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## **Chapter 9th: Force and Laws of Motion**

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1. Which of the following has more inertia: (a) a rubber ball and a stone of the same size? (b) a bicycle and a train? (c) a five-rupees coin and a one-rupee coin?

Answer:

Inertia is the measure of the mass of the body. The greater is the mass of the body; the greater is its inertia and vice-versa.

(a) Mass of a stone is more than the mass of a rubber ball for the same size. Hence, inertia of the stone is greater than that of a rubber ball.

(b) Mass of a train is more than the mass of a bicycle. Hence, inertia of the train is greater than that of the bicycle.

(c) Mass of a five rupee coin is more than that of a one-rupee coin. Hence, inertia of the five rupee coin is greater than that of the one-rupee coin.

2. In the following example, try to identify the number of times the velocity of the ball changes:  
"A football player kicks a football to another player of his team who kicks the football towards the goal. The goalkeeper of the opposite team collects the football and kicks it towards a player of his own team".

Also identify the agent supplying the force in each case.

Answer:

The velocity of football changes four times.

First, when a football player kicks to another player, second when that player kicks the football to the goalkeeper. Third when the goalkeeper stops the football. Fourth when the goalkeeper kicks the football towards a player of his own team.

Agent supplying the force:

→ First case – First player

→ Second case – Second player

→ Third case – Goalkeeper

→ Fourth case – Goalkeeper

3. Explain why some of the leaves may get detached from a tree if we vigorously shake its branch.

Answer:

Some leaves of a tree get detached when we shake its branches vigorously because branches comes in motion while the leaves tend to remain at rest due to inertia of rest.

4. Why do you fall in the forward direction when a moving bus brakes to a stop and fall backwards when it accelerates from rest?

Answer:

In a moving bus, a passenger moves with the bus due to inertia of motion. As the driver applies brakes, the bus comes to rest. But, the passenger tries to maintain to inertia of motion. As a result, a forward force is exerted on him.

Similarly, the passenger tends to fall backwards when the bus accelerates from rest because when the bus accelerates, the inertia of rest of the passenger tends to oppose the forward motion of the bus. Hence, the passenger tends to fall backwards when the bus accelerates forward.

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1. If action is always equal to the reaction, explain how a horse can pull a cart.

Answer:

A horse pushes the ground in the backward direction. According to Newton's third law of motion, a reaction force is exerted by the Earth on the horse in the forward direction. As a result, the cart moves forward.

2. Explain, why is it difficult for a fireman to hold a hose, which ejects large amounts of water at a high velocity.

Answer:

When a fireman holds a hose, which is ejecting large amounts of water at a high velocity, then a reaction force is exerted on him by the ejecting water in the backward direction. This is because of Newton's third law of motion. As a result of the backward force, the stability of the fireman decreases. Hence, it is difficult for him to remain stable while holding the hose.

3. From a rifle of mass 4 kg, a bullet of mass 50 g is fired with an initial velocity of  $35 \text{ m s}^{-1}$ .

Calculate the initial recoil velocity of the rifle.

Answer:

Mass of the rifle,  $m_1 = 4 \text{ kg}$

Mass of the bullet,  $m_2 = 50 \text{ g} = 0.05 \text{ kg}$

Recoil velocity of the rifle =  $v_1$

Bullet is fired with an initial velocity,  $v_2 = 35 \text{ m/s}$

Initially, the rifle is at rest.

Thus, its initial velocity,  $v = 0$

Total initial momentum of the rifle and bullet system =  $(m_1 + m_2)v = 0$

Total momentum of the rifle and bullet system after firing:

$$= m_1 v_1 + m_2 v_2 = 0.05 \times 35 = 4v_1 + 1.75$$

According to the law of conservation of momentum:

$$\text{Total momentum after the firing} = \text{Total momentum before the firing} \quad 4v_1 + 1.75 = 0$$

$$v_1 = -1.75 / 4 = -0.4375 \text{ m/s}$$

The negative sign indicates that the rifle recoils backwards with a velocity of 0.4375 m/s.

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4. Two objects of masses 100 g and 200 g are moving along the same line and direction with velocities of  $2 \text{ m s}^{-1}$  and  $1 \text{ m s}^{-1}$ , respectively. They collide and after the collision, the first object moves at a velocity of  $1.67 \text{ m s}^{-1}$ . Determine the velocity of the second object.

Answer:

Mass of one of the objects,  $m_1 = 100 \text{ g} = 0.1 \text{ kg}$

Mass of the other object,  $m_2 = 200 \text{ g} = 0.2 \text{ kg}$

Velocity of  $m_1$  before collision,  $v_1 = 2 \text{ m/s}$

Velocity of  $m_2$  before collision,  $v_2 = 1 \text{ m/s}$

Velocity of  $m_1$  after collision,  $v_3 = 1.67 \text{ m/s}$

Velocity of  $m_2$  after collision =  $v_4$

According to the law of conservation of momentum:

Total momentum before collision = Total momentum after collision

Therefore,  $m_1 v_1 + m_2 v_2 = m_1 v_3 + m_2 v_4$

$$2(0.1) + 1(0.2) = 1.67(0.1) + v_4(0.2)$$

$$0.4 = 0.167 + 0.2v_4$$

$$v_4 = 1.165 \text{ m/s}$$

Hence, the velocity of the second object becomes 1.165 m/s after the collision.

**Page No: 128****EXERCISES**

1. An object experiences a net zero external unbalanced force. Is it possible for the object to be travelling with a non-zero velocity? If yes, state the conditions that must be placed on the magnitude and direction of the velocity. If no, provide a reason.

Answer:

Yes, an object may travel with a non-zero velocity even when the net external force on it is zero.

A rain drop falls down with a constant velocity. The weight of the drop is balanced by the up thrust and the velocity of air. The net force on the drop is zero.

2. When a carpet is beaten with a stick, dust comes out of it. Explain.

Answer:

When the carpet is beaten, it is suddenly set into motion. The dust particles tend to remain at rest due to inertia of rest, therefore the dust comes out of it.

3. Why is it advised to tie any luggage kept on the roof of a bus with a rope?

Answer:

When a bus starts suddenly, the lower part of the luggage kept on the roof being in contact with the bus begins to move forward with the speed of bus, but the upper part tends to remain at rest due to inertia of rest. Therefore, the upper part is left behind and hence luggage falls backward. So, it is advised to tie any luggage kept on the roof of a bus with a rope.

4. A batsman hits a cricket ball which then rolls on a level ground. After covering a short distance, the ball comes to rest. The ball slows to a stop because

- (a) the batsman did not hit the ball hard enough.
- (b) velocity is proportional to the force exerted on the ball.
- (c) there is a force on the ball opposing the motion.
- (d) there is no unbalanced force on the ball, so the ball would want to come to rest.

Answer:

The ball slows down and comes to rest due to opposing forces of air resistance and frictional force on the ball opposing its motion. Therefore the choice (c) there is a force on the ball opposing the motion is correct.

5. A truck starts from rest and rolls down a hill with a constant acceleration. It travels a distance of 400 m in 20 s. Find its acceleration. Find the force acting on it if its mass is 7 metric tonnes (*Hint*: 1 metric tonne = 1000 kg).

Answer:

Initial velocity,  $u = 0$

Distance travelled,  $s = 400$  m

Time taken,  $t = 20$  s

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

Or,  $400 = 0 + \frac{1}{2} a (20)^2$

Or,  $a = 2 \text{ ms}^{-2}$

Now,  $m = 7 \text{ MT} = 7000 \text{ kg}$ ,  $a = 2 \text{ ms}^{-2}$

Or,  $F = ma = 7000 \times 2 = 14000 \text{ N}$  Ans.

6. A stone of 1 kg is thrown with a velocity of  $20 \text{ m s}^{-1}$  across the frozen surface of a lake and comes to rest after travelling a distance of 50 m. What is the force of friction between the stone and the ice?

Answer:

Initial velocity of the stone,  $u = 20 \text{ m/s}$

Final velocity of the stone,  $v = 0$

Distance covered by the stone,  $s = 50 \text{ m}$

Since,  $v_2 - u_2$

$0 = 2as$ ,

Or,  $0 - 20^2 = 2a \times 50$ ,

Or,  $a = -4 \text{ ms}^{-2}$

Force of friction,  $F = ma = -4 \text{ N}$

7. A 8000 kg engine pulls a train of 5 wagons, each of 2000 kg, along a horizontal track. If the engine exerts a force of 40000 N and the track offers a friction force of 5000 N, then calculate:

- (a) the net accelerating force;
- (b) the acceleration of the train; and
- (c) the force of wagon 1 on wagon 2.

Answer:

(a) Force exerted by the engine,  $F = 40000 \text{ N}$

Frictional force offered by the track,  $F_f = 5000 \text{ N}$

Net accelerating force,  $F_a = F - F_f = 40000 - 5000 = 35000 \text{ N}$

Hence, the net accelerating force is 35000 N.

(b) Acceleration of the train =  $a$

The engine exerts a force of 40000 N on all the five wagons.

Net accelerating force on the wagons,  $F_a = 35000$  N

Mass of the wagons,  $m = \text{Mass of a wagon} \times \text{Number of wagons}$

Mass of a wagon = 2000 kg

Number of wagons = 5

$$\therefore m = 2000 \times 5 = 10000 \text{ kg}$$

Total mass,  $M = m = 10000$  kg

From Newton's second law of motion:

$$F_a = Ma$$

$$a = \frac{F_a}{M} = \frac{35000}{10000} = 3.5 \text{ ms}^{-2}$$

Hence, the acceleration of the wagons and the train is  $3.5 \text{ m/s}^2$ .

(c) Mass of all the wagons except wagon 1 is  $4 \times 2000 = 8000$  kg

Acceleration of the wagons =  $3.5 \text{ m/s}^2$

Thus, force exerted on all the wagons except wagon 1

$$= 8000 \times 3.5 = 28000 \text{ N}$$

Therefore, the force exerted by wagon 1 on the remaining four wagons is 28000 N.

Hence, the force exerted by wagon 1 on wagon 2 is 28000 N.

8. An automobile vehicle has a mass of 1500 kg. What must be the force between the vehicle and road if the vehicle is to be stopped with a negative acceleration of  $1.7 \text{ m s}^{-2}$ ?

Answer:

Mass of the automobile vehicle,  $m = 1500$  kg

Final velocity,  $v = 0$  (finally the automobile stops)

Acceleration of the automobile,  $a = -1.7 \text{ ms}^{-2}$

From Newton's second law of motion:

$$\text{Force} = \text{Mass} \times \text{Acceleration} = 1500 \times (-1.7) = -2550 \text{ N}$$

Hence, the force between the automobile and the road is  $-2550$  N, in the direction opposite to the motion of the automobile.

9. What is the momentum of an object of mass  $m$ , moving with a velocity  $v$ ?

- (a)  $(mv)^2$  (b)  $mv^2$  (c)  $\frac{1}{2}mv^2$  (d)  $mv$

Answer:

(d)  $mv$

Mass of the object =  $m$

Velocity =  $v$

Momentum = Mass x Velocity

Momentum =  $mv$

10. Using a horizontal force of 200 N, we intend to move a wooden cabinet across a floor at a constant velocity. What is the friction force that will be exerted on the cabinet?

Answer:

The cabinet will move with constant velocity only when the net force on it is zero.

Therefore, force of friction on the cabinet = 200 N, in a direction opposite to the direction of motion of the cabinet.

11. Two objects, each of mass 1.5 kg are moving in the same straight line but in opposite directions. The velocity of each object is  $2.5 \text{ ms}^{-1}$  before the collision during which they stick together. What will be the velocity of the combined object after collision?

Answer:

Mass of one of the objects,  $m_1 = 1.5 \text{ kg}$

Mass of the other object,  $m_2 = 1.5 \text{ kg}$

Velocity of  $m_1$  before collision,  $u_1 = 2.5 \text{ m/s}$

Velocity of  $m_2$ , moving in opposite direction before collision,  $u_2 = -2.5 \text{ m/s}$

Let  $v$  be the velocity of the combined object after collision. By the law of conservation of momentum,

Total momentum after collision = Total momentum before collision,

Or,  $(m_1 + m_2) v = m_1 u_1 + m_2 u_2$

Or,  $(1.5 + 1.5) v = 1.5 \times 2.5 + 1.5 \times (-2.5)$  [negative sign as moving in opposite direction]



Or,  $v = 0 \text{ ms}^{-1}$

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12. According to the third law of motion when we push on an object, the object pushes back on us with an equal and opposite force. If the object is a massive truck parked along the roadside, it will probably not move. A student justifies this by answering that the two opposite and equal forces cancel each other. Comment on this logic and explain why the truck does not move.

Answer:

The logic is that Action and Reaction always act on different bodies, so they can not cancel each other. When we push a massive truck, the force of friction between its tyres and the road is very large and so the truck does not move.

13. A hockey ball of mass 200 g travelling at  $10 \text{ m s}^{-1}$  is struck by a hockey stick so as to return it along its original path with a velocity at  $5 \text{ m s}^{-1}$ . Calculate the change of momentum occurred in the motion of the hockey ball by the force applied by the hockey stick.

Answer:

Mass of the hockey ball,  $m = 200 \text{ g} = 0.2 \text{ kg}$

Hockey ball travels with velocity,  $v_1 = 10 \text{ m/s}$

Initial momentum =  $mv_1$

Hockey ball travels in the opposite direction with velocity,  $v_2 = -5 \text{ m/s}$

Final momentum =  $mv_2$

Change in momentum =  $mv_1 - mv_2 = 0.2 [10 - (-5)] = 0.2 (15) = 3 \text{ kg m s}^{-1}$

Hence, the change in momentum of the hockey ball is  $3 \text{ kg m s}^{-1}$ .

14. A bullet of mass 10 g travelling horizontally with a velocity of  $150 \text{ m s}^{-1}$  strikes a stationary wooden block and comes to rest in 0.03 s. Calculate the distance of penetration of the bullet into the block. Also calculate the magnitude of the force exerted by the wooden block on the bullet.

Answer:

Initial velocity,  $u = 150 \text{ m/s}$

Final velocity,  $v = 0$  (since the bullet finally comes to rest)

Time taken to come to rest,  $t = 0.03 \text{ s}$

According to the first equation of motion,  $v = u + at$

Acceleration of the bullet,  $a$

$$0 = 150 + (a \times 0.03 \text{ s}) \quad a = -150 / 0.03 = -5000 \text{ m/s}^2$$

(Negative sign indicates that the velocity of the bullet is decreasing.)

According to the third equation of motion:

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

$$0 = (150)^2 + 2(-5000)s$$

$$= 22500 / 10000$$

$$= 2.25 \text{ m}$$

Hence, the distance of penetration of the bullet into the block is 2.25 m.

From Newton's second law of motion:

Force,  $F = \text{Mass} \times \text{Acceleration}$

Mass of the bullet,  $m = 10 \text{ g} = 0.01 \text{ kg}$

Acceleration of the bullet,  $a = 5000 \text{ m/s}^2$

$$F = ma = 0.01 \times 5000 = 50 \text{ N}$$

Hence, the magnitude of force exerted by the wooden block on the bullet is 50 N.

15. An object of mass 1 kg travelling in a straight line with a velocity of  $10 \text{ m s}^{-1}$  collides with, and sticks to, a stationary wooden block of mass 5 kg. Then they both move off together in the same straight line. Calculate the total momentum just before the impact and just after the impact. Also, calculate the velocity of the combined object.

Answer:

Mass of the object,  $m_1 = 1 \text{ kg}$

Velocity of the object before collision,  $v_1 = 10 \text{ m/s}$

Mass of the stationary wooden block,  $m_2 = 5 \text{ kg}$

Velocity of the wooden block before collision,  $v_2 = 0 \text{ m/s}$

$$\therefore \text{Total momentum before collision} = m_1 v_1 + m_2 v_2$$

$$= 1(10) + 5(0) = 10 \text{ kg m s}^{-1}$$

It is given that after collision, the object and the wooden block stick together.

Total mass of the combined system  $= m_1 + m_2$

Velocity of the combined object =  $v$

According to the law of conservation of momentum:

Total momentum before collision = Total momentum after collision

$$m_1 v_1 + m_2 v_2 = (m_1 + m_2) v$$

$$1 (10) + 5 (0) = (1 + 5) v$$

$$v = 10 / 6$$

$$= 5 / 3$$

The total momentum after collision is also 10 kg m/s.

Total momentum just before the impact =  $10 \text{ kg m s}^{-1}$

Total momentum just after the impact =  $(m_1 + m_2) v = 6 \times 5 / 3 = 10 \text{ kg ms}^{-1}$

Hence, velocity of the combined object after collision =  $5 / 3 \text{ ms}^{-1}$

16. An object of mass 100 kg is accelerated uniformly from a velocity of  $5 \text{ m s}^{-1}$  to  $8 \text{ m s}^{-1}$  in 6 s. Calculate the initial and final momentum of the object. Also, find the magnitude of the force exerted on the object.

Answer:

Initial velocity of the object,  $u = 5 \text{ m/s}$

Final velocity of the object,  $v = 8 \text{ m/s}$

Mass of the object,  $m = 100 \text{ kg}$

Time take by the object to accelerate,  $t = 6 \text{ s}$

Initial momentum =  $mu = 100 \times 5 = 500 \text{ kg m s}^{-1}$

Final momentum =  $mv = 100 \times 8 = 800 \text{ kg m s}^{-1}$

Force exerted on the object,  $F = mv - mu / t$

$$= m (v-u) / t$$

$$= 800 - 500$$

$$= 300 / 6$$

$$= 50 \text{ N}$$

Initial momentum of the object is  $500 \text{ kg m s}^{-1}$ .

Final momentum of the object is  $800 \text{ kg m s}^{-1}$ .

Force exerted on the object is 50 N.

17. Akhtar, Kiran and Rahul were riding in a motorcar that was moving with a high velocity on an expressway when an insect hit the windshield and got stuck on the windscreen. Akhtar and Kiran started pondering over the situation. Kiran suggested that the insect suffered a greater change in momentum as compared to the change in momentum of the motorcar (because the change in the velocity of the insect was much more than that of the motorcar). Akhtar said that since the motorcar was moving with a larger velocity, it exerted a larger force on the insect. And as a result the insect died. Rahul while putting an entirely new explanation said that both the motorcar and the insect experienced the same force and a change in their momentum. Comment on these suggestions.

Answer:

The suggestion made by Kiran that the insect suffered a greater change in momentum as compared to the change in momentum of the motor car is wrong.

The suggestion made by Akhtar that the motor car exerted a larger force on the insect because of large velocity of motor car is also wrong. The explanation put forward by Rahul is correct. On collision of insect with motor car, both experience the same force as action and reaction are always equal and opposite. Further, changes in their momenta are also the same. Only the signs of changes in momenta are opposite, i.e., change in momenta of the two occur in opposite directions, though magnitude of change in momentum of each is the same.

18. How much momentum will a dumbbell of mass 10 kg transfer to the floor if it falls from a height of 80 cm? Take its downward acceleration to be  $10 \text{ m s}^{-2}$ .

Answer:

Mass of the dumbbell,  $m = 10 \text{ kg}$

Distance covered by the dumbbell,  $s = 80 \text{ cm} = 0.8 \text{ m}$

Acceleration in the downward direction,  $a = 10 \text{ m/s}^2$

Initial velocity of the dumbbell,  $u = 0$

Final velocity of the dumbbell (when it was about to hit the floor) =  $v$

According to the third equation of motion:

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

$$v^2 = 0 + 2 (10) 0.8$$

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

Hence, the momentum with which the dumbbell hits the floor is

$$= mv = 10 \times 4 = 40 \text{ kg m s}^{-1}$$

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### **ADDITIONAL EXERCISES**

1. The following is the distance-time table of an object in motion:

Time in seconds	Distance in metres
0	0
1	1
2	8
3	27
4	64
5	125
6	216
7	343

(a) What conclusion can you draw about the acceleration? Is it constant, increasing, decreasing, or zero?

(b) What do you infer about the forces acting on the object?

Answer:

(a) There is an unequal change of distance in an equal interval of time.

Thus, the given object is having a non - uniform motion. Since the velocity of the object increases with time, the acceleration is increasing.

(b) The object is in accelerated condition. According to Newton's second law of motion, the

force acting on an object is directly proportional to the acceleration produced in the object. So, we can say unbalanced force is acting on the object.

2. Two persons manage to push a motorcar of mass 1200 kg at a uniform velocity along a level road. The same motorcar can be pushed by three persons to produce an acceleration of  $0.2 \text{ m s}^{-2}$ .

With what force does each person push the motorcar?

(Assume that all persons push the motorcar with the same muscular effort)

Answer:

Mass of the motor car = 1200 kg

Only two persons manage to push the car. Hence, the acceleration acquired by the car is given by the third person alone.

Acceleration produced by the car, when it is pushed by the third person,

$$a = 0.2 \text{ m/s}^2$$

Let the force applied by the third person be  $F$ .

From Newton's second law of motion:

Force = Mass  $\times$  Acceleration

$$F = 1200 \times 0.2 = 240 \text{ N}$$

Thus, the third person applies a force of magnitude 240 N.

Hence, each person applies a force of 240 N to push the motor car.

3. A hammer of mass 500 g, moving at  $50 \text{ m s}^{-1}$ , strikes a nail. The nail stops the hammer in a very short time of 0.01 s. What is the force of the nail on the hammer?

Answer:

Mass of the hammer,  $m = 500 \text{ g} = 0.5 \text{ kg}$

Initial velocity of the hammer,  $u = 50 \text{ m/s}$

Time taken by the nail to stop the hammer,  $t = 0.01 \text{ s}$

Velocity of the hammer,  $v = 0$  (since the hammer finally comes to rest)

From Newton's second law of motion:

$$\text{Force, } f = m(v-u) / t$$

$$= 0.5(0-50) / 0.01$$

$$= -2500 \text{ N}$$

The hammer strikes the nail with a force of  $-2500\text{ N}$ . Hence, from Newton's third law of motion, the force of the nail on the hammer is equal and opposite, i.e.,  $+2500\text{ N}$ .

4. A motorcar of mass  $1200\text{ kg}$  is moving along a straight line with a uniform velocity of  $90\text{ km/h}$ . Its velocity is slowed down to  $18\text{ km/h}$  in  $4\text{ s}$  by an unbalanced external force. Calculate the acceleration and change in momentum. Also calculate the magnitude of the force required.

Answer:

Mass of the motor car,  $m = 1200\text{ kg}$

Initial velocity of the motor car,  $u = 90\text{ km/h} = 25\text{ m/s}$

Final velocity of the motor car,  $v = 18\text{ km/h} = 5\text{ m/s}$

Time taken,  $t = 4\text{ s}$

According to the first equation of motion:

$$v = u + at$$

$$5 = 25 + a(4)$$

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

Negative sign indicates that it's a retarding motion i.e. velocity is decreasing.

$$\text{Change in momentum} = mv - mu = m(v - u)$$

$$= 1200(5 - 25) = -24000\text{ kg m s}^{-1}$$

$$\text{Force} = \text{Mass} \times \text{Acceleration}$$

$$= 1200 \times -5 = -6000\text{ N}$$

$$\text{Acceleration of the motor car} = -5\text{ m/s}^2$$

$$\text{Change in momentum of the motor car} = -24000\text{ kg m s}^{-1}$$

Hence, the force required to decrease the velocity is  $6000\text{ N}$ .

(Negative sign indicates retardation, decrease in momentum and retarding force)