Chapter #5: Force & Motion

**Force:**
- Mathematically speaking, "push or pull" acting on an object.
- Causes Acceleration.

**Newtonian Mechanics:**

Relation how force & acceleration it causes was first understood by Sir Isaac Newton.
That is why it is called the Newtonian Mechanics.

It focuses on its three primary laws of motion.

**Limitations:**
1. Not valid for \( V \rightarrow C \) (very very high speeds)
2. Not valid for objects on the scale of atomic structure (Quantum Mech).

Valid for everyday situations.

\( \Rightarrow \) Good approximation of GR.

\( \text{QM} \rightarrow \text{NM} \rightarrow \text{GR} \)

Atomic Scale \( \rightarrow \) Mid Range \( \rightarrow \) Large Scale
Before starting the Newton’s laws, let’s get to understand the concept of force before Newton.

Before Newton, in Mechanics:

Force: “Some influence necessary to keep a body moving. Otherwise the body would stop.”

The “natural state” of objects was at rest, intuitively reasonable (due to friction).

BUT

Envision a frictionless surface?
→ Does not slow an object.
→ The object would keep moving forever at a constant speed.

All this implies that “Friction is a force.”

Now comes to Newton’s laws.
First Law of Motion

If no net force acts on a body ($F_{\text{net}} = 0$), the body’s velocity cannot change; that is, the body cannot accelerate.

Characteristics of Force

- Force is a vector.
- Unit: $1 \text{N} = 1 \text{kgm/s}^2$.

Net force is the vector sum of all forces on an object.

Principle of Superposition

\[ \vec{F}_3 = \vec{F}_1 + \vec{F}_2 \]

A net force has the same impact as a single force with identical magnitude and direction.
Limitations of Newton's 1st Law

- Not valid in all frames.

A framework that is used for the observation and mathematical description of physical phenomena.
It usually consists of the following parameters:

- Observer
- Coordinate System
- Clock; assigning times at positions w.r.t. to the coordinate system.

1) Inertial Frames:
- In which Newton's laws hold.
- Rest or moving with constant speed. $a = 0$

2) Non-Inertial Frames:
- Don't hold.
- Moving with variable speed. $A \neq 0$. 
Pseudo force (fake, not real)

The deflection (apparent) is caused not by a force as required by Newton's laws but the fact that we see the puck from a non-inertial frame.

That is why we take the ground as inertial frames.

Newton's 2nd Law of Motion

Before stating the law, let's cover its conditions.
Mass? “Measure of the amount of matter or stuff in an object that resists the change in motion when a force is applied on it.”

In philosophical point of view, you cannot define mass but that’s another debate.

\[ m \alpha \frac{1}{a} \]

From daily life experience:

Now, comes to 2nd law

\[ F = m \alpha \]

Recipe:

i) Identify the body in question, and only include forces that act on that body

ii) Separate the Problem axes (they are independent).

Big mass small acceleration
\[ F_{\text{net}, x} = ma_x \]
\[ F_{\text{net}, y} = ma_y \]
\[ F_{\text{net}, z} = ma_z \]

"The acceleration component along a given axis is caused **ONLY** by the sum of the force components along that same axis, and not by force components along any other axis."

**Points to Ponder**

- If the net force on a body is zero, it doesn't imply that there are no forces acting on it, e.g., ![force diagram].
- But the acceleration is zero. I.e., the forces & the body are in equilibrium.

**Free-Body Diagram:** "Helps to solve problems with forces"

- Considerable body is shown in the diagram only.
- Forces are drawn as vector arrows with their tails on the body."
Coordinate System is shown. Acceleration is NEVER part of a free-body diagram - only forces on a body are present.

\[ F_2 \rightarrow \text{Tire} \rightarrow F_1 \]

Free Body Diagram:

\[ F_2 \quad F_1 \quad x \]

System: A system consists of one or more bodies.

- External Forces: Any force on the body inside a system exerted by bodies outside the free system is an external force.
- Internal Forces: Forces b/w bodies in a system are not included in a FBD because they don't accelerate the system.