⚙️ Chapter 3 – Laws of Motion

🚀 1. Introduction

Kinematics told us *how* things move. Now it's time to ask the deeper question — *why* they move.
That's where the **Laws of Motion** come in. These three simple rules by **Sir Isaac Newton** explain almost every motion you can imagine — from a falling leaf to the orbit of the Moon.

Motion exists everywhere. But an object doesn't move or stop randomly; it reacts only when a **force** acts on it. These laws form the foundation of **mechanics**, the very heart of physics.

⚖️ 2. Concept of Force

A **force** is any external influence that changes or tries to change the state of motion of a body.

Force=mass×acceleration\text{Force} = \text{mass} × \text{acceleration}Force=mass×acceleration SI unit : Newton (N)\text{SI unit : Newton (N)}SI unit : Newton (N)

- Force has **magnitude and direction** → it's a **vector**.
- No net force → either object is **at rest** or moving with **constant velocity**.
- Net force ≠ 0 → motion changes (accelerates or decelerates).

🧠 3. Newton's First Law of Motion – Law of Inertia

"A body continues in its state of rest or uniform motion in a straight line unless acted upon by an external unbalanced force."

It defines **inertia** — the natural tendency of objects to resist change.

Type of Inertia	Example
Inertia of Rest	Passenger jerks forward when bus starts.
Inertia of Motion	Passenger jerks backward when bus stops.
Inertia of Direction	Mud splashes tangentially off a rotating wheel.

No external force → no change in motion.

⚙️ 4. Momentum and Newton's Second Law

4.1 Linear Momentum

p=mvp = m vp=mv

It’s a vector quantity, unit: kg m/s.

4.2 Newton’s Second Law

The rate of change of momentum of a body is directly proportional to the applied force and takes place in the direction of the force.

F=dpdt=maF = \frac{dp}{dt} = m aF=dtdp=ma

If m = 1 kg, a = 1 m/s² → F = 1 N.

This law defines **force** quantitatively and connects cause (force) to effect (acceleration).

🎯 5. Impulse

When a large force acts for a very short time (like a bat hitting a ball):

Impulse(J)=F×Δt=Δp\text{Impulse} (J) = F × Δt = ΔpImpulse(J)=F×Δt=Δp

Unit : N·s = kg m/s.

Impulse explains why soft cushions or helmets extend impact time → reduce force.

🌍 6. Newton’s Third Law – Action and Reaction

For every action, there is an equal and opposite reaction.

Forces always appear in **pairs** on different objects.

Examples:

- You push a wall; wall pushes back equally.
- Gun recoils when firing a bullet.
- Rocket launches by expelling gases downward.

Action and reaction never cancel, because they act on different bodies.

🧭 7. Free Body Diagram (FBD)

To analyze forces, isolate one body and draw all forces on it: weight, tension, normal, friction, etc.
This simple technique is how you solve all mechanics questions in NEET — from pulleys to inclines.

🧮 8. Friction

Friction is the **resisting force** that acts opposite to relative motion of two surfaces.

Types

1. **Static friction** → prevents motion (before sliding).
2. **Kinetic friction** → acts when sliding occurs.
3. **Rolling friction** → much smaller, for rolling bodies.

f≤μsN(static),f=μkN(kinetic)f ≤ μ_s N \quad(\text{static}), \qquad f = μ_k N \quad(\text{kinetic})f≤μsN(static),f=μkN(kinetic)

Here μ = coefficient of friction (no unit).

Angle of repose = $\tan^{-1}\mu$.

🪂 9. Application Examples

- **Inclined Plane:** component $mg \sin\theta$ down slope; normal = $mg \cos\theta$.
- **Pulley systems:** tension same through light string, neglect mass of pulley.
- **Lift problems:** Apparent weight = $m(g \pm a)$.
- **Circular motion:** Centripetal force = mv^2/r (acts toward center).

⚖️ 10. Law of Conservation of Momentum

In absence of external forces, total momentum remains constant.

m1u1+m2u2=m1v1+m2v2m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2m1u1+m2u2=m1v1+m2v2

Used in gun recoil, rocket propulsion, collisions, explosions.

Example:
Bullet (0.01 kg) fired at 400 m/s → Gun (2 kg) recoils $v = -(0.01\times400)/2 = -2$ m/s.

🧠 11. Equilibrium of Forces

A body is in **equilibrium** if net force and net moment are zero.
For 2D equilibrium: $\Sigma F_x = 0$, $\Sigma F_y = 0$.

Example: A block on smooth floor tied by two strings — tensions adjust so horizontal forces cancel.

🧩 12. Mass and Weight

- **Mass** → amount of matter (doesn't change).
- **Weight** → gravitational force W = mg (varies with location).

At moon, g ≈ 1/6 of Earth → same mass, less weight.

🧾 13. Tension in String

If mass m hangs from string: T = mg (at rest).
If accelerating upward: T = m(g + a).
If downward: T = m(g − a).

For massless pulley with two masses m_1, m_2:

a=(m1−m2)gm1+m2a = \frac{(m_1-m_2)g}{m_1+m_2}a=m1+m2(m1−m2)g
T=2m1m2gm1+m2T = \frac{2m_1m_2g}{m_1+m_2}T=m1+m22m1m2g

🌟 14. Real-Life Applications

- Seatbelts apply Newton's First Law.
- Rocket thrust = Third Law.
- Car tyres use friction for acceleration.
- Elevators and amusement rides obey Second Law.

🧾 15. Summary

1. 1st Law → defines inertia.
2. 2nd Law → defines force (F = ma).
3. 3rd Law → forces occur in pairs.
4. Friction opposes motion.
5. Momentum is conserved if no external force.
6. Apparent weight changes in accelerating frames.

Master these; every mechanics problem ahead uses them.