4 LAWS OF MOTION

1 OMQ + 1 VSAQ + 1 SAQ [1 M + 2M + 4M = 7 M]

CONCEPTS & DEFINITIONS

1.1 In this chapter, we study (i) 'The 3 Newton's laws of motion and their consequences (Inertia,Momentum, Force, Impulse) (ii) Laws of Conservations (Momentum, Energy) (iii) equilibrium of a particle (iv) Basic forces in mechanics (v) Friction types (vi) Circular Motion.

2.1 **Newton's First law: 'Every body continues to be in its state of rest or uniform motion, in a straight line, unless compelled by some external force to change that state'.**

2.2 **Newton's Second law: 'The 'rate of change of momentum' of a body is directly proportional to the applied force acting on the body and takes place in the direction in which the force acts.**

2.3 **Newton'sThird law: 'To every action, there is always an equal and opposite reaction'.**

3.0 Inertia, Momentum (p), Force (F) and Impulse(J) :

3.1 Inertia: Inertia is an inherent property of a body , by which it opposes any change in its state. It is the resistance to change the state of uniform motion or rest.

Newton's First law is also called Law of Inertia. Inertia is of three types.

(i) Inertia of Rest : The resistance of a body to change its 'state of rest' by itself.
Ex: The passenger in a stationary Train , falls backward ,when the Train **starts suddenly**.

(ii) Inertia of Motion : The resistance of a body to change its 'state of motion' by itself.
Ex : When the bus stops suddenly ,our feet stop due to the friction. But the rest of the body continuous to move forward due to inertia of motion. So we fall farwards.

(iii) Inertia of direction : The resistance of a body to change its 'direction' by itself.
Ex : When a bus, travelling in a straight path suddenly turns towards left, the passengers get themselves pressed towards the right due to inertia of direction.

3.2.1 Momentum (p): The **force** needed **to stop a moving body**, in a given time,depends on the product of (i) the mass of the body (ii) the velocity of the body.
(More the mass , more force is needed to stop ; more the velocity , more force is needed)

Def : The product of mass and velocity of a moving body is called Momentum (p) of the body.
Formula: $p = mv$

Units and Dimensions: SI unit is kg ms^{-1} . And D.F = $[MLT^{-1}]$

Note 1: Momentum is '**massive velocity**'-A measure of quantity of motion of a moving body.
Note 2: Momentum is a vector quantity.
Note 3: Change in momentum $\Delta p = \Delta mv = m(\Delta v)$

3.2.2 Law of conservation of Momentum : When there is 'no resultant external force', the total momentum of all the interacting bodies in a system , remain constant.

In otherwards, Total momentum before collision = Total momentum after collision

Mathematically, $\mathbf{m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2}$

Applications of the law of conservation of linear momentum:

i) **Explosion of bomb:** When a stationary bomb explodes into two pieces, then according to law of conservation of linear momentum

Total momentum before explosion = Total momentum after explosion.

$\Rightarrow 0 = m_1v_1 + m_2v_2 \Rightarrow m_1v_1 = -m_2v_2$

Thus, the momenta of the two pieces after explosion are equal and opposite. Hence they must travel opposite to each other.

ii) **Motion of a Rocket and a Jet plane:** In Rockets / Jet planes,the fuel is burnt in the 'combustion chamber' and the gases escape through narrow openings with large velocity. Then the escaping gas acquire large backward momentum. This imparts an equal forward momentum to the rocket, according to the law of conservation of linear momentum.

3.3 Force: Force is the physical quantity ,that changes or tries to change , the state of rest or uniform motion , along a straightline.

Ex : According to Newton's law of Gravitation, there is a positive attractive Gravitational force between every two bodies in the Universe.

Frictional force, Electromagnetic force, Nuclear force are some other examples.

Formula: Force **F = m a**

Units of force :

One newton : The magnitude of force which, when acting on a body of mass 1 kg produces an acceleration of $1ms^{-2}$ in it, is called one newton.

SI unit : **newton (N)** (or) **kg ms^{-2}**

CGS unit : **dyne (or) gm cm s^{-2}**

Conversions: 1N = 10^5 dyne; 1 kg weight = 9.8N; 1g wt = 980 dyne.

Dimensions: $[M^1L^1T^{-2}]$

Since, $F = ma \Rightarrow [F]=[M]\,[L^1T^{-2}] = [M^1L^1T^{-2}]$

3.4 Impulse (J) : The product of **force** and **time** for which the force acts is called Impulse.

Also, the **change** produced in the **linear momentum** due to some force acting on a body, will be equal to impulse of the force.

Impulse = **Force** × time

$J = F \times t = (ma) \times t = m\left(\frac{v-u}{t}\right) \times t = m(v-u) = mv - mu$ = Change in momentum

Units and Dimensions : S.I unit is N.s (or) $kg.ms^{-1}$, and D.F = $[MLT^{-1}]$

Impulsive force : A **very large force** acting on a body for a very **small interval of time**

Applications of Impulse :

i) **Motor vehicles are provided with shock absorbers (shockers) :** When vehicles move on uneven roads, shock absorbers increase the time of impulse. As a result, impulsive force decreases. Hence, passengers get better comfort.

ii) **A cricket fielder pulls his hands backwards, while catching a ball to avoid injury:** In this way, he increases time of impulse and the force on hands is reduced.

iii) **A person falling on a hard floor receives more injuries than falling on a sandy floor:** Even though the change in momentum (impulse) is same in both the cases, the time of impulse is less in the 1st case. So impulsive force is more. Due to this, the man falling on hard floor receives severe injuries.

iv) **China wares and glass wares are wrapped in straw or paper pieces before packing to avoid damage:** Straw and paper bits increase the time of impulse, so impulsive force decreases.

4. Equilibrium of a particle: Two forces $\bar{F}_1$ and $\bar{F}_2$ acting on a particle keep it in equilibrium if $\bar{F}_1 = -\bar{F}_2$

Equilibrium under three concurrent forces $\bar{F}_1, \bar{F}_2, \bar{F}_3$ requires that the vector sum of the three forces is zero vector. i.e., $\bar{F}_1 + \bar{F}_2 + \bar{F}_3 = \bar{0}$

5. Basic forces in nature: (i) Gravitational force (ii) Electro Magnetic force (iii) strong nuclear force and (iv) weak nuclear force

6.0 Friction : The force which opposes , the relative motion between two surfaces in contact, is called friction.
The direction of frictional force is parallel / tangential to the surfaces in contact.

6.1 Types of friction: There are three types of friction . They are
i) Static friction ii) Kinetic / sliding friction iii) Rolling friction.

i) **Static Friction (f_s) :** The resistance force encountered by a body in static condition ,while tending to move under the action of an external force, is called static friction.
Note: The maximum static frictional force is called "Limiting Friction(f_L)".

ii) **Kinetic/Sliding friction (f_k) :** The resistance force encountered by a sliding body on the surface is known as kinetic friction (or) sliding friction.

iii) **Rolling friction (f_r) :** The resistance force encountered by a rolling body on the surface is known as rolling friction.

Imp. Formulae

1. Momentum **P = mv**
2. Force **F = ma**
3. Impulse **J= F × t (or) J = mv–mu**
4. Law of conservation of momentum: $\mathbf{m_1u_1+m_2u_2 = m_1v_1+m_2v_2}$
5. Frictional force $\mathbf{f=\mu N}$
6. For an inclined plane, $\mathbf{N = mg\cos\theta}$.