

NEWTON'S LAWS OF MOTION

THE FOUNDATION OF CLASSICAL MECHANICS

WHY IT MATTERS

- Newton's laws describe how objects move and why they change their motion.
- They are the basis of mechanics and important in every field of science and engineering.
- Essential for NEET, JEE & Board Exams.

KEY TAKEAWAYS

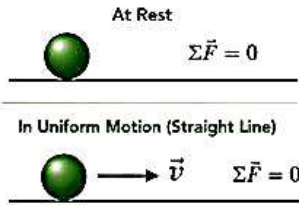
- Law I:** Inertia – Objects resist change in their state of rest or uniform motion.
- Law II:** Force causes acceleration. Greater the force, greater the acceleration.
- Law III:** Every action has an equal and opposite reaction.
- Laws are valid in inertial frames of reference.
- Vector nature of force is essential.

COMMON SYMBOLS

- \vec{F} : Force (N)
- m : Mass (kg)
- \vec{a} : Acceleration ($m\ s^{-2}$)
- \vec{v} : Velocity ($m\ s^{-1}$)
- u : Initial velocity ($m\ s^{-1}$)
- t : Time (s)
- \vec{p} : Linear momentum ($kg\ m\ s^{-1}$)
- $\Sigma \vec{F}$: Resultant force (N)
- F_{12} : Force on 2 due to 1 (N)
- F_{21} : Force on 1 due to 2 (N)
- g : Acceleration due to gravity ($\approx 9.8\ m\ s^{-2}$)

1 NEWTON'S FIRST LAW OF MOTION (LAW OF INERTIA)

An object remains at rest or continues to move with uniform velocity in a straight line unless acted upon by an external unbalanced force.



Inertia

The property of an object by virtue of which it resists any change in its state of rest or uniform motion.

Types of Inertia

- Inertia of rest
- Inertia of motion
- Inertia of direction

INERTIAL AND NON-INERTIAL FRAMES

Inertial Frame

A frame in which Newton's laws are valid.

Example: A train moving with constant velocity.



Non-Inertial Frame

A frame in which Newton's laws are not valid.

Examples: An accelerating train, elevator in motion.



2 NEWTON'S SECOND LAW OF MOTION (LAW OF ACCELERATION)

The rate of change of momentum of an object is directly proportional to the resultant external force and occurs in the direction of the force.

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

For constant mass:

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

In scalar form (1D):

$$F = ma$$

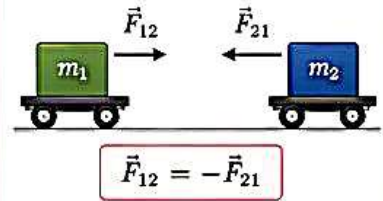
SI Unit: Newton (N) = $kg\ m\ s^{-2}$

Implications

- Greater the force, greater the acceleration.
- Greater the mass, smaller the acceleration.
- Acceleration is in the direction of the net force.

3 NEWTON'S THIRD LAW OF MOTION (LAW OF ACTION-REACTION)

To every action, there is always an equal and opposite reaction.



Where,

- \vec{F}_{12} = Force on body 2 due to body 1
- \vec{F}_{21} = Force on body 1 due to body 2

Characteristics

- Forces always occur in pairs.
- They act on two different bodies.
- They are equal in magnitude and opposite in direction.
- They are of the same nature.

SPECIAL CASES (USING $F = ma$)

- If $F = 0 \Rightarrow a = 0$ (no acceleration)
- If m is constant and F is constant, a is constant.
- If F is constant and m increases, a decreases.
- If F is constant and m decreases, a increases.

"Force is the cause of change in motion."

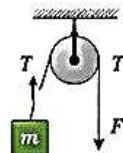
PULLEY SYSTEM

1 IDEAL PULLEY ASSUMPTIONS

- Pulley is massless
- Pulley is frictionless (no friction in axle)
- String is light (massless) and inextensible
- Tension is same throughout the string

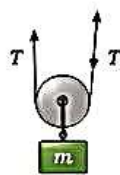
Under these assumptions, mechanical energy is conserved.

2 SINGLE FIXED PULLEY



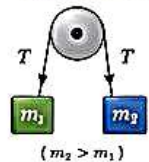
- Changes direction of force
- Mechanical advantage = 1
- $F = T = mg$ (for equilibrium)

3 SINGLE MOVABLE PULLEY



- Load is supported by two segments of string
 - Mechanical advantage = 2
- $$T = \frac{mg}{2}$$

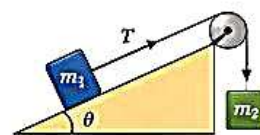
4 ATWOOD MACHINE (TWO MASS SYSTEM)



$$a = \frac{(m_2 - m_1)g}{m_1 + m_2}$$

$$T = \frac{2m_1 m_2 g}{m_1 + m_2}$$

5 INCLINED PLANE WITH PULLEY



If system in equilibrium:

$$T = m_1 g \sin \theta = m_2 g$$

6 KEY CONCEPTS

- Same string = same tension
- Acceleration of connected bodies is related (use constraint equations).
- Apply Newton's laws separately on each body.
- Draw FBD for each mass.

FRICTION (A COMMON FORCE)

Types

- Static friction (f_s):** Acts when body is at rest.
- Kinetic friction (f_k):** Acts when body is in motion.
- Limiting friction (f_{max}):** Maximum value of static friction.

$$f_s \leq f_{max} = \mu_s N$$

$$f_k = \mu_k N$$

Where,
 μ_s = Coefficient of static friction
 μ_k = Coefficient of kinetic friction
 N = Normal reaction

Generally, $\mu_k < \mu_s$

APPLICATIONS OF NEWTON'S LAWS

Seat Belt



Due to inertia of motion, body tends to move forward when car stops suddenly.

Rocket Propulsion (Law III)



Hot gases are pushed downward, rocket moves upward.

Walking



Foot pushes ground backward, ground pushes body forward.

Recoil of Gun (Law III)



Gun exerts force on bullet forward, bullet exerts equal force backward on gun.

SOLVED EXAMPLE

A block of mass 5 kg is pulled by a horizontal force of 20 N on a frictionless surface. Find the acceleration.

Given: $m = 5\ kg, F = 20\ N$

On applying Newton's second law:

$$F = ma \Rightarrow a = \frac{F}{m} = \frac{20}{5} = 4\ m\ s^{-2}$$



IMPORTANT POINTS

- Newton's laws are valid only in inertial frames.
- Force is a vector quantity.
- Resultant force determines the motion.
- In absence of external force, momentum remains constant.
- Action and reaction forces do not cancel each other as they act on different bodies.

IMPORTANT FORMULAS

- Newton's Second Law (General) $\vec{F} = \frac{d\vec{p}}{dt}$
- Newton's Second Law (Constant mass) $\vec{F} = m\vec{a}$
- Third Law $\vec{F}_{12} = -\vec{F}_{21}$
- Momentum $\vec{p} = m\vec{v}$
- Impulse $\vec{J} = \vec{F}\Delta t = \Delta\vec{p}$

KEY TAKEAWAYS

- COM simplifies the analysis of system motion.
- Motion of COM depends only on the resultant external force.
- Internal forces cancel in pairs.
- Linear & angular momentum are powerful conservation principles.
- These concepts are widely used in mechanics, astronomy, and engineering.



PRO TIP

- Always identify all forces. Draw a neat FBD.
- Choose the right axis.
- Apply $\Sigma \vec{F} = m\vec{a}$ component-wise.
- For pulley problems, use constraint equations.



REMEMBER

Understand the concept deeply, practice problems regularly and apply in real-life situations!