

Module 1 Laws of Motion Part - 1

This module is designed to help you to:

- describe the basic concepts of motion and uniform motion;
- explain the effects of external force on motion through Aristotle's views on motion;
- introduce the concept of inertia through Galileo's law;
- use Newton's first law of motion to study the relation between inertia, uniform motion and external force;
- relate mass and velocity to momentum;
- explain Newton's second law of motion - force as rate of change of momentum;
- introduce the concept of impulse.

Content

5.1.1 Introduction

5.1.2 Aristotle's fallacious concept of external force and internal forces

5.1.3 The law of inertia

5.1.4 Newton's first law of motion

5.1.4.1 Difference between Galileo's law of inertia and Newton's first law of motion

5.1.5 Need to define momentum as a separate physical quantity

5.1.6 Newton's second law of motion

5.1.7 Instantaneous force

5.1.8 Summary

5.1.1 Introduction

Motion is an integral part of our daily life as it is responsible for a vast variety of applications. Walking or using a transport involves motion, clouds flying in the sky involve motion, raindrops falling on the ground involve motion, water moving turbines to generate electricity in a hydroelectric power station involves motion, strong wind moving windmills involves motion, Earth moving about its axis causing the phenomenon of night and day involves motion, Earth moving around the Sun which gives the concept of time measurement and change of season involves motion. The motion of the moon causes high tide and low tide which facilitates the movement of ships in and out of harbour. Can you think of other examples of motion that significantly affect our lives?

Because of these and many other such critical and important applications, it is imperative for us to study the cause of motion, types of motion, and attributes of motion. By developing an understanding about motion, we can solve a wide variety of problems affecting our daily lives. The first concept of motion was put forward by Aristotle (384 BC to 322 BC). Though this idea was flawed, it gave the initial understanding about motion. Finally, the modern theory of motion was put forward by Galileo Galilei, J Kepler, and Isaac Newton.

5.1.2 Aristotle's fallacious concept of external and internal forces

The Greek thinker, Aristotle, held the view “**An external force is required to keep a body in motion**”.

It is a common experience that any moving particle needs a net external force to act upon it for it to accelerate; for example, a moving ball coming to rest under the influence of friction, or a stone coming to rest due to gravity pulling it down.

Such daily observations clearly demonstrate that a net external force acting on a body or a system of particles will not let it move with uniform linear motion but would rather disrupt any uniform motion.

5.1.3 The law of Inertia

Facilitate the students to study the motion of an object on an inclined plane as shown in Fig. 5.1.1(a) and Fig. 5.1.1(b) and summarize their observations.

- **Activity 5.1.1-** Study of the law of Inertia using a double inclined plane (Galileo experiment)

Apparatus: A double inclined track, a ball bearing of diameter 2.5 cm or more, an accurate spirit level, about 15 to 20 small glass plates each of about 3cm x 3cm x 2mm size, a wooden block, a screw gauge.

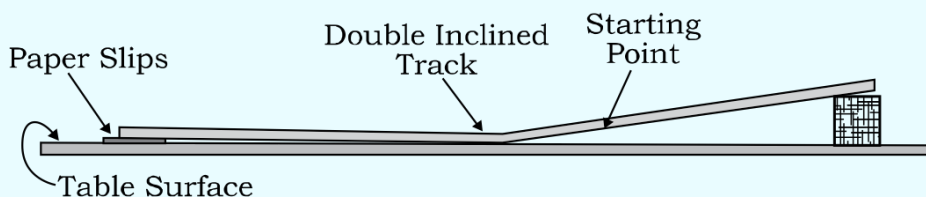


Fig. 5.1.1 (a) Slips of paper having no crease to make one arm of the double inclined track accurately horizontal

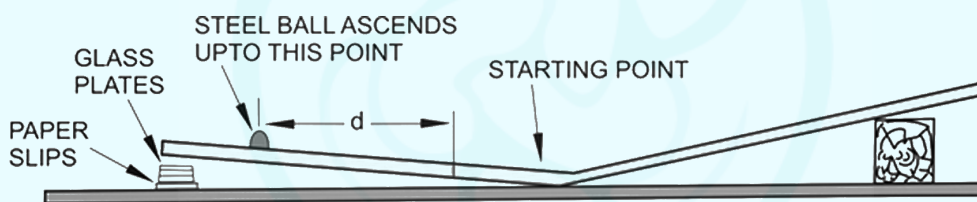


Fig. 5.1.1 (b) Small glass plates placed on slips of paper enable a measured small inclination to one arm of the double inclined track

- Procedure:**
1. Lay the double incline track on the table and clean it with cotton or tissue paper.
 2. Insert a wooden block under the right arm such that it is raised by 3 to 4 cm.
 3. Make the other arm horizontal using a spirit level.

4. Check the levelling of the horizontal arm by placing a ball at different places. This ball should remain at rest at every point.
5. Now place the ball at a distance of 5 cm or 10 cm on the raised arm and release it.
6. Note the distance d travelled by the ball on the left arm.
7. Raise the end of the left arm by putting a glass plate under it and measure the thickness of the glass plate and again release the same ball from the same point and measure the distance travelled by the ball on the left arm.
8. Repeat the process for various inclinations of the left arm. The inclination can be changed by changing the number of plates.
9. Now draw a graph showing the variation of $1/d$ with a slope of left arm or number of plates n .
10. Do you find that slope of left arm $\propto$ no. of plates.

Observations

No. of glass plates (slope)	1	2	3	4	5	Mean
Distance of ascent (d) cm						
$1/d$ (cm^{-1})						

Conclusion: The graph (Fig.5.1.2) is a straight line and if we extrapolate the graph it passes through the origin which means when the left arm is horizontal or $n = 0$ then $1/d = 0 \Rightarrow d = \infty$ i.e. ball when released from the raised arm will travel an infinite distance which contradicts Aristotle's view that an external force is needed to keep a body in motion. .

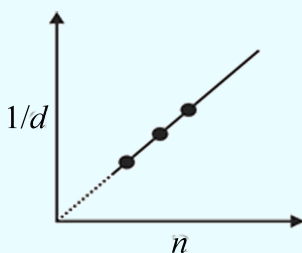


Fig. 5.1.2 $1/d$ vs n

Galileo, thus, arrived at a new insight on the motion of bodies that had been missed out by Aristotle – the state of rest and the state of uniform linear motion are equivalent. In both cases, there is no net force acting on the body. Therefore, it is incorrect to say that a net force is needed to keep a body in uniform motion – as proposed by Aristotle. In other words, if the net external force is zero, a body at rest continues to remain at rest and a body in uniform motion continues to remain in uniform motion. This property of the body is called inertia.

Galileo's law of inertia

Galileo, through the inclined plane experiment, demonstrated the tendency of an object to remain in a particular state only (either state of rest, uniform motion, or direction of motion). This is the law of inertia. This contradicted the Aristotelian view that it is an external force that maintains an object in a state of uniform motion.

Mass: It is the inherent property of any material object which is the amount of matter contained in the body. It is the measure of inertia of a body.

Activity 5.1.2: A cycle and a truck move with the same constant velocity. Which of the two will have greater amounts of inertia? Discuss.

5.1.4 Newton's first law of motion

Galileo extrapolated simple observations on the motion of bodies on inclined planes and arrived at the law of inertia. Newton's first law of motion is the same law rephrased: **the tendency of an object is to remain in a particular state only (either state of rest, uniform motion) unless compelled by some net external force to act otherwise.** In simple terms, the first law is: **if the net external force on a body is zero, there is no change in its state of motion.**

5.1.4.1 Difference between Galileo's law of inertia and Newton's first law of motion

Galileo's law of inertia discusses the property of any object to resist change in its existing state of motion whether at rest or in uniform linear motion.

Newton's first law of motion also explains the conditions in which the state of the body i.e. at rest or uniform linear motion is likely to change, namely through the introduction of a net external force.

Consider Fig. 5.1.3. A book of mass m is lying on a table that is at rest. Fig. 5.1.3 shows two forces W and R . Therefore, we conclude from the first law that $W = R$. This equality sometimes leads to misconception. Here R is the contact force (normal reaction) of the table on the book and equals the weight of the book.

Whenever a body is at rest or in uniform linear motion then the normal reaction, which is a self-adjusting force, adjusts itself in such a manner so as to cancel out the effect of its weight.

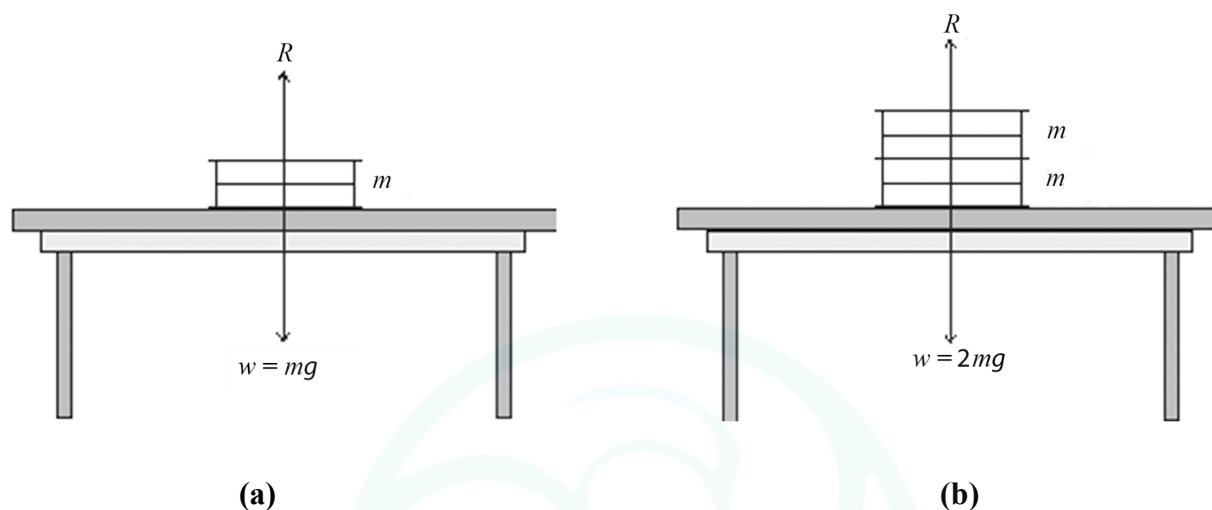


Fig. 5.1.3 Self-adjusting nature of reaction force

A statement often encountered is: since $W = R$, forces balance and, therefore, the book remains at rest. This is incorrect reasoning. The correct statement is: since the book is observed to be at rest, the net external force on it must be zero, according to the first law. This implies that the normal reaction force R must be equal and opposite to the gravitational force acting on the book in the form of weight. If the other statement was to be true i.e. $W = R$, hence there is no net external unbalanced force, thus the book is at rest, then also we arrive at the same result but the problem arises when we put another book of mass m on the table. This reasoning has already equated the normal reaction force with the weight of the first book and hence adding another book will lead to a situation that the net external force is now unbalanced which is contradictory to the self-adjusting nature of the

normal reaction force. However, if the starting point is kept as that of the single book or both the books together were at rest and hence the net external force is zero.

Thus, the normal reaction force will always balance the weight of the books till such time that the weight does not exceed the load-bearing capacity of the table.

Example 5.1.1 An astronaut accidentally gets separated from his small spaceship accelerating in interstellar space at a constant rate of 100 m s^{-2} . What is the acceleration of the astronaut the instant after he is outside the spaceship? Assume that there are no nearby stars to exert gravitational force on him.

Solution: So long as the astronaut is inside the spaceship, the astronaut has the same acceleration as the spaceship by virtue of being inside the spaceship. The moment the astronaut is detached from the spaceship, the external force acting on the spaceship causing it to accelerate is no longer acting on the astronaut. Hence the astronaut will detach from the spaceship with the same velocity which was the instantaneous velocity of the spaceship at the instant of detachment. From that instant, there is no external force acting on the astronaut, hence the astronaut will continue to move with uniform velocity.



Let Us Reflect

Q.5.1.1 Look at Fig.5.1.4. Which part of the string will break?

- (a) When a sudden jerk is given at D.
- (b) When tension is gradually increased at D.

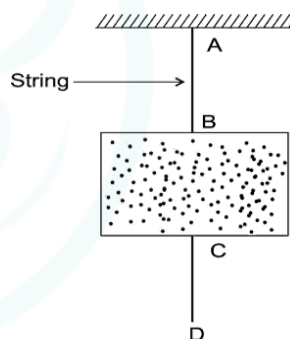


Fig.5.1.4

Q.5.1.2 Give the magnitude and direction of the net force acting in the following cases-

- (a) a drop of rain falling down with a constant speed;

- (b) a cork of mass 10 g floating on water;
- (c) a kite skillfully held stationary in the sky;
- (d) a car moving with a constant velocity of 30 km h^{-1} on a rough road;
- (e) a high-speed electron in space far from all material objects, and free of electric and magnetic fields.

Q.5.1.3 A pebble of mass 0.05 kg is thrown vertically upwards. Give the direction of the net force on the pebble.

- (a) During its upward motion.
- (b) During its downward motion.
- (c) At the highest point where it is momentarily at rest. Do your answers change if the pebble was thrown at an angle of 45° with the horizontal direction? Ignore air resistance.

Q.5.1.4 Give the magnitude and direction of the net force acting on a stone of mass 0.1 kg,

- (a) just after it is dropped from the window of a stationary train;
 - (b) just after it is dropped from the window of a train running at a constant velocity of 36 km h^{-1} ;
 - (c) just after it is dropped from the window of a train accelerating with 1 m s^{-2} ;
 - (d) lying on the floor of a train which is accelerating with 1 m s^{-2} , the stone being at rest relative to the train.
- Neglect the air resistance throughout.

Q.5.1.5 A ball is travelling with uniform translational velocity.

Given below are four statements, one or more of which can be the meaning of the above statement.

- I. It is at rest with reference to a particular inertial frame.
- II. The path can be a straight line or circular and the ball travels with uniform speed.
- III. Every point mass constituting the ball has the same velocity (in magnitude and direction) and the velocity is constant over time.
- IV. The centre of the ball moves with constant velocity and the ball spins about its centre uniformly.

Which among the above is/are true?

- (A) Only I
- (B) I and II
- (C) I and III

(D) Only IV



A.5.1.1 (a) If the force is large and sudden, thread CD breaks because as CD is jerked, the pull is not transmitted to AB instantaneously (transmission depends on the elastic properties of the body). Therefore, before the mass moves, the CD part of the thread breaks.

(b) AB, because the force on the upper thread will be equal to the sum of the weight of the body and the applied force, the two together being larger than what the thread can withstand.

A.5.1.2 (a) to (d) No net force acts according to Newton's first law.

(e) No force, since it is far away from all material agencies producing electromagnetic and gravitational forces.

A.5.1.3 The only force in each case is the force of gravity, (neglecting effects of air) equal to 0.5 N vertically downward. The answers do not change, even if the motion of the pebble is not along the vertical. The pebble is not at rest at the highest point. It has a constant horizontal component of velocity throughout its motion.

A.5.1.4 (a) 1 N vertically downwards

(b) same as in (a)

(c) same as in (a); force at an instant depends on the situation at that instant, not on history.

(d) 0.1 N in the direction of motion of the train.

A.5.1.5 (C) A ball moving with uniform velocity is equivalent to being at rest, because in another inertial frame moving with the velocity of the ball, the ball is at rest. All inertial frames are equivalent. So, it is true. Over and above this, each point of the ball moves with the same translational velocity, which is the velocity of the ball. So, III is also true.

5.1.5 Need to define momentum as a separate physical quantity

Consider the case of an accident involving a bicycle rider. Suppose rider A has another bicycle rider B coming from the opposite direction and colliding with him. This collision has some impact on A. Consider a similar collision of A with another rider C having the same mass as B but moving twice as fast. Imagine the impact this can have on A.

Once more consider a similar collision of A with a rider D having the same speed as B but having mass twice as that of B. Imagine the impact this can have on A. It is clear that the effect of a collision on A depends not only on the speed of the colliding object but also on its mass.

Thus we need to define a quantity that depends both on the mass and speed (or velocity) of the colliding object.

We, therefore, define momentum as a product of mass and velocity, i.e. $\vec{p} = m \vec{v}$.

5.1.6 Newton's second law of motion

Newton's first law refers to a case when the net external force on a body is zero. The second law refers to the general situation when there is a net external force on a body. It relates the net external force to the acceleration of the body. The second law states that: **The rate of change of momentum of a body is directly proportional to the applied force and takes place in the direction in which the force acts.**

$$\vec{F} \propto \frac{d\vec{p}}{dt} = \frac{d(m\vec{v})}{dt} = m \frac{d\vec{v}}{dt} + \vec{v} \frac{dm}{dt} = m \frac{d\vec{v}}{dt} ; \text{ if } m \text{ is constant } \frac{dm}{dt} = 0$$

It reduces to

$$\vec{F} = m\vec{a} \quad (5.1.1)$$

Thus, the second law of motion is a relation between force and acceleration.

- Momentum is a vector quantity. It is applicable to a single point particle; it also applies to a system of particles or a rigid body.
- The above equation is a local relation. This means that the force at a point in space at a particular instant is related to the acceleration of that point object at that instant.
- In scalar terms, Eq(5.1.1) can be written as

$$F_x = \frac{dp_x}{dt} = ma_x$$

$$F_y = \frac{dp_y}{dt} = ma_y$$

$$F_z = \frac{dp_z}{dt} = ma_z \quad (5.1.2)$$

This means that if a force is not parallel to the velocity of the body, but makes some angle with it, it changes only the component of velocity along the direction of the force. The component of velocity normal to the force remains unchanged. For example, in the motion of a projectile under the vertical gravitational force, the horizontal component of velocity remains unchanged (neglecting air resistance).

- Consider a system of particles with each particle having a different mass moving under the influence of a different net external force. The vector addition will lead to the resultant force.

5.1.7 Instantaneous force: It is the external force acting on an object at a particular instant in time. It is important to define instantaneous force where the external force is a function of time and is varying with time.

Instantaneous acceleration: The acceleration with which the object is moving at a particular instant of time when under the influence of a time-varying external force e.g. motion of a rocket, motion of a balloon from which air is escaping.

Consider these-

- Force is not always in the direction of motion. Depending on the situation, F may be along v , opposite to v , normal to v or may make some other angle with v . In every case, it is in the direction of the concerned force that matters.

Activity 5.1.3: Study (a) the motion of a cricket ball thrown by a fielder to the bowler following its trajectory (b) circular motion and direction of centripetal acceleration and centripetal force taking an example from everyday experiences.

- If $v = 0$ at any instant, i.e. if a body is momentarily at rest, it does not mean that force or acceleration are necessarily zero at that instant. For example, when a ball thrown upward reaches its maximum height, $v = 0$ but the force continues to be equal to its weight mg and its acceleration is not zero but has the value g .
- Force on a body at a given time is determined by the situation at the location of the body at that time. Force is not 'carried' by the body from its earlier history of motion. The moment after a stone is released out of an accelerated train, there is no horizontal force (or acceleration) on the stone, if the effects of the surrounding air are neglected. The stone then has only the vertical downwards force of gravity. However, it moves with horizontal velocity equal to the velocity of the train at the time of its release till it touches the ground. According to Newton's second law

$$\vec{F} \propto \text{rate of change of momentum, due to applied force } \frac{d\vec{p}}{dt} (= m\vec{a}),$$

if the mass remains constant. We may write $\vec{F} = k m \vec{a}$. Here the constant of proportionality k depends on the choice of the system of units. In SI system of unit, we define 1 N (newton) of force as the force which when acts on a mass of 1 kg, produces an acceleration of 1 m s^{-2} . Thus, in SI system, $k = 1$ and hence $\vec{F} = m\vec{a}$.

In the second law of motion $\vec{F} = m\vec{a}$, $\vec{F}$ stands for the net force due to all material agencies external to the body. Acceleration $\vec{a}$ is the effect of the applied force.

- Centripetal force should not be regarded as yet another kind of force. It is simply a name given to the force that provides inward radial acceleration to a body in a circular motion. Generally, some material forces like tension, gravitational force, electrical force, frictional force, provide the centripetal force to the body in circular motion.
- Impulse is the product of force and time which equals the change in momentum. The notion of impulse is useful when a large force acts for a short time to produce a measurable change in momentum. Since the time of action of the force is very short, one can assume that there is no appreciable change in the position of the body during the action of the impulsive force. When a batsman hits a cricket ball for a boundary, the contact time between the ball and the bat is often very small. The ball changes its momentum through the change of both the magnitude and direction of the velocity and moves on. One can observe that the bat moves only after it

has lost its contact with the ball, indicating the actual contact time is very small. Here the impact between the bat and the ball may be taken as an impulse on the ball that brings about a change in its momentum.

Does the bat also experience impulse? If so, what is its effect?

Example 5.1.2 Two identical billiard balls strike a rigid wall with the same speed but at different angles, and get reflected without any change in speed, as shown in Fig. 5.1.5(a) and 5.1.5(b). What is (i) the direction of the force on the wall due to each ball? (ii) the ratio of the magnitude of impulse imparted to the balls by the wall?

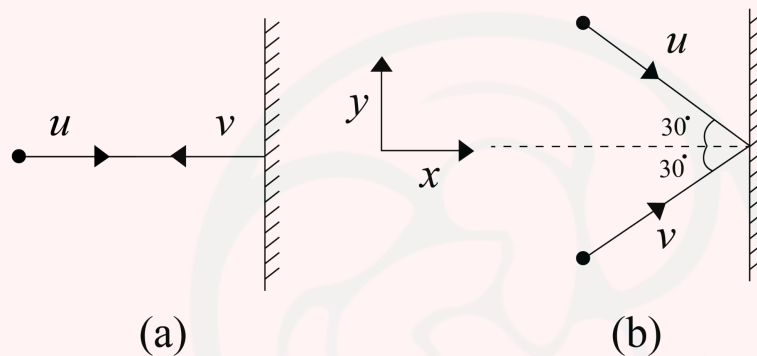


Fig.5.1.5

Solution: (i) (a) Force on the wall due to ball is normal to wall and along x -direction

(b) Normal to wall along x -direction

(ii) ratio is $\frac{2}{\sqrt{3}} = 1.15$



Let Us Reflect

Q.5.1.6 Why impulse is referred to as impulse force even though its units are those of momentum.

Continuous Professional Development

Q.5.1.7 A cricket ball of mass 150 g has an initial velocity $\mathbf{u} = (3\hat{i} + 4\hat{j}) \text{ m s}^{-1}$ and a final velocity $\mathbf{v} = -(3\hat{i} + 4\hat{j}) \text{ m s}^{-1}$ after being hit.

The change in momentum (final momentum-initial momentum) is (in kg m s^{-1})

- (A) Zero.
- (B) $-(0.45\hat{i} + 0.6\hat{j})$
- (C) $-(0.9\hat{i} + 1.2\hat{j})$
- (D) $-5(\hat{i} + \hat{j})$

Q. 5.1.8 In the previous problem, the magnitude of the momentum transferred during the hit is

- (A) Zero.
- (B) 0.75 kg m s^{-1}
- (C) 1.5 kg m s^{-1}
- (D) 14 kg m s^{-1}

Q. 5.1.9 A truck starts from rest and accelerates uniformly at 2.0 m s^{-2} . At $t = 10 \text{ s}$, a stone is dropped by a person standing on the top of the truck (6 m high from the ground). What are the (i) velocity, and (ii) acceleration of the stone at $t = 11 \text{ s}$? Neglect air resistance.

Q.5.1.10 A body of mass 2 kg placed at P is experiencing the following external forces (Fig.5.1.6).

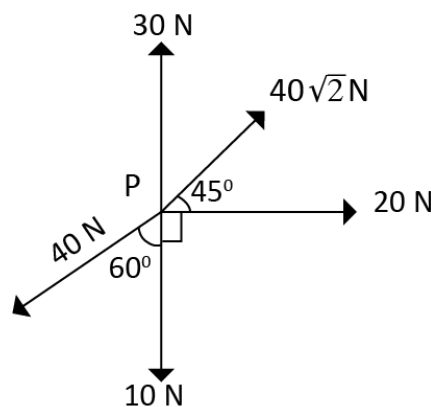


Fig. 5.1.6

- (i) Calculate the direction and magnitude of net external force and acceleration acting on the body. Take all the forces acting in the x - y plane.
- (ii) If the gravitational force acts in the negative y -direction then is it coplanar with these forces?



Answers

A.5.1.6 Impulse is defined as the product of the force acting on an object and the time duration for which it acts on the object. Mathematically,

$$\text{Impulse} = \vec{F} \cdot t = m \cdot \frac{\Delta \vec{v}}{t} \cdot t = m \cdot \Delta \vec{v}$$

This is equal to the product of mass and change in velocity due to the application of force on the object or the change in momentum due to the force acting on the object. Hence impulse is referred to as impulse force even though its units are those of momentum. Thus, the origin of the impulse is the application of a force on an object producing a change in velocity and hence momentum.

A.5.1.7 (C)

A.5.1.8 (C)

A.5.1.9 (i) Velocity of car (at $t = 10$ s) $= 0 + 2 \times 10 = 20 \text{ m s}^{-1}$

By the First Law, the horizontal component of velocity is 20 m s^{-1} throughout.

Vertical component of velocity (at $t = 11$ s) $= 0 + 10 \times 1 = 10 \text{ m s}^{-1}$

Velocity of stone (at $t = 11$ s) $= \sqrt{20^2 + 10^2} = \sqrt{500} = 22.4 \text{ m s}^{-1}$ at an angle of

$\tan^{-1}(1/2)$ with the horizontal.

(ii) 10 m s^{-2} vertically downwards.

[Note the use of first law in this question to infer that the horizontal component of velocity is 20 m s^{-1} throughout the motion.]

A.5.1.10 (i) The magnitude of net external force is 47.36 N and its direction is 57.62° with the x -axis. The magnitude of the acceleration is 23.68 m s^{-2} and the direction is the same as that of external force.

(ii) If g is along $(-y)$, then it will be coplanar.

Example 5.1.3 A body of mass 0.40 kg moving initially with a constant speed of 10 m s^{-1} to the north is subject to a constant force of 8.0 N directed towards the south for 30 s . The instant the force is applied, assume $t = 0$, the position of the body at that time to be $x = 0$, and predict its position at $t = -5 \text{ s}$, 25 s , 100 s .

Solution: $F = ma$; $-8 \text{ N} = 0.40 a$; $a = -20 \text{ m s}^{-2}$ $0 \leq t \leq 30 \text{ s}$

$$t = -5 \text{ s} : x = u t = -10 \times 5 = -50 \text{ m}$$

$$t = 25 \text{ s} : x = u t + \left(\frac{1}{2}\right) a t^2 = (10 \times 25 - 10 \times 625) \text{ m} = -6000 \text{ m}$$

$t = 100 \text{ s}$: First consider motion up to 30 s

$$x_1 = 10 \times 30 - 10 \times 900 = -8700 \text{ m}$$

At $t = 30 \text{ s}$,

$$v = 10 - 20 \times 30 = -590 \text{ m s}^{-1}$$

For motion from 30 s to 100 s :

$$x_2 = -590 \times 70 = -41300 \text{ m}$$

$$x = x_1 + x_2 = -50 \text{ km}$$

Example 5.1.4. Fig. 5.1.7 shows the position-time graph of a body of mass 0.04 kg . Suggest a suitable physical context for this motion. What is the time between two consecutive impulses received by the body? What is the magnitude of each impulse?

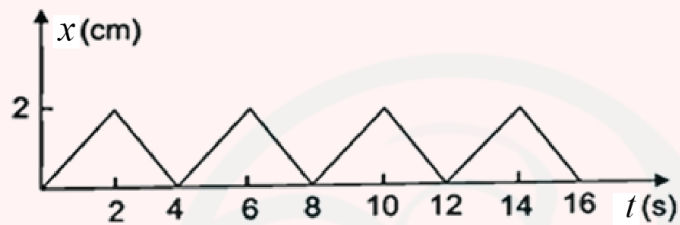


Fig.5.1.7

Solution : Mass of the body is 0.04 kg. Resolving the velocity components of the body before and after the change in direction of the body at $x = 2$ cm and $t = 2$ s it is seen that the body reverses its direction after every $t = 2$ s and covering distance $x = 2$ cm. Thus between reversing its direction every 2 s the body moves with a constant speed of $v = \frac{x}{t}$. refer Fig 5.1.8.

Momentum associated with the body between $t = 0$ s and $t = 2$ s is

$$\vec{P}_i = 0.04 \times 0.01 \text{ kg m s}^{-1}$$

$$= 4 \times 10^{-4} \text{ kg m s}^{-1}$$

Momentum associated with the body.

Between $t = 2$ s and $t = 4$ s is

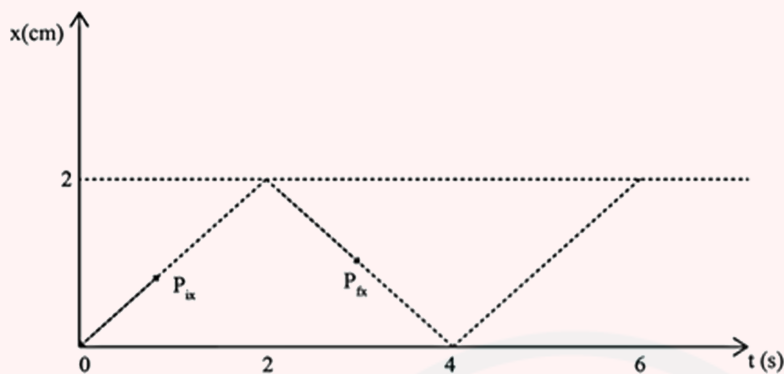


Fig. 5.1.8

$$\vec{P}_f = 0.04 \times (0.01) \text{ kg m s}^{-1}$$

$$= -4 \times 10^{-4} \text{ kg m s}^{-1}$$

Thus the impulse imparted to the body is

$$I = [\vec{P}_f - \vec{P}_i] = [(-4 \times 10^{-4}) - (4 \times 10^{-4})] \text{ N s}$$

$$= -8 \times 10^{-4} \text{ N s}$$

From the graph this appears to be the motion of a mass attached to a spring and oscillating. The time between two consecutive impulses received by the body is 2 s. The magnitude of each impulse is

$$8 \times 10^{-4} \text{ N s.}$$

Example 5.1.5. The velocity-time graph of a body of mass 5 kg is shown in Fig. 5.1.9.

(a) Find acceleration between (i) 0 to 5 second (ii) 5 to 15 second.

(b) Is the force acting on the body is same during 0 to 5 second and 15 to 20 second? justify.

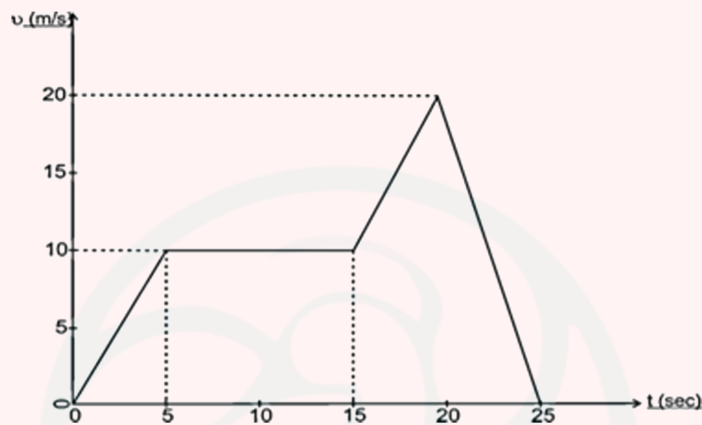


Fig. 5.1.9

Solution: (a) (i) 2 m s^{-2}

(ii) 0

(b) $a = 2 \text{ m s}^{-2}$ for both the cases. so, $F = ma = 5 \times 2 = 10 \text{ N}$. Hence, force acting on the body for both cases will be the same.

5.1.8 Summary

- Aristotle's view that a force is necessary to keep a body in uniform motion is wrong. A force is necessary in practice to counter the opposing force of friction.
- Galileo extrapolated simple observations on the motion of bodies on inclined planes and arrived at the law of inertia. Newton's first law of motion is the same law rephrased below.
- "Every body continues to be in its state of rest or of uniform motion in a straight line unless compelled by some external force to act otherwise". In simple terms, the first law is "if the external force on a body is zero, its acceleration is zero".
- Momentum ($\vec{p}$) of a body is the product of its mass (m) and velocity ($\vec{v}$), given by $\vec{p} = m\vec{v}$
- Newton's second law of motion:

"The rate of change of momentum of a body is proportional to the applied force and takes place in the direction in which the force acts". Thus,

$$\vec{F} = k \frac{d\vec{p}}{dt} = k \frac{d(m\vec{v})}{dt} = km \frac{d\vec{v}}{dt} + k\vec{v} \frac{dm}{dt} = km \frac{d\vec{v}}{dt}; \text{ if } m \text{ is constant } \frac{dm}{dt} = 0 = km\vec{a}$$

where $\vec{F}$ is the net external force on the body and $\vec{a}$ its acceleration. We set the constant of proportionality $k = 1$ in SI units. Then

$$\vec{F} = \frac{d\vec{p}}{dt} = m\vec{a}$$

- The SI unit of force is newton: $1 \text{ N} = 1 \text{ kg m s}^{-2}$.
- The second law is consistent with the first Law ($\vec{F} = 0$ implies $\vec{a} = 0$)
It is a vector equation
- It is applicable to a particle, and also to a body or a system of particles, provided $\vec{F}$ is the total external force on the system and $\vec{a}$ is the acceleration of the system as a whole.

- $\vec{F}$ at a point at a certain instant determines $\vec{a}$ at the same point at that instant. That is the second law is a local law; $\vec{a}$ at an instant and it does not depend on the history of motion.
- Impulse is the product of force and time which equals the change in momentum. The notion of impulse is useful when a large force acts for a short time to produce a measurable change in momentum. Since the time of action of the force is very short, one can assume that there is no appreciable change in the position of the body during the action of the impulsive force.

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