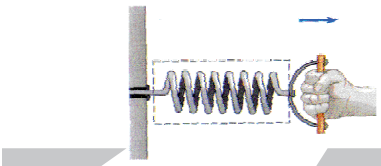
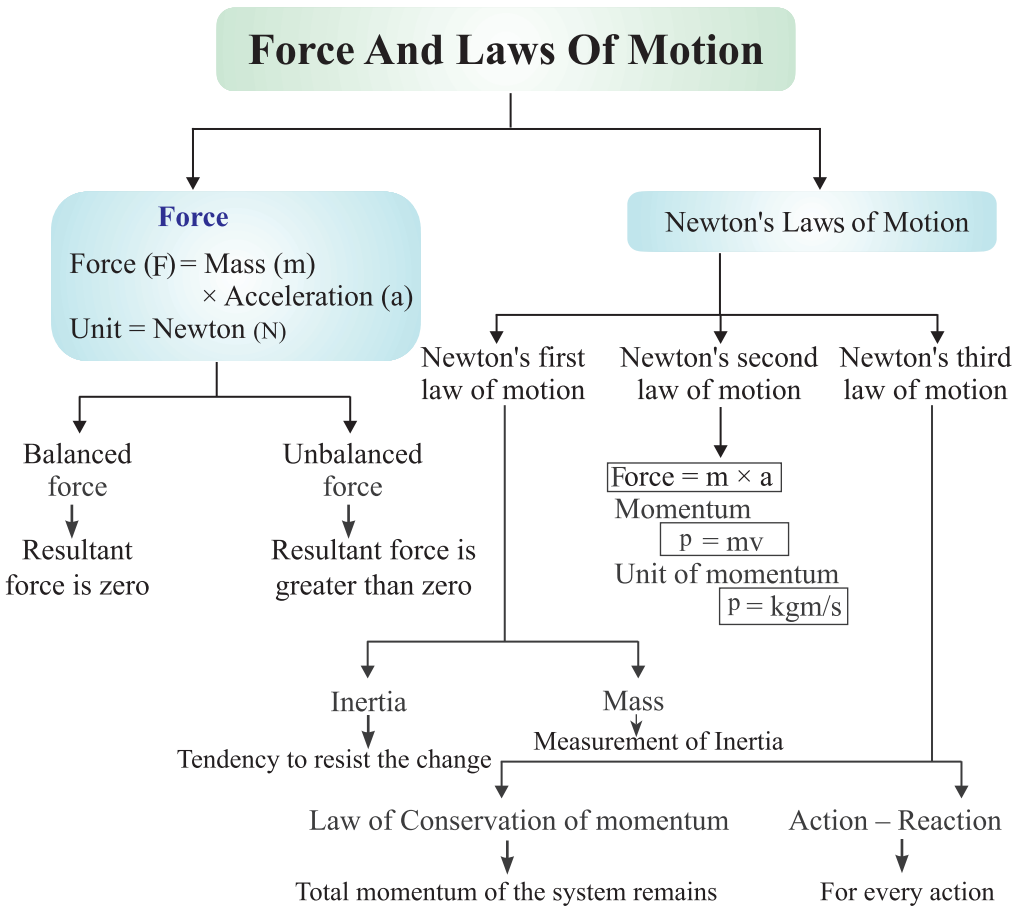


Chapter - 8

Force And Laws Of Motion

CONCEPT MAPPING



Force :

Force : It is the force that enables us to do any work. To do anything, either we pull or push the object. Therefore, pull or push is called force.

Example, to open a door, either we push or pull it. A drawer is pulled to open and pushed to close.

Effects of Force

(i) Force can move a stationary body or object. For example, a football can be set to move by kicking it, *i.e.,* by applying a force.

(ii) Force can stop a moving body. For example, by applying brakes, a running cycle or a running vehicle can be stopped.

(iii) Force can change the direction of a moving object. For example, by applying force, *i.e.,* by moving handle, the direction of a running bicycle can be changed. Similarly by moving steering, the direction of a running vehicle is changed.

(iv) Force can change the speed of a moving body. By accelerating, the speed of a running vehicle can be increased or by applying brakes the speed of a running vehicle can be decreased.

(v) Force can change the shape and size of an object. For example, by hammering, a block of metal can be turned into a thin sheet. By hammering, a stone can be broken into pieces.

Forces are mainly of two types :

(A) Balanced forces

(B) Unbalanced forces

(A) Balanced Forces

- If the resultant of applied forces is equal to zero, these are called balanced forces.

  Example, In a tug of war if both the teams apply similar magnitude of forces in opposite directions, rope does not move in either side. This happens because of balanced forces in which resultant of applied forces become zero.

- Balanced forces do not cause any change of state of an object. Balanced forces are equal in magnitude and opposite in direction.
- Balanced forces can change the shape and size of an object. For example, when forces are applied from both sides over a balloon, the size and shape of balloon are changed.

(B) Unbalanced Forces

- If the resultant of applied forces are greater than zero, the forces are called unbalanced forces. An object in rest can be moved because of applying Unbalanced forces.
- Unbalanced forces can do the following :
  * Move a stationary object
  * Increase the speed of a moving object
  * Decrease the speed of a moving object
  * Stop a moving object
  * Change the shape and size of an object

Laws of Motion :

Galileo Galilei : Galileo was the first to say that objects move with a constant speed when no force acts on them. This means if an object is moving on a frictionless path and no other force is acting upon it, the object would be moving in uniform motion forever. That is, there is no unbalanced force working on the object.

- But practically it is not possible for any object. Force of friction, force of air and many other forces are always acting upon an object.

Newton's Laws of Motion :

Newton studied the ideas of Galileo and gave the three laws of motion. These laws are known as Newton's laws of motion.

Newton's First Law of Motion (Law of Inertia) :

Any object remains in the state of rest or in uniform motion along a straight line, until it is compelled to change the state by applying external unbalanced force.

Explanation : If any object is in the state of rest, then it will remain in rest until an external force is applied to change its state. Similarly, an object will remain in uniform motion in a straight line until any external force is applied over it to change its state. This means all objects resist a change in their state. The state of any object can be changed by applying external forces only.

Newton's First Law of Motion in Everyday Life :

(a) A person standing in a bus falls backward when bus starts moving suddenly. This happens because the person and bus both are at rest while bus is not moving, but as the bus starts moving, the legs of the person start moving along with bus but upper portion of his/her body has the tendency to remain at rest. Because of this, the person falls backwards if he is not alert.

(b) A person standing in a moving bus falls forward if driver applies brakes suddenly. This happens because when bus is moving, the person standing in it is also in motion along with bus. But when driver applies brakes the speed of bus decreases suddenly or bus comes to the state of rest suddenly.In this condition the legs of the person which are in contact with the bus come to rest while the upper part of his/her body has the tendency to remain in motion. Because of this person falls forwards if he / She is not alert.

(c) Before hanging the wet clothes over laundry line, usually many jerks are given to the clothes to get them dried quickly. Because of jerks, droplets of water from the pores of the cloth fall on the ground and reduced amount of water in clothes dries them quickly. This happens because when suddenly clothes are in motion by giving jerks, the water droplets in it have the tendency to remain at rest and they are separated from clothes and fall on the ground.

(d) When a pile of coins on the carom-board is hit by a striker, only the coin at the bottom moves away leaving rest of the pile of coins at the same place. This happens because when the pile is struck with a striker, the coin at the bottom comes in motion while remaining coins in the pile have the tendency to remain at rest and they vertically fall on the carom-board and remain at same place.

(e) Seat belt in cars saves the passengers when sudden brake is applied, by stopping them from moving forwards.

Mass and Inertia

- The property of an object because of which it resists a change in its state is called inertia. Inertia of an object is measured by its mass. Inertia is directly proportional to the mass. This means inertia increases with increase in mass and decreases with decrease in mass. A heavy object will have more inertia than the lighter one.
- In other words, the natural tendency of an object that resists the change in state of uniform motion or rest of the object is called inertia.

- Since a heavy object has more inertia, thus it is difficult to push or pull a heavy box over the ground than the lighter one. Similarly, a greater opposing force is needed to stop a heavy body than a light body in the same time, if they are moving with the same speed.

Momentum

- Momentum is the quantity of motion an object has.
- The product of mass and velocity is called the momentum. Momentum is denoted by 'p'.

  Therefore, Momentum of the object = Mass × Velocity

  Or, $p = m \times v$

Where, p = momentum, m = mass of the object and v = velocity of the object.

Momentum, Mass and Velocity

- Since momentum is the product of mass and velocity ($p = m \times v$) of an object. It means momentum is directly proportional to both mass and velocity. Momentum increases with increase of either mass or velocity of an object.
- This means if a lighter and a heavier object are moving with same velocity, the heavier object will have more momentum than the lighter one.
- If a small object is moving with great velocity, it has tremendous momentum. And because of momentum, it can harm an object more severely. For example, a small bullet having a little mass even kills a person when it is fired from a gun.
- Usually, road accidents prove more fatal because of high speed. This happens because vehicle running with high speed has high momentum.

Momentum of an object which is in the state of rest :

Let an object with mass 'm' be in the state of rest.

Since, object is at rest, its velocity, $v = 0$

Now, we know that

$$\text{Momentum} = \text{mass} \times \text{velocity}$$

Or $$p = m \times 0 = 0$$

Thus, the momentum of an object at rest *i.e.,* non-moving, is equal to zero.

Unit of momentum :

SI unit of mass = Kilogram i.e. kg

SI unit of velocity = meter per second *i.e.,* m/s

We know that $\text{Momentum } (p) = m \times v$

Therefore, $p = \text{kg} \times \text{m/s}$

Or $p = \text{kg m/s}$

Therefore, SI unit of momentum = kg m/s

Numerical Problems Based on Momentum

Type I. Calculation of Momentum

Example 1. *What will be the momentum of a stone having mass of 10 kg when it is thrown with a velocity of 2 m/s ?*

Solution : Mass (m) = 10 kg

Velocity (v) = 2 m/s

Momentum (p) = ?

We know that, $\text{Momentum } (p) = \text{Mass } (m) \times \text{Velocity } (v)$

Therefore, $p = 10 \text{ kg} \times 2 \text{ m/s} = 20 \text{ kg m/s}$

Thus, the momentum of the stone = 20 kg m/s. **Ans.**

Example 2. *The mass of a goods lorry is 4000 kg and the mass of goods loaded on it is 20000 kg. If the lorry is moving with a velocity of 2 m/s, what will be its momentum ?*

Solution : Given, Velocity (v) = 2 m/s

Mass of lorry = 4000 kg, Mass of goods on the lorry = 20000 kg

Therefore, Total mass (m) on the lorry = 4000 kg + 20000 kg = 24000 kg

Momentum (p) = ?

We know that, Momentum (p) = Mass (m) × Velocity (v)

Therefore, p = 24000 kg × 2 m/s

Or p = 48000 kg m/s

Thus, the momentum of the lorry = 48000 kg m/s. **Ans.**

Example 3. *A car having mass of 1000 kg is moving with a velocity of 0.5 m/s. What will be its momentum ?*

Solution : Given, Velocity of the car (v) = 0.5 m/s

Mass of the car (m) = 1000 kg

Momentum (p) = ?

We know that, Momentum (p) = Mass (m) × Velocity (v)

Therefore, p = 1000 kg × 0.5 m/s = 500 kg m/s

Thus, momentum of the car = 500 kg m/s. **Ans.**

Statement of Newton's Second Law of Motion

Rate of change of momentum of an object is proportional to applied unbalanced force in the direction of force.

Mathematical expression (Derivation)

Suppose, Mass of an object = m kg

Initial velocity of an object = u m/s

Final velocity of an object = v m/s

So, Initial momentum, $p_1 = mu$, Final momentum, $p_2 = mv$

$\therefore$ Change in momentum = Final momentum – Initial momentum

$$p = p_2 - p_1$$

$$p = mv - mu$$

$$p = m(v - u)$$

$\therefore$ Rate of change of momentum $= \dfrac{\text{Change in momentum}}{\text{Time taken}}$

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

- According to IInd law, this rate of change is momentum is directly proportional to force.

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

We know that, $\dfrac{v-u}{t} = a$ (From Ist equation of motion)

$$F \propto ma$$

So, $$F = kma$$

Where k is a constant. Its value = 1.

$\therefore$ Taking k = 1, we get F = ma

Hence, the product of mass and acceleration gives force applied.

SI unit of force = kg m/s^2 or Newton (N)

Q. Define 1 Newton.

Ans. When an acceleration of 1 m/s^2 is seen in a body of mass 1 kg, then the force applied on the body is said to be 1 Newton.

Proof of Newton's First Law of Motion from Second Law

First law states that if external force F = 0, then a moving body keeps moving with the same velocity, or a body at rest continues to be at rest.

So, $F = 0$

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

(a) A body is moving with initial velocity u, then

$$0 = \frac{m(v-u)}{t}$$

$$= m(v-u) = 0 \text{ x } t = 0$$

$$v - u = \frac{0}{m} = 0 \qquad \Rightarrow \qquad v - u = 0$$

So, $v = u$

Thus, final velocity is also same.

(b) A body is at rest *i.e.,* $u = 0$.

Therefore, from above $u = v = 0$

So, the body will continue to be at rest

Newton's Third Law of Motion

To every action there is an equal and opposite reaction.

Note : Action and reaction act on two different objects.

Applications :

(i) Walking on a road.

(ii) A boat moves back when we deboard it.

(iii) A gun recoils.

(iv) Rowing of a boat.

QUESTIONS

VERY SHORT ANSWER TYPE QUESTIONS

1. Can force be negative? If yes, is it possible?
2. What is the tendency of a body to resist its change of state called ?
3. Inertia is also measured by.....of an object.
4. Higher the mass of an object, higher is its..... .
5. Force/Acceleration is determined by.....
6. Why does the load from the cage above the seats in a bus falls down when suddenly brakes are applied ?
7. When a tree is shaken, its fruits and leaves fall down. Why?
8. Define momentum of a body.
9. On what factors does the momentum of a body depend?
10. Why is it difficult to walk on a slippery road?

SHORT ANSWER TYPE QUESTIONS

1. Quantity of motion contained in a body is..... .
2. Unit of momentum is..... .
3. Define 1 Newton.
4. Although we know that a moving body keeps moving indefinitely until an external force is applied on it, then why does a ball stop when we slide it on ground (without stopping it) ?
5. Why is it difficult to stop a truck suddenly than a motorbike ?
6. When a metro suddenly stops all the passengers fall forward on its floor. Why does this happen ?

7. We have atmosphere above us that exerts a huge pressure on our shoulders, head and whole body. Why don't we get crushed under it ?

8. A coin of mass 1 kg and a stone of mass 5 kg are thrown down the Eiffel Tower with an acceleration of 10 m/s^2. Which one would reach ground early and why ?

9. Give applications of the First law of motion. (Law of inertia)

10. (a) Friction is measured in..... .

(b) Distinguish between balanced and unbalanced forces.

LONG ANSWER TYPE QUESTIONS

1. (a) Derive the first law of Newton from the second law.

(b) Find the force required to stop a car of mass 1000 kg with two passengers each of 50 kg sitting inside, if it is moving at 60 km/hr speed and takes 5 s to stop.

2. For how long should a force of 100 N act on a body of 20 kg so that it acquires a velocity of 100 m/s? [Hint - using formula $F = ma$. $v = u + at$]

3. (a) Find the acceleration produced by a force of 5 N acting on a mass of 10 kg.

(b) Which would require a greater force : (a) accelerating a 10 gm mass by 5 m/s^2 or (b) a 20 gm mass by 2 m/s^2?
[Hint:convert mass into kg].

4. The velocity of a body of mass 10 kg increases from 4 m/s to 8 m/s when a force acts on it for 2s.

   (a) What is the momentum before the force acts on the body ?

   (b) What is the momentum after the force acts?

   (c) What is the gain in momentum per second?

   (d) What is the value of force?

$$\left[\text{Hint: } a = \frac{v-u}{t} \text{ and } F = ma\right]$$

Answers to Long Answer Type Questions

1. (b) -11000/3 N
2. 20 secs.
3. (a) 0.5 m/s^2

   (b) A greater force of 0.05 N is required for accelerating a 10 gm mass.
4. (a) 40 kg.m/s

   (b) 80 kg.m/s

   (c) 20 $kg.m/s^2$

   (d) 20 N.

OBJECTIVE TYPE QUESTIONS :

I MCQ.

(i) A truck and a car are moving with equal velocity, on applying brakes, both will stop after certain distance and then :

(a) Truck will cover less distance before stopping.

(b) Car will cover less distance before stopping.

(c) Both will cover equal distance.

(d) None of the above.

(ii) In which of the following cases, the net force is not zero ?

(a) An object floating in air

(b) A ball freely falling from a certain height.

(c) A cork floating on the surface of water

(d) All the cases.

(iii) A force acts on a body of mass 3kg such that its velocity changes from $4ms^{-1}$ to $10\ ms^{-1}$. The change in momentum of the body is :

(a) $42Kgms^{-1}$ (b) $2Kgms^{-1}$ (c) $18Kgms^{-1}$ (d) $14Kgms^{-1}$

(iv) While opening a tap with two fingers, the forces applied are:

(a) equal in magnitude (b) Parallel to each other

(c) opposite in direction (d) All of the above

(v) **The engine of a car produces an acceleration of $4ms^{-2}$ in a car. If this car pulls another car of same mass, what is the acceleration produced?**

(a) $8ms^{-2}$ (b) $2ms^{-2}$ (c) $4ms^{-2}$ (d) $0.5ms^{-2}$

(vi) A force of 100N acts on a body of mass 2kg for 10 sec. The change in the velocity of the body is

(a) $100ms^{-1}$ (b) $250ms^{-1}$ (c) $500ms^{-1}$ (d) $1000ms^{-1}$

II Assertion and Reason type questions :

Choose the appropriate answer from the following choices :

- **Assertion Reasoning Questions :-**

Read the Assertion (A) and Reason (R) statements carefully and mark the correct option out of the following :

a) Both Assertion (A) and Reason (R) are true, and (R) is correct explanation of the assertion (A)

b) Both (A) and (R) are true, but (R) is not current explanation of (A).

c) (A) is True but (R) is false.

d) (A) is False but (R) is true.

(i) **Assestion (A) :** If the external force on the body is zero, then its acceleration is zero.

Reason (R) : Acceleration does not depend on force.

(ii) **Assertion (A) :** If two objects of different masses have same momentum, the lighter

body possess greater velocity.

Reason (R) : For all bodies momentum always remains same.

(iii) **Assertion (A) :** Newton's third law of motion is applicable only when bodies are in motion.

Reason (B) : Newton's third law applies to all types of forces eg., gravitaional, electric or magnetic force etc.