9

FORCE AND LAWS OF MOTION

TEXTBOOK QUESTIONS AND THEIR ANSWERS

Q. 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 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.

Q. 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.

Ans. The velocity of 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.

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

Ans. When the branch is suddenly set in motion, the leaves attached to it tend to continue in their state of rest, on account of inertia of rest. This generates a lot of strain at the junction of leaves and the branch. Due to this strain, some leaves get detached from the branch.

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

Ans. Before the application of the brakes, the bus and the persons in it are in the state of motion. When the brakes are suddenly applied, the bus comes to the state of rest, but the passengers on account of inertia of motion tend to continue in the state of motion. Thus, they fall in forward direction.

Conversely, when the bus is in the state of rest, the passengers in it have inertia of rest. When the bus accelerates suddenly, the passengers tend to continue in their state of rest and hence are left behind, relative to the position of bus. Thus, they fall in the backward direction.

Q.5 If action is always equal to the reaction, explain how a horse can pull a cart?

Ans. It is true that 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.

However, if we analyse the problem carefully, then horse not only applies force on the cart, but also pushes the earth backward with his feet. In this action of the horse, the earth reacts back and pushes it in the forward direction. Now, 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 to move in the forward direction.

It is this unbalanced force applied by the earth, which makes the system of horse and cart to move in the forward direction.

Q. 6 Explain, why is it difficult for a fireman to hold a hose, which ejects large amount of water at a high velocity.

Ans. The above observation can be explained on the basis of law of conservation of momentum. When the system of the hose and water is not ejecting any water, its momentum is zero. When the water gushes out from the hose with a high velocity, it has momentum in the forward direction. Thus, in order to conserve momentum, the hose tends to move in the backward direction and hence, is difficult to hold.

Q. 7 From a rifle of mass 4 kg, a bullet of mass 50 g is fired with an initial velocity of 35 ms^{-1}. Calculate the initial velocity of the recoil of gun.

Ans. Initial mass of rifle = 4 kg

Let initial velocity of recoil of rifle = v

$\therefore$ Initial momentum of the rifle $= 4 \text{ kg} \times v$

Initial mass of bullet $= 50 \text{ g} = 0.05 \text{ kg}$

Initial velocity of bullet $= 35 \text{ ms}^{-1}$

$\therefore$ Initial momentum of bullet $= 0.05 \text{ kg} \times 35 \text{ ms}^{-1}$

By the law of conservation of momentum,

Momentum of the rifle = Momentum of bullet

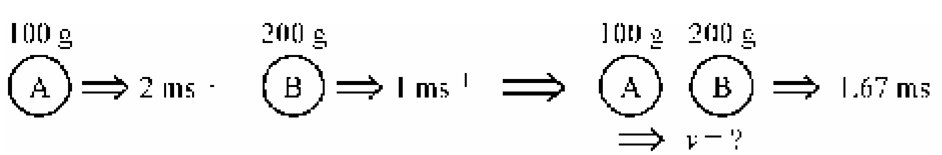
$$\Rightarrow \quad 4 \text{ kg} \times v = 0.05 \text{ kg} \times 35 \text{ ms}^{-1}$$

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

$$= \mathbf{0.4375 \text{ ms}^{-1}}.$$

Q. 8. Two objects of masses 100 g and 200 g are moving along the same line and direction with velocities of 2 ms^{-1} and 1 ms^{-1} respectively. They collide and after the collision, the first object moves with a velocity of 1.67 ms^{-1}. Determine the velocity of second object.

Ans.



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

$\therefore$ Initial momentum of A = 100 g × 2 ms^{-1} = 200 g ms^{-1}

Initial momentum of B = 200 g × 1 ms^{-1} = 200 g ms^{-1}

$\therefore$ Total momentum of A and B before collision

= (200 + 200) gms^{-1} = 400 g ms^{-1}

Let the velocity of A after collision = v

$\therefore$ Momentum of A after collision = 100 g × v

Also, momentum of B after collision= 200 g × 1.67 ms^{-1}

= 334 g ms^{-1}

$\therefore$ Total momentum of A and B after collision

= 100 g × v + 334 g ms^{-1}.

Now, by the law of conservation of momentum,

Momentum of A and B after collision

= Momentum of A and B before collision

$\Rightarrow$ 100 g × v + 334 g ms^{-1} = 400 g ms^{-1}

$\Rightarrow$ 100 g $\times$ v = (400 – 334) g ms^{-1}

$\Rightarrow$ v = ms^{-1} = **0.66 ms^{-1}.**

Q. 9 An object experiences a net zero external unbalanced force. Is it possible for the object to be travelling with 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. No, the object will not be able to travel with non-zero velocity, for the simple reason that there is net zero external unbalanced force. However, this will apply only on the surface of earth where forces of gravity and friction always act on the object.

However, if the object is in deep space and is completely free from the forces of friction and gravitation, such that it is moving with non-zero velocity, then it will continue moving with the same velocity and in the same direction.

Q.10 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 tends to continue in its state of rest, on account of inertia of rest. Thus, in a way dust is left behind relative to carpet and hence, comes out in air.

Q. 11 Why is it advised to tie luggage kept on the roof of a bus with 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 on account of inertia of motion continues moving forward and is likely to fall off the bus. Conversely, if a stationary bus accelerates suddenly, the luggage on account of the inertia of rest, continues in the same state 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.

Q. 12 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 down to 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 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 "there is force on the ball opposing the motion." This force is the force of friction between the ball and the surface of ground.

Q. 13 A truck starts from rest and rolls down the hill with a constant acceleration. It travels a distance of 400 m in 20 s. Find its acceleration. Find the force acting on it, its mass is 7 metric tonnes. [Hint : 1 metric tonne = 1000 kg].

Ans. Initial velocity of truck (u) = 0 (As truck is initially at rest)

Distance covered (S) = 400 m

Time (t) = 20 s

Acceleration (a) = ? (To be calculated)

Mass of truck (m) = 7 t = 7000 kg

($\because$ 1 metric tonne = 1000 kg)

Force on truck (F) = ? (To be calculated)

Applying , $$S = ut + \frac{1}{2}at^2$$

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

$\Rightarrow$ $$400 \text{ m} = 200a \text{ s}^2$$

$\therefore \quad a = \dfrac{400\ \text{m}}{200\ \text{s}^2} = \mathbf{0.5\ ms^{-2}}$

Force on truck (F) = ma

$= 7000\ \text{kg} \times 0.5\ \text{ms}^{-2} = \mathbf{3500\ N.}$

Q.14 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) = Zero (As the stone comes to rest)

Distance covered by the stone (S)= 50 m

Acceleration of stone (a) = ? (To be calculated)

Force acting on the stone due to friction (F)

= ? (To be calculated)

Applying , $v^2 - u^2 = 2aS$

$(0)^2 - (20\ \text{ms}^{-1})^2 = 2\ a \times 50\ \text{m}$

$-400\ \text{m}^2\text{s}^{-2} = 100\ am$

$$\therefore \qquad a = \frac{-400\text{m}^2\text{s}^{-2}}{100\text{m}} = -4\text{ms}^{-2}$$

$$= -4 \text{ ms}^{-2}.$$

$\therefore$ Force of friction (F) = ma

$= 1 \text{ kg} \times -4 \text{ ms}^{-2} =$ **– 4 N.**

Q.15 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 40,000 N and the track offers a friction 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

$\therefore$ Net accelerating force of engine = (40000 – 5000) N

= **35000 N**

(b) Mass of engine + 5 wagons $= 8000\,\text{kg} + 2000\,\text{kg} \times 5$

$= 18000$ kg

Applying $F = ma$

$\Rightarrow$ $35000 \text{ N} = 18000 \text{ kg} \times a$

$\therefore$ $a = \dfrac{35000 \text{ N}}{18000 \text{ kg}} = \mathbf{1.94 \text{ ms}^{-2}}$.

(c) Force of wagon 1 on wagon 2, $(F) = ma$

$= 2000 \text{ kg} \times 1.94 \text{ ms}^{-2}$

$=$ **3880 N.**

Q. 16 An automobile vehicle has mass of 1500 kg. What must be the force between the vehicle and the 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 $(a) = -1.7 \text{ ms}^{-2}$

$\therefore$ Force of friction between the road and vehicle $(F) = ma$

$\Rightarrow$ $F = 1500 \text{ kg} \times -1.7 \text{ ms}^{-2}$

$=$ **– 2550 N.**

Negative sign means force is acting in the direction opposite to the direction of motion of the vehicle.

Q. 17 What is the momentum of an object of mass m, moving with a velocity v? Choose the correct answer.

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

Ans. The correct answer is *mv*.

Q.18 Using a horizontal force of 200 N, we intend to move wooden cabinet across a floor at constant velocity. What is frictional 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.

Q. 19 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 combined object after collision.

Ans. The velocity of combined object will be zero.

Proof : Let the object be A and B moving from opposite direction is same straight line.

∴ Momentum of A $= m \times v = 1.5 \text{ kg} \times 2.5 \text{ ms}^{-1}$

$= 3.75 \text{ kg ms}^{-1}$

Also, momentum of B $= m \times -v = 1.5 \text{ kg} \times -2.5 \text{ ms}^{-1}$

$= -3.75 \text{ kg ms}^{-1}$

If, V is the velocity of the objects after collision, then :

Combined momentum after collision = 3 kg × V

By the law of conservation of momentum,

Combined momentum of A and B = Momentum of A + Momentum of B

$$3 \text{ kg} \times V = 3.75 \text{ kgms}^{-1} - 3.75 \text{ kgms}^{-1}$$

$$\Rightarrow \quad 3 \text{ kg} \times V = 0$$

$$\therefore \quad V = 0$$

Q. 20 According to the third law of motion, when we push an object, the object pushes back on us with 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 his logic and explain, why the truck does not move.

Ans. The logic of the boy is entirely wrong, because the truck is going to move only due to the unbalanced force which is produced when the boy pushes the earth with his feet in the backward direction. However, this force produced by the reaction of earth is insufficient to overcome the force of friction offered by the wheels of the truck and hence, it does not move.

Q. 21 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 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}

∴ Initial momentum of ball = mu^1 = 0.2 kg × 10 ms^{-1}

= 2 Ns

Final velocity of ball (u_2) = – 5 ms^{-1}

(Minus sign denotes that ball is moving in opposite direction.)

∴ Final momentum of ball = mu_2 = 0.2 kg × – 5 ms^{-1}

= –1 Ns

∴ Change in momentum = Final momentum – Initial momentum

= – 1 Ns – 2 Ns = **– 3 Ns.**

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

Q. 22. 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 0.3 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 [As the bullet comes to rest]

Time (t) = 0.3 s

Acceleration on bullet (a)= ? [To be calculated]

Distance penetrated by bullet (S)= ? [To be calculated]

Force acting on wooden block (F) = ? [To be calculated]

Applying, v = u + at

$\Rightarrow \quad 0 = 150\ ms^{-1} + a \times 0.3\ s$

$\Rightarrow \quad -a \times 0.3\ s = 150\ ms^{-1}$

$\therefore \quad a = -\dfrac{150\ ms^{-1}}{0.3\ s} = \mathbf{-500\ ms^{-2}}$

Applying, $S = ut + \dfrac{1}{2}at^2$

$= 150\ ms^{-1} \times 0.3\ s + \dfrac{1}{2} \times -500\ ms^{2}$

$\times (0.3\ s)^2$

$= 45\ m - 22.5\ m = \mathbf{22.5\ m}$

Applying, $F = ma$

Force acting on bullet (F)= 0.01 kg × – 500 ms^{-2} = **– 5 N.**

Minus sign denotes that wooden block exerts force in the direction, opposite to the direction of wooden block.

Q. 23 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 combined object.

Ans. For object : $m_1 = 1$ kg

$u_1 = 10\ ms^{-1}$

For wooden block : $m_2 = 5$ kg

$u_2 = 0$

$\therefore$ Momentum just before collision $= m_1u_1 + m_2u_2$

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

$= 10\ kg\ ms^{-1}$

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

Let velocity after collision $= v$

∴ Momentum after collision = 6 kg × v.

By the law of conservation of momentum,

Momentum after collision= Momentum before collision

$$\Rightarrow 6\text{ kg} \times \text{v} = 10\text{ kg ms}^{-1}$$

$$\therefore \quad \text{v} = \frac{10\text{ kg ms}^{-1}}{6\text{ kg}} = \mathbf{1.67\ ms^{-1}}.$$

Q. 24 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 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 ($p_{initial}$) = mu = 100 kg × 5 ms^{-1} = 500 Ns

Final momentum (p_{final}) = mv = 100 kg × 8 ms^{-1} = 800 Ns

$$\text{Force exerted on the object (F)} = \frac{mv - mu}{t}$$

$$= \frac{(800-500)\ \text{Ns}}{6\ \text{s}} = \frac{300\ \text{Ns}}{6\ \text{s}} = \mathbf{50\ N.}$$

Q.25 Akhtar, Kiran and Rahul were riding 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 insect suffered a greater change in momentum as compared to the change in momentum of the motorcar because the change in the velocity of insect was much more than that of the motorcar. Akhtar said that since the motor-car 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 motor-car and insect experienced the same force and a change in their momentum. Comment on these suggestions.

Ans. Kiran's suggestion is incorrect as momentum is always conserved, i.e., change in momentum of insect must be equal to that of motorcar.

Akhtar's suggestion is incorrect for the same reason as above.

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.

Q. 26 How much momentum will a dumbbell of mass 10 kg transfer to the floor, if it falls from a height of 80 cm? Take downward acceleration to be 10 ms^{-2}.

Ans. Mass of dumb-bell (m) = 10 kg

Initial velocity (u) = 0 [On same height its velocity is zero]

Final velocity (v) = ? [To be calculated]

Distance (S) = 80 cm = 0.8 m

Acceleration (a) = 10 ms^{-2}

Applying, $v^2 = u^2 + 2aS$

$\Rightarrow \quad v^2 = (0)^2 + 2 \times 10 \text{ ms}^{-2} \times 0.8 \text{ m}$

$\Rightarrow \quad v^2 = 16 \text{ m}^2\text{s}^{-2}$

$\therefore \quad v = \sqrt{16 \text{ m}^2\text{s}^{-2}} = 4 \text{ ms}^{-1}$

$\therefore$ Momentum of dumbbell transferred to ground = mv

= 10 kg × 4 ms^{-1} = 40 **Ns.**

Q. 27 The following is the distance-time table of an object in motion.

Time in seconds	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Distance in metres	**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 forces acting on the object?

Ans. (a) When body is initially at rest, its acceleration can be calculated by using the formula $\boldsymbol{a} = \frac{2\,\boldsymbol{S}}{\boldsymbol{t}^2}$. The table given below shows the acceleration of body.

Time in seconds	0	1	2	3	4	5	6	7
Distance in metres	0	1	8	27	64	125	216	343
Acceleration, $a = \frac{2\,S}{t^2}$ in ms^{-2}	0	2	4	6	8	10	12	14

From the table above, it clear that acceleration of body is increasing with time, i.e., it is moving with variable acceleration.

(b) As the acceleration is increasing with time, therefore, the body is acted upon by unbalanced forces.

Q. 28 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 same muscular effort.]

Ans. As two person can make the motorcar to move with uniform velocity, it is obvious that total force applied by them on the motorcar is balanced with the force of friction acting in the opposite direction.

From the above discussion, it is clear that it is the force of one more person which produces an acceleration of 0.2 ms^{-2}.

∴ Force of one person = Mass × Acceleration

= 1200 kg × 0.2 ms^{-2} = **240 N.**

Q.29 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 nail on the hammer?

Ans. The force of nail on the hammer F

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

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

$$= \frac{0.50\ \text{kg}\left(0 - 50\ \text{ms}^{-1}\right)}{0.01\ \text{s}} = \mathbf{-2500\ N.}$$

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

Q. 30 A motorcar of mass 1200 kg is moving along a straight line with uniform velocity of 90 kmh^{-1}. Its velocity is slowed down to 18 kmh^{-1} in 4 s, by an unbalanced external force. Calculate the acceleration and change in momentum. Also calculate the magnitude of force required.

Ans. (i) Initial velocity of the car (u) = 90 kmh^{-1} = 25 ms^{-1}

Final velocity of the car (v) = 18 kmh^{-1}

= 5 ms^{-1}

Time (t) = 4 s

Acceleration (a) = ? (To be calculated)

Applying, $v = u + at$

$$\Rightarrow \quad 5\ ms^{-1} = 25\ ms^{-1} + a \times 4\ s$$

$$\therefore \quad -a \times 4\ s = 20\ ms^{-1}$$

$$\Rightarrow \quad a = -\frac{20\ ms^{-1}}{4\ s} = \mathbf{-5\ ms^{-2}.}$$

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

$$= 1200\ kg\ (5\ ms^{-1} - 25\ ms^{-1})$$

$$= 1200\ kg \times -20\ ms^{-1}$$

$$= \mathbf{-24000\ Ns.}$$

(iii) Magnitude of force (F) $= \dfrac{m(v-u)}{t}$

$$= \frac{-24000\ Ns}{4\ s} = \mathbf{-6000\ N.}$$

Q. 31. A large truck and a car, both moving with a velocity of magnitude v, have a head on collision and both of them come to halt after that. If the collision lasts for 1 second.

(a) Which vehicle experiences the greater force of impact?

(b) Which vehicle experiences the greater change in momentum?

(c) Which vehicle experiences the greater acceleration?

(d) Why is the car likely to suffer more damage than the truck?

Ans. (a) Both vehicles experience same force of impact as the action and reaction are equal and opposite.

(b) The truck experiences a greater change in momentum on account of its greater mass.

(c) The car experiences a greater change in acceleration, as the force remaining same, the acceleration is inversely proportional to the mass.

(d) The car will suffer more damage, because of greater change in acceleration.