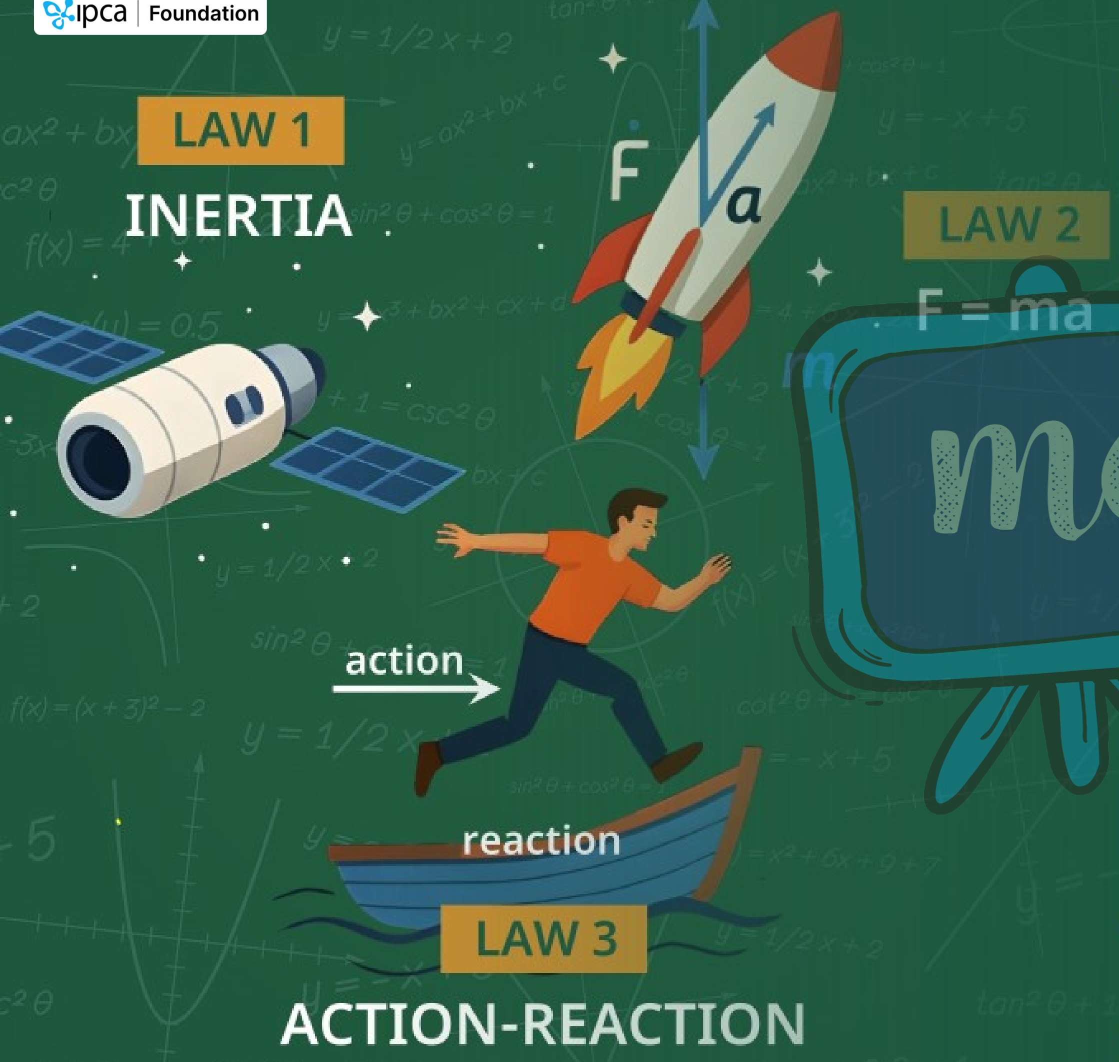

CLASS – 11

PHYSICS

Chapter – 4

Laws of Motion

Part – 2

Newton's Second Law of Motion

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OVERVIEW

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1. Newton's First Law of Motion
2. Newton's Second Law of Motion
3. Newton's Third Law of Motion
4. Common Forces in Mechanics
5. Circular Motion

MOMENTUM

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

1000 kg

3000 kg

MOMENTUM

- The product of mass and velocity of an object moving with linear motion is called linear motion.

$$\vec{P} = m\vec{v}$$

- It is vector quantity whose direction is the direction of velocity of the object.

- It is the measure of quantity of motion of the object.
- Unit : kg.metre/sec
- Dimension : $[M^1L^1T^{-1}]$

mv

$kg \frac{m}{s}$

Case : 1st

$P = mv$

- If v = constant

then $p \propto m$

$m_1 > m_2 \quad \therefore \; p_1 > p_2$

for two objects

$$\frac{p_1}{p_2} = \frac{m_1}{m_2}$$

M_1 M_2

Case : 2nd

- If m = constant

  then $p \propto v$

  $p = mv$

  $v_1 > v_2$ $p_1 > p_2$

  for two objects

  $$\frac{p_1}{p_2} = \frac{v_1}{v_2}$$

Case : 3rd

✧ If p = constant

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

$m_2 > m_1$ $\qquad$ $v_2 > v_1$

for two objects

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

$$K.E = \frac{1}{2} m v^2$$

$$p = mv$$

$$K.E = \frac{1}{2} m v^2 \frac{m}{m}$$

$$= \frac{m^2 v^2}{2m}$$

$$K.E = \frac{(mv)^2}{2m}$$

$$* \boxed{K.E = \frac{p^2}{2m}} \qquad \boxed{p = \sqrt{2m\,K.E}}$$

NEWTON'S SECOND LAW OF MOTION

According to this law, "The rate of change of momentum of a body is directly proportional to external force applied on it.

$$\vec{F} \propto \frac{\Delta \vec{p}}{\Delta t}$$

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

Real Law of motion

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

$$\vec{F} = k\frac{d\vec{p}}{dt}$$

$k = 1$

$$\vec{F} = \frac{d\vec{p}}{dt}$$

$$\vec{F} = \frac{d\vec{P}}{dt}$$

m = const

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

$$\vec{F} = m\frac{d\vec{v}}{dt}$$

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

Where k is proportionality constant whose value is 1.

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

$$\vec{F} = \lim_{\Delta t \to 0}\frac{\Delta\vec{p}}{\Delta t}$$

$$\vec{F} = \frac{d\vec{p}}{dt}$$

$$\therefore \vec{p} = m\vec{v}$$

$$\vec{F} = \frac{d}{dt}mv$$

$$\vec{F} = m\frac{d\vec{v}}{dt}$$

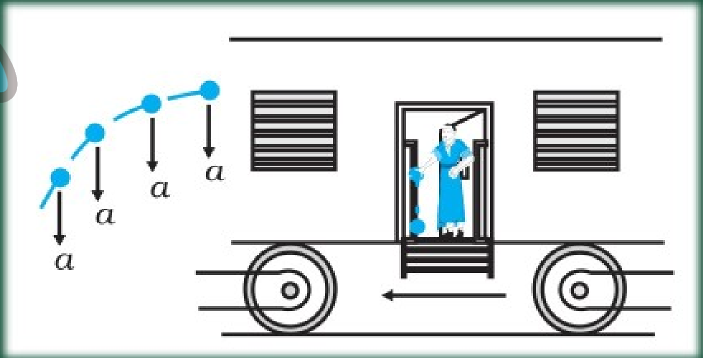
$$\vec{F} = m\vec{a}$$

- The product of mass of the object and acceleration produced in it is equal to the applied force.

When mass is variable

$$\vec{F} = \frac{d\vec{p}}{dt} = \frac{d(m\vec{v})}{dt}$$

$$* \quad \vec{F} = \vec{v}\frac{dm}{dt}$$



DO YOU KNOW?

The second law of motion is a vector law.

$$\therefore \vec{F} = m\vec{a}$$

$$F_x\hat{i} + F_y\hat{j} + F_z\hat{k} = m(a_x\hat{i} + a_y\hat{j} + a_z\hat{k})$$

$$F_x = \frac{dp_x}{dt} = ma_x$$

$$F_y = \frac{dp_y}{dt} = ma_y$$

$$F_z = \frac{dp_z}{dt} = ma_z$$

UNIT OF FORCE

In M.K.S. system : Newton

$\because$ F = ma

When m = 1kg and a = 1m/sec^2

then F = 1 newton

"The force, which produces an acceleration of 1m/sec^2 in a body of mass 1kg, is equal to 1 newton."

1 newton = 1kg × 1msec^{-2}

In C.G.S. system : Dyne

$\because$ F = ma

When m = 1gm and a = 1cm/sec^2

then F = 1 dyne

"The force, which produces an acceleration of 1cm/sec^2 in a body of mass 1gm, is equal to 1 dyne."

$1 N = 10^5$ Dyne

$1 \frac{kg\,m}{s^2} = 10^5 \frac{g\,cm}{s^2}$

1 dyne = 1gm × 1cm sec^{-2}

WEIGHT

The weight of a body is equal to gravitational force acting on it.

Weight $w = mg$

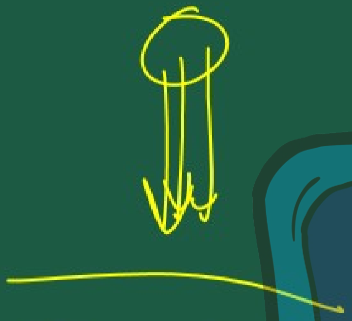
Where g is acceleration due to gravity.

- The unit of weight is newton.

1kg weight = 1kg × gm/sec^2

= g newton

= 9.8 newton



$F = mg$

$F = mg$

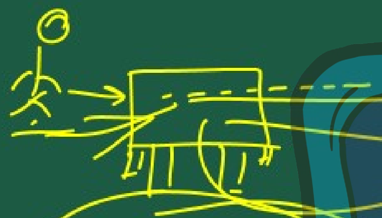
$F = mg$

$W = mg$

$g = 9.8 m/s^2$

IMPULSE

- The total effect of a force on the motion of a body is called impulse of the force.
- The product of applied force on a body and time interval for which the force is imposed is called impulse of the force.



large force

low time

$$\vec{I} = \vec{F} \cdot t$$

- Impulse is a vector quantity. The direction of impulse is along the direction of force.
- Unit : Newton × second
- Dimension : $[M^1L^1T^{-1}]$

$M^1L^1T^{-2}\ T^1$

IMPULSE - MOMENTUM THEOREM

$$\because \vec{F} = \frac{d\vec{P}}{dt}$$

$$d\vec{P} = \vec{F}dt$$

$$\Rightarrow \int_{t_1}^{t_2} F \cdot dt = \int_{p_1}^{p_2} dP$$

$$I = \left[P\right]_{p_1}^{p_2} = \left[P_2 - P_1\right]$$

$$\vec{I} = \Delta\vec{P}$$

$$d\vec{P} = \vec{F}dt$$

$$\int_{P_1}^{P_2} d\vec{P} = \int_{t_1}^{t_2} \vec{F}\, dt$$

$$(\vec{P})_{P_1}^{P_2} = \vec{F}\,(t)_{t_1}^{t_2}$$

$$\vec{P}_2 - \vec{P}_1 = \vec{F}\,(t_2 - t_1)$$

$$\vec{P}_2 - \vec{P}_1 = \vec{F}\,\Delta t$$

$$\vec{I} = \vec{P}_2 - \vec{P}_1$$

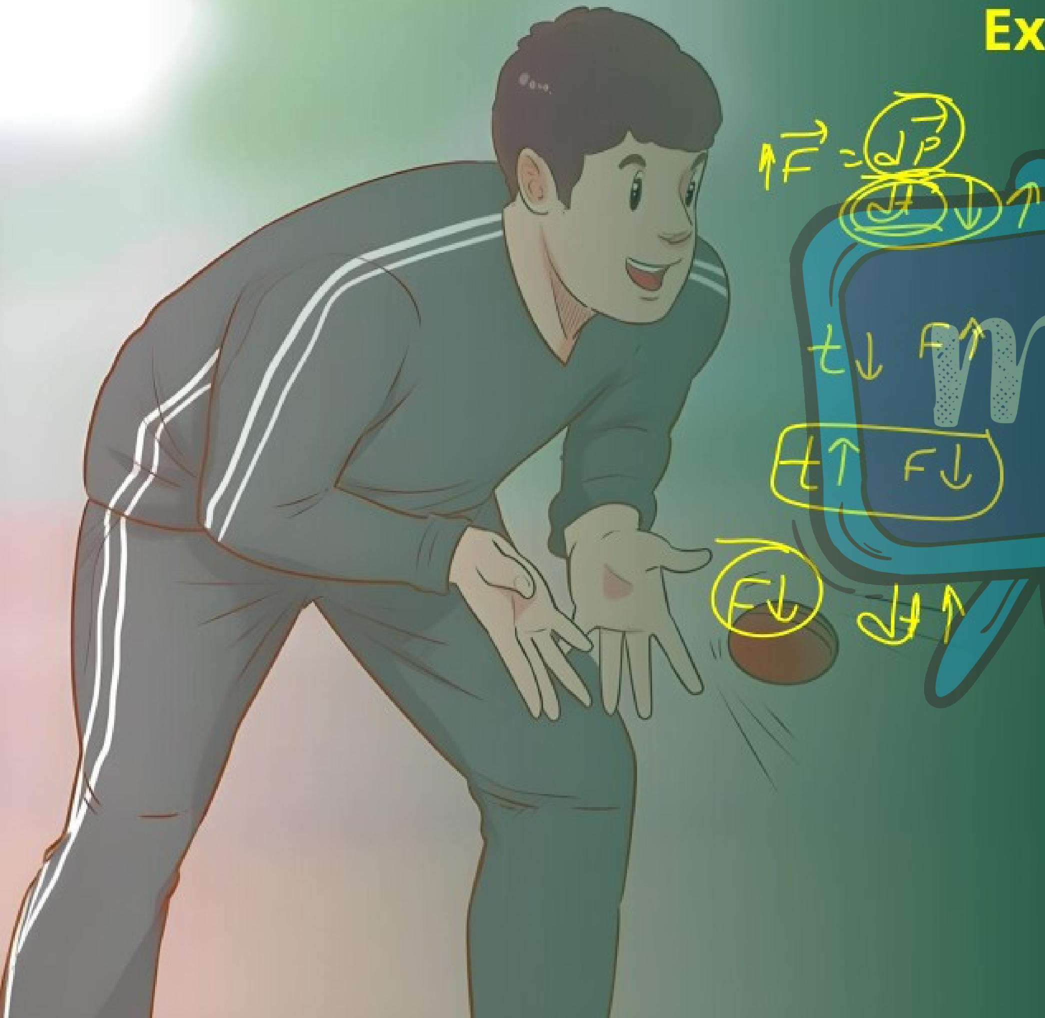
$$\vec{I} = \Delta\vec{P}$$

- The impulse of a force is equal to change im momentum due to that force.

$$\vec{F}_1 t_1 = \vec{F}_2 t_2$$

$$t_1 < t_2$$

$$F_1 > F_2$$



Example :

A cricketer increases the time of catching ball by moving back his hands while catching a fast moving ball so that force exerting on the hands can be reduced to a small magnitude.

Special Case :

$$F = ma$$

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

$$F \propto t = m(v - u)$$

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

$$I = \Delta P$$

EXAMPLE

2. A bullet of mass 0.04 kg moving with a speed of 90 ms^{-1} enters a heavy wooden block and is stopped after a distance of 60 cm. What is the average resistive force exerted by the block on the bullet?

$m = 0.04\ kg$

$m = 4 \times 10^{-2}\ kg$

$u = 90\ m/s$

$s = 60\ cm$

$= 60 \times 10^{-2}\ m$

$= 0.6\ m$

$v = 0$

$a = ?$

$F = ma$

EXAMPLE

$a = \frac{v^2 - u^2}{2s} = \frac{0 - u^2}{2s}$

$a = -\frac{90 \times 90}{2 \times 0.6}$

$a = -6750\ m/s^2$

$F = ma$

$= 4 \times 10^{-2} \times 6750$

$F = -270\ N$

Answer : The retardation 'a' of the bullet (assumed constant) is given by

$$a = \frac{-u^2}{2s} = \frac{-90 \times 90}{2 \times 0.6} ms^{-2} = -6750 ms^{-2}$$

The retarding force, by the second law of motion, is

$= 0.04\ kg \times 6750\ m\ s^{-2} = 270\ N$

The actual resistive force, and therefore,

EXAMPLE

retardation of the bullet may not be uniform. The answer therefore, only indicates the average resistive force.

EXAMPLE

3. The motion of a particle of mass m is described by $y = ut + \frac{1}{2}gt^2$. Find the force acting on the particle.

$y = ut + \frac{1}{2}gt^2$

$\frac{dy}{dt} = u + \frac{1}{2}g(2t)$

$v = u + gt$

$a = \frac{dv}{dt} = 0 + g$

$a = g$

$F = ma$

$F = mg$

EXAMPLE

Answer : We know

$$y = ut + \frac{1}{2}gt^2$$

Now,

$$v = \frac{dy}{dt} = u + gt$$

$$\text{acceleration, } a = \frac{dv}{dt} = g$$

Then the force is given by

$$F = ma = mg$$

EXAMPLE

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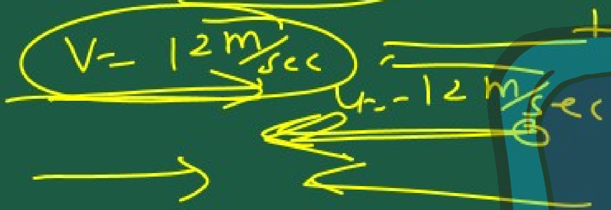
Thus the given equation describes the motion of a particle under acceleration due to gravity and y is the position coordinate in the direction of g.

EXAMPLE

4. A batsman hits back a ball straight in the direction of the bowler without changing its initial speed of 12 m s^{-1}. If the mass of the ball is 0.15 kg, determine the impulse imparted to the ball. (Assume linear motion of the ball)

$\vec{I} = \Delta\vec{p}$



$m = 0.15$ kg

$I = m(v - u)$

$I = 0.15(12 - (-12))$

$= 0.15 \times 24$

$I = 3.60$ N-s

EXAMPLE

Answer : Change in momentum

$= 0.15 \times 12 - (-0.15 \times 12)$

$= 3.6$ N s,

Impulse = 3.6 N s

in the direction from the batsman to the bowler.

This is an example where the force on the ball by the batsman and

EXAMPLE

the time of contact of the ball and the bat are difficult to know, but the impulse is readily calculated.

LEARNING OUTCOMES

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1 To know about 'Momentum' and 'Impulse'

2 To study for 'Newton's second law of motion'

ASSESSMENT

1 | One kg weight is equal to–

A. 1 newton

B. 9.8 newton

C. 980 newton

D. 98 newton

ASSESSMENT

2 A body of mass 40gm is moving with a constant velocity of 2cm/sec on a horizontal frictionless table. The force on the table is–

- A 39200 dyne
- B 160 dyne
- C 80 dyne
- D zero dyne

$u = 2\ cm/sec$

$F = \mu mg$

$= 40g \times 980$

$= 39200$

ASSESSMENT

3 A ball of mass 0.2kg moves with a velocity of 20m/sec and it stops in 0.1 sec, then the force on the ball is–

- A 40 N
- B 20 N
- C 4 N
- D 2 N

$m = 0.2\ kg$

$u = 20 m$ $t = 0.1 sec$

$F = ?$ $v = 0$

$v = u + at$

$a = \frac{v-u}{t} = \frac{0-20}{0.1}$

$a = \frac{-20}{0.1} = -200\ m/s^2$

$F = 0.2 \times -200 = -40N$

ASSESSMENT

4 | Newton's second law gives the measure of–

A Acceleration

B Force

C Momentum

D Angular velocity