Newton's Laws of Motion

Apply to objects on which forces act.

NL1 If $\Sigma \vec{F} = 0$, the velocity of the object does not change (neither magnitude nor direction).
So if $v$ starts zero, it stays zero. ($a = 0$)
Really three equations: $\Sigma F_x = 0$, $\Sigma F_y = 0$, $\Sigma F_z = 0$

NL2 If $\Sigma \vec{F} \neq 0$, then $\Sigma \vec{F} = m\vec{a}$. $m$ is the object's inertial mass. Really three equations:
$\Sigma F_x = ma_x$, $\Sigma F_y = ma_y$, $\Sigma F_z = ma_z$
(Note that mass is the same in all directions)

Since $a = 0 \Rightarrow v = \text{constant}$, the distinction between NL1 and NL2 disappears.

NL3 When any two objects $A$ and $B$ interact,
$F_{A \text{ on } B} = - F_{B \text{ on } A}$ (Action/reaction pairs)
$F_{xA \text{ on } B} = - F_{xB \text{ on } A}$ $F_{yA \text{ on } B} = - F_{yB \text{ on } A}$ $F_{zA \text{ on } B} = - F_{zB \text{ on } A}$
Action/reaction pairs always act on different objects.

Weight We will learn much more about gravity later, but for now, weight is the force of gravity, given by $w = mg$

Close to earth's surface, $g = 9.8 \text{ m/s}^2$ and is positive down. Every object acted on by
gravity experiences such a force. The \( m \) is the object's gravitational mass. The two types of mass, inertial and gravitational, have been compared and determined to be numerically equal to great accuracy. This equivalence is not obvious, and in fact, is a result not well understood as to why.

Example: A mass \( m \) in free fall. The only force acting on an object in free fall is its weight.

\[
\text{Free Body Diagram} \quad y \Downarrow \quad \begin{cases} \text{\( F = w = mg \)} \\
\Sigma F_x = 0, \quad \text{Thus by NL1 } \quad v_x = \text{Constant, i.e. } a_x = 0 \\
\Sigma F_y = -mg, \quad \text{Thus by NL2 } \quad a_y = -g \\
\end{cases}
\]

A mass in free fall experiences projectile motion.

Example: A mass \( m \) resting on the ground.

\[
\text{Free Body Diagram} \quad y \Downarrow \quad \begin{cases} \text{\( n \)} \\
\Sigma F_y = -mg, \quad \text{Thus by NL2 } \quad a_y = -g \\
\end{cases}
\]

The mass is observed to not be moving. \( v_x = v_y = 0 \)
Thus by NL1, \( \Sigma F_x = 0 \) and \( \Sigma F_y = 0 \).

There are no forces in the \( x \) direction, but we know there is a weight force in the negative \( y \) direction. Thus there must be another force \( n \) in the positive \( y \) direction as shown. This force is called a normal force and acts in a direction perpendicular to the surface.

Thus \( \Sigma F_y = 0 \implies n + (-w) = 0 \)

\[ n - mg = 0 \]

\[ n = mg \]

This is the force of the ground acting on the mass. By NL3, the ground feels an equal but opposite force, that is, a force of value \( mg \) acting down on the ground.

What is the action/reaction pair for the weight force \( w \)? The earth feels a force of gravity, \( w \) acting in the positive \( y \) direction. You can think of this as acting at the earth’s center.

Remember, the forces of an action/reaction pair always act on different objects. They can be contact forces such as normal forces as well as friction and spring forces (more to come) or they can be forces which act at a distance such as gravity and electromagnetic forces (Physics 68).
Example: "Apparent weight" in an elevator.

You stand on a massless scale in an elevator moving at constant velocity (or at rest). The scale reads 500N. What is your mass?

The scale reading is the normal force you exert on its top surface.

Free Body Diagram - Scale

\[ \Sigma F_y = 0 \]

\[ 500N, F_{\text{elevator on scale}} \]

\[ g \]

\[ 500N, F_{\text{you on scale}} \]

Action/reaction pair

\[ 500N, F_{\text{scale on you}} \]

Free Body Diagram - You

\[ \Sigma F_y = 0 \]

\[ m = ? \]

\[ w = mg \]

Thus \( 500N - mg = 0 \), \( m = \frac{500N}{9.8m/s^2} = 51.0kg \)

Now elevator accelerates down ↓

What is your "apparent weight" (i.e. the reading of the scale)

Free Body Diagram - You

\[ \Sigma F_y = ma_y \]

\[ a_y = -a = -3m/s^2 \]

\[ n - mg = ma_y \]

\[ n = m(a_y + g) = 51.0kg(-3m/s^2 + 9.8m/s^2) \]

\[ n = 347N \] (Force Scale on you)

Now calculate the scale's reading if you and the elevator are accelerating up at 2.0m/s².