CHAPTER 9

Force and Laws of Motion

EXAM DRILL

ANSWERS

1. If on applying same force on the bodies, same acceleration is produced, then their inertial masses are same.

2. No, as the masses of two bodies on which action-reaction apply may be different. If the masses of bodies are same, then the magnitude of acceleration will be same.

3(i) $m_1 = 40$ kg, $u_1 = 4$ m/s and

$m_2 = 60$ kg, $u_2 = 3$ m/s

The total momentum of the two skaters before the collision

$m_1 u_1 - m_2 u_2 = 40 \times 4 - 60 \times 3$

$= -20$ kg m/s

3(ii) Let v be the velocity of the two entangled skaters after the collision, then the total momentum is

$= (m_1 + m_2) \times v$

$= (40 + 60) \times v = 100\,v$ kg m/s

3(iii) According to the law of conservation of momentum, equating the momenta of the system before and after collision we get,

$100 \times v = -20$

$\therefore \quad v = -\frac{20}{100} = -0.2$ m/s

3(iv) Two skaters moves with a velocity $-$ 0.2 m/s after collision. Negative sign shows that they will move together in west direction.

4(i)

Time (s)	Distance (m)	Velocity $= \frac{d_2 - d_1}{t}$ (m/s)
2	8	$\frac{8-0}{2} = 4$
4	64	$\frac{64-8}{2} = 28$
6	216	$\frac{216-64}{2} = 76$
8	512	$\frac{512-216}{2} = 148$
10	1000	$\frac{1000-512}{2} = 244$

4(ii) Forces acting on the object are increasing with time, since acceleration is increasing with time.

4(iii) **(a) :** From the above table we can see that velocity is changing in unequal amount in equal intervals of time. Therefore, acceleration is non-uniform. Since the velocity is increasing with time, we can say that acceleration is increasing non-uniformly.

4(iv) **(b) :** Newton's second law of motion can be used to calculate the force acting on an object in motion

i.e., Force = mass × acceleration

5. **(d) :** Conservation of momentum in a collision between particles can be understood from both Newton's second and third law.

6. **(c) :** The inertia of a body is directly proportional to its mass.

So, $\frac{\text{inertia of father}}{\text{inertia of son}} = \frac{\text{mass of father}}{\text{mass of son}} = \frac{60\text{ kg}}{30\text{ kg}} = \frac{2}{1}$

OR

(c) : An opposing force of friction acts on the ball.

7. **(a)**

8. **(a) :** According to newton's third law of motion, the boat will move away from the shore.

OR

(d) : Momentum measures the amount of motion of a body.

9. **(d) :** The greater the change in the momentum in a given time, the greater is the force that needs to be applied.

10. **(c) :** $a = \frac{v}{t} = \frac{30\text{ m/s}}{8.0\text{ s}} = 3.75\text{ ms}^{-2}$

$\therefore \quad F = ma = (2800\text{ kg})(3.75\text{ m s}^{-2}) = 10500$ N

OR

(a) : Force is the rate of change of momentum.

So, momentum is constant when force is zero.

If p = constant, then no force acts on the body.

11. **(d) :** When no external force acts on a system, the linear momentum is constant. When external forces act on the system, the linear momentum of a system can change.

12. **(d) :** Linear momentum, $p = mV$.

As $V = 0$, therefore $p = 0$.

13. **(a) :** In quick collision, time of impact is small which increases the impact of force.

14. **(a) :** When net force due to all external forces is zero, a body at rest will continue to be at rest.

15. **(a)** The passengers in a speeding bus have inertia of motion. When the bus is suddenly stopped the feet of passengers comes to rest, while the body is still tends to be in motion due to inertia and hence thrown forward.

(b) When ground is covered with snow or sand, our foot can exert much smaller force in the form of backward action.

16. No because the combined momentum of the ball and the earth is conserved. The ball attracts the earth by the same force as the earth attracts the ball. When the ball moves upward, its momentum decreases in the upward direction but simultaneously the momentum of the earth decreases in the downward direction at the same rate. Similarly, when the ball falls down, its momentum increases in the downward direction but simultaneously the momentum of the earth increases in the upward direction at the same rate.

17. According to Galileo, no force was needed to keep a body in constant velocity which means the natural state of a body is to oppose the change in its state of motion. Galileo gave this remarkable conclusion, not only by pure thinking but by doing experiments. From the experimental observation Galileo argued that if a body is in motion, it will continue to move with the same speed, and along the same straight line path provided it is not affected by any external act. Uniform motion along a straight line did not require any force to maintain it. Sir Isaac Newton developed these conclusions in the form of his famous three laws of motion.

18. Let the masses of the two objects be $3x$ and $5x$. Let F_1 and F_2 be the two forces with accelerations a_1 and a_2 respectively.

$\therefore$ $F_1 = 3xa_1$ and $F_2 = 5xa_2$

Since, $\frac{F_1}{F_2} = \frac{5}{3}$ (given)

$\therefore$ $\frac{3xa_1}{5xa_2} = \frac{5}{3}$ or $\frac{a_1}{a_2} = \frac{25}{9}$

19. Given m = mass of bullet = 50 g = 0.050 kg

M = mass of tiger = 60 kg

v = Velocity of bullet = 75 m s^{-1}

V = Velocity of tiger = –10 m s^{-1}

($\because$ it is coming from opposite direction)

n = no. of bullets fired per second at the tiger so as to stop him.

p_i = momentum of the system before firing

$p_f = n(mv) + MV$

$\because$ From the law of conservation of momentum,

$p_i = p_f$

$\Rightarrow$ $0 = n(mv) + MV$

$\Rightarrow$ $n = -\frac{MV}{mv} = \frac{-60\times(-10)}{0.05\times75} = 160$

20. Given, mass of the cricket ball, m = 0.2 kg

initial velocity of ball, u = 20 m/s

Final velocity, $v = 0$

Time taken by the ball to come to rest, t = 0.4 s

Thus, $a = \frac{v-u}{t} = \frac{0-20}{0.4}$ $\Rightarrow$ $a = -50$ m s^{-2}

So, force required to stop the ball,

$F = ma$ = (0.2 kg) (50 m/s^2) = 10 N

OR

(a) A karate player applies the blow with large velocity in a very short interval of time on the ice slab which therefore exerts large amount of force on it and suddenly breaks the ice slab.

(b) A vehicle moving on mountains is in the inertia of motion. At a sudden turn there is a tendency of the vehicle to fall of the road due to sudden change in the line of motion. Hence the roads are inclined inwards so that the vehicle does not fall down the mountain.

21. Mass of a bullet is much greater than the mass of an air molecule. Therefore, even when both have almost the same speed, linear momentum of bullet is much larger than the linear momentum of an air molecule. Hence the force required to stop a bullet will be much bigger than the force required to stop an air molecule. That is why a bullet fired from a gun is more dangerous than an air molecule.

22. Here $v = 0$, u = 80 m s^{-1}

$\therefore$ Acceleration, $a = \frac{v-u}{t} = \frac{0-80}{8} = -10\text{ m s}^{-2}$

Frictional force of the floor on the ball,

$$F = ma = \frac{50}{1000}\times(-10) = -0.5\text{ N}$$

The minus sign represents retarding force.

OR

(a) Yes it is possible. Newton's first law tells us that motion requires no force. An object in motion continues to move at constant velocity in the absence of external forces.

(b) Yes it is also possible. A stationary object can have several forces acting on it, but if the sum of all these external forces is zero, there is no net force and the object remains stationary.

23. Newton's first law explains about the unbalanced force required to bring change in the position of the body.

Second law explains about the amount of force required to produce a given acceleration.

Newton's third law explains how these forces acting on a body are interrelated.

OR

Three examples based on Newton's third law are :

(i) Swimming : We push the water backward to move forward.

action - water is pushed behind

reaction - water pushes the swimmer ahead

(ii) Firing gun : A bullet fired from a gun and the gun recoils.

action - gun exerts force on the bullet

reaction - bullet exerts an equal and opposite force on the gun

(iii) Launching of rocket

action - hot gases from the rocket are released

reaction - the gases exert upward push to the rocket

24. Initial momentum of the first sphere $= m_1u_1$

$= 0.1 \times 3 = 0.3$ kg m s^{-1}

Initial momentum of the second sphere $= m_2u_2$

$= 0.2 \times 2 = 0.4$ kg m s^{-1}

After the collision,

Final momentum of the first sphere $= m_1v_1$

$= 0.1 \times 2.5 = 0.25$ kg m s^{-1}

Final momentum of the second sphere $= m_2v_2$

$= 0.2 \times v_2$ kg m s^{-1}

where v_2 is the velocity of the second sphere after collision.

Now, according to conservation of linear momentum,

initial momentum = final momentum

$\therefore \quad m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$

$(0.3 + 0.4) = (0.25 + 0.2\, v_2)$

or $\quad 0.2\, v_2 = 0.7 - 0.25$ or $0.2\, v_2 = 0.45$

or $\quad v_2 = \dfrac{0.45}{0.2} = 2.25$ m s^{-1}

25. Suppose m = mass of a body, u = initial velocity of the body along a straight line,

F = an external force applied on the body, which is constant in magnitude,

t = time for which the force is applied,

v = final velocity of the body along the same straight line, after t second.

Initial linear momentum of the body, $p_1 = mu$

Final linear momentum of the body, $p_2 = mv$

Change in linear momentum fo the body $= p_2 - p_1 = mv - mu$ $= m(v - u)$

According to second law of motion,

$$F \propto \frac{\text{Change in linear momentum}}{\text{time taken}} = \frac{m(v-u)}{t} \quad \text{...(i)}$$

But $\dfrac{(v-u)}{t} = \dfrac{\text{change in velocity}}{\text{time taken}}$ = rate of change of velocity = acceleration of the body = a

Therefore, from eqn. (i), $F \propto ma$

or $\quad F = kma \quad$ ...(ii)

where k is a constant of proportionality.

One unit of force is defined as the amount which produces unit acceleration in a body of unit mass, *i.e.*, $a = 1$ m s^{-2}

$\therefore \quad$ 1 unit of force $= k \times 1$ kg $\times$ 1 m s^{-2} or $k = 1$.

Putting this value of k in eqn. (ii), we get, $F = ma$

This is the mathematical form of Newton's second law of motion. It states that force acting on a body is the product of mass and acceleration of the body.

26. Inertia : The natural tendency of an object to resist change in their state of rest or of motion is called inertia.

The mass of an object is a measure of its inertia.

Types of inertia

Inertia of rest: The object at rest will continue to remain at rest unless acted upon by an external unbalanced force.

Inertia of motion: The object in the state of uniform motion will continue to remain in motion with same speed unless it is acted upon by an external unbalanced force.

Inertia of direction: An object moving along a straight line will continue to move along the same direction unless some external force acts on the object.

Three examples of inertia in daily life are:

(i) When we are travelling in a vehicle and suddenly brakes are applied, we tend to fall forward.

(ii) When we shake the branch of a tree vigorously, leaves fall down.

(iii) If we want to remove the dust from carpet we beat the carpet so that dust fall down.

27. (a) Newton's first law of motion : An object remains in a state of rest or uniform motion in a straight line unless acted upon by an external unbalanced force.

Newton's second law of motion : The rate of change of momentum of an object is directly proportional to the applied unbalanced force in the direction of the force.

Newton's third law of motion : To every action, there is an equal and opposite reaction. And the forces of action and reaction always acts on two different bodies.

(b) Momentum of the particle,

$p = mv = 9 \times 10^{-25} \times 6 \times 10^{2}$

$= 54 \times 10^{-23}$ kg m s^{-1} $= 5.4 \times 10^{-22}$ kg m s^{-1}

OR

Mass the car, $m = 1500$ kg

Let us calculate the value of acceleration by using the first equation of motion.

Initial velocity, $u = 0$ (car starts from rest)

Final velocity, $v = 30$ m/s
Time taken, $t = 10$ s
Now, putting these values in the equation

$v = u + at$

we get, $30 = 0 + a \times 10$

$10a = 30$

$a = \frac{30}{10}$ m s^{-2} = 3 m s^{-2}

Now, $F = m \times a$
or $F = 1500 \times 3$ N = 4500 N
Thus, the force required in this case is 4500 N.

28. (a) Here, mass of car, $m = 1000$ kg
distance, s = ?
In the first two seconds, the speed-time graph is OA.
s = area of ΔOAE

$= \frac{\text{base} \times \text{height}}{2} = \frac{OE \times EA}{2}$

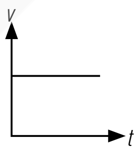
$s = \frac{2 \times 15}{2} = 15$ m

(b) Initial speed, u = 15 m s^{-1}
final speed, $v = 0$
time taken, $t = 1$ s
braking force, F = ?

As $F = ma = \frac{m(v-u)}{t}$, $F = \frac{1000\,(0-15)}{1}$
$F = -15000$ N
Negative sign is for opposing force.

29. (a) In cricket field, the fielder gradually pulls his hands backward while catching a ball. The fielder catches the ball and gives swing to his hand to increase the time during which the high velocity of the moving ball decreases to zero.
The acceleration of the ball is decreased and therefore the impact of catching the fast moving ball is reduced.
If not done so, then the fast moving ball will exert large force and may hurt the fielder.

(b) Net external force = zero.
It means, acceleration $\left(a = \frac{F}{m}\right)$ of the particle is zero.



In other words, particle is moving with constant velocity. Velocity-time graph of such a particle is represented by a curve parallel to time-axis.

OR

For bullet
mass, $m_1 = 0.03$ kg
initial velocity, $u_1 = 0$
Final velocity, $v_1 = 100$ m/s

For rifle,
mass, $m_2 = 3$ kg
initial velocity, $u_2 = 0$
final velocity, v_2 = ?
Now, according to law of conservation of momentum
$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$
$0 = 0.03 \times 100 + 3v_2$
$\therefore \quad v_2 = -1$ m/s
Here, negative sign means that the direction of velocity of rifle is opposite to that of bullet.

Now, acceleration of the rifle, $a = \frac{v_2 - u_2}{t} = \frac{v_2 - 0}{0.003}$ m/s^2

or $a = \frac{-1}{0.003}$ m/s^2

$\therefore$ Force on the rifle, $F = m \times a$

$F = 3 \times \frac{-1}{0.003}$ m/s^2 = -1000 N

Negative sign shows that the force of recoil is opposite to the direction of velocity of the bullet.

30. Before breaking, the body was at rest. The linear momentum of the body was thus $p = mv = 0$.
The body breaks due to internal forces. As the external force acting on it is zero, its linear momentum will remain constant, *i.e.*, zero.
The linear momentum of the first part is
$p_1 = m_1v_1$ = (200 g)(12 m s^{-1}), towards the east. For the total momentum to remain zero, the linear momentum of the other part must have the same magnitude and should be opposite in direction. It therefore moves towards the west. If its speed is v_2, its linear momentum is
$p_2 = m_2v_2$ = (100 g)v_2.
Thus, (200 g)(12 m s^{-1}) = (100 g)v_2
or v_2 = 24 m s^{-1}.
The velocity of the other part is 24 m s^{-1} towards west.

OR

(a) kg m s^{-1} = mass $\times$ velocity = linear momentum
N-s = (kg m s^{-2}) $\times$ s = kg $\times$ m s^{-1} = linear momentum

(b) Crockery is wrapped in straw or papers to avoid breakage. In case of mishandling, the impact takes longer time to travel to crockery through straw/papers. As t increases, F decreases, *i.e.*, impact on crockery reduces, preventing the chances of breakage.

(c) From $F = ma$, $m_1 = \frac{F}{a_1} = \frac{5}{8}$ kg and $m_2 = \frac{F}{a_2} = \frac{5}{24}$ kg

Total mass, $m = m_1 + m_2 = \frac{5}{8} + \frac{5}{24} = \frac{15+5}{24} = \frac{20}{24}$ kg

Net acceleration, $a = \frac{F}{m} = \frac{5}{20/24} = 6$ m s^{-2}