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 inertia? What gives the measure of inertia?

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. According to Newton's third law every force is accompanied by an equal and opposite force. How can movement ever take place?

Movement of bodies is possible because though the forces of action and reaction are equal in magnitude and opposite in direction, they do not get cancelled as they act on two different bodies.

3. 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.

4. 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.

5. 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.

$\bar{p}_i = 0$

Final momentum of the two fragments is given by

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

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

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

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

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

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

6. 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

7. Can coefficient of friction be greater than one?

Coefficient of friction may be greater than one. Example : silicone rubber

8. 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

9. 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.

10. 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.

SAQs

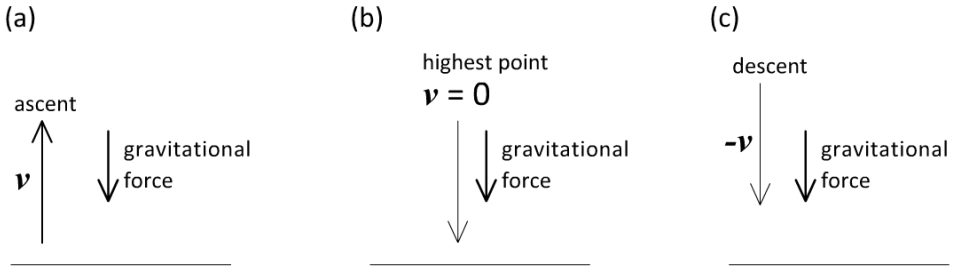
1. A stone of mass 0.1 kg is thrown vertically upwards. Give the magnitude and direction of the net force on the stone (a) during upward motion (b) during its downward motion (c) at the highest point where it momentarily comes to rest

Neglecting the effect of air drag, the gravitational force acting on the body is always downwards.
Magnitude of the gravitational force is

$F = mg$

F = 0.1 x 9.8

F = 0.98 N



2. 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

3. 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.

4. 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.

$F_r = \mu_r N$

5. Explain advantages and disadvantages of friction

Refer to class notes (click here for PDF)

6. Mention methods to decrease friction

Refer to class notes (click here for PDF)

7. State law of rolling friction.

(a) Rolling friction is proportional to the normal reaction of the body
(b) Rolling friction depends on the area of contact surface
(c) Rolling friction depends of the radius of curvature of the body

8. Why is pulling the lawn roller preferred to pushing it?

Consider a lawn roller of mass m. Let a force F be applied to it at an angle θ w.r.t. the horizontal.

Case I (pushing the lawn roller)

Considering horizontal components of forces we get

$$F_f - F\cos(\theta) = 0$$

$$\mu_r N = F\cos(\theta) \quad \text{--- (i)}$$

Considering vertical components of forces we get

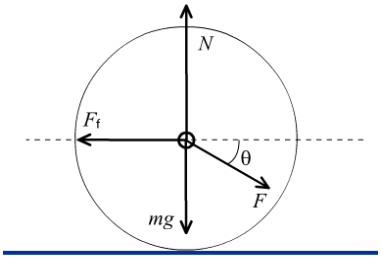
$$N - mg - F\sin(\theta) = 0$$

$$N = mg + F\sin(\theta) \quad \text{--- (ii)}$$

Substituting this in eq(i) we get

$$\mu_r \left[mg + F\sin(\theta)\right] = F\cos(\theta)$$

$$F_{push} = \frac{\mu_r mg}{\left[\cos(\theta) - \mu_r \sin(\theta)\right]}$$



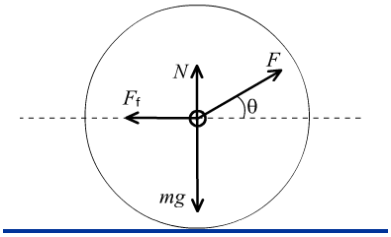
Pushing the lawn roller

Case II (pulling the lawn roller)

Considering horizontal components of forces we get

$$F_f - F\cos(\theta) = 0$$

$$\mu_r N = F\cos(\theta) \quad \text{--- (i)}$$



Pulling the lawn roller

Considering vertical components of forces we get

$$N + F\sin(\theta) - mg = 0$$

$$N = mg - F\sin(\theta) \quad \text{--- (ii)}$$

Substituting this in eq (i) we get

$$\mu_r\left[mg - F\sin(\theta)\right] = F\cos(\theta)$$

$$F_{pull} = \frac{\mu_r mg}{\left[\cos(\theta) + \mu_r \sin(\theta)\right]}$$

LAQs

1. (a) State Newton's second law of motion and hence derive $F = ma$ from it.

(b) A body is moving in a circular path so that its speed always remains constant. Should there be force acting on the body?

(a) 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

$$F \propto \frac{d\bar{p}}{dt}$$

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

$$F = k\frac{d(m\bar{v})}{dt}$$

Assuming mass of the body to remains constant during the motion

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

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

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

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

(b) Yes, there should be a net force acting on a body moving in a circular path with uniform speed as there is a continuous change in velocity due to change in direction of motion. This change in velocity is acceleration that is caused by the force (called centripetal force).

Laws of motion

2. A block of mass 4 kg is resting on a rough horizontal plane and is about to move when a horizontal force of 30N is applied on it. If g = 10 ms^{-2}, find the total contact force exerted by the plane on the block.

Considering horizontal components of forces

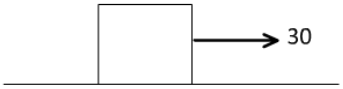
$30 - F_f = 0$

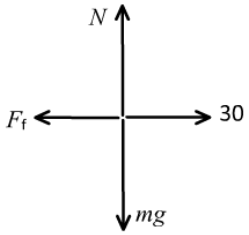
$F_f = 30$ --- (i)

Considering vertical component of forces

$N - mg = 0$

$N = 40$ --- (ii)





Total force exerted by the ground is

$F = \sqrt{F_f^2 + N^2}$

$F = \sqrt{30^2 + 40^2}$

$F = 50$ N