Physics

Standard

IX

Part - 1

Government of Kerala
Department of General Education

Prepared by
State Council of Educational Research and Training (SCERT) Kerala
2024

ST-305-1-PHYSICS(E)-9-VOL-1

THE NATIONAL ANTHEM

Jana-gana-mana adhinayaka, jaya he
Bharatha-bhagya-vidhata
Punjab-Sindh-Gujarat-Maratha
Dravida-Utkala-Banga
Vindhya-Himachala-Yamuna-Ganga
Uchchala-Jaladhi-taranga
Tava subha name jage,
Tava subha asisa mage,
Gahe tava jaya gatha.
Jana-gana-mangala-dayaka jaya he
Bharatha-bhagya-vidhata
Jaya he, jaya he, jaya he,
Jaya jaya jaya, jaya he

PLEDGE

India is my country. All Indians are my brothers and sisters. I love my country, and I am proud of its rich and varied heritage. I shall always strive to be worthy of it.

I shall give respect to my parents, teachers, and all elders, and treat everyone with courtesy.

To my country and my people, I pledge my devotion. In their well-being and prosperity alone lies my happiness.

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Typesetting and Layout : SCERT
First Edition : 2024
Printed at : KBPS, Kakkanad, Kochi-30

PREFACE

Dear learners,

This book is designed to help you understand the basic concepts and principles of Physics, and to attain the ability and confidence to apply them in real life situations and contexts.

This textbook will lead you through the frontiers of knowledge and awe–inspiring visuals to the depths of Physics. Your science laboratories will sprout new life when each sight raises the question in you - how and why? The ideas and concepts thus acquired will enable you to have lofty dreams to contemplate on and fulfill them through action.

Each activity in this book will change your perspective from **I** to **We**, upholding the notion that science is for the betterment of society. May you be able to raise new questions, share knowledge, arrive at the apt concepts, impart them to the society and lay the scientific foundation for countering superstitions with science.

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Director
SCERT, Kerala

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Contents

Certain icons are used in this textbook for convenience

For further reading (Evaluation not required)

ICT Possibilities

Questions that may be raised by students

Let's Assess

Continuous assessment questions

Extended Activities

THE CONSTITUTION OF INDIA

PREAMBLE

WE, THE PEOPLE OF INDIA, having solemnly resolved to constitute India into a [1][**SOVEREIGN SOCIALIST SECULAR DEMOCRATIC REPUBLIC**] and to secure to all its citizens :

JUSTICE, social, economic and political;

LIBERTY of thought, expression, belief, faith and worship;

EQUALITY of status and of opportunity; and to promote among them all

FRATERNITY assuring the dignity of the individual and the [2][unity and integrity of the Nation];

IN OUR CONSTITUENT ASSEMBLY this twenty-sixth day of November, 1949 do **HEREBY ADOPT, ENACT AND GIVE TO OURSELVES THIS CONSTITUTION.**

1. Subs. by the Constitution (Forty-second Amendment) Act, 1976, Sec.2, for "Sovereign Democratic Republic" (w.e.f. 3.1.1977)
2. Subs. by the Constitution (Forty-second Amendment) Act, 1976, Sec.2, for "Unity of the Nation" (w.e.f. 3.1.1977)

1 Refraction of Light

Have you had such an experience?

Many of such experiences are related to the various phenomena of light.

- Have you ever observed the straw in a glass of lemonade? Does it appear bent? What could be the reason?

Fig. 1.1

We see an object when the light falling on the object gets reflected and falls on our eyes. Don't you think the light rays reflected from the straw dipped in lemonade travel through different mediums before they reach our eyes?

Let's do an activity.

Fill three-fourth of a trough with water. Add two or three drops of milk into it. Cover the trough with a transparent sheet of paper. Fill the remaining space in the trough with smoke. Then flash the light from a laser torch as shown in figure 1.2 (a) and observe the path of light. Draw your observation in the science diary.

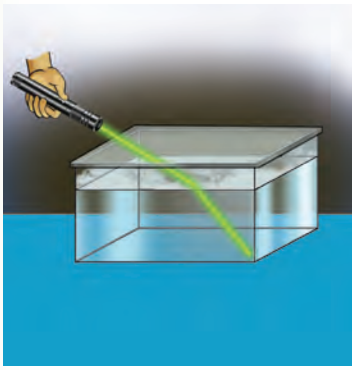
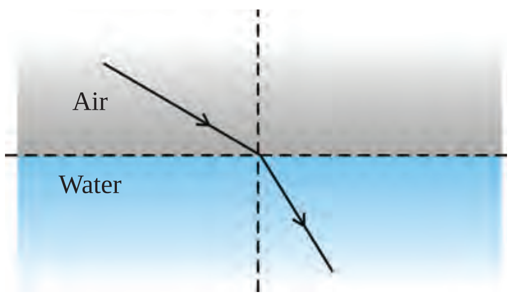


Fig. 1.2 (a)



Ray diagram showing the path of light

Fig. 1.2 (b)

- Which are the mediums through which light travels within the trough?
- How will the path of light ray be, when it passes through only one medium?

- Is there any deviation in the direction of the ray of light when it enters obliquely from one medium to another?
- Where does the ray of light undergo a change in direction?

Will there be a deviation in the direction of a ray of light incident normally?

Allow light from a laser torch to fall perpendicular to the surface of the water taken in the trough.

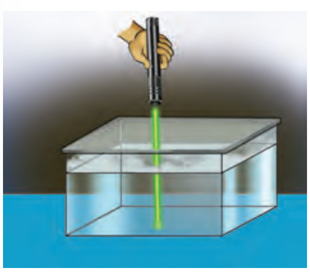


Fig. 1.3 (a)

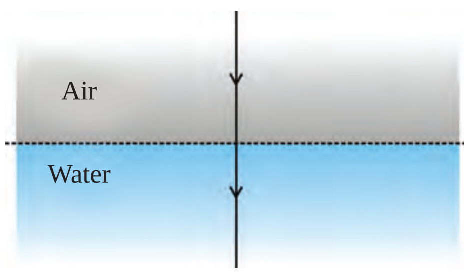


Fig. 1.3 (b)

- Is there a deviation in the path of the ray of light? Record your observation in the science diary.

When light travels through a single medium, the path of light will be a straight line. A ray of light undergoes a deviation at the surface of separation when it enters obliquely from one medium to another. There will be no deviation in the path of the ray of light incident normally.

What causes a deviation in the path of the light ray when it passes from one medium to another?

Observe the speed and direction of a toy car moving from a smooth surface to a rough surface.

- Is there a change in the direction of motion of the car?
- Where does this change occur?
- Did the car move with the same speed on both surfaces?

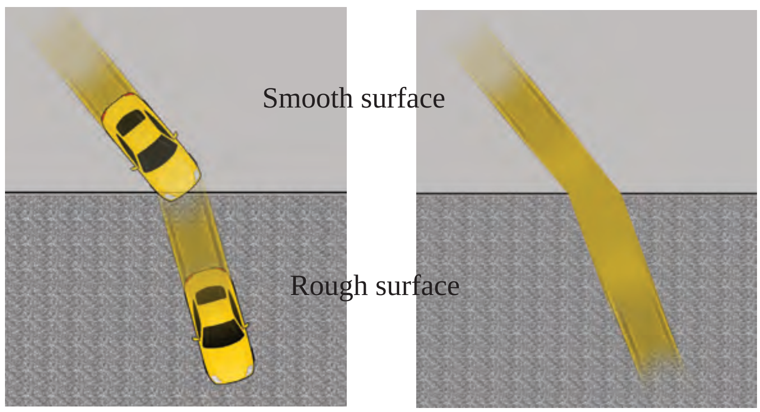


Fig. 1.4 (a) Fig. 1.4 (b)

The change in direction is caused by the change in the speed of the car as it moves from one surface to the other.

The speed of light is different in different mediums. The change in the speed of light causes the change in the direction of the ray of light, when it passes from one medium to another. Examine the table showing the speed of light through various mediums.

Medium	Speed of light (approximate)
Air	3×10^8 m/s
Water	2.25×10^8 m/s
Glass	2×10^8 m/s
Diamond	1.25×10^8 m/s

Table 1.1

The speed of light differs in various mediums due to the difference in their optical densities.

The ability of a medium to influence the speed of light through the medium is its optical density.

The speed of light will be lower in a medium of higher optical density (optically denser medium). The speed of light will be higher in a medium of lower optical density (optically rarer medium). Note that optical density has no relation with material density.

Arrange the mediums in Table 1.1 in the increasing order of their optical densities.

Air < -------- < -------- < Diamond

Refraction

Let's do an activity to understand the reason behind a straw appearing bent when dipped in lemonade.

Fig. 1.5 (a)

Fig. 1.5 (b)

A straw is kept obliquely in a glass as shown in the figure 1.5 (a). Then the glass is filled with water. What difference do you observe? Draw your observations in the science diary.

- Why does the straw appear bent?

A straw is kept in a trough. Observe the path of the rays of light from the straw falling on the eyes before and after filling the trough with water.

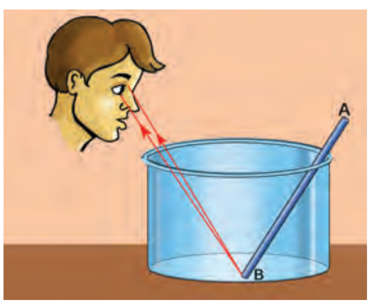


Fig. 1.6 (a)

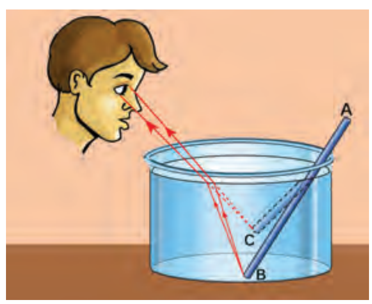


Fig. 1.6 (b)

- Is there a deviation for the ray of light falling on the eye from point B of the straw before pouring water?

After the water is poured, the ray of light from the immersed part of the straw entering air from water is deviated at the surface of separation.

- Doesn't the ray of light appear to come from C, though it is actually coming from B?

The straw appears bent, as the actual position B seems to have risen to the position C.

PhET → Bending Light → Intro

When a ray of light enters obliquely from one medium to another of different optical densities, it undergoes a deviation at the surface of separation of the mediums. This phenomenon is refraction.

The ability of light to undergo refraction in a medium depends on the optical density of the medium. The optical density is in turn, related to the refractive index of the medium. The role of refractive index is very important in designing various optical devices. Let's see what refractive index of a medium is.

Refractive index

Refractive index of a medium is the ratio of the speed of light in vacuum to the speed of light in the medium.

If c denotes the speed of light in vacuum and v the speed of light in a medium, then

$$\text{Refractive index (n)} = \frac{\text{The speed of light in vacuum (c)}}{\text{The speed of light in the medium (v)}}$$

$$n = \frac{c}{v}$$

The speed of light in vacuum (c) = 3×10^8 m/s

The speed of light in different mediums is given in the table below. Find the refractive index of each medium and complete the table.

Medium	Speed of light (v)	Refractive index (n)
Air	3×10^8 m/s	$n = \frac{c}{v} = \frac{3 \times 10^8 \text{ m/s}}{3 \times 10^8 \text{ m/s}} = 1$
Glass	2×10^8 m/s	
Water	2.25×10^8 m/s	

Table 1.2

If the refractive index of diamond is 2.4, what is the speed of light that passes through it?

How is the speed of light related to refractive index?

The speed of light is less in a medium of higher refractive index. Don't you know the relationship between the speed of light and optical density? If so, write down how optical density is related to refractive index in the science diary.

You have understood that a ray of light entering obliquely from one medium to another with different optical densities undergoes deviation at the surface of separation of the two mediums.

Is the deviation of light the same when it enters from air to water and from water to air when the angle of incidence is the same?

Observe the figures.

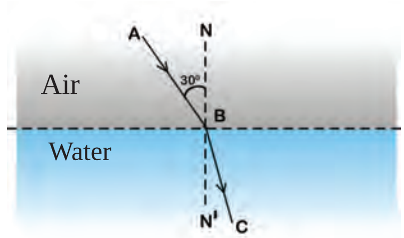


Fig. 1.7 (a)

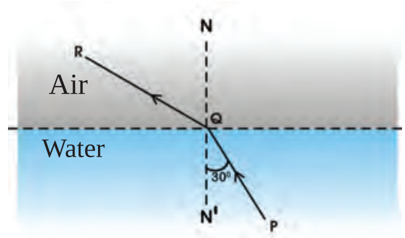


Fig. 1.7 (b)

The ray falling on the surface of separation of the two mediums is the incident ray. The ray which undergoes refraction is the refracted ray. The angle between refracted ray and the normal (NN′) is the angle of refraction. If so,

- find the incident ray, refracted ray, angle of incidence and angle of refraction from each figure and complete the table.

	Figure 1.7 (a)	**Figure 1.7 (b)**
Incident ray	AB	
Refracted ray		
Angle of incidence (i)	∠ABN	
Angle of refraction (r)	∠CBN′	
The angle of refraction is greater than/less than the angle of incidence		

Table 1.3

What peculiarities do you see in the deviation of refracted ray of light when it enters from air to water and from water to air? Record them in the science diary.

- How does the direction of light change when a ray of light enters obliquely from air to water?

  (deviates towards the normal / deviates away from the normal)

- How does the direction of light change when a ray of light enters obliquely from water to air?

  (deviates towards the normal / deviates away from the normal)

Observe the figures that show light passing through different pairs of mediums.

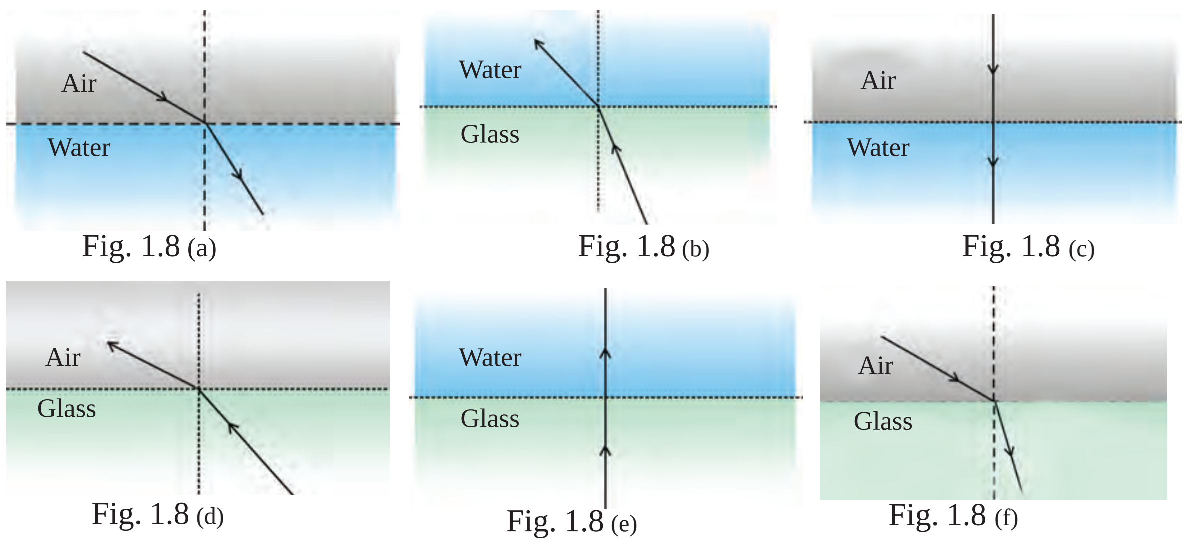


Fig. 1.8 (a) Fig. 1.8 (b) Fig. 1.8 (c) Fig. 1.8 (d) Fig. 1.8 (e) Fig. 1.8 (f)

Find answers to the following questions based on the optical densities of mediums and record them in the science diary.

a) Which are the figures in which the ray of light enters obliquely from an optically denser medium to a rarer medium?

b) In this case, to which direction does the refracted ray deviate?

(towards the normal / away from the normal)

c) Choose the figures in which the refracted ray deviates towards the normal.

d) In which situation will a ray of light deviate towards the normal as it passes from one medium to another?

(from an optically denser medium to a rarer medium/from an optically rarer medium to a denser medium)

e) There is no refraction of light in figures 1.8 (c) and 1.8 (e). What may be the reason?

- When light enters from one medium to another, the incident ray, the refracted ray and the normal at the point of incidence, will be on the same plane.
- When light enters from an optically rarer medium to a denser medium, it deviates towards the normal.
- When light enters from an optically denser medium to a rarer medium, it deviates away from the normal.
- A ray incident normally at the surface of separation of mediums does not undergo refraction.

Refraction in a glass slab

Allow light from a laser torch to fall on a glass slab as shown in the figure.

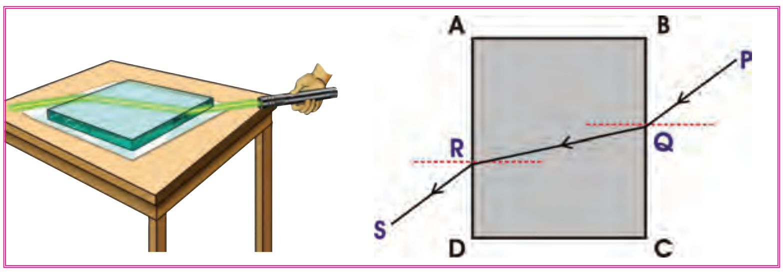


Fig. 1.9 (a) Fig. 1.9 (b)

Did you observe the path of light?

- At which points do refraction occur for the ray of light?
- Draw the ray diagram showing the refraction of a ray of light in a glass slab in the science diary.
- Allow light to incident normally on the glass slab. Does refraction occur?

Refraction – Some Practical Activities

Put a coin in a vessel. Walk backwards looking at the coin. When the coin disappears, ask one of your classmates to pour water into the vessel.

- What do you observe? Analyse the figure and find out the reason.

Fig. 1.10 (a)

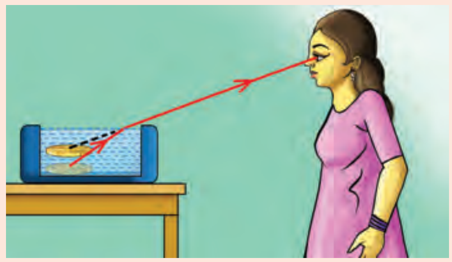


Fig. 1.10 (b)

On pouring water, the ray of light coming from the coin undergoes refraction and reaches the eye. Hence, the coin becomes visible again.

Place a glass slab on the letters in a textbook. The letters appear raised. What may be the reason? Find out.

Observe the figure 1.11 and let's do a similar activity.

You can see a coin lying under the water in a trough. Try to take the coin out by looking through any one side of the trough. Can you do it with ease? What may be the reason?

Fig. 1.11

The bottom of a pond appears elevated when viewed from a distance than from a nearer point. Why?

People who engage in bow fishing aim at a point slightly below the perceived position of the fish. Why?

Are you now familiar with certain situations related to refraction? Let's familiarise ourselves with some situations related to atmospheric refraction.

Atmospheric Refraction

Why do stars at a greater distance twinkle?

Observe the figures.

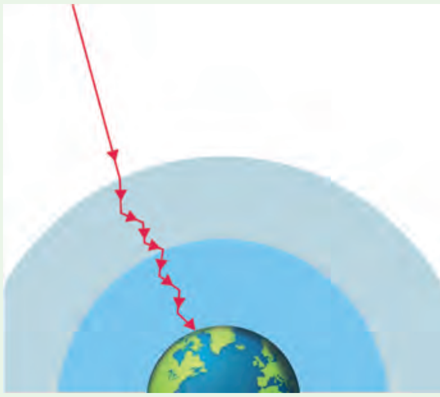


Fig. 1.12 (a)

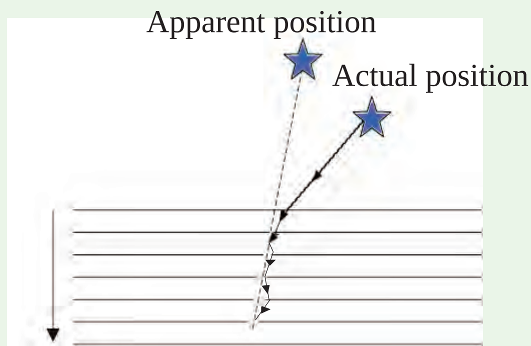


Fig. 1.12 (b)

- Does the ray of light from the star reach our eyes by travelling in a straight line?
- An illustration of the path of a ray of light from a distant star through the Earth's atmosphere is given in figure 1.12 (a). Doesn’t the ray of light undergo irregular deviations? What may be the reason?

Stars appear as point sources of light because they are at a greater distance from the Earth compared to the planets. The light coming from the stars reaches our eyes by traversing through the atmosphere. The optical density of the medium through which the light travels goes on changing as the physical conditions (pressure, temperature etc.) of the layers of atmosphere change continuously. Hence, the light undergoes an irregular refraction. Therefore, when the light rays from the stars reach the eyes after refracted several times, the star cannot be seen continuously at the same position. This is the reason for the twinkling of stars.

Even after the Sun has passed the western horizon, the Sun is visible for some more time. Similarly, the Sun can be seen a few seconds before it reaches the eastern horizon in the morning. What is the reason?

Analyse figure 1.13 and record the explanation in the science diary.

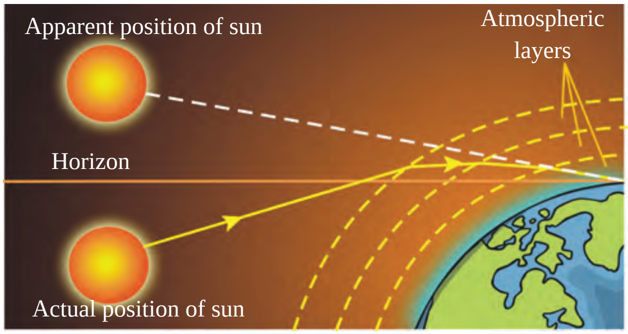


Fig. 1.13

You are now familiar with many situations related to refraction.

Will refraction occur whenever light enters obliquely from one medium to another?

Total Internal Reflection

Fig. 1.14

Haven't you seen decorative lamps as shown in figure 1.14? When light passes through these fibres, it emerges only through the fibre tips. What may be the reason?

Let's do some activities to understand this.

Allow light from a laser torch to fall at different angles on the surface of water taken in a trough.

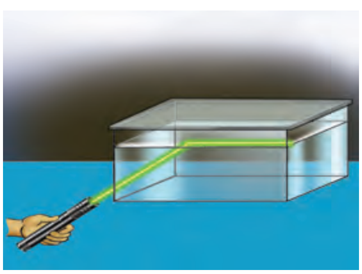


Fig. 1.15 (a)

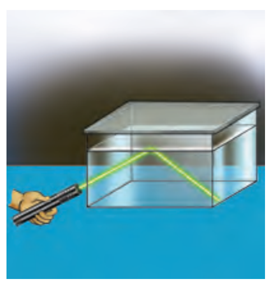


Fig. 1.15 (b)

- Which are the mediums through which light passes inside the trough?
- Does the light enter from an optically denser medium to a rarer medium or from an optically rarer medium to a denser medium?

ST-305-2-PHYSICS(E)-9-VOL-1

- Increase the angle of incidence gradually. What do you observe?

Here the light enters from an optically denser medium to a rarer medium. The angle of refraction goes on increasing with the increase in the angle of incidence. The incident ray reflects back to the water completely when the angle of incidence is above a specific value.

- When does the light reflect completely to the same medium, without refraction?

Try out an experiment.

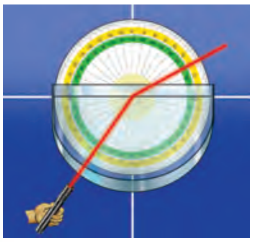


Fig. 1.16

Draw a circle on a chart paper. Mark angles on the paper as if two protractors are placed together. Keeping this on the surface of a table, place a thick semicircular glass slab on the circle drawn on the chart paper as shown in figure 1.16. Allow the light from a laser torch to fall on this slab at different angles. Observe the angle of incidence and angle of refraction in each case. Draw the ray diagram in the science diary.

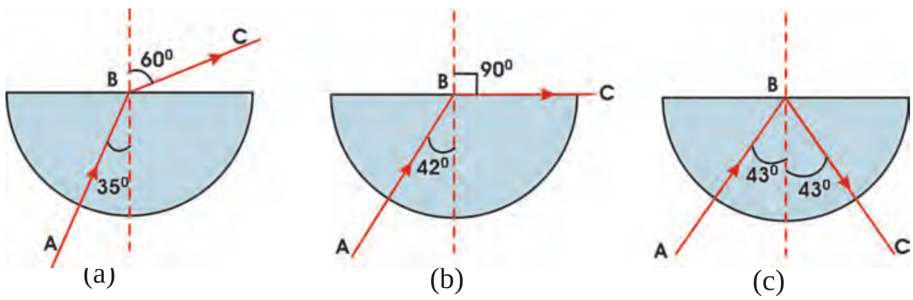


Fig. 1.17

- From which medium to which does the ray of light enter?

  (from an optically denser medium to a rarer medium / from an optically rarer medium to a denser medium)

- What is the change in the angle of refraction when the angle of incidence increases?
- What is the angle of incidence when the angle of refraction is 90^o?
- What peculiarity do you notice when the light is incident at an angle greater than this angle of incidence?

When a ray of light enters from an optically denser medium to a rarer medium, the angle of incidence at which the angle of refraction becomes 90° is the critical angle. In the glass-air pair, the critical angle is 42°.

When a ray of light enters from an optically denser medium to a rarer medium, at an angle of incidence greater than the critical angle, the ray is reflected back completely to the same medium without undergoing refraction. This phenomenon is total internal reflection.

The path of light through different mediums is given. Analyse the figures and answer the following questions.

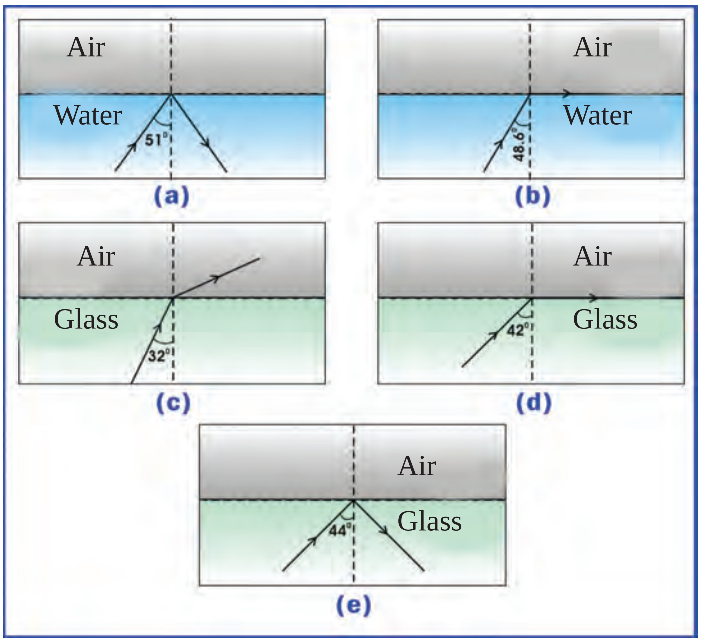


Fig. 1.18

If only one medium is mentioned while stating the critical angle, the second medium will be either air or vacuum.

a) **Which of the above figures represent total internal reflection?**

b) **What is the critical angle of glass in this case?**

c) **Will total internal reflection occur for a ray of light entering from water to air at an angle of 50°? Why? What is the critical angle for the water-air pair?**

d) **What are the two conditions required for total internal reflection to occur?**

Observe figure 1.19

- The bottom of the aquarium is seen above the surface of water. What may be the reason?

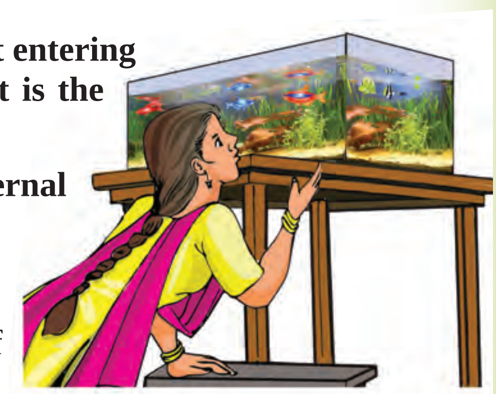


Fig. 1.19

The light coming from the bottom of the aquarium undergoes total internal reflection at the surface of water. Hence, the bottom is seen above the surface of water. Isn't the distance from the surface of the water to the bottom of the aquarium the same as the distance from the surface to the image caused by total internal reflection?

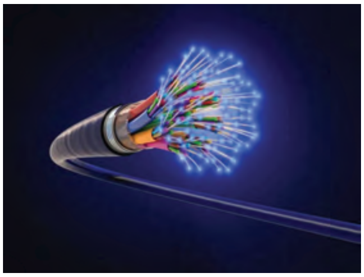


Fig. 1.20 (a)

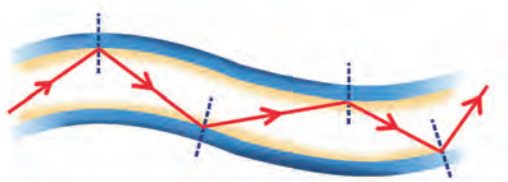


Fig. 1.20 (b)

Charles. K. Kao was awarded the Nobel Prize in Physics in 2009 for his achievements in the field of transmission of light through optical fibres.

One end of each optical fibre in the decorative lamp is connected to a suitable source of light. Light rays from this source travel through the fibre. While travelling through the fibre, as shown in figure 1.20 (b) it makes an angle of incidence greater than the critical angle with the walls of the fibre. Hence the light undergoes successive total internal reflection and emerges through the other end.

Let's observe the optical illusions caused by total internal reflection in our surroundings.

- During summer season there seems to be water logging on roads when viewed from a distance. What may be the reason?

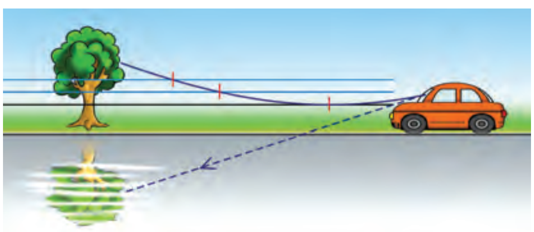


Fig. 1.21 (a)

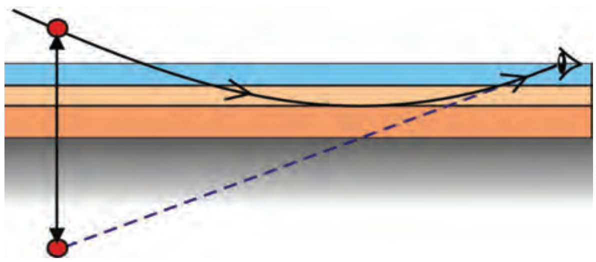


Fig. 1.21 (b)

The layers of air closer to the road have a low optical density as it is warmer than the upper layers. The optical density of the air increases gradually as we go higher.

When light rays coming from the surrounding objects pass through different layers of air with different optical densities, they undergo refraction and then total internal reflection as seen in the figure. Such deviated light rays fall on our eyes. Hence their image appears to have formed on roads. This phenomenon is known as mirage. Such familiar images are usually seen on the surface of water. Now do you understand why water seems to be logged on roads when viewed from a distance?

Cycle reflector
Fig.1.22 (a)

Applications of Total Internal Reflection

Reflector :

Haven't you observed reflectors in the tail lamps of vehicles? A large number of small prisms are fixed inside them (figure 1.22 (a)). How does a ray of light incident on a prism get reflected? It can be explained on the basis of the critical angle of glass.

The light ray is incident normally on the side PQ. Hence, there is no refraction. You know that the critical angle of glass is 42^o. The angle of incidence at A and B is 45^o. Hence the light falling on A undergoes total internal reflection and reaches B. There it undergoes total internal reflection again and comes out of the reflector as shown in the figure. Doesn't the same process happen in other prisms in the reflector as well?

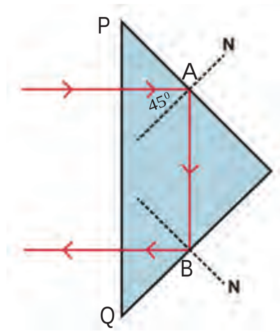


Fig. 1.22 (b)

Periscope :

You are familiar with periscopes made of mirrors. Periscopes are also made using prisms to increase visual clarity.

Observe how the total internal reflection is made use of in a periscope (figure 1.23).

Based on the figure, examine how prisms are used in periscopes and record in the science diary.

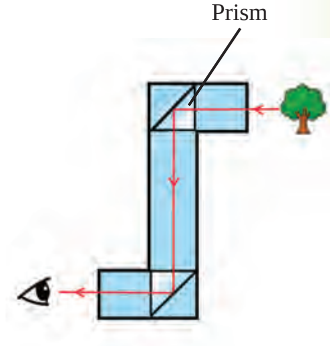


Fig. 1.23

Optical Fibre :

The invention of optical fibres brought about revolutionary changes in the field of telecommunications. You have already learned how total internal reflection of light is made use of in optical fibre cables (OFC). Based on this phenomenon, communication signals (optical signals) also travel through optical fibres in the form of light rays.

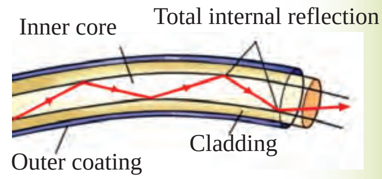
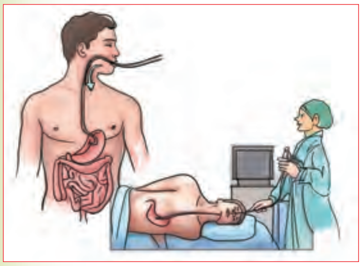


Fig.1.24

Thousands of optical signals can be sent simultaneously through a single cable without the loss of intensity. Such signals can be sent to distant places with the speed of light. This is the reason for using optical fibre cables in communication.



Endoscopy

Fig. 1.25

The use of optical fibres in the medical field is increasing day by day. Collect information regarding this and present in the class.

? Statements regarding total internal reflection and reflection from plane mirror are given. Tabulate them suitably.

- Occurs only when a ray of light enters from an optically denser medium to a rarer medium at an angle greater than the critical angle.
- The ray of light is not completely reflected.
- Reflection occurs on a surface at any angle of incidence.
- The ray of light is completely reflected.

Reflection from a plane mirror	Total internal reflection
• The ray of light is not completely reflected. •	• •

Table 1.4

Let's Assess

1. Ray diagram showing the path of light through mediums A and B is given.

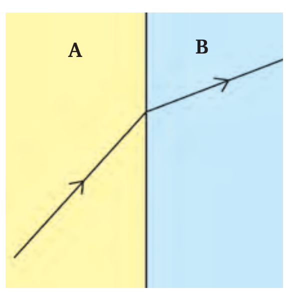


Fig. 1.26

a) In which medium will the speed of light be less – A or B ?

b) Which will be the optically denser medium? Justify your answer.

2. Complete the given diagram. Mark the angle of incidence and angle of refraction.

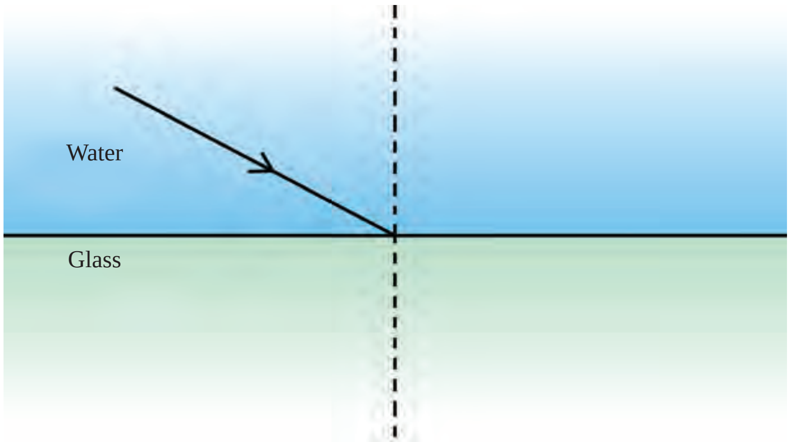


Fig. 1.27

3. Light passes from medium X to Y.

Here, the angle of refraction is greater than the angle of incidence.

a) In which medium is the speed of light more?

b) Which is the medium of larger refractive index?

c) Draw the path of light.

4. Refractive index of different mediums are given in the table.

Medium	Refractive index
Crown glass	1.52
Glycerine	1.47
Sunflower oil	1.47
Water	1.33
Flint glass	1.62

Table 1.5

a) In which medium does light travel with maximum speed?

b) Will a ray of light entering obliquely from glycerine to sunflower oil deviate? Explain the reason.

c) Light is transmitted from glass to each medium listed in Table 1.5. If light is incident at an angle of 30°, which medium will have the largest angle of refraction? Why?

5. Observe the figure. Ray of light incident on two mediums is depicted.

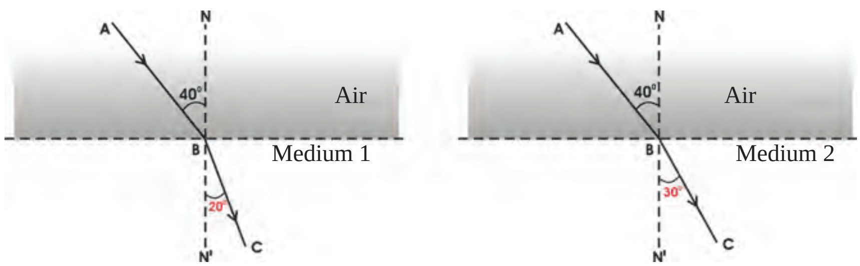


Fig. 1.28

a) Which is the medium of higher optical density? Why?

b) Which is the medium of greater refractive index?

6. Observe the figures.

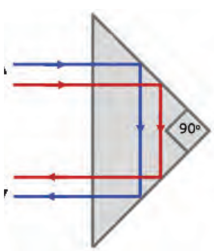


Fig. 1.29 (a)

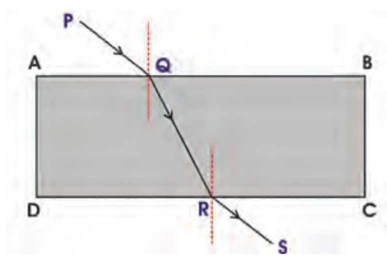


Fig. 1.29 (b)

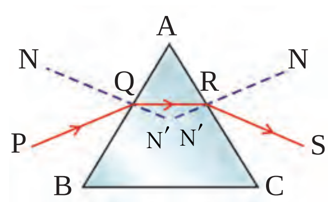


Fig. 1.29 (c)

a) Which figure indicates total internal reflection?

b) Which figures indicate refraction?

7. The critical angle of glass is 42°. Choose the angle of incidence for which total internal reflection takes place.

a) 40° b) 49° c) 38° d) 42°

8. We can see many small prisms in the reflectors used in motorcycles. Describe the benefits of using them.

9. Observe the table.

Medium	Refractive index
Air	1.0003
Water	1.33
Kerosene	1.44
Turpentine oil	1.47
Crown glass	1.52
Diamond	2.42

Table 1.6

a) Choose the medium in which light has the least speed.

b) The speed of light in air is 3×10^8 m/s. What is the speed of light in kerosene?

c) When a ray of light enters obliquely from air to diamond, will the refracted ray deviate towards the normal, or away from the normal? Justify your answer.

10. The path of light through mediums A, B, C and D are given. Choose the correct figures. (The optical density of the mediums are in the order A<B<C<D)

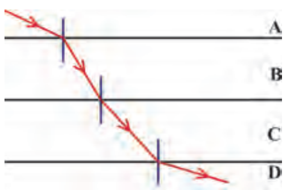


Fig. 1.30 (a)

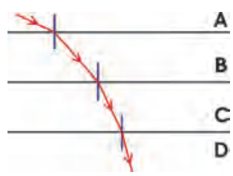


Fig. 1.30 (b)

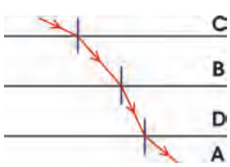


Fig. 1.30 (c)

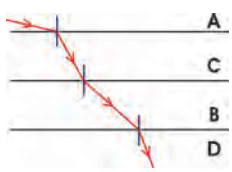


Fig. 1.30 (d)

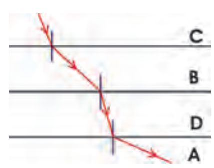


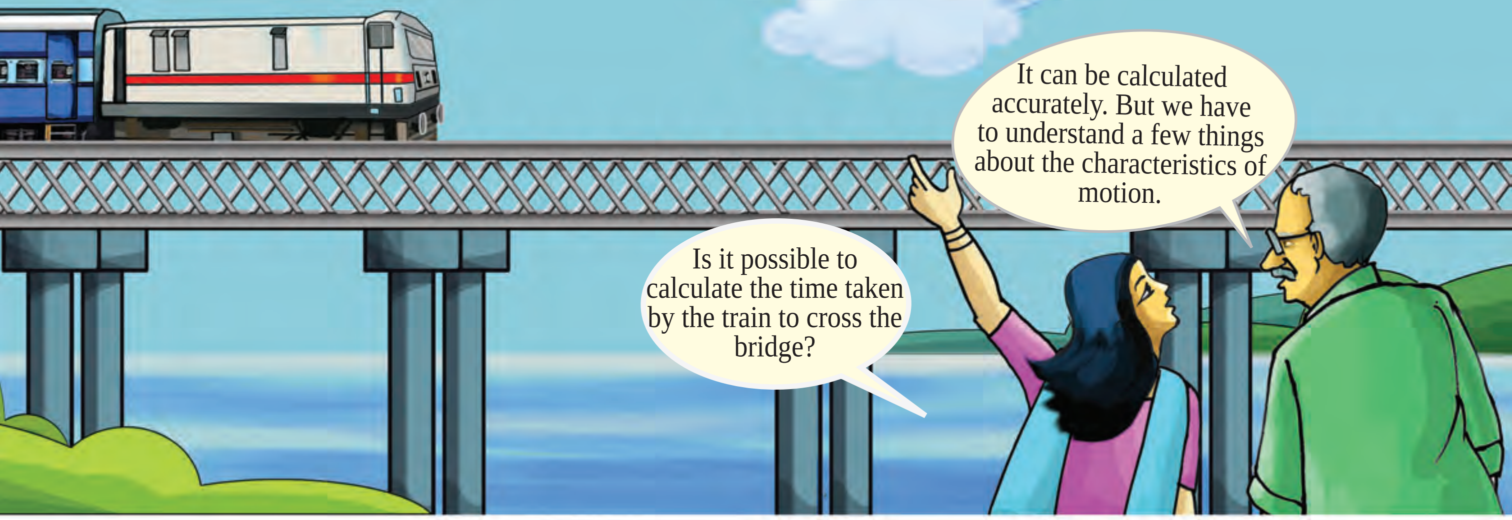
Fig. 1.30 (e)

11. Speed of light in ethanol is lesser than that in methanol. Which medium has lower refractive index? Why?

Extended Activities

1. Make periscopes using prisms instead of mirrors. Exhibit them.
2. Find out the critical angle in different mediums like glycerine, water, coconut oil, glass etc., through an experimental project and compare them. Prepare a project report including different stages like objective, materials, method of study, results etc.
3. Can the angle of refraction be 90^{o} when light enters from an optically rarer medium to a denser medium? Do an activity and write it down in the science diary.

2 Equations of Motion



Observe the figure.

Did you ever have such a doubt like the one raised by the child? Let's try to find the answer.

A, B, C and D are four electric poles erected on the side of the road. The distance between any two adjacent poles is 40 m.

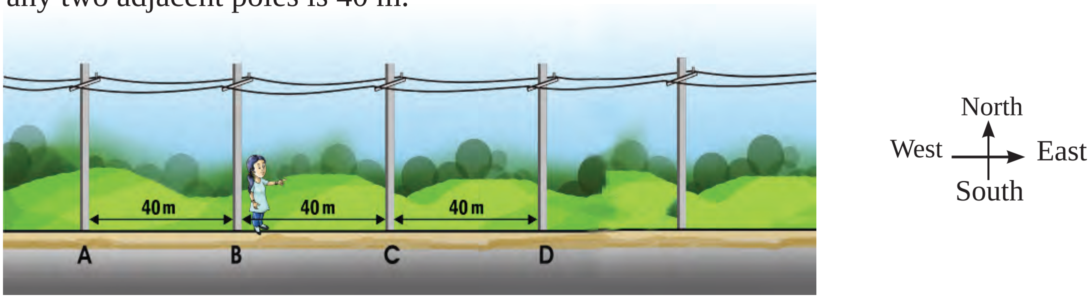


Fig 2.1

A child starts walking from pole B, passes C and reaches D. After that, the child returns from D and reaches the pole C.

- What is the total distance travelled by the child?
- What is the distance between the current position C and the initial position B of the child?
- If the child travels 40 m from B, which are the possible positions of the child?
- In which direction should the child travel 40 m to reach C from B?

(towards the east /towards the west)

The distance between the initial position B of the child and the current position C is the measure of the change in the position of the child. If the child travels 40 m from B in the eastward direction, the child can reach C. Here 40 m eastward from B to C is the displacement of the child.

Displacement

Displacement is the straight line distance between the initial position and the final position in a definite direction. Displacement is denoted by the symbol s. Unit of displacement is metre (m) which is also the unit of distance.

Vector quantities are the physical quantities having direction specified with magnitude. Vector quantities have both magnitude and direction. Quantities that do not require direction are scalar quantities.

- Is displacement a vector or a scalar?

Let's consider another situation.

- If the child travels 40 m in the westward direction from B, the current position of the child is ....

If the displacement from B in the forward direction (towards the east) is considered as positive, the displacement in the backward direction (towards the west) should be considered as negative. (These can also be considered in the reverse order). Once the direction is determined, the positive and negative directions should not be changed thereafter. Here, B is the initial position and A is the final position. Hence the displacement is negative.

Complete Table 2.1 based on the child's travel.

Stages of path covered by the child	Distance covered	Displacement
Directly from B to C	40 m	
Starts from B, reaches D and returns to C		40 m (from B to C)
Starts from B and reaches D	80 m	80 m (from B to D)
From B to A		− 40 m (from B to A)
Starts from B, reaches A and returns to B		Zero

Table 2.1

- The child moved from A to D and returned to A. What is the distance covered? What is the displacement? Aren't the initial position and final position the same?

  Isn't it clear from the table that the magnitude of displacement of an object can be zero or equal to or less than the distance covered?

- Write down the situations in which the distance covered and displacement are equal.

Two different paths taken by a child to move from position P through Q are depicted.

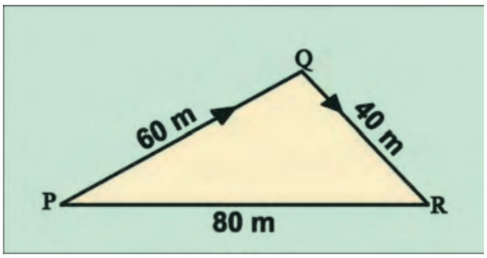


Fig 2.2 (a)

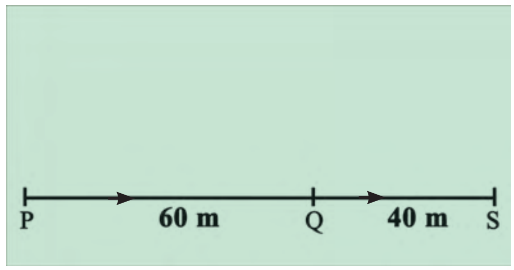


Fig 2.2 (b)

a) What is the distance covered in figure 2.2(a)? What is the displacement?

b) What is the distance covered as per the motion in figure 2.2(b)? What is the displacement?

c) In which situation is the magnitude of the distance and displacement equal?

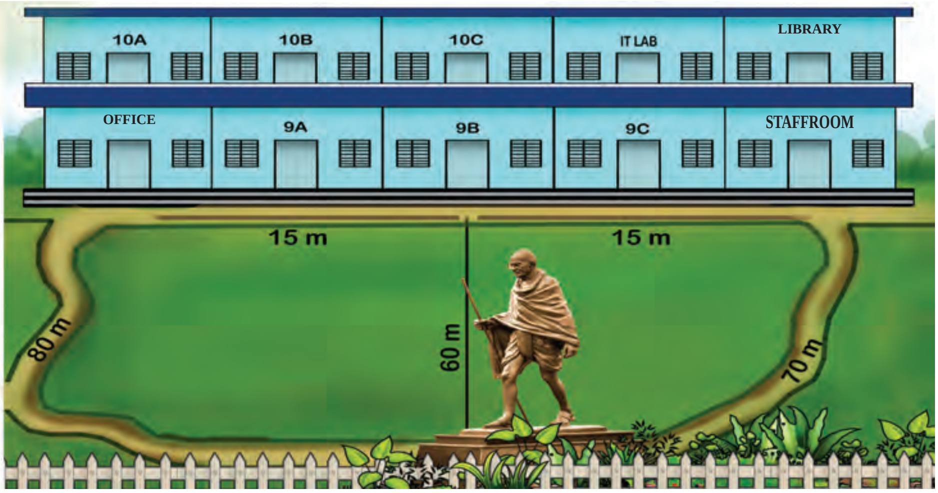
Magnitude of displacement and distance covered are equal only when an object is moving along a straight line in the same direction.

Tabulate the differences between distance and displacement related to the path traversed by a person in Table 2.2.

Distance	Displacement
Length of the path covered	
	Can be zero
Scalar	

Table 2.2

The classrooms and some other locations of a school are depicted.



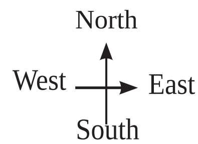


Fig. 2.3

During the interval, a student from Class 9B went to the staff room. The child then proceeded to the statue of the Father of the Nation in the school garden and returned to the class via the school office.

Complete Table 2.3 based on the path followed by the child.

Child's path	Distance (m)	Displacement (m)
When the child reaches the corridor in front of the staff room from Class 9B		
When the child reaches the garden near the statue of the Father of the Nation from 9B via the staff room		
When the child returns to Class 9B		

Table 2.3

Velocity

An illustration of a child's path is given in the figure. A child travels from P and reaches R through Q in 18 s.

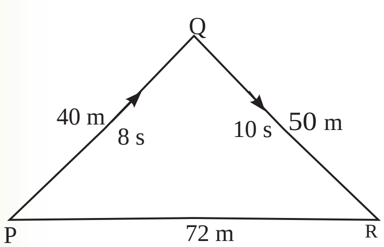


Fig 2.4

- What is the total distance covered by the child to reach R from P through Q?
- What is the speed of the child when the child travels from P to R through Q?
- What is the displacement of the child?

- Isn't the child's displacement of 72 m taking place in 18 s?
  Let's find out the displacement in one second.

$$\text{Displacement in one second} = \frac{\text{Displacement}}{\text{Time}}$$

$$= \frac{72\text{ m}}{18\text{ s}}$$

$$= 4\text{ m/s}$$

The displacement in unit time is the velocity.

- What is its direction? (P $\rightarrow$ R / R $\rightarrow$ P / P $\rightarrow$ Q $\rightarrow$ R)

Didn't you understand that the direction of displacement and velocity are the same?

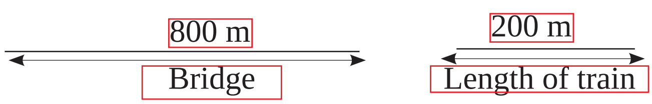
Velocity **(v)** = $\frac{\text{..............}}{\text{..............}}$; That is, $\mathbf{v = \frac{s}{t}}$

$$\text{Unit of velocity} = \frac{\text{Unit of displacement}}{\text{Unit of time}}$$

$$= \frac{\text{............}}{\text{..............}} = \text{..............}/\text{..............}$$

> Velocity is the displacement of an object in unit time.
>
> Velocity is a vector quantity. The direction of velocity and displacement are the same. The unit of velocity is m/s.
>
> The displacement of an object does not depend on the path of the object. But to calculate velocity, the total time taken to cover the actual distance should be considered.

Now, let's consider the doubt raised by the child at the beginning of this lesson. A train of length 200 m travels with a velocity of 20 m/s. What is the time taken by this train to cross a straight bridge of length 800 m?



Displacement = Length of the bridge + Length of the train

s = 800 m + 200 m

= 1000 m

Velocity (v) = 20 m/s

$$\text{Time (t)} = ?$$

$$t = \frac{s}{v} = \frac{1000 \text{ m}}{20 \text{ m/s}}$$

$$\text{Time} = 50 \text{ s}$$

Calculate the speed and velocity of the child from P to Q in figure 2.4. What inferences can you draw from this?

A vehicle travels along a straight line with a velocity of 25 m/s and covers a distance of 400 m. Calculate the time taken for this.

What is the displacement of an object moving with a velocity of 36 m/s in one minute?

Uniform Velocity and Non uniform Velocity

Information related to the journey of three cars, each travelling a distance of 200 m is given. Observe their characteristics of motion and answer the questions.

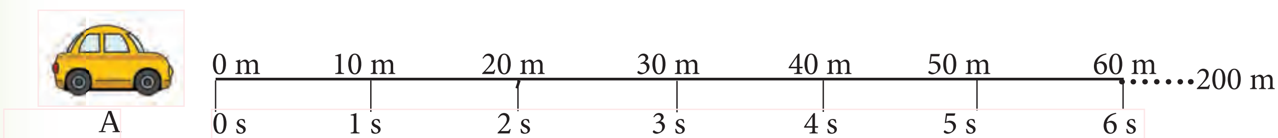


Fig 2.5 (a)

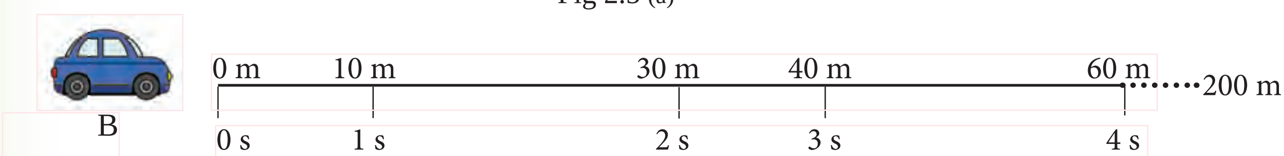


Fig 2.5 (b)

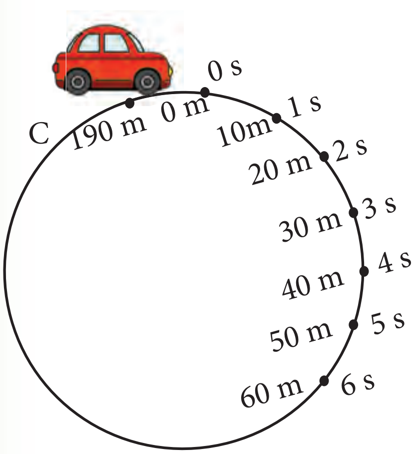


Fig 2.5 (c)

- Is the velocity of Car A always the same? Why?
- What about the velocity of Car B? Why?
- Haven't you noticed the mud sticking to the tyres of vehicles being thrown off when they rotate? Does the mud splash in the same direction every time?

  Isn't the direction of motion of an object moving along a circular path always changing?

  If the direction of motion of an object changes, the velocity of the object will also change.

- Is the velocity of Car C the same every second? Does the velocity change? Even though the magnitude of the speed does not change, the velocity changes because the direction changes.

An object moving in the same direction is in uniform velocity, if the magnitude of the displacement is equal at equal intervals of time.

If speed and direction change, velocity will also change. Even if any one of these changes, the velocity will vary. If the velocity of an object changes, then it will be in Non uniform velocity.

Complete the table based on the information in figures 2.5 (a), (b), (c).

Vehicle	Uniform velocity	Non uniform velocity	Reason
Car A	✓		Neither the magnitude nor the direction of the velocity changes.
Car B			
Car C			Magnitude of velocity does not change. Direction changes.

Table 2.4

You have understood what uniform velocity and non uniform velocity are.

? Classify the situations given below, as uniform velocity and non uniform velocity. Record it in the science diary.

- Motion of a stone dropped from a height
- When light travels through vacuum
- A bus starts from a bus stop and is moving forward
- A train travelling at a uniform speed in the same direction
- Swinging on a swing

Uniform velocity	Non uniform velocity
•	• Motion of a stone dropped from a height •

Table 2.5

The velocity of a bus starting from a bus stop keeps changing. Will the change in velocity be the same in each second?

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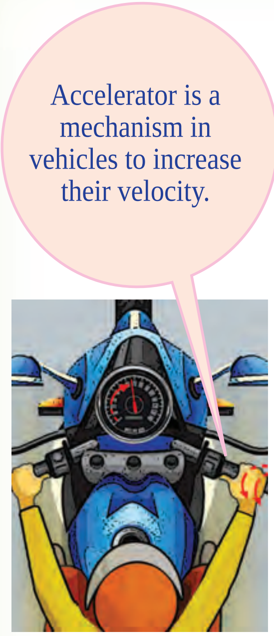


Fig.2.6

Acceleration

Imagine that you are sitting in a bus. When the bus starts and moves forward in a straight line, doesn't the velocity change?

The data related to the straight line motion of the bus is given below. Analyse the information and answer the questions.

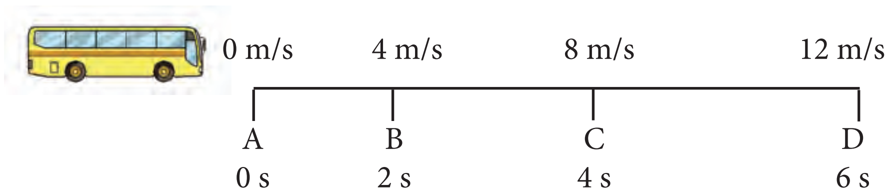


Fig.2.7

- When the bus travels from A to B, the velocity at A is.............. (initial velocity / final velocity)
- The velocity at B is...........

  (initial velocity / final velocity)
- While considering the motion from B to C, velocity at B is............

Complete the table using the data of the motion of the bus.

Path travelled by the bus	In each stage		Change in velocity (v - u) m/s	Time taken for change in velocity (t) s	Rate of change of velocity $\left(\frac{v-u}{t}\right)$ m/s²
	Initial velocity (u) m/s	Final velocity (v) m/s			
From A to B	0	4	4	2	$\frac{4\ m/s}{2\ s} = 2\ m/s^2$
From B to C					
From C to D					

Table 2.6

Acceleration is the change in velocity of an object in unit time, or the rate of change of velocity.

$$\text{Acceleration} = \frac{\text{change in velocity}}{\text{time}} \quad ; \quad a = \frac{v - u}{t}$$

Acceleration is a vector quantity.

You have calculated the change in velocity of the bus in each second or the rate of change of velocity. This is the acceleration of the bus.

$$\text{Unit of acceleration} = \frac{\text{Unit of change in velocity}}{\text{Unit of time}}$$

$$= \frac{.............}{.............}$$

$$= ....$$

A car is moving along a straight road with a velocity of 10 m/s. It is given an acceleration of 5 m/s^2. Calculate the velocity of the car after 2 s.

Initial velocity u = 10 m/s

acceleration a = 5 m/s^2

time t = 2 s

Final velocity v = ?

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

$$v - u = at$$

$$v = u + at = 10 + 5 \times 2$$

$$= 20 \text{ m/s}$$

To calculate the final velocity, we can use the equation **v = u + at**

The velocity of an object changes from 4 m/s to 28 m/s in 4 s. Calculate the acceleration.

Have a look at the scene in an amusement park. List the instances in which acceleration occurs.

- **Motion of a giant wheel**
-

Fig. 2.8

Find instances of acceleration in your daily life and record them in the science diary.

- **Motion of a coconut falling from a coconut tree**
-

Can you think of some instances in everyday life where the velocity decreases? Expand the list by giving more examples.

- **Train arriving at a station**
- **The upward motion of a stone thrown upwards**
-

Is there an acceleration when the speed decreases?

Observe the figure.

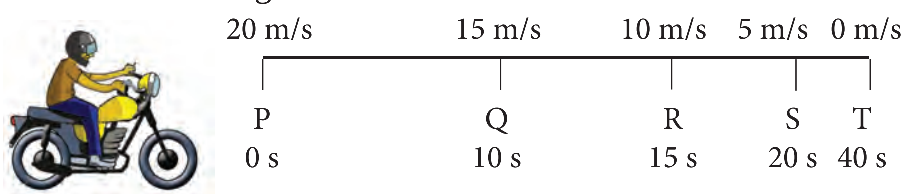


Fig. 2.9

The information related to the motion of a motorbike is given in the figure.

Complete the table by analysing the figure 2.9

Stages of motion	In each stage		Change in velocity (v - u) m/s	Time taken for change in velocity t (s)	Rate of change of velocity (Acceleration) $\left(a = \frac{v-u}{t}\right)$ m/s^2
	Initial velocity (u) m/s	Final velocity (v) m/s			
From P to Q	20	15	-5	10	$\frac{-5}{10} = -0.5$
From Q to R					
From R to S					
From S to T					

Table 2.7

It is seen that velocity is decreasing here.

The rate of decrease in velocity is negative acceleration or retardation.

Its unit is also m/s^2.

- **Should negative sign be given while writing the value of retardation?**
- **An object starts from rest and attains a velocity of 10 m/s in 5 s.**
  - **a) What is its acceleration?**
  - **b) What is the acceleration if it comes to rest in 5 s? What is the retardation?**
- **A vehicle travelling at a speed of 5 m/s is brought to rest in 2 s by applying brakes. Calculate the retardation of the vehicle.**
- **If the velocity of an object in the 2nd second is 40 m/s and 30 m/s in the 4th second, what is its acceleration? What is its retardation? What is its velocity at the 8th second?**

Uniform Acceleration, Non uniform Acceleration

- Was the acceleration obtained as per Table 2.6 the same on each occasion?
- What about the acceleration obtained as per Table 2.7?

An object is in uniform acceleration if the rate of change of velocity is equal at equal intervals of time. But if the rate of change of velocity of an object varies differently at equal intervals of time, then it is in non uniform acceleration.

You have acquired some ideas about speed, velocity and acceleration. Over speeding of vehicles cause accidents. We must strictly follow traffic rules to reduce accidents. Are accidents caused only by overspeeding of vehicles? Shouldn't pedestrians also follow the traffic rules?

Which are the traffic rules for pedestrians to follow?

- Pedestrians should walk along the right side of the road.
- Cross the road only at the zebra crossing, obeying the traffic signal.
-

Road signs and road markings have been implemented to reduce road accidents and to ensure safety.

Road signs can be broadly classified into three categories.

Haven't you noticed sign boards erected on roadsides? Some of them are in circular, triangular or rectangular shapes. It is important to note the characteristics of each of them.

Mandatory signs Signs indicating mandatory compliance	Cautionary signs Warning signs	Informatory signs Basic information indicators
		

Fig 2.10 (a)

Note the examples for mandatory, cautionary and informatory signs.

i. Mandatory Signs

These signs are warning signs that must compulsorily be followed.

No Parking

No Bicycles

No Horn

Fig 2.10 (b)

ii. Cautionary Signs

These signs are meant to warn about the road conditions in the journey ahead.

Hump

Narrow bridge

School ahead

Fig 2.10 (c)

iii. Informatory Signs

These signs provide information about the direction in which the driver has to go, the distance to various places and the availability of other facilities.

Petrol pump

Police station

Hospital

Fig 2.10 (d)

In addition to the signs mentioned above, collect more symbols for each category, prepare separate posters and display them on the school bulletin board.

Road Marking

Where vehicles are allowed to cross in a controlled manner

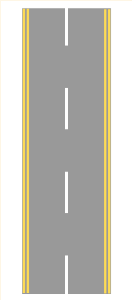


Fig 2.11 (a)

Where vehicles are not allowed to cross

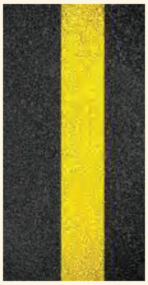


Fig 2.11 (b)

Zebra crossing

Fig 2.11 (c)

Do accidents occur only because traffic rules are disobeyed?

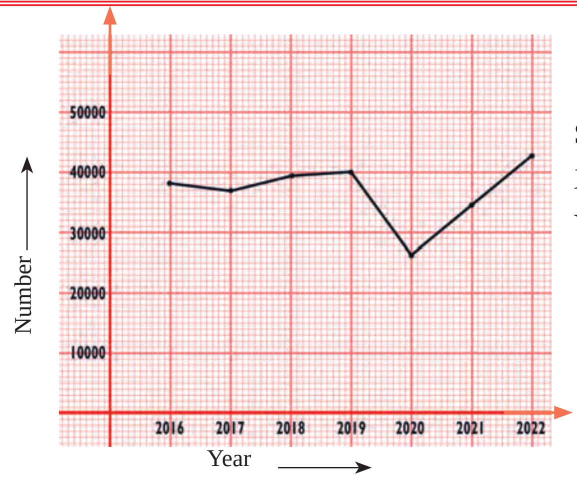
In dim light, drivers may not be able to see pedestrians walking along the side of the road or crossing the road wearing dark clothes. It invites accidents. Isn't it advisable to wear light coloured clothes during these times?

Prepare and present a seminar paper on the topic 'Students and Road Safety'.

Hints :

- Crossing the road
- Moving in groups along the road
- Playing near the road
- Driving a motor vehicle before obtaining a license
- Safe cycling
- Road signals
-

A graph showing the number of road accidents in Kerala from 2016 to 2022 is given below.



Scale

X axis - 1 cm = 1 Year

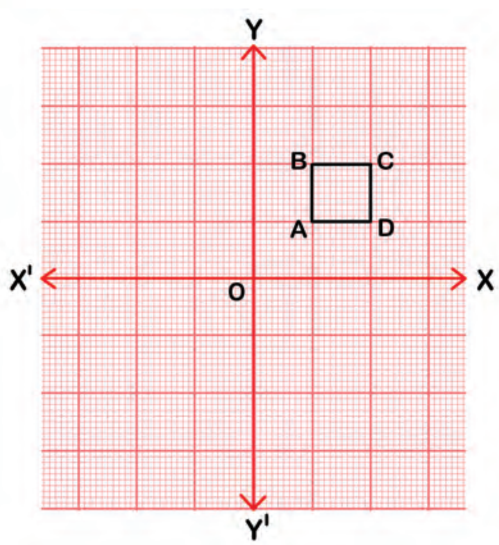
Y axis - 1 cm = 10000 Number

Source : Official website of Kerala Police

Graph 2.1

- What information can be gathered from the above graph?
- List down your findings.

Graphical Representation of Motion



Graph 2.2

A graph is a two-dimensional diagram. In a graph the horizontal line XX′ is the X axis and the vertical line YY′ is the Y axis. The point where the axes meet is the origin O.

OX is the positive axis (towards the right from the origin) and OX′ is the negative axis (towards the left from the origin). Similarly OY is considered as positive and OY′ is considered as negative. Axes are number lines.

There are several segments of length 1cm and breadth 1cm in a graph. The area of the segment ABCD is 1cm^2. A graph is named by the quantities expressed in the Y and X axes respectively.

A graph can be used to understand and illustrate the relation between quantities and to formulate equations based on them. Mathematical calculations, real time information, formulation of conclusions etc., are also possible through graphs.

Check the graph 2.1 and answer the questions given below.

- In which year is the number of accidents the least?
- How many accidents occurred in 2019?

ExpEYES → Distance Measurement using SR04 Echo Module Plotting Graphs

Position - Time Graph

Information regarding the motion of an object is given in the table below. How can we draw a graph using these measurements? Choose an appropriate scale.

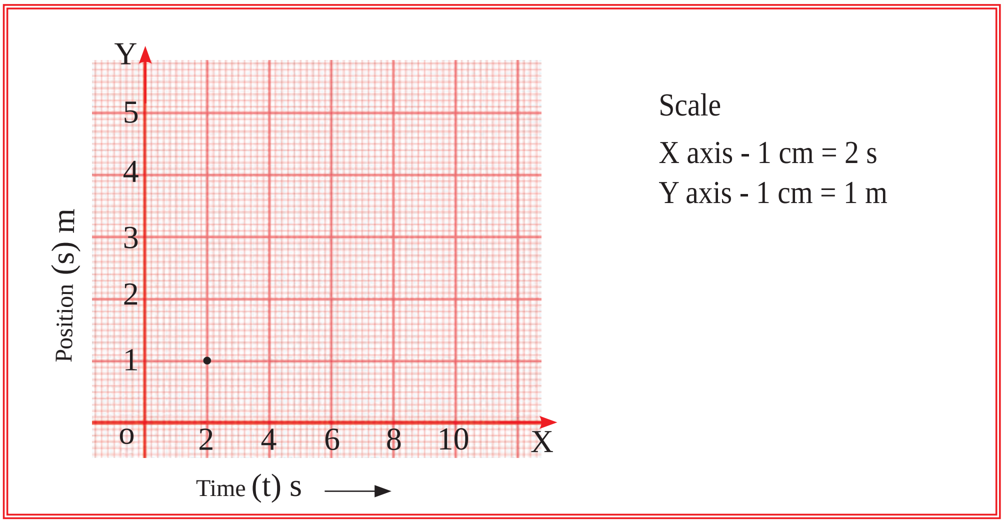
Look at the given example.

X axis - Time (s)	2	4	6	8	10
Y axis – Position (m)	1	2	3	4	5

Table 2.8

Draw the axes X′OX and Y′OY on the given graph paper. Mark O at the point of intersection of the axes. Determine the appropriate scale and plot position on the Y-axis and time on the X-axis according to the scale. Mark the co-ordinates given in the table as points on the graph paper.

Example : (2, 1) When the time is 2 s and the position is 1m, mark the point which lies above 2 in the X axis and against 1 in the Y axis. Mark the other points in the same way and join the points obtained.



Graph 2.3

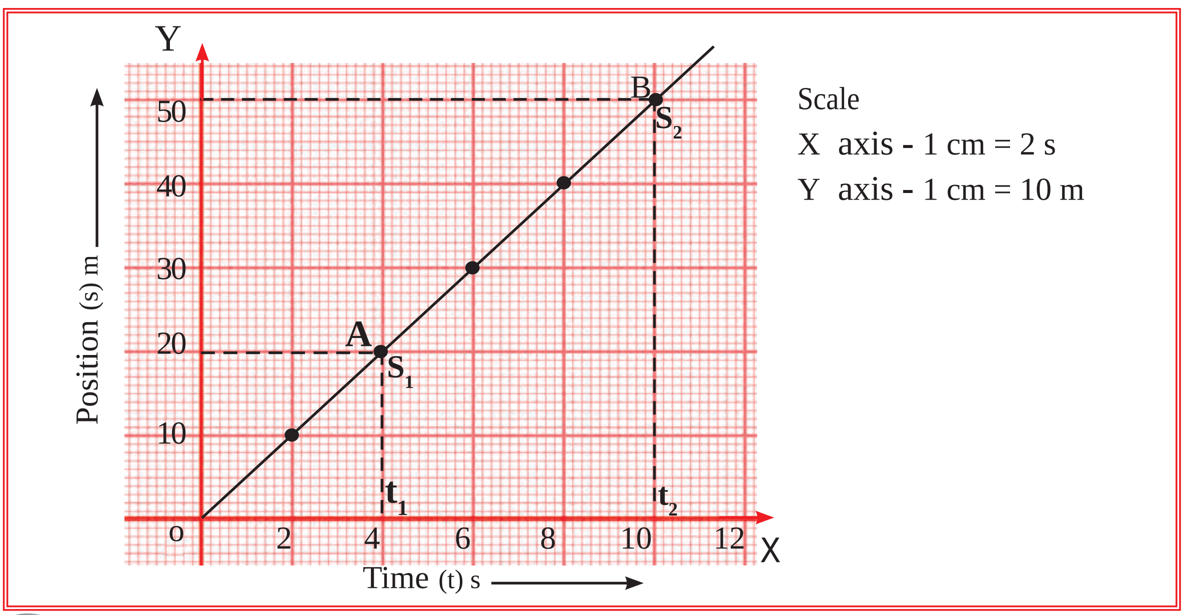
- What is the nature of the graph obtained?

  (a horizontal straight line / an inclined straight line /a curved line)
- By what name is this graph known?
- From the shape of the graph obtained, what is the nature of the velocity of the object?

  (uniform velocity/non uniform velocity)
- What is the displacement of the object in 5 s?
- What is the time taken to travel 1.5 m?

Let's consider another situation.

Position-time graph of the motion of a car is given.



Graph 2.4

How can we find the velocity of the car from A to B from Graph 2.4?

- What is the displacement of the car from A to B in the graph?
- What is the time taken by the car to travel from A to B?

$$\text{Velocity} = \frac{\text{Displacement}}{\text{Time}} = \frac{s_2 - s_1}{t_2 - t_1} = \text{------} = \text{------}$$

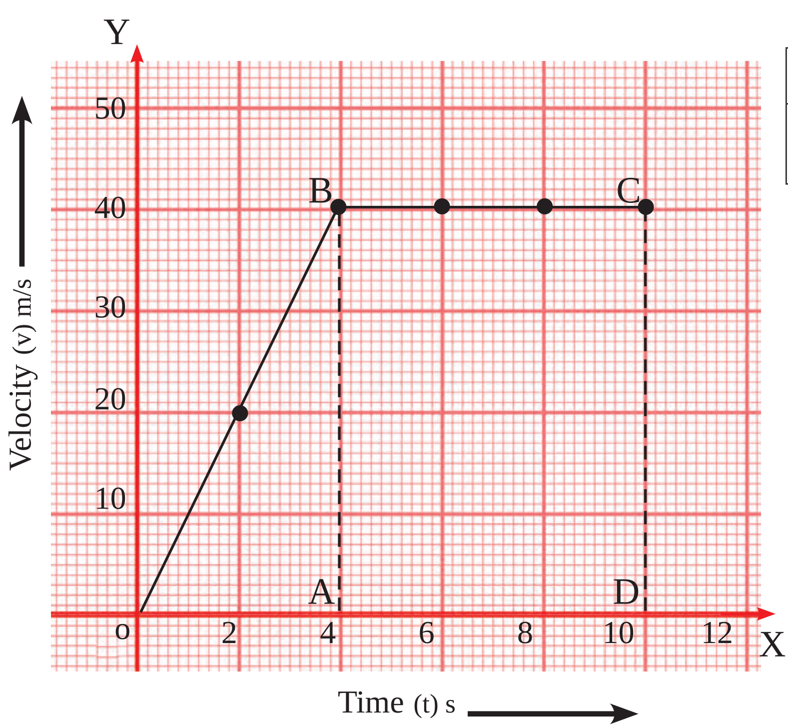
- What is the position of the car at the sixth second in the graph?
- Which type of velocity does this car have?

  (uniform velocity / non uniform velocity)
- Find out the velocity of the car between 6 s and 8 s from the graph.

A suitable scale has to be taken to limit the data of the graph to the size of the graph paper. As the scale increases, the size of the graph decreases. But the value of the physical quantity indicated by the graph does not change.

Velocity - Time Graph

Observe the given table and velocity-time graph related to the motion of a vehicle.



Time (s)	0	2	4	6	8	10
Velocity (m/s)	0	20	40	40	40	40

Scale

X axis - 1 cm = 2 s

Y axis - 1 cm = 10 m/s

Graph 2.5

A velocity-time graph is a graph that plots velocity on the Y-axis and time on the X-axis.

- From the graph, find the displacement of the vehicle between the fourth and tenth second.

$$\text{Velocity} = \frac{\text{Displacement}}{\text{Time}}$$

- Then, displacement = velocity × time

On the graph, it will be equal to AB × AD (Equal to the area of the rectangle ABCD)

- Isn't this equal to the area of the portion below BC on the graph?

  s = 40 m/s × 6 s = 240 m

On a velocity-time graph, displacement of an object within a definite time interval is equal to the area of the portion under the graph at that interval.

- Find the displacement during the first 4 s from Graph 2.5.
- What is the change in velocity in the first 4 s? What is the acceleration?
- What is the acceleration of this vehicle between 4 s and 10 s?

We have learned that displacement, velocity, time, acceleration etc., can be found out from the velocity - time graph.

Graphs can also be used to formulate equations.

Equations of Motion

The notations given below are commonly used to formulate equations of motion.

For an object moving with uniform acceleration -

Initial velocity u Final velocity v

Displacement s Acceleration a

Time taken for the change in velocity t

We can use the equation $\mathbf{v = u + at}$ to understand the relation between velocity and time.

We can use the equation $\mathbf{s = ut + \frac{1}{2}at^2}$ to find the relation between displacement and time.

The relation between displacement and velocity can be found using the equation $\mathbf{v^2 = u^2+2as}$. These three equations are the equations of motion.

These equations are applicable only for objects in uniform acceleration.

Equations of Motion

$$v = u + at$$

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

$$v^2 = u^2 + 2as$$

A body starts from rest and acquires a velocity of 20 m/s in 2 s and 40 m/s in 6 s. What is the displacement of the object during this time interval?

Initial velocity, $u = 20$ m/s   **Time** $t = t_2 - t_1 = 6\text{ s} - 2\text{ s} = 4\text{ s}$

Final velocity, $v = 40$ m/s

$$\text{Acceleration, } a = \frac{v-u}{t}$$

$$= \frac{40\text{ m/s} - 20\text{ m/s}}{4\text{ s}}$$

$$= \frac{20\text{ m/s}}{4\text{ s}}$$

$$= 5\text{ m/s}^2$$

$$\text{Displacement, } s = ut + \frac{1}{2}at^2$$

$$= (20\text{ m/s} \times 4\text{ s}) + \left[\frac{1}{2} \times 5\text{ m/s}^2\,(4\text{ s})^2\right]$$

$$= 80\text{ m} + 40\text{ m}$$

$$= 120\text{ m}$$

If the velocity of a car increases from 6 m/s to 16 m/s in 10 s,

a) calculate the acceleration of the car.

b) what is the displacement of the car during this time?

a) $u = 6$ m/s

$v = 16$ m/s

$t = 10$ s

$$\text{Acceleration, } a = \frac{v-u}{t}$$

$$= \frac{16\text{ m/s} - 6\text{ m/s}}{10\text{ s}}$$

$$= \frac{10\text{ m/s}}{10\text{ s}}$$

$$= 1\text{ m/s}^2$$

b) Displacement, s $= ut + \frac{1}{2} at^2$

$= (6\ m/s \times 10\ s) + \left[\frac{1}{2} \times 1\ m/s^2 \times (10\ s)^2\right]$

$= 60\ m + 50\ m$

$= 110\ m$

The velocity of a train that started from a railway station becomes 90 km/h in 10 minutes. Calculate the acceleration of the train.

u = 0

v = 90 km/h

$= \frac{90 \times 5\ m/s}{18}$

= 25 m/s

> $1\ km/h = \frac{1000\ m}{3600\ s}$
>
> $= \frac{5}{18}\ m/s$

t = 10 minute

= 600 s

Acceleration, $a = \frac{v - u}{t}$

$= \frac{25\ m/s - 0\ m/s}{600\ s}$

$= \frac{1}{24}\ m/s^2$

An object falls down from rest and moves with an acceleration 10 m/s^2, hits the groundwith a velocity 20 m/s. From what height does the object fall?

u = 0

a = 10 m/s^2

v = 20 m/s

$v^2 = u^2 + 2as$

$(20\ m/s)^2 = 0^2 + 2 \times 10 \times s$

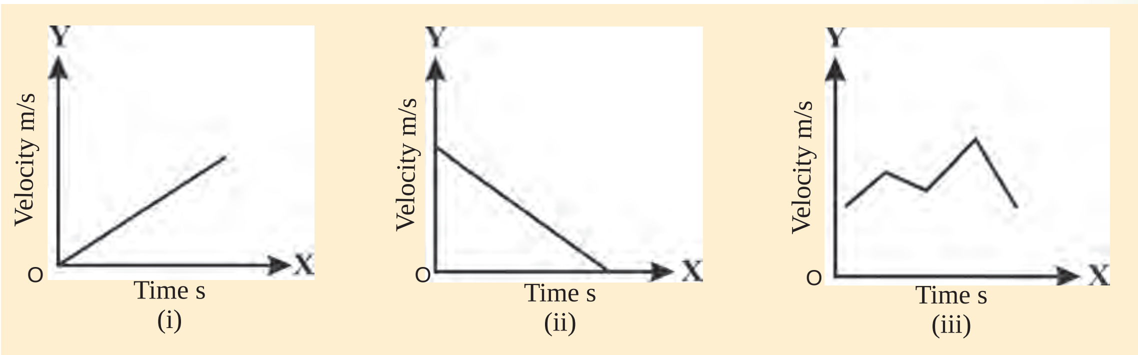
$400 = 20 \times s$

$s = \frac{400}{20}$

= 20 m

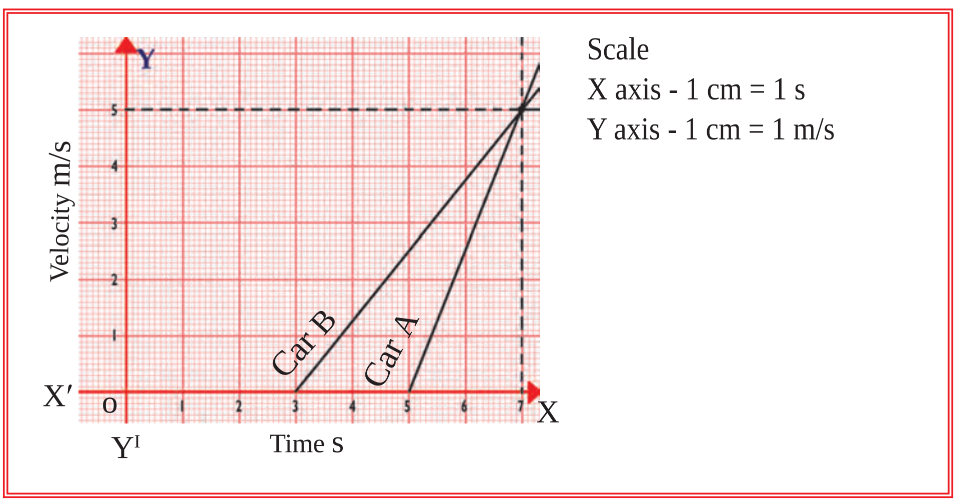
Let's Assess

1. A car starts from rest and moves with uniform acceleration. Calculate the acceleration of the car if it covers a distance of 200 m in 20 s.
2. If an object starts from rest and moves with an acceleration of 2 m/s^2, what will be the velocity of the object after 10 s?
3. Three different graphs related to the motion of a vehicle are given below. Analyse the graphs and find the characteristics of the motion.



Graph 2.6

4. Graph related to the motion of Car A and Car B is given.
   a) Which car has more acceleration? Why?
   b) Redraw the graph by changing the scale and compare the graphs.



Graph 2.7

5. Observe the figure.

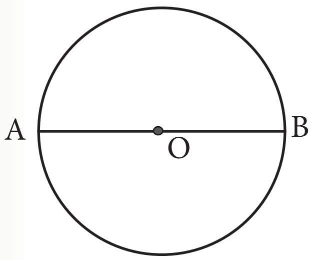


Fig. 2.12

A child runs along a circular path of circumference 440 m at a constant speed. The radius of the circular path is 70 m. The time taken to run from A and reach A in clockwise direction through B is 80 s. Find the distance, displacement, speed and velocity in each case in the table.

Situation	Distance	Displacement	Speed	Velocity
When it reaches B				
When it reaches A				

Table 2.9

6. A train starts from rest and attains a speed of 72 km/h in 5 minute. Find the acceleration and displacement of the train.

7. Analyse Table 2.10 and draw the velocity-time graph.

X Time (s)	0	2	4	6	8	10
Y Velocity (m/s)	10	15	20	20	20	15

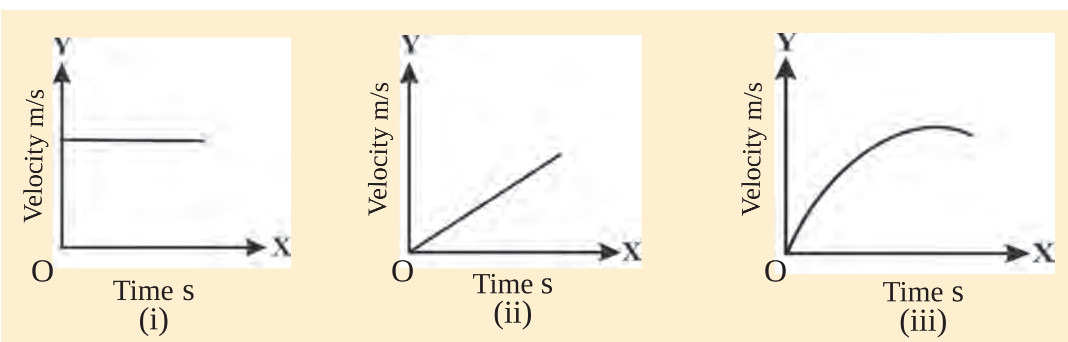
Table 2.10

a) From the graph, find the time interval during which there is no acceleration.

b) Find the time interval during which deceleration occurs.

c) Find the displacement between the fourth second and the eighth second.

8. Observe the graphs.



Graph 2.8

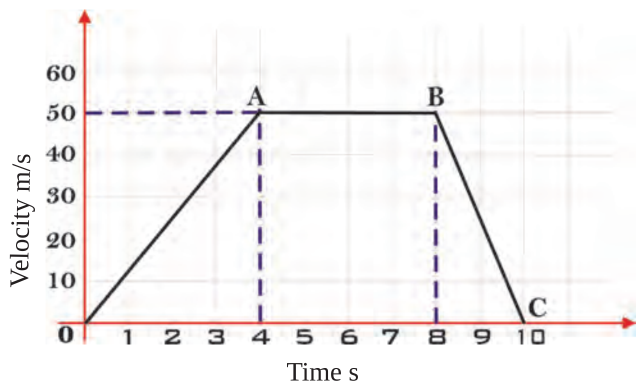
In which graph,

a) does the object have uniform acceleration?

b) does the object have uniform velocity?

c) does the object have acceleration and deceleration?

9. The velocity-time graph of an object in straight line motion is given.



Graph 2.9

Identify the regions of the graph where the object is moving with :

a) acceleration.

b) uniform velocity.

c) deceleration.

10. It is not safe for pedestrians to wear dark coloured clothes at night and in conditions with dim light. The school authorities decided to choose a dark coloured uniform for your school. Record your response to the decision. Justify the answer with respect to road safety.

11. In the figure given below, a child travels from P to S through Q and R and comes back straight to P.

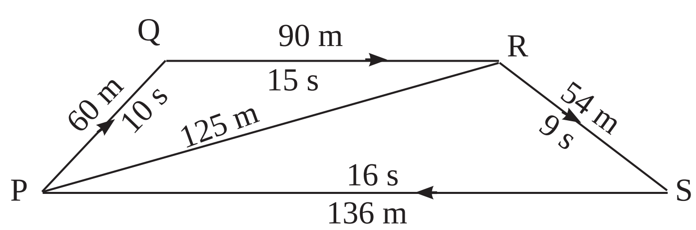


Fig 2.13

Analyse the figure and complete the table given below.

Starting from P	Speed	Velocity
On reaching Q		
On reaching R		
On reaching S		
While returning to P		

Table 2.11

12. A stone is thrown vertically upwards with a velocity of 20 m/s. ($a = -10\ m/s^2$)
    a) What is the maximum height that the stone has reached?
    b) How far will this stone travel in 3 s after it is thrown?
    c) How high will the stone be from the ground, 3 s after it is released?

13. An object is moving with a speed of 40 m/s. If it is given a deceleration of 8 m/s^2,
    a) how long will it take to come to rest?
    b) what is the displacement of the object in this time?

14. An object is moving with a velocity of 20 m/s. This object is given an acceleration of 5 m/s^2. What is the velocity when the displacement is 120 m?

15. A bullet travelling with a velocity of 60 m/s comes to rest after penetrating 2 cm into a wooden block. What is the acceleration of this bullet? How much is its deceleration?

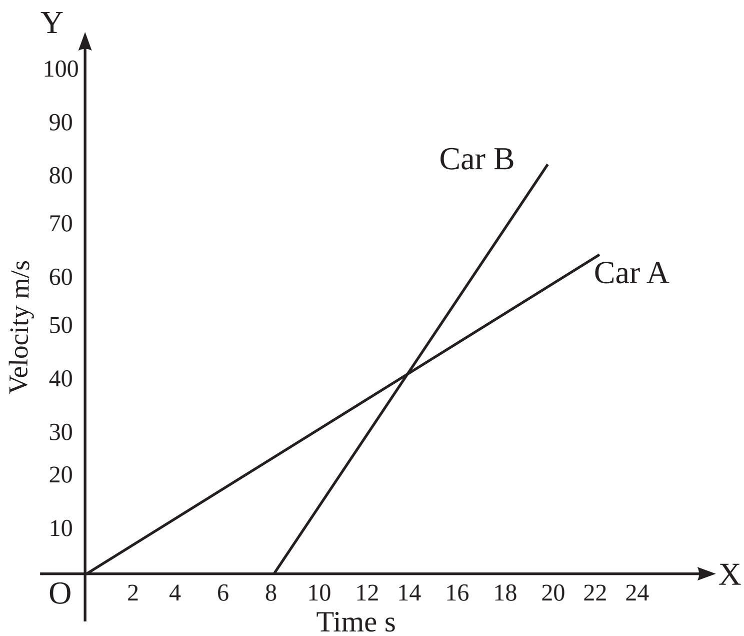
16. Observe the table illustrating the motion of an object, select an appropriate scale and draw the graph. Interpret the graph and write down the answers to the questions given below.

Time s	0	5	10	15	20	25	30
Velocity m/s	20	25	30	30	30	25	20

Table 2.12

    a) Which is the time interval with no acceleration?
    b) Which is the time interval with deceleration?
    c) Calculate the displacement of this object in 30 s.

17. The velocity- time graph of the motion of Car A and Car B is given below.



Graph 2.10

a) Which car started first?

b) How much time did each car take to attain the same speed?

c) Which car possesses more acceleration?

d) Which car has more displacement?

Extended Activities

1. The Science Club organises an awareness class on ‘Road accidents due to overspeeding.’ Prepare the necessary slides for the presentation.

   (Hints : traffic rules, signboards, traffic rules to be followed by pedestrians, etc.)

2. An object is thrown upwards with a velocity of 30 m/s. It returns to the same position after some time. Draw the velocity-time graph of this object and display it in the class (Consider the deceleration as 10 m/s^2).

3. Prepare a project on whether the safety measures implemented in your area are adequate to reduce road accidents.

- Project planning can be done with the help of your teacher.
- Bring relevant findings to the attention of the Road Safety Authority.

(For more information, the services of the National Transportation Planning and Research Centre (NATPAC) and the Motor Vehicles Department can be availed.

The report should include:

- Introduction
- Hypothesis
- Objectives
- Methodology
- Analysis
- Results
- Conclusion
- Suggestions

3 Laws of Motion

Various situations associated with motion are depicted in the above picture. Look at the child catching the cricket ball.

- While catching the ball, why did the child move his hand backwards along with the ball?

Tug of war between two teams is shown in figure 3.1.

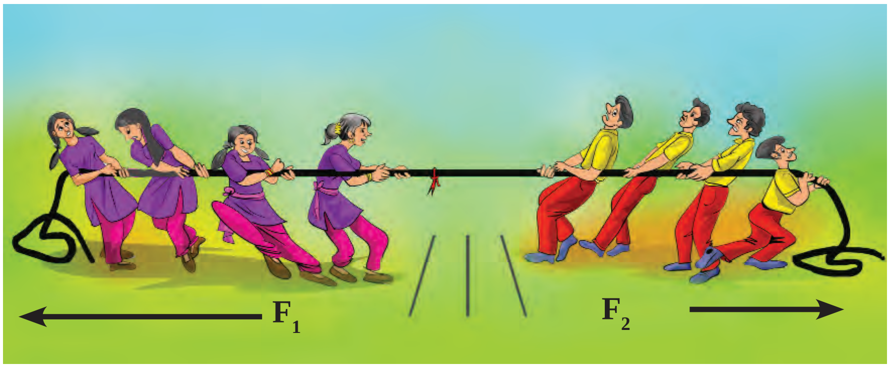


Fig. 3.1

- The rope moves only in one direction even though both the teams are applying force. Why?
- Is the force applied by both teams the same?
- Which team applied more force?
- Wasn't it the excess force that caused the motion?

Here F_1 is acting in the direction of the winning team and F_2 in the opposite direction. If so, the effective force is in the direction of the winning team. If force in a particular direction is considered as positive, the force in the opposite direction is negative. This is because force is a vector quantity.

When more than one force is applied on an object at the same time, the sum of the forces acting on the object will be the effective force or resultant force.

- What will be the resultant force if 100 N force is applied on an object in the east direction and 150 N force in the west direction?

If the force applied in the east direction is considered as positive, then the force in the opposite direction (west) is negative (it can be taken in the reverse order also).

Here, the resultant force = 100 N + (–150 N) = –50 N. Isn't the force applied in the east direction positive? Now you might have understood that the resultant force is 50 N towards west.

Complete the Table 3.1 by analysing the following figures.

Fig. 3.2 (a)

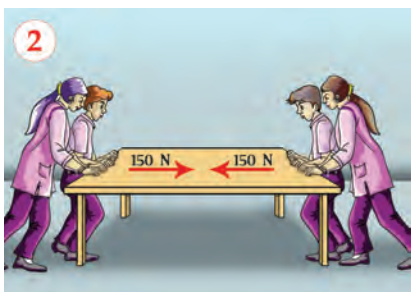


Fig. 3.2 (b)

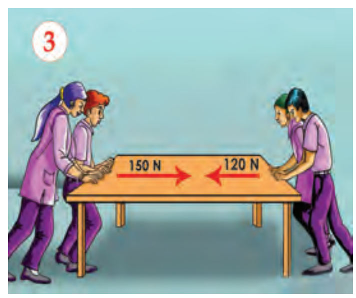


Fig. 3.2 (c)

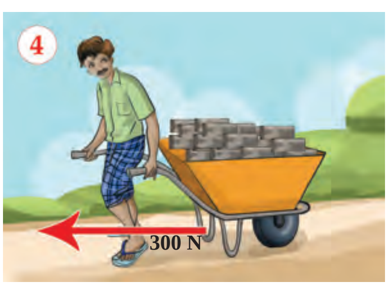


Fig. 3.2 (d)

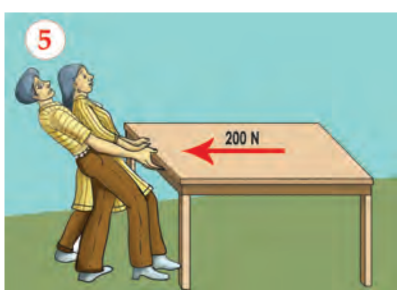


Fig. 3.2 (e)

Fig. 3.2 (f)

Figure	Force F_1 (N)	Force F_2 (N)	Resultant force (N)
1			
2	150	-150	0
3			
4			
5			
6			

Table 3.1

- In which of these situations is the resultant force zero?
- Which are the situations where the resultant force is not zero?
- Which are the situations where there is no motion?

The forces acting on a body are said to be balanced forces, if the resultant force is zero. Such forces can neither move an object at rest nor change the direction or speed of an object in motion.

The forces acting on a body are said to be unbalanced forces if the resultant force is not zero. Such forces can either move an object at rest or change the direction or speed of an object in motion.

In the tug of war shown in the figure 3.1, is the resultant force experienced on the rope balanced or unbalanced?

Do all forces cause motion?

Let's do an activity.

Fix a pulley each at the both ends of a wooden plank of length about 1.2 m and breadth 10 cm. Keep this plank on a table. Place a toy car in the middle of the plank as shown in figure 3.3. Hang pans of equal mass on strings attached to the two ends of the toy car. Place 200 g weight each in both the pans.

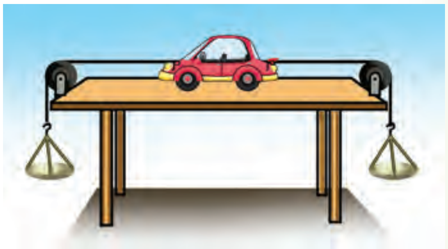


Fig. 3.3

PhET→ Forces and Motion : Basics

PhET→ Friction

- Does the toy car move?
- Are these forces balanced or unbalanced?
- Add 50 g more to any one of the pans. What do you observe?
- Are the forces balanced or unbalanced in this case?
- When the toy car is moving, if 50 g more is added to the pan in the direction in which the car moves, what change can be observed in the motion of the car?
- When the car is moving, a mass of 200 g more is added to the pan attached to the string in the opposite direction of the motion of the car. What is the change observed?
- Are the forces balanced or unbalanced in the above situation?
- What do you understand from these activities?
- Does the body move in the direction of resultant force?

  (moves / does not move)
- When does the speed of the car increase?

  (when the magnitude of the resultant force increases / decreases)
- Was the force that moved the car applied from inside the car or from outside?
- In which situation does the direction of motion change?

In all these cases the force was given externally. Hence all of them are external forces. An external force can be balanced or unbalanced.

An unbalanced external force acting on an object either changes or tends to change its state of rest, state of motion, direction or speed of motion. This change will be in the direction of the unbalanced force.

Fig. 3.4

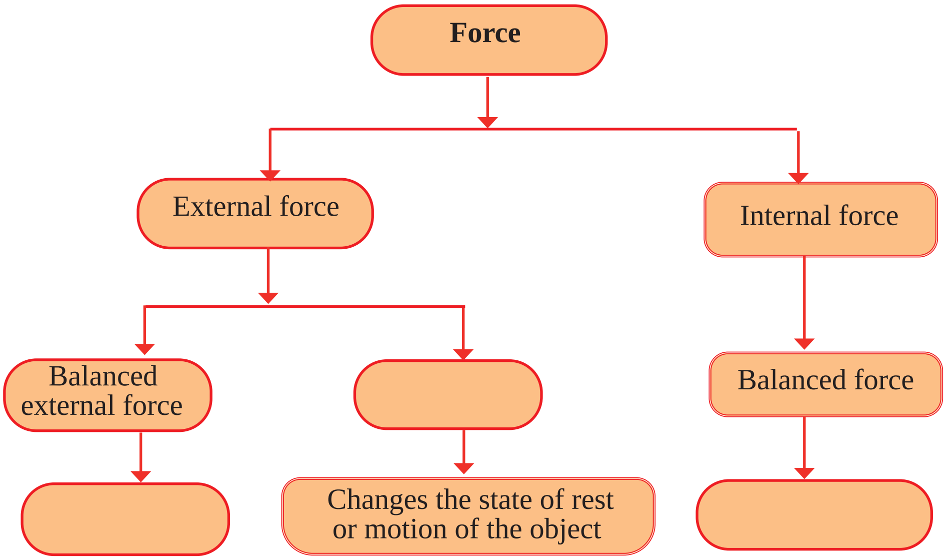
Observe the figure.

- Can a vehicle move if pushed from inside?
- Isn't it an internal force?
- All internal forces are - - - - - - - - - - - - - - -

  (balanced / unbalanced)

All internal forces are balanced forces. Hence the state of rest or motion of a body does not change on applying an internal force.

Complete the chart and redraw it in the science diary.



Galileo's Observations

A revised version of the experiment done by Galileo, almost four decades ago is given below.

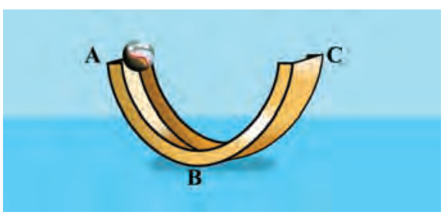


Fig. 3.5 (a)

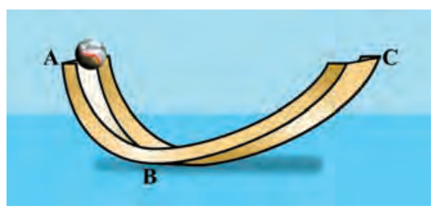


Fig. 3.5 (b)

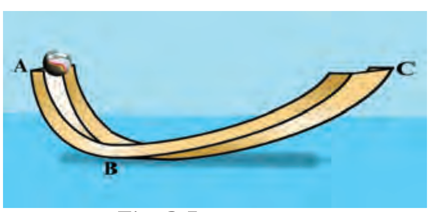


Fig. 3.5 (c)

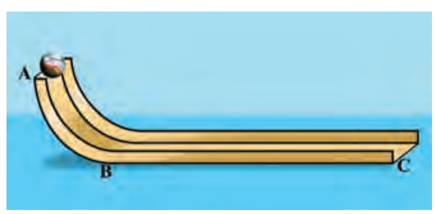


Fig. 3.5 (d)

A wiring channel is used for doing this experiment. The end C of the wiring channel is gradually lowered to horizontal level as shown in the figures.

- What do you observe, if in each case, a marble is rolled from the end A in the wiring channel?

Galileo Galilei

Lifetime : 1564 - 1642

Place of Birth : Pisa in Italy

From early childhood Galileo was interested in Mathematics and Philosophy. In 1581, in his first science book, 'The Little Balance', he mentioned the Archimedes' method of finding relative density. He observed the Saturn and Venus using his own telescope and argued that all the planets were revolving around the Sun. He was able to give some ideas about inertia through his inclined plane experiment.

- Does the distance travelled by the marble increase or decrease in each situation?
- When did the marble travel the longest distance?

The marble covers more distances as the slope decreases.

When the marble falls down it has a tendency to reach the original height. This tendency makes the marble move longer distances as the slope decreases.

- Why did the marble come to rest after traversing some distance?
- What would have happened if the force of friction was absent?
- What would have happened if no external force was applied to the marble?
- Write your inference from the above observation.

An unbalanced external force is to be applied in the opposite direction of motion of a body to bring it to rest. An unbalanced external force is not required to maintain uniform motion along a straight line.

This was Galileo's inference.

We can summarise the information acquired from the toy car experiment and Galileo's experiment as follows.

An unbalanced external force is essential to change the state of rest or uniform motion of a body.

Newton's First Law of Motion

Newton analysed and consolidated the scientific observations of predecessors such as Galileo. This enabled him to put forward new ideas and inferences on the motion of bodies subjected to forces. This paved the way for the formulation of Newton's laws of motion.

Every body will continue in its state of rest or uniform motion in a straight line unless and until an unbalanced external force acts on it. This is Newton's first law of motion.

The first law of motion helps us to define the physical quantities inertia and force.

- What is force?

Force is that which can change or tend to change the state of rest or uniform motion of a body along a straight line.

Inertia

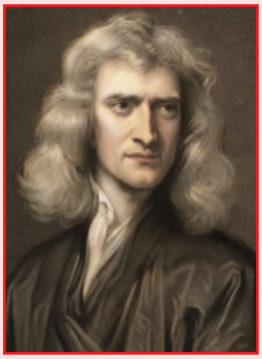
Did you notice that passengers standing in a bus tend to fall backwards when the bus at rest moves forward suddenly? Before the bus moved forward, weren't the passengers and the bus stationary? When the bus moves forward suddenly, the passengers tend to fall backwards because of the tendency to continue in the state of rest. This tendency is the inertia of rest.

- Why do the passengers standing in a bus tend to fall forward when the moving bus stops suddenly?
    - A body at rest cannot change its state of rest by itself. This is inertia of rest.
    - A body in uniform motion cannot change its state of motion by itself. This is inertia of motion.

Analyse the above ideas and write down a practical definition for inertia.

Compare it with the definition given below.

Sir Isaac Newton



Life time : 1643 - 1727

Place of Birth : England

Sir Isaac Newton was a philosopher, physicist, mathematician and an astronomer.

Major contributions : Proved that the motion of all objects on the Earth and celestial spheres are based on the same laws of nature. The force of gravitation and laws of motion are well explained in his book 'Principia Mathematica'. Even today, this book is the foundation stone of Mechanics. The corpuscular theory of light and calculus are his contributions. He is known as the Father of Calculus. He invented the reflecting telescope.

Inertia of a body is the tendency of the body to continue in its state of rest or uniform motion.

Do the following activities and write down the observations in the science diary.

Fig. 3.6 (a)

Fig. 3.6 (b)

Place a paper on a table. Keep a closed flat bottomed bottle filled with water over the paper. Quickly pull the paper horizontally.

- What happened to the bottle?
- Name the inertia possessed by the bottle.

Fig. 3.7 (a)

Place a glass filled with water on a desk. Slowly move it forward and gradually increase its speed. Stop it suddenly.

- What do you observe? Name the inertia possessed by the water.

Stack some carrom coins, one above the other, as shown in figure 3.7 (b). Place a plastic cup filled with water above it. Using a long plastic scale, quickly strike out the carrom coins one by one from the bottom.

Fig. 3.7 (b)

- Does the cup possess inertia? Which type?

Based on the knowledge gained from the activities you have done, write down the following statements related to inertia in the table (Table 3.2) appropriately.

- On shaking the branch of a mango tree, the mangoes get detached and fall down.
- A participant in long jump competition, runs some distance and then jumps.
- Travelling in a car without wearing seat belt is dangerous.
-

Inertia of rest	Inertia of motion
• When a bus moves forward suddenly, the standing passengers tend to fall backward. •	• A ball set rolling on a horizontal floor keeps moving forward. •

Table 3.2

Expand the table by including more examples for inertia of rest and inertia of motion.

Is there any relation between the mass of a body and inertia?

Mass and Inertia

Place a paper on a table. Take two identical flat bottomed bottles. Fill one of them with sand. Place the bottles vertically on the paper. Quickly pull the paper horizontally.

Fig. 3.8

- Which bottle does not topple over?
- Which bottle has a higher mass?
- Which bottle possesses more inertia?
- Based on the above observations, what is the relation between mass and inertia?

Which one possesses greater inertia-an empty barrel or a tar filled barrel? Give reason.

Why should people run in a zig-zag manner to escape from an elephant attack?

From the following, write the situations where an unbalanced force is experienced.

a) Brakes are applied on a car moving with a velocity of 20 m/s.

b) A book is supported by the hand.

c) An artificial satellite travels with uniform speed.

A force of 200 N is applied on a body in one direction and another force of 250 N in the opposite direction.

a) Calculate the resultant force.

b) If it moves, what will be the direction of motion?

Let's examine some facts related to bodies in motion.

Momentum

Have you ever seen pits formed when coconuts fall on the loose soil in coconut plantations? Isn't it due to the impact made by the coconut on the soil? Will a pit of the same depth be formed if the coconut is placed gently? Such an impact can be exerted only by a body in motion. This property of a body in motion is momentum.

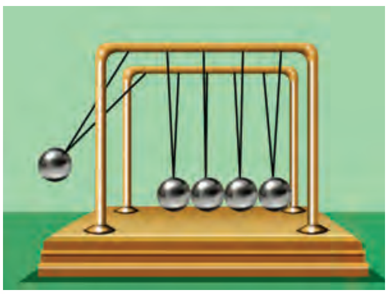


Fig. 3.9

Observe figure 3.9.

A device known as Newton's cradle is shown.

Pull back the balls in a Newton's cradle and release them in the following order. Write down the observations in the science diary.

- First ball alone
- First two balls
- First three balls
- First four balls

When the first ball alone hits the next ball, the momentum thus transferred by it reaches the last ball through the other balls and results in the last ball being tossed off.

When the first two balls together hit the next ball, they form a moving system and the momentum of this system is transferred to the last two balls. Hence the last two balls are tossed off.

What are the factors that influence this momentum?

In the Newton's cradle, pull back one ball alone to a small distance and release it. What do you see? The last ball moves out only a little. When the same ball is pulled back further and released, it hits with a greater velocity. Now we can see that the last ball covers a greater distance on moving out. Isn't it due to the increase in the velocity of the first ball?

- If so, which factor influenced the momentum of the ball?

We have seen that when a system of two balls together hit the others in the Newton's cradle, the last two balls are tossed out. This is due to the increase in the mass of the hitting system.

- In this case, what decided the momentum of the balls?

We have seen that the impact produced by a body in motion increases with the increase in its mass or velocity.

The momentum of a body in motion is the product of its mass (m) and velocity (v). ie., momentum, p = mv. Momentum is a vector quantity. The direction of momentum is the same as that of its velocity.

Unit of momentum = Unit of mass × Unit of velocity
= .... × .... = ...

Calculate the momentum of a body of mass 200 kg moving with a velocity 16 m/s.

The momentum of a body moving with a velocity 20 m/s is 200 kgm/s. What is its mass?

Calculate the momentum of a bullet of mass 60 g moving with a velocity 200 m/s. What is its momentum when it is at rest?

Rate of Change of Momentum

- A body of mass 20 kg is at rest. When a force is applied on it for 5 s, its velocity changes to 30 m/s. Find the change in momentum of the body.

Initial momentum = mu = 20 kg × 0 = 0

Final momentum = mv = 20 kg × 30 m/s = 600 kgm/s

Change in momentum = mv – mu = 600 kgm/s – 0 = 600 kgm/s

What will be its change in momentum in unit time or its rate of change of momentum?

$$\text{Rate of change of momentum} = \frac{\text{Change of Momentum}}{\text{Time}}$$

$$= \frac{600 \text{ kgm/s}}{5 \text{ s}}$$

$$= 120 \text{ kgm/s}^2$$

A body of mass 100 kg starts from rest and acquires a velocity of 30 m/s in the fourth second. If so,

a) what is its initial momentum?

b) what is its final momentum?

c) what is the change in momentum?

d) what is the rate of change of momentum?

A body of mass 20 kg is at rest. The velocity at various instances when a force of varying magnitude is applied on it for a time interval of 5 s is given. Calculate the initial momentum, final momentum and the rate of change of momentum of the body in each case.

Force N	Velocity acquired m/s	Initial momentum kgm/s	Final momentum kgm/s	Change in momentum kgm/s	Rate of change of momentum kgm/s^2
F	30	0	20 kg ×30 m/s = 600	600 – 0 = 600	$\frac{600 \text{ kgm/s}}{5 \text{ s}} = 120$
$\frac{F}{2}$	15				
2F	60				

Table 3.3

Complete the table and find the relation between the rate of change of momentum and the force applied on them.

Newton's Second Law of Motion

The rate of change of momentum of a body increases with the increase in the applied force. This was first enunciated by Sir Isaac Newton. This is Newton’s second law of motion.

The rate of change of momentum of a body is directly proportional to the unbalanced force acting on the body. The change of momentum takes place in the direction of the resultant force.

Let's try to express it mathematically.

Let a body of mass m move with a velocity u. On applying a force F for a time t, the velocity changes to v.

Initial velocity of the body = u Final velocity = ...

Initial momentum = mu Final momentum = ...

Change in momentum = ...

Rate of change of momentum = $\frac{m(v-u)}{t}$ = ma

According to Newton's second law of motion $F \propto ma$

So, $F = k\,ma$

where k is a constant

The SI unit of force is newton (N). A force of 1 N is defined as the force required to produce an acceleration of 1 m/s^2 on an object of mass 1 kg. That is, m = 1 kg, a = 1 m/s^2. Then, F = 1 N

Therefore, $F = kma$; $1\,N = k \times 1\,kg \times 1\,m/s^2$; $k = 1$

$$\mathbf{F = ma}$$

This is the equation for calculating force.

A body of mass 12 kg is moving with an acceleration of 4 m/s^2. Calculate the force applied.

A force of 40 N is applied on a body of mass 20 kg. Calculate the acceleration produced.

A vehicle of mass 1000 kg is travelling with a velocity of 90 km/h. The vehicle comes to rest when brakes are applied for 5 s. Calculate the force applied.

Initial velocity u = 90 km/h

$$= 90 \times \frac{5}{18}\ m/s$$

$$= 25\ m/s$$

Final velocity v = 0

Mass m = 1000 kg

$$F = ma$$

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

$$= \frac{1000(0-25)}{5}\ N$$

$$= -5000\ N$$

Oh! There is a negative sign for this force. Why?

Force is a vector quantity. The negative sign indicates that the force applied is in a direction opposite to the motion of the vehicle.

The velocity of a body of mass 10 kg changes from 6 m/s to 18 m/s in 4 s.

a) What is the rate of change of momentum?

b) What is the force applied?

c) Calculate the acceleration of the body.

d) What will be its velocity if this force is applied for 6 s?

mass m = 10 kg, initial velocity u = 6 m/s, final velocity v = 18 m/s

a) **Rate of change of momentum** $= m\dfrac{(v-u)}{t}$

$$= \frac{10\ \text{kg}\ (18\ \text{m/s} - 6\ \text{m/s})}{4\ \text{s}} = 30\ \text{N}$$

b) **Force** F = **Rate of change of momentum** $= 30\ \text{N}$

c) **Acceleration** $a = \dfrac{F}{m} = \dfrac{30\ \text{N}}{10\ \text{kg}} = 3\ \text{m/s}^2$

d) **Final velocity** $v = u + at = 6\ \text{m/s} + 3\ \text{m/s}^2 \times 6\ \text{s} = 24\ \text{m/s}$

Fig. 3.10

A shot of mass 7 kg rolled on a level ground, with a velocity 2 m/s, came to rest in 5 s.

a) Which force brought it to rest?

b) Calculate the magnitude of this force.

Have you ever thought about the time interval required for the force to be transferred to the nail when a nail is hammered? Didn't this occur in a fraction of a second? Let's examine the peculiarities of this type of force.

Impulsive Force and Impulse of Force

Can you find out the peculiarities of the forces applied in the following situations?

- hitting the ball with a cricket bat
- kicking the ball while playing football

Aren't large forces applied here for a very short interval of time? Such forces are the impulsive forces.

Impulsive force is a very large force applied for a very short interval of time. The product of the force and the time is the impulse of the force.

Impulse of force (I) = Force (F) × Time (t), I = F × t.

The unit of impulse of force = unit of force × unit of time

= .... × .... = ...

The impulse of force $= F\,t = \frac{m\,(v-u)\,t}{t} = mv - mu$

The impulse of force is equal to the change in momentum. This is impulse-momentum principle.

A ball of mass 200 g is moving with a velocity of 30 m/s. A person catches the ball.

a) If the time taken to bring the ball to rest is as follows, what will be the force felt on the arm in each case? i) 0.3 s ii) 0.2 s iii) 0.1 s

b) In all the answers you arrived at, the magnitude of the force is negative. What does this indicate?

c) Analyse the answers and arrive at a common conclusion.

Based on the conclusions formulated, find the reason for the following statements.

a) Cricket players move their hands backwards along with the ball while catching a fast moving ball.

b) In the game of football, while the goal keeper catches the ball coming into the goal post, he moves his hands backwards along with the ball.

c) A foam bed is placed in a pole vault pit.

d) Sponge or hay is kept between glass vessels while packing.

Fig. 3.11

Think about a situation in which no force is applied while considering the second law of motion.

$F = ma \qquad a = \frac{F}{m}$

$F = 0$ then $a = 0$

There will be no acceleration if no force is applied. An object in motion with no acceleration will continue in its motion in a straight line or an object at rest will continue in its state of rest. Isn't this the first law of motion? Does it not mean that the second law of motion is on par with the first law of motion?

Have you ever run on the sand on a beach? Have you ever felt any difficulty in walking through a muddy terrain? What if you are walking on a firm ground? You are able to walk fast on a firm ground and find it difficult to walk through a muddy terrain. What may be the reason? In which direction do you apply force while walking on a ground? What is the direction of motion? To know more about this, let's familiarise with Newton's third law of motion.

Newton's Third Law of Motion

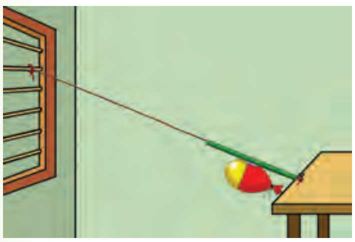


Fig. 3.12 (a)

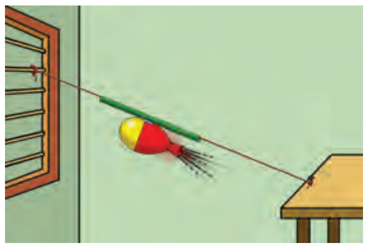


Fig. 3.12 (b)

As shown in the figure, a straw is passed through a smooth plastic thread tied diagonally. Attach an inflated balloon to the straw with cello tape and release the air from the balloon. What do you observe?

- What is the direction of air flow from the balloon?
- What is the direction of motion of the balloon?

A and B are two identical spring balances.

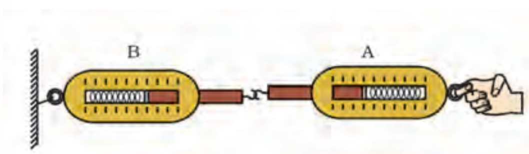


Fig. 3.13

Fix one end of the spring balance B firmly to the grill of a window. Apply a force 40 N on the spring balance B using A. What is the reading shown by each spring balance? Aren't they the same?

- Are the forces in the same direction or in the opposite direction?

The reading shown by one spring balance is action and the other is reaction.

That is, every action has a reaction. One of these forces is action and the other is reaction.

We can formulate Newton's third law of motion from these findings.

For every action (force) there is an equal and opposite reaction. This is Newton's third law of motion.

A car will not move if we push it sitting inside. But we can move the front seat by pushing it sitting on the back seat. How is it possible?

An option for sliding the front seats is provided. While sitting in the back seat and pushing the front seat, we are totally outside the front seat. Hence we are able to exert an unbalanced external force. But when we are pushing the car sitting inside, the same force that is exerted on the car is transferred through our body to the platform of the car. Thus the force becomes balanced. Hence the car will not move. On pushing the car by standing on the road, the car moves as an unbalanced external force is acting on it.

Which happens first – action or reaction?

Action and Reaction

Action and reaction act on two different bodies simultaneously. When force acts on two different bodies, the force on one body can be considered as the action and the force acting in the opposite direction on the other body as the reaction force. They occur in pairs only. Whenever there is an action, there is a reaction.

Find the reason for the following statements and record them in the science diary.

- **While rowing a boat the water is pushed back, but the boat moves forward.**
- **When a rocket is launched, gases are produced in its chamber by the combustion of fuels. These gases which are at high pressure move in one direction at high speed. But the rocket is propelled in the opposite direction.**
- **When a person jumps from a boat onto a shore, the boat moves backwards.**

Fig. 3.14

In the previous experiment using spring balance, aren't the forces equal in both the directions?

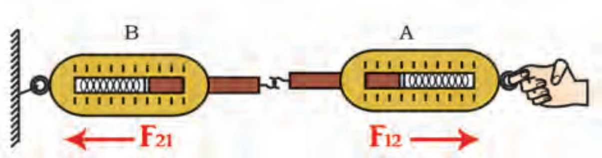


Fig. 3.15

Forces occur only in pairs. F_{12} is the force exerted by the first body on the second body. What about F_{21}? It is the force exerted by the second body on the first body. If so, according to Newton's third law of motion $F_{12} = -F_{21}$.

Static | Motion in accordance with the third law of motion | Continues in motion due to inertia

Fig. 3.16

Answer the following questions and justify them.

a) Action and reaction are equal and opposite. If so, will they cancel each other?

b) If you are pushing a vehicle standing on ice, will the vehicle move?

Based on the third law of motion, establish how an internal force becomes a balanced force. (Hint : When an internal force is applied, both the action and reaction are experienced on the same object.)

Let's Assess

1. A body of mass 5 kg travelling with a velocity 144 km/h comes to rest in 4 s. Calculate its

   a) initial momentum b) final momentum

   c) change in momentum d) rate of change of momentum

2. A hockey ball of mass 200 g hits a hockey stick with a speed 20 m/s and returns with the same speed through the same path. What is the change in momentum?

3. What is the rate of change of momentum of a loaded truck of mass 10,000 kg, if its velocity changes from 15 m/s to 12 m/s in 4 s?

4. Which of the following does not belong to the group?

   (force, momentum, velocity, speed)

5. A cup is covered with a cardboard and a coin is kept on the cardboard.

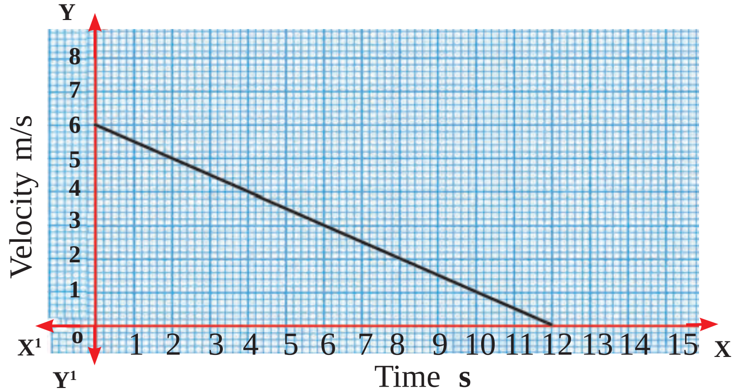
   a) What happens to the coin when the cardboard is struck off suddenly?

   b) Why does it happen?

6. To clean a carpet, we hold it up and hit it with a stick. The dust falls off. Give reason.

7. When a horse pulls the cart, the horse cart moves forward. The cart in turn pulls the horse with an equal and opposite force. But the horse and the cart go ahead. Explain how this is possible.

8. The velocity - time graph of a body of mass 250 g moving on a surface is given. Calculate the force of friction exerted by the surface.



Graph 3.1

9. A body of mass 500 g moves with a velocity of 40 m/s. On applying a force for 4 s, the velocity changes to 80 m/s. Calculate the force applied.

10. A person of mass 50 kg runs with a velocity of 8 m/s and makes a long jump. Another person of mass 60 kg makes the jump with a velocity 7 m/s. Compare their momenta.

11. Calculate the force required to stop a vehicle of mass 14,000 kg by applying a retardation of 1.8 m/s^2.

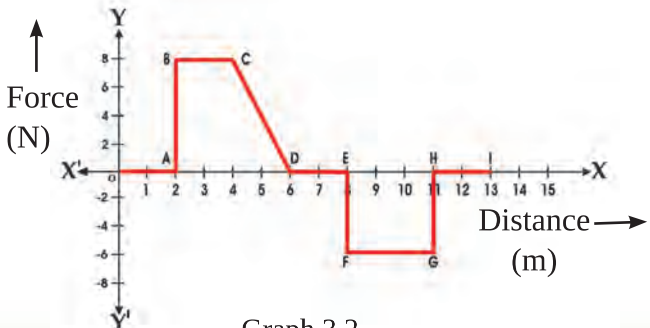
12. A force is applied on a body of mass 20 kg for 2 s and its velocity changes from 10 m/s to 50 m/s. The same force is applied on another body of mass 10 kg moving with a velocity of 20 m/s for 2 s in the direction of its motion. Calculate the final velocity.

13. A bullet of mass 20 g hits a wooden block with a velocity of 100 m/s and comes to rest after penetrating 4 cm.

    a) What is the acceleration of the bullet? b) What is the retardation of the bullet?

    c) Calculate the force exerted by the bullet on the plank.

14. A graph showing the application of force on a body of mass 10 kg is given. The magnitude of force changes as indicated in the graph. (Frictional force need not be considered.)



Graph 3.2

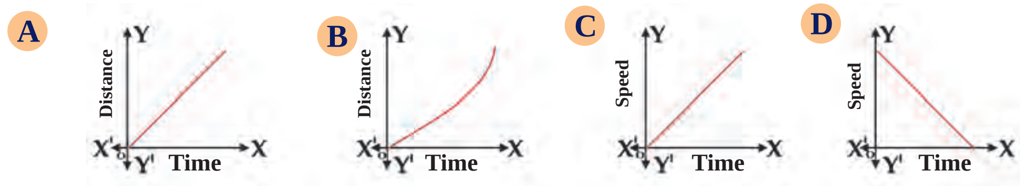
a) What is the acceleration of the body when it is at 3 m?

b) Which are the instances when the body has uniform velocity?

c) Which are the instances when the body has uniform acceleration?

d) Which is the instance when the body has retardation?

15. Which is the graph showing zero resultant force?



Graph 3.3

16. The figure shows forces applied on an object at rest. What is its acceleration? What is its displacement in 2 s?

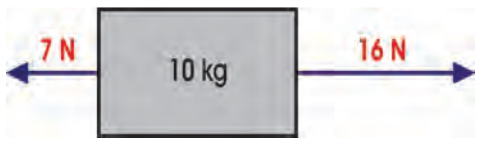


Fig. 3.17

17. Observe the figure.

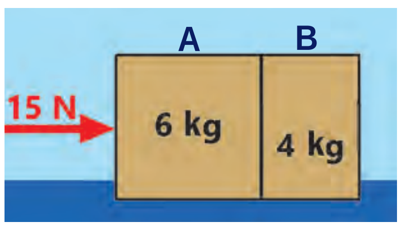


Fig. 3.18

A and B are two objects of masses 6 kg and 4 kg respectively. They are placed touching each other on a frictionless surface. Calculate the force exerted by object B on object A, when a force of 15 N is applied on them.

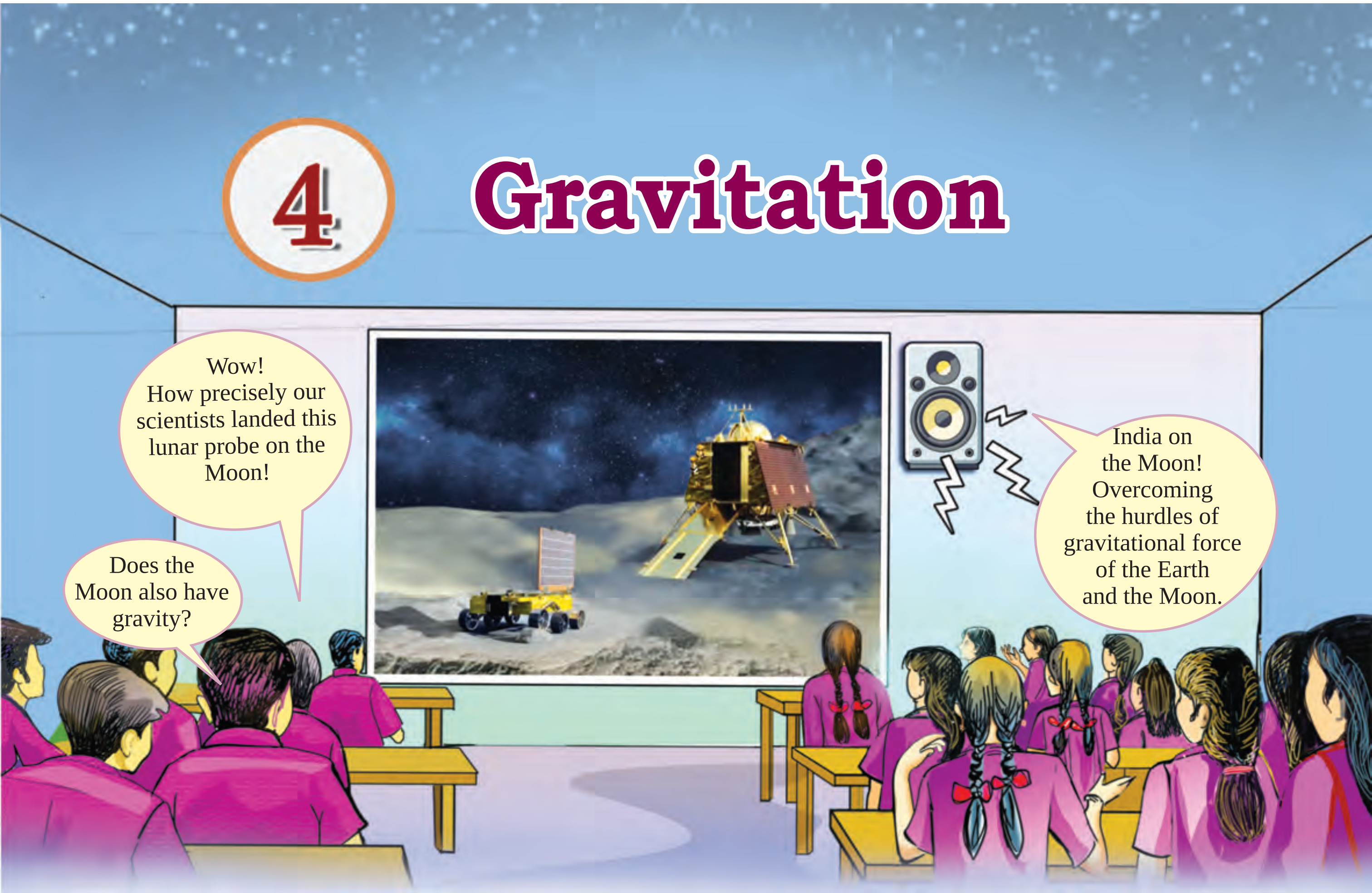
Extended Activities

1. Prepare and present a seminar paper on how overload and overspeed of vehicles affect road safety.

2. Write a report on how the concept of impulse can be used to explain the working of shock absorber in vehicles and discs in the spinal cord. Present it in the Science Club.

3. Present a seminar on some real life situations in which the concepts related to force are utilised.

4 Gravitation



You may have noticed that fruits and leaves fall to the ground from the trees around us. Have you ever wondered why a stone thrown up and a bird's feather fall to the ground?

- From where did the stone and the feather get the force they needed to fall?
- Imagine dropping stones in wells at various places around the Earth. Aren't stones attracted to the bottom of the well?
- Do the people standing on the opposite hemisphere of the Earth fall down? Isn't this due to the attraction of the Earth?

Fig. 4.1

Fig. 4.2

Can we measure this force of attraction?

Earth attracts all objects. The direction of this force is towards the centre of the Earth. This force of attraction is the force of gravity.

Let's do an activity.

Fasten a spring balance to the grill of a window.

Pull its hook with your hand.

- Why did the spring stretch?

The spring is stretched due to the force applied by the hand.

- What is the reading on the spring balance?
- Isn't this the force that we applied?
- What is the unit of force?

Fig 4.3

Suspend a mass of 100 g from a spring balance.

- Why did the spring stretch?
- Which is the force that pulled down the 100 g mass?
- What is the reading on the spring balance?

Isn’t this the force that attracted the object to the Earth?

Let’s see the factors on which this force of attraction depends.

Repeat the experiment using a 200 g mass instead of a 100 g mass.

- Why does the spring balance experience more stretching force?
- What happens to the force of attraction as mass increases?

    (increases /decreases)

- If so, write down a factor that influences the force of attraction.

Is mass the only factor that influences the force of attraction?

The force of attraction on an object at different positions on the Earth is given in the table.

Mass of the object (kg)	Height from the surface of the Earth (m)	Attractive Force (N)
100	On the surface (0)	980
100	1,00,000	950
100	10,00,000	730

Table 4.1

Analyse the table and answer the following questions.

- Where did the object of mass 100 kg experience a greater force of attraction?

  (on the surface /at a height of 1,00,000 m / at a height of 10,00,000 m)

- As the distance from the Earth to the object increases, the force of attraction exerted by the Earth

  (increases / decreases)

Record what you have learnt about gravity in your science diary.

- Earth attracts all objects to its centre.
- As the mass of the object increases, the force of attraction increases.
- As the distance from the object increases, the force of attraction decreases.

Is Earth alone exerting such a force of attraction?

Thanu Padmanabhan

Life time : 1957 - 2021
Birth Place: Thiruvananthapuram

He won gold medals in BSc and MSc from University College, Thiruvananthapuram. He gave fundamental contributions in the field of cosmology and gravitation. He introduced a new approach to the gravitational cosmology which is different from that of Newton and Einstein. He received many honours like Padma Shri, Kerala Shastra Puraskaram etc.

Have you heard about high tides and low tides that occur on the Earth? Aren't tides caused by the influence of gravitational force on the Earth by the Moon and the Sun?

- If the Sun and the Moon exert a force on the Earth, wouldn't the other celestial bodies of the universe also exert a mutual force of attraction between them?

Universal Law of Gravitation

Sir Isaac Newton was the first to formulate a comprehensive law of the force of attraction between objects in the universe. This is the Universal Law of Gravitation.

Universal Law of Gravitation

All objects in the universe attract each other. The force of attraction between two objects is directly proportional to the product of their masses and inversely proportional to the square of the distance between them.

If F is the force between two objects of masses m_1 and m_2, separated by a distance d, then,

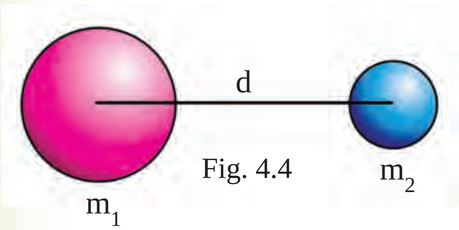


Fig. 4.4

$F \propto m_1 \times m_2 \qquad F \propto \frac{1}{d^2}$

therefore, $F \propto \frac{m_1 m_2}{d^2}$

ie., $\mathbf{F = G \frac{m_1 m_2}{d^2}}$

PhET→ Gravity Force Lab

G is known as gravitational constant. The value of G is 6.67×10^{-11} Nm^2/kg^2. The value of G is constant everywhere in the universe. The scientist, Henry Cavendish later on determined the value of G through experiments.

When two objects of mass 1 kg each are separated by a distance of 1 m, the force of attraction between them will be G newton.

Complete the table 4.2 based on Newton's Universal Law of Gravitation and answer the questions given below.

Sl.No	Mass of the objects kg		Distance between the objects m	Mutual force of attraction N
1	5	10	2	$\frac{G \times 10 \times 5}{2^2} = 12.5\,G$
2	10	10	2	G × ---------- = ----------
3	10	30	2	G × ---------- = ----------
4	5	10	4	G × ---------- = ----------
5	5	10	1	G × ---------- = ----------
6	5	10	$\frac{1}{2}$	G × ---------- = ----------

Table 4.2

- Two mutually attracting objects are placed at a fixed distance between them. If the mass of one of them is doubled, how many times will the force of attraction between them be?
- What if the mass of one object is doubled and the mass of the other tripled?

- What if the distance between the objects is doubled?
- What if the distance between the objects is halved?
- What if the distance between the objects is quartered?
- Calculate the gravitational force of attraction between two children of masses 40 kg and 50 kg when they are 2 m apart.

$m_1 = 40$ kg $m_2 = 50$ kg $d = 2$ m

$$F = G\frac{m_1 m_2}{d^2} = \frac{6.67 \times 10^{-11} \times 40 \times 50}{(2)^2} \text{ N}$$

$$F = 500 \times 6.67 \times 10^{-11} \text{ N}$$

$$= 3335 \times 10^{-11} \text{ N}$$

$$F = 3.335 \times 10^{3} \times 10^{-11} \text{ N}$$

$$F = 3.335 \times 10^{-8} \text{ N}$$

$$F = 0.00000003335 \text{ N}$$

Fig. 4.5

Haven't you realised that the force of attraction between the children is not felt because it is very feeble? This force is very small that it cannot even be compared to other forces like frictional force, magnetic force etc. Therefore, this force is not experienced in everyday life!

Here, the children of mass 40 kg and 50 kg attract each other with a force of 3.335×10^{-8} N. This means that both of them are experiencing the same force of attraction.

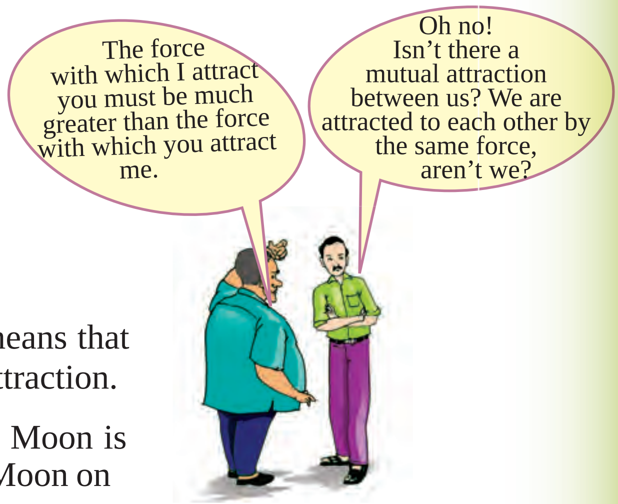


Fig. 4.6

? If the force of attraction of the Earth on the Moon is F, what will be the force of attraction of the Moon on the Earth?

We know that objects accelerate due to continuous application of force. If so, will there be an acceleration due to the force of gravity?

Acceleration due to Gravity

Isn't it the gravitational force that causes the detached coconut to fall from a coconut tree? The coconut falls down because of the downward acceleration produced by the unbalanced force exerted by the Earth on the coconut.

Fig. 4.7

A heavy body and a light body are dropped down together from a certain height.

- Which one reached first?
- Which one will experience greater acceleration?

According to Newton's second law of motion, F = ma

If F is the force of attraction of the Earth and m is the mass of the object, then a is the acceleration due to the force of attraction of the Earth.

The acceleration of objects by the force of gravity is known as acceleration due to gravity. It is denoted by the letter g.

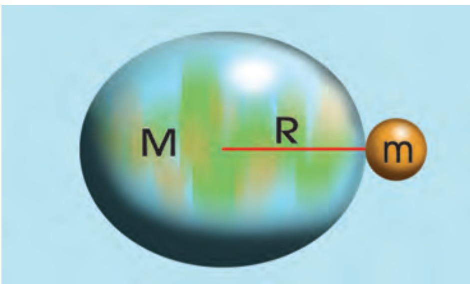


Fig. 4.8

Let's consider the mass of the object as m, mass of the Earth as M and the radius of the Earth as R, then according to the Law of Gravitation, the force of attraction exerted by the Earth is,

$$F = \frac{GMm}{R^2}$$

But, according to the second law of motion, the force required to give acceleration g to an object of mass m is F=mg.

ie., $$mg = \frac{GMm}{R^2}$$

$$\mathbf{g = \frac{GM}{R^2}}$$

How to calculate the distance from the centre of the earth to the coconut on the coconut tree.

When we consider the distance between the centre of the Earth and the top of the coconut tree, shouldn't we add radius of the earth and the height of the coconut tree?

As the height of the coconut tree is very small compared to the radius of the Earth, the addition of this distance with the radius of the Earth will not change the value significantly.

- What is the unit of g?
- Is the mass of the object included in this equation?

From this equation it is clear that the acceleration due to gravity is independent of the mass of the object.

Haven't you understood why objects of different masses falling simultaneously from the same height reach the ground at the same time?

- If mangoes and leaves fall down from a mango tree at the same time, will they reach the ground together? What will be the reason?
- A piece of paper and a coin are dropped down together from the same height. What do you observe?
- Repeat the above activity after crumpling the paper. What difference do you observe now?

It is due to the influence of air that objects like leaves, feather, paper, etc., fall down slowly.

With the advent of technology to create vacuum, this inference was proved by experiments. Feather and coin experiment is one of them.

Feather and Coin Experiment

A coin and a feather are placed in a long transparent tube. When it is held vertically and then suddenly turned upside down, it is seen that the feather reaches the bottom shortly after the coin. If the air inside the tube is removed and the experiment is repeated, it can be seen that both the feather and the coin reach the bottom simultaneously.

Based on this experiment, are you able to explain why feather, leaf, paper, etc., fall slowly on to the ground?

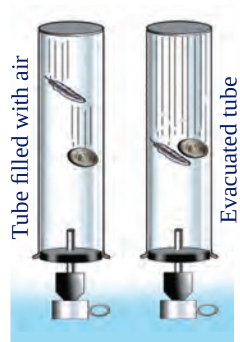


Fig. 4.9

Let's calculate the value of g on the Earth.

Mass of the Earth M $= 6 \times 10^{24}$ kg

Radius R $= 6.4 \times 10^{6}$ m

$$g = \frac{\text{----------}}{\text{----------}} = \frac{\text{----------}}{\text{----------}} = 9.8 \text{ m/s}^2$$

Is the acceleration due to gravity the same everywhere on the Earth?

Observe the figure.

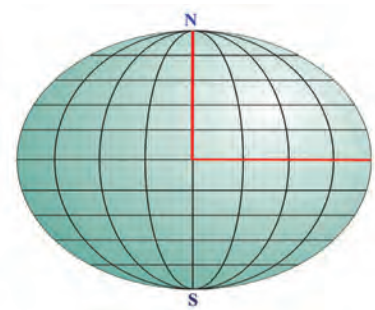


Fig. 4.10

- Does the Earth have a perfect spherical shape?
- Which region of the Earth is the farthest from its centre?

  (polar region / equatorial region)
- Which region lies closer to the centre of the Earth?
- How does the value of g vary as the distance from the Earth's centre to the surface changes?

  Verify your answer using the equation, $g = \frac{GM}{R^2}$
- Where is the value of g maximum?

  (at the polar region /at the equatorial region)
- The forces of attraction on an object at the centre of the Earth, from all sides of the Earth are equal. If so, what will be the value of g at the centre? Discuss and record.

Approximate value of g in the equatorial region = 9.78 m/s^2.

Approximate value of g in the polar region = 9.83 m/s^2.

Fig. 4.11

Gravitational force is a force of mutual attraction. When the engine ceases working, the aeroplane falls down to the Earth. But the Earth does not move towards the aeroplane even though the aeroplane attracts the Earth. Why? Let's examine.

Let's calculate the gravitational force between an aeroplane and the Earth when the aeroplane of mass 10000 kg is at a height 10 km above the surface of the Earth.

m = 10000 kg = 10^4 kg

Height from the surface of the earth, d = 10 km = 10000 m = 10^4 m

$$F = \frac{GMm}{R^2}$$

$$F = \frac{G \times 6 \times 10^{24} \text{kg} \times 10^4 \text{ kg}}{(6.4 \times 10^6 + 10^4 \text{m})^2}$$

$$= \frac{(6.67 \times 10^{-11} \times 6 \times 10^{28})}{(6.41 \times 10^6)^2} \text{ N}$$

$$= 97400 \text{ N}$$

Let's find the acceleration of the aeroplane produced by the above force.

F = mg

$$g = \frac{F}{m} = \frac{97400}{10000} = 9.74 \text{ m/s}^2.$$

Isn't the aeroplane exerting the same force on the Earth as that exerted by the Earth on the aeroplane?

Let's calculate the acceleration of the Earth due to the force exerted by the aeroplane

$$g = \frac{F}{M} = \frac{97400}{6 \times 10^{24}} = 1.6 \times 10^{-20} \text{ m/s}^2 = 0.000000000000000000016 \text{ m/s}^2.$$

The acceleration of the Earth is almost zero. Although the forces of attraction between the aeroplane and the Earth are equal, the Earth will not experience any considerable acceleration. This is due to the enormous mass of the Earth, as compared to the aeroplane.

When the same force is applied, objects with a greater mass will experience lesser acceleration.

Will the values of acceleration due to gravity on the Earth and the Moon be the same?

Acceleration due to gravity on the Moon

Mass of the Moon $M = 7.34 \times 10^{22}$ kg

Radius of the Moon $R = 1.74 \times 10^{6}$ m

$$g = \frac{GM}{R^2}$$

$$g_{Moon} = 1.62 \text{ m/s}^2$$

$$\frac{g_{Moon}}{g_{Earth}} = \frac{\text{Value of g on the Moon}}{\text{Value of g on the Earth}}$$

$$= \frac{\ldots\ldots\ldots\ldots}{\ldots\ldots\ldots\ldots}$$

$$= \text{----------------}$$

That is, the value of g on the Moon is approximately $\frac{1}{6}$ th of the value of g on the Earth.

Black hole

Black holes are cosmic matter with such a strong gravity that even light cannot escape from them.

Based on Albert Einstein's theory on gravitation, the possibility of the presence of black holes was predicted in 1916. But proper evidence of its presence was found in 2017. Scientists could create a shadow image of a massive black hole at the centre of a distant galaxy named M 87. Evidence of a giant black hole at the centre of the Milky Way, our galaxy, has been recently established.

Stars which have several times the mass of the Sun are likely to turn into black holes in the last stages of their evolution. There are many such black holes in galaxies.

An artificial satellite of mass 10000 kg stops working and falls down to the Earth. We know that attraction between objects is mutual. The satellite attracts the Earth with the same force with which the Earth attracts the satellite.

Height from the Earth = 5000 m, Radius of the Earth $R = 6.4 \times 10^{6}$ m

a) What is the acceleration of the satellite?

b) What is the acceleration of the Earth?

(Mass of the Earth = 6×10^{24} kg)

An object of mass 10 kg is allowed to fall to the ground from a height of 20 m.

a) How long will it take to reach the ground?

b) Calculate the time required to reach the ground, if it is on the Moon.

$$g_{Earth} = 10 \text{ m/s}^2, \; g_{Moon} = 1.62 \text{ m/s}^2$$

A stone is thrown vertically upwards from the lunar surface. If the stone returns in 6 s,

a) what is the initial velocity of the stone?

b) what is the distance that can be covered by the stone?

c) what will be the position of the stone after 4 s?

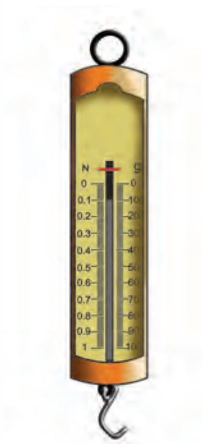
We usually say that a sack of cement weighs 50 kg and a sack of cement has a mass of 50 kg. Do they mean the same? Let's analyse.

Mass and Weight

You have learned that the mass of an object is the quantity of matter contained in it. Which instrument is used to measure mass? Mass of an object is determined by comparing it with the mass of another object using a common balance. What is the unit of mass?

Common balance
Fig. 4.12 (a)

Weight is a force. The weight of the object on the Earth is the gravitational force exerted by the Earth on that object. When an object is on the Moon or other celestial bodies, the weight of the object at that place is the force exerted by those bodies on the object. If the mass of an object is m, then its weight will be mg. Weight is measured using devices such as spring balance, platform balance, etc. The unit of weight is newton (N).



Spring balance
Fig. 4.12 (b)

Another unit of weight is kilogram weight (kgwt). Usually kilogram weight is marked as kg on a spring balance. What is the weight of an object of mass 50 kg?

1 kilogram weight (1 kgwt)

One kilogram weight (1kgwt) is the force of attraction exerted by the Earth on an object of mass one kilogram.

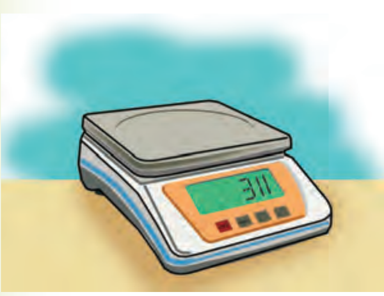
$F = ma = mg$

$1\ \text{kgwt} = 1\ \text{kg} \times 9.8\ \text{m/s}^2 = 9.8\ \text{kgm/s}^2 = 9.8\ \text{N}$

ie., 1 kgwt = 9.8 N.

Weight of an object of mass 50 kg = mg = $50\ \text{kg} \times 9.8\ \text{m/s}^2 = 490\ \text{N}$

This is also known as 50 kgwt.



Platform balance
Fig. 4.12 (c)

The mass of an object is 10 kg. Calculate its weight on the Earth. What would be its weight if it were on the moon? ($g_{Moon} = 1.62\ \text{m/s}^2$)

Weight on the Earth = mg = $10 \times 9.8 = 98\ \text{kgm/s}^2 = 98\ \text{N}$

$g_{Moon} = 1.62\ \text{m/s}^2$

Weight on the Moon = $mg_{Moon} = 10 \times 1.62 = 16.2\ \text{N}$

The mass of an object remains the same everywhere in the universe. Then what about its weight? Compare mass and weight and complete the table.

Mass	Weight
• **Measured using common balance**	• **Measured using spring balance**
•	•

Table 4.3

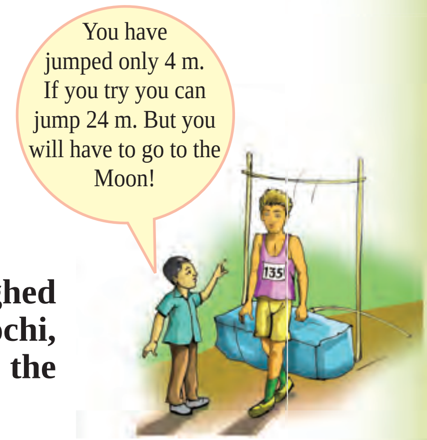


Fig. 4.13

- **When goods shipped from Kochi to England were weighed in England using the same spring balance used in Kochi, the weight was found to be 20 N more. What could be the reason? Discuss and write it in the science diary.**
- **Is an object heavier at the poles or at the equator? Justify your answer.**
- **What will be the weight of an object at the centre of the Earth?**

Does the weight of an object change while falling down to the Earth?

Free Fall and Weightlessness

Hook a 20 g mass on a spring balance and hold it. Bring it down quickly.

- What will be the change in the reading at this time?

  (increases /decreases)

If these are allowed to fall freely, the reading can be seen as zero.

> If an object is allowed to fall freely from a height, it will fall to the ground only under the gravitational force of the Earth. Such a motion is called free fall.

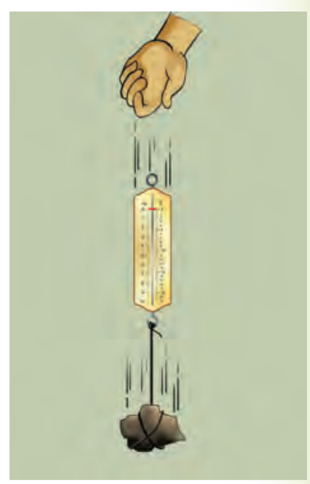


Fig. 4.14

We know that a freely falling object has acceleration. The force required for acceleration is provided by the force of gravity. It is also clear from the experiment that if the entire force of gravity is used to provide acceleration, the object will be weightless.

What are the instances in which weightlessness is experienced?

- For a person who orbits the Earth in space stations
-

- **Why does a freely falling body experience weightlessness? Write it down in your science diary.**

Isn't the motion of a freely falling stone in a straight line? But what type of motion do artificial satellites have? Write down examples for such types of motion.

- Whirling a stone tied to a string
-

Fig. 4.15

Circular Motion

A stone tied to a string is whirled as shown in the figure 4.15. Isn't its motion in a circular path? This is circular motion. If the stone moving along a circular path covers equal distances at equal intervals of time, then it is in uniform circular motion.

- Does this object have uniform velocity though it has uniform speed? Why?
- Does this object experience any force?
- If the string is released from the hand, in which direction will the stone move? Won't it be along the tangent? (figure 4.16).

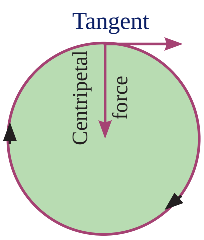


Fig. 4.16

The rate of change of velocity is acceleration. Acceleration of an object moving along a circular path is centripetal acceleration. The force required for this acceleration is centripetal force. Who gave this force? Isn't it our hand?

- If there is no centripetal force, can there be circular motion?

It is due to the centripetal force that electrons revolve around the nucleus of an atom, planets revolve around the Sun, the Moon revolves around the Earth etc.

It is due to the centripetal force that vehicles negotiating curves on a road tend to skid or roll off the curve. Mass and speed of the vehicle and curvature of the road are the factors that influence the tendency of the vehicle to roll over.

Negotiating a curve

The path travelled by a body should be considered circular even if it is not a full circle and only an arc. That is why we say that vehicles are moving along a circular path while negotiating a curve.

Will the path followed by the objects moving under centripetal force be circular or curved?

- If so, from where do the artificial satellites orbiting around the Earth get their centripetal force?
- Isn't it the Earth's gravitational force that is acting as the centripetal force?

Chandrayaan-3, which marked a new beginning in India's field of science, overcame the same gravitational force and landed on the moon.

Wouldn't satellites require a lot of energy to overcome Earth's gravity and enter the outer space? Hence large rockets are used to launch satellites. This increases the expense of the mission. The technological advancements used for the launch of Chandrayaan helped it to land on the Moon using less powerful rockets than the lunar missions of other nations. The speed of the lander will increase on reaching the Moon due to the Moon's gravity. Soft landing was done by gradually reducing this increased speed. It was this excellence in technology that the children praised at the beginning of this lesson.

Let's Assess

1. If an object is lifted from the centre of the Earth to its surface, will the mass and weight of the object change? Justify the answer.
2. The weight of an object of mass 5 kg is determined using a spring balance. If the object and the spring balance are dropped down together, what will be the weight of the object while falling down? What is the reason?
3. Will there be a change in the mass and weight of an object brought to the Moon from the Earth? Justify the answer.
4. An object is allowed to fall from the top of a tower of height 100 m. At the same time, another object was thrown vertically up with a velocity 25 m/s in order to collide with the object falling down (g_{Earth} = 10 m/s^2, g_{Moon} = 1.62 m/s^2).
   a) Calculate the time taken by them to collide.
   b) Find out the height from the ground at which they collide.
   c) Would the answers obtained in the above case change, if this activity was carried out on the Moon? Justify.
5) The gravitational force on the lunar surface is approximately $\frac{1}{6}$th that of the Earth.
   a) What is the weight of an object of mass 10 kg on the Earth?
   b) If this object is taken to the surface of the Moon, what will be its mass and weight?
6. Objects with a larger mass are attracted by the Earth more strongly than objects with a smaller mass. So, if an object with a larger mass and an object with a smaller mass are allowed to fall from the same height,
   a) which one will reach the ground first?
   b) Justify the answer.
7. Explain the difference between mass and weight.
8. The masses of a stone and a hydrogen-filled balloon are equal. If both are placed on the same ground, will the force of attraction exerted by the Earth on them be the same? Justify the answer.
9. A stone falling from the top of a tall building reaches the ground in 2 s (g = 9.8 m/s^2).

a) Calculate the height of the building.

b) What will be the velocity of the stone just before touching the ground?

10. Find examples of circular motion from the following and tabulate.

- Electrons revolving around the nucleus
- A child running a 100 m sprint
- Planets revolving around the Sun
- A train running along a railway track with no curves
- Moon orbiting around the Earth

11. What will be the weight of an object of mass 10 kg on a planet having twice the mass and three times the radius of the Earth?

12. The mass of a planet is half of the Earth and the radius is $\frac{1}{4}$ times that of the Earth. The acceleration due to gravity of the planet is ..... times that of the Earth.

a) $\frac{1}{4}$ b) 4 c) $\frac{1}{8}$ d) 8

13. A body falling freely from a certain height takes 50 s to reach the ground. How much time will the same object take to fall from the same height on another sphere having twice the radius and twice the mass of the Earth? (Answer : $50\sqrt{2}$ s).

14. The mass of an object is 100 kg. Calculate its weight at the centre of the Earth, the polar region, the equatorial region, the Moon and the Jupiter (g on the Jupiter = 23.1 m/s^2).

Extended Activities

1. Make a still model of the Solar System and exhibit it in the class. It should include the Moon and an artificial satellite orbiting the Earth.

2. The values of g in various planets are given. There is an object of mass 100 kg. Determine the weight of the object on these planets.

Planet	Acceleration due to gravity in m/s^2 (Approximate value)	Weight(N)
Earth	9.8	
Mercury	3.7	
Venus	8.9	
Mars	3.7	
Saturn	9.00	
Uranus	8.7	
Neptune	11.00	

Table 4.4

CONSTITUTION OF INDIA

Part IV A

FUNDAMENTAL DUTIES OF CITIZENS

ARTICLE 51 A

Fundamental Duties- It shall be the duty of every citizen of India:

(a) to abide by the Constitution and respect its ideals and institutions, the National Flag and the National Anthem;

(b) to cherish and follow the noble ideals which inspired our national struggle for freedom;

(c) to uphold and protect the sovereignty, unity and integrity of India;

(d) to defend the country and render national service when called upon to do so;

(e) to promote harmony and the spirit of common brotherhood amongst all the people of India transcending religious, linguistic and regional or sectional diversities; to renounce practices derogatory to the dignity of women;

(f) to value and preserve the rich heritage of our composite culture;

(g) to protect and improve the natural environment including forests, lakes, rivers, wild life and to have compassion for living creatures;

(h) to develop the scientific temper, humanism and the spirit of inquiry and reform;

(i) to safeguard public property and to abjure violence;

(j) to strive towards excellence in all spheres of individual and collective activity so that the nation constantly rises to higher levels of endeavour and achievements;

(k) who is a parent or guardian to provide opportunities for education to his child or, as the case may be, ward between age of six and fourteen years.

CHILDREN'S RIGHTS

Dear Children,

Wouldn't you like to know about your rights? Awareness about your rights will inspire and motivate you to ensure your protection and participation, thereby making social justice a reality. You may know that a commission for child rights is functioning in our state called the ***Kerala State Commission for Protection of Child Rights.***

Let's see what your rights are:

- Right to freedom of speech and expression.
- Right to life and liberty.
- Right to maximum survival and development.
- Right to be respected and accepted regardless of caste, creed and colour.
- Right to protection and care against physical, mental and sexual abuse.
- Right to participation.
- Protection from child labour and hazardous work.
- Protection against child marriage.
- Right to know one's culture and live accordingly.
- Protection against neglect.
- Right to free and compulsory education.
- Right to learn, rest and leisure.
- Right to parental and societal care, and protection.

Major Responsibilities

- Protect school and public facilities.
- Observe punctuality in learning and activities of the school.
- Accept and respect school authorities, teachers, parents and fellow students.
- Readiness to accept and respect others regardless of caste, creed or colour.

Contact Address:

Kerala State Commission for Protection of Child Rights

'Sree Ganesh', T. C. 14/2036, Vanross Junction

Kerala University P. O., Thiruvananthapuram - 34, Phone : 0471 - 2326603

Email: childrights.cpcr@kerala.gov.in, rte.cpcr@kerala.gov.in

Website : www.kescpcr.kerala.gov.in

Child Helpline - 1098, Crime Stopper - 1090, Nirbhaya - 1800 425 1400

Kerala Police Helpline - 0471 - 3243000/44000/45000

Online ***R. T. E Monitoring : www.nireekshana.org.in***