Astronauts in orbit about Earth

1. Weigh exactly what they weigh on Earth
2. are weightless
3. Weigh slightly less than they do on Earth
Astronaut on Moon
lightly places
Ping pong ball
in Space
beside him.

1. Ping pong ball
floats away

2. Ping pong ball falls to surface
   of Moon

3. Ping pong ball stays where
   Astronaut placed it.
What is an ORBIT?
IF in orbit ... do you have weight?
ARE you Accelerating
Throw Ball - look at curve

If in orbit you are constantly Accelerating
even if speed constant
\( \vec{V} \) direction always changing

"Orbit" is falling in a closed circle!

Circular Motion

\[ \Delta S = r \Delta \theta \]
\( m \text{ radians} \)
\[ \Delta s = r \Delta \theta \quad \text{often see } s = r \theta \]

\[ \begin{align*}
\Delta \mathbf{v} &= \mathbf{v} \Delta \theta \\
\frac{\Delta \mathbf{v}}{\Delta t} &= \frac{\mathbf{v} \Delta \theta}{\Delta t} = \frac{\mathbf{v} \frac{\Delta s}{r}}{\Delta t} \\
\frac{\Delta \mathbf{v}}{\Delta t} &= \mathbf{v} \frac{\Delta s}{r}
\end{align*} \]

by analogy

\[ \Delta \mathbf{v} = \mathbf{v} \frac{\Delta s}{r} \]

in limit of \( \Delta t \to \text{small} \)

\[ \frac{d\mathbf{v}}{dt} = \mathbf{v} \frac{ds}{dt} \frac{1}{r} \]

\[ 1 \ddot{a} = \frac{1v^2}{r} \]

Condition for circular motion

\( \Rightarrow \) radial acceleration

acceleration is toward center of circle and

has magnitude \( \frac{1v^2}{r} \)

Also called centripetal acceleration

\( \dot{v} \) here often called "tangential" velocity

\( \Rightarrow \) it is just the instantaneous velocity which happens to be tangential because motion is circular!!
Example: Shuttle

\[ a = \frac{V^2}{r} \]

\[ 9.8 \text{ m/s}^2 = \frac{V^2}{r} \]

\[ \text{at shuttle height} \]

\[ (\text{not exactly true}) \]

Earth

What is \( V \) of Shuttle to have closed orbit

\[ 9.8 \text{ m/s}^2 = \frac{V^2}{r} \]

\[ \frac{V^2}{r} = \frac{\frac{7962}{92.568}}{100 \text{ cm}} \times \frac{\frac{1}{234 \text{ cm}}}{\text{12 in}} \times \frac{\frac{\text{ft}}{5280 \text{ ft}}}{\text{s}} \times \frac{3600 \text{ s}}{\text{hr}} \]

\[ = \frac{1844 \text{ Mi/ft}}{17.812} \]

We will do many things/probs etc. with circular motion.

Remember: Circular Motion \( \iff \) \[ a = \frac{V^2}{r} \] radially.
Newton's Laws

I: Law of Inertia
A body persists in its state of motion unless acted on by an external net force.

II: Force Law
The acceleration of an object is proportional to the net force applied to it and inversely proportional to the mass of the object.

\[ \sum \mathbf{F} = m\mathbf{a} \]

III: Law of Action and Reaction
For every action, there is an equal and opposite reaction.
Newton's laws of Motion - Sir Isaac Newton (1687)

foundation of classical Mechanics

1\st Law of Motion - Law of inertia

A body acted on by no force moves at constant velocity (possibly zero) and zero acceleration.

-or-

A body persists in its state of motion unless acted on by an external net force

-or-

other... All say the same thing

2\nd Law of Motion - Force Law

The acceleration of an object is inversely proportional to its mass and the net force applied to it and

\[ \sum F = ma \]

\[ \text{if } \sum F = 0, \ a = 0 \]

Slightly more mathematical formulations

3\rd Law of Motion - Law of Action and Reaction

For every action there is an equal and opposite reaction.
3rd law is hardest to see conceptually.

"Throw ball on ice" ... you apply force to ball
ball applies force to you

" Recoil of a gun "

All should become clean up examples

Sometimes students find the 1st law hard to swallow
Can anyone think of an example where the 1st law is not true ??

Car ... Stop + gas to engine ... slows + stops
Car ... Stop + pushing ... it stops

⇒ Think of a world w/o friction or Air resistance
to get a conceptual view of the 1st law.
⇒ let objects "move on ice " + "in vacuum"
in your mind.

Friction + Air resistance keep the 1st law from
seeming to be true in real life. This is incorrect.
These are retarding forces ... you just aren't
always aware of them.

2nd law is almost intuitive

Its sort of a circular definition

\[ F \xrightarrow{\text{Big } M} \xrightarrow{\text{small } a} \]
\[ \xrightarrow{\text{ice}} \]

\[ F \xrightarrow{\text{small } M} \xrightarrow{\text{Big } a} \]
\[ \xrightarrow{\text{ice}} \]
\[ F = ma \]

\[ Force \text{ Meas. in Newtons} \equiv \text{kg m/s}^2 \]

\[ \text{This is inertial Mass in units} \]

\[ How\text{ does this relate to weight?} \]

Gravitational force

\[ |F| = \frac{G m_1 m_2}{r^2} \]

\[ \text{let} \quad m_1 = M_{\text{Earth}} \]

\[ |F| = \frac{G M_{\text{Earth}} m_2}{r_e^2} \]

\[ r_e = \text{radius of earth} = 6.38 \times 10^6 \text{ m} \]

\[ G \equiv \text{gravitational constant} = 6.67 \times 10^{-11} \text{ N m}^2/\text{kg}^2 \]

\[ \text{describes how strong gravity is as a force} \]

\[ M_{\text{Earth}} = 5.97 \times 10^{24} \text{ kg} \]

\[ \frac{G M_{\text{Earth}}}{r_e^2} \equiv g = 9.8 \text{ m/s}^2 \]

\[ \text{Weight is the magnitude of the force of gravity due to earth's grav. attraction near earth's surface} \]

\[ \text{Weight} = |F| = mg = 9.8 \text{ m/s}^2 \]

\[ \text{Weight on Moon} = m \left( \frac{GM_{\text{Moon}}}{r_{\text{Moon}}^2} \right) \]
The unit of weight is Newton (NOT Kg) in MKS

\[ \text{System} \quad \text{Force} \quad \text{Mass} \quad \text{Acceleration} \]

\[
\begin{array}{cccc}
\text{MKs} & \text{Newton} & \text{kg} & \text{m/s}^2 \\
\text{Cgs} & \text{dyne} & \text{gm} & \text{cm/s}^2 \\
\text{English} & \text{pound} & \text{slug} & \text{ft/s}^2 \\
\end{array}
\]

in English system

\[ F = ma \]

\[ \text{Weight (pounds)} = \text{Mass (slugs)} \times 32 \text{ ft/s}^2 \]

\[ g = \frac{G M e}{r^2} \text{ in English units} \]

Example of the preliminary:

Newton's laws become clear with these examples.

Let's do examples!

Use/significance of Newton's laws becomes clear through examples.
The Path to Enlightenment

1. Understand Problem, Draw Neat diagram of overall problem
2. Draw Free body diagram of each relevant object - label with forces
3. Choose convenient coordinate system for each object
4. Apply Newton's Second Law \( \mathbf{F} = m \mathbf{a} \) in appropriate orthogonal coordinates (coordinates chosen for each body must be related to those chosen for other bodies)
5. Keeping Symbols in place (No #s yet!)
   Solve resulting set of equations simultaneously
6. Check answer with limiting cases and dimensional Analysis!
Air-Sea Rescue

Rope Most likely to break when

1. Helicopter hovers at rest
2. Helicopter moves upward at const speed
3. Helicopter moves downward at const speed
4. Helicopter accelerates upward
5. Helicopter accelerates downward