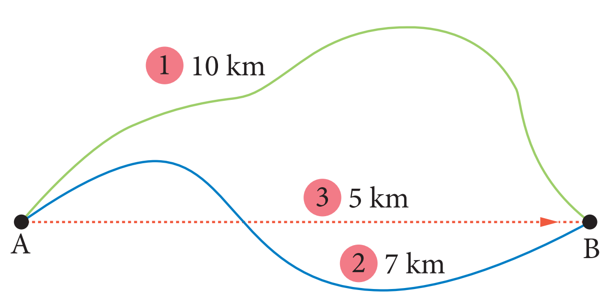
From the above examples, we could conclude that when an object travels from one place to another, it will reach faster if it travels along the straight line path. The straight line path is the shortest distance between two points.

In this lesson we are going to study about distance and displacement, speed and velocity, acceleration, distance - time graph, velocity - time graph, centre of gravity and stability.

2.1 Distance and Displacement

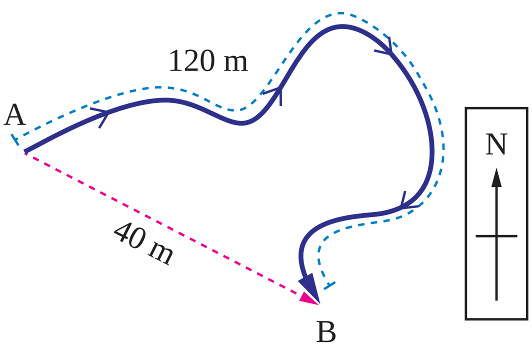
The total length of a path taken by an object to reach one place from another place is called distance. The shortest distance from the initial position to the final position of an object is called displacement. Both distance and displacement possess the same unit. The SI unit distance and displacement is metre (m).

The figure given below shows the motion of a person between two places A and B.

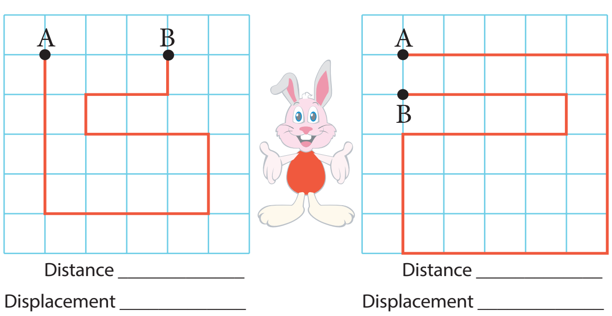


He travels 10 km along the first path. Along the second path, he travels 7 km. The distance between A and B in the case of first path is 10 km. In the case of second path, the distance is 7 km. The shortest distance between the two places is 5 km which is represented by the third path. So, the displacement is 5 km (In east direction).

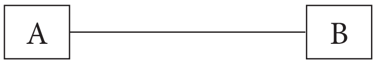
The path of an object moving from point A to point B is shown in the figure. Total distance travelled by the object is 120 m. The displacement of the object is 40 m (south - east direction).



The path in which a rabbit ran is shown in the figure below. Let us consider that each square is in an unit of one square meter. The rabbit starts from point A and reaches the point B. Find the distance and displacement of it in the two figures. When will the distance and displacement be equal? (The starting point and the finishing point should be different).



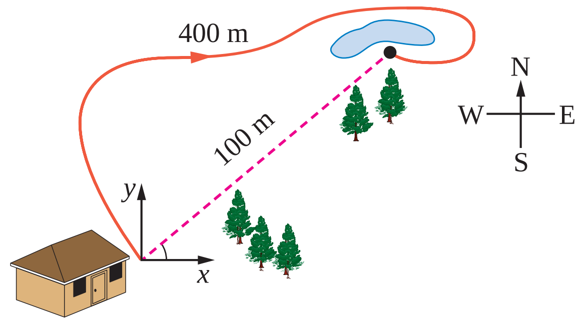
When we represent the displacement, we use a positive or negative sign depending on the direction in which it travels.



Let us consider the point A as the starting point. While the object moves from A to B the displacement is considered to be positive and it is negative, when it travels from B to A.

Subha goes to the nearby playground from her home. Look at the picture and answer the following questions.

1. What is the distance she travelled?
2. What is her displacement?



Can you answer the following questions?

❖ The distance travelled by an object is 15 km and its displacement is 15 km. What do you infer from this?

❖ The distance travelled by a person is 30 km and his displacement is 0 km. What do you infer from this?

DO YOU KNOW?

Nautical mile

Nautical mile is the unit for measuring the distance in the field of aviation and sea transportation. One nautical mile is 1.852 km.

The unit for measuring the speed of aeroplanes and ships is knot. It means that they travel one nautical mile in one hour.

2.2 Speed - Velocity

2.2.1 Speed

In sixth standard you have already studied about speed in detail. Speed is the rate of change of distance.

Speed = Distance / Time

The unit of speed is metre/second (m/s). We can classify speed into two types.

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Uniform speed

If a body in motion covers equal distances in equal intervals of time, then the body is said to be in uniform speed.

Non- uniform speed

If a body covers unequal distances in equal intervals of time, the body is said to be in non-uniform speed.

$$\text{Average Speed} = \frac{\text{Total distance travelled}}{\text{Time taken to travel the distance}}$$

DO YOU KNOW?

1 km/h = 5/18 m/s

How we got this ?

1 km = 1000 m; 1 h = 3600 s

1 km / h = 1000 m / 3600 s = 5/ 18 m /s

DO YOU KNOW?

Know the speed

Tortoise	0.1 m/s
Person walking	1.4 m / s
Falling raindrop	9-10 m / s
Cat running	14 m/s
Cycling	20-25 km/h
Cheetah running	31 m/s
Bowling speed of fast bowlers	90-100 miles /h
Badminton smash	80-90 m/s
Passenger jet	180 m/s
Rocket	5200 m/s

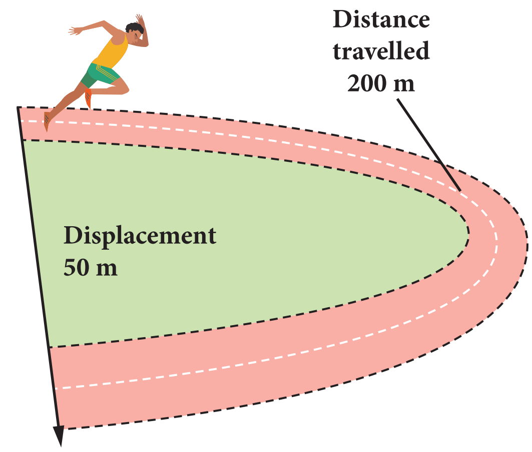
2.2.2 Velocity

Velocity is the rate of change in displacement.

Velocity (v) = Displacement / Time

SI unit of velocity is metre / second (m/s).

Look at the figure. An athlete takes 25 s to complete a 200 m sprint event. Find her speed and velocity.



$$\text{Speed} = \frac{\text{Distance}}{\text{Time}} = \frac{200}{25} = 8 \text{ m/s}$$

$$\text{Velocity} = \frac{\text{Displacement}}{\text{Time}} = \frac{50}{25} = 2 \text{ m/s}$$

Uniform velocity

A body is said to have uniform velocity, if it covers equal displacement at equal intervals of time in the same direction. **E.g.** Light travels through vacuum.

Non-uniform velocity

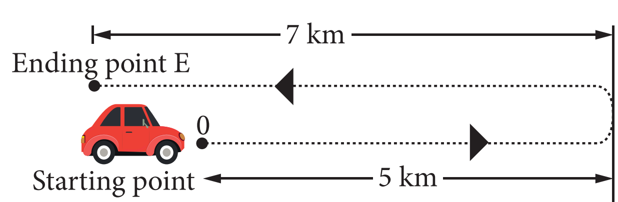
If either speed or direction changes, the velocity is non-uniform. **E.g.** A train starting and moving out of the station.

Average velocity

If the total displacement of an object is divided by the total time taken by the object we get the average velocity.

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

In the figure given below, a car travels 5 km due east and makes a U – turn to travel another 7 km. If the time taken for the whole journey is 0.2 h, calculate the average velocity of the car.



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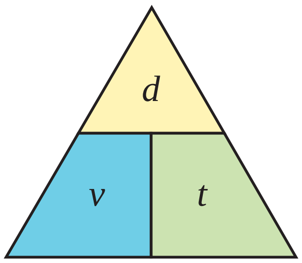
Average velocity = Total displacement/Time taken. (Taking the direction due east of point O as positive)

Average velocity = (5 – 7) / 0.2
= –2 / 0.2
= –10 km/h or – 10 × 5/18
= – 25/9 = –0.28 m / s

The triangle method can help you to recall the relationship between velocity (v), displacement (d), and time(t).



v = d / t , t = d / v, d = v × t

Answer the following questions.

- ❖ Calculate the velocity of a car travelling with a uniform velocity covering 100 m in 4 seconds.
- ❖ Usain Bolt covers 100 m in 9.58 seconds. Calculate his speed. If Usain Bolt competes with a Cheetah which is running at a speed of 30 m/s, who will be the winner?
- ❖ You are walking along east direction covering a distance of 4 m, then 2 m towards south, then 4 m towards west and at last 2 m towards north. You cover the total distance in 21 seconds. What is your average speed and average velocity?

2.3 Acceleration

Acceleration is the rate of change of velocity. In other words, if a body changes its speed or direction then it is said to be accelerated.

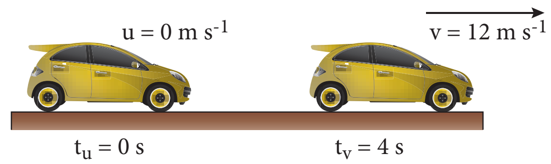
$$\text{Acceleration} = \frac{\text{Change in velocity}}{\text{Time}}$$

$$= \frac{\text{Final velocity (v) – Initial velocity (u)}}{\text{Time}}$$

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

SI unit of acceleration is m/s^2

A car at rest starts to travel in a straight line path. It reaches a velocity of 12 m/s in 4 s . What is its acceleration, assuming that it accelerates uniformly?



Initial velocity, u = 0 m/s (Since the car starts from rest)
Final velocity (v) = 12 m /s
Time taken (t) = 4 s

$$\text{Acceleration (a)} = \frac{(v-u)}{t} = \frac{(12-0)}{4} = 3\,m/s^2$$

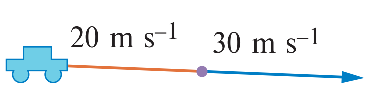
DO YOU KNOW?

See how brisk I am !

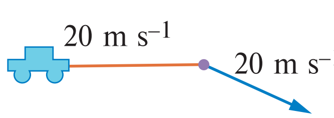
My name is cheetah. I can run at great speed. Do you know what my speed is? It is 25 m/s to 30 m/s. My speed changes from 0 to 20 m/s in 2 second. See how good my acceleration is ! Can you calculate it?

2.3.1 Positive acceleration

If the velocity of an object increases with respect to time, then the object is said to be in positive acceleration.



(a) Change in speed



(b) Change in direction

(c) Change in both speed and direction

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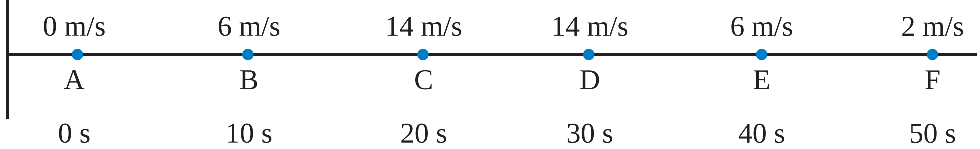
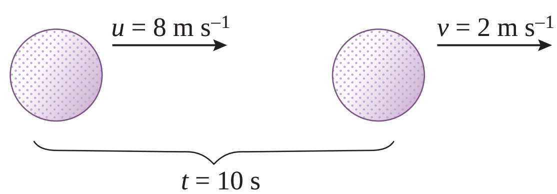
The velocity of a train at different times is given in the figure. Analyse this and complete the table .



The distance travelled by train	Initial velocity (u) m/s	Final velocity (v) m/s	Change in velocity (v – u) m/s	Time taken (t) s	Acceleration = Change in velocity / Time a = (v – u) / t m / s²
A-B	0	6	6	10	0.6
B-C					
C-D					
D-E					
E-F					

2.3.2 Negative acceleration or Deceleration or Retardation

If the velocity of an object decreases with respect to time, then the object is said to be in negative acceleration or deceleration or retardation.



The velocity of a golf ball rolling in a straight line changes from 8 m/s to 2 m/s in 10 s. What is its deceleration, assuming that it is decelerating uniformly ?

Initial velocity (u) = 8 m/s

Final velocity (v) = 2 m/s

Time taken(t) = 10 s

Acceleration (a) $= \frac{(v - u)}{t} = \frac{(2 - 8)}{10} = -0.6\,m/s^2$

The deceleration is –0.6 m/s^2

2.3.3 Uniform acceleration

An object undergoes uniform acceleration when the change (increase or decrease) in its velocity for every unit of time is the same.

The table given below shows the uniform acceleration of a bus.

Time (s)	1	2	3	4	5
Velocity (m/s)	20+20	40+20	60+20	80+20	100 + 20
	(acceleration)				
Velocity (m/s)	100 – 20	80-20	60-20	40-20	20-20
	(deceleration)				

When the velocity of the object is increasing by 20 m/s the acceleration is 20 m/s^2. When the velocity of the object is decreasing by 20 m/s the deceleration is 20 m/s^2.

2.3.4 Non – uniform acceleration

An object undergoes non–uniform acceleration if the change in its velocity for every unit of time is not the same.

Time (s)	0	1	2	3	4	5
Velocity (m/s)	0	10	40	60	70	50
Change in Velocity (m/s)	0	10	30	20	10	20

Note here that the change in velocity is not the same for every second. Thus, the moving object is undergoing non-uniform acceleration.

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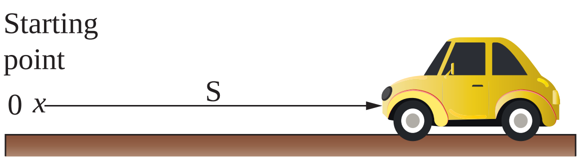
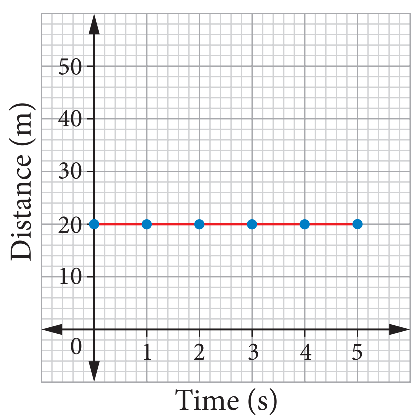
2.4 Distance – Time Graphs

A car travelling along a straight line away from the starting point O is shown in the figure. The distance of the car is measured for every second. The distance and time are recorded and a graph is plotted using the data. The results for four possible journeys are shown below.



a. Car at rest

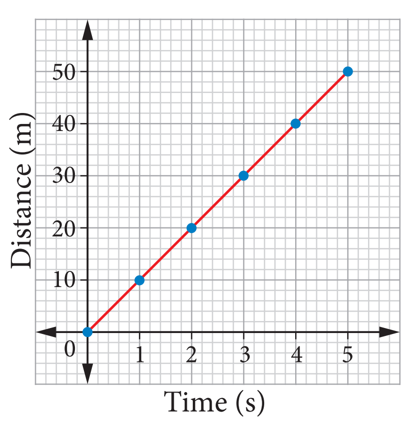
Time (s)	0	1	2	3	4	5
Distance (m)	20	20	20	20	20	20



The graph has zero gradient. i.e. the distance is constant for every second. Thus, the car is at rest.

b. Car travelling at uniform speed of 10ms^{-1}

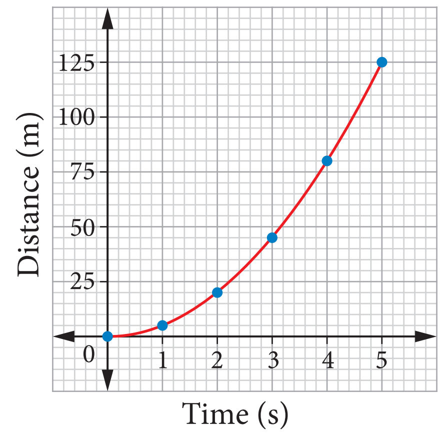
Time (s)	0	1	2	3	4	5
Distance (m)	0	10	20	30	40	50



The graph has constant gradient. The distance increases 10 m in every second. Thus, the car moves with uniform speed.

c. Car travelling at increasing speed

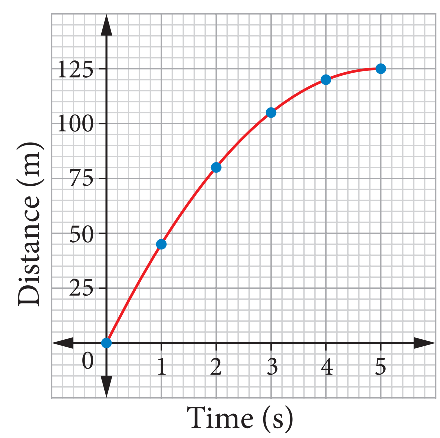
Time (s)	0	1	2	3	4	5
Distance (m)	0	5	20	45	80	125



The graph has an increasing gradient, i.e. That is, the speed increases.

d. Car travelling at decreasing speed

Time (s)	0	1	2	3	4	5
Distance (m)	0	45	80	105	120	125



The graph has a decreasing gradient. That is, the speed decreases.

2.5 Speed – Time Graphs

Let us consider a bus travelling from Thanjavur to Trichy. The speed of the bus is measured for every second. The speed and time are recorded and a graph is plotted using the data. It is known as speed-time graph. The results for four possible journeys are shown.

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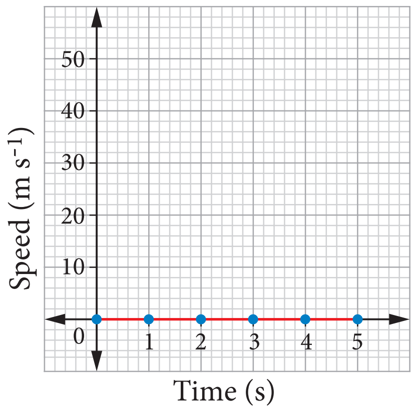
a. Bus at rest

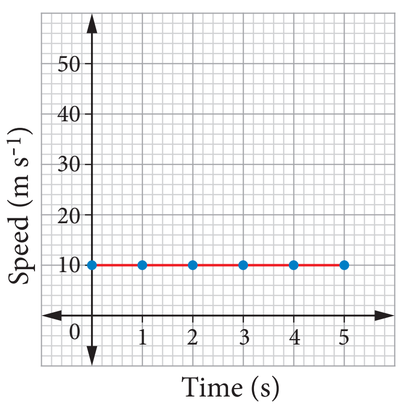
Time (s)	0	1	2	3	4	5
Speed (ms^{-1})	0	0	0	0	0	0



The speed of the bus remains at 0 ms^{-1}. So, the bus has zero acceleration.

b. Bus travelling at uniform speed of ms^{-1}

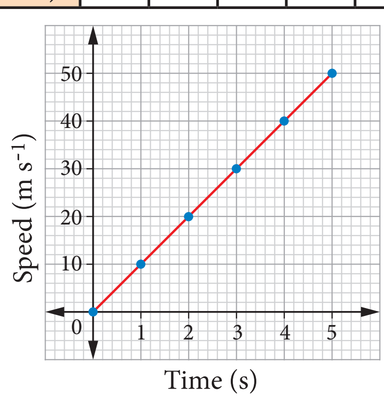
Time (s)	0	1	2	3	4	5
Speed (ms^{-1})	10	10	10	10	10	10



The speed of the bus remains at 10 ms^{-1}. Here, slope of the line is zero. So, the bus has zero acceleration.

c. Bus travelling uniform acceleration

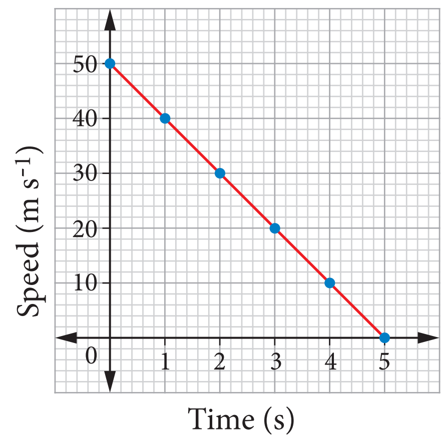
Time (s)	0	1	2	3	4	5
Speed (ms^{-1})	10	10	20	30	40	50



The speed of the bus increases by 10 ms^{-1} every second. Hence, the graph has a positive and constant gradient, and the acceleration is constant.

d. Bus travelling uniform deceleration

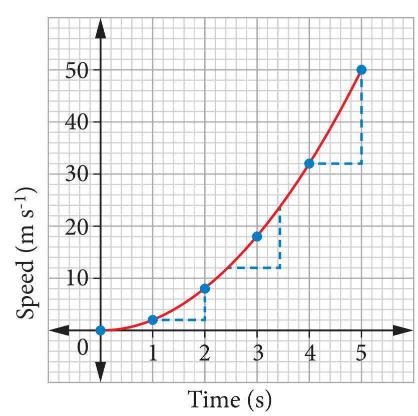
Time (s)	0	1	2	3	4	5
Speed (ms^{-1})	50	40	30	20	10	0



The speed of the bus decreases by 10 ms^{-1} very second. Hence, the graph has a negative and constant gradient and the acceleration is negative and constant.

e. Bus travelling with increasing acceleration (Non-uniform acceleration)

Time (s)	0	1	2	3	4	5
Speed (ms^{-1})	10	2	8	18	32	50



The speed of the bus is increasing with time. Hence, the graph has a positive and increasing gradient and the acceleration increases.

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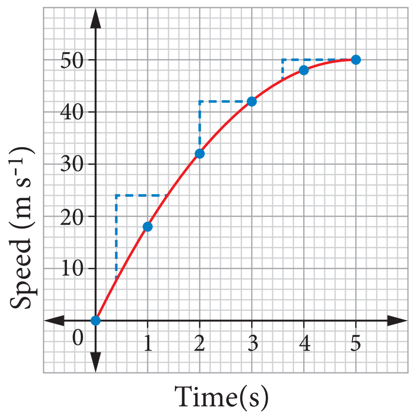
f. Bus travelling with decreasing acceleration (non-uniform acceleration)

Time (s)	0	1	2	3	4	5
Speed (ms^{-1})	10	18	32	42	48	50

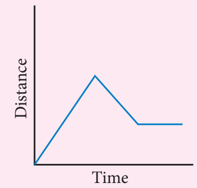


The speed is decreasing with time. Hence, the graph has a positive and decreasing gradient, and the acceleration decreases.

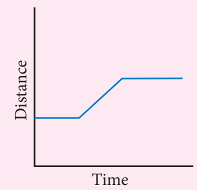
2.5.1 Comparison between Distance – Time and Speed – Time Graphs

The Speed – Time graphs and Distance – Time graphs may look very similar. But, they give different information. We can differentiate them by looking at the labels.

Graph and Story

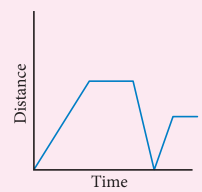


Raju began walking to his school. Suddenly he remembered that he forgot his pen and walked back home. But he stopped suddenly when he heard a noise.



Rani was waiting for her mother for some time. When she saw her mother, she ran out of her home hugged her and stood there for a while.

Imagine and write a story on your own for the given graph?



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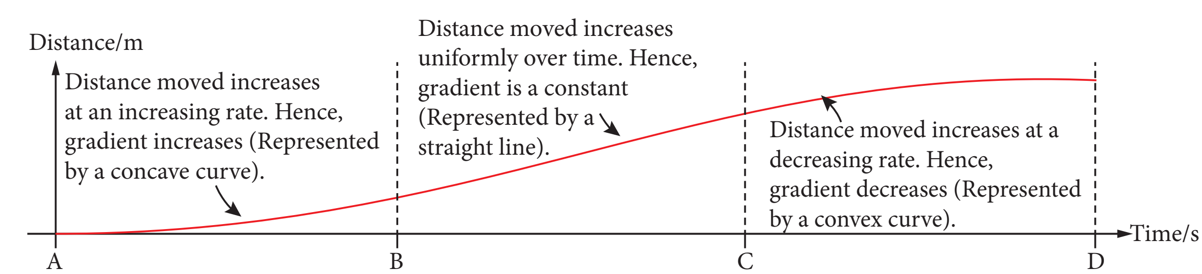
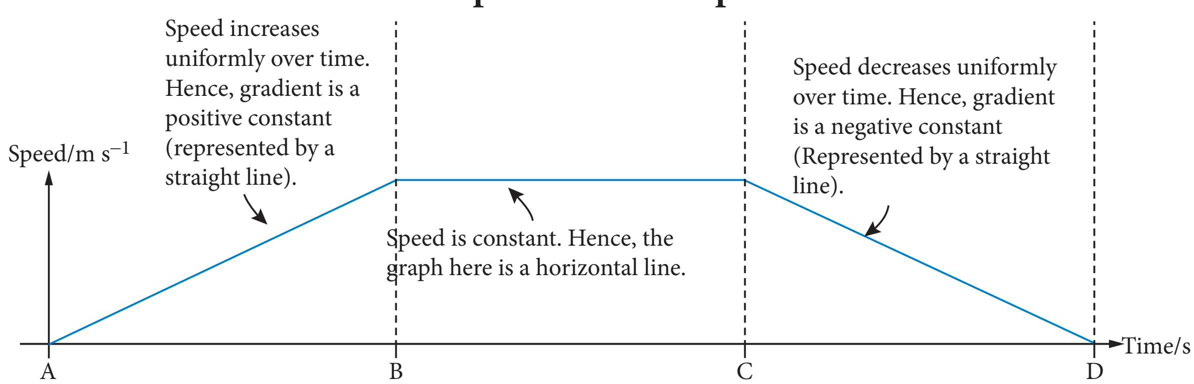
From A to B	From B to C	From C to D
Car accelerates uniformly from rest.	Car moves at constant speed.	Car decelerates uniformly to a stop.

Distance–Time Graph



Speed–Time Graph



2.6 Centre of Gravity

Try to balance a cardboard on your finger tip. What do you observe? You can notice that there is only one point at which the cardboard is balanced. The point at which the cardboard is balanced is called the centre of gravity of the cardboard.

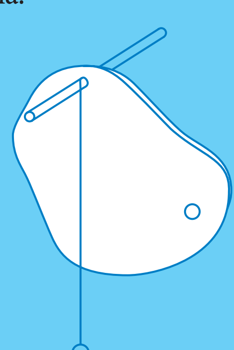
The centre of gravity of an object is the point through which the entire weight of the object appears to act. How do we find the centre of gravity of an object ?

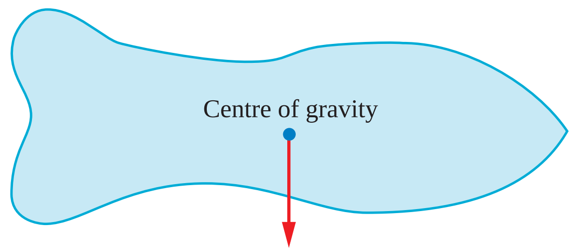
ACTIVITY 1

What about irregular shaped objects ?

Apparatus: Irregularly shaped card, string, pendulum bob, stand

1. Make three holes in the lamina.
2. Suspend the lamina from the optical pin through one of the holes as shown in figure.
3. Suspend the plumbline from the pin and mark the position of the plumbline on the lamina.
4. Draw lines on the lamina representing the positions of the plumbline.
5. Repeat the above steps for the other holes.
6. Label the intersection of the three lines as X, the position of the centre of gravity of the lamina.

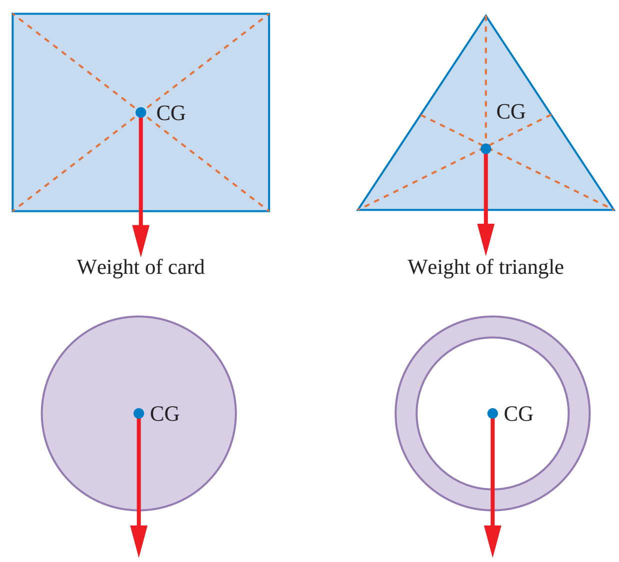




Total pull of the earth (weight) appears to act through the centre of gravity

2.6.1 Centre of gravity of regular – shaped objects

Generally the centre of gravity of the geometrical shaped objects lie on the geometric centre of the object.



The ruler is in equilibrium when supported at its centre of gravity. For a regular object such as a uniform meter ruler, the centre of gravity is at the centre of the object. When the object is supported at that point, it will be balanced. If it is supported at any other point, it will topple.

2.7 Stability

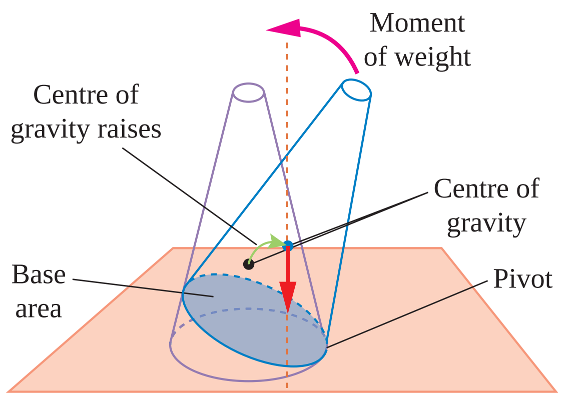
Stability is a measure of the body's ability to maintain its original position. Three types of stability are:

a. Stable equilibrium
b. Unstable equilibrium
c. Neutral equilibrium

Let us demonstrate them by taking a frustum.

Stable Equilibrium

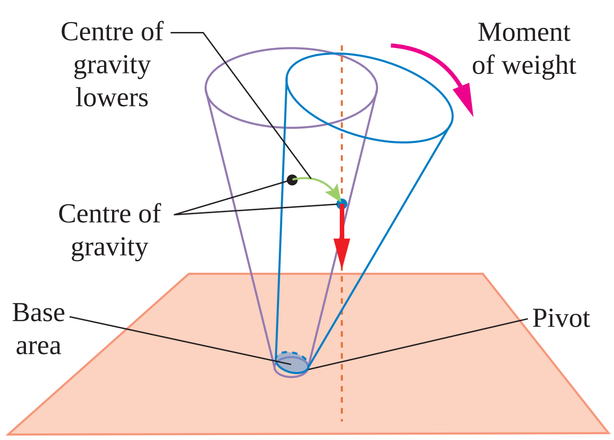
In stable equilibrium, the frustum can be tilted through quite a big angle without toppling.



Its centre of gravity is raised when it is displaced. The vertical line through its centre of gravity still falls within its base. So, it can return to its original position.

Unstable Equilibrium

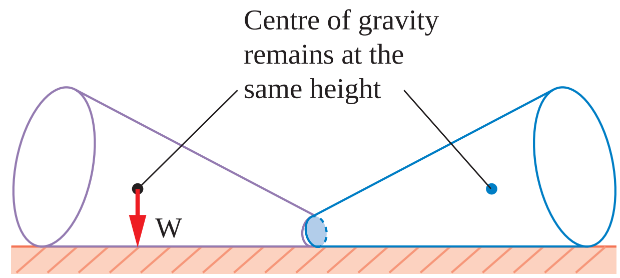
In this equilibrium, the frustum will topple with the slightest tilting. Its centre of gravity is lowered when it is displaced.



Here, the vertical line through its centre of gravity falls outside its base. So, it will not come back to its position.

Neutral Equilibrium

It causes frustum to topple. The frustum will roll about but does not topple. Its centre of gravity remains at the same height when it is displaced. The body will stay at any position to which it has been displaced.



2.7.1 Condition for Stability

Stability can be increased by the following ways.

- Lowering its centre of gravity
- Increasing the area of its base
- A heavy base lowers the centre of gravity So, the object will be stable.
- A broad base makes the object more stable.

DO YOU KNOW?

The Thanjavur Doll

It is s type of traditional toy made in Thanjavur from terracotta material. The centre of gravity and the total weight of the doll is concentrated at its bottom most point, generating a dance-like continuous movement with slow oscillations.

2.7.2 Real Life Applications of Centre of Gravity

In order to have stability, the luggage compartment of a tour bus is located at the bottom and not on the roof.

- Extra passengers are not allowed on the upper deck of a crowded double decker bus.

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- Racing cars are built low and broad for stability.
- Table lamps and fans are designed with large heavy bases to make them stable.

Points to Remember

❖ The total length of a path taken by an object to reach one place from the another place is called distance.

❖ The shortest distance from the initial to the final position of an object.

❖ Acceleration is the rate of change in velocity. SI unit of acceleration is m/s^2.

❖ Velocity is the rate of change in displacement. SI unit of velocity is metre / second (m/s).

❖ The centre of gravity of an object is the point through which the entire weight of the object appears to act.

❖ Generally the centre of gravity of the geometrical shaped object lie on the geometric centre of the object.

❖ Stability is a measure of the body's ability to maintain its original position.

❖ The three types of stability are: stable equilibrium, unstable equilibrium, neutral equilibrium.

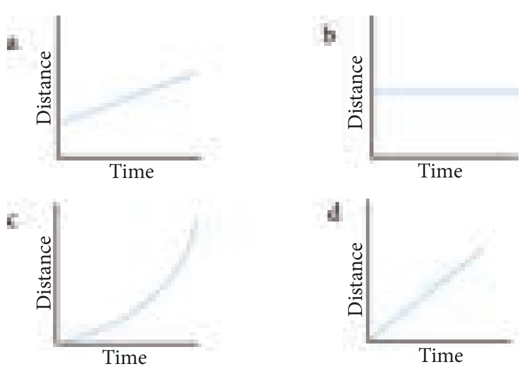
Evaluation

I. Choose the best answer.

1. A particle is moving in a circular path of radius *r*. The displacement after half a circle would be

   a. Zero b. R c. 2 *r* d. *r* / 2

2. Which of the following figures represent uniform motion of a moving object correctly?

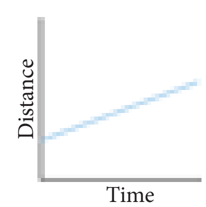


3. Suppose a boy is enjoying a ride on a merry go round which is moving with a constant speed of 10 m/s. It implies that the boy is

   a. at rest
   b. moving with no acceleration
   c. in accelerated motion
   d. moving with uniform velocity

4. From the given v-t graph it can be inferred that an object is

   a. in uniform motion b. at rest
   c. in non - uniform motion
   d. moving with uniform accelerations



5. How can we increase the stability of an object?

   a. Lowering the centre of gravity
   b. Raising the centre of gravity
   c. Increasing the height of the object
   d. Shortening the base of the object

II. Fill in the blanks.

1. The shortest distance between two places is ___________.
2. The rate of change of velocity is__________.

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3. If the velocity of an object increases with respect to time, then the object is said to be in__________ acceleration.
4. The slope of the speed–time graph gives __________.
5. In __________ equilibrium, the centre of gravity remains at the same height when it is displaced.

III. Match the following.

Displacement	Knot
Light travelling through vacuum	Geometric centre
Speed of ship	Metre
Centre of gravity of geometrical shaped objects	Larger base area
Stability	Uniform velocity

IV. Analogy

1. Velocity : metre / second :: Acceleration : __________ .
2. Length of scale : metre :: Speed of aeroplane : __________ .
3. Displacement / Time : Velocity :: Speed / Time : __________ .

V. Answer very briefly.

1. Asher says all objects having uniform speed need not have uniform velocity. Give reason.
2. Saphira moves at a constant speed in the same direction. Rephrase the same sentence in fewer words using concepts related to motion.
3. Correct your friend who says that acceleration gives the idea of how fast the position changes.

VI. Answer briefly.

1. Show the shape of the distance – time graph for the motion in the following cases. a. A bus moving with a constant speed. b. A car parked on a road side.
2. Distinguish between speed and velocity.
3. What do you mean by constant acceleration?
4. What is centre of gravity ?

VII. Answer in detail.

1. Explain the types of stability with suitable examples.
2. Write about the experiment to find the centre of gravity of the irregularly shaped plate.

VIII. Numerical problems.

1. Geetha takes 15 minutes from her house to reach her school on a bicycle. If the bicycle has a speed of 2 m/s, calculate the distance between her house and the school.
2. A car starts from rest and it is travelling with a velocity of 20 m /s in 10 s. What is its acceleration?
3. A bus can accelerate with an acceleration of 1 m / s^2. Find the minimum time for the bus to attain the speed of 100 km / s from 50 km / s.

IX. Fill in the boxes.

S.No.	First Move	Seconde Move	Distance (m)	Displacement
1.	Move 4 metres east	Move 2 metres west	6	2 m east
2.	Move 4 metres north	Move 2 metres south		
3.	Move 2 metres east	Move 4 metres west		
4.	Move 5 metres east	Move 5 metres west		
5.	Move 5 metres south	Move 2 metres north		
6.	Move 10 metres west	Move 3 metres east		

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