Newton's Law of Motion

5.1 Force

Force is a central concept in all of physics. It is a vector quantity- must describe the direction in which it acts as well as magnitude. A force is an action that produces a deformation and / or acceleration. The net force on a body is the sum of all forces acting on the body. We sometimes refer to the net force as the total force, the resultant force, or unbalanced force. When several force act simultaneously on an object, the object accelerates only if the net force acting on it, isn't equal to zero. When the velocity of an object is constant, the object is said to be equilibrium; that is

$\vec{F}_{net} = 0$ or $\vec{F}_{net,x} = 0$, $\vec{F}_{net,y} = 0$ and $\vec{F}_{net,z} = 0$

If the particle at rest, then we called static equilibrium, but if the particle moving with a constant velocity then we called dynamic equilibrium.

5.2 Newton's First Law (Law of Inertia)

Everybody continues in its state of rest, or in uniform motion in a right line (straight line) unless it is compelled to change that state by forces impressed upon it.

$\vec{F} = 0 \Longrightarrow \vec{v} = constant$

- Fixed direction
- Fixed magnitude

A body with no forces acting on it is called a force body. Most bodies we normally see, stop when left alone, because

- Presence of frictional forces
- Air pucks, air- tracks give a hint of the persistence of motion

5.3 Reference Frames

Law is not valid in all frames. Valid in special frames (inertial reference frames)

Test for inertial reference frame:

- Take a free body (no forces acting)
- If it persists in a state of uniform motion

Any other reference frame in uniform translational motion relative to the first is also an inertial frame. A frame in accelerated motion relative to the first is not an inertial frame. Earth based frame: not inertial → effect small

5.4 Newton's Second Law

This law established the relationship between force, acceleration and mass.

"The change in motion (acceleration) is proportional the motive force impressed, and is made in the direction of the right line (straight line) in which the force impressed"

$\vec{F} = m\vec{a} = \frac{d\vec{p}}{dt}$ ($\frac{d\vec{p}}{dt}$ more correct statement will discuss later)

- Valid only in inertial reference frames
- $\vec{a} \propto \vec{F}$ in the same direction

Units: $\vec{F} = m\vec{a}$

$$= (Kg)\left(\frac{m}{s^2}\right) = N \qquad m = 1Kg, \vec{a} = 1\ \left(\frac{m}{s^2}\right) \Longrightarrow F = 1N$$

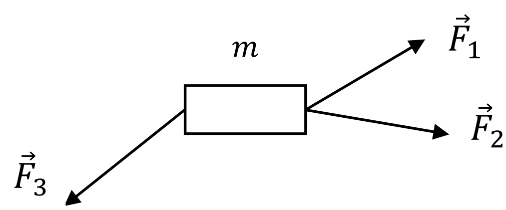
5.5 Definition of Mass and Weight

A body's mass is a measure of resistance a body offer to changes in it velocity. Large masses have a small accelerations due to given force. The mass of body is an intrinsic property of that body, and, therefore, doesn't change if the body is moved to a different place. The mass of a body is a ***scalar quantity***. A body's mass not it's weight, where the weight varies with location; a body's weight is not an intrinsic property of that body, the weight W of a body is the magnitude of the downward force it exerts an any object which supports it. Thus, $W = mg$, where m is the mass of body and g is the local acceleration due to gravity. Since weight is a force, it is measured in newton.

5.6 Superposition of Force

If several force $\vec{F}_1, \vec{F}_2$, $\vec{F}_3$ acts simultaneously on a body then the acceleration is the same as that produced by the single force:

$$\vec{F}_{Net} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \cdots$$



$\vec{F}_{Net}$ (Net / resultant force Newton's Second Law)

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

$\vec{F}_1 = m\vec{a}_1$ (Force produce individual accelerations)

$$\vec{F}_2 = m\vec{a}_2$$

$$\vec{F}_3 = m\vec{a}_3$$

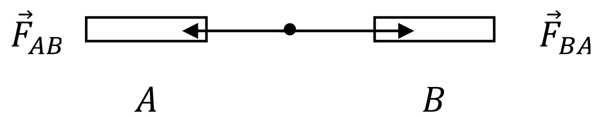
$$\vec{F}_1 + \vec{F}_1 + \vec{F}_1 + \cdots m[\vec{a}_1 + \vec{a}_2 + \vec{a}_2 + \cdots]$$

$$\vec{F}_{Net} = m\vec{a} = \left[\sum F_x = ma_x, \sum F_y = ma_y, etc\right]$$

5.7 Newton's Third Law

Newton's third law states that "to every action (force) there is always opposed an equal reaction (force); or, the mutual action of two bodied upon each other are always equal and direction to contrary parts.

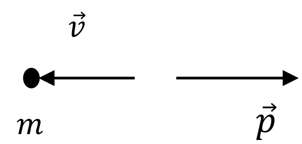
$$\vec{F}_{AB} = \vec{F}_{BA}$$



5.8 Momentum of a Particle

Newton's Laws are more precisely stated in terms of momentum. The momentum of a particle of mass m, moving with velocity is defined to be

$$\vec{p} = m\vec{v} \qquad \left[\frac{Kg.m}{s}\right]$$



Law-1: When no forces are acting, the momentum of a particle constant$[F = 0 \Longrightarrow v = constant], p = constan$

Law-2: Rate of change of linear momentum equals the applied force

$$\vec{F} = \frac{d\vec{p}}{dt} \qquad \text{(most general statement)}$$

Law-3: Rate of change of momentum generated by an action force on one body is exactly opposite to the rate of change of momentum generated by the reaction force on the other body.

5.9 Gravitation Force

Newton's postulate: every pair of particles in the universe exerts on one another a mutual gravitational force of attraction. This force is proportional to the product of the masses and inversely proportional to the square of the distance between them.

$$F_g = G\frac{m_1 m_2}{r_{12}^2}$$

$$G = 6.673 \times 10^{-11}\left(\frac{N.m^2}{Kg^2}\right)$$

Consider a mass m at the surface of the earth which has a mass M_E and radius R_E

$$F_g = m\left(\frac{M_E G}{{R_E}^2}\right) = mg$$

The contact force $\vec{w}$ is called the weight of the object

$$\vec{w} = m\vec{g}$$

5.10 Centripetal Force

We can write the magnitude F_c of the centripetal forces as,

$$F_c = \frac{mv^2}{R} = ma_c$$

$\vec{a}_c$ and $\vec{F}_c$ are directed toward the center of curvature of the particle path

5.11 A Normal Force

A normal force $\vec{N}$ is the force on a body from a surface against which the body presses. The normal force is always perpendicular to the surface. The magnitude of the normal force is:

$$\vec{N} = m(g + g_y)$$

5.12 Tension

When a cord (or cable, or other such object) is attached to a body and pull taut. The cord pulls on the body with force $\vec{T}$ directed away from the body and along the cord. The force is often called a tension force because the cord said to be under tension.

5.13 Frictional Force

Frictional forces play an important role in the motion of real objects. Surface in constant exert two forces on each other:

1. Normal; force ⊥ to surface
2. Parallel ; friction, force of friction always opposes

relative motion or potential relative motion of the surface.

- Arise from adhesion between atoms in the two surfaces.
- Proportional to normal force between surfaces
- Independent of area of constant
- Independent of speed

Kinetic Friction (surface in relative motion)

$f_k = \mu_k N$

μ_k coefficient of kinetic friction $(0 < \mu_k < 1)$

N contact (normal) force

- Proportional to N
- f_k parallel to the surface of contact .