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Physics

Laws of Motion

Lecture - 03

By - Akash Shravan Sir

Topics *to be covered*

1. Linear Momentum ($p = mv$)
2. Newton's Second Law of Motion
3. Newton's Third Law of Motion

4) Newton's Laws of Motion Part 2

Recap *of previous lecture*

1. Linear Momentum ($p = mv$)
2. Newton's Second Law of Motion
3. Newton's Third Law of Motion

Momentum [P]

$p \propto v$

$p \propto m$

$P = mv$

Linear Momentum (p = mv)

$v = 0$
$p = 0$

Linear momentum of a body is the product of its mass and velocity.

- The linear momentum of a body is denoted by the letter *p*. Generally the word momentum is used for linear momentum.
- For a body of mass *m* moving with velocity *v*, linear momentum *p* is expressed as

$$p = mv$$

- It is a vector quantity in the direction of motion of the body (i.e., along the velocity of body).

$P = \underline{m}v$

Unit

$= kg\,\frac{m}{sec}$

$\frac{gm \cdot cm}{sec}$

Rate of Change of Momentum

- Let a force F be applied on a body of mass m for time t due to which its velocity changes from u to v. Then

  Initial momentum of the body = mu

  Final momentum of the body = mv

- Change in momentum of the body in t second = $mv - mu = m(v - u)$

  Rate of change of momentum

  $$= \frac{\text{Change in momentum}}{\text{Time}} = \frac{m(v-u)}{t}$$

  But acceleration $a = \dfrac{\text{Change in velocity}}{\text{Time}} = \dfrac{v-u}{t}$

  $\therefore$ Rate of change of momentum = $m\,a$ = mass × acceleration

Rate of Change of Momentum

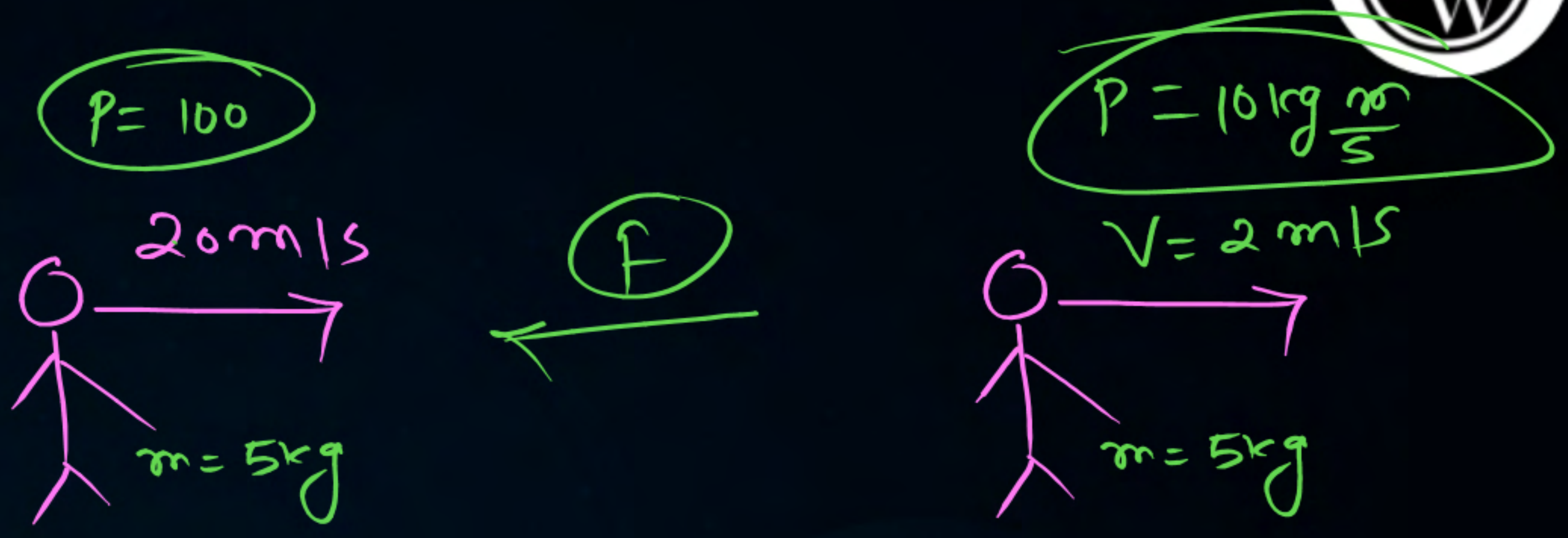
- For a body of mass m moving with velocity v, its linear momentum is $p = mv$. In time Δt, if its linear momentum changes by Δp on applying a force on it, then the rate of change of linear momentum is

$$\frac{\Delta p}{\Delta t} = \frac{\Delta (mv)}{\Delta t} = m\frac{\Delta v}{\Delta t} \text{ (if mass } m \text{ remains constant)}$$

But $\frac{\Delta v}{\Delta t} = a$ (acceleration),

so rate of change of momentum

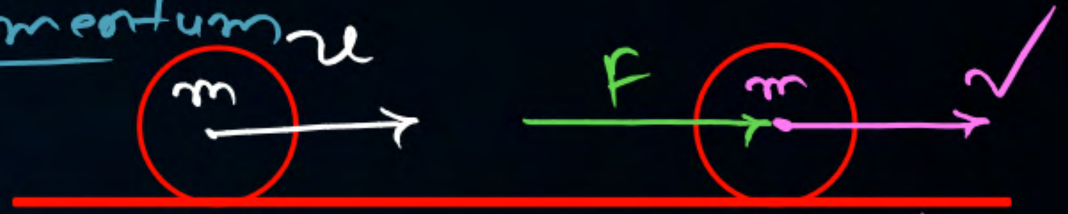
$$\frac{\Delta p}{\Delta t} = ma = \text{mass} \times \text{acceleration.}$$



P= 100
20m/s
m= 5kg
F
P = 10 kg m/s
V= 2 m/s
m= 5kg

Force ∝ rate of change in momentum

$$F \propto \frac{\text{final momentum} - \text{Initial momentum}}{\text{time}}$$



$P_1 = mu$ $\quad$ $P_2 = mv$

time = t

$$F \propto \frac{mv - mu}{t}$$

$$F \propto m\left[\frac{v-u}{t}\right]$$

$$F \propto ma$$

$$F = kma$$

K depends on medium

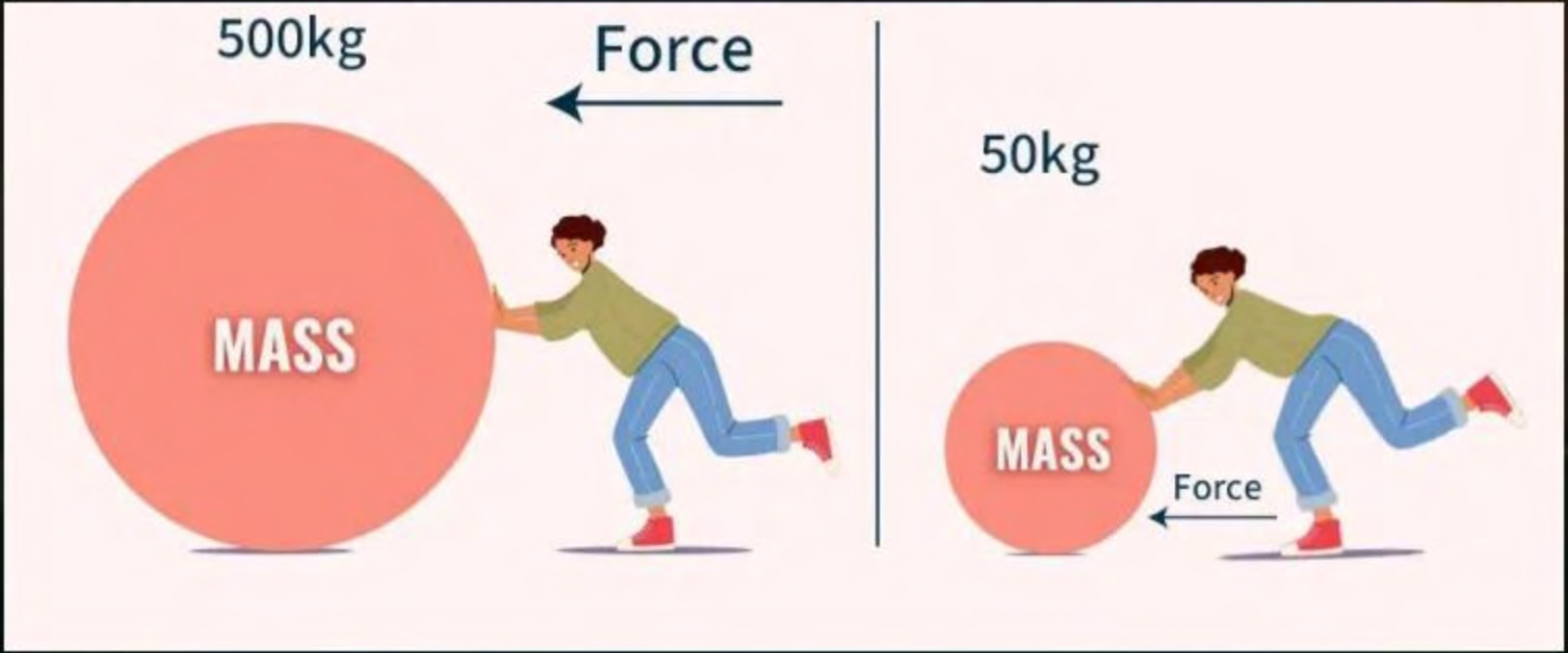
for air $K = 1$

$$F = ma$$

Experiment

Experimentally Newton found that the acceleration produced in a body is directly proportional to the force applied on it.


F=ma

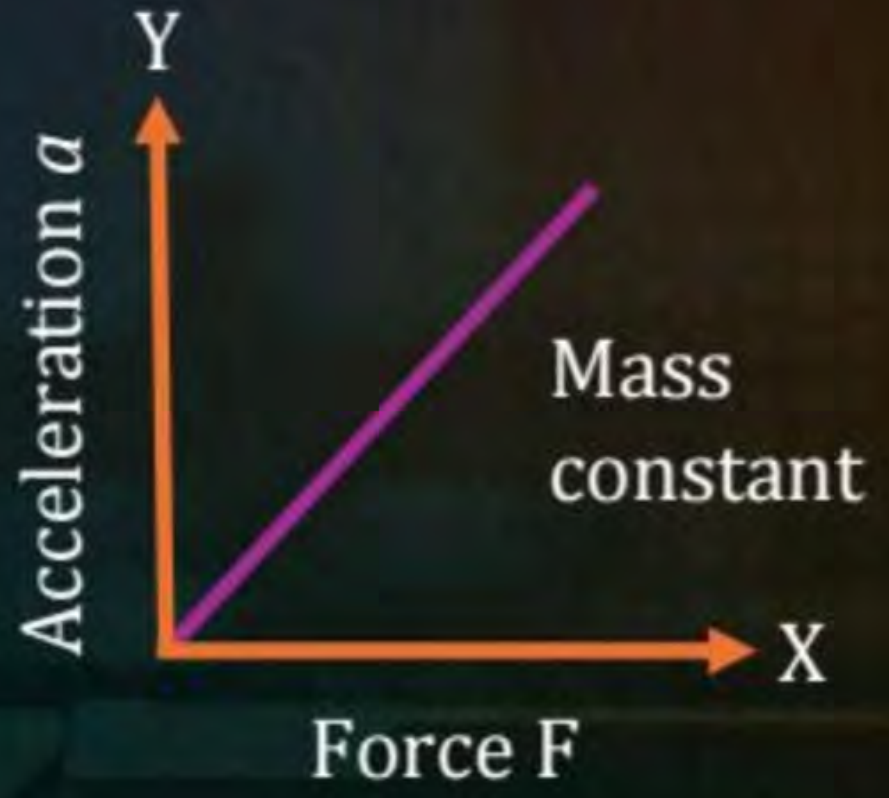

500kg
Force
MASS
50kg
MASS
Force

Newton's Second Law of Motion

On the basis of his experiments, Newton concluded that

(i) The acceleration produced in a body of given mass is directly proportional to the force applied on it. i.e., $a \propto F$ (if mass remains constant).

A graph plotted for acceleration a against force F is a straight line as shown in Fig.



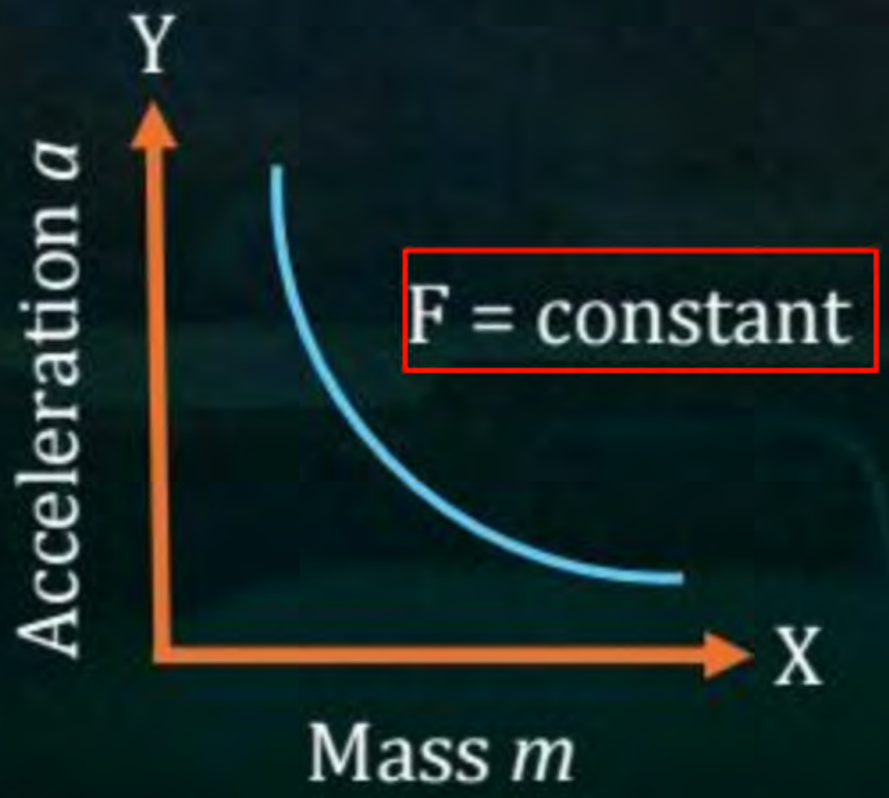
Graph showing the variation of acceleration with force

Newton's Second Law of Motion

i.e., $a \propto \frac{1}{m}$ (for a given force F). A graph plotted for acceleration a against mass m is a curve (hyperbola) as shown in Fig. .

$F = ma$

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



Graph showing the variation of acceleration with mass

C.G.S. and S.I. Units of Force

The force is related to mass and acceleration as:

Force = mass × acceleration

or $F = ma$

On this basis, the S.I. unit of force is **newton**.

One newton is the force which when acts on a body of mass 1 kg, produces an acceleration of $1\ m\ s^{-2}$. i.e., **1 newton = 1 kg × 1 m s^{-2}**

C.G.S. and S.I. Units of Force

The standard symbol of newton is N.

In C.G.S. system, the unit of force is **dyne**.

One dyne is the force which when acts on a body of mass 1 g, produces an acceleration of 1 cm s^{-2}. i.e., **1 dyne = 1 g × 1 cm s^{-2}**

Relationship between newton and dyne

1 newton $= 1\ kg \times 1\ m\ s^{-2}$

$= 1000\ g \times 100\ cm\ s^{-2} = 10^5\ g \times cm\ s^{-2}$ \

$= 10^5$ dyne.

Thus 1 newton $= 10^5$ dyne

S.I

(N)

$f = ma$

$1N = 1kg \; 1\frac{m}{s^2}$

MKS

$Kg \frac{m}{s^2}$

C.G.S

Dyne

$1 \text{dyne} = 1 gm \; 1 \frac{cm}{s^2}$

$1 N = \ldots \text{dyne}$

A → 10^7

B → 10^{-7}

C → 10^5

D → 10^{-5}

Newton's Second Law of Motion In Terms of Rate of Change of Momentum

When force is applied on a body, it produces acceleration in the body due to which the velocity and hence the momentum of body changes.

∴ Force = Rate of change of momentum

or $F = \frac{\Delta p}{\Delta t} = \frac{\Delta (mv)}{\Delta t}$

$= ma$ (if mass remains constant)

Thus Newton's second law of motion can be stated in terms of change in momentum as follows.

Newton's Second Law of Motion In Terms of Rate of Change of Momentum

Statement: According to Newton's second law of motion, the rate of change of momentum of a body is directly proportional to the force applied on it and the change in momentum takes place in the direction in which the force is applied.

Newton's second law is the fundamental law of motion. The first law of motion is also included in the second law. This we can see as follows.

To obtain Newton's first law of motion from second law of motion

From Newton's second law, $F = m\,a$

If $F = 0$, then $a = 0$

$f = ma$

let $f = 0$

$0 = ma$

$a = 0$

$\frac{v-u}{t} = 0$

$v - u = 0$

$v = u$

Examples:

(1) While catching a ball, the cricketer withdraws his hands along with the ball.

(2) Athletes often lands on sand (or foam) after taking a high jump.

(3) When the glass vessels fall on a hard floor, they break, but they do not break when they fall on a carpet (or sand).

Question

How much force is required to produce an acceleration of 2 m s^{-2} in a body of mass 0.8 kg?

Question

A force acts for 0.1 s on a body of mass 1.2 kg initially at rest. The force then ceases to act and the body moves through 2 m in the next 1.0 s. Find the magnitude of force.

Question

What does Newton's Second Law of Motion state?

(A) Every action has an equal and opposite reaction

(B) Force is directly proportional to mass

$F = ma$

(C) Force is the product of mass and acceleration

(D) A body at rest remains at rest

Question

What does Newton's Second Law of Motion state?

(A) Every action has an equal and opposite reaction

(B) Force is directly proportional to mass

(C) Force is the product of mass and acceleration

(D) A body at rest remains at rest

Ans. **(C)** Force is the product of mass and acceleration

Question

If the net force acting on a body is zero, the acceleration is:

(A) Maximum

(B) Constant

(C) Zero

(D) Infinite

$F = ma$

$F = 0$

$ma = 0$

$a = 0$

Question

If the net force acting on a body is zero, the acceleration is:

(A) Maximum

(B) Constant

(C) Zero

(D) Infinite

Ans. (C) Zero

Question

A 2 kg object accelerates at 3 m/s². What is the force acting on it?

(A) 6 N

(B) 1.5 N

(C) 0.67 N

(D) 5 N

$m = 2\,kg$

$a = 3\,m/s^2$

$F = ma$

$= 2 \times 3$

$a = 6\,m/s^2$

Question

A 2 kg object accelerates at 3 m/s^2. What is the force acting on it?

(A) 6 N

(B) 1.5 N

(C) 0.67 N

(D) 5 N

Ans. (A) 6 N

Question

Unit of force in SI system is:

(A) kg

(B) m/s^2

(C) Newton

(D) Dyne

Question

Unit of force in SI system is:

(A) kg

(B) m/s^2

(C) Newton

(D) Dyne

Ans. (C) Newton

Question

If mass is halved and force is constant, the acceleration will be:

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

(A) Halved

(B) Doubled

(C) Same

(D) Zero

Question

If mass is halved and force is constant, the acceleration will be:

(A) Halved

(B) Doubled

(C) Same

(D) Zero

Ans. (B) Doubled

Question

A force of 10 N is applied to a 5 kg object. Find the acceleration.

Question

A force of 10 N is applied to a 5 kg object. Find the acceleration.

Solution.

$$F = ma \Rightarrow a = \frac{F}{m} = \frac{10}{5} = 2\ m/s^2$$

Question

Find the force required to accelerate a 10 kg mass at $4\ m/s^2$.

Question

Find the force required to accelerate a 10 kg mass at 4 m/s^2.

Solution.

$$F = ma = 10 \times 4 = 40 \text{ N}$$

Question

A body of mass 1 kg is moving with an acceleration of 2.5 m/s^2. Calculate the net force.

Question

A body of mass 1 kg is moving with an acceleration of 2.5 m/s^2. Calculate the net force.

Solution.

$$F = ma = 12 \times 2.5 = 30\ N$$

Question

A 20 N force acts on a body of mass 4 kg. What is the acceleration?

Question

A 20 N force acts on a body of mass 4 kg. What is the acceleration?

Solution.

$$F = \frac{F}{m} = \frac{20}{4} = 5\ m/s^2$$

Question

A car of mass 1000 kg is accelerating at 3 m/s^2. What is the driving force?

Question

A car of mass 1000 kg is accelerating at $3\ m/s^2$. What is the driving force?

Solution.

$$F = ma = 1000 \times 3 = 3000\ N$$

Question

The linear momentum of a body of mass m moving with velocity v is:

(A) v/m

(B) m/v

(C) mv

(D) $1/mv$

Question

The linear momentum of a body of mass m moving with velocity v is:

(A) v/m

(B) m/v

(C) mv

(D) $1/mv$

Ans. (C) mv

Question

The unit of linear momentum is:

(A) N s

(B) kg m s^{-2}

(C) N s^{-1}

(D) kg^2 m s^{-1}

Question

The unit of linear momentum is:

(A) N s

(B) kg m s^{-2}

(C) N s^{-1}

(D) kg^2 m s^{-1}

Ans. (A) N s

Question

The correct form of Newton's second law is:

(A) $F = \frac{\Delta p}{\Delta t}$

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

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

(D) $F = mv$

Question

The correct form of Newton's second law is:

(A) $F = \frac{\Delta p}{\Delta t}$

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

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

(D) $F = mv$

Ans. (A) $F = \frac{\Delta p}{\Delta t}$

Question

The acceleration produced in a body by a force of given magnitude depends on

(A) size of the body

(B) shape of the body

(C) mass of the body

(D) none of these

Question

The acceleration produced in a body by a force of given magnitude depends on

(A) size of the body

(B) shape of the body

(C) mass of the body

(D) none of these

Ans. **(C)** mass of the body

Newton's Third Law of Motion

Statement: According to Newton's third law of motion, to every action there is always an equal and opposite reaction.


Thank You