Chapter 6

Newton's Law Of Motion

PRESENTING AND INTRODUCING NEWTON'S LAW OF MOTION

Force And Their Effects

A force is like a push or pull that makes a body move or tries to make it move.
Velocity determines the state of motion.

What capabilities does force possess?

- Make the body move in a different direction.
- Modify the velocity of the body.
- Modify the bodily configuration.

It's also possible to experience more than one of the effects mentioned above.

Force is a vector quantity

- It faces a certain way.
- It has a size or amount.
- It adheres to the principles of vector algebra.

Fundamental Forces In Nature

Gravitational force

The gravitational force between two objects increases as the product of their masses increases, and it decreases as the square of the distance between them increases.

$$F \propto \frac{m_1 \cdot m_2}{r^2}$$

Where m_1 and m_2, we're referring to the masses of two objects, and r represents the distance separating them.

Strong nuclear force

They operate among the nucleons, specifically protons and neutrons, within a nucleus, keeping them bound together. The most powerful among all the fundamental forces.

Weak nuclear force

These forces play a crucial role in facilitating the transformation of a neutron into a proton and vice versa, leading to the achievement of stability.
A force characterized by a significantly restricted reach, possessing a range considerably smaller than the dimensions of a proton or a neutron.

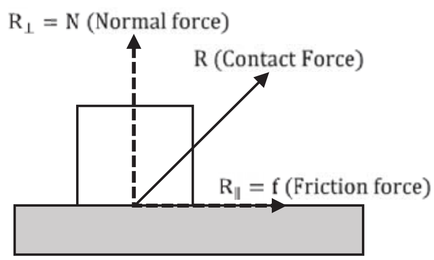
Electromagnetic force

Electrostatic: The force between particles resulting from their electric charge.
Electrodynamic: Force produced by the movement of charged particles.

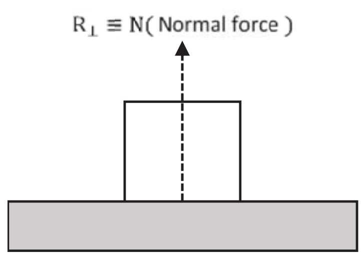
Some Standard Forces

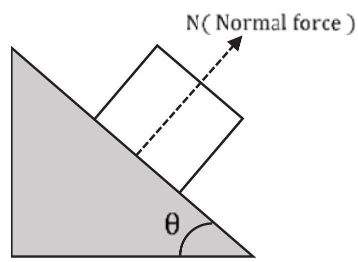
Contact force

- When two objects touch each other, they feel a force called contact force.
- Its nature is electromagnetic.
- The part that points directly away from the surface is called the normal force, while the part parallel to the surface is termed friction force.



Normal force or normal reaction





The normal reaction always exhibits a pushing tendency.
It is consistently perpendicular to the surface, always at a 90-degree angle.

Weight at the surface of the Earth

The force a body undergoes due to gravity is called its weight. While applicable to all bodies with mass, we specifically calculate it for a body near Earth's surface as follows:

$$F = \frac{G \times \text{ mass of Earth } \times \text{ mass of the body}}{(\text{ radius of Earth })^2}$$

Where

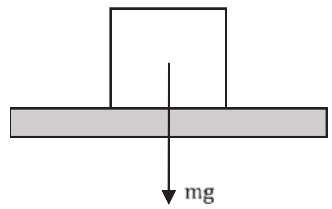
$$\frac{G \times \text{ mass of Earth}}{(\text{ radius of Earth })^2} = g \text{ (constant)}$$

g = acceleration due to gravity of earth

The weight of an object with mass "m" near the Earth's surface is "mg," and it is directed toward the center of the Earth.

m = mass of block

g = acceleration due to gravity of Earth

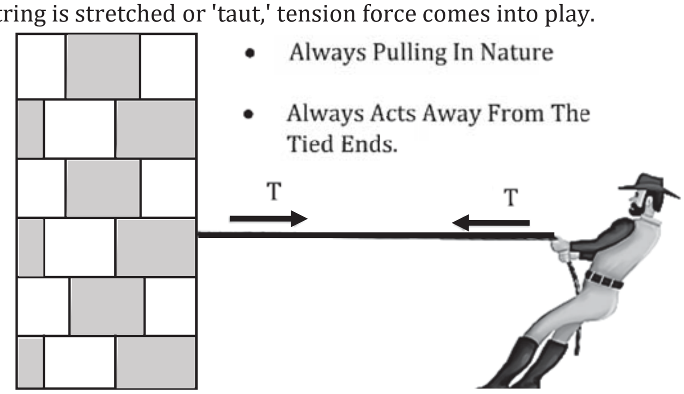


Introducing Tension

When you pull a string (or rope) from both ends, the force that resists any change in its original length is called tensile force or tension.

When the string is loose or 'slack,' there is no tension force.

When the string is stretched or 'taut,' tension force comes into play.



> Unless stated otherwise, assume the string has no mass, and the tension force remains constant throughout.

Newton's Laws of Motion

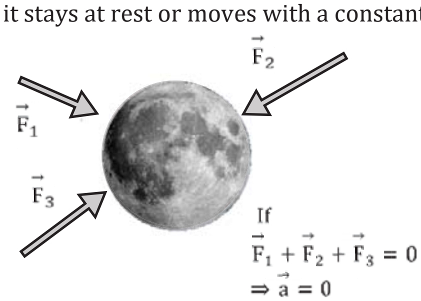
Three fundamental laws that established the groundwork for classical mechanics. They elucidate the connection between a body, the forces acting on it, and the body's motion in response to those forces.

Newton's First Law of Motion

An object will stay at rest or continue moving in a straight line at a constant speed unless an external force compels it to change its state.

OR

If the total vector sum of the forces acting on a particle is zero, then the particle remains unaccelerated, meaning it stays at rest or moves with a constant velocity.



- The first law is also referred to as the law of inertia.

Inertia

The reluctance of a particle to alter its state of rest or constant motion in a straight line. It comes in three types:

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

Newton's Second Law of Motion

The acceleration of a particle, measured from an inertial frame (such as the ground), is determined by the vector sum of all the forces acting on the particle, and divided by its mass.

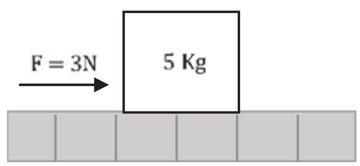
$$\vec{a} = \frac{\vec{F}}{m}$$
$$\vec{F} = m\vec{a}$$

The speed at which an object's momentum changes is directly related to the net external force applied and occurs in the direction of that force.

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

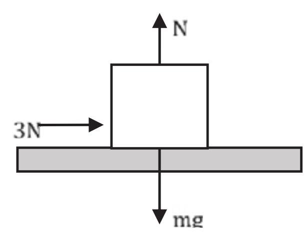
$$\vec{F} \propto \frac{d\vec{p}}{dt} = k\frac{d}{dt}(m\vec{v}) \text{ (Mass is constant)}$$
$$\vec{F} = m\frac{d\vec{v}}{dt} = m\vec{a}(\,'k' = 1)$$

Ex. On a frictionless surface, there is a 5kg block. At $t = 0$, a force of $3N\hat{i}$ is exerted on it. Calculate the acceleration of the block.



Sol.

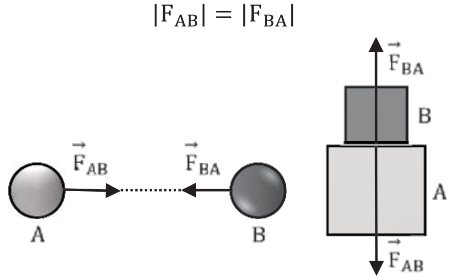
$$\vec{a} = \frac{\vec{F}}{m}$$
$$\vec{F} = m\vec{a}$$
$$a = \frac{3}{5} = 0.6ms^{-2}$$



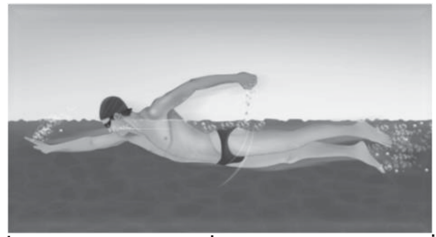
Newton's Third Law of Motion

If one object, A, pushes or pulls on another object, B, with a force, $\vec{F}$, then B pushes or pulls back on A with a force of $\vec{F}$. These forces operate along the imaginary line connecting the two objects.

$$\vec{F}_{AB} = \text{ Force applied on A by B}$$
$$\vec{F}_{BA} = \text{ Force applied on B by A}$$
$$|\vec{F}_{AB}| = |\vec{F}_{BA}|$$



Action-Reaction pair



Action Rocket pushes the Burnt fuel down	Reaction The burnt fuel Pushes the rocket up	Action Swimming Pushes The water back	Reaction The eater pushes the Swimmer forward

Conditions for Action - Reaction pairs

- Occur simultaneously
- Act in opposite direction
- Act along the same line
- Act on different objects
- Have equal magnitude and same nature

Interesting fact: Physics behind pushing a box

As per Newton's third law of motion, when you exert force to push a box, the box simultaneously exerts an equal and opposite force on you. Despite these forces being equal and opposite, they don't cancel each other out to yield a zero resultant force. Ever wondered about the logic behind this and how the box can still move?

Certainly, based on the third law, the action-reaction pair involves forces acting on two distinct bodies. In this scenario, the box exerts a reaction force of equal magnitude on our hand. Consequently, the net force acting on the box is not zero. Therefore, propelled by the action force, the box moves forward.