Laws of motion

Note : Answers given below are intended only as a reference for the questions asked in board examinations. These answers are NOT an attempt at a detailed discussion related to the question.

VSAQs

1. What is the law of inertia? Which scientist formulated it?

Inertia is the property of a body by the virtue of which it tends to oppose any change in its state of rest or of uniform motion in a straight line.
Mass is the measure of inertia.

2. What do you understand by the term momentum?

Linear momentum ($\boldsymbol{p}$) is defined as the product of the mass (m) of the body and its linear velocity ($\boldsymbol{v}$).

$$\boldsymbol{p} = m\,\boldsymbol{v}$$

It is a vector quantity and its SI unit is kg ms^{-1}.

3. Write the SI units of momentum in (a) CGS system (b) SI system

CGS unit of momentum is g cms^{-1}. SI unit of momentum is kg ms^{-1}.

4. Define absolute units of force in CGS as well as SI system.

In CGS system, unit of force is dyne. One dyne is the amount of force required to give a mass of 1 gram an acceleration of 1 cms^{-2}.

In SI, unit of force is newton (N). One newton is the amount of force required to give a mass of 1 kilogram an acceleration of 1 ms^{-2}.

5. State principle of conservation of linear momentum.

If the net external force acting on the system is zero, then the total linear momentum f the system remains constant.

$$\boldsymbol{F} = \frac{\mathrm{d}\boldsymbol{p}}{\mathrm{d}t}$$

If $\boldsymbol{F} = 0$

$$\frac{\mathrm{d}\boldsymbol{p}}{\mathrm{d}t} = 0$$

$$\Rightarrow \boldsymbol{p} = \text{ constant}$$

6. When a bullet is fired from a gun, the gun gives a kick in the backward direction. Explain.

Initial momentum (p_i) of the bullet and gun system is zero.

$$\overline{p}_i = 0$$

Final momentum of the system is given by

$$\overline{p}_f = m_B\overline{v}_B + m_G\overline{v}_G$$

Firing of a bullet is due to the action of internal forces and hence there is no change in momentum of the system. Using conservation of momentum we get

$$\overline{p}_f = \overline{p}_i$$

$$m_B\overline{v}_B + m_G\overline{v}_G = 0$$

$$\overline{v}_G = -\frac{m_B\overline{v}_B}{m_G}$$

Negative sign indicates that the gun recoils in a direction opposite to that of the bullet.

7. Why does a cricketer pull his hands back while catching the ball?

Catching a ball involves a certain amount of change in its momentum. This change in momentum is the product of force ($\boldsymbol{F}$) and time (dt).

$$\boldsymbol{J} = \boldsymbol{F}\,\mathrm{d}t$$

Pulling the hands back increases time of interaction between the ball and the hand and therefore lesser force acts on the ball (and on the hand) as the ball comes to rest.

8. Why does a heavy rifle not recoil as strongly as a light rifle using the same cartridges?

Initial momentum (p_i) of the bullet and gun system is zero.

$$\overline{p}_i = 0$$

Final momentum of the system is given by

$$\overline{p}_f = m_B\overline{v}_B + m_G\overline{v}_G$$

Firing of a bullet is due to the action of internal forces and hence there is no change in momentum of the system. Using conservation of momentum we get

$$\overline{p}_f = \overline{p}_i$$

$$m_B\overline{v}_B + m_G\overline{v}_G = 0$$

$$\overline{v}_G = -\frac{m_B\overline{v}_B}{m_G}$$

From the above relation it is observed that as the mass of the gun is increased (while using the same cartridges) its recoil velocity decreases.

9. If a bomb at rest explodes into two pieces, the pieces must travel in opposite directions. Explain.

Initial momentum (p_i) of the unexploded bomb is zero.

$$\overline{p}_i = 0$$

Final momentum of the two fragments is given by

$$\overline{p}_f = m_1\overline{v}_1 + m_2\overline{v}_2$$

Explosion is due to the action of internal forces and hence there is no change in momentum of the system. Using conservation of momentum we get

$$\overline{p}_f = \overline{p}_i$$

$$m_1\overline{v}_1 + m_2\overline{v}_2 = 0$$

$$m_1\overline{v}_1 = -m_2\overline{v}_2$$

Negative sign indicates that the fragments move in opposite directions. Therefore it is observed that fragments

10. Define force. What are the basic forces in nature?

Quantitatively net force acting on a body is equal to the rate of change of momentum of a body. Qualitatively force is an agent that causes a change in the state (size, shape, motion) of a body. Four basic forces in nature are (i) strong nuclear forces (ii) weak nuclear forces (ii) electromagnetic forces (iv) gravitational forces

11. Define one newton.

One newton is the amount of force required to give a mass of 1 kilogram an acceleration of 1 ms^{-2}.

12. What do you understand by impulse? Write its SI unit.

Impulse is defined as the product force and the small interval of time for which the force acts.

$$\boldsymbol{J} = \boldsymbol{F}\,\mathrm{d}t$$

Its SI unit is Ns.

13. Explain the following

(a) Why do we jerk wet clothes before spreading them on a rope?

When the wet cloth is jerked, it is set into a sudden motion, while the drops remain at rest due to inertia. This separates the water drops from the cloth.

(b) Why does dust fly off when a carpet is hit with a stick?

When the carpet is hit with a stick, it is set into a sudden motion. Dust particles on it continue to remain at rest due to inertia. This separates the dust particles from the carpet.

(c) Why do fruits fall off the branches in a strong wind?

Wind causes the branches to sway with it. When the wind changes speed or direction suddenly, the branches also move accordingly. Fruits, due to their larger mass, cannot change their state of rest (or motion) suddenly and are therefore detached from branches and fall off.

14. Can coefficient of friction be greater than one? Give a reason.

Coefficient of friction may be greater than one. This occurs when there are strong adhesive forces between the atoms/molecules of the two surfaces in contact.
Example : silicone rubber

15. What happens to coefficient of friction if the weight of the body is doubled?

There is no change in coefficient of friction as coefficient of friction only depends on the nature of surfaces in contact.

16. Why does the car with a flattened tyre stop sooner than the one with inflated tyres?

Car with flat tyres comes to rest due to

(a) Nature of the surfaces in contact changes

(b) Area of contact surface increases

17. A horse has to pull harder during the start of the motion than later. Explain.

To set a body into motion we have to overcome the limiting frictional force. To sustain motion we have to overcome sliding/kinetic frictional force. Limiting friction force is greater than sliding/rolling frictional force hence it is harder to start the motion.

SAQs

1. What do you understand by the term inertia? What are its kinds? Give to examples of each kind.

Refer to class notes (click here for PDF)

2. State Newton's three laws of motion. Give one example each to explain the first and the third laws.

Refer to class notes (click here for PDF) slides 2, 5 & 10

3. State Newton's second law of motion and hence derive $F = ma$ from it.

Newton's 2nd law : The rate of change of momentum of a body is equal to the net force acting and takes place in the direction of the net force

$$F \propto \frac{\mathrm{d}\bar{p}}{\mathrm{d}t}$$

$$F = k\,\frac{\mathrm{d}\bar{p}}{\mathrm{d}t} \quad \text{where k is a constant}$$

$$F = k\,\frac{\mathrm{d}(m\bar{v})}{\mathrm{d}t}$$

Assuming mass of the body to remains constant during the motion

$$F = k\ m\,\frac{\mathrm{d}(\bar{v})}{\mathrm{d}t}$$

$$F = k\ m\bar{a}$$

The value of k is set to one in order to define one newton of force. Hence we get

$$F = m\bar{a}$$

4. State Newton's three laws and discuss their significance.

1st law : Every body continues to be in a state of rest or of uniform motion in a straight line unless exerted upon by an external force.

Newton's first law defines inertia and equilibrium of a body.

The property of a body by which it tends to continue its state (of rest or of uniform motion in a straight line) is called inertia.

Laws of motion

Equilibrium is a state characterized by the net force acting on the body being zero.

2nd law : Rate of change of linear momentum of a body is directly proportional to the net external force acting on it and takes place in the direction of the applied force.

$$\boxed{\boldsymbol{F}_{\text{net}} = k\frac{d\boldsymbol{p}}{dt}}$$

Newton's second law gives us a quantitive definition of force

3rd law : Action and reaction are two forces of equal magnitude, opposite direction and acting on two different bodies.

$$\boldsymbol{F}_{\text{action}} = -\boldsymbol{F}_{\text{reaction}}$$

The third law tells us that forces always act in pairs.

5. What do you understand by the following terms? Give examples of each one.

(a) Contact forces (b) Non-contact forces

Refer to class notes (click here for PDF)

6. Show that impulse is the change in momentum.

Refer to class notes (click here for PDF)

7. Why are shock absorbers used in motorcycles and cars?

Shock absorbers are used in vehicles to reduce the force acting on the vehicles due to changes in momentum as the vehicles pass on a rough road.

Let the change in momentum in a vehicle as it passes over a uneven road be Δp. Then we get

$$\Delta\bar{p} = \bar{F}\,\mathrm{d}t$$

Due to the presence of shock absorbers, time of interaction increases and it results in decreases in the amount of force n the vehicle (for the same change in momentum). This reduces the damage to the vehicle.

8. Define the terms momentum and impulse. State and explain the law of conservation of linear momentum. Give examples.

Linear momentum is defined as the product of mass of a body and its velocity.

$$\bar{p} = m\bar{v}$$

Impulse is defined as the product of force and the small interval of time for which the force acts on a body.

$$\boldsymbol{J} = \boldsymbol{F}\,\mathrm{d}t$$

Law of conservation of linear momentum

When the net external force acting on a system is zero then the total linear momentum of the system remains constant.

$$\bar{F} = \frac{\mathrm{d}\bar{p}}{\mathrm{d}t}$$

When the applied force is zero then we get

$$\frac{\mathrm{d}\bar{p}}{\mathrm{d}t} = 0$$

Therefore p = constant

Example : recoil of a gun when a bullet is fired from it

9. Explain the terms limiting friction, dynamic friction and rolling friction.

Limiting friction : The maximum possible value of static friction acting on a body is called limiting friction

$F_{lim} = \mu_s N$

Dynamic friction : Frictional force that acts on a body which in sliding motion relative to the contact surface is called dynamic friction.

$F_k = \mu_k N$

Rolling friction : Frictional force that acts on a body which rolling over the surface with which it is in contact is called rolling friction.

$F_r = \mu_r N$

10. Explain advantages and disadvantages of friction

Refer to class notes (click here for PDF)

11. Mention methods to decrease friction

Refer to class notes (click here for PDF)

12. Under what condition will a car skid on a leveled surface road?

Refer to class notes (click here for PDF)

13. Briefly explain centrifugal force with suitable examples.

Refer to class notes (click here for PDF)

14. Derive an expression for maximum velocity of a car moving in a circular motion on a level road.

Refer to class notes (click here for PDF)

15. Determine the maximum acceleration of a train in which a box lying on its floor will remain stationary given that the coefficient of static friction between the box and the train's floor is 0.18.

Coefficient of static friction is 0.18

Therefore the maximum frictional force on it is

$F = \mu mg$

This force can cause the body to accelerate along with the train so that it remains stationary with respect to the train. Therefore

$ma = \mu mg$

$a = \mu g$

$a = 0.18 \times 9.8$

$a = 1.76\ ms^{-2}$

LAQs

1. Derive an expression for maximum velocity of a car moving in a circular motion on a banked road.
   Refer to class notes (click here for PDF)