Force and Linear motion

Competency

Applies the relations connected with force and linear motion to fulfil life necessities.

Competency level	Subject Content
1. 1 Uses graphs related to motion to describe the movement of an object.	• Distance *(d)* and displacement. *(s)* • Distance - time graphs *(d-t)* • Displacement - time graph *(s-t)* • Information obtained from *(d-t)* and *(s-t)* graphs. • Speed and velocity *(v)*
1. 2 Investigates how an object moved, using speed - time and velocity - time graphs.	• Acceleration and deceleration *(a)* • Speed *(v - t)* time graphs • Velocity - time graphs *(v - t)* • Information that could be obtained from *(v - t)* graphs.
1. 3. Forecasts the mode of linear motion of objects.	• Equations of motion • $v = u + at$ • $s = ut + 1/2\, at^2$ • $v^2 = u^2 + 2as$ • $s = \left(\frac{v+u}{2}\right) t$ • Usage of above equations.

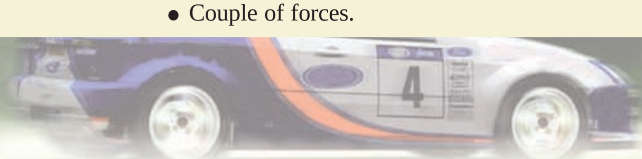
1. 4. Investigates the applications of force in day-to-day life using Newton laws of motion.	• Newton laws of motion
	  • First law.
	  • Concept of force.

1. 5. Conducts experiments to find the magnitude of force.	• Concept of momentum
	• Newton laws of motion.
	  • Second law • $F = ma$ equation.
	  • SI unit of force (N) • Value of force.

1. 6. Uses various methods of occuring interaction between objects.	• Newton laws of motion. • Third law • Action • Reaction.
1. 7. Manupulate life activities using friction appropriately.	• Friction. • Frictional force. • Limiting frictional force.

1. 8. Investigates equilibrium of various objects under the action of coplanar forces.	• Equilibrium of coplanar forces
	  • Equilibrium of two forces
	  • Equilibrium of three forces
	    • Forces meeting at a single point. • Parallel forces.

1. 9. Conducts experiments to change the rotating effect of forces.	• Moment of force
	  • Factors affecting the moment of a force.
	  • Units of moment of force - (N m)
	    • Couple of forces.



1.1 Motion of objects

Distance and displacement

Fig : 1.1 The position of objects change when they move.

When an object is in motion, its position changes with time. The amount of movement, irrespective of the path or the direction could be denoted by the **distance**.

Fig. 1.2 shows a route that a child travelled.

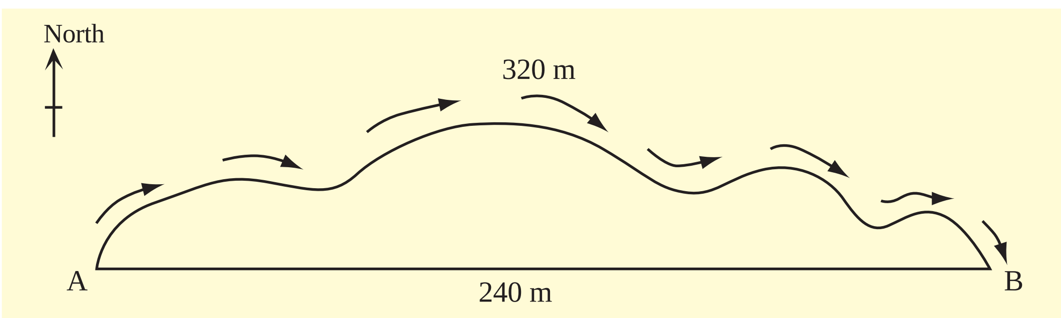


Fig : 1.2

The child travelled along the route shown by arrows. The distance along the route from A to B is 320 m. Let us assume that the time taken for this movement was 80 seconds.

Initially the child was at A. After 80 seconds, he moved to B.

The shortest distance from A to B is considered as the **displacement**. Thus the displacement after 80 s is 240 m.

In this regard, it is essential to give the direction. Now the child is 240 m to the East from the initial position.

Observe the Fig 1.2 and try to understand the difference between **distance** and **displacement.**

Fig 1.3 shows two routes that a student may travel. The distance of one route is 360m and the other route is 400m. However, the displacement of the student is always 240m.

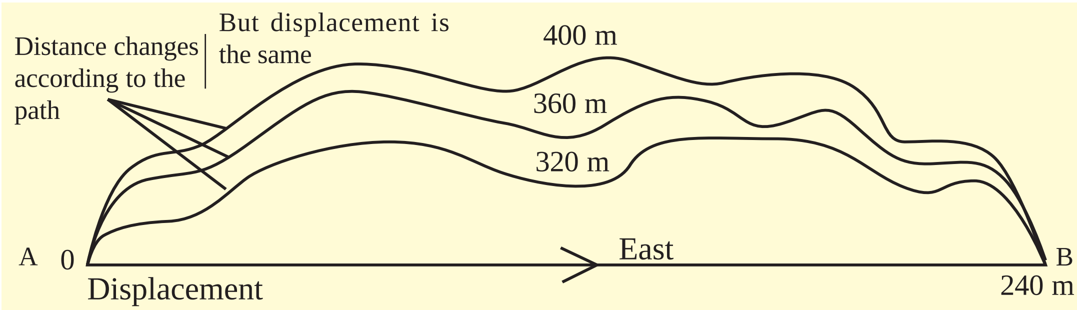


Fig : 1.3 Various distances for the same displacement

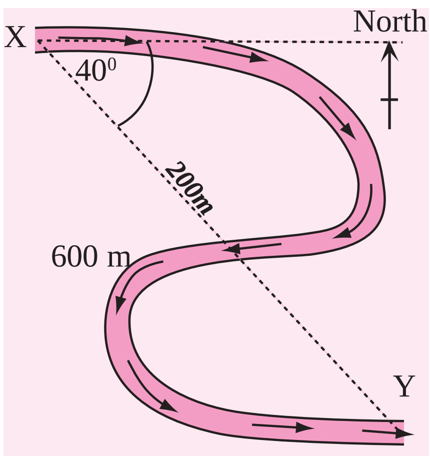


Fig : 1.4 Displacement is a vector quantity

A motor vehicle travels from X to Y along the curved route shown in Fig 1.4. The distance from X to Y along the route is 600 m. After 50 seconds, the vehicle reaches to the position Y. The distance that the vehicle travelled is 600 m.

What is the displacement of the vehicle? What is the position of the vehicle relative to position X, after 50 seconds ? To express this, the linear distance and the direction from X to Y is necessary.

Linear distance from X to Y is 200 m. Direction is 40^0 from East to South.

The position of the vehicle after 50 seconds (the displacement in 50 s) = $\underbrace{200\text{ m}}_{\text{Magnitude}}$ $\underbrace{40^0 \text{ from East to South}}_{\text{Direction}}$

Given below are various positions of a child moving along a straight path.

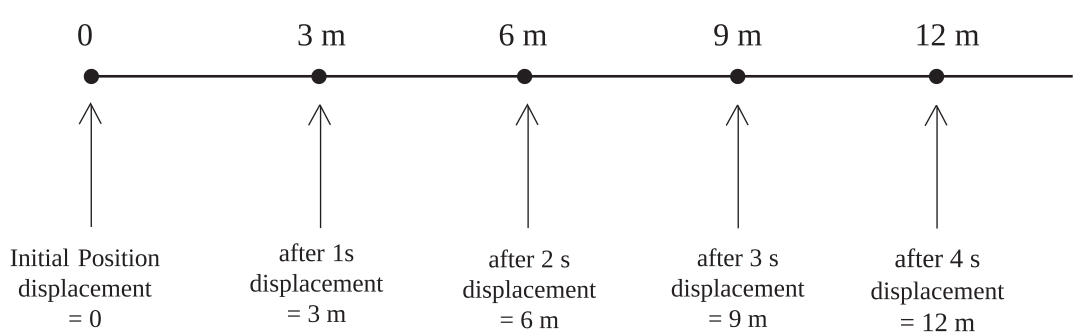


Fig : 1.5 Various positions of a moving child.

- Initially the child is at position 0. (displacement = 0)
- After 1 s, the child is 3 m directly away from the initial position (displacement = 3 m)
- After 2 s, the child is 6 m directly away from the initial position (displacement = 6 m)
- After 3 s, the child is 9 m directly away from the initial position (displacement = 9 m)
- After 4 s, the child is 12 m directly away from the initial position (displacement = 12 m)

- If the displacement is 12 m even after 5 s, what do you mean by that? It says that the child is still 12 m away from the initial position. He has not moved during the 5th second.

- If the displacement is 12 m even after 6 s, the child is still at the same position. He has neither moved forward nor the backward. No motion takes place during time of constant displacement.

- If the child turned and came back 6 m along that same straight path during 7th second, what is the position of the child after 7 s ? Now the child is 6 m away from the initial position.

That is, time (t) = 7 s, displacement ***(s)*** = 6 m

- If the child returned 6 m during the next second the displacement is zero now. The child is at the initial position now.

That is, when $t =$ 8 s, diplacement (s) = 0

Table for above data is given below.

Time (t) in seconds (s)	0	1	2	3	4	5	6	7	8
Displacement (s) in meters (m)	0	3	6	9	12	12	12	6	0

- If the child moves another 6 m to the same direction during 9th second;

time $t =$ 9 s
displacement $s =$ -6 m

Displacement takes a negative (—) value, if the motion takes place to the opposite of the initial direction.

Now let us consider the motion of an object along a straight path from A to B as shown in Fig. 1.6. It moves 100 m from A to B and returns 60 m back.

- What is the distance travelled ?
- What is the displacement?

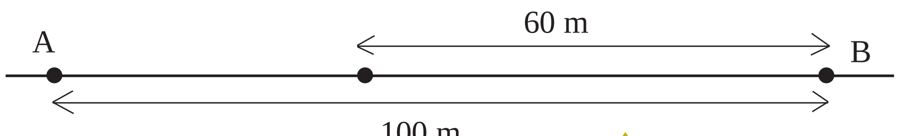


Fig : 1.6 Distance and displacement

Distance Travelled = 100 + 60 = 160 m
This gives the total distance travelled to any direction (backward or forward)

Only the amount of distance moved is considerd here. Direction is not considered. Thus distance has only a **magnitude**. with only a magnitude are known as **scalar Quantities.**

- Distance is a scalar quantity.

Displacement = (100) + (- 60)
= 40 m

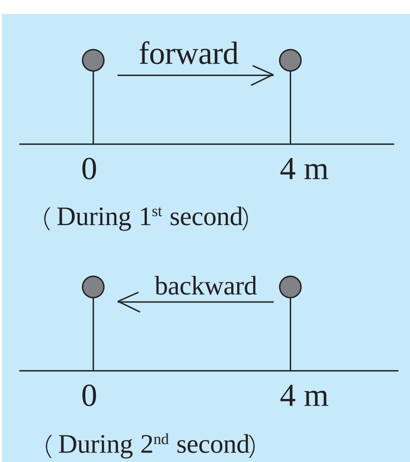
This gives the present position of the object. It is 40 m away from the of initial position. Magnitude and direction are requied to ilustrate displacement. Quantities with a magnitude and a direction are known as **vector quantities**.

- Displacement is a vector quantity.

SI unit for both distance and displacement is metre (m).

Data regarding of motion of a child along a linear path is given in the table below.

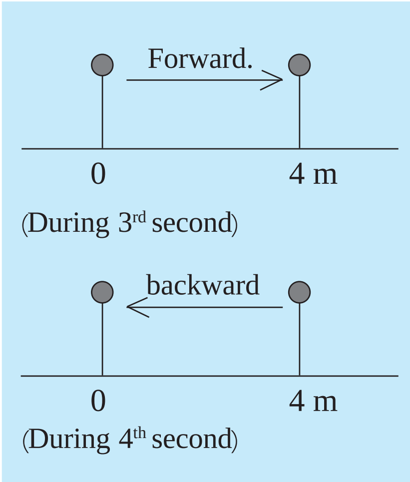
Time (s)	0	1	2	3	4
Displacement (m)	0	4	0	4	0



Let us try to understand the motion represent in the above table, consider that the time is 0, when starting to measure time. At that same time displacement is also 0.

After 1s, the position of the child is 4 m away from the initial position.

Displacement being 0 after 2 s shows that the child has returned to the initial position after 2 seconds. Can you imagine about the direction which the child travelled ? The direction of motion is backward or opposite direction.



After 3rd second the child has moved again 4m away from the initial position to the former direction.

Being the displacement 0, after 4th second, it shows that the child moved 4 m backward again, and he is in the initial position again.

Let us consider the total distance that the child travelled.

1. 4 m forward
2. 4 m backward
3. 4 m forward
4. 4 m backward

$4 + 4 + 4 + 4 = 16$ m

Direction is not considered for the total distance travelled. It is clear that the distance is a scalar quantity.

- Being the displacement is zero after 4 s, It is understood that the child is in the initial position at that time.

Speed and Velocity

Speed is the rate of change of distance. That is the amount of distance travelled during a unit period of time to any direction.

$$\text{Speed} = \frac{\text{Distance}}{\text{Time}}$$

Velocity is the rate of change of displacement. That is the change of displacement taken place during a unit period of time.

$$\text{Velocity} = \frac{\text{Change of displacement}}{\text{Time}}$$

The SI unit of both speed and velocity is metres per second (m s^{-1})

The distance - time table for the motion of the above mentioned child is tabu lated below.

Time Seconds (s)	0	1	2	3	4
Distance (d) Meters (m)	0	4	8	12	16

It is clear that the distance travelled was 4 m during each second. It does not say anything about the direction. Distance time graph for this data is given in Fig :1.7

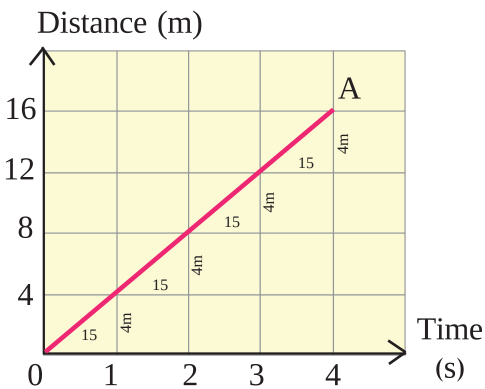
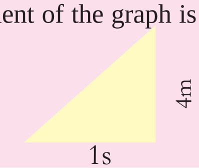


Fig : 1.7 Variation of distance with time

Distance - time graph

- A graph that describes the variation of distance with time is a distance-time graph. These graphs are drawn by taking distance on y- axis and time on ***x*** - axis.

The gradient of the graph is the speed.



$= 4 \text{ m s}^{-1}$

Displacement - time graph

- These graphs are drawn by denoting displacement on y - axis and time on ***x*** - axis.

Let us draw the displacement - time graph for the above mentioned motion.

Time (s)	0	1	2	3	4
Displacement (m)	0	4	0	4	0

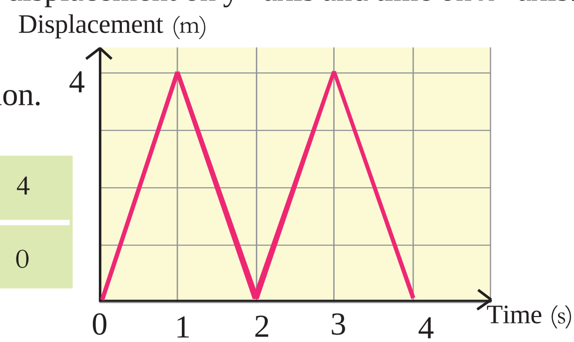


Fig : 1.8 Variation of displacement with time

Let us consider the following table. It gives data on the motion of a child along a linear path.

time, (s)	0	1	2	3	4	5	6	7	8
Displacement, (s)	0	3	6	9	12	12	12	6	0

- When time, $t = 1$ s, child is 3 m away from the initial point. That is, the displacement is 3 m
- When $t = 2$ s, displacement is 6 m. That is because the movement during the 2nd second is another 3 m to the same direction.
- When $t = 3$ s, displacement is 9 m because of the motion during the 3rd second is 3 m more to the same direction.
- When $t = 4$ s, displacement 12 m because of the child moved additional 3 m to the same direction during 4th second.
- When $t = 5$ s diplacement is 12 m. This shows that no motion has taken place during 5th second.
- When $t = 6$ s, again the diplacement is 12 m. No displacement has taken place during 6th second also.
- When $t = 7$ s, displacement is 6 m. This indicates that the child has moved 6 m back and the child is 6 m away from the initial position to the original direction of motion.

- When t = 8 s, displacement is zero (0). It indicates that the child has moved back another 6 m and is in the orginal position.

Changes of displacement during first 4 seconds	=	(+ 12 m) – (0)
Time taken for that	=	4 s
The rate of change of displacement during first 4 seconds }	=	$\dfrac{\text{Change of displacement}}{\text{Time taken}}$
	=	$\dfrac{(+12\text{ m}) - (0)}{4\text{ s}}$
∴ The velocity	=	3 m s^{-1}

During the first 4 seconds, it was a uniform velocity of 3 metres per second.

- There was no change of displacement from t = 4 s to t = 6 s. The child has not moved, hence the velocity is zero.

Change of displacement from 6^{th} Second to 8^{th} second. $= (0 - 12)$ m

Time taken $= 2$ s

The rate of change of displacement during that time. } $= \dfrac{(0-12)\text{ m}}{2\text{ s}} = -6\text{ m s}^{-1}$

The velocity $= -6\text{ m s}^{-1}$

Direction (to the reverse / opposite direction)

magnitude of velocity

Let us draw the displacement - time graph for the above motion.

Displacement - time graph is drawn by taking displacement on y - axis and time on *x* - axis. The variation of displacement according to the time could be studied by such a graph.

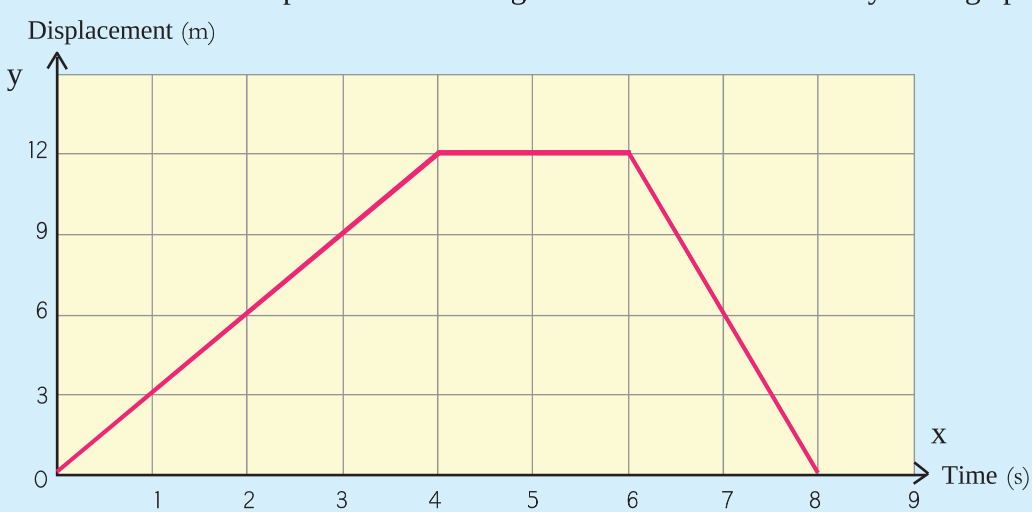


Fig : 1.9 Displacement - time graph

Change of position in first 4 s = (12 – 0) m
This is the difference between the relative co-ordinates of y - axis.
The time taken = 4 s
This is the difference between the relative co-ordinates of ***x*** - axis.

$$\text{Velocity} = \frac{(12-0)\ \text{m}}{(4-0)\ \text{s}} = \frac{\text{difference of y - co-ordinates}}{\text{difference of } \boldsymbol{x} \text{ - co-ordinates}}$$

The gradient of the graph = velocity = 3 m s^{-1}
Therefore velocity during the first 4 seconds = 3 m s^{-1}
Child did not move between the time, ***t*** = 4 s to t = 6 s.
Change of position between the time, ***t*** = 6 s and ***t*** = 8 s = (0 – 12) m
Time taken = 2 s
∴ The rate of change position (velocity) = gradient of the graph during 6s-8s time period

$$= \frac{(0-12)\ \text{m}}{2\ \text{s}}$$

$= -6$ m s^{-1}
= 6 m s^{-1} (to the opposite direction)

Solved Example

Displacement - time data of an object which moved along a straight path towards south is given in the table below.

Time ***t*** (s)	0	1	2	3	4	5	6	7	8	9	10
Displacement ***s*** (m)	0	4	8	12	16	16	16	16	16	8	0

i Draw the displacement - time graph for this motion.
ii Discribe the motion during first 4 seconds.
iii During which time interval was the object at rest without motion? How did you know it?
iv Find the velocity of the object during t = 8 s to t = 10 s

i)

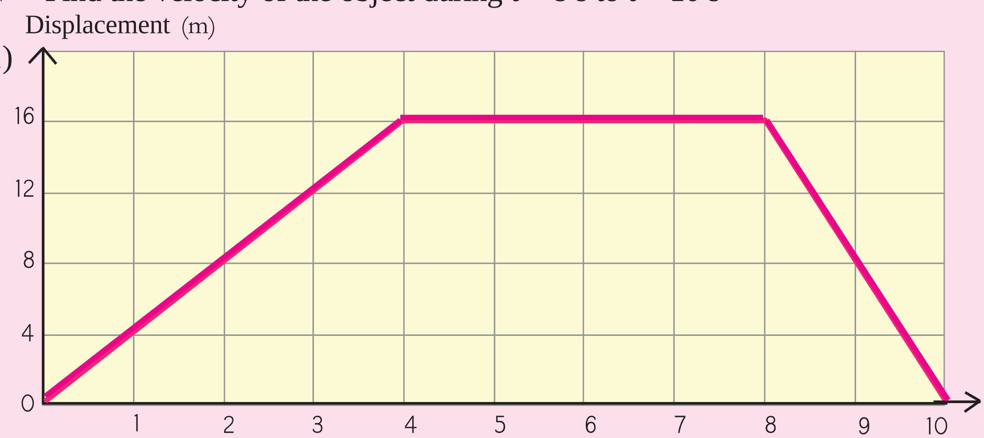


Fig. 1.10 Displacement - time graph

ii) The object moved in uniform velocity during first 4 seconds.

$$\text{That uniform velocity} = \frac{\text{Change of displacement}}{\text{Time taken}}$$

$$= \frac{(16-0)\text{ m}}{(4-0)\text{ s}}$$

$$= 4\text{ m s}^{-1}$$

iii) The object did not move during time , t = 4 s to t = 8 s. That is because there was no change of displacement during that time. The object was at same place during t = 4 s to t = 8 s. There should be an increase or a discrease of displacement for a motion to taken place.

iv) The velocity of the object during t = 8 s to t = 10 s

$$= \frac{\text{Change of displacement}}{\text{Time taken}}$$

$$= \frac{(0-16)\text{ m}}{(10-8)\text{ s}}$$

$$= -8\text{ m s}^{-1}$$

Here, a negative result is obtained because of the direction of the velocity is to the opposite side, during t = 8 s to t = 10 s. The magnitude of velocity is 8 m s^{-1}

1. 2 Motion of objects with varying velocity

Now let us consider the motion with varying velocities. Consider the data given below.

Time t (s)	0	1	2	3	4	5	6	7	8	9	10	11	12
Velocity (m s^{-1})	0	2	4	6	8	10	12	12	12	12	8	4	0

During the first 6 seconds, velocity is increased by 2 m s^{-1} at each second.

Change of velocity during first 6 seconds } = (12 – 0) m s^{-1}

Time taken = 6 s

$$\text{The rate of change of velocity} = \frac{\text{Change of velocity}}{\text{Time taken}}$$

$$= \frac{(12 - 0)\text{ m s}^{-1}}{(6-0)\text{ s}}$$

$$= 2\text{ m s}^{-2}$$

The rate of change of velocity is defined as the acceleration.

Therefore acceleration during first 6 seconds = 2 m s^{-2}

Acceleration of $2\ m\ s^{-2}$ means that the change of velocity during each second is $2\ m\ s^{-1}$. Here the change is positive. Therefore the **acceleration is positive**. This means that the velocity is increased by $2\ m\ s^{-1}$ by each second.

Velocity is not changed during t = 6 s to t = 9 s. Object moves at a uniform velocity during that period of time. This uniform velocity is 12 metres per second ($12\ m\ s^{-1}$). During the last 3 seconds (t = 9 s to t = 12 s) velocity has been decreased from 12 to $0\ m\ s^{-1}$.

Here, the change of velocity $= (0 - 12)\ m\ s^{-1}$

Acceleration during that 3 seconds $= \dfrac{\text{Change of velocity}}{\text{Time taken}} = \dfrac{(0 - 12)\ m\ s^{-1}}{(12-9)\ s}$

$= -4\ m\ s^{-2}$

Here a **negative value** for accelaration is obtained because of the **discrease of velocity by 4 m s^{-1} in each second**

Negative acceleration is known as **decelaration.**

The above decelaration is $= 4\ m\ s^{-2}$

Velocity - Time graphs

These graphs are drawn by denoting velocity on y - axis and time on ***x***-axis. The gradient (slope) of such graphs denote the acceleration.

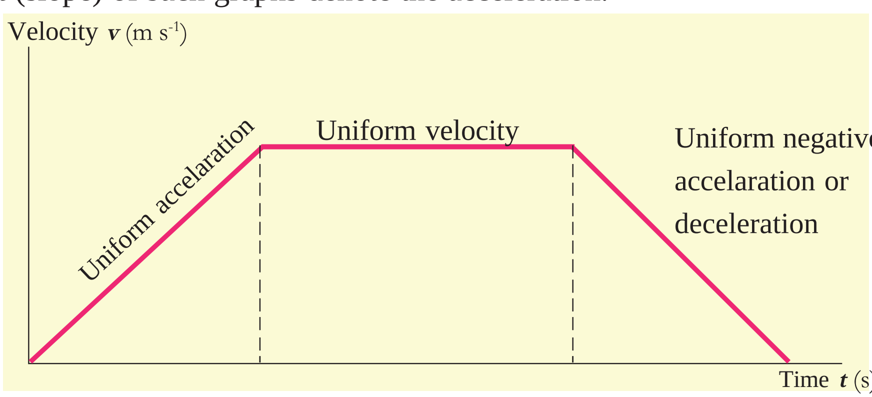
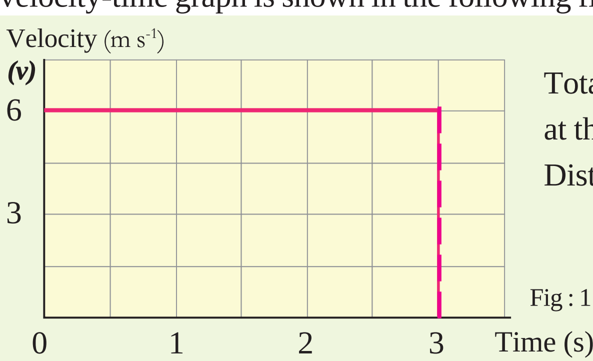


Fig : 1.11 Velocity - time graph

Let us consider an object moving in a uniform velocity of $6\ m\ s^{-1}$, for 3 seconds. Its velocity-time graph is shown in the following figure.



Total distance travelled during 3 s, at the velocity of $6\ m\ s^{-1}$

Distance of the object $=$ velocity $\times$ time

$= 6\ m\ s^{-1} \times 3\ s = 18m$

Fig : 1.12 Velocity - time graph for uniform velocity

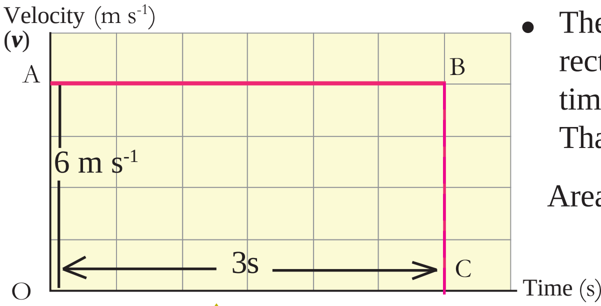


Fig : 1.13 Displacement is given by the area of ABCO

- The numerical value of the area of the rectangle ABCO, under the velocity - time graph, is also 18.

  That is : $= 6\ m\ s^{-1} \times 3\ s$

  Area of the ABCO = 18 m

  This is equal to the total displacement

- Assume an object, commencing its motion from stillness moves along a straight path, in a uniform acceleration of 3 m s^{-2} for 4 s

Initial velocity	= 0
Velocity after 1 s	= 3 m s^{-1}
Velocity after 2 s	= 6 m s^{-1}
Velocity after 3 s	= 9 m s^{-1}
Velocity after 4 s	= 12 m s^{-1}
Mean velocity during 4 seconds	$= \left(\frac{0 + 12}{2}\right)$ m s^{-1}
Total distance travelled during this time	= mean velocity × time

$$= \frac{(0 + 12)}{2}\ m\ s^{-1} \times 4\ s$$

$$= 24\ m$$

Area of the triangle OAB = $\frac{12 \times 4}{2} = 24$

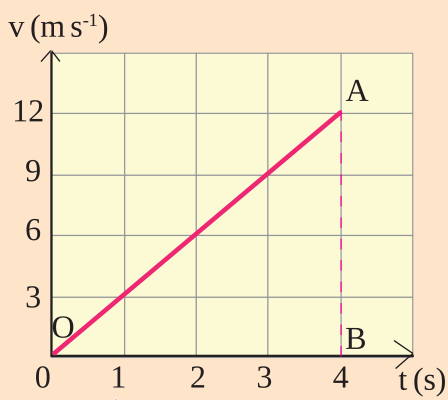


Fig : 1.14 Displacement is given by the area of OAB

The distance travelled is 24 m. Because of the object travelled in a straight line and is 24 m away from where it started, the dispalcement is 24 m.

Displacement = The numerical value of the area between the velocity - time graph and time axis.
= The area of the traingle AOB

Acceleration due to gravity

Acceleration due to gravity (***g***) is the accelaration gained by an object when gravitational force is exerted on the object.

When an object in stillness, starts to fall down vertically, its velocity increases by 10 ms^{-1} approximately per each second.

When an object is projected vertically upwards, its velocity decreases by 10 m s^{-1} approximately per each second.

Thus, it is clear that the acceleration due to gravity is approximatly 10 m s^{-2}

$$g = 10\ ms^{-2}$$

Solved Examples

1. A fruit on a tree falls down vertically to the ground in 4 seconds.
   - i. Prepare a table to show the change of velocity with time.
   - ii. Draw the velocity - time graph.
   - iii. What was the height to the fruit, from the ground ?

i.

Time (s)	0	1	2	3	4
Velocity (m s^{-1})	0	10	20	30	40

ii.

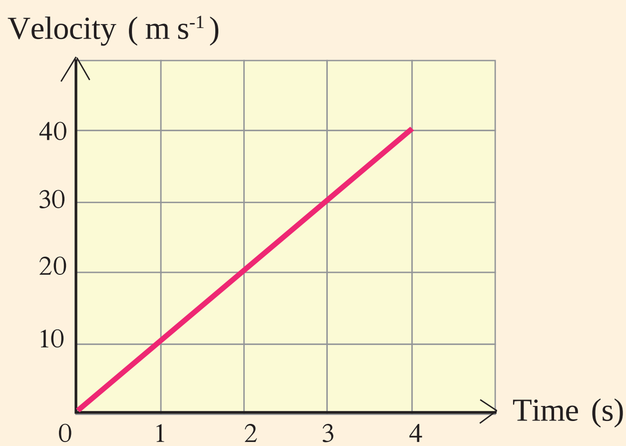


Fig : 1.15 Velocity time graph for a falling object

iii. Height to the fruit = area under the graph

displacement $= \dfrac{40\ m\ s^{-1} \times 4\ s}{2}$

$= 80$ m

2. An object was projected vertically up with an initial velocity of 30 m s^{-1}. Draw the velocity time graph to show its total motion to the highest point and returning back to the initial point.

Table of velocity vs.time.

Time (s)	0	1	2	3	4	5	6
Velocity (m s^{-1})	30	20	10	0	-10	-20	-30

(returning down)

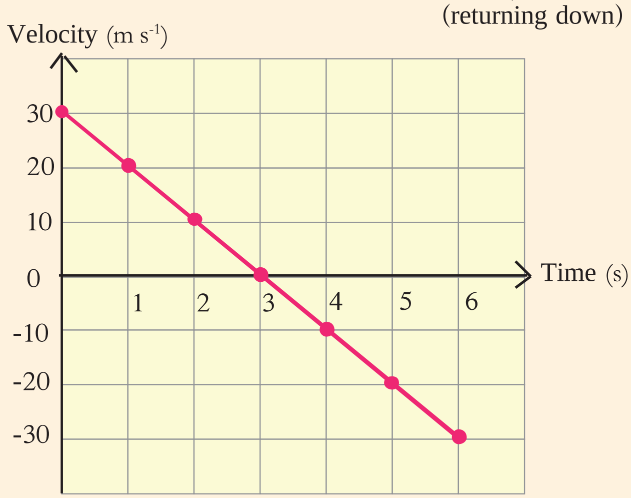


Fig :1.16 Velocity - time graph for the motion of an object projected up wards

1.3 Equations of motion for the Linear Motion

- Assume the motion of an object with the initial velocity of u and moving in a uniform acceleration of a for a time period of t.

Velocity change in t seconds $= at$

$\therefore$ Velocity after t seconds (v) = initial velocity + velocity change

$= u + at$

$$\therefore v = u + at \qquad (1)$$

1

$$v = u + at$$

Think of an object moving in uniform acceleration. Its velocity changes uniformly in each unit of time.

This is the 1^{st} equation of motion for the linear motion.

- Let us find the distance of the motion of an object, moving with a uniform acceleration for a given time.

For this, the mean velocity should be multiplied by the time of motion.

$$\text{Mean velocity} = \frac{\text{initial velocity} + \text{final velociy}}{2}$$

$$\text{Mean velocity} = \frac{u+v}{2}$$

$$\therefore \text{ Displacement } s = \left(\frac{u+v}{2}\right) \times t$$

But $v = u + at$

$$\therefore s = \frac{[u + (u + at)]\, t}{2}$$

$$s = ut + {}^{1}/_{2}\, at^2 \quad \text{——} \; (2)$$

2

$$\boxed{s = ut + {}^{1}/_{2}\, at^{2}}$$

This is the 2nd equation of motion for the linear motion.

$$v = u + at$$

$$\therefore at = v - u$$

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

Displacement of the motion of an object that moves in uniform acceleration = Mean velocity × time

$$s = \left(\frac{u+v}{2}\right) \times t$$

When the motion is in a straight path, the distance equals the displacement

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

$$s = \left(\frac{v+u}{2}\right) \left(\frac{v-u}{a}\right)$$

$$= \frac{v^2 - u^2}{2a}$$

$$\therefore v^2 - u^2 = 2as$$

$$\therefore v^2 = u^2 + 2as \quad \text{————} \; (3)$$

3

$$\boxed{v^{2} = u^{2} + 2as}$$

This is the 3rd equation of motion for the linear motion.

- If an object starts its motion from stillness then,

$$u = 0$$

If acceleration is 2 m s^{-2}, the change of velocity (change is positive) is 2 m s^{-1} per second. If the change of velocity occur for 5 seconds,

The change of velocity for 5 seconds $= 2\ \text{m s}^{-2} \times 5\ \text{s}$
$= 10\ \text{ms}^{-1}$

$\therefore$ Velocity after 5 seconds $v = u + at$
$= 0 + 2\ \text{ms}^{-2} \times 5\ \text{s}$
$v = 10\ \text{ms}^{-1}$

- An object starts its motion from stillness and moves in acceleration of 1.5 m s^{-2} for 8 s. Then it moves in that velocity, uniformly for another 8 s and stops its motion during the last 4 s with a uniform deceleration.

i. a) What is the velocity at the end of 8 seconds ?
   b) What is the displacement travelled during that time ?
ii. What is the displacement travelled in uniform velocity ?
iii. What is the deceleration during last 4 seconds ?
iv. What is the displacement travelled in deceleration ?

i. a) The velocity at the end of initial 8 s } $\mathbf{v} = u + at$
$= 0 + 1.5 \times 8$
$= 12\ \text{m s}^{-1}$

b) Displacement travelled during initial 8 s } $s = ut + \frac{1}{2} \times at^2$
$= (0 \times 8) + \frac{1}{2} \times 1.5 \times 8^2$
$= 0 + \frac{1}{2} \times 1.5 \times 64$
$s = 1.5 \times 32$
$= 48\ \text{m}$

ii. Displacement travelled in uniform velocity } $= 12\ \text{m s}^{-1} \times 8\ \text{s}$
$= 96\ \text{m}$

iii. If the acceleration during last 4 s is ***a***,

$$v = u + at$$
$$0 = 12 + a(4)$$
$$-12 = 4a$$
$$4a = -12$$
$$a = -3\ \mathrm{m\,s^{-2}}$$

Because a is a negative value, acceleration decreases by 3 $\mathrm{ms^{-1}}$ per second.

$\therefore$ Deceleration = 3 $\mathrm{ms^{-2}}$

iv.
$$s = ut + \frac{1}{2}at^2$$
$$s = (12 \times 4) + \frac{1}{2} \times (-3) \times 4^2$$
$$s = 48 - 24 = 24\ \mathrm{m}$$

1.4 Newton laws of motion and concept of force

Newton's first law

If not an external unbalanced force is exerted, the objects at rest maintain their stillness and those in motion moves in a uniform velocity.

- **Concept of force**

If a force is applied on an object towards its direction of motion, the velocity increases. If the force is applied to the oppostite direction, velocity decreases.

When an object is pushed and released along the floor, its velocity decreases and finally stops. This is because a frictional force acts against the motion, If an external force, which is equal to the frictional force is applied on the object towards the direction of motion, it will move in a uniform velocity. If the external force applied to the direction of motion is larger than the frictional force, that excess amount of force is referred to as **unbalanced force**. Acceleration is always due to this unbalanced force.

Work cannot be done without applying a force. Therefore force could be define as the agent that makes work to be done.

1.5 Magnitude of force

Concept of Momentum

Momentum of an object is the product of its mass and velocity.

Momentum = Mass × Velocity

= m × v

If an object is at rest, there is no momentum,

Because ***v*** = 0

Velocity is essential for an object to have momentum. Momentum is a vector quantity. It's direction lies in the direction of velocity.

- When the mass = 5 kg
  and velocity = 1 m s^{-1} the momentum of an object = mv
  = 5 × 1 = 5 kg m s^{-1}

When the mass = 5 kg
and velocity = 2 m s^{-1}
The momentum of the object } = mv
= 5 × 2 = 10 kg m s^{-1}

When the mass = 5 kg
and velocity = 4 m s^{-1}
The momentum of the object } = mv
= 5 × 4 = 20 kg m s^{-1}

When the velocity of an object increases , the momentum also increases. When a force is applied towards the direction of motion of an object, its velocity increases. Hence momentum also increases.

Newton's Second Law

The rate of change of momentum of an object is directly propotional to the unbalanced force (*F*) acting, and takes place in the direction in which force acts.

Force rate of change of momentum

If the velocity of an object (of mass ***m***) is increased from ***u*** to ***v*** during a time period of ***t***, because of the action of force ***F*** ;

$$F \quad \frac{mv - mu}{t}$$

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

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

$$F \quad ma$$

$$\therefore \quad F = kma$$ (***k*** = constant)

Fig : 1.17 Issac Newton

Definition of a Newton

Force required to produce an acceleration of 1m s^{-2} to a mass of 1 kg is known as 1 N

Therefore constant $\boldsymbol{k} = 1$

$\therefore \quad F = ma$

Force = mass × acceleration

$$F = ma$$

Magnitude of Force

We have already learnt that the SI unit of force is newton (N).

One newton is the amount of force necessary to give a mass of 1 kg, an acceleration of 1 m s^{-2}.

$\therefore$ The force necessary to give a mass of 5 kg, an acceleration of 1 m s^{-2} is 5 N

Therefore the force necessary to give a mass of 5 kg, an acceleration of 3 m s^{-2}

$$\left.\begin{aligned} F &= ma \\ &= 5\ \text{kg} \times 3\ \text{m s}^{-2} \\ &= 15\ \text{N} \end{aligned}\right.$$

Solved Examples

- What is the force necessary to give a mass of 10 kg, an acceleration of 4 m s^{-2}?

  Force $(F) = ma$ = 10 kg x 4 m s^{-2} = 40 N

- What is the force necessary to give a mass of 8 kg, an acceleration of 2.5 m s^{-2}?

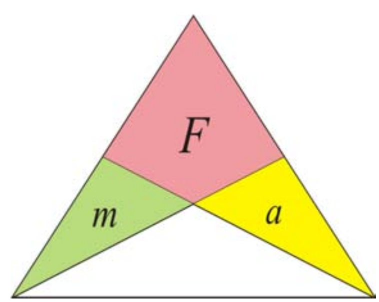
  $F = ma$

  F = 8 kg x 2.5 m s^{-2} = 20 N

Knowledge Testing

Complete the following table.

Force (F)	Mass (m)	Acceleration $(\boldsymbol{a})$
	60 kg	50 cm s^{-2}
100 N		4 m s^{-2}
60 N	120 kg	
4 N	16 kg	
	500 g	20 m s^{-2}



1.18 Fig ⬆ Relationship between force, mass and acceleration.

Gravitational force

Weight is the force of gravity on an object. Objects in free fall accelerate due to gravity. Newtons Second Law tells us that force = mass x accelaration hence, the force of gravity on an object in free fall is its mass x g, where g is the accelartion due to gravity. Thus the weight of an object can be worked out from its mass using this formula.

Therefore ; $\boldsymbol{w = mg}$

1.6 Newton's Third law

Newton's third law is the law associated with the mutual action of two objects.

Activity 1

Place two pieces of boards on some marbles as shown in the Fig 1.19. Sit yourself on one board and ask one of your friends to sit on the other. Push each other by placing the palms together.

What happens ?
Both will be pushed to opposite directions.

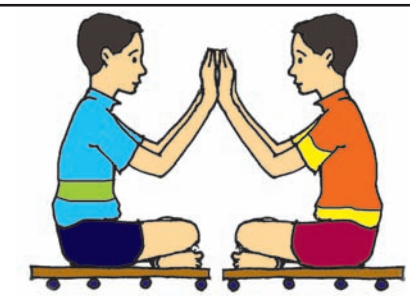


Fig :1.19 Demonstration of action and reaction

Here, the push by one person can be considered as the **action** and the push on him by the other person could be considered as the **reaction**.

Activity 2

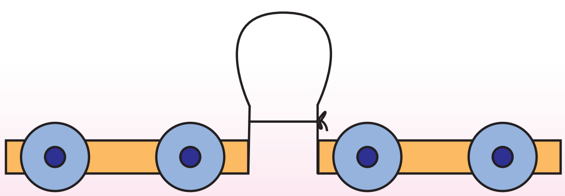


Fig : 1.20 Demonstrating action and reaction using trolleys

Take two equal trolleys. Fix a bent spring blade to one trolley as shown in the Figure : 1.20. Tie both ends of the spring with a piece of thread to form a curve. Keep the other trolley touched to the free end of the spring.

Then burn the piece of thread. Both trolleys will move to the opposite directions. The distance they travel will be approximately equal.

Can you identify the action and reaction for this instance.

Activity 3

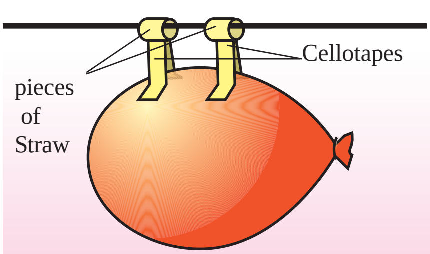


Fig :1.21 Demonstrating action and reaction uisng a balloon

Hang an inflated balloon on a horizontal wire using two pieces of drinking straws and cellotape as shown in Fig : 1.21 Carefully remove the thread tied to the mouth of the balloon. The balloon will move to the opposite direction of the flow of air.
Flowing of air is the action. Motion of balloon is the reation, which is equal in amount and opposite in direction.

A block of wood kept on a horizontal table is shown in Fig : 1.22. The weight of the block is ***W***. This is the action by the block on the table. The reaction applied by the table, against the weight is ***R***. The block of wood is at equilibrium because ;

W* = *R

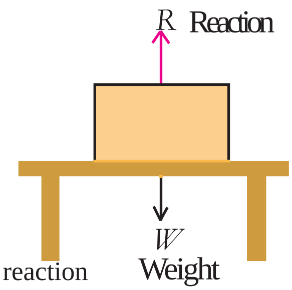


Fig : 1.22 ➡ Weight and the normal reaction

■ **Newton's third law could be expressed as follows;**

For every action, there is a reaction which is equal in magnitude and opposite in direction. Action and reaction cannot act on the same body. Two bodies should be involved in this regard.

1.7 ➡ Frictional force

Push and release an object along a horizontal floor. What happens to its speed with time ?

The speed decreases and the object comes to rest. It is clear that a force which opposes the motion is exerted by the contacting surfaces.

As shown in Fig : 1.23 draw a block of wood on a horizontal table, using a Newton balance.

The force drawn (X) is indicated on the balance.

If the block does not move, it implies that the frictional force (F) is equal to the force drawn.

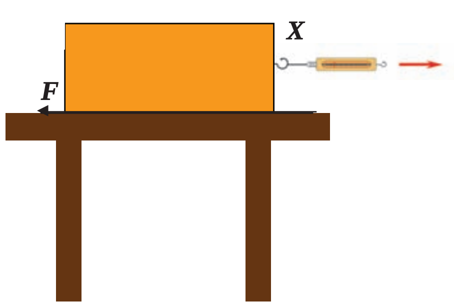


Fig : 1.23 ⬆ Demonstrating limiting frictional force

Now increase the pulling force. If the block still does not move, it implies that the frictional force also equally increases with the drawing force.

When two objects in contact are at rest and one (the block of wood) is about to move relatively to the other (the surface of the table), a force is generated by the contacting surfaces to oppose the motion.

When there is a relative motion between two contacting surfaces also, a force is generated to prevent the motion.

The forces acting between two contacting surfaces which prevent or retard the relative motion are known as **frictional forces.**

The property that generates frictional forces is known as **friction.**

Think

Fig 1.24

For what is the treads on tyres and ridges on shoes ?

Limiting Frictional Force

As mentioned earlier, when the pulling force applied on the block of wood on the table is increasing, the block just starts to move. Record that reading on the spring balance.

When the pulling force is increased, the frictional force also increases. But the relative motion, at one stage, implies that the frictional force can reach up to a maximum value for the given contacting surfaces. That maximum frictional force is known as the **limiting frictional force** for that contacting surfaces.

Factors affecting friction

Carry out the following activities to investigate the factors affecting friction.

Activity - 1

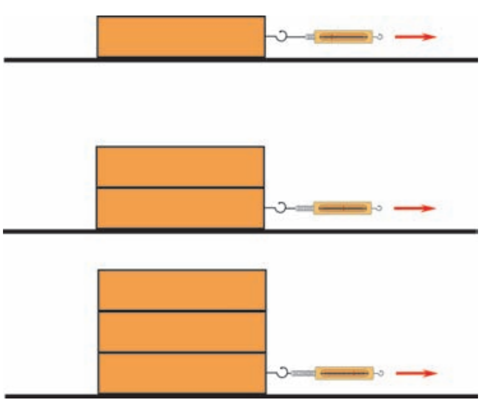


Fig : 1.25 Normal reaction and friction

- Take three equal boxes filled with sand.
- Place one box on a horizontal table - top. Using a newton balance, find the minimum force that should be applied to just start the motion of sand box.
- Put another box filled with sand, on the previous one. Find the minimum force to be applied to start motion as above.
- Repeat the activity using three boxes of sand.
- It is observed that, when number of boxes (weight of the object) is increased, the horizontal force for motion is also should be increased.

- When the weight of an object increases the normal reaction also increases.
- That is, when normal reaction increases, the minimum force that should be applied to start motion is also increased.
- The minimum force that should be applied horizontally to the surface to start motion, is equal to the limiting frictional force.
- Therefore it could be concluded that when the normal reaction applied on an object is increased, the limiting frictional force on the object also is increased.

Activity - 2

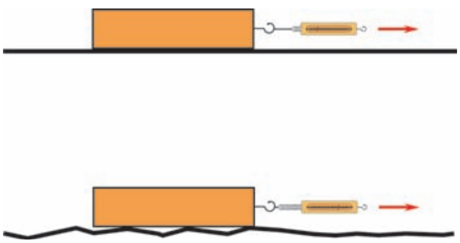


Fig : 1.26 Nature of contacting surfaces and friction.

- Place a wooden box on a horizontal table and find the minimum horizontal force that should be applied to just move it.
- Paste a piece of sand paper to the surface of the box, which was contacted with the table top and repeat the above activity.
- The results of this activity reveal that the minimum force applied to move the object increases with the roughness of contacting surfaces.

It concludes that the nature of contacting surfaces affect the limiting frictional force.

Activity - 3

- Take a wooden cuboid with different surface areas as shown in the Fig : 1.27 below.

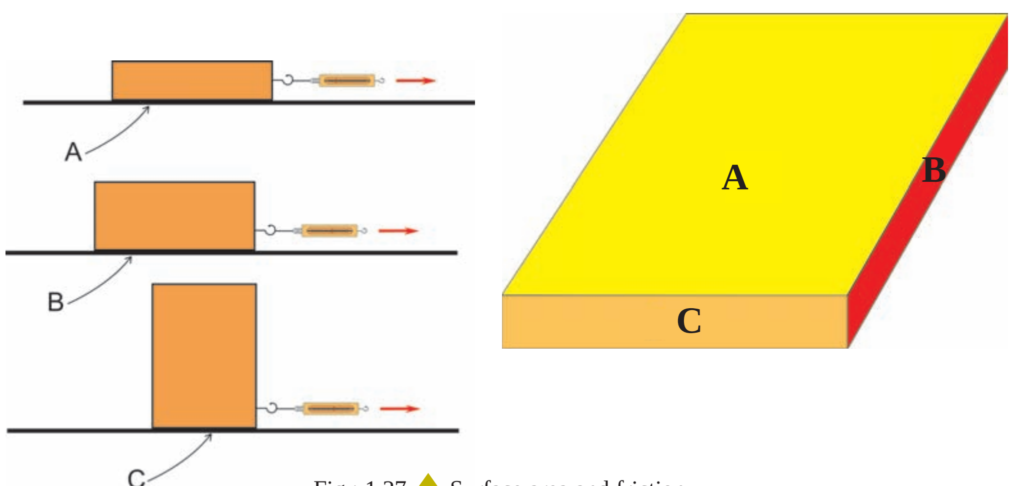


Fig : 1.27 Surface area and friction

- Place the surfaces of different area on the table and find the minimum force that should be applied to just move the wooden cuboid.
- The minimum force that should be applied in each instance will be the same.

It could be concluded that the contact surface area does not affect the limiting frictional force.

Frictional forces acting on objects moving in uniform velocity

Think of an object which is already moving on a surface in uniform velocity. In this instance, a force which is equal to the frictional force is acting towards the direction of motion.

If the force applied for motion differs from frictional force, then the difference between those two forces is known as the **unbalanced force**.

i.e. If a force of 15 N is applied towards the direction of motion while the frictional force is 12 N, then the unbalanced force is 15 N − 12 N (that is 3 N). The object accelerates because of this force.

If the frictional force is 12 N and force applied for motion is 9 N,

the unbalanced force = 9 N − 12 N

= − 3 N

There will be a negative acceleration, because the unbalanced force is negative. That is a deceleration.

Practical applications of frictional force

- When moving machine parts are contacting each other they are worn out and energy is also wasted because of friction. To prevent this ball bearing, roler bearing and lubricants are applied.
- Frictional force is useful in walking, climbing trees and running motor vehicles. Using shoes with grooved soles, using a ring made of rugs to climb trees and using grooved - treaded tyres for vehicles are methods of increasing frictional force in the above mentioned situations.
- Frictional force could be increased by making the contact surfaces rougher and it could be decreased by making them smoother. On railway lines frictional force is increased by putting sand on the rails. On carom boards, frictional force is reduced by applying boric powder.

1.8 Equilibrium of coplanar forces

Keep a ring on a horizontal table top and apply two coplanar forces to opposite directions using spring balances as shown below.

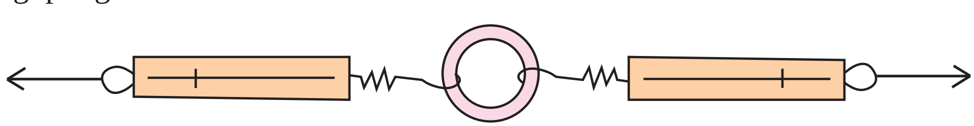


Fig : 1.28 Equilibrium of an object under two linear forces

Observe the readings of two spring balances. It could be observed that if the reading of one balance is larger than the other, the ring moves towards that direction. And if the readings of both balances are equal, the ring stays at rest.

Why are the reading of balance equal when the ring is at rest ? It is because both forces are equal in magnitude, opposite in direction and acts along a single line.

Given below in Fig : 1.29 shows the coplanar forces in equilibrium.

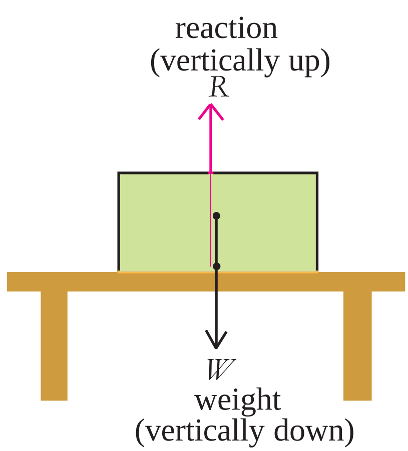


Fig : 1.29 Weight and normal reaction

The object on the table is at rest because its weight and the reaction by the horizontal surface on the object are equal in magnitude and opposite in direction and act on the same straight time.

Think of an object hung by a string. If it is at rest, it is because a force equal to the weight of the object is acting vertically upward along the string.

If two coplanar forces, acting on a point are equal in magnitude and opposite in direction, then they are at equilibrium. The object under such forces is at rest.

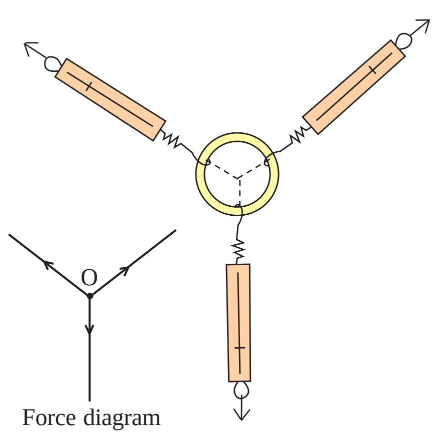


Fig : 1.30 Equilibrium of an object under three coplanar forces

Equilibrium of three coplanar forces

Place a ring on a horizontal plane and draw it to three directions, using three spring balances, as shown in the Fig : 1.30 below. Apply the forces till the ring is at rest. When the ring is at rest, it is because three coplanar forces acting on the ring are in equilibrium.

If three coplanar forces acting on an object are at equilibrium, the object under these froces is at rest.

When the positions of spring balances are denoted by straight lines and are extended towards each other, they will meet at point O. Thus three coplanar forces acting on an object meet at a single point.

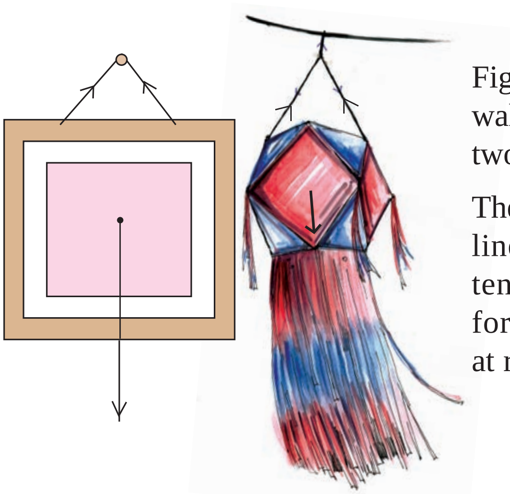


Fig : 1.31 shows a framed picture, hung on a wall. The weight of the picture is balanced by two tension forces acting along the strings.

The figure also shows a vesak lantern hung on a line. Weight of the lantern is balanced by two tension forces acting along the strings. Three forces are in equilibrium. Hence the lantern is at rest.

Fig : 1.31 Equilibrium of objects under three coplanar forces

Equilibrium of three parallel forces

When the strip of wood shown in the Fig : 1.32 below is at rest;

Reading on spring balance A = The sum of readings on spring balances B and C

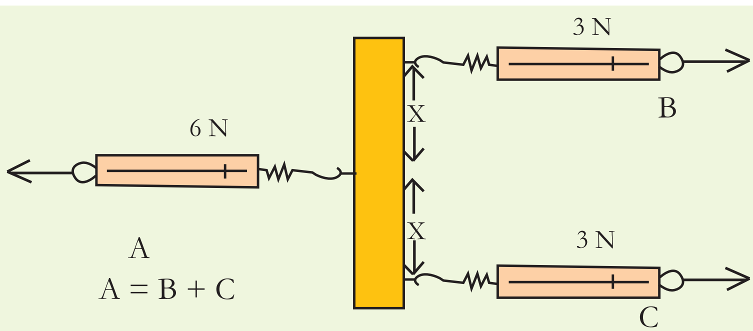


Fig : 1.32 Demonstrating the equilibrium of an object under three parallel forces

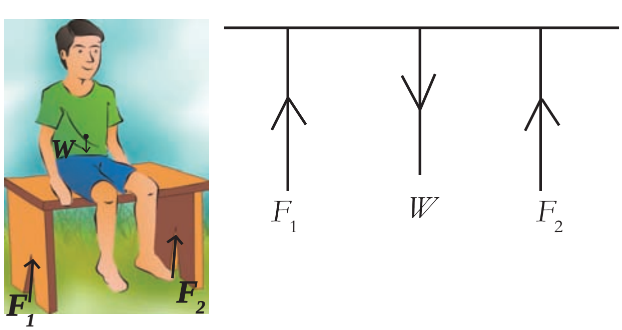


Fig : 1.33 Equilibrium of an object under three parallel forces

Fig : 1.33, shows A child is sitting on the very centre of a bench. His weight is W. Forces exerted upwards vertically by the legs of the bench are F_1 and F_2, $F_1 = F_2$, Sum of the forces F_1 and F_2 is equal to the force, ***W***. Therefore these three parallel forces are in equilibrium.

$$F_1 + F_2 = \boldsymbol{W}$$

1.9 Turning effect of a force

Turning effect and the moment of a force

Think of an instance where a force is applied to turn an object around an axis or a point. Assume that the volume or the shape of the object is not changed by the force applied. The result of such force is called the rotating effect. The physical quantity associated with the turning effect is called the moment of force. The moment of force depends on product of magnitude of force and the perpendicular distance to the line of action from the point of rotation.

X is a strip of wood which can be rotated freely round the point O. One of its ends is connected to a spring as shown in Fig. 1.34

Fix metal rings to the points A and B of the strip as shown in the figure,

Let OA = 4 cm

AB = 4 cm

Draw the strip by a force of 1N applied to the point B, using a spring balance.

Observe the rotating effect of the strip of wood round O and measure the extension of the spring.

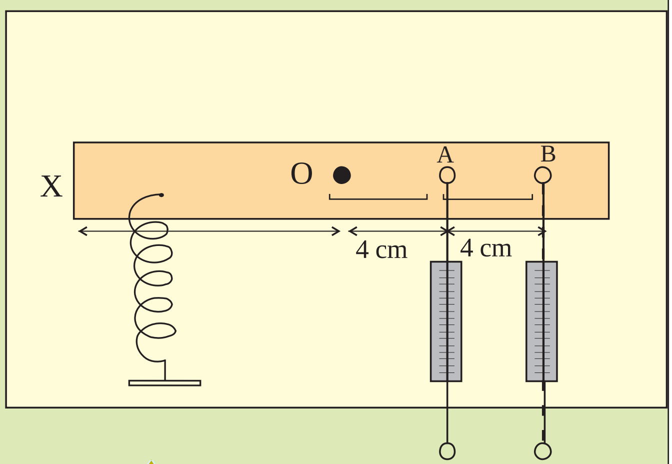


Fig : 1.34 Change of turning effect according to distance

Then draw the strip by the same force applied to A and also measure the extension of the spring. We see that the change in extension of spring increases, and there by the rotating effect is enhanced.

Which is the point that a greater rotating effect could be exerted by appling the same amount of force ? You may have observed that it is B. The reason is that the perpendicular distance from the point of rotation to the line of action is larger, in situation B.

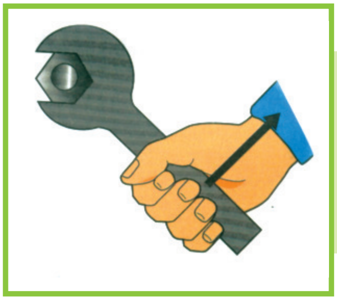
To obtain the same moment as, 1 N is applied to B, twice the initial force should be applied to A.

The moment of force = Magnitude of force × Perpendicular distance to the line of action from the point of rotation

Unit of the moment of couple of forces = Nm

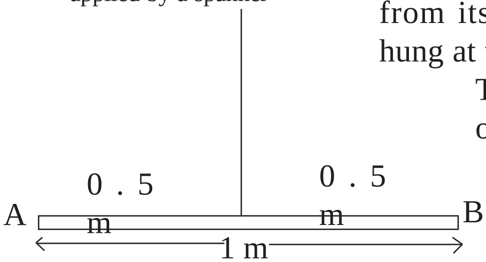
The moment of a force could be increased by either increasing the magnitude of the force or by increasing the perpendicular distance to the line of action of force from the axis of rotation.

Turning or the rotation of an object takes place because of the moment of force applied.



Think of an instance of loosening a nut using a spanner. What is the place of the spanner, that a larger force is necessary to be applied to loosen the nut ?

Fig : 1.35 Moment of force applied by a spanner



- A uniform wooden bar of the length of 1 m is hung from its center and balanced. A weight of 10 N is hung at the end B.

The moment of the weight (force) of 10 N $= 10 \text{ N} \times 0.5 \text{ m}$
$= 5 \text{ N m}$ Clock wise

What should be done to maintain the balance of the bar ?

Another weight of 10 N should be hung to the end A. Then there would be a moment of 5 N m (10 N × 0.5 m) anti clockwise. And the bar would be in equilibrium.

Turning of a steering wheel, opening and closing of a door and turning the handle of a bicycle are instances of application of moment of forces.

Is it easy to open or close a door by applying a force far away of the hinge or closer to the hinge?

The moment is larger when the force is applied far away of the hinge. Hence it is easy to open or close the door by applying the force far away of the hinge.

Fig : 1.36 Who is applying the larger moment of force

Fig : 1.37 Couple of forces applied on a tap

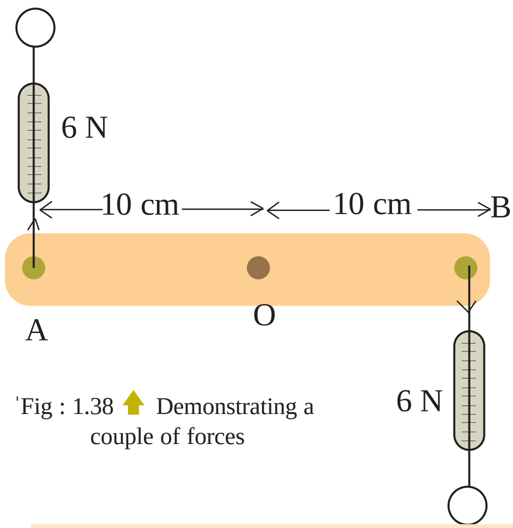


Fig : 1.38 Demonstrating a couple of forces

● Couple of forces

Couple of forces are two parallel forces which are equal in magnitude and opposite in direction and are applied on an object to rotate it. Opening or closing a water tap and turning the steering wheel of a vehicle are some instances where couple of forces are in action.

Take a strip of wood, which is 20 cm long, and fix it to a board in such a way that it could be rotated round the point O. (See fig 1.38) Fix two metal rings at the distance of 10 cm from either sides of O. Initially, the strip is at equilibrium. Fix two spring balances to the rings, A and B, and draw them to opposite directions to turn the wooden strip. It will be observed that the readings of spring balances are the same.

Thus, the forces which are opposite and parallel in direction are equal in magnitude in a couple of forces.

The moment of couple of forces = Magnitude of force × Perpendicular distance between the lines of action of two forces

Unit of the moment of couple of forces = Nm

The moment of force at A $= 6\ \text{N} \times \frac{10}{100}\ \text{m} = 0.6\ \text{N m}$ (clockwise)

The moment of force at B $= 6\ \text{N} \times \frac{10}{100}\ \text{m} = 0.6\ \text{N m}$ (clockwise)

The object rotates clockwise because of both forces.

∴ The moment of couple of forces $= 0.6\ \text{N m} + 0.6\ \text{N m}$

$= 1.2\ \text{N m}$ (clockwise)

Perpendicular distance between the lines of action of two forces $= (10 + 10)\ \text{cm} = \frac{20}{100}\ \text{m} = 0.2\ \text{m}$

When the magnitude of **one force** is multiplied by the perpendicular distance of the lines of action of two forces also, the moment of the couple of forces could be obtained.

Thus the moment of couple of forces $= 6\ \text{N} \times 0.2\ \text{m} = 1.2\ \text{N m}$

Summary

- The amount of motion of an object is given by the distance.
- The change of position of an object is given by the displacement.
- Rate of change of distance is the speed.
- Rate of change of displacement is the velocity. That is, the velocity is the speed towards a given direction.
- Average Speed $= \dfrac{\text{Distance}}{\text{Time}}$; Velocity $= \dfrac{\text{Change of displacement}}{\text{Time taken}}$
- Distance and speed are scalar quantities. Displacement and velocity are vector quantities.
- Rate of change of velocity is acceleration.
- Acceleration due to gravity is the acceleration caused by the gravitational force.
- Equations of motion are;
  - $v = u + at$
  - $s = ut + 1/2\ at^2$
  - $v^2 = u^2 + 2as$
  - $s = \left(\dfrac{u + v}{2}\right) t$
- Use of above equations
- SI unit of force is Newton (N)
- If two coplanar forces, acting on a point are equal in magnitude and opposite in direction, they are at equilibrium.
- If three coplanar forces acting on an object are in equilibrium, that object is at rest. The lines of action of those three forces meet at a single point.
- The rotating effect of a force is the moment of that force.
- The moment of a force is the product of the force and the perpendicular distance from the rotating point to the line of action of that force.

Exercises

(1) Given below is a table that shows the variation of velocity of an object moved on a linear path, with time.

Time (s)	0	1	2	3	4	5	6	7	8	9	10	11	12
Velocity (ms^{-1})	0	3	6	9	12	15	18	18	18	18	12	6	0

i. Draw the velocity - time graph to denote this motion.

ii. What was the acceleration of the object during first 6 s (the time between ***t*** = 0s and ***t*** = 6 s) ?

iii. What was the time interval that the object moved in uniform velocity ?

iv. What was the deceleration of the object during ***t*** = 9 s and ***t*** = 12 s ?

v. What was the distance that the object moved during first 6 s ?

vi. What was the distance that the object moved during ***t*** = 9 s and ***t*** = 12 s ?

(2)i. What is acceleration due to gravity ?

ii. A pebble at rest was dropped and it took 6 s to reach the ground. Draw the velocity - time graph for this motion. Using the graph, find the height that the pebble had fallen.

iii. Draw the velocity - time graph for the motion of an object projected vertically up with an initial velocity of 20 ms^{-1} and returns back to the earth.

(3) i. Solve the following problems using equations of motion.

a) An object at rest, starts its motion with a uniform acceleration and reaches the velocity of 20 ms^{-1} after 4 s.

1) What is the acceleration of the object ?

2) Find the distance that the object travelled during that time period.

b) An object at rest, starts its motion with a uniform acceleration of 1.5 $m\,s^{-2}$ and travels for 6 s.

1) What is the velocity of the object after 6 s ?

2) What is the distance travelled during that time ?

ii. State Newton's first law of motion.

iii. State the equation derived from Newton's second law of motion.

iv. When a force of 15 N was applied to an object with a mass of 6 kg, what will be its acceleration ?

v. Give three instances where Newton's third law of motion is applied.

(4)i. What is 'limiting frictional force' ?

ii. Give three methods of decreasing friction.

iii. Give two examples for instances where three coplanar forces acting on a single point are at equilibrium

iv. What is the moment exerted by a force?

v. Write a formula to find the moment of a force.

vi. What is the unit of moment of a force ?

vii. Clarify the term "couple of forces" and give two examples.

(5) AB is a uniform bar of a length of 1.2 m. It is balanced at its centre. What is the moment of a force of 8 N, hung at the end B. What is the weight, that should be hung 0.2 m away from the end A, to maintain the balance of the bar ?