NEWTON'S LAWS OF MOTION

Newton's Laws are the foundation of Classical (Newtonian) Mechanics. They were published by Isaac Newton in 1687 along with the law of gravitation in the Principia. They have far reaching applications/implications in every branch of science. Nonetheless, these laws have their limitations. They need to be modified when applied to objects moving near the speed of light or when applied to microscopic particles. As we will see Newton's Laws are very simple to state but are NOT so simple to apply. Only with practice does one become better at learning to apply Newton's Laws.

Newton's Laws are empirical laws, deduced from experiment; they cannot be derived from anything more fundamental!

Critical to understanding Newton's Laws of Motion is the concept of **FORCE**. What is a force? Let's begin with the 4 fundamental forces of nature:

1. Gravitational Force
2. Electromagnetic Force
3. Strong Nuclear Force
4. Weak Interaction

All forces that we encounter in nature fall into one of these types of forces. What are some common forces that you've encountered and experienced?

1. Gravity (your weight)
2. Electricity
3. Pushes
4. Pulls
5. Physical contact
6. Collisions

In general, any time two or more objects interact, there is a force involved.

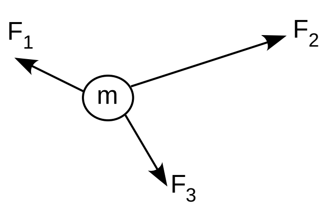
FORCE – The interaction between two or more objects or the interaction between an object(s) and the surrounding environment.

Also very important in understanding Newton's Laws of Motion are the terms ***net (resultant) force*** ***and external force***.

Resultant Force – *The vector sum of the forces acting on a body.*

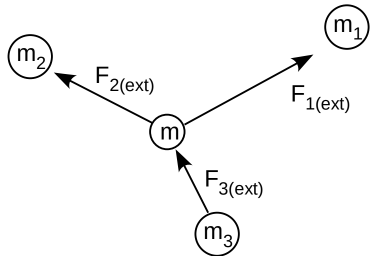
$$\boxed{\sum \mathbf{F} = \mathbf{F_1} + \mathbf{F_2} + \mathbf{F_3} + ...}$$ *(Resultant Force)*

Ex.



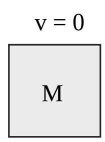
$$\sum \mathbf{F} = \mathbf{F_1} + \mathbf{F_2} + \mathbf{F_3}$$

External Force *– Forces exerted on a body by other bodies in the environment (surroundings)*



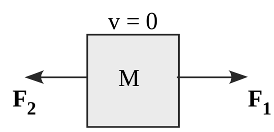
FIRST LAW

A body at rest remains at rest and a body in uniform motion (constant velocity) remains in uniform motion unless it is acted on by a non-zero net (resultant) external force.



$\Sigma \mathbf{F}=0$

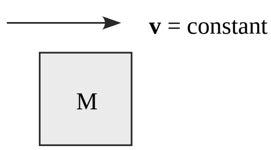
"body remains at rest"



$\mathbf{F_1 = -F_2}$

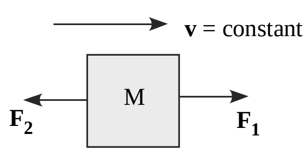
$\Sigma \mathbf{F} = \mathbf{F_1 + F_2 = (-F_2) + F_2 = 0}$

"body remains at rest"



$\Sigma \mathbf{F}=0$

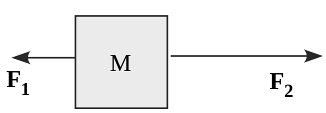
"body continues at constant **v**"



$\mathbf{F_1 = -F_2}$

$\Sigma \mathbf{F} = \mathbf{F_1 + F_2 = (-F_2) + F_2} = 0$

"body continues at constant **v**"



$\Sigma \mathbf{F} = \mathbf{F_1 + F_2} \not\equiv 0$

$\mathbf{F_1 \not\equiv F_2}$

"body cannot be at rest or move at constant v"

SECOND LAW

The net (resultant) external force on a body is equal to the product of the body's mass and acceleration.

$\boxed{\sum \vec{F} = m\vec{a}}$ Newton's 2nd Law

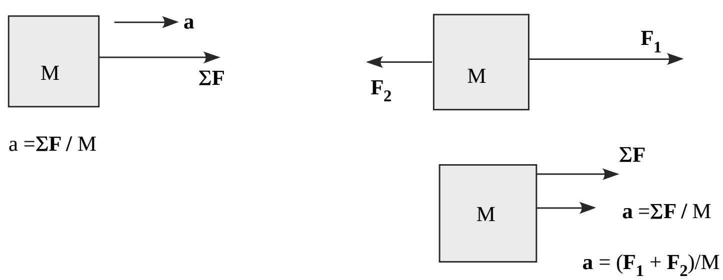
In component form,

$$\boxed{\begin{aligned} \sum F_x &= ma_x \\ \sum F_y &= ma_y \\ \sum F_z &= ma_z \end{aligned}}$$

1. $\sum \vec{F}$ is the net (resultant) external force on a body.

2. The quantity $m\vec{a}$ is not a force. The quantity $m\vec{a}$ is a vector equal in magnitude and direction to the net external force acting on a body.

3. Note that the 1st Law is just a special case of his 2nd Law when $\sum \vec{F} = 0$ and thus $\vec{a} = 0$.



THIRD LAW

If two bodies interact, the force that body 1 exerts on body 2 is equal and opposite to the force that body 2 exerts on body 1.

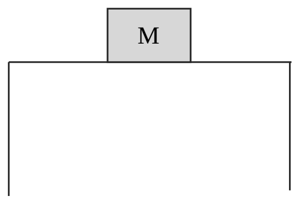
1. The two forces are called an action-reaction pair and always act on <u>different bodies</u>. The two forces are due to the interaction between two different objects.

2. Action-reaction forces have the same magnitude but opposite direction.

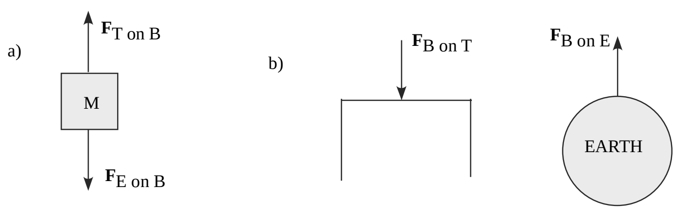
3. N3L is true if the bodies are at rest or in motion.

Ex. Newton's 3rd Law

Consider a block on a table-top as shown below:



a) What are the forces acting on the block?
b) What is the reaction force to each force acting on the block?
c) What are the action-reaction pairs?



c) $\mathbf{F}_{\text{T on B}} = - \mathbf{F}_{\text{B on T}}$

$\mathbf{F}_{\text{E on B}} = - \mathbf{F}_{\text{B on E}}$

Units of Force $\boxed{\sum \vec{F} = ma}$

MKS (SI)	1 Newton(N) = 1 kg • m/s^2
cgs	1 dyne(d) = 1 g • cm/s^2
British Eng.	1 pound (lb) = 1 slug • ft/s^2

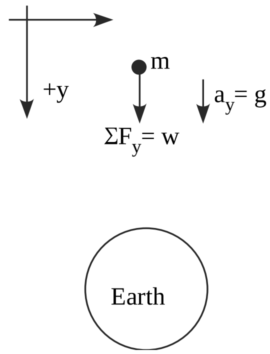
Mass and Weight

Inertia – A measure of the tendency of resistance of an object to changes in its initial state of motion.

Mass - The property of an object that specifies how much inertia it has. It is an intrinsic property of the object.

Weight - A measure of the gravitational force exerted on an object.

Consider an object in free-fall near the earth's surface:



Applying N2L to the object:

$\Sigma F_y = ma_y$

$\boxed{w = mg}$ Weight of a Body

Ex. m = 100 kg

$W_E = mg_E = 100\text{kg} \cdot 9.8 \text{ m/s}^2 = 980\text{N}$ (on earth)
$W_m = mg_m = 100\text{kg} \cdot 1.6 \text{ m/s}^2 = 160\text{N}$ (on moon)

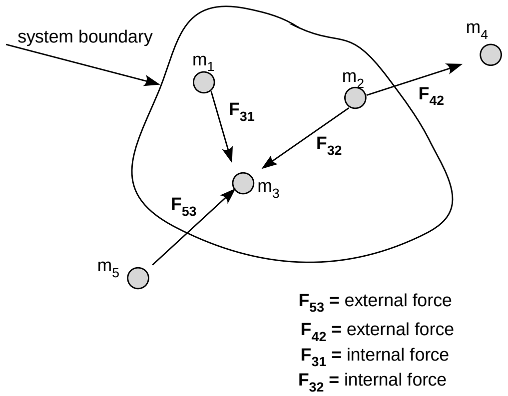
$W_E / W_m \approx 6$ or $W_m = (1/6)W_E$

<u>Using Newton's Laws</u>

When applying Newton's Laws to a system we are only interested in the **<u>external</u>** force acting on the system.

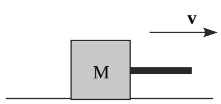
A system can be a single particle or object or several particles or objects. Once you define a system, the system boundary divides the universe into the system and the environment outside the system

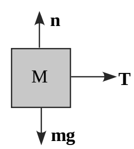
<u>External Force</u> – a force exerted on a system by bodies outside the system.



A diagram of the external forces acting on a system is called a **<u>Free-Body Diagram</u>**.

Consider a block of mass M being pulled to the right by a rope on a frictionless surface.





<u>Free-Body Diagram</u>

The force **N** is called a <u>normal force</u>. It is a contact force perpendicular to the surface.

<u>STEPS IN USING NEWTON'S LAWS</u>

1. Define your system and then draw a sketch of system.
2. Draw the Free-Body Diagram of system.
3. Insert a coordinate system.
4. Find the x and y-components of each external force on system.
5. Apply N2L along the x and y-axis separately.
6. Solve for the required quantity.

<u>USING NEWTON'S 1ST LAW (SYSTEMS IN EQUILIBRIUM)</u>

<u>Def</u>: A body at rest or moving with constant velocity is said to be in equilibrium.

$$\sum \vec{F} = m\vec{a} = 0 \text{ (since } \vec{a} = 0)$$

$$\sum \vec{F} = 0 \Rightarrow \left\{ \begin{array}{l} \sum F_x = 0 \\ \sum F_y = 0 \\ \sum F_z = 0 \end{array} \right\} \text{ Condition for Body in Equilibrium}$$