- ***Object*** - Anything with mass.
- ***System*** - An object or a collection of objects; not necessarily physically connected to each other.
- ***Force*** $[M][L]/[T]^2$- A mathematical construct used to describe interactions between two objects/systems.

Newton's Laws of motion

1st law) Defines equilibrium state of systems and definition of inertial reference frames.

"An object moving with a constant velocity will continue to move with the same speed and direction unless an interaction with another object(s) produces a net external force."

2nd law) Cause/effect description for departures from equilibrium as defined by the 1st law.

"The net external force cause a system to change its velocity (i.e. causes a system to accelerate)"

$$\sum \vec{F}_{\substack{external \\ on\ system}} = m_{system}\, \vec{a}_{cm}$$

- *cm* - center of mass

3rd law) Objects interact symmetrically.

"Force pairs"

$$\left|\vec{F}^{A}_{12}\right| = \left|\vec{F}^{A}_{21}\right|$$

If coordinate systems are the same for both objects:

$$\vec{F}^{A}_{21} = -\vec{F}^{A}_{21}$$

Mechanical Advantage (MA)

$$MA\ [dimensionless] = \frac{\left|\vec{F}^{A}\right|_{without\ device}}{\left|\vec{F}^{A}\right|_{with\ device}}$$

FORCES

$*\ [Dimensions] \xrightarrow{\text{SI units}} [L] \rightarrow m,\ [M] \rightarrow kg,\ [T] \rightarrow s$

Free Body Diagrams (FBD)

Procedure:

- Define system
- Identify and draw non-contact forces:

$$\vec{F}^{g}_{E1}$$

- Identify and draw contact forces:

$$\vec{F}^{T},\ \vec{F}^{N}_{12},\ \vec{F}^{fk}_{12}\ \ldots$$

- Define and clearly label a coordinate system:
  - Usually, but not always, helpful if you align one of the axes along the direction of acceleration if the system is accelerating. Else, try orienting the coordinate system in such a way that the majority of the forces are aligned with the axes; this will reduce the number of times you need to use trig functions when breaking forces into components.
- Apply Newton's 2nd law of motion.

Ideal Pulley

- Pulley has negligible mass compared to the objects connected to it.
- Pulley has no friction between its bearings and the axel or surface the bearings contact.

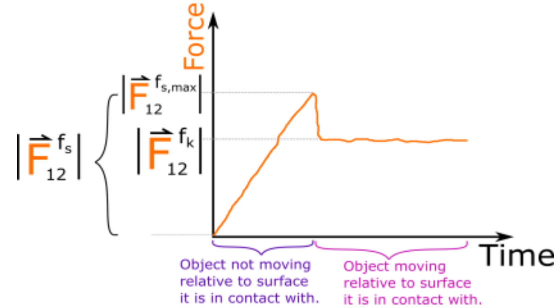
Coupled systems

- Systems, and/or objects are coupled if there is a geometric constraint linking the motion of the two together.
  - Example: If two objects are connected by a rope wrapped around an ideal pulley, the distance one object moves is the same distance the other object moves. This distance for each is traveled in the same amount of time, which eventually leads to the objects sharing the same magnitude of acceleration.
- If a rope of negligible mass is used with an ideal pulley(s), then the tension is a constant value along all parts of the continuous rope.

Friction

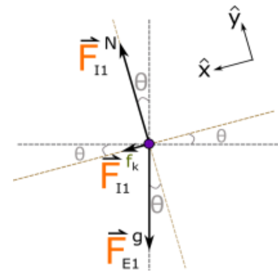
- The direction of friction will always be parallel to the two surfaces in contact, and in a direction that opposes the relative direction (or desired relative direction) of motion between the two surfaces in contact.

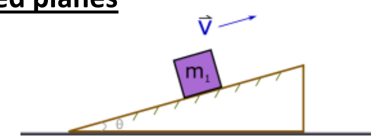
$$\left|\vec{F}^{fk}_{12}\right| = \mu_k \left|\vec{F}^{N}_{12}\right| \quad ; \quad \left|\vec{F}^{fs,max}_{12}\right| = \mu_s \left|\vec{F}^{N}_{12}\right| \quad ; \quad \left|\vec{F}^{fs}_{12}\right| < \mu_s \left|\vec{F}^{N}_{12}\right|$$



Inclined planes

Example FBD:





- Normal force is always perpendicular to surface of incline.
- Friction is always parallel to surface of incline.

Uniform Circular Motion (UCM)

- By definition, tangential component of velocity v_t is constant, and radial component of velocity v_r is zero, thus speed, $|\vec{v}|$, is constant. The velocity is not constant since its direction is always changing; always tangent to circular path.

$$\vec{v} = \langle v_t, v_r \rangle = \langle constant, 0 \rangle$$

- By definition, radial component of acceleration is constant, $a_r = \frac{v_t^2}{R}$, and tangential component of acceleration a_t is zero, thus the magnitude of acceleration, $|\vec{a}|$, is constant. The acceleration is not constant because its direction is always changing; always points towards the center of the circular path.

$$\vec{a} = \langle a_t, a_r \rangle = \langle 0, \frac{v_t^2}{R} \rangle$$

Radius of circle $[L] = R$