NCERT SOLUTIONS

Force and Laws of Motion

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IN CHAPTER QUESTIONS

PART - 1

Q1. 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 ?

Ans. Mass of a body is the measure of its inertia i.e., more the mass, more is the inertia. Keeping this in mind :

(a) Stone has more inertia.

(b) Train has more inertia.

(c) Five rupees coin has more inertia.

Q2. 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.

Ans. The velocity of the football changes four times

First time the velocity changes when the player applies force to kick the ball towards another player of his team.

Second time the velocity changes when the other player kicks the ball towards the goal.

Third time the velocity changes when the goalkeeper collects the ball by applying force in the direction opposite to the direction of the motion of the ball.

Fourth time the velocity changes when the goalkeeper kicks the ball towards the player of his own team by applying force.

Q3. Explain why some of the leaves may get detached from a tree if we vigorously shake its branch.

Ans. When we shake a branch of a tree vigorously, some of the leaves may get detached on account of inertia of rest of the leaves. The branch comes in motion and the leaves try to be in the position of rest. Therefore, they get detached.

Q4. Why do you fall in the forward direction when a moving bus applies brakes to stop and fall backward when it accelerates from rest ?

Ans. When a moving bus applies brakes, our feet come to rest with the bus. But upper part of our body continues to move forward on account of inertia of motion. That is why we tend to fall in the forward direction.
However, when the bus accelerates from rest, lower part of our body moves with the bus. The upper part of the body tries to maintain itself at rest on account of inertia of rest. Therefore, we tend to fall backwards.

PART - 2

Q1. If action is always equal to the reaction, explain how a horse can pull a cart.

Ans. When a horse pulls a cart with a certain force, then the cart pulls the horse with the same force and the system of horse and cart should not move.
But, if we analyse the problem carefully, then horse not only applies force on the cart, but also pushes the earth backward with his feet. The earth reacts back to this action of the horse and pushes it in the forward direction. The force applied by the horse on the earth is insufficient to move the earth, but the force applied by the earth is sufficient to make the horse move in the forward direction.
This unbalanced force applied by the earth makes the system of horse and cart move in the forward direction.

Q2. Explain, why is it difficult for a fireman to hold a hose pipe which ejects large amounts of water at high velocity.

Ans. We can explain the above observation on the basis of law of conservation of momentum. When the system of hose and water is not ejecting any water, its momentum is zero. When the water issues out from the hose with a high velocity, it has momentum in the forward direction. Therefore, in order to conserve momentum, the hose tends to move in the backward direction and hence is difficult to hold.
or
The ejection of large amounts of water at a high velocity from a hosepipe results in the development of an equal force of reaction on the hosepipe in the backward direction. That is why it becomes difficult for the fireman to hold the hosepipe.

Q3. From a rifle of mass 4 kg, a bullet of mass 50 g is fired with a speed of 35 ms^{-1}. Calculate the recoil speed of the rifle.

Ans. Mass of rifle = 4 kg

Let velocity of recoil of rifle = v

Momentum of the rifle = 4 × v

Mass of bullet = 50 g = $\frac{50}{1000}$ kg = 0.05 kg

Velocity of bullet = 35 ms^{-1}

Momentum of bullet = 0.05 × 35

Using the law of conservation of momentum,

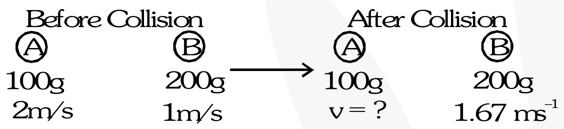
momentum of the rifle + momentum of the bullet

$= 4 \times v - 0.05 \times 35 = 0$

or $\quad v = \frac{0.05 \times 35}{4} = 0.4375 \ ms^{-1}$

Q4. Two objects of masses 100 g and 200 g are moving along the same line and direction, with velocities 2 ms^{-1} and 1 ms^{-1}, respectively. They collide and after the collision, the second object moves with a velocity of 1.67 ms^{-1}. Determine the velocity of the first object.

Ans.



Let the 100 g and 200 g objects be A and B as shown in the above figure.

Initial momentum of A $= \frac{100}{1000} \times 2 = 0.2$ kg ms^{-1}

Initial momentum of B $= \frac{200}{1000} \times 1 = 0.2$ kg ms^{-1}

∴ Total momentum of A and B before collision

$= 0.2 + 0.2 = 0.4$ kg ms^{-1}

Let the velocity of A after collision = v

∴ Momentum of A after collision $= \frac{100}{1000} \times v = 0.1v$

Also, momentum of B after collision

$= \frac{200}{1000} \times 1.67 = 0.334$ kg ms^{-1}

∴ Total momentum of A and B after collision

$= 0.1 \times v + 0.334$

Using the law of conservation of momentum,

momentum of A and B after collision = momentum of A and B before collision

$0.1 \times v + 0.334 = 0.4$

$0.1 \times v = 0.4 - 0.334$

$\Rightarrow \quad v = \frac{0.066}{0.1} = 0.66 \ ms^{-1}$

EXERCISES

Q1. 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.

Ans. Yes, when external unbalanced force on an object is zero, the object can travel with a non-zero velocity. Such a motion will be a uniform motion. The conditions for this are :

(i) Magnitude of velocity must be constant

(ii) Direction of velocity must be constant i.e., it travels in a straight line without change in direction.

Q2. When a carpet is beaten with a stick, dust comes out of it. Explain.

Ans. Initially, the carpet and loose dust in it are in the state of rest. When the carpet is hit with a stick, it is suddenly set into motion, but the loose dust in it remains in the state of rest because of inertia of rest. Thus, in a way, dust is left behind relative to carpet and hence comes out in air.

Q3. Why is it advised to tie any luggage kept on the roof of a bus with a rope?

Ans. Luggage on the top of the bus is a loose fixture and not a compact part of the bus. Thus, when a speeding bus brakes suddenly, the luggage continues moving forward because of inertia of motion and is likely to fall off the bus. Conversely, if a stationary bus accelerates suddenly, the luggage continues in the same state because of inertia, and hence is left behind relative to bus, such that it falls backward. To avoid the falling of luggage, it is tied with a rope.

Q4. 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.

Ans. Correct answer is option (c).
There is a force on the ball opposing the motion.

This force is the force of friction between the ball and the surface of ground.

Q5. 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.)

Ans. Initial velocity of truck, u = 0 ; time, t = 20 s ; distance covered, s = 400 m; acceleration, a = ?; mass of truck, m = 7 metric tonnes = 7000 kg ; force on truck, F = ?

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

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

$\Rightarrow 400 = 200\ a$ or $a = \frac{400}{200} = 2\ ms^{-2}$

Force on truck, F = ma = 7000 × 2 = 14000 N

Q6. A stone of 1 kg is thrown with a velocity of 20 ms^{-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 ?

Ans. Mass of stone, m = 1 kg ; initial velocity of stone, u = 20 ms^{-1} ; final velocity of stone, v = 0 ; distance covered by the stone, s = 50 m ; acceleration of stone, a = ? ; force acting on the stone due to friction, F = ?

We know, $v^2 - u^2 = 2as$

$(0)^2 - (20)^2 = 2a \times 50$

or $-400 = 100\ a$

$a = \frac{-400}{100} = -4\ ms^{-2}$

∴ Force of friction, F = ma = 1 × (–4) = –4 N

Negative sign signifies that force of friction is acting in the direction opposite to the direction of motion of the stone.

Q7. An 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 frictional force of 5000 N, then calculate:

(a) the net accelerating force

(b) the acceleration of the train

(c) the force of wagon 1 on wagon 2

Ans. (a) Force exerted by the engine = 40,000 N

Force of friction exerted by the tracks = 5000 N

As the force of friction always acts opposite to the direction of applied force,

∴ Net accelerating force of engine

= 40000 – 5000 = 35000 N

(b) Mass of 5 wagons = 2000 × 5 = 10000 kg

We know, F = ma

or 35000 = 10000 × a

$\Rightarrow \quad a = \frac{35000}{10000} = 3.5\ m/s^2$

(c) Force of wagon 1 on wagon 2 =
mass of 4 wagons behind wagon 1 ×
acceleration
$F = 4 \times 2000 \times 3.5 = 28000$ N

Q8. 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 ms^{-2} ?

Ans. Mass of the vehicle, m = 1500 kg ; negative acceleration, a = –1.7 ms^{-2}
∴ Force of friction between the road and vehicle
$F = ma = 1500 \times (-1.7) = -2550$ N
Negative sign means force is acting in the direction opposite to the direction of motion of the vehicle.

Q9. What is the momentum of an object of mass m, moving with a velocity v ?

(a) $(mv)^2$ (b) mv^2 (c) $1/2mv^2$ (d) mv

Ans. Correct answer is option (d).

Q10. 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 ?

Ans. In order to move the cabinet with constant velocity, the net force acting on it should be zero, such that the forces are balanced.
This is possible only if the frictional force is 200 N and acts in the direction opposite to the direction of motion of the cabinet.

Q11. 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 ms^{-1} before the collision during which they stick together. What will be the velocity of the combined object after collision ?

Ans. Let the objects be A and B moving from opposite directions in the same straight line.
∴ Initial momentum of A = m × v
$= 1.5 \times 2.5 = 3.75$ kg ms^{-1}
Also, initial momentum of B
$= m \times v = 1.5 \times (-2.5) = -3.75$ kg ms^{-1}.
If v is the velocity of the objects after collision, then final momentum after collision = 3 × v
Using the law of conservation of momentum, final momentum of A and B = initial momentum of A + initial momentum of B
or $3 \times v = 3.75 - 3.75$
or $3 \times v = 0$ or $\mathbf{v = 0}$

Q12. 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.

Ans. When we push a massive truck parked along the roadside, it does not move. The justification given by the student that the two opposite and equal forces cancel each other is totally wrong. This is because forces of action and reaction never act on one body. There is no question of their cancellation. The truck does not move because the push applied is far less than the force of friction between the truck and the road. We also do not move because the force of reaction acting on us (due to pushing the truck) is less than force of friction between us and the road.

Q13. A hockey ball of mass 200 g travelling at 10 ms^{-1} is struck by a hockey stick so as to return it along its original path with a velocity of 5 ms^{-1}. Calculate the change of momentum which occurred in the motion of the hockey ball by the force applied by the hockey stick.

Ans. Mass of ball, m = 200 g = 0.2 kg ; initial velocity of ball, u_1 = 10 ms^{-1} ; final velocity of ball, $u_2 = -5$ ms^{-1}

(Negative sign denotes that ball is moving in opposite direction)

Initial momentum of ball = $mu_1 = 0.2 \times 10 = 2$ Ns

Final momentum of ball = $mu_2 = 0.2 \times (-5) = -1$ Ns

$\therefore$ Change in momentum =

Final momentum – initial momentum =

$(-1) - (2) = -3$ Ns

Negative sign denotes that change in momentum is in the direction opposite to the direction of initial momentum of the ball.

Q14. A bullet of mass 10 g travelling horizontally with a velocity of 150 ms^{-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.

Ans. Mass of bullet, m = 10 g = 0.01 kg ; initial velocity of bullet, u = 150 ms^{-1} ; final velocity of bullet, v = 0 ; time, t = 0.03 s ; acceleration of bullet, a = ? ; force exerted by wooden block, F = ? ; distance penetrated by bullet, s = ?

We know, $v = u + at$

or $0 = 150 + a \times 0.03$

or $-a \times 0.03 = 150$

or $a = \frac{-150}{0.03} = -5000\ ms^{-2}$

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

$= 150 \times 0.03 + \frac{1}{2} \times (-5000) \times (0.03)^2$

$= 4.5 - 2.25 = 2.25$ m

We know, F = ma

Force acting on bullet,

$F = 0.01 \times (-5000) = -50$ N

Negative sign denotes that wooden block exerts force in a direction opposite to the direction of motion of the bullet.

Q15. An object of mass 1 kg travelling in a straight line with a velocity of 10 ms^{-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.

Ans. For object : $m_1 = 1$ kg ; $u_1 = 10\ ms^{-1}$

For wooden block : $m_2 = 5$ kg ; $u_2 = 0$

Momentum just before collision

$= m_1u_1 + m_2u_2 = 1 \times 10 + 5 \times 0 = 10\ kg\ ms^{-1}$

Since, momentum is conserved,

momentum before collision = momentum after collision = 10 kg ms^{-1}

Mass after collision $= (m_1 + m_2) = 1 + 5 = 6$ kg

Let velocity after collision = v

$\therefore$ Momentum after collision $= 6 \times v$

Using the law of conservation of momentum,

momentum after collision = momentum before collision

$\therefore 6 \times v = 10$ or $v = \frac{10}{6} = 1.67\ ms^{-1}$

Q16. An object of mass 100 kg is accelerated uniformly from a velocity of 5 ms^{-1} to 8 ms^{-1} in 6 s. Calculate the initial and final momentum of the object. Also, find the magnitude of the force exerted on the object.

Ans. Mass of object, m = 100 kg ; initial velocity,

u = 5 ms^{-1} ; final velocity, v = 8 ms^{-1} ; time,

t = 6 s

Initial momentum $= mu = 100 \times 5 = 500$ Ns

Final momentum $= mv = 100 \times 8 = 800$ Ns

Force exerted on the object

$F = \frac{mv - mu}{t} = \frac{800 - 500}{6} = \frac{300}{6} = 50$ N

Q17. 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 change in their momentum. Comment on these suggestions.

Ans. Kiran's suggestion is not correct because momentum is always conserved i.e. change in momentum of insect must be equal and opposite to that of motorcar.
Akhtar's suggestion is also not correct.
Rahul's suggestion is correct i.e., insect and motorcar experience same force and change in momentum.
However, the insect dies, because it is unable to bear the large force and large change in momentum.

Q18. How much momentum will a dumb-bell of mass 10 kg transfer to the floor if it falls from a height of 80 cm and does not rebound ? Take its downward acceleration to be 10 ms^{-2}.

Ans. Mass of dumb–bell, m = 10 kg ; initial velocity, u = 0 ; final velocity, v = ? ; distance, s = 80 cm = 0.8 m ; acceleration, a = 10 ms^{-2}

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

$$v^2 - (0)^2 = 2 \times 10 \times 0.8$$

$$v^2 = 16$$

$$v = \sqrt{16} = 4\ ms^{-1}$$

$\therefore$ Momentum of dumb-bell transferred to ground = mv = 10 × 4 = 40 kg ms^{-1}.

ADDITIONAL EXERCISES

Q1. The following is the distance-time table of an object in motion

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

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

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

Ans. (a) A careful observation of the distance-time table shows that $s \propto t^3$.

It is known that, in uniform motion $s \propto t$, and for motion with uniform acceleration $s \propto t^2$. In the present case, $s \propto t^3$. Therefore, we conclude in this case that acceleration must be increasing with time.

(b) As F = ma, therefore, $F \propto a$. Hence, the force must also be increasing with time.

Q2. 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 ms^{-2}. With what force does each person push the motorcar ? (Assume that all persons push the motorcar with the same muscular effort.)

Ans. As two persons can make the motorcar move with uniform velocity, it is clear that total force applied by them on the motorcar is balanced by the force of friction acting in the opposite direction. It is force of one more person which produces an acceleration of 0.2 ms^{-2}.

$\therefore$ Force of one person = mass × acceleration = 1200 × 0.2 = 240 N

Q3. A hammer of mass 500 g, moving at 50 ms^{-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 ?

Ans. The force of nail on the hammer

$$F = \frac{\text{Change in momentum of hammer}}{\text{Time}}$$

$$F = \frac{m(v-u)}{t} = \frac{0.5(0-50)}{0.01} = -2500 \text{ N}$$

Negative sign denotes that the force of nail on the hammer is acting in the direction opposite to that of motion of hammer.

Q4. A motorcar of mass 1200 kg is moving along a straight line with a uniform velocity of 90 km/h. Its velocity is slowed down to18 km/h in 4 s by an unbalanced external force. Calculate the acceleration and change in momentum. Also calculate the magnitude of the force required.

Ans. (i) Initial velocity of the car, u = 90 km/h = 25 ms^{-1}; final velocity of the car, v = 18 km/h = 5 ms^{-1} ; time, t = 4 s ; acceleration, a = ?

We know, $v = u + at$

$5 = 25 + a \times 4$

$\therefore \quad -a \times 4 = 20$ or $a = \frac{-20}{4} = -5\ ms^{-2}$

(ii) Change in momentum, $\Delta p = m\,(v - u)$

$= 1200\,(5 - 25) = 1200 \times (-20) = -24000$ Ns

(iii) Magnitude of force

$$F = \frac{m(v-u)}{t} = \frac{-24000}{4} = -6000 \text{ N}$$

Q5. A large truck and a car, both moving with a velocity of magnitude v, have a head-on collision. If the collision lasts for 1 s,

(a) Which vehicle experiences greater force of impact ?
(b) Which vehicle experiences greater change in momentum ?
(c) Which vehicle experiences greater acceleration ?
(d) Why is the car likely to suffer more damage than the truck ?

Ans. Let mass of truck = M ; mass of car = m ; velocity of truck = v ; time for which collision lasts, t = 1 s ; velocity of car = –v (Negative sign for opposite direction of motion).

(a) On collision, both the vehicles experience the same force, as action and reaction are equal.

(b) Change in momentum of truck is equal and opposite to change in momentum of car, i.e., both the vehicles experience the same change in momentum.

(c) As acceleration = force / mass, and force on each vehicle is same, therefore,

acceleration $\propto \frac{1}{\text{mass}}$.

As mass of car is smaller, therefore, acceleration of car is greater than the acceleration of the truck.

(d) The car is likely to suffer more damage than the truck, as it is lighter. The acceleration i.e. change in velocity/time of car is more than that of the truck.