



Chapter # 3

Dynamics



Student Learning Outcomes

After completing this chapter, students will be able to:

- Illustrate that mass is a measure of the quantity of matter in an object
- Explain that the mass of an object resists change from its state of rest or motion (inertia)
- Describe universal gravitation and gravity. State Newton's Law of gravitation. (Include problems related to gravitation.)
- Define and calculate weight [weight is the force exerted on an object having mass by a planet's gravity and use $w = mg$]
- Define and calculate gravitational field strength [This includes being able to state that a gravitational field is a region in which a mass experiences a force due to gravitational attraction. Students should be able to define gravitational field strength (g) as force per unit mass use the equation gravitational field strength = weight/mass $g = w/m$ (and know that this is equivalent to the acceleration of free fall)]
- Justify and illustrate that use of mechanical and electronic balances to measure mass [understanding the internal workings of the electronic balance is not required; just how to practically use the instrument in appropriate situations]
- Justify and illustrate the use of a force meter (spring balance) to measure weight.
- Differentiate between contact and noncontact forces
- Differentiate between different types of forces [including weight (gravitational force), friction, drag, air resistance, tension (elastic force), electrostatic force, magnetic force, thrust (driving force), and contact force]
- State that there are four fundamental forces and describe them in terms of their relative strengths [These are the gravitational, electromagnetic, strong and weak nuclear forces Students should know that Pakistani scientist won the Noble Prize for helping prove that the weak force and the electromagnetic force are actually unified]
- Represent the forces acting on a body using free body diagrams
- State and apply Newton's first law
- Identify the effect of force on velocity [It may change the velocity of an object by changing its direction of motion or its speed]
- Determine the resultant of two or more forces acting in the same plane
- State and apply Newton's second law in terms of acceleration
- State and apply Newton's third law.
- Explain with examples how Newton's third law describes pairs of forces of the same type acting on different objects

- State the limitations of Newton's laws of motion
- Describe and identify states of equilibrium
- Analyse the dissipative effect of friction
- Analyse the dynamics of an object reaching terminal velocity
- Differentiate qualitatively between rolling and sliding friction
- Justify methods to reduce friction
- Define and calculate momentum
- Define and calculate impulse [Use the equation impulse = $F \Delta t = m \Delta V$]
- Apply the principle of the conservation of momentum to solve simple problems in one dimension
- Define resultant force in terms of momentum.

Subject Questions & Answers

Introduction

Q. What is dynamics?

Ans. Dynamics:

Dynamics is concerned with the forces that produce change in the motion of bodies

OR It is the branch of mechanics which deals with forces and their action on the motion of bodies.

OR Dynamics deals with forces and their effects on the motion of objects.

3.1

Concept of Force

Q.1. Define force. Give examples. Also write the types of forces.

Ans. Force: A force is a push or a pull that starts, stops or changes the magnitude and direction of velocity of a body.

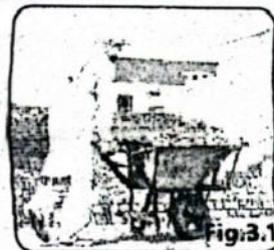
OR The agency which moves or tends to move, stops or tends to stop the motion of a body is called force.

Examples:

- When we are sitting in a car, we push against the seat as the car turns round a corner.
- Some forces we apply on other bodies and some are acting on us.

Force applying on objects: Force transfers energy to an object.

Examples: A man who moves a wheelbarrow with its load. The man first applies force to lift it and then applies force to push it. He applies a different amount of force on each handle when turning the wheelbarrow around the corner in order to keep it from tipping over.



Force acting on us:

- Some forces of gravity acting downward,
- The force of friction which helps us to walk on the ground and many others.

Types of forces: There are two major types of forces.

(1) Contact forces (2) Non-contact forces.

Q.2. Explain contact force and its examples.

Ans. Contact force:

- A contact force is a force that acts at the point of contact between two objects
- Applied forces (push, pull and twist) are contact forces.

Examples: Some examples of contact forces are given below

(i) Friction (ii) Drag (iii) Thrust (iv) Normal force
(v) Air Resistance (vi) Tension Force (vii) Elastic Force

- Friction:** It is the force that resists motion when the surface of one object comes in contact with the surface of another.
- Drag:** The drag force is the resistant force caused by the motion of a body through a fluid. It acts opposite to the relative motion of any object moving with respect to surrounding fluid.
- Thrust:** It is an upward force exerted by a liquid on an object immersed in it. When we try to immerse an object in water, we feel an upward force exerted on the object. This force increases as we push the object deeper into the water. A ship can float in the sea due to this force which balances the weight of the ship.
- Normal Force:** It is the force of reaction exerted by the surface on an object lying on it. This force acts outward and perpendicular to the surface. It is also called the support force upon the object.
- Air Resistance:** It is the resistance (opposition) offered by air when an object falls through it.
- Tension Force:** It is the force experienced by a rope when a person or load pulls it.
- Elastic Force:** It is a force that brings certain materials back to their original shape after being deformed. Examples are rubber bands, springs, trampoline etc.

Q.3. Explain Non-contact forces and its examples.

Ans. Non-contact forces: A non-contact force is defined as the force between two objects which are not in physical contact.

Action-at-a-Distance: The non-contact forces can work from a distance. That is why, these are sometimes called as action-at-a-distance.

Field Forces: There is always a field linked with a non-contact force. Due to this property, non-contact forces are also called field forces.

Examples: A few examples of non contact forces are described below:

(i) Gravitational force (ii) Electrostatic Force
(iii) Magnetic force (iv) strong and weak Nuclear forces

- Gravitational force:** When we throw an object upward, it is the gravitational force

of the Earth that brings it back to the Earth.

OR The gravitational force is an attractive force that exists among all bodies which have mass.

Long Range force:

The gravitational force is a long range force given by Newton's law of gravitation:

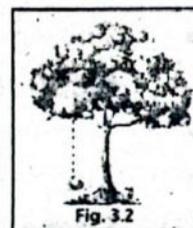
$$F = \frac{Gm_1 m_2}{r^2}$$

Where m_1 and m_2 are two masses distant r apart and G is constant of gravitation.

Its value is $6.67 \times 10^{-11} \text{ Nm}^2 \text{ kg}^{-2}$.

Examples:

- An apple falling down from a tree is one of the best examples of gravitational force.
- The Sun's gravitational force keeps the Earth and all other planets of our solar system in fixed orbits.
- Similarly, the gravitational force of Earth keeps the Moon in its orbit.



Weight: An object resting on a surface exerts a downward force called its weight.

(ii) **Electrostatic force:** An electrostatic force acts between two charged objects. The opposite charges attract each other and similar charges repel each other.

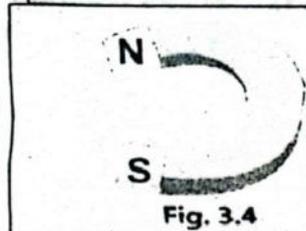
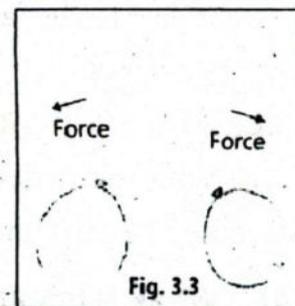
Examples: Gravitational force, electrostatic force is also a long - range force.

(iii) **Magnetic Force:** It is a force which a magnet exerts on other magnets and magnetic materials like iron, nickel and cobalt.

Example: Iron pins attracted in the presence of a magnet without any physical contact.

Magnetic force between the poles: Magnetic force between the poles

of two magnets can be either attractive or repulsive. This can be observed very easily by bringing different poles of two magnets close to each other. Like poles repel and unlike poles attract each other.



(iv) Strong and Weak Nuclear Forces:

These are also non-contact forces acting between the subatomic particles.

3.2

Fundamental Forces

Q.4. Into which forces Fundamental forces divided? Explain.

Ans. There are four fundamental forces in nature. These are:

1. Gravitational force
2. Electromagnetic force
3. Strong nuclear force
4. Weak nuclear force

(1) Gravitational Force:

The gravitational force is a force that pulls two masses towards each other

$$F = \frac{G m_1 m_2}{r^2}$$

- It is the weakest one among all four fundamental forces.
- It is a long-range force.
- In a way this force extends to infinite distance.

(2) Electromagnetic force:

- It is the force that causes the interaction between electrically charged particles.
- Electrostatic and magnetic forces come under this category.
- These are long range forces.

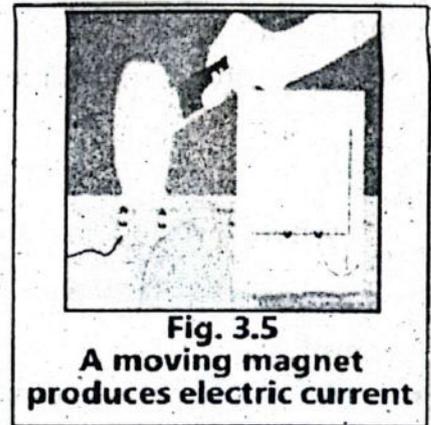


Fig. 3.5
A moving magnet produces electric current

Electromagnetic fields:

- The areas in which these forces act are called electromagnetic fields.
- Electromagnetic forces are stronger than gravitational and weak nuclear forces.

(3) Strong nuclear forces:

It holds the atomic nuclei together by binding the protons and neutrons in the nucleus over coming repulsive electromagnetic force between positively charged protons. It is also a short-range force with the order of 10^{-14} m. If the distance between nucleons increases beyond this range, this force ceases to act.

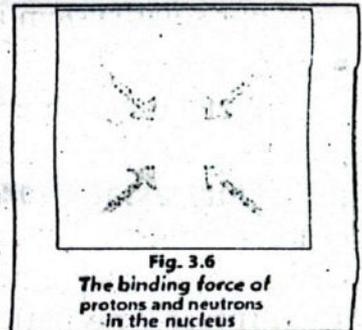


Fig. 3.6
The binding force of protons and neutrons in the nucleus

(4) Weak Nuclear Force:

Weak nuclear force is responsible for the disintegration of a nucleus.

Example: The weak nuclear force executes the β -decay (beta decay) of a neutron, in which a neutron transforms into a proton.

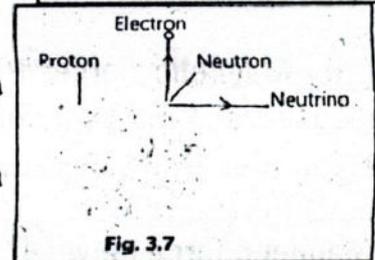


Fig. 3.7

Process: In the process, a β -particle (electron) and an uncharged particle called antineutrino are emitted. In other words, we can say that due to weak nuclear force radioactive decay of atoms occurs.

Weak nuclear force is stronger than the gravitational force but weaker than the electromagnetic force. It is a short-range force of the order 10^{-17} m.

Q.5. What is weak nuclear force? Explain the unification of weak Nuclear and Electromagnetic forces.

Ans: Weak nuclear force: Weak nuclear force is responsible for the disintegration of a nucleus.

Unification of weak Nuclear and Electromagnetic Forces:

A Pakistani Scientist Dr. Abdus Salam along with Sheldon Glashow and Steven Weinberg were awarded in 1979 Nobel Prize in Physics.

For their contributions to the unification of the weak nuclear force and electromagnetic force as electroweak force. This is known as Weinberg-Salam Theory.

Electroweak Force: At a very high temperature, the electromagnetic force and weak nuclear force is unified as electroweak force.

3.3 Forces in a Free - Body Diagram

Q.6. Write a note on forces in a free-body diagram.

Ans. Free-body diagrams are used to show the relative magnitudes and directions of all the forces acting on an object in a given situation.

Example: Usually, the object is represented by a box and the force arrows are drawn outward from the centre of the box in the directions of forces as shown in Fig 3.8 (b). The length of a force arrow (line) reflects the magnitude of the force and the arrow head indicates the direction in which the force acts. Each force is labelled to indicate the exact type of force.

External forces: External forces acting on an object may include friction, gravity, normal force, drag, tension in a string or a human force due to pushing or pulling.

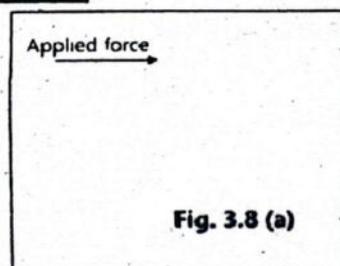


Fig. 3.8 (a)

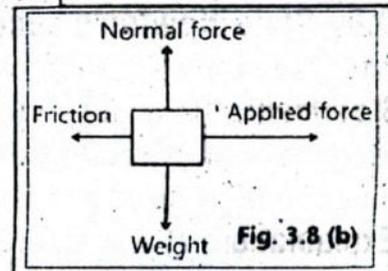


Fig. 3.8 (b)

3.4 Newton's Laws of Motion

Q.7. State Newton's first law of motion. Also Explain it with example:

Ans: Newton's first law of motion states that.

Statement: "A body continues its state of rest or of uniform motion in a straight line unless acted upon by some external force".

Examples No 1: A book placed on a table remains there unless a force is applied to move it.

Examples No 2: A ball rolling on floor should continue to move with the same velocity in the absence of an applied force. But practically, we see that it is not true. The ball stops after covering some distance. In fact, an opposing force (friction) causes the ball to stop.

Examples No 3: When a fast-moving bus stops suddenly, the passengers tend to bend forward. It is because they want to continue their motion. On the other hand, when the bus starts moving quickly from rest, the passengers are pushed back against the seat. This time, the tendency of passengers is to retain their state of rest.

Examples No 4: A bus moving on the road should continue its motion without any force exerted by the engine. But practically, we see that if the engine stops working, the bus comes to rest after covering some distance. It is because of the friction between the tyres of the bus and the road. All the bodies moving on the earth are stopped by the force of friction.

If you were in outer space and throw an object away where no force acted upon it, the object would continue to move forever with constant velocity.

Force: Force is an agency which changes or tends to change the state of rest or of uniform motion of a body.

In simple words, we can say that force causes acceleration.

Q.8. Write a note on Inertia. OR Explain Inertia.

Ans. Inertia: The property of a body to maintain its state of rest or of uniform motion in a straight line is called inertia.

Inertia Depends upon mass: The mass of an object is a measure of its inertia. The greater the mass of an object, the greater is its inertia.

Example: A net force is required to change the velocity of objects. For instance, a net force may cause a bicycle to pick up speed quickly. But when the same force is applied to a truck, any change in the motion may not be observed. We say that the truck has more inertia than a bicycle.

Q.9. State Newton's second law of motion. Also explain its derivation.

Ans. Newton's second law can be stated as:

Statement: "If a net external force acts upon a body, it accelerates the body in the direction of force. The magnitude of acceleration is directly proportional to the magnitude of force and is inversely proportional to the mass of the body.

Explanation: If a net force of magnitude F acts on a body of mass m and produces an acceleration of magnitude a , then the second law can be written mathematically as.

Derivation:

$$a \propto F$$

$$\text{and } a \propto \frac{1}{m}$$

$$\text{So, } a \propto \frac{F}{m}$$

$$\text{or } a = (\text{constant}) \frac{F}{m}$$

The value of constant will be 1. therefore.

$$a = 1 \times \frac{F}{m}$$

$$\text{or } F = ma$$

Comparison with first law of motion: First law of motion provides the definition of force, i.e. a force produces an acceleration in a body. By the second law of motion ($F = ma$), we can calculate mathematically, the amount of force required to produce a certain amount of acceleration in a body of known mass.

Unit: The SI unit of force is Newton (N).

One Newton: One newton is the force which produces an acceleration of 1 ms^{-2} in a body of mass 1 kg .

$$1\text{N} = 1 \text{ kg ms}^{-2}$$

Q.10. State Newton's third law of motion. Also Explain forces acts in pairs with examples.

Ans: Newton's third law is stated as.

Statement: "For every action, there is always an equal and opposite reaction.

Explanation: Whenever there is an interaction between two bodies A and B, such that the

body A exerts a force on body B, the force is known as action of A on B. In response to this action, the body B exerts a force on the body A. This force is known as reaction of B on A.

Example: When we press a spring, the force exerted by our hand on the spring is action. Our hand also experiences a force exerted by the spring.

On two Different bodies: Since, action and reaction do not act on the same body but they act on two different bodies, so they can never balance each other. Thus, Newton's law can also be stated as:

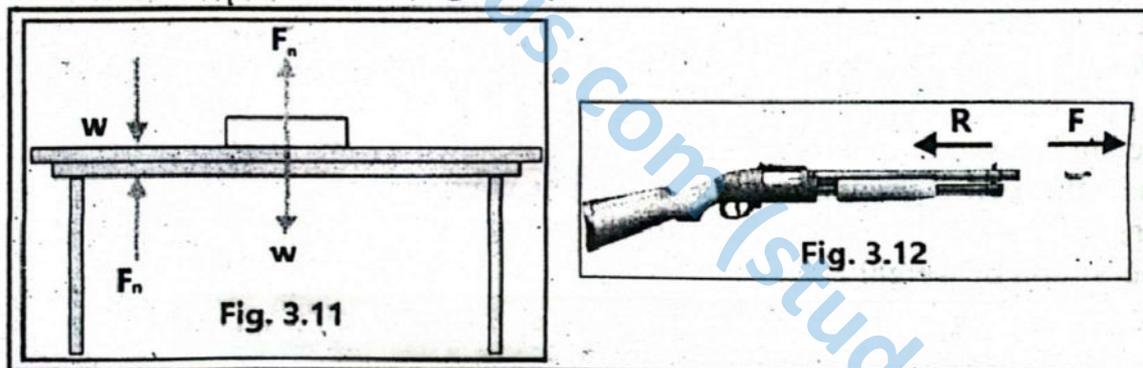
Another statement: "If one body exerts a force on a second body, the second body also exerts an equal and opposite force on the first body.

Forces act in Pairs: Forces act in pairs when two objects interact, i.e action and reaction forces. We often notice a force that seems to make something happen but usually we do not notice the other force involved.

Example No 1: Consider a block lying on a table as shown in Fig 3.11.

The force acting downward on the block is the weight. The block exerts a downward force on the table equal to its weight w . The table also exerts a reaction force F_n on the block. The two forces on the block balance each other and the block remains at rest.

Example No. 2: When a bullet is fired from a gun, the bullet moves in the forward direction with a force F . This is the force of action. The gun recoils in the backward direction with a reaction force R (Fig. 3.12).



3.5 Limitations of Newtons Laws of Motion

Q.11. What are the limitations of Newton's laws of Motion? Explain its types.

Ans. Newton's laws of motion can be applied with very high degree of accuracy to the motion of objects and velocities which we come across in everyday life.

Relativistic velocities: The problems arise when we deal with the motion of elementary particles having velocities close to that of light. These velocities are known as relativistic velocities.

Example: Then some astonishing result come into play. For example, mass of objects starts increasing, length of objects appearing shorter and time duration of events becomes longer.

Types of Mechanics: The problems can be solved by two types of mechanics are

following.

(1) Relativistic Mechanics (2) Quantum Mechanics

(1) **Relativistic Mechanics:** It is concerned with the motion of bodies having a speed close to that of light so that the behaviour is described by the theory of relativity rather than Newtonian mechanics.

(2) **Quantum Mechanics:** It is the field of physics, that explains how extremely small objects simultaneously have the characteristics of both particles (matter) and waves. Physicists call this the wave - particle duality.

Conclusion: The conclusion is that Newton's laws of motion are not exact for all types of motion, but provide a good approximation, unless an object is small enough or moving close to the speed of light.

3.6

Mass and Weight

Q.12. Explain Mass and weight?

Ans. Mass: The characteristic of a body which determines the magnitude of acceleration produced when a certain force acts upon it is known as mass of the body.

Example: The weight of the object is 5kg, it is not true. Infact, 5kg is the mass of the object.

- Mass is a scalar quantity.
- It remains the same everywhere.
- The SI unit of mass is kilogram (kg).
- It is denoted by 'm'.
- Mass is measured by an ordinary balance.

Weight: The weight of an object is equal to the force with which the Earth attracts the body towards its centre.

Example: If I weight 24kg on earth, then my mass on the moon will be 6 to the weight on the earth i.e., 4kg on the moon.

- Weight is a vector quantity.
- The value of weight does not remains same every where.
- A spring balance is used to measure the weight.
- The SI unit of weight is Newton (N).
- It is denoted by 'w'

3.7

Mechanical and Electronic Balances

Q.13. What is balances scales? Explain the following

(1) Mechanical Balances (2) Electronic Balances (3) Force Meter.

Ans. Balance scales: Balance scales are commonly used to compare masses of objects or to weigh objects by balancing them with standard weights.

1. **Mechanical Balances:** Mechanical balances are of two types.

Type I:

Construction and its use:

- A mechanical balance consists of a rigid horizontal beam that oscillates on a central knife edge as a fulcrum.
- It has two end knife edges equidistant from the centre.
- Two pans are hung from bearings on the end knife edges.
- The material to be weighed is put in one pan. Standard weights are put on the other

pan.

- The deflection of the balance may be indicated by a pointer attached to the beam.
- The weights on the pan are adjusted to bring the beam in equilibrium.

Type II:

- There is another type of mechanical balances which are used to weigh heavy items like flour bags, cement bags, steel bars etc. These are called mechanical platform balances.

Platform balances:

Construction and use:

- Standard weights are not required to use this balance
- Its reason is that the fulcrum of the beam of such a balance is kept very near to its one end. Therefore, much smaller weights have to be put at the other end of beam to bring it to equilibrium.
- These smaller weights have already been calibrated to the standard weights.

(2) Electronic Balances:

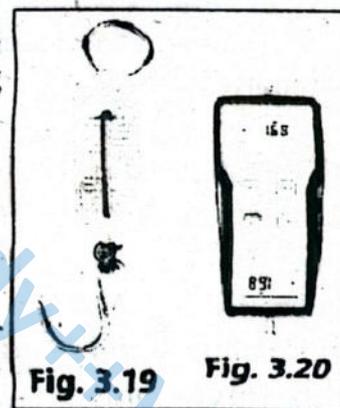
Construction: No standard weights are required to use an electronic balance. Only it has to be connected to a power supply. There are some models which can operate by using dry cell batteries. An electronic balance is more precise than mechanical balance.

Use: When an object is placed on it, its mass is displayed on its screen. Now-a-days, electronic balances also display the total price of the material if the rate per kg is fed to the balance.



(3) Force Meter: A force meter is a scientific instrument that measures force. It is also called as a newton meter or a spring balance.

- Now a days digital force meters are also available
- Mechanical and electronic balances are measure mass of the objects in kilogrammes or its multiples. On the other hand, force meter measures force directly in newtons (N).
- An ordinary force meter has a spring inside it. Upper end of the spring is attached to a handle.
- A hook is attached to the lower end the spring that holds the object.
- A pointer is also attached to the spring at its upper end.
- A scale in newtons is provided along the spring such that the pointer coincides with zero of the scale when nothing is hung with the hook.
- The object to be weighed is hung with the hook. The mass of the object causes the spring to compress.
- The pointer indicates the weight of the object.
- In some spring balances, the scale measures the mass which can be readily converted into newtons by multiplying the mass in kg with the value of $g = 10 \text{ ms}^{-2}$
- A digital force meter measures directly the weight of the object in newtons.



Q.14. Define friction and dissipative effect of friction with examples?

Ans. Friction: Friction is force that tends to prevent the bodies from sliding over each other.

Dissipative Effect of Friction: Friction is a dissipative force such as the friction force between solids or the drag force in motions through fluid.

Role of energy: Energy is wasted in doing work against friction. The lost energy appears in the forms of heat.

Example No 1: A very common example of energy dissipation is the rubbing of hands, when we rub our hands, heat is generated due to friction and our hands become warm.

Example No 2: Temperature of machines rises due to friction that can cause many problems.

Example No 3: Tyres of vehicles wear out after being too hot due to friction between tyres and road.

Example No 4: Shooting of stars seen in the sky at night also happen due to friction of air.

These are actually asteroids that enter the Earth's atmosphere. As they are moving, air resistance causes generation of heat. Their temperature becomes so high that they start burning and ultimately disintegrate.

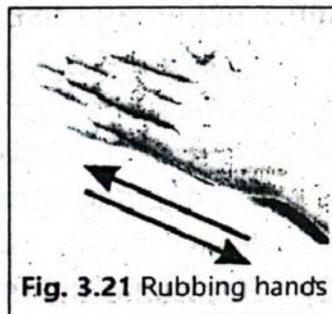


Fig. 3.21 Rubbing hands

Q.15. Explain sliding friction and its categories.

Ans. Sliding friction:

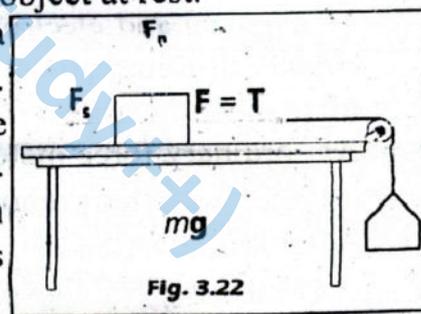
The resistance created by any two objects when sliding against each other.

Categories: Sliding friction can be divided into two categories.

- (1) Static friction (2) kinetic friction

(1) Static friction: The static friction is a force that keeps an object at rest.

Explanation: Let us consider the motion of a block on a horizontal surface. The arrangement is shown in Fig. 3.22. When a weight is put in the pan, a force $F = T$ equal to the sum of this weight and weight of the pan acts on the block. This force tends to pull the block. At the same time an opposing force appears that does not let the block move. This opposing force is the static friction F_s .



Kinetic Friction: The force that acts on an object in motion, opposing its effects.

Explanation: If we go on adding more weights in the pan one by one in small steps, a stage will come when the block starts sliding on the horizontal surface. This is the limit of static friction that is equal to the total weights including pan.

When the block is sliding, friction still exists. It is known as kinetic friction.

Q. 16. Define terminal velocity. Write its principle and explain it.

Ans. Terminal velocity: The highest velocity attained by an object falling through a fluid

is called terminal velocity.

Explanation: When an object falls freely, it is accelerated by an amount $g = 10 \text{ ms}^{-2}$. But practically the acceleration may be different. Air resistance plays an important role in determining how fast an object accelerates when it falls.

Example: If we drop a cricket ball and a piece of Styrofoam of the same weight from a certain height, they will hit the ground at the same time only if there were no air resistance. Both would fall with the same acceleration $g = 10 \text{ ms}^{-2}$. Practically the ball, in air, would drop faster. The Styrofoam having larger surface would face greater opposing force of the air.

Principle: The faster an object falls the more air resistance will be exerted on it. A speed is finally attained at which the upward force of air resistance balances the downward force of gravity.

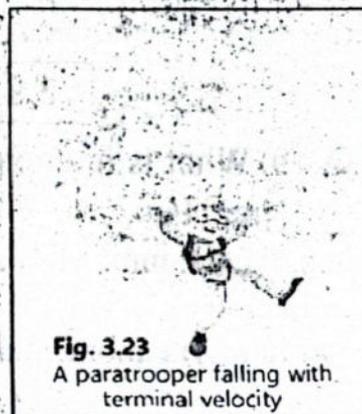


Fig. 3.23
A paratrooper falling with terminal velocity.

When this happens, the object stops accelerating. It keeps falling at a constant velocity.

Even a heavy object like a meteorite does not gain an infinite velocity as it falls to Earth.

Example: This principle applies to paratroopers. Air resistance acting against the large surface area of a parachute allows for descent at a safer velocity.

Q.17. Write an explanatory note on rolling friction.

Ans. Rolling friction: When an object rolls over a surface, the friction produced is called rolling friction.

Concept of wheel: In our everyday life, we observe that a body with wheels faces less friction as compared to a body of the same size without wheels.

Concept of ball bearings: Ball bearings also play the same role as is played by the wheels. Many machines in industry are designed with ball bearings so that the moving parts roll on the ball bearing and friction is greatly reduced. The rolling friction is about one hundred times smaller than the sliding friction.

Reason: The reason for the rolling friction to be less than the sliding friction is that there is no relative motion between the wheel and the surface over which it rolls. The wheel touches the surface only at a point. It does not slide.

Q.18. Describe some methods to reduce friction.

Ans. The following methods are used to reduce friction.

- (i) The parts which slide against each other are highly polished.
- (ii) Since, the friction of liquids is less than that of solid surfaces, therefore, oil or grease is applied between the moving parts of the machinery.
- (iii) As rolling friction is much less than the sliding friction, so sliding friction is converted into rolling friction by the use of ball bearings in the machines and wheels under the heavy objects.

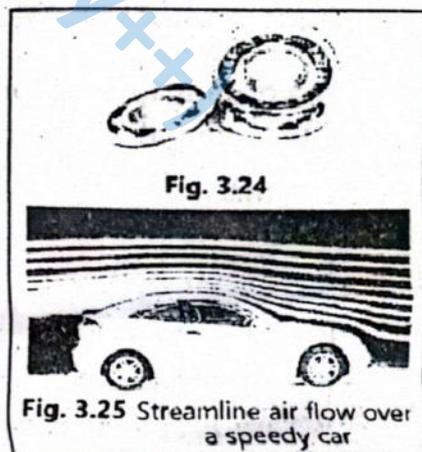


Fig. 3.25 Streamline air flow over a speedy car

- (iv) Frictional force does not act only among solids, high speed vehicles, aeroplanes

and ships also face friction while moving through air or water. If the front of a vehicle is flat, it faces more resistance by air or water. Therefore, the bodies moving through air or water are streamlined to minimize air or water friction.

Streamline flow: The air passes smoothly over the slanting surface of vehicle. This type of flow of air is known as streamline flow.

3.9

Momentum and Impulse

Q. 19. What is momentum and impulse? Derive the relation between momentum and impulse.

Ans. Momentum: Momentum of a body is the quantity of motion it possess due to its mass and velocity.

Formula: The momentum of a body is given by the product of its mass (m) and velocity (v).

$$P = mv$$

Unit: The unit of momentum is kg ms^{-1} . It can also be written as (Ns).

Vector quantity: Momentum is a vector quantity because it needs magnitude, unit and direction for its description.

Impulse: Impulse is defined as $F \times \Delta t$ or $m \Delta v$ equal to the total change in momentum.

Therefore, Impulse = $F \times \Delta t = m \Delta v$

Dividing by Δt ,

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

Where $m(\Delta v)$ is the change in momentum Δp .

Above equation gives us the value of force in terms of momentum i.e. force acting on an object per unit time.

$$F = \frac{\Delta p}{\Delta t}$$

When a large force F acts on an object for a short interval of time, the impulse of the force is defined as the total change in momentum of the object.

Explanation: It is very difficult to calculate the exact magnitude of the force. However, initial velocity v_i of the ball and final velocity v_f after collision can be found easily.

Derivation: During a time interval, the average acceleration is given by.

$$a = \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{\Delta t}$$

According to Newton's second law of motion the value of average force acting during the interval Δt will be

$$\therefore \Delta v = v_f - v_i$$

$$F = ma$$

$$F = m \left(\frac{\Delta v}{\Delta t} \right)$$

or $F \times \Delta t = m (\Delta v)$

$$F \times \Delta t = m (v_f - v_i)$$

Where F and Δt cannot be exactly known but their product which is equal to the change of momentum ($mv_f - mv_i$) can be calculated.

Newton's second law of motion in terms of momentum.

The rate of change of momentum of a body is equal to the force on it.

$$\text{So } F = \frac{\Delta p}{\Delta t}$$

The direction of change in momentum is that of the force.

3.10 Principle of Conservation of Momentum

Q. 20. State and explain the principle of conservation of momentum.

Ans: System: The collection of objects is known as system.

Isolated system: If no external force acts on any object of the system, it is known as isolated system.

Consider a system of two balls of masses m_1 and m_2

Before collision: Suppose that the balls are moving with velocities v_1 and v_2 along a straight line in the same direction.

Total momentum of the system before collision = $m_1 v_1 + m_2 v_2$

After collision:

After sometime, they collide with each other and their velocities become v_1' and v_2'

Total momentum of the system after collision = $m_1 v_1' + m_2 v_2'$

The final momentum is equal to the initial momentum

Total momentum of the system before collision = Total momentum of the system after collision.

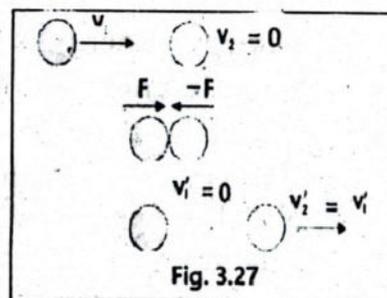
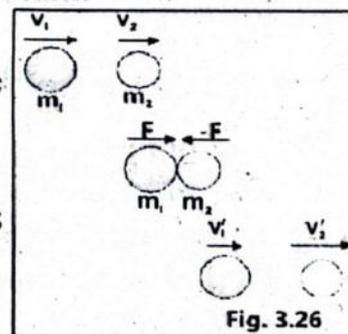
$$\text{so, } m_1 v_1 + m_2 v_2 = m_1 v_1' + m_2 v_2'$$

Explanation: To explain this principle, let us consider the collision of two identical balls in which the second ball is at rest.

The principle of conservation of momentum is applicable not only to macro-objects but also for micro-objects like atoms and molecules.

When there is collision of two balls, there is a transfer of momentum from one ball to another. The ball at rest gains momentum and starts moving whereas the striking ball slows down. If the balls are identical, we will observe that there is a total transfer of momentum. The striking ball comes to rest and the other ball starts moving with the same speed. It means that second ball gains momentum equal to that lost by the first one. If the first ball stops after collision, the second ball moves with the momentum of the first ball. This suggests that the total momentum of the two balls after collision remains the same as total momentum before collision.

$$\text{so, } m_1 v_1 + m_2 v_2 = m_1 v_1' + m_2 v_2'$$



Conceptual Long Questions

1. Explain the concept of centripetal force. Derive the expression for the force required to keep an object moving in a circular path.

Ans. Centripetal force is the force that acts on an object moving in a circular path, directed toward the center of the circle or the axis of rotation. This force is

responsible for changing the direction of the object to keep it moving along the circular path rather than in a straight line.

The centripetal force F_c can be derived from the requirement that an object moving in a circle with radius r and velocity v .

Centripetal acceleration: $a_c = \frac{v^2}{r}$

Centripetal force:

using Newton's second law.

$$F_c = m a_c = m \frac{v^2}{r} = \frac{mv^2}{r}$$

Key points:

- The direction of centripetal force is towards the centre.
 - Without this force, the object would move tangentially due to inertia.
2. Explain the concept of work, energy and power. Derive the work-energy theorem?

Ans. Work is done when a force is applied to an object and the object moves in the direction of the force.

$$W = F \cdot d \cos\theta$$

Energy: Energy is the capacity to do work.

- **Kinetic energy:** Energy of motion: $K.E = \frac{1}{2} mv^2$
- **Potential energy:** $P.E = mgh$

Power: Power is the rate at which work is done. $P = \frac{W}{t}$

Work-Energy theorem:

The net work done on an object is equal to its change in kinetic energy.

$$W_{\text{net}} = \Delta K.E = \frac{1}{2} m (v_f^2 - v_i^2)$$

Proof: Using Newton's second law.

$$F = ma \quad \text{and} \quad a = \frac{v_f^2 - v_i^2}{2S}$$

$$W = F \cdot S = m \cdot \frac{v_f^2 - v_i^2}{2}$$

$$W = \Delta K.E$$

Examples

Example 3.1: A 10 kg block moves on a frictionless horizontal surface with an acceleration of 2ms^{-2} . What is the force acting on the block?

Solution:

$$\text{Mass of a block} = m = 10\text{kg}$$

$$\text{Acceleration} = a = 2\text{ms}^{-2}$$

$$\text{Force} = F = ?$$

By Newton's second law of motion

$$F = ma$$

So, $F = 10\text{kg} \times 2 \text{ ms}^{-2}$

$$F = 20\text{N}$$

Thus, the force acting on the block is 20N.

Example 3.2: A force of 7500N is used to move a truck of mass 3000kg. Find the acceleration produced in the truck. How long will it take to accelerate the truck from 36kmh^{-1} to 72kmh^{-1} speed?

Solution:

$$\text{Mass of truck} = m = 3000\text{kg}$$

$$\text{Force applied} = F = 7500\text{N}$$

$$\text{Acceleration} = a = ?$$

$$\text{Initial speed} = v_i = 36\text{kmh}^{-1}$$

$$v_i = \frac{36 \times 1000\text{m}}{60 \times 60\text{s}} = 10\text{ms}^{-1}$$

$$\text{Final speed} = v_f = 72\text{kmh}^{-1}$$

$$v_f = \frac{72 \times 1000\text{m}}{60 \times 60\text{s}} = 20\text{ms}^{-1}$$

By Newton's second Law,

$$F = ma$$

or $a = \frac{F}{m}$

So, $a = \frac{7500\text{N}}{3000\text{kg}} = 2.5\text{ms}^{-2}$

By, first equation of motion

$$v_f = v_i + at \quad \text{or}$$

$$t = \frac{v_f - v_i}{a}$$

So, $t = \frac{20\text{ms}^{-1} - 10\text{ms}^{-1}}{2.5\text{ms}^{-2}} = 4\text{s}$

Thus, Time taken to accelerate the truck is 4s.

Example 3.3: A bullet of mass 15g is fired by a gun. If the velocity of the bullet is 150ms^{-1} , what is its momentum?

Solution:

$$\text{Mass of bullet} = m = 15\text{g} = 0.015\text{kg}$$

$$\text{Velocity of bullet} = v = 150\text{ms}^{-1}$$

$$\text{Momentum} = p = ?$$

as $p = mv$

So, $p = 0.015\text{kg} \times 150 \text{ ms}^{-1}$

$$p = 2.25 \text{ kgms}^{-1}$$

Thus, the momentum of bullet is 2.25 kgms^{-1} .

Example 3.4 A cricket ball of mass 160g is hit by a bat. The ball leaves the bat with a velocity of 52ms^{-1} . If the ball strikes the bat with a velocity of -28ms^{-1} (opposite direction) before hitting, find the average force exerted on the ball by the bat. The ball remains in contact with the bat for $4 \times 10^{-3}\text{s}$.

Solution:

$$\text{Mass of ball} = m = 160\text{g} = 0.16\text{kg}$$

$$\text{Initial velocity} = v_i = -28\text{ms}^{-1}$$

$$\text{Final velocity} = v_f = 52\text{ms}^{-1}$$

$$\text{Time of contact} = t = 4 \times 10^{-3}\text{s}$$

$$\text{Average force} = F = ?$$

Using formula:

$$\text{By, } F = \frac{m(v_f - v_i)}{t}$$
$$F = \frac{0.16\text{kg}[52\text{ms}^{-1} - (-28\text{ms}^{-1})]}{4 \times 10^{-3}\text{s}}$$

$$F = 3200\text{N}$$

Thus, the force exerted on the ball is 3200N by the bat.

Example 3.5: A bullet of mass m_1 is fired by a gun of mass m_2 . Find the velocity of the gun in terms of velocity of bullet v_1 just after firing.

Solution: Before firing, the velocity of bullet as well as that of gun was zero. Therefore, total momentum of bullet and gun was also zero. After firing, the bullet moves forward with velocity v_1 whereas the gun moves with velocity v_2 .

According to law of conservation of momentum.

$$\text{Total momentum before firing} = \text{Total momentum after firing}$$

$$\text{So, } 0 = m_1 v_1 + m_2 v_2$$

$$\text{or, } m_2 v_2 = -m_1 v_1$$

$$v_2 = \frac{-m_1 v_1}{m_2}$$

Thus, the negative sign in this equation, indicates that the gun moves backward, i.e. opposite to the bullet. It is because of the backward motion of the gun that the shooter gets a jerk on his shoulder.

Example 3.6: A ball of mass 3kg moving with the velocity of 5ms^{-1} collides with a stationary ball of mass 2kg and then both of them move together. If the friction is negligible, find out the velocity with which both the balls will move after collision.

Solution:

$$\text{Mass of first ball} = m_1 = 3\text{kg}$$

$$\text{Velocity of first ball} = v_1 = 5\text{ms}^{-1}$$

before collision

Mass of second ball = $m_2 = 2\text{kg}$

Velocity of second ball = $v_2 = 0$

Velocity of both the balls after collision = $v = ?$

Total mass of balls after collision = $m_1 + m_2$

By law of conservation of momentum,

Total momentum before collision = Total momentum after collision

$$m_1 v_1 + m_2 v_2 = (m_1 + m_2)v$$

$$3\text{kg} \times 5\text{ms}^{-1} + 0 = (3\text{kg} + 2\text{kg})v$$

$$15\text{kgms}^{-1} = 5\text{kg} \times v$$

$$v = 3\text{ms}^{-1}$$

Thus, The velocity with which both the balls will move after collision is 3ms^{-1} .

Quick Quiz

1. Newton's was born in:

- (a) January 4, 1643 (b) January 5, 1643 (c) January 6, 1643 (d) January 7, 1643

2. The weight of 100g mass is:

- (a) 1N (b) 1.5N (c) 2N (d) 3N

ANSWERS:

1. (a) 2. (a)

Mini Exercise

1. What is the name of Newton's famous book?

Ans. The name of Newton's famous book is "Principia Mathematica".

2. Where and when Newton was born?

Ans. Sir Issac Newton was born in Lincolnshire on January 4, 1643.

3. Inspace, an astronaut throws a wrench, as a reaction he moves in opposite direction.

Ans. Yes, due to the conservation of momentum. When the astronaut throws the wrench, the force exerted on the wrench pushes it forward, and an equal and opposite force pushes the astronaut backward.

4. Why tread on the tyres reduce the chances of skidding?

Ans. On a wet road, the spaces in the tread pattern provide places for water to collect. Therefore, water does not form a wet layer between the tyre surface and the road surface, where it would reduce friction and allow the tyre to slip. Thus, tread on the tyres reduce the chances of skidding.

5. Why some frogs can cling to a vertical surface?

Ans. Some frogs can cling to a vertical surface, such as this leaf, because of the static friction between their feet and the surface.

6. What happen when a shuttle re-enters the earth atmosphere?

Ans. When a shuttle re-enters the Earth's atmosphere, the friction caused by the atmosphere raises the surface temperature of the shuttle to over 950°C .

7. Why friction in human joints is very low?

Ans. Friction in human joints is very low because our bodies contain a natural lubricating system. Consequently, though our bones rub against each other at the points as we move, yet bones do not normally wear out, even after many years of use.

8. Write a note on hovercraft.

Ans. A hovercraft is a kind of ship that can move over the surface of water and ground both. Air is

ejected underneath by powerful fans forming a cushion of air. The hovercraft moves over the cushion of air which offers very small resistance.

9. How the momentum of the arrow changes?

Ans. The arrow penetrates into the apple, and in response, the momentum of the apple changes. Conversely, the apple applies an opposing force to the arrow, and in response the momentum of the arrow changes.

10. Why fragile break easily?

Ans. Fragile objects such as glassware may break easily due to jerks or by the direct impact with hard objects during their transportation.

11. How to protect fragile?

Ans. To protect them soft, packing materials are used for these objects. These materials reduce the effect of quick change in momentum.

12. How to pack fragile object?

Ans. Special materials like styrofoam, corrugated cardboard sheets, bubble wrap are used for the packing of such objects.

13. What is crumple zone?

Ans. A crumple zone of an automobile is a structural feature designed to compress during an accident to absorb deformation energy from the impact.

14. Where is crumple zone are located?

Ans. Crumple zones are located in front and behind of the main body of the vehicle.

15. What is the working of crumple zone?

Ans. Crumple zone work by managing crash energy absorbing within the outer parts of the vehicle, rather than being directly transmitted to the occupants. This is achieved by controlled weakening of outer parts (plastic bumpers etc) of the vehicle, while strengthening of the passenger cabin.

16. How seat belt reduced the chances of hitting the passengers against the windshield of steering wheel?

Ans. When a moving car stops suddenly, the passengers move forward toward the windshield, seatbelt prevent the passengers from moving. Thus, chances of hitting the passengers against the windshield or steering wheel are reduced.

Additional MCQs

1. How many types forces have:

- (a) Four (b) Two (c) Three (d) Five

2. Which force is not a contact force:

- (a) Drag (b) Thrust (c) Elastic (d) Gravitational

3. Force exerted by a liquid on an object is:

- (a) Friction (b) Drag (c) Thrust (d) Elastic

4. Force experienced by a rope is:

- (a) Tension (b) Elastic (c) Normal (d) Air resistance

5. The force between two objects which are not in physical contact is:

- (a) Contact (b) Friction (c) Non contact (d) Drag

6. An apple falling down from a tree is an example of:
 (a) Gravitational force (b) Magnetic force
 (c) Elastic force (d) Weak and strong force
7. What is the value of G if $F = G \frac{m_1 m_2}{r^2}$?
 (a) $6.67 \times 10^{10} \text{ Nm}^2 \text{ kg}^{-2}$ (b) $6.67 \times 10^{-11} \text{ Nm}^2 \text{ kg}^{-2}$
 (c) $6.67 \times 10^{-10} \text{ Nm}^2 \text{ kg}^{-2}$ (d) $6.67 \times 10^9 \text{ Nm}^2 \text{ kg}^{-2}$
8. A Pakistani Scientist Dr. Abdus Salam along with sheldon Glashow and steven weinberg were awarded in:
 (a) 1980 (b) 1981 (c) 1970 (d) 1979
9. Which force is responsible for the disintegration of nucleus?
 (a) Strong nuclear force (b) Electromagnetic force
 (c) Gravitational force (d) Weak nuclear force
10. Newton was born in:
 (a) January 5, 1643 (b) January 6, 1643 (c) January 4, 1643 (d) January 3, 1643
11. The property of a body to maintain its state of rest or in a straight line is called:
 (a) Force (b) Inertia (c) Momentum (d) Impulse
12. Inertia depends upon:
 (a) Mass (b) Velocity (c) Displacement (d) Time
13. 1 Newton = ?
 (a) 1 kgms^{-2} (b) 1 kgms (c) $1 \text{ kgm}^{-1}\text{s}^{-1}$ (d) $1 \text{ kg}^{-1}\text{m}^{-1}\text{s}^{-1}$
14. The unit of force is:
 (a) Meter (b) Newton (c) Newton meter (d) Kilogram
15. Which of the following relation is correct?
 (a) $F = -ma$ (b) $F = m - a$ (c) $F = ma$ (d) $F = m/a$
16. Law of inertia is also know as:
 (a) First law of motion (b) Second law of motion
 (c) Third law of motion (d) Momentum
17. The SI unit of weight is:
 (a) Ns (b) Ns^{-1} (c) N (d) kg
18. Spring balance is used to measure:
 (a) Temperature (b) Weight (c) Mass (d) length
19. A mass of 6kg is moving with acceleration of 2ms^{-2} force acting on it is:
 (a) 12N (b) 10N (c) 8N (d) 3N
20. Weight is a:
 (a) Vector (b) Scalar (c) Vector and scalar (d) None of these
21. SI unit of mass is:
 (a) 1kg (b) N (c) ms^{-1} (d) ms^{-2}
22. Ordinary balance is used to measure:
 (a) Temperature (b) Mass (c) Weight (d) Length
23. Force that appears the motion of the moving object is called:
 (a) Momentum (b) Friction (c) Inertia (d) Impulses

24. Rubbing hands is an example of:
 (a) Inertia (b) Momentum (c) Impulse (d) Friction
25. How many types friction have?
 (a) two (b) three (c) four (d) five
26. According to law of conservation of momentum recoil velocity of gun:
 (a) $v' = \frac{mv}{M}$ (b) $v' = \frac{M}{m}v$ (c) $v' = \frac{mV}{M}$ (d) $v' = \frac{M}{m}V$
27. In isolated system, the momentum after collision of two bodies:
 (a) Increase (b) Constant (c) Decrease (d) Zero
28. The product of mass and acceleration is:
 (a) Momentum (b) Force (c) Inertia (d) Torque
29. Which relation is correct?
 (a) $P = m \times v$ (b) $P = \frac{m}{v}$ (c) $P = \frac{v}{m}$ (d) $P = v \times m$
30. SI unit of momentum is:
 (a) Ns (b) 1 kgms^{-1} (c) Newton (d) both a, b
31. Total change in momentum of the object is called:
 (a) Impulses (b) Force (c) Inertia (d) Displacement

ANSWERS:

1. (b) 2. (d) 3. (b) 4. (a) 5. (c) 6. (a) 7. (b)
 8. (d) 9. (d) 10. (c) 11. (b) 12. (a) 13. (a) 14. (b)
 15. (c) 16. (a) 17. (c) 18. (b) 19. (a) 20. (a) 21. (a)
 22. (b) 23. (b) 24. (d) 25. (a) 26. (a) 27. (b) 28. (b)
 29. (a) 30. (d) 31. (a)

Conceptual MCQs

1. Newton's first law state that:
 (a) Every action has an equal and opposite reaction.
 (b) Force equals mass times acceleration.
 (c) An object at rest stays at rest unless acted upon by an external force.
 (d) The rate of change of momentum is proportional to the applied force.
2. What is the net force acting on an object moving at constant velocity?
 (a) Zero (b) Equal to the mass of the objects
 (c) Proportional to its acceleration
 (d) Equal to the gravitational force acting on the object
3. When a car suddenly stops, passenger punch forward due to:
 (a) Gravitational force (b) Inertia
 (c) Centripetal force (d) Friction
4. A ball is dropped from a height. Neglecting air resistance, its acceleration is:
 (a) Increasing (b) Decreasing (c) Constant (d) Zero

5. **Two objects of different masses are dropped from the same height in a vacuum. They will:**
(a) Hit the ground at the same time
(b) Hit the ground at the times due to different masses
(c) Acceleration differently (d) None of these above
6. **If the net force acting on an object is doubled, its acceleration will:**
(a) Remain constant (b) Be halved (c) Doubled
(d) Depend on its velocity
7. **A person standing in an elevator feels lighter when the elevator is:**
(a) Accelerating downward (b) Accelerating upward
(c) Moving at constant speed upward (d) At rest
8. **The force that keeps an object moving in a circular path is called:**
(a) Centrifugal force (b) Gravitational force (c) Normal force (d) Centripetal force
9. **Which of the following quantities is a measure of inertia?**
(a) Weight (b) Mass (c) Velocity (d) Acceleration
10. **A book resting on a table does not fall because:**
(a) Gravity acts upward
(b) The table exerts a downward force equal to the book's weight
(c) The net force on the book is zero (d) There is no force acting on the book
11. **What is the direction of the net force on an object moving in a circular path?**
(a) In the direction of the motion. (b) Tangential to the circle.
(c) Radically inward. (d) Radically outward.
12. **A ball is thrown vertically upward. At the maximum height, what is the velocity of the ball?**
(a) Zero (b) Maximum upward
(c) Maximum downward (d) Zero acceleration
13. **Which of the following quantities is not a vector?**
(a) Force (b) Velocity (c) Displacement (d) Work
14. **If two objects of different masses are dropped from the same height in a vacuum? What will be their acceleration due to gravity?**
(a) The heavier object will accelerate faster.
(b) The lighter object will accelerate faster.
(c) Both objects will have the same acceleration.
(d) Both objects will not accelerate.
15. **A car of mass 1000kg is moving with a velocity of 20m/s. What is the car's kinetic energy?**
(a) 10,000J (b) 200,000J (c) 400,000J (d) 300,000J
16. **A body of mass 5kg is acted upon by a constant force of 10N. What will be the body's acceleration?**
(a) 2m/s^2 (b) 5m/s^2 (c) 10m/s^2 (d) 50m/s^2
17. **The work done by a force is maximum when the angle between the force and displacement is:**
(a) 0° (b) 45° (c) 90° (d) 180°

a fluid. It acts opposite to the relative motion of any object moving with respect to surrounding fluid.

8. Which is force of thrust?

Ans. It is an upward force exerted by a liquid on an object immersed in it. When we try to immerse an object in water, we feel an upward force exerted on the object. This force increases as we push the object deeper into the water. A ship can float in the sea due to this force which balances the weight of the ship.

9. Define normal force.

Ans. It is the force exerted by the surface on an object lying on it. This force acts outward and perpendicular to the surface. It is also called the support force upon the object.

10. What is air resistance?

Ans. It is the resistance (opposition) offered by air when an object falls through it.

11. What is tension force?

Ans. It is the force experienced by a rope when a person or load pulls it.

12. Define elastic force with example.

Ans. It is a force that brings certain materials back to their original shape after being deformed. Examples are rubber bands, springs, trampoline etc.

13. Define action-at-a-distance.

Ans. The non-contact forces can work from a distance. That is why these are sometimes called as action-at-a-distance.

14. Define field force.

Ans. There is always a field linked with a non-contact force. Due to this property, non-contact forces are also called field forces.

15. Define gravitational forces.

Ans. When we throw an object upward, it is the gravitational force of earth that brings it back to the Earth.

16. Define weight.

Ans. An object resting on a surface exerts a downward force called its weight.

17. Define electrostatic force.

Ans. An electrostatic force acts between two charged objects. The opposite charges attract each other and similar charges repel each other.

Examples: Like gravitational force, electrostatic force is also a long-range force.

18. What is magnetic force?

Ans. It is a force which a magnet exerts on other magnets and magnetic materials.

Example: like iron, nickel and cobalt.

19. What is strong and weak nuclear force?

Ans. These are also non-contact forces acting between the subatomic particles.

20. How many fundamental forces are there in nature? Into which forces fundamental force are divided?

Ans. There are four fundamental forces in nature. These are:

- i. Gravitational force
- ii. Electromagnetic force

iii. Strong nuclear force iv. Weak nuclear force

Every force comes under any of these forces.

21. What is electromagnetic force?

Ans. It is the force that causes the interaction between electrically charged particles. These are long range forces. Electro-static and magnetic force come under this category. Electromagnetic forces are stronger than gravitational and weak nuclear forces.

22. What is strong nuclear force?

Ans. • A strong nuclear force is a short-range force.

• The strong nuclear force is responsible to keep protons and neutrons together inside the nucleus.

• Range of this force is of the order of 10^{-14}m .

23. What is weak nuclear force?

Ans. Weak nuclear force is responsible for the disintegration of a nucleus. For example, the weak nuclear force executes the β -decay (beta decay) of a neutron, in which a neutron transforms into a proton. In the process, a β -particle (electron) and an uncharged particle called antineutrino are emitted. In other words, we can say that due to weak nuclear force radioactive decay of atoms occurs. However weak nuclear force is stronger than the gravitational force but weak than the electromagnetic force. It is a short-range force of the order 10^{-17}m .

24. Define neutrino.

Ans. In the process, a β -particle (electron) and an uncharged particle called a neutrino.

25. Define electro weak force.

Ans. At a very high temperature, the electromagnetic force and weak nuclear force is unified as electro weak force.

26. State Newton's first law of motion.

Ans. A body continues its state of rest or of uniform motion in a straight line unless acted upon by some external force.

27. Define inertia.

Ans. The property of a body to maintain its state of rest or uniform motion in a straight line is called inertia.

28. What is mass?

Ans. The characteristic of a body which determines the magnitude of acceleration produced when a certain force act upon it is known as mass of the body.

29. State second law of motion.

Ans. If a net external force acts upon a body, it accelerates the body in the direction of force. The magnitude of acceleration is directly proportional to the magnitude of force and is inversely proportional to the mass of the body.

30. Define one Newton.

Ans. One newton is the force which produces an acceleration of 1ms^{-2} in a body of mass 1kg .
 $1\text{N} = 1\text{kgm}^{-2}$

31. State Newton's third law of motion.

Ans. For every action there is always an equal and opposite reaction.

32. Define relativistic velocities.

Ans. The problems arise when we deal with the motion of elementary particles having velocities close to that of light. These velocities are known as relativistic velocities. For example, mass of objects starts increasing, length of object appearing shorter and time duration of events becomes longer.

33. Differentiate between mass and weight.

Ans. Mass: The characteristic of a body which determines the magnitude of acceleration produced when a certain force acts upon it is known as mass of the body. Mass is a scalar quantity denoted by 'm'. It remains the same everywhere. Practically, mass is measured by an ordinary balance. The SI unit of mass is kilogram (kg).

Weight: The weight of an object is equal to the force with which the Earth attracts the body towards its centre. By Newton's law, $F = ma$, the weight of a body 'w' will be given by $w = mg$, where g is the gravitational acceleration. As the value of g varies from place to place and also with altitude, therefore, the value of weight does not remain the same everywhere.

34. What are balance scales? Write its types.

Ans. Balance scales are commonly used to compare masses of objects or to weigh objects by balancing them with standard weights.

35. Define mechanical platform balances.

Ans. There is a type of mechanical balances which are used to weigh heavy items like flour bags, cement bags, steel bars, etc. These are called mechanical platform balances.

36. Define friction.

Ans. The force that opposes the motion of the moving object is called friction.

37. What is long range force and short range force?

Ans. Long range forces act over large distances without physical contact while short range forces act only at very small distances typically within atomic or subatomic scales.

38. Write the names of types of friction.

Ans. i. Static friction **ii.** Kinetic friction

39. Define sliding friction and write its types.

Ans. Sliding friction: The resistance created by any two objects when sliding against each other.

Sliding friction can be divided into two categories.

i. Static friction **ii.** Kinetic friction

40. Define rolling friction.

Ans. When an object rolls over a surface, the friction produced is called rolling friction.

41. Define terminal velocity.

Ans. The highest velocity attained by an object falling through a fluid is called terminal velocity.

42. Write two methods to reduce friction.

Ans. The following methods are used to reduce friction:

- i. The parts which slide against each other are highly polished.
- ii. Since, the friction of liquids is less than that of solid surfaces, therefore, oil or gases is applied between the moving part of machinery.
- iii. As rolling friction is much less than the sliding friction, so sliding friction is converted into rolling friction by the use of ball bearing in the machines and wheels under the heavy objects.
- iv. Frictional force does not act only among solids, high speed vehicles, aeroplanes and ships also face friction while moving through air or water. If the front of a vehicle is flat, it faces more resistance by air or water. Therefore, the bodies moving through air or water are streamlined to minimize air or water friction. The air passes smoothly over the slanting surface of vehicle. This type of flow of air is known as streamline flow. The vehicles designed from the front are said to be streamline.

43. Define momentum write. Its formula and its unit.

Ans. The momentum of a moving body is the product of its mass and velocity. Like velocity momentum is also a vector quantity. The SI unit of momentum is kg ms^{-1} . It can also be written as Ns . **Formula:** $p = m \times v$

44. Define impulse.

Ans. When a large force F acts on an object for a short interval of time, the impulse of the force is defined as the total change in momentum of the object.

45. State Newtons law of motion in terms of momentum.

Ans. The rate of change of momentum of a body is equal to the force acting on it. The direction of change in momentum is that of the force.

46. State law of conservation of momentum.

Ans. If no external force acts on an isolated system, the final total momentum of the system is equal to the initial total momentum of the system.

47. Write four examples of contact and non-contact forces.

OR Differentiate between contact and non-contact forces.

Ans. Contact: A contact force is a force that acts at the point of contact between two objects. Applied forces (push a pull and twist) are contact forces. Some other examples of contact forces are the following.

Examples: i. Friction ii. Drag iii. Thrust iv. Normal force

Non-Contact: A non-contact force is defined as the force between two objects which are not in physical contact. The non-contact forces can work from a distance.

That is why these are sometimes called as action-at-a-distance. There is always a field linked with a non-contact force. Due to this property, non-contact forces are also called field forces. A few examples of non-contact forces are describe below.

Example: i. Gravitational force ii. Electrostatic force
 iii. Magnetic force iv. Strong and weak nuclear forces

48. **What is long range and short range force?**

Ans. Long range: Long range act over large distances without physical contact, such as gravitational, electromagnetic and nuclear weak forces. Example: gravity between Earth and Moon.

Short range: Short range force act only at very small distance typically within atomic or subatomic scales, such a strong nuclear force. Example: force holding protons and neutrons in a nucleus.

49. **Write the value of G.**

Ans. It is a long-range force given by Newton's law of gravitation $F = G \frac{m_1 m_2}{r^2}$ where m_1 and m_2 are two masses distance r apart and G is constant of gravitation. Its value is $6.67 \times 10^{-11} \text{ Nm}^2 \text{ kg}^{-2}$.

50. **State Newton's law of Gravitation.**

Ans. Statement: "Every particles in the universe attracts every other particles with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between their center.

Mathematically: $F = G \frac{m_1 m_2}{r^2}$

51. **State law of inertia.**

Ans. "An object will remain at rest, or continue to move in a straight line at a constant speed, unless acted upon by an external force."

52. **Prove $F = ma$?**

Ans. Statement: If a net force of magnitude 'F' acts on a body of mass 'm' and produce an acceleration of magnitude 'a', then second law can be written mathematically as:

Derviation: and

$$a \propto F$$

$$a \propto \frac{1}{m}$$

So $a \propto \frac{F}{m}$ or $a (\text{constant}) \frac{F}{m}$

the value of constant will be 1:

$$a = 1 \times \frac{F}{m} \quad \text{or} \quad F = ma$$

Conceptual Short Questions

1. **Why there is link between non-contact force with field?**

Ans. Non-contact force are linked to field because field describe how these force are transmitted through space. A field represents the region where an object can exert a force on another object without direct contact such as gravitational electric or magnetic fields.

2. Which forces come under the category of electro-magnetic force?

Ans. Force under the category of electro-magnetic force include:

- Electric force
- Magnetic force
- Coulomb force

These forces arise from electric charges and their motion.

3. How strong nuclear force make proton does not let them more apart?

Ans. The strong nuclear force binds protons and neutrons together in the nucleus by overcoming the repulsive electromagnetic force between positively charged protons. It only at very short ranges (about 10^{-14} meter) but it is extremely strong, ensuring protons remain tightly bound.

4. Why Newton first law is some time called law of inertia?

Ans. Newton's first law is also called law of inertia because it describes an object's tendency to resist changes to its states of motion or rest. This property of resisting change is known as inertia.

5. What is the role of the normal force in maintaining equilibrium?

Ans. The normal force is the force exerted by a surface that is perpendicular to the surface. It supports an object against gravity and prevents it from falling through the surface. In equilibrium, the normal force balances the gravitational force acting on an object.

6. How does gravitational force vary with distance from the Earth?

Ans. Gravitational force decreases with the square of the distance from the center of the Earth. The force is inversely proportional to the square of the distance between the two masses involved, as described by Newton's law of universal Gravitation.

7. What is the difference between elastic and inelastic collisions?

Ans. In an elastic collision, both momentum and kinetic energy are conserved. In an inelastic collision, momentum is conserved but kinetic energy is not.

8. What is the difference between impulse and momentum?

Ans. Momentum is the product of an object's mass and its velocity ($p = mv$). Impulse, on the other hand, is the change in momentum caused by a force applied over a period of time ($J = F \Delta t$).

9. What is the difference between static friction and kinetic friction?

Ans. Static friction is the frictional force that resists the motion between two surfaces in contact. Kinetic friction, on the other hand, is the frictional force that acts when two surfaces are sliding over each other. Kinetic friction is usually less than static friction.

10. Action and reaction are always equal and opposite in direction. Then how does a body move?

Ans. According to Newton's third law of motion, action and reaction are always equal and opposite in direction. But action and reaction always act on different bodies so they do not cancel the effect of each other and under this condition of forces the body moves irrespective to this, that action and reaction are equal but opposite in direction.

11. What is power in the context of dynamics?

Ans. Power is the rate at which work is done or energy is transferred, given by:

$$P = \frac{W}{t}$$

Where 'W' is work and 't' is time.

Exercise Questions

A Multiple Choice Questions

Tick (✓) the correct answer:

- 3.1 When we kick a stone, we get hurt. This is due to:
(a) inertia (b) velocity (c) momentum (d) reaction
- 3.2 An object will continue its motion with constant acceleration until:
(a) the resultant force on it begins to decrease.
(b) the resultant force on it is zero.
(c) the resultant force on it begins to increase.
(d) the resultant force is at right angle to its tangential velocity.
- 3.3 Which of the following is a non-contact force?
(a) Friction (b) Air resistance
(c) Electrostatic force (d) Tension in the string
- 3.4 A ball with initial momentum p hits a solid wall and bounces back with the same velocity. Its momentum p' after collision will be:
(a) $p' = p$ (b) $p' = -p$ (c) $p' = 2p$ (d) $p' = -2p$
- 3.5 A particle of mass m is moving with velocity v collides with another particle of the same mass at rest. The velocity of the first particle after collision is:
(a) v (b) $-v$ (c) 0 (d) $-1/2$
- 3.6 Conservation of linear momentum is equivalent to:
(a) Newton's first law of motion (b) Newton's second law of motion
(c) Newton's third law of motion (d) None of these
- 3.7 An object with a mass of 5kg moves at constant velocity of 10ms^{-1} . A constant force then acts for 5 seconds on the object and gives it a velocity of 2ms^{-1} in the opposite direction. The force acting on the object is:
(a) 5N (b) -10N (c) -12N (d) -15N
- 3.8 A large force acts on an object for a very short interval of time. In this case, it is easy to determine:
(a) magnitude of force (b) time interval
(c) product of force and time (d) none of these
- 3.9 A lubricant is usually introduced between two surfaces to decrease friction. The lubricant:
(a) decreases temperature (b) acts as ball bearings
(c) prevents direct contact of the surfaces (d) provides rolling friction

ANSWERS:

1. (d) 2. (b) 3. (c) 4. (b) 5. (c) 6. (c) 7. (c)
 8. (c) 9. (c)

B Short Answer Questions

3.1. What kind of changes in motion maybe produced by a force?

Ans: A force can produce the following changes in motion.

- Change in speed
- Change in direction
- Change in shape

These changes depend on the magnitude, direction and point of application of the force.

3.2 Give 5 examples of contact forces.

Ans: Examples of contact forces are following:

- Friction
- Air resistance
- Drag
- Tension force
- Thrust
- Electric force
- Normal force

3.3 An object moves with constant velocity in free space. How long will the object continue to move with this velocity?

Ans: The object will continue to move with constant velocity indefinitely, as long as no external force acts on it.

3.4. Define impulse of force.

Ans: Impulse of Force: Impulse of force is the product of a force and time interval over which it acts. It equals to the change in momentum of an object.

3.5 Why has not Newton's first law been proved on Earth?

Ans. Newton's first law has not been fully proved on Earth because external force like friction and air resistance are always present. It is impossible to completely eliminate all external forces acting on an object on Earth.

3.6. When sitting in a car which suddenly accelerates from rest, you are pushed back into the seat, why?

Ans. You are pushed back into the seat due to inertia, as your body resists the change in motion and tends to remain at rest while the car accelerates forward.

3.7 The force expressed in Newton's second law is a net force. Why is it so?

Ans. The force in Newton's second law is a net force because it represents the vector sum of all forces acting on an objects, determining its acceleration according to

$$F_{\text{net}} = ma$$

3.8 How can you show that rolling friction is lesser than the sliding friction?

Ans. Rolling friction is less than sliding friction because less surface area is in contact during rolling, reducing resistance.

- This can be shown by comparing the effort needed to slide an object verses rolling it.

3.9 Define terminal velocity of an object.

Ans. Terminal velocity is the constant maximum velocity of an object reaches, when the force of air resistance equals the gravitational force acting on it, resulting is zero net acceleration.

3.10 An astronaut walking in space wants to return to his spaceship by firing a hand rocket. In what direction does he fire the rocket?

Ans. The astronaut fires the rocket in the direction opposite to the spaceship to propel himself toward it, according to Newton's third law of motion.

C Constructed Response Questions

3.1 Two ice skaters weighing 60kg and 80 kg push off against each other on a frictionless ice track. The 60 kg skater gains a velocity of 4ms^{-1} . Considering all the relevant calculations involved, explain how Newton's third law applies to this situation.

Ans. Newton's third law states that for every action, there is an equal and opposite reaction. When the skater of mass 60kg applies a force on the skater of mass 80kg, the 80kg skater applies an equal and opposite force on the 60kg skater.

Calculation: since there are no external force, momentum is conserved.

$$m_1v_1 + m_2v_2 = 0$$

Mass of the first skater = $m_1 = 60\text{kg}$

Mass of the second skater = $m_2 = 80\text{kg}$

Velocity of the first skater = $v_1 = 4\text{ms}^{-1}$

Required:

Velocity of the second skater = $v_2 = ?$

Formula: $m_1v_1 + m_2v_2 = 0$

Solution: By using $m_1v_1 + m_2v_2 = 0$

$$60\text{kg} \times 4\text{ms}^{-1} + 80\text{kg} \times v_2 = 0$$

$$240\text{kgms}^{-1} + 80v_2 = 0$$

$$v_2 = \frac{-240\text{kgms}^{-1}}{80\text{kg}}$$

$$v_2 = -3\text{ms}^{-1}$$

Result: The velocity of the 80kg skater is 3ms^{-1} (The negative sign indicates that the second skater moves in the opposite direction to the first skater)

3.2 Inflatable air bags are installed in the vehicles as safety equipment. In terms of momentum, what is the advantage of air bags over seat belts?

Ans. Airbags, compared to seatbelts, offer a significant advantage by increasing the time over which the occupant's momentum changes during a collision. This results in a smaller force exerted on the occupant, reducing the risk of injury.

3.3 A horse refuses to pull a cart. The horse argues, "according to Newton's third law, whatever force I exert on the cart, the cart will exert an equal and opposite force on me. Since the net force will be zero, therefore I have no chance of accelerating (pulling) the cart." What is wrong with this reasoning?

Ans. The horse's reasoning is flawed because Newton's third law involved action-reaction acting on different objects, not cancelling each other out. The force the horse exerts on the cart (action) is matched by the cart's force on the horse

(reaction), but these forces act on separate objects.

- To pull the cart, the horse applies a force on the ground. The ground exerts an equal and opposite reaction force on the horse, allowing it to accelerate forward.
- Simultaneously, the horse pulls the cart, causing the cart to accelerate. The net force on the system depends on the interaction between the horse, cart and ground.

3.4 When a cricket ball hits high, a fielder tries to catch it. While holding the ball he/she draws hands backward. Why?

Ans. By drawing their hands backward, the fielder increase the time over which the ball's momentum changes, reducing the force exerted on their hands and preventing injury.

3.5 When someone jumps from a small boat onto the river bank, why does the jumper often fall into the water? Explain.

Ans. When someone jumps from a small boat, they push the boat backward due to Newton's third law.

Since the boat is small and light, it moves in the opposite direction as the opposite direction as the person jumps. This backward motion of the boat can reduce the jumper's forward momentum, causing them to misjudge their landing and fall into the water instead of reaching the river bank.

3.6 Imagine that if friction vanishes suddenly from everything, then what could be the scenario of daily life activities.

Ans. If friction vanishes suddenly, most daily activities would become impossible. People would be unable to walk, as there would be no grip between their feet and the ground. Vehicles would lose friction and be unable to accelerate, steer, or brake. Objects would slide indefinitely on surfaces, making tasks like writing, holding items on operating machinery unfeasible. Buildings and structures relying on friction for stability could collapse, leading to wide spread chaos.

D Comprehensive Questions

3.1. Explain the concept of force by practical examples.

Ans. For answer see Q. No. 1, 2, 3, 4, 5, 6

3.2. Describe Newton's laws of motion.

Ans. For answer see Q. No. 7, 9, 10

3.3. Define momentum and express Newton's 2nd law of motion in terms of change in momentum.

Ans. For answer see Q. No. 19

3.4. State and explain the principle of conservation of momentum.

Ans. For answer see Q. No. 20

3.5. Describe the motion of a block on a table taking into account the friction between the two surfaces. What is the static friction and kinetic friction?

Ans. For answer see Q. No. 15

3.6. Explain the effect of friction on the motion of vehicle in context of tyre surface and braking force.

Ans. Friction between the tyres and the road surface is essential for vehicle motion. The tyre tread pattern and rubber compound are designed to maximize this friction, providing grip for acceleration and braking. The braking force is directly proportional to the tyre road friction; low friction (e.g. on wet or icy roads) reduces braking force and increases stopping distance. Exceeding the maximum static friction leads to tyre skidding and reduced braking effectiveness. Friction is a force that opposes motion between two surfaces in contact. In vehicles, friction between the tyres and the road surface is crucial for both acceleration and braking.

The tyre surface is designed to maximize friction. The tread pattern (the grooves and ridges on the tyre) increases the contact area between the tyre and the road, providing more grip. The rubber compound itself is formulated to have a high coefficient of friction with various road surfaces (asphalt, concrete, etc.) A worn tyre has less tread, reducing the contact area and thus the friction. Wet or icy roads also reduce friction because a layer of water or ice reduces the direct contact between the tyre and the road surface.

When brakes are applied, the braking system acts on the wheels, creating a torque that tyre to slow the wheels' rotation. This action, however, depends on the friction between the tyres and the road. The braking force is the force that slows the vehicle down. This force is directly proportional to the friction force between the tyres and the road. If the friction is low (e.g on ice), the braking force will be reduced, leading to a longer stopping distance. The maximum braking force is limited by the maximum static friction force between the tyres and the road. If the braking force exceeds the maximum static friction force, the tyres will skid (kinetic friction takes over, which is less than static friction), and the braking force will decrease.

E Numerical Problems

3.1. A 10 kg block is placed on a smooth horizontal surface. A horizontal force of 5N is applied to the block. Find:

(a) the acceleration produced in the block.

(b) the velocity of block after 5 seconds.

Sol. Mass of the block = $m = 10\text{kg}$, Initial velocity = $v_i = 0$,

Force applied = $F = 5\text{N}$

time = $t = 5\text{s}$

Required: Acceleration = $a = ?$

Final velocity = $v_f = ?$

Formula: $F = ma$

$v_f = v_i + at$

Solution:

(a) By Newton's second law of motion

$$F = ma$$

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

$$a = \frac{5\text{N}}{10\text{kg}}, \quad a = 0.5\text{ms}^{-2}$$

(b) By first equation of motion.

$$v_f = v_i + at$$

$$v_f = 0 + (0.5\text{ms}^{-2})(5\text{s})$$

$$v_f = 2.5\text{ms}^{-1}$$

Thus, a) The acceleration produced in the block is 0.5ms^{-2} .

b) The velocity of block after 5 seconds is 2.5ms^{-1} .

3.2. The mass of a person is 80kg. What will be his weight on the Earth? What will be his weight on the Moon? The value of acceleration due to gravity of Moon is 1.6m s^{-2} .

Sol. Mass = $m = 80\text{kg}$

Acceleration due to gravity on moon = 1.6ms^{-2}

Acceleration due to gravity on earth = 10ms^{-2}

Required:

Weight on Earth = ?

Weight on Moon = ?

Formula: Weight = Mass \times Acceleration due to gravity

Solution:

(a) On Earth

as $w = m \times g$ (Earth)

So, $w = 80\text{kg} \times 10\text{ms}^{-2}$

$w = 800\text{N}$

(b) On Moon

as $w = m \times g$ (Moon)

So, $w = 80\text{kg} \times 1.6\text{ms}^{-2}$

$w = 128\text{N}$

Result: a) The weight of a person on the Earth is 800N.

b) The weight of a person on the Moon is 128N.

3.3. What force is required to increase the velocity of 800 kg car from 10ms^{-1} to 30ms^{-1} in 10 seconds?

Sol. Mass = $m = 800\text{kg}$

Initial velocity = $v_i = 10\text{ms}^{-1}$

Final velocity = $v_f = 30\text{ms}^{-1}$

Time = $t = 10\text{s}$

Required:

Force = ?

Formula: $F = ma$

Solution:

To find force, first we find acceleration

as
$$a = \frac{v_f - v_i}{t}$$

So,
$$a = \frac{30\text{ms}^{-1} - 10\text{ms}^{-1}}{10\text{s}}$$

$$a = \frac{20\text{ms}^{-1}}{10\text{s}}$$

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

Now we find force.

As we know, $F = ma$

$$F = 800\text{kg} \times 2\text{ms}^{-2}$$

$$F = 1600\text{N}$$

Result: Thus, The force to increase the velocity is 1600N.

3.4. A 5g bullet is fired by a gun. The bullet moves with a velocity of 300ms^{-1} . If the mass of the gun is 10 kg, find the recoil speed of the gun.

Sol. Mass of the bullet = $m_b = 5\text{g} = 0.005\text{kg}$

Mass of the gun = $m_g = 10\text{kg}$

Velocity of the bullet = $v_b = 300\text{ms}^{-1}$

Required:

Velocity of the gun = $v_g = ?$

Formula:

$$m_b v_b + m_g v_g = 0$$

Solution:

Total Initial momentum before fired = Total Final momentum after fired

$$0 = m_b v_b + m_g v_g$$

then, $m_g v_g = -m_b v_b$

$$v_g = -\frac{m_b v_b}{m_g}$$

$$v_g = -\frac{0.005 \times 300}{10}$$

$$v_g = -\frac{1.5}{10}$$

$$v_g = -0.15\text{ms}^{-1}$$

Result: The speed of the gun is 0.15ms^{-1} (the negative sign indicates the gun moves in the opposite direction to the bullet).

3.5. An astronaut weighs 70 kg. He throws a wrench of mass 300g at a speed of 3.5ms^{-1} . Determine:

(a) the speed of astronaut as he recoils away from the wrench,

(b) the distance covered by the astronaut in 30 minutes.

Sol. Mass of the wrench = $m_w = 300\text{g} = 0.3\text{kg}$

Mass of the Astronaut = $m_a = 70\text{kg}$

Speed of the wrench = $v_w = 3.5\text{ms}^{-1}$

Required:

Speed of the astronaut = $v_a = ?$

Distance covered by the astronaut in 30min = $d = ?$

Formula:

(a) $m_w v_w + m_a v_a = ?$

(b) $d = ?$

Solution:

According to law of conservation of momentum, the total momentum before the wrench is thrown is zero, as both astronaut and wrench are initially at rest.

So,

a. Initial momentum = Final momentum

as, $0 = m_w v_w + m_a v_a$

then, $m_a v_a = -m_w v_w$

$$v_a = -\frac{m_w v_w}{m_a}$$

$$v_g = -\frac{0.3 \times 3.5}{70}$$

$$v_g = -\frac{1.05}{70}$$

$$v_g = -0.015 \text{ ms}^{-1}$$

b. Distance = Speed \times Time

$$d = v_a \times t$$

so, $d = 0.015 \times 1800$

$$d = 27 \text{ m}$$

$$\therefore \begin{cases} t = 30 \text{ min} = 30 \times 60 \text{ sec} \\ t = 1800 \text{ s} \end{cases}$$

Result: a. The astronaut recoils with a speed of 0.015 ms^{-1} . The negative sign indicates that the astronaut moves in the direction opposite to the wrench.

b. The astronaut covers a distance of 27 meters in 30 minutes.

3.6. A $6.5 \times 10^3 \text{ kg}$ bogie of a goods train is moving with a velocity of 0.8 m s^{-1} . Another bogie of mass $9.2 \times 10^3 \text{ kg}$ coming from behind with a velocity of 1.2 ms^{-1} collides with the first one and couples to it. Find the common velocity of the two bogies after they become coupled.

Sol. Mass of the first bogie = $m_1 = 6.5 \times 10^3 \text{ kg}$

Mass of the Astronaut = $m_2 = 9.2 \times 10^3 \text{ kg}$

Velocity of the first bogie = $v_1 = 0.8 \text{ ms}^{-1}$, velocity of the second bogie = $v_2 = 1.2 \text{ ms}^{-1}$

Required:

Common velocity of both bogies after they become coupled = $v_f = ?$

Formula:

By law of conservation of momentum.

$$m_1 v_1 + m_2 v_2 = (m_1 + m_2) v_f$$

Solution:

a. Initial momentum = Final momentum

$$m_1 v_1 + m_2 v_2 = (m_1 + m_2) v_f$$

Solution:

$$(6.5 \times 10^3 \text{ kg}) \times (0.8 \text{ ms}^{-1}) + (9.2 \times 10^3 \text{ kg}) \times (1.2 \text{ ms}^{-1}) = (6.5 \times 10^3 + 9.2 \times 10^3) v_f$$

$$5200 + 11040 = (15.7 \times 10^3)v_f$$

$$16240 = (15.7 \times 10^3)v_f$$

$$\Rightarrow v_f = \frac{16240}{15.7 \times 10^3} \text{ms}^{-1}$$

$$v_f = 1.034 \text{ms}^{-1}$$

Result: The common velocity of the two bogies after they become coupled is 1.03ms^{-1} .

3.7. A cyclist weighing 55 kg rides a bicycle of mass 5 kg. He starts from rest and applies a force of 90 N for 8 seconds. Then he continues at a constant speed for another 8 seconds. Calculate the total distance travelled by the cyclist.

Sol.

$$\text{Cyclist mass} = m_1 = 55 \text{ kg}$$

$$\text{Bicycle's mass} = m_2 = 5 \text{ kg}$$

$$\text{Total mass} = m_1 + m_2$$

$$= 55 + 5 = 60 \text{ kg}$$

$$\text{Initial velocity} = v_i = 0 \text{ ms}^{-1}$$

$$\text{Force} = F = 90 \text{ N}$$

$$\text{Time} = t = 8 \text{ s}$$

Required:

$$\text{Total distance} = d = ?$$

Formula:

$$d_1 = v_i t + \frac{1}{2} a t^2$$

$$d_2 = v \times t$$

Solution: First, we calculate the acceleration using Newton's second law

$$F = ma$$

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

so,
$$a = \frac{90}{60}$$

$$a = 1.5 \text{ms}^{-2}$$

Now, we calculate distance d_1 .

$$d_1 = v_i t + \frac{1}{2} a t^2$$

$$d_1 = 0 + \frac{1}{2} (1.5) (8)^2 = 48 \text{ m}$$

For the calculation of d_2 , we need to calculate the speed.

$$v_f = v_i + at$$

$$v_f = 0 + (1.5) (8)$$

$$v_f = 12 \text{ms}^{-1}$$

Now, we calculate d_2

$$d_2 = v \times t$$

$$d_2 = 12\text{ms}^{-1} \times 8\text{s}$$

$$d_2 = 96\text{m}$$

Now, we calculate the total distance.

$$\begin{aligned}d_{\text{total}} &= d_1 + d_2 \\ &= 48 + 96 = 144\text{m}\end{aligned}$$

Result: The total distance travelled by the cyclist is 144 meter.

3.8. A ball of mass 0.4 kg is dropped on the floor from a height of 1.8 m. The ball rebounds straight upward to a height of 0.8 m. What is the magnitude and direction of the impulse applied to the ball by the floor?

Sol. Mass of the ball = $m = 0.4\text{kg}$

Initial height = $h_1 = 1.8\text{m}$

Final height after rebound = $h_2 = 0.8\text{m}$

Gravitational acceleration = $g = 10\text{ms}^{-2}$

Required: Impulse = ?

Formula: $I = \Delta p = m(v_2 - v_1)$

Solution:

- The potential energy at the initial height is converted to kinetic energy i.e

$$mgh = \frac{1}{2}mv_1^2$$

or $\frac{1}{2}v_1^2 = gh$

$$v_1^2 = 2gh$$

$$v_1 = \sqrt{2gh}$$

$$v_1 = \sqrt{2 \times 10 \times 1.8}$$

so, $v_1 = \sqrt{36}$

$$v_1 = 6\text{ms}^{-1}$$

Since the ball is falling, this velocity is directed downward, so we take it as negative.

$$v_1 = -6\text{ms}^{-1}$$

- The kinetic energy just after impact is converted to potential energy. i.e.

$$\frac{1}{2}mv_2^2 = mgh$$

$$v_2^2 = 2gh$$

$$v_2 = \sqrt{2gh_2}$$

$$v_2 = \sqrt{2 \times 10 \times 0.8}$$

$$v_2 = \sqrt{16}$$

$$v_2 = 4\text{ms}^{-1}$$

Now, we calculate impulse

$$I = \Delta p = m(v_2 - v_1)$$

$$I = 0.4(4 - (-6))$$

$$I = 0.4(4 + 6)$$

$$I = 0.4(10)$$

$$I = 4\text{Ns}$$

$$\text{Impulse} = 4\text{Ns}$$

Since the impulse is positive, the direction of the impulse is upward.

3.9. Two balls of masses 0.2 kg and 0.4 kg are moving towards each other with velocities 20ms^{-1} and 5ms^{-1} respectively. After collision, the velocity of 0.2kg ball becomes 6ms^{-1} . What will be the velocity of 0.4 kg ball?

Sol. Mass of 1st ball = $m_1 = 0.2\text{kg}$

Velocity of 1st ball before collision = $v_1 = 20\text{ms}^{-1}$

Mass of 2nd ball = $m_2 = 0.4\text{kg}$

Velocity of 2nd ball before collision = $v_2 = -5\text{ms}^{-1}$

(Since it is moving toward ball 1, we take the velocity as negative)

Velocity of 1st ball after collision = $v_1' = 6\text{ms}^{-1}$

Required:

Velocity of 2nd ball after collision = $v_2' = ?$

Formula:

By conservation of momentum

Solution: $m_1v_1 + m_2v_2 = m_1v_1' + m_2v_2'$

$$m_1v_1 + m_2v_2 = m_1v_1' + m_2v_2'$$

so, $(0.2)(20) + (0.4)(-5) = (0.2)(6) + (0.4)v_2'$

$$4 - 2 = 1.2 + 0.4v_2'$$

$$2 = 1.2 + 0.4v_2'$$

$$2 - 1.2 = 0.4v_2'$$

$$0.8 = 0.4v_2'$$

$$v_2' = \frac{0.8}{0.4} = 2\text{ms}^{-1}$$

Result: The velocity of the 0.4kg ball after the collision is 2ms^{-1} .

