Chapter-9

Force and Motion

In this chapter we will study about force and motion. Before proceeding with the study of force and motion we will learn as to how are various physical quantities expressed.

Generally, the physical quantities are expressed by their unit and numeric value. While expressing some physical quantities even the direction is to be mentioned along with the unit and numeric value.

Physical quantities are classified into :

(a) Scalar quantities

(b) Vector quantities

9.1 Scalar and Vector Quantities :

(a) Scalar quantities : The physical quantities which can be expressed by only the magnitude are known as the scalar quantities. Scalar quantities do not specify direction. Mass, time, speed, density, energy, power etc. are the examples of scalar quantities. For example if the mass of a body is 5 kg, then no direction is required to be mentioned for expressing it.

(b) Vector quantities : There are many physical quantities whose magnitude, alone, cannot describe them completely. We can understand this with the help of the following examples.

(1) Fig. 9.1 (a) and (b) shows the distance travelled by a student. The distance AB = 4 meters and distance BC is 3 meters. The distance travelled by the student in both the journeys is 7 meters but the displacement between the starting point A and the end point C is different in the two cases. In the first situation the displacement is of 7 meters where the movement is in the same direction. However, in the second case the displacement is of 5 meters (AC) and its direction is at an angle of θº from AB.

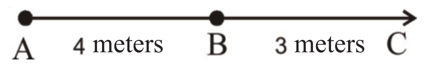

Fig. 9.1 (a) Two displacements in the same direction

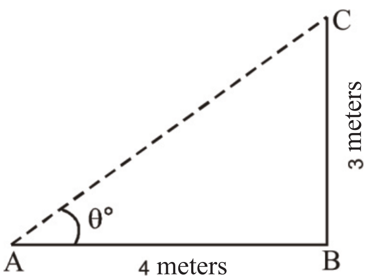

Fig. 9.1 (b) Two perpendicular displacements

(2) Two equal force F are working on a body having mass M, as shown in the fig. 9.2 [The direction of the force applied is shown by the arrows in the figure.

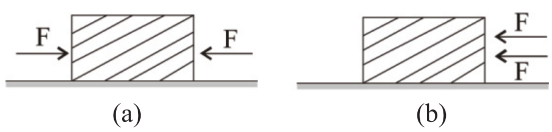

Fig. 9.2 Forces applied on a body

We can say that the body in 9.2 (a) will remain static on appliccation of the force while in 9.2 (b) the body will move when force is applied.

Thus it is clear from the above examples that the physical quantities like force, displacement etc. are expressed in terms of their magnitude along with the directions.

This type of quantities are known as the vector quantities.

The physical quantities which require magnitude and a direction to be described completely are known as the vector quantities.

Presenting the vector quantities : Vectors are shown with an arrow like line. The length of the line fragment of the arrow is in proportion with the magnitude of the physical quantity while the arrow denotes the direction of the vector.

For example, if we have to depict the velocity of 30m/s in East direction, then we will take an appropriate scale (for example 10m/s=1cm) and will draw a line to the sacle (as shown in fig. 9.3) with the direction of the arrow towards East : Thus the vector QP will display the desired velocity in terms of the magnitude and the direction.

Point Q is the root point (or the tail point) of this vector and the point P is the apex. The vector line fragment from Q to P is denoted as $\overrightarrow{QP}$. [Here the direction of the arrow from Q to P is in the direction of the vector].

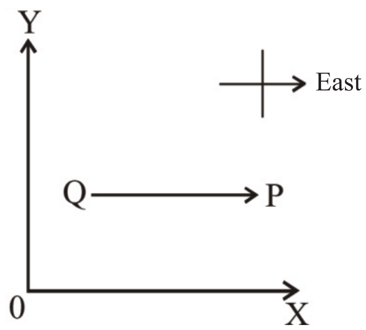

Fig. 9.3 Depiction of Vector

Representation of Vector : Following can be the methods of writing a vector :

(i) The alphabet of the tail is written first followed by that of the head and an arrow is marked on them. For example the above vector is depicted as $\overrightarrow{QP}$.

(ii) The vector can be symbolized by Bold alphabets or with an arrow above the alphabet For example : The vector $\overrightarrow{QP}$ can also be depicted as A or $\vec{A}$, where $\vec{A}=\overrightarrow{QP}$. In books both the methods are used but when writing it down it is always easy to draw an arrow above the alphabet the magnitude of the vector is expressed by the symbol or $|\vec{A}|$ or simple alphabet A. The magnitude of a vector is also known as intensity.

The magnitude of the vector $\vec{A}$ will be $|\vec{A}|$ or A.

Unit Vector :

The unit vector of a vector $\vec{A}$ is the vector whose magnitude is unit and the direction is same as that of the vector A. The unit vector of vector $\vec{A}$ is represented by $\hat{A}$ (Note - $\hat{A}$ szis pronounced as A cap)

It is expressed in the following manner :

$$\vec{A}=|\vec{A}|\hat{A}$$

i.e. $$\hat{A}=\frac{\vec{A}}{|\vec{A}|}=\frac{\text{vector}}{\text{magnitude of the vector}}=\text{unit vector}$$

Thus the unit vector can be obtained by dividing the vector with its magnitude.

9.2 Motion :

In our daily life we find some things static and others in a state of motion. The buildings, trees etc. around us are still while the cars on the road, the child walking down or running, the flowing water, flying bird etc. make us realize motion. Many times we are unable to perceive motion directly but it is inferred from the indirect evidence. For example the motion of air is inferred from the movement of leaves and branches.

Motion is a change in position of a body, particle or an object with respect to time. Similarly, no change in position of the object, with the passage of time expresses a static state of the object.

Same thing can be perceived by a person in a state of motion and by another it may be inferred to be static. For example the passengers of a train appears to be in motion to a person standing near the rail line while for a passenger in the train his co-passengers are not in a state of motion because their relative distance does not change. It is clear from these observations that change in position is a comparative phenomenon. Therefore the state of motion and static state are always in relation to a reference point called the origin point.

Reference Point :

To have a complete knowledge of the position of an object one need to know the displacement of the object from the point of origin (i.e. reference point) and the angle of the reference axis with the line joining the point of origin and the present position of the object. This is known as the direction of motion.

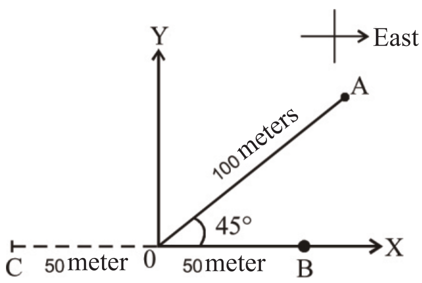

Fig. 9.4 Position in relation to the reference point

In fig. 9.4 the object A is situated at a distance of 10 meters from the reference point O. The angle between OA line and OX axis is of 45º and OX is in East direction. Here the line OA is forming an angle of 45º towards North. Therefore the object A is 100 meter away from the reference point O making an angle of 45º from East to North. Similarly the object B is 50 meters East from the point of reference; object C is 50 meters west of the point of reference. Therefore motion can be comprehensively defined as : "Continuous change in the position of an object with time, relative to the point of reference is known as the motion of the object."

Motion of the object can be of many types. Some main types are :

(i) Simple linear motion : If the object moves along a simple straight line, it is known as simple linear or rectilinear motion. Example : Movement of a ball in a long straight pipe.

(ii) Circular motion : When a particle or an object moves on a circular path it is known as the circular motion. Example : Movement of a stone tied to a rope which is moved horizontally.

(iii) Oscillatory motion : To and fro motion of an object around a mean position that is repeated at a regular time interval is known as the oscillatory motion. Example : Motion of a pendulum in a clock having pendulum.

Block/Lump or Particle :

Usually while studying motion of objects we consider them to be a mass or a particle. If during movement the object do not break up into pieces it may be effectively visualized as a unit and is called a block or a lump. The entire mass of the block is supposed to be centralized at a point known as the center of mass. When the shape of the object is negligible as compared to the distance travelled by it, it is considered to be a particle. For example the size of a ball in comparison to the distance travelled by it in a field, is considered to be a particle.

9.3 Distance and Displacement :

The distance AB and BC in fig. 9.1 (a) and (b) are 3.0 meter and 4.0 meter respectively. But AC distance is different in both cases. The simple linear distance between the initial and the final position of the object is known as its **displacement**. It is a vector quantity. On the other hand, the distance travelled to reach the final position from the initial position is a scalar quantity. In displacement we mention the direction in which the distance is to be measured. Both distance and displacement are concerned with measure of length. Hence they are expressed in the unit of length. The SI unit (international unit) for both is meter. If the measurement of displacement is expressed without mentioning the direction then it is known as the magnitude of displacement.

In fig. 9.1. (a) the magnitude of the distance covered and the displacement is the same i.e. 7 meters. In fig. 9.1 (b) the distance AB+BC = 7.0

meters while the displacement will be 5 meter (i.e. AC) at an angle of θ° from AB.

9.4 Speed :

The distance travelled by a moving body in unit time is known as its speed. Generally, objects are in a state of non-uniform motion, therefore, we express it in term of average speed. The average speed is determined by dividing the total distance travelled in a given time interval by the total time taken.

$$\text{Average Speed} = \frac{\text{Distance travelled by the object}}{\text{Time taken to cover the distance}}$$

$$v_{av} = \frac{d}{t}$$

here the object is covering a distance d in time t.

Speed is a scalar quantity. Its unit in SI system is meter/second [m/s]. The speed of vehicles used for travelling is generally expressed in terms of kilometer/hour (km/h).

Example 9.1 : A student covers a distance of 100 km in two hours by his vehicle. Determine the average speed of the student's vehicle.

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

$$= \frac{100 \text{ km}}{2 \text{ h.}}$$

$$= 50 \text{ km/h.}$$

9.5 Velocity :

Along with the speed of a body, it is also essential to know the direction in which it is moving. The distance covered by a body in unit time in a particular direction, is known as its velocity. Velocity is a vector quantity. To determine the velocity the displacement of the body is divided by the time taken for the displacement. If displacement is denoted by s time by t and velocity by v then

$$\text{Velocity} = \frac{\text{Distance (in a particular direction)}}{\text{Time}}$$

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

$$\vec{v} = \frac{\vec{s}}{t} \qquad \text{.......................... (9.1)}$$

Time t is always positive hence the direction of velocity is always the same as that of the displacement. If in a one dimensional motion the distance towards right hand side from the point of origin is taken as positive and that towards left hand side is taken as negative then if the displacement is positive even velocity will be positive while in case of negative displacement the velocity will be negative. The SI unit of velocity is meter /second (m/s).

If a body covers a distance s in a particular direction in time t with a uniform velocity, then the velocity of the body will be

$$\vec{v} = \frac{\vec{s}}{t}$$

or $\vec{s} = \vec{v} \times t$

If only the magnitude is considered then

$$s = v \times t \qquad \text{...... (9.2)}$$

Example 9.2 : A bus is moving in east direction. It covers a distance of 200 km in four hours. Determine the velocity of the bus.

Solution : $= \frac{200 \text{ Km}}{4 \text{ h}}$

Here Distance = 200 km (in east direction)
Time = 4 h

$$\text{Therefore velocity} = \frac{200 \text{ Km}}{4 \text{ h}}$$

$$= 50 \text{ km/h (in east direction)}$$

Hence the velocity of the bus is 50km/h towards east.

9.6 Difference between Speed and Velocity :

Speed is the magnitude of motion. For example if two scooters are moving at a speed of 40km/h in opposite directions then their speed will be similar but their velocity will be different. Speed is a scalar quantity while velocity is a vector quantity.

9.7 Uniform motion :

If an object covers a uniform distance in a uniform time interval then the motion of that object is said to be a uniform motion. For example, suppose we are travelling in a car and we have a wrist watch which can show time to the accuracy of second. Taking one of the mile-stone on the road as the point of origin, note the time at every consecutive mile-stone.

Suppose our observation comes out to be as under :

Number of milestone (distance in km.)	Time (in second)
Origin mile stone	Zero second
1 km mile stone	100 second
2 km mile stone	200 second
3 km mile stone	300 second
4 km mile stone	400 second
5 km mile stone	500 second

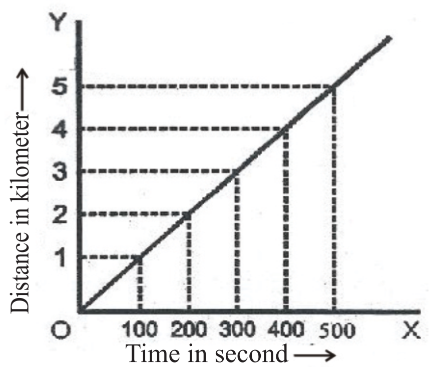

Fig. 9.5 The distance -time graph for a uniform motion

If we draw a graph between the distance travelled by the car and the time taken to cover that distance, for the observations recorded above, then the graph comes out to be a straight line as shown in fig. 9.5. This straight line denotes a uniform motion. The slope of the distance time graph denotes the speed of the body.

The distance - time graph of a journey provides us with some important information about the journey. The slope of the curve informs us about the low or high speed. Fig. 9.6 shows the journey-curve of another car. It is clear from the curve that the car moves with a uniform speed from the origin upto the time t_1 and covers a distance x. The car remains static at that point for the time interval t_1 to t_2 i.e. the car has stopped at point x for the given time interval (t_1 to t_2). Here the slope of the line AB is zero therefore the speed is zero. Then the car moves back from x to the point of origin during the time interval t_2 to t_3. The motion again is a uniform motion; but the slope of BC is more than that of OA- which means that the speed of the car during the return journey was more as compared to the speed while going to x.

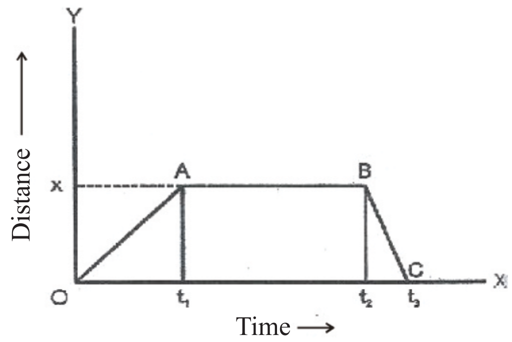

Fig. 9.6 Distance -time graph of the non-uniform velocity

9.8 Non-uniform Motion and Acceleration :

We know that the velocity of a moving car, scooter, cycle etc. does not remain uniform at the time of journey. Usually, the vehicles move with a non-uniform velocity. We all have experienced a journey by train. We know that the velocity of the train between two stations is not uniform. At a railway station, while starting, its velocity increases from zero and then at the next station its velocity again decreases down to zero.

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The change in velocity per second is known as acceleration. It is denoted by a. Thus the rate of change of velocity of an object is known as acceleration.

If the initial velocity of an object is u and after time t the velocity is v then the acceleration will be :

$$\text{acceleration} = \frac{\text{Change in velocity}}{\text{time taken for the change}}$$

$$\vec{a} = \frac{\vec{v} - \vec{u}}{t} \qquad \text{........... (9.3)}$$

In case of a motion with uniform acceleration the value of its acceleration and average acceleration will be the same at any given point of time.

The acceleration is positive when there is an increase in velocity and it is negative when the velocity decreases. In case of a simple linear motion the direction of the acceleration will either be in the direction of the velocity or in its opposite direction. Negative acceleration is also known as deceleration. It is clear from equation 9.3 that when a body moves with a uniform velocity, its acceleration will be zero. i.e. when $v = u$; $a = 0$

Unit : The unit of acceleration is obtained by dividing the unit of velocity with that of time.

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

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

$$= m/s^2$$

Thus the SI unit of acceleration is meter/second^2 (m/s^2).

9.9 Graphical Representation of Motion :

A line graph is used to study velocity. Line graph is used to demonstrate the inter-dependence of two physical quantities. For example for a body in motion a line graph may be used to show the dependence of a physical quantity, like the velocity, acceleration, distance etc. on time.

Velocity time graph :

(i) For a body moving with uniform velocity : The velocity-time graph of an object (cycle, scooter, train, bus etc.) moving with a uniform velocity v is shown in fig. 9.7. Since the velocity remains constant with time hence in the graph the curve appears parallel to the x axis in the form of a simple line.

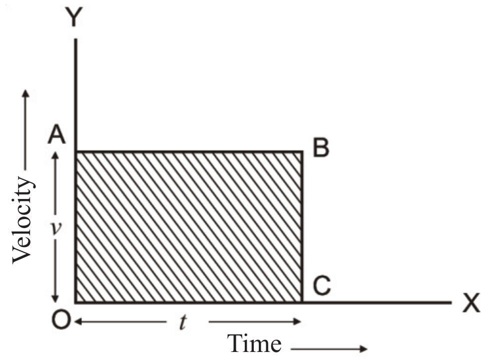


Fig. 9.7 Velocity-time graph

An object moving with constant velocity v covers distance s in time t, then the distance travelled by it can be calculated using formula 9.2

$s = v \times t$

In fig. 9.7 OC on the axis OX denotes time t and OA on axis OY is the velocity V. Therefore the area of the rectangle OABC

$= v \times t$

i.e. on a velocity time graph the value of the distance covered in time t is equal to the value of the area ABCO. In other words, the area between the curve of a velocity-time graph and the X axis denotes the distance travelled in time t.

(ii) For a body moving with uniform acceleration : Fig. 9.8 shows the velocity-time graph of a body moving with uniform acceleration. The equation for the velocity of a body moving with uniform acceleration can be obtained from this velocity-time graph.

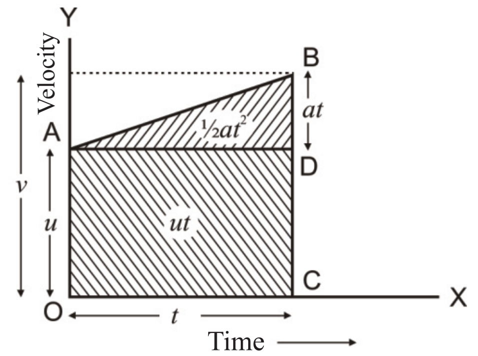


Fig. 9.8 Velocity-time graph of a body moving with uniform acceleration.

In this graph the initial velocity of the body is u which increases to v with time t. If the body would have been moving with a uniform velocity u then the distance travelled by it in time t would be equal to the area of the field AOCD of the graph. Here the velocity is changing because of the accelerated motion of the object. The distance s covered by it in the time interval t will be equal to the area of AOCDB in the graph. The shape AOCDB is a trapezium

Therefore Distance **s** = Area of AOCDB

= Area of the rectangle AOCD + area of the triangle ADB.

$$= AO \times OC + \frac{1}{2} AD \times BD$$

Here OC and AD are parallel which are equal to u and BD = BC – CD = (v–u)

Therefore distance s = ut + ½ t (v–u)...(9.4)

If the uniform acceleration of the body is 'a'

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

$\therefore\ v - u = a \times t$

or $v = u + at$ 9.5

On placing the value of (v–u) from equation 9.5 in equation 9.4

$$s = ut + \frac{1}{2}t(at)$$

$$= ut + \frac{1}{2}at^2 \quad .... 9.6$$

Equation 9.6 shows the relation for determining the distance s covered in time t by a body moving with uniform acceleration.

From equation 9.5 $t = \frac{v-u}{a}$. On placing it in equation 9.6 we get

$$s = u\left[\frac{v-u}{a}\right] + \frac{1}{2}a\left[\frac{v-u}{a}\right]^2$$

On simplifying it

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

or $2as = v^2 - u^2$

or $v^2 = u^2 - 2as$ 9.7

Equations 9.5, 9.6 and 9.7 are known as the equations for a uniform acceleration motion.

(iii) The velocity time graphs for non-uniform acceleration motion are shown in fig. 9.8 (a) and (b)

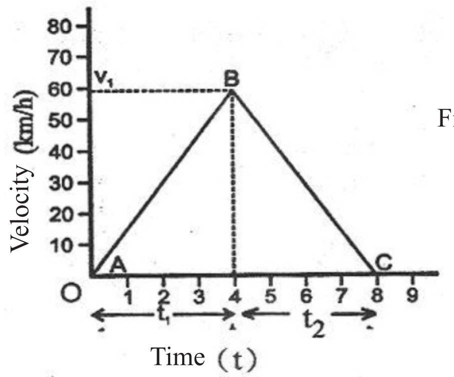


Fig. (a)

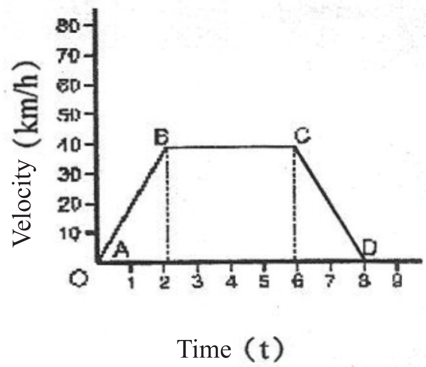


Fig. (b)

Fig. 9.9 Non-uniform acceleration motion (a) and (b)

In fig. 9.9 (a) the velocity increases from zero to v_1 in time t_1. From A to B the object is moving with a positive acceleration while during time t_2 the body shows negative acceleration from B to C.

In fig. 9.9 (b). The object is moving with positive acceleration for the first 2 seconds. The velocity then remains uniform from 2 to 6 seconds i.e. acceleration is zero. The acceleration then becomes negative between 6 to 8 second time interval and after 8 second the velocity becomes zero.

Example 9.4 : Starting from rest, a train attains a speed of 72 km/h in 10 minutes. If the acceleration of the train is uniform then determine (a) Acceleration of the train (b) The distance covered by the train while attaining this velocity.

Solution :

Given $u = 0$, $v = 72$ km/h $t = 10$min

$$v = 72 \frac{km}{h}$$

$$= \frac{72 \times 1000}{60 \times 60} \frac{m}{s}$$

$= 20$ m/s.

Similarly $t = 10$ mins

$= 10 \times 60 = 600$ s

(i) If the acceleration of the train is **a** then

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

$$= \frac{20 - 0}{600}$$

$$= \frac{1}{30} \text{ m/s}^2$$

(ii) We will use the formula $v^2 = u^2 + 2as$ to determine the distance

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

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

$$= \frac{(20)^2 - 0}{2 \times \frac{1}{30}}$$

$$= \frac{(20)^2 \times 30}{2}$$

$$= \frac{20 \times 20 \times 30}{2}$$

$= 6000$ m

$= 6.0$ km

Example 9.5 The initial velocity of an object is 4m/s. This object is moving with an acceleration of 2m/s^2. Find the velocity of the object after 5 seconds and the distance covered by it.

Solution :

Given $u = 4$ m/s $t = 5$ sec $a = 2$m/s^2

Velocity $v = u + at$

$v = 4 + 2 \times 5$

$= 14$ m/s

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

$= 4 \times 5 + \frac{1}{2} \times 2(5)^2$

$= 20 + 25$

$= 45$ m

9.10 Force :

In the previous section we have studied about the motion of an object. In day to day life we observe that some efforts are to be made to bring objects from a state of rest into a state of motion or to bring a moving body to a static condition. For example we have to push a static table to move it or brakes are applied to stop a moving vehicle. Thus the physical quantity to bring about a change in the static condition or in the moving condition or the effort to bring about a change is the force. It is not essential that the state of motion changes when force is applied to the object, for example the wall remains static even on application of force with the hands.

Force is the physical quantity which brings about a change in the state of motion or in the state of rest or even tries to bring about the change. It is a vector quantity.

We should know the following three things in order to get complete information regarding the force being applied on a body.

(i) The point of action of the force being applied i.e. the point at which the force is working.

(ii) Magnitude of the force.

(iii) Direction of the work done by the force.

Therefore force is a vector quantity which has a direction along with the magnitude.

9.11 Newton's Laws of Motion :

Sir Isaac Newton was the first one to establish the laws governing the motion of objects. We get the actual definition of force from these laws. The quantitative relation between the applied force and the state of motion of the object is also obtained from them. Scientist Galileo had performed some experiments in seventeenth century which later on laid the foundation of the Newton's laws.

On the basis of his experiments Galileo stated that if an object is moving in a simple linear manner then it will continue to move on that simple line with the same velocity unless some type of external force is not acting on it. This last clause is most important and essential. For example - When we roll a ball on the floor it stops after covering some distance. The velocity of a mass decreases as it moves up and ultimately becomes zero and it falls back on the ground. In these examples some external forces are acting on the moving objects because of which their movement changes.

In the first example the frictional force working between the ball and the floor hinders the motion of the ball because of which it slows down and ultimately becomes static. In the second example the gravitational force of the earth hinders motion. If these hindering forces are removed some how then the object, once in a state of motion will always continue to move with the same velocity.

9.12 Newton's First Law of Motion :

According to this law, an object in a state of rest tends to remain in the state of rest and a body moving in a direction with a particular velocity will continue to move with that velocity in that direction until and unless an external force is applied to it. The object opposes any change in its state of rest or of motion. This property of the object is known as **inertia**. The object remains in the state of the motion in which it is, unless some external force does not work on it. Therefore force is to be applied if the static condition of an object is to be changed. It is because of this, that Newton's first law is also known as the **Law of Inertia**. This law of motion can be divided into two parts.

1. Law of Inertia of Rest : According to this law a body in a state of rest will remain in the state of rest until some external force works on it.

Examples of the Inertia of Resting state :

Many examples of this law exist in our day to day life. We will describe some of them over here. For the purpose we will perform some activities.

Activity 9.1 : Take an empty glass. Cover it with a thick, smooth card board piece and place a five rupee coin on it. Now strike forcefully at the card board as shown in fig. 9.10 with your fingers. You will observe that cardboard moves away while the coin falls in the glass.

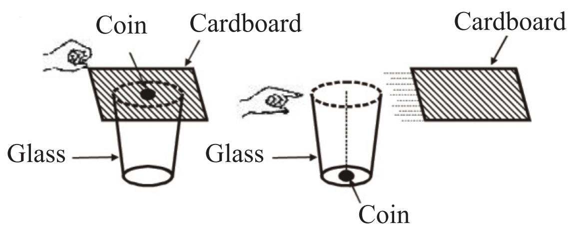


Fig. 9.10

Why the coin did not move away with the card board? It is because the inertia of the coin keeps it in the state of rest whereas the cardboard moves because of the sudden application of force on it.

Activity 9.2 : Stack 8-10 similar coins (i.e. all of rupees one or two or five etc.). Take another coin and strike it with your fingers in such a manner that it collides with the lower most coin of the stack. It will be seen that only the lowermost coin will be displaced from the stack and the others remain stacked together. This again is because the inertia of the remaining coins prevent them from moving.

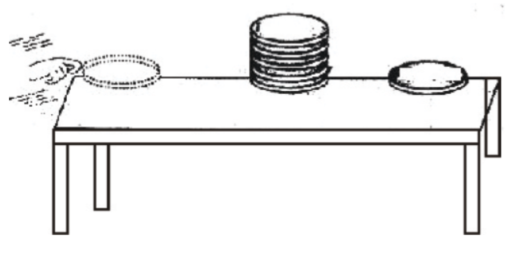


Fig. 9.11

Some other events of inertia of rest in daily life include :

(i) The passengers of a bus or a car experience a push towards back side if the vehicle is suddenly moved from a state of rest. This is because of the inertia of rest of the passenger.

(ii) The dust particles come out from dirty quilts, mats etc. if they are hung and then struck at with a stick because of this inertia.

(iii) If a horse starts running suddenly the rider falls back. The reason for this also is the inertia of rest.

(iv) Again it is because of the inertia of rest that fruits fall down when branches are shaken.

2. Law of Inertia of Motion :

According to this Law if an object is moving it will continue to move with uniform velocity in a straight line until some external force works on it.

Examples of Inertia of Motion :

(i) You must have seen the event of broad jump. In it the player, before leaping forward, comes running with a speed. At the time of jumping his inertia of motion is maintained and he is able to jump for a greater distance.

(ii) If brakes are applied to a speeding vehicle, the passengers bend forward. This is because of the inertia of motion. When the vehicle was moving the entire body was in a state of motion. However, when brakes are applied the lower half of the body which is in contact with the vehicle becomes static while the upper half remains in the state of motion because of inertia. As a result the passenger bends forward. Seat belt is tied by passengers in planes and vehicles when there are possibilities of sudden change in velocity.

(iii) When a person jumps off a moving bus or train he falls head on. This is because when in the vehicle, whole of his body was moving with the same velocity. When he jumps down his legs become static on coming in contact with the ground while the upper part of the body is in a state of motion with the speed of the vehicle. Therefore he falls head on. To avoid falling off, one should run for some distance in the direction of the motion of the vehicle after jumping off. Then after gradually the entire body balances itself and stops. However, it is better to board off the vehicle once it has stopped.

Inertia and Mass

The inertia of all objects is not equal. It is our daily experience that if we apply force to throw a rubber ball and an iron ball of the same radii it is always easier to throw the rubber ball. Similarly, it is easy to carry an empty bag as compared to one filled with books. It means all the objects do not resist the change in its state of motion equally. The resistance to the change in the state of motion of an object depends on its mass.

Greater the mass of an object, higher will be its inertia. Hence, the mass of an object is the measure of its inertia.

9.13 Newton's Second Law of Motion :

A cricket ball moving with a normal velocity is easily caught hold of by the fielder whereas it may be fatal for the person trying to stop a bullet fired from a gun, although it's mass is very less as compared to that of the ball. Therefore, the quantity obtained by multiplying the mass of the object with its velocity is highly meaningful i.e. is of great significance. Newton presented the concept of momentum by the statement of his Second Law of Motion.

The momentum of a moving body is defined by mass and velocity. If the mass of the moving body is depicted by m and its velocity by $\vec{v}$ then the momentum p of the body will be :

$$\vec{p} = m\vec{v} \qquad .... (9.8)$$

If we consider only the magnitude then

$$p = mv$$

Momentum also is a vector quantity. The SI unit of momentum is kg m/sec (kilogram meter per second).

The Newton's Second Law of Motion for a moving object is expressed as :

The rate of change of the momentum of an object is directly proportional to the force applied on it and its direction is the same as that of the force applied.

Suppose the velocity of a body of mass m is $\vec{u}$. The velocity changes from $\vec{u}$ to $\vec{v}$ after time t when a force $\vec{F}$ is applied on the body in the direction of its velocity, then :

Initial momentum $\vec{p}_1 = m\vec{u}$ ......(9.9)

Momentum after time t $\vec{p}_2 = m\vec{v}$ ...... (9.10)

Change in momentum in time t

$\Delta\vec{p} = \vec{p}_2 - \vec{p}_1 = m(\vec{v} - \vec{u})$

Therefore the rate of change of momentum

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

From Newton's second law

$$F \alpha \frac{m(\vec{v} - \vec{u})}{t}$$

or $\vec{F} = K \frac{m(\vec{v} - \vec{u})}{t}$ where K is a constant

Here $\frac{(\vec{v} - \vec{u})}{t}$ is the rate of change of velocity i.e. acceleration a.

Therefore $\vec{F} = Km \times \vec{a}$ .... (9.11)

We take the unit of force in a way so that the value of constant K remains one.

Placing the value of K as 1 in equation.

9.11 we get

$\vec{F} = m\vec{a}$ .... (9.12)

Now we can derive the unit of force from equation 9.12. By substituting the international unit for mass and acceleration in the equation we get

$$\text{Unit of force } F = \frac{\text{Kilogram} \times \text{meter}}{\text{second}^2}$$

$$= \frac{\text{Kilogram} \times \text{meter}}{\text{second}^2} = \text{Kg m/s}^2$$

This unit of force is named as Newton symbolized by N.

$$\left[N = \frac{\text{Kg m}}{s^2} \right]$$

We obtain a method of measuring force from the Newton's second law. If we know the mass of an object and the acceleration generated in that body on application of the force, then we can measure that force. Other units of force are dyne and poundal

1 Newton = 10^5 dyne and

1 Poundal = 13825.7 dyne

Example 9.6 : How much force is required to generate an acceleration of 10m/s^2 in an object having mass of 5kg? If the force is doubled what

surface of the ground backwards and the earth, in turn, apply the same amount of force on our feet as a reaction, in the opposite direction, as a result we move forward. Now you must have understood why it is difficult to move on sand or smooth floor.

(ii) While swimming in water, the swimmer pushes the water backwards with his hands and feet (i.e. applies force). The reaction of this force pushes him forward.

(iii) The water is moved backwards with the help of oars while rowing a boat. The water applies a force on the boat, as a reaction, because of which the boat moves forward.

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

$= \frac{100N}{5 \text{ kg}}$

Fig. 9.12 Movement of Boat on water

(iv) The propeller blades of the aircraft throws the air backwards so the force applied by the displaced air moves the aircraft forward.

(v) When bullet is fired from a gun the force is applied on the bullet in the forward direction. An equal force is applied on the gun in the opposite direction. But the mass of gun is much greater than that of the bullet therefore the gun moves in the backward direction with very less velocity and the shoulder of the gun-man experiences a slight backward push.

Fig. 9.13 The action and reaction forces, while firing a gun

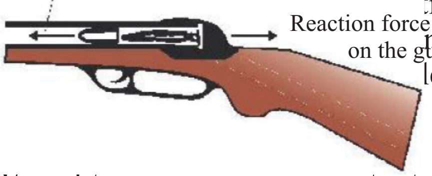
(vi) When rockets are propelled gases escape from the tail end at a very high speed and as a reaction the rocket is propelled in the direction opposite to that of the escape of gases and it rises high up in the space.

We may get confused that if each force of action has an opposing force of reaction then how the objects move? From the above examples it is very clear that the forces of action and reaction although are equal and are applied in opposite directions, they cannot nullify each other because they work on two different objects. Equal forces applied in opposite directions can nullify each other only when they work on a single object and that too in the same simple line. On the basis of the above mentioned examples and experiments we get the following information regarding the Newton's Third Law of Motion.

(1) Every action has a reaction.

(2) The forces of action and reaction are ... s.

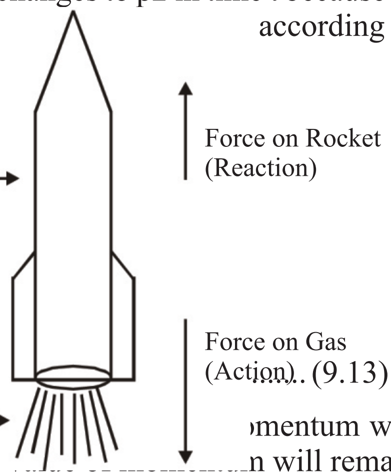
(... ion work ... nce their ... le.



9.15 Co

We obtain a very important law of conservation of momentum from Newton's Second Law of Motion. Suppose the initial momentum p_1 of a body of mass m changes to p_2 in time t because of the application of force F on it. Then according to the Second Law of Motion

We obtain a very important Law of Conservation of Momentum from Newton's Second Law of Motion. Suppose the initial momentum p1of a body of mass m changes to p2 in time t because of the applicat ... according to the Second ...



or

Nov ... (9.13)

Thi ... omentum will be zero or t ... n will remain constant. This is known as the Law or Theory of Conservation of Momentum. It can be expressed as under : "It the external force applied on a body or a system is zero then the entire momentum of that system remains conserved i.e. the value of momentum remains constant with time."

We will understand it by the following examples :

(1) To understand the Law of Conservation of Momentum we will consider a simple situation in which there are only two particles (Fig. 9.15), A and B which are glass balls whose mass is m_1 and m_2 respectively and initial velocity is u_1 and u_2. Suppose

Fig. 9.15 Collision of two balls

The momentum of ball A before and after the collision is m_1u_1 and m_1v_1 respectively. Therefore, the rate of change of momentum of ball A will be

Similarly, for ball B the rate of change in momentum will

If the force applied by A on B is F_{12} and that applied by B on A if F_{21} then according to Newton's Second Law of Motion :

$$\rightarrow \frac{(\vec{p}_2 - \vec{p}_1)}{t}$$

$$\rightarrow \frac{\vec{p}_2 - \vec{p}_1}{t}$$

$\rightarrow \ \rightarrow$

Now according to the Third Law of Motion the force exerted by A on B will be equal but opposite in direction to the force applied on A by B

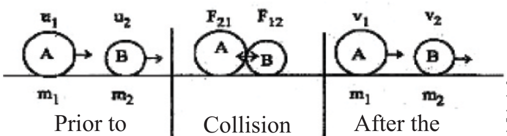
Therefore $F_{12} = -F_{21}$

or $m_1(v_1 - u_1) = -m_2(v_2 - u_2)$

$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$ 9.14

This refers to that the total momentum before the collision is equal to the total momentum after the collision.

Thus we observe that the total momentum of the system before the collision is equal to the total momentum after the collision i.e. momentum is conserved when no external force is acting on the system. This result is in ... on of ... bomb ... Since



Prior to Collision | Collision | After the Collision

its velocity is zero its initial momentum will be zero. Now if it explodes in two parts whose mass are in the ratio of 2:1, then after explosion their velocity will be in a linear manner but in opposite direction in such a manner that the entire momentum after explosion comes out to be zero.

Suppose the mass of the larger piece is 2m and velocity is v_1 and the mass of the smaller piece is m and its velocity is v_2, then after explosion

$$\frac{m_1(v_1 - u_1)}{t}$$

$$2mv_1 + mv_2 = 0$$

$$\frac{m_2(v_2 - u_2)}{t}$$

$$F_{12} = \frac{m_1(v_1 - u_1)}{t}$$

Fig. 9.16 Momentum in an explosive bomb

$$F_{21} = \frac{m_2(v_2 - u_2)}{t}$$

This means that the piece of mass m will move in opposite direction to the one having mass 2m with a velocity $2v_1$.

9.16 Friction :

We are well versed with friction. This force opposes the mutual motion between two objects. The frictional force is always applied opposite to the direction of motion.

$$\frac{m_1(v_1 - u_1)}{t} \quad \frac{m_2(v_2 - u_2)}{t}$$

It is a common observation that a ball covers greater distance on a surface as smooth as glass, as compared to that on a rough road. It is easy to cycle on an asphalt concrete road as compared to cycle on a rough road. The friction can be reduced by smoothing the surface but it cannot be eliminated completely. Friction even works on objects moving in air. Now we will consider the dependence of the frictional force that occurs between two surfaces.

Limiting Friction : Try to push a brick placed on a table with your finger. Initially when the value of the force being applied is less the brick will not move. At this time the force applied on the brick and its frictional force are in balance with each other and are acting in opposite directions. As we increase the force being applied even the frictional force increases and at the point when the value of the force applied increases more than a limit, the brick moves. The magnitude of the force which is just enough to move the brick (i.e. neither more nor less than that required) is known as the limiting friction.

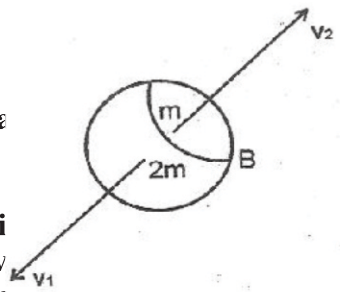


Fig. 9.17(a ... a finger to

Slidi ... hat develops betw ... object slides on top of a surface is known as the sliding friction. The sliding friction acts to the point till there is relative movement of the two objects. Force of friction operates even when the external force being applied is removed, as a result the velocity of the body decreases and ultimately it comes to a halt.

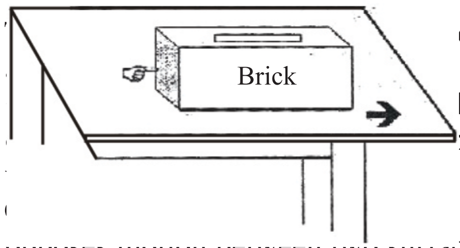
Rolling Friction : As shown in fig. 9.17, if a brick is placed on 3-4 cylindrical rollers like pencil or cylindrical pieces of iron and is pushed, it moves easily. The friction experienced by bodies moving on wheels or on rollers is known as the rolling friction.

Fig. 9.17(b) Rolling motion for moving a brick

The value of rolling friction between two similar surfaces is less than that of the sliding friction. Therefore tyres and rollers are used in various machines.

Friction on objects moving in air and fluid :

Force of friction acts on bodies moving in air or liquid too, however, this force is less as compared to that on solid surface. When meteors enter the earth's atmosphere they experience the air's force of friction because of their very high velocities, emit intense heat and start glowing. Most of them vaporises before reaching the earth's surface.



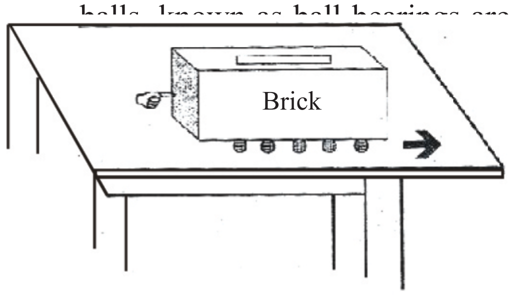
... or-cars, ... special ... he force ... by them ... always opposes motion between two surfaces. The parts of a machine which are in a state of motion keep rubbing and become warm. This is because of friction and the wear off of parts. We have to apply the necessary force in order to keep the object moving with the uniform velocity, to refute the force of friction.

We can control friction but only upto a limit, by using the following methods :

(i) Friction is less on smooth surfaces, therefore the friction can be reduced by making the surface of the moving parts of the machine, smooth.

(ii) The vehicles, air-crafts and engines of the trains are made of a special shape in order to reduce friction.

(iii) Rolling friction is always very less as compared to the sliding friction. It is because of this reason that small steel balls known as ball bearings are used ... chine ... otion, ... s are ... e too. ... which ... e of



substances known as lubricants, are used to reduce friction lubricants may be solid, liquid or gaseous. In light machines like cycle, watches etc. thin oil is used as a lubricant where as in heavy machines thick oil or grease is used. When lubricant is applied between the two moving surfaces, its particles occupy the spaces between the irregular regions of the surface and forms a thin layer between them. Now the movement is in this layer thus reducing friction. Compressed air is also used as a lubricant. Air under high pressure is passed in between the moving components of some machines. This not only reduces the friction but also prevent dust particles from settling on the surface. Similarly, the powder used on a carom-board acts as a lubricant while playing.

Need of friction : Although the force of friction reduces the efficiency of machines by dissipating their energy but under many situations there is a need to increase friction. The match box and match sticks are made rough to increase friction so that the match sticks ignite easily. While walking when we lift the foot to place it forward, the other leg counters the reaction force generated because of the presence of friction. Similar is the case with the tyres of the vehicles. The tyre applies a backward force in order to move ahead. The reaction force generated due to friction prevents the tyre from skidding and the tyre rolls in the forward direction. If the force of friction is less, as is the case in sand and mud, the tyre will keep revolving at that point only when force is applied. The rough surface of vehicle tyres increases the force of friction while moving on the road. This increases their grip and prevents skidding. The vehicles are halted by using brakes, because of the force of friction.

Now you must have understood the reason of our slipping when we place our foot on the banana peel and why it is difficult to walk on a smooth floor. Again the reason is lack of friction in the two cases.

Advantages and Disadvantages of Friction :

Advantages of Friction :

1. Friction helps us to walk. On friction-less floor we will slip and fall.
2. Force of friction is helpful in the movement of tyres on the road. Without friction it will be difficult to move ahead or turn the vehicles around.
3. The vehicles come to a halt on applying brakes because of friction.
4. The transfer of rotation power from the motor to the machine through the belt or chain is possible because of the existence of the force of friction.
5. The wall and wood holds nail or screw because of friction.
6. Without friction we cannot hold a pen or pencil in our hand to write.
7. It will not be possible to tie a knot or weave a cloth without the availability of friction.

Disadvantages of Friction :

1. Energy is dissipated because of friction. This reduces the efficiency of machines.
2. In vehicles nearly 20% more fuel consumption is there because of friction.
3. The components of machine wear and tear because of friction.
4. It is due to friction that heat is generated in machines which hinders their smooth working and cause damage.

9.17 Thrust and Pressure :

Thrust : The vertical force applied to the surface of an object is known as thrust. Its SI unit is Newton.

Pressure : Force applied per unit area on an object is known as pressure. It is a scalar quantity.

Its SI unit is Newton per meter square (N/m^2) which is known as Pascal (Pa)

1 Pascal = 1 Newton per meter square

1 Pa = 1 N/m^2

Pressure depends on the following two factors :

1. The force applied
2. Area of the surface

If the area of two surfaces is equal, then, more the force applied greater will be the pressure. If same force is applied than the object with greater surface area will experience less pressure.

9.18 Buoyancy :

The ship made up of iron and steel do not sink in sea water while a sheet of same weight of iron or steel will sink. Similarly, the iron nail sinks in water while the cork floats. To understand such phenomenon we will have to understand buoyancy.

"Buoyancy is the property of a fluid to exert an upward force, also known as upthrust, on a body that is submerged in it."

In a fluid the following two forces act upon an object :

First : The force of gravitation of earth on the object (weight of the object), in downward direction

Second : Force of buoyancy of water on the object, in upward direction.

The sinking or floating of the object in water depends on the relative values of the two forces.

1. If the weight of the object is more than the force of buoyancy, then the object will sink.
2. If the weight of the object is less than the force of buoyancy, then it will float in a partially submerged manner.
3. If the weight of the object is equal to the force of buoyancy then the body will be completely submerged but will float.

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$

Fig. 9.18 On placing on water surface, the iron nail sinks while the cork floats

The knowledge of an object sinking or floating in water can be acquired by its density. If the density of the object is less than the density of the water, then the body will float in water. On the other hand, if the density of the object is more than the density of water, it will sink.

9.19 Archimedes' Principle :

A stone is tied to a spring balance and is weighed. Note its weight. Now note the weight when this stone is dipped in water filled in a vessel. A change in weight will be observed.

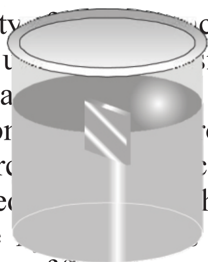
You will observe that there is decrease in the reading on submerging it in water. This decrease will be equal to the weight of the water displaced by the stone.

Fig 9.19 (1) Weight of the stone suspended in air (2) Weight of the stone on submerging it in water.

"When an object is partially or completely immersed in a fluid, it experiences a force in the upward direction which is equal to the weight of the fluid displaced by it. This force is known as the buoyancy force." This is known as the Archimedes' Principle.

Uses :

1. It is useful in determining the relative density ... ce.
2. It is u ... signing ships and subma...
3. Lactor ... ometer are based on Arc ... iple. (Lactometer is use ... he purity of milk while ... used to find the density of fluids).
4. This explains the floating of ice on water.



9.20 Density :

Mass of a unit volume of a substance is known as its density

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

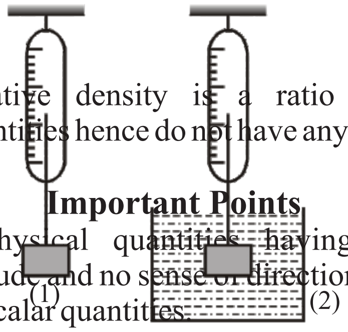
$$d = \frac{m}{V}$$

SI unit of density is Kg/m^3 or Kgm^{-3}.

9.21 Relative Density :

Generally the density of a substance is expressed in relation to the density of water. The ratio of the density of substance and that of water is known as the relative density of that substance.

$$\text{Relative Density} = \frac{\text{Density of a substance}}{\text{Density of water}}$$



Relative density is a ratio of similar quantities hence do not have any unit.

Important Points

1. The physical quantities having only the magnitude and no sense of direction are known as the scalar quantities.
2. The physical quantities which require a direction along with magnitude, for their expression, are known as vector quantities.
3. The vector obtained on dividing a vector A with its magnitude is known as the unit vector.

$$\hat{A} = \frac{\vec{A}}{|\vec{A}|}$$

4. Continuous change in the position of an object from the reference point is known as motion.
5. The motion of the body is known as the uniform motion if the body covers same distance in the same specific time interval.
6. If the body covers different distances in a specific time interval then the motion of the body is said to be non-uniform.
7. Distance travelled by an object in unit time is known as its speed. It is a scalar quantity. The distance travelled by an object, in a particular direction in unit time is known as velocity. It is a vector quantity. The unit for both, i.e. speed and velocity is m/s.
8. Acceleration is the rate of change of velocity. Its unit is m/s^2.
9. Uniformly accelerated motion of an object is expressed by the three equations :
   (i) $v = u + at$
   (ii) $v = ut + \ at^2$
   (iii) $v^2 = u^2 + 2as$
10. Force is the physical quantity which brings about a change in the state of motion or the state of rest of a body.
11. Imbalanced force generates motion in an object.
12. A body remains in its state of rest or in a state of motion along a simple line, until and unless a non-balanced force acts upon it. The tendency of a body to resist a change in the state of rest or of motion is known as its inertia. This is Newton's First Law of Motion.
13. Newton's Second Law of Motion :- The rate of change of momentum is directly proportional to the force applied on the object. The direction of the change in momentum is always in the direction of the force applied.
14. Newton's Third Law of Motion :- For every action there is an equal and opposite reaction and these act on two different objects.
15. Force of friction always resist the motion of the body. Friction depends on the smoothness and roughness of the two surfaces which are in motion in contact with each other. Force of friction can be controlled to some limit. →
16. The force applied on unit area of an object is known as Pressure. The unit of force is N/m^2 or Pascal (Pa).
17. When a solid is immersed in a fluid, an upward force equal to the weight of the fluid displaced by it, is applied on it. This is known as the Force of Buoyancy.
18. If the density of a solid is more than the density of the fluid, then it sinks. However, if the density of the solid is less than the density of the fluid then it will float.

Questions

Objective type questions :

1. Which of the following is a vector quantity :
(a) Work (b) Time
(c) Mass (d) Gravitational force

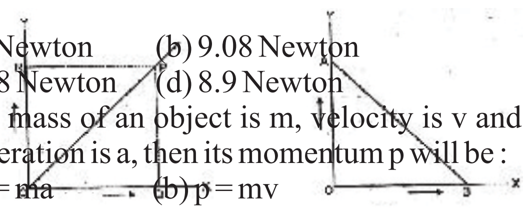
2. Two forces of 4N and 3N are working on the same body in opposite directions. Then the magnitude of the force on the particle will be :
(a) 5 N (b) 7N
(c) IN (d) Between IN and 7N

3. Rate of change of velocity is :
(a) Force (b) Momentum
(c) Acceleration (d) Displacement

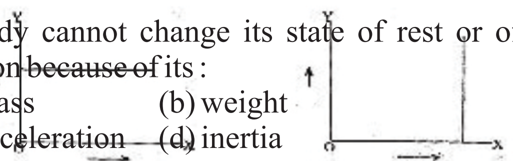
4. Unit of momentum is :
(a) Newton meter
(b) Newton Kilogram/meter
(c) Newton meter/second
(d) Kilogram meter/second

5. The velocity time graph of an object moving with uniform velocity is

(a) (b)



(c) (d)



6. The momentum of an object depends upon :
(a) Mass of the object
(b) Displacement of the object
(c) Time taken for displacement
(d) All of the above

7. The equation relating the Force (F) mass (m) and acceleration (a) is :
(a) F = ma (b) m = aF
(c) a = mF (d) ma =

8. Unit of force is :
(a) Kilogram – meter – second
(b) Kilogram – meter – $second^2$
(c) Kilogram – meter / $second^2$
(d) Kilogram – meter / second

9. If a body moves in a straight line with a uniform velocity and no external force is applied to it, then
(a) Its velocity will increase
(b) Velocity will remain constant
(c) The body will stop after sometime
(d) Speed will increase

10. The inertia of an object depends upon :
(a) Center of gravity of the object
(b) Mass of the object
(c) Gravitational acceleration
(d) Shape of the object

11. An object of 5 Kg weight is moving in a simple line with an acceleration of 10m/s. The magnitude of the force working on the object will be :
(a) 50 N (b) 0.5 N
(c) Zero (d) 2 N

12. When a force is applied on an object :
(a) Its motion may change
(b) The direction of its motion may change
(c) Its shape may change
(d) All of the above

13. The weight of a body having mass 1 Kg will be:
(a) 1 Newton (b) 9.08 Newton
(c) 9.8 Newton (d) 8.9 Newton

14. If the mass of an object is m, velocity is v and acceleration is a, then its momentum p will be :
(a) p = ma (b) p = mv
(c) p = m/v (d) p = v/m

15. A body cannot change its state of rest or of motion because of its :
(a) mass (b) weight
(c) acceleration (d) inertia

16. If the force applied on the surface of an object is doubled, then the pressure will :
(a) reduce to half (b) not change
(c) double itself (d) become four times

Very short answers type question :

1. What will be the acceleration of a body moving with a uniform velocity of 40m/s after 10s?
2. A moving body of mass m and having a velocity u collides with the wall and rebounds with the velocity u. What will be the change in its momentum?
3. What will be the distance covered in 30 mins by a train moving with a velocity of 20km/h.
4. The area between the velocity time graph of a

moving object and its time axis is equal to what?

5. The principle of rocket is based on which one of the Newton's laws.
6. What is the direction of the force of friction of a moving bicycle?
7. Why a cricket player pulls his hands gradually with the moving ball while holding a catch?
8. Why a player runs for some distance prior to jumping in a high jump /broad jump event.
9. Why a person standing in a moving bus falls in the forward direction if the bus halts suddenly?
10. What will be the magnitude of the force on a body moving with constant velocity?
11. What efforts should be made by a person standing in the middle of a frozen lake to reach the shore?
12. What is 1 Newton force?
13. What is Inertia?
14. On applying brakes the vehicle stops. What will be the momentum of the vehicle in the process?
15. What is the momentum of the gun and its bullet before it is fired?
16. What is Thrust?
17. What is the unit of Relative Density?

Short answer type questions :

1. Define :
   (i) Displacement (b) Velocity
   (iii) Acceleration
2. What is meant by Uniform Motion? Give an example?
3. If action is always equal to reaction, then explain how the horse cart pulled by a horse, moves forward?
4. The fruits fall down when branches are shaken forcefully. Give reason.
5. Explain the reason why some space is left empty in the tanker while filling water in it?
6. Explain why the boat moves in the opposite direction when the passenger jumps out of it?
7. Comment on the following statement - "On any object two forces work in a pair, only one force is not possible on it at a given time.
8. Differentiate between the dynamic friction and the rolling friction
9. What is the Law of Conservation of Momentum? Explain with the help of an example?
10. Suggest method to reduce friction.
11. The linear momentum of a car and a truck are equal. Whose velocity will be more?
12. Explain the advantages and disadvantages of friction.
13. What happens when we shake a wet cloth? Explain your observation.
14. Why a person pulling out water from a well falls backward if the rope breaks off suddenly.
15. Explain why a person getting off from a moving bus falls in the forward direction.
16. The ship made of iron floats on the surface while a sheet made up of iron sinks. Explain.
17. Differentiate between Density and Relative Density.
18. Write the Archimedes' Principle.

Essay type answer questions :

1. Explain scalar and vector quantities. What is the way of writing a vector quantity? Define unit vector.
2. Explain Uniform and Non-uniform Motion. Find the equation of motion with the help of velocity time graph.
3. Define the Equations of Balanced and Unbalanced forces. Explain with the help of suitable diagram that only unbalanced force can generate motion in an object.
4. Explain the Newton's Laws of motion taking examples from the day to day life. Establish the relation between force, mass and acceleration on the basis of the Second Law.
5. What is meant by Inertia? Explain taking two example.
6. Define Momentum. With the help of diagram show that the Momentum is conserved during the direct collision of two moving objects.

Numerical Questions :

1. A ship having a mass of 3×10^7 Kg is in a state of rest. It is pulled to a distance of 3m by applying a force of 5×10^4 N. If the friction of water is negligible then find the speed of the ship.
2. The speed of a bus increases from 25km/h to 70 km/h in 5s. Determine the mean acceleration of the bus.
3. The momentum of a child riding a bicycle is 400 kg m/s. The cycle is moving with a velocity of 5 m/s. Find the mass of the child along with

the bicycle.

4. A child throws a ball in the upward direction and then catches it after 8 sec. Then determine
   (a) the velocity with which the ball was thrown up
   (b) At what height will the velocity of the ball will become zero?

   ($g = 9.8\ m/s^2$)

Answer Key

1. (d)	2. (c)	3. (c)	4. (d)	5. (c)
6. (d)	7. (a)	8. (c)	9. (c)	10. (b)
11. (a)	12. (d)	13. (c)	14. (b)	15. (d)
16. (c)				

Numerical formula

1. 0.1 m/s 2. $2.5 m/s^2$ 3. 80 Kg.
5. (a) 39.2 m/s 6. 78.4 m