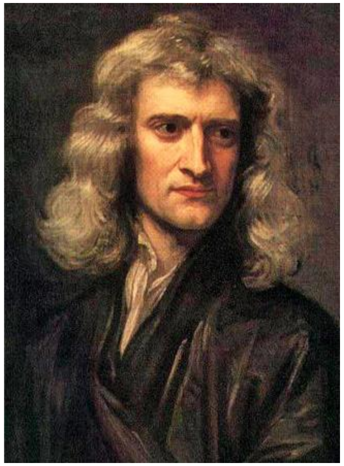
Today’s Topics

Wednesday, September 11, 2019 (Week 2, lecture 6) – Chapter 3.

1. Newton’s Laws
2. Momentum & Energy
3. Gravity
4. Circular Motion

Isaac Newton: Founder of Classical Mechanics

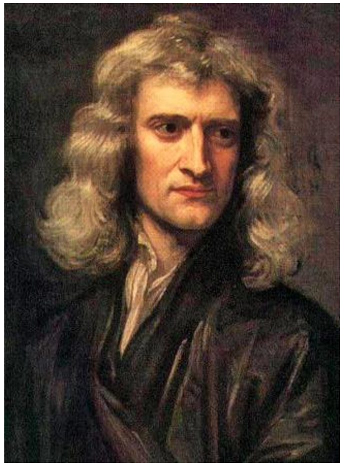


Newton (1689) [by G. Kneller]

Sir Isaac Newton (1643-1727)

- Cambridge U.
- Founded **Classical Mechanics**.
- Co-discovered **Calculus**.
- Major contributions to **Optics & Astronomy**.

Isaac Newton: Founder of Classical Mechanics



Newton (1689) [by G. Kneller]

Sir Isaac Newton (1643-1727)

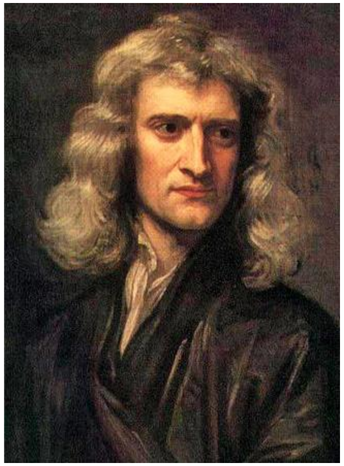
- Cambridge U.
- Founded **Classical Mechanics**.
- Co-discovered **Calculus**.
- Major contributions to **Optics & Astronomy**.

Classical Mechanics

- "Newton's Laws" of classical mechanics.
- Law of universal gravitation.
- Newton's laws are used for ***calculating planetary & stellar motion***.

(+ Einstein's "Special Relativity")

Isaac Newton: Founder of Classical Mechanics



Newton (1689) [by G. Kneller]

Sir Isaac Newton (1643-1727)

- Cambridge U.
- Founded **Classical Mechanics**.
- Co-discovered **Calculus**.
- Major contributions to **Optics & Astronomy**.

Classical Mechanics

- "Newton's Laws" of classical mechanics.
- Law of universal gravitation.
- Newton's laws are used for ***calculating planetary & stellar motion***.

(+ Einstein's "Special Relativity")

Astronomy

- **Optics:** white light & colors, refraction.
- Invented the **reflecting telescope**.

Newton's Laws

of Classical Mechanics

1st Law: An object moves at constant velocity if there is no net force acting on it.

[**fine print:** in an inertial reference frame]

2nd Law: Force = mass $\times$ acceleration.

3rd Law: For any force, there is always an equal and opposite reaction force.

Newton's 1st Law

An object moves at constant velocity if there is no net force acting on it.

[**fine print:** in an inertial reference frame]

Note: *This law is a variation on the* *Galilean relativity* *statement.*

Newton's 2nd Law

Force = Mass × Acceleration

or

$$F = ma$$

F = net force
m = mass
a = acceleration

[**fine print:** in an inertial reference frame]

Newton's 2nd Law

Force = Mass × Acceleration

or

$$F = ma$$

F = net force
m = mass
a = acceleration

[**fine print:** in an inertial reference frame]

Note 1: This equation is mostly useful if you know the net force applied.

Note 2: If the acceleration is zero, then the net force is zero.

Newton's 3rd Law

For any force, there is always an equal and opposite reaction force

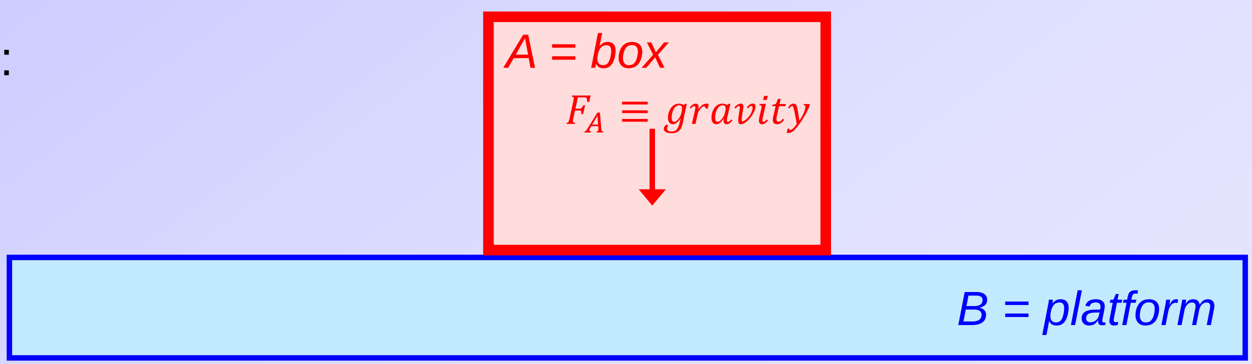
$$F_{A \to B} = -F_{B \to A}$$

Newton's 3rd Law

For any force, there is always an equal and opposite reaction force

$$F_{A \to B} = -F_{B \to A}$$

Example:

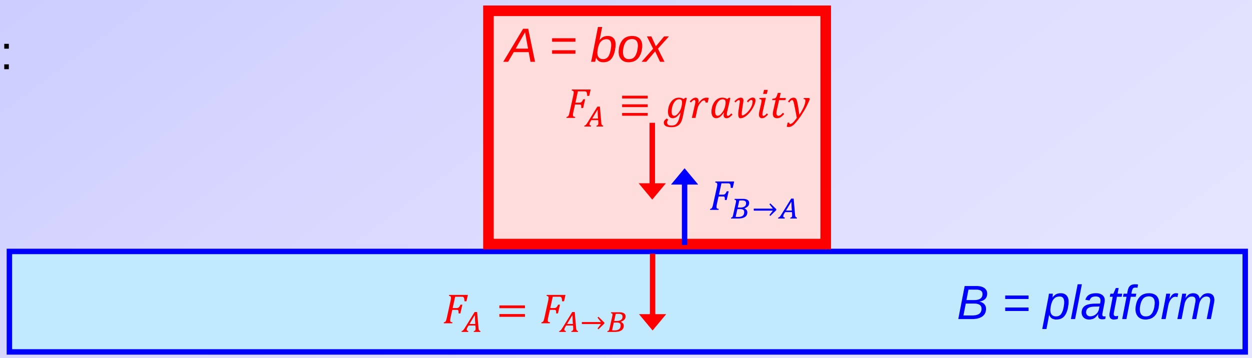


Newton's 3rd Law

For any force, there is always an equal and opposite reaction force

$$F_{A \rightarrow B} = -F_{B \rightarrow A}$$

Example:

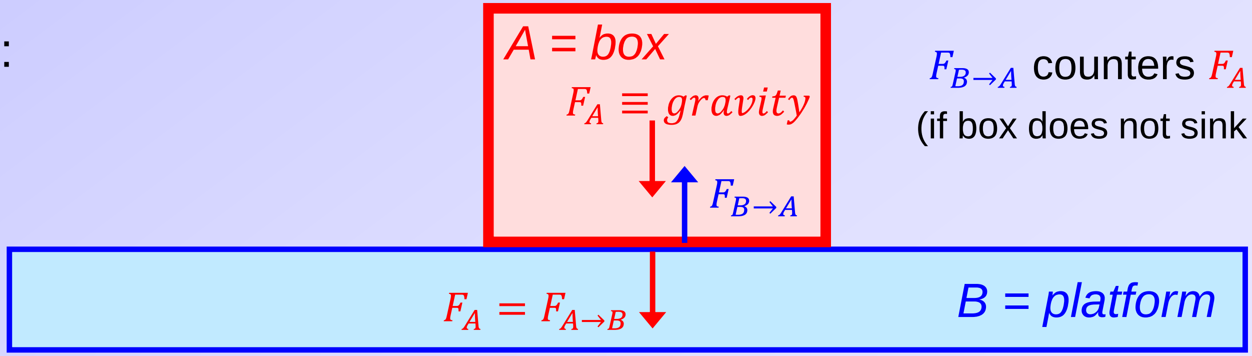


Newton's 3rd Law

For any force, there is always an equal and opposite reaction force

$$F_{A \to B} = -F_{B \to A}$$

Example:



$F_{B \to A}$ counters F_A exactly.
(if box does not sink into platform)

Newton's 3rd Law: Rocket Thrust

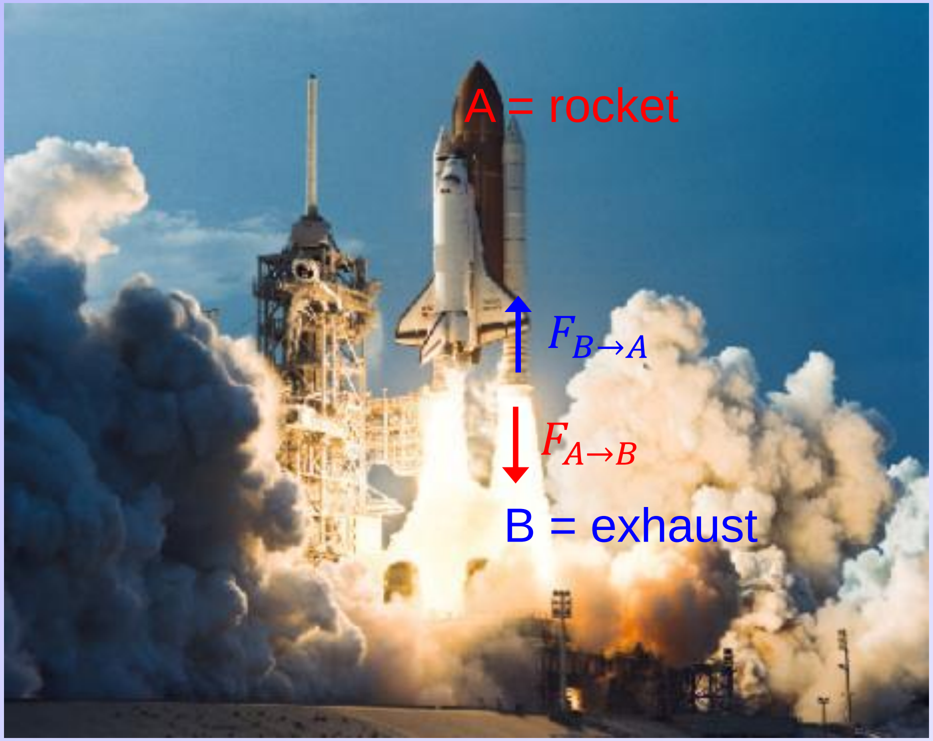
A rocket accelerates by pushing on its exhaust.

A rocket does NOT push on the air to accelerate.

A rocket does NOT push on its platform to accelerate.

Newton's 3rd Law: Rocket Thrust

A rocket accelerates by pushing on its exhaust.



A rocket does NOT push on the air to accelerate.

A rocket does NOT push on its platform to accelerate.

Conservation of Momentum

momentum = mass $\times$ velocity

total momentum
= sum of the momenta of all the sub-parts of a system

Conservation of Momentum

momentum = mass × velocity

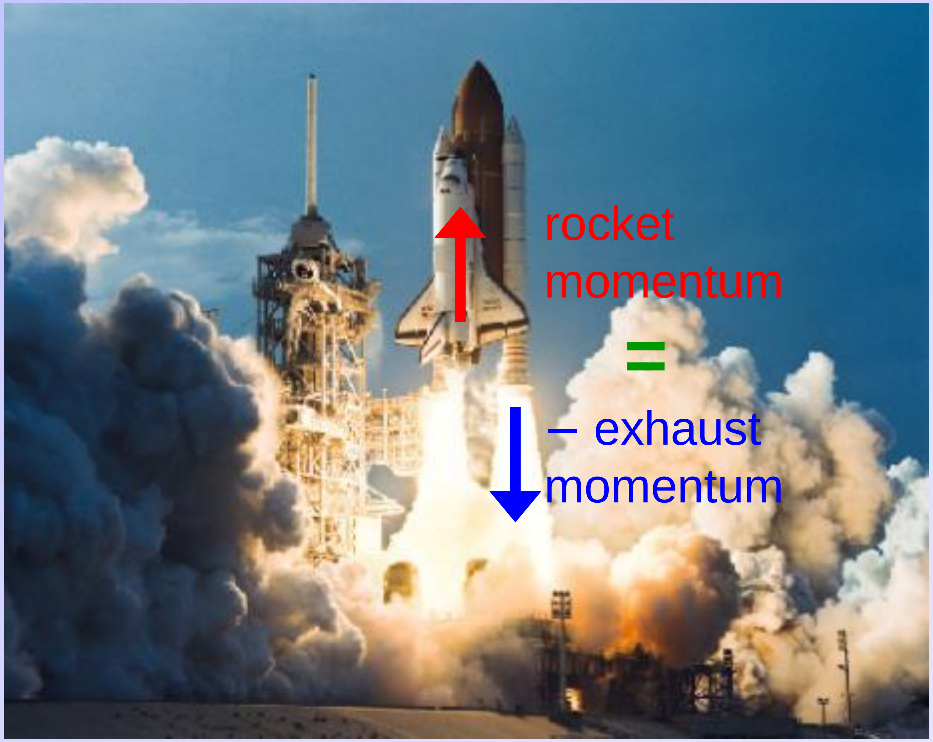
total momentum
= sum of the momenta of all the sub-parts of a system

Conservation Law
The total momentum of a closed system never changes.

no external objects enter
no external forces

Momentum Conservation: Rocket Thrust

$$\text{Momentum}_{\text{rocket}} + \text{Momentum}_{\text{exhaust}} = 0$$



Conservation of Energy

$$\text{Kinetic Energy} = E_k = \frac{1}{2}mv^2$$

m = mass
v = speed

Potential Energy = “stored” energy

example: gravitational potential energy

Total Energy
= sum of the energies of all the sub-parts of a system

Conservation of Energy

Kinetic Energy $= E_k = \frac{1}{2}mv^2$

m = mass
v = speed

Potential Energy = “stored” energy

example: gravitational potential energy

Total Energy
= sum of the energies of all the sub-parts of a system

Conservation Law
The total energy of a closed system never changes.

Gravity

Newton figured out that the same force that is responsible for a ***falling apple*** is also responsible for keeping the ***Moon in orbit*** around the Earth.

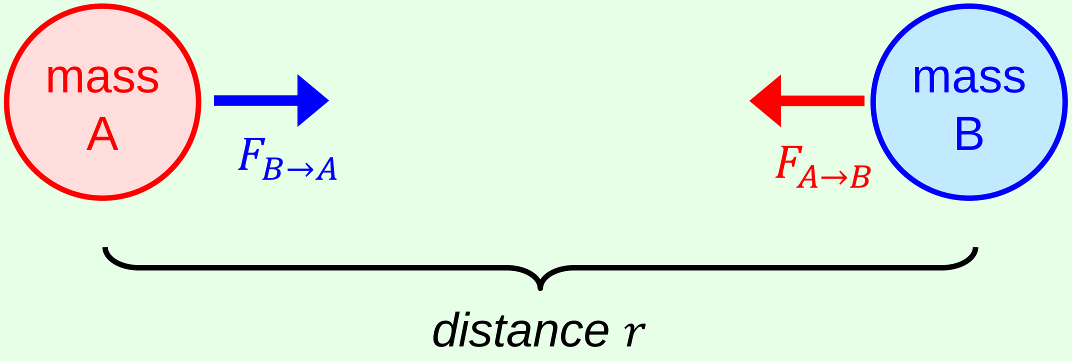
Gravity

Newton figured out that the same force that is responsible for a ***falling apple*** is also responsible for keeping the ***Moon in orbit*** around the Earth.

Newton's law of universal gravitation

All masses attract each other according to the following relation:

$$F_{A\to B} = -G\frac{M_A M_B}{r^2} = -F_{B\to A}$$



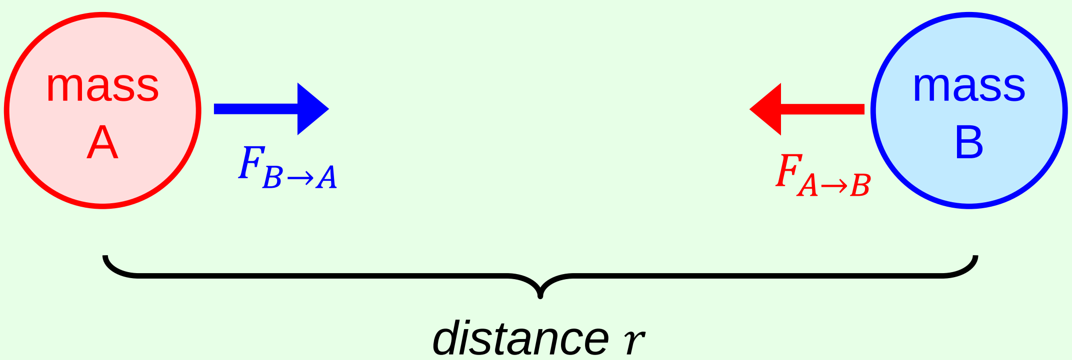
Gravity

Newton figured out that the same force that is responsible for a ***falling apple*** is also responsible for keeping the ***Moon in orbit*** around the Earth.

Newton's law of universal gravitation

All masses attract each other according to the following relation:

$$F_{A\to B} = -G\frac{M_A M_B}{r^2} = -F_{B\to A}$$



Properties

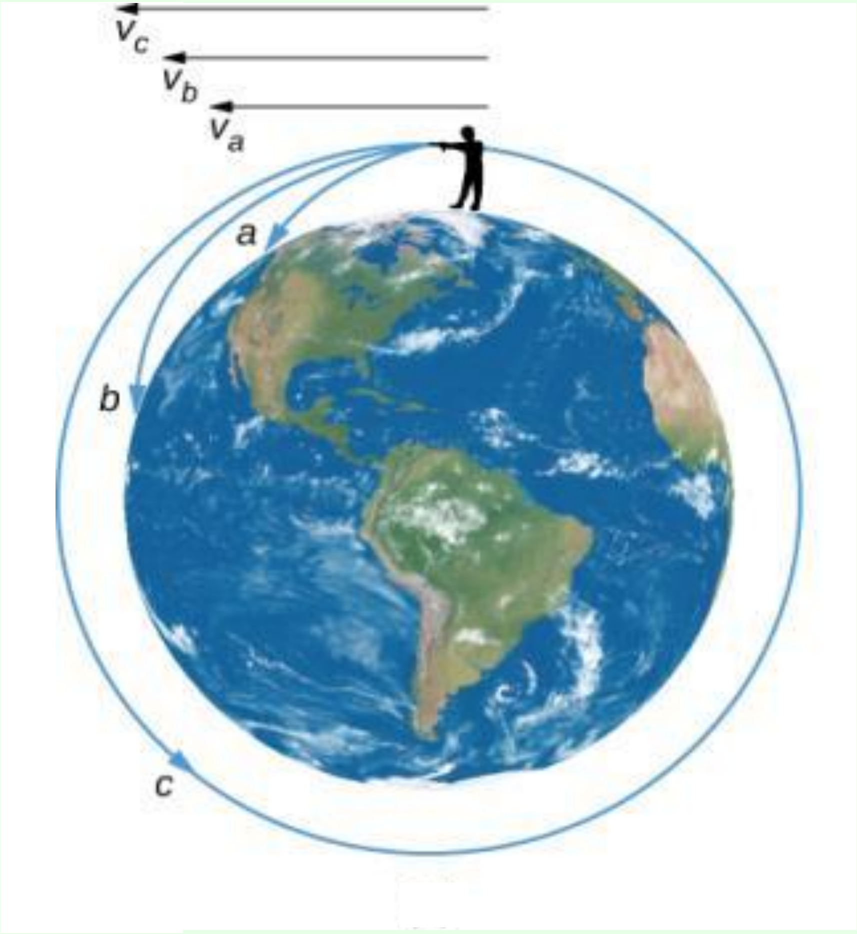
- Falls off as $1/r^2$.
- Proportional to M_A.
- Proportional to M_B.
- $G =$ Newton's constant $= 6.67430(15) \times 10^{-11}$ $m^3/Kg \cdot s^2$

Why do all objects

fall

at the same rate?

Orbiting is free falling while missing Earth

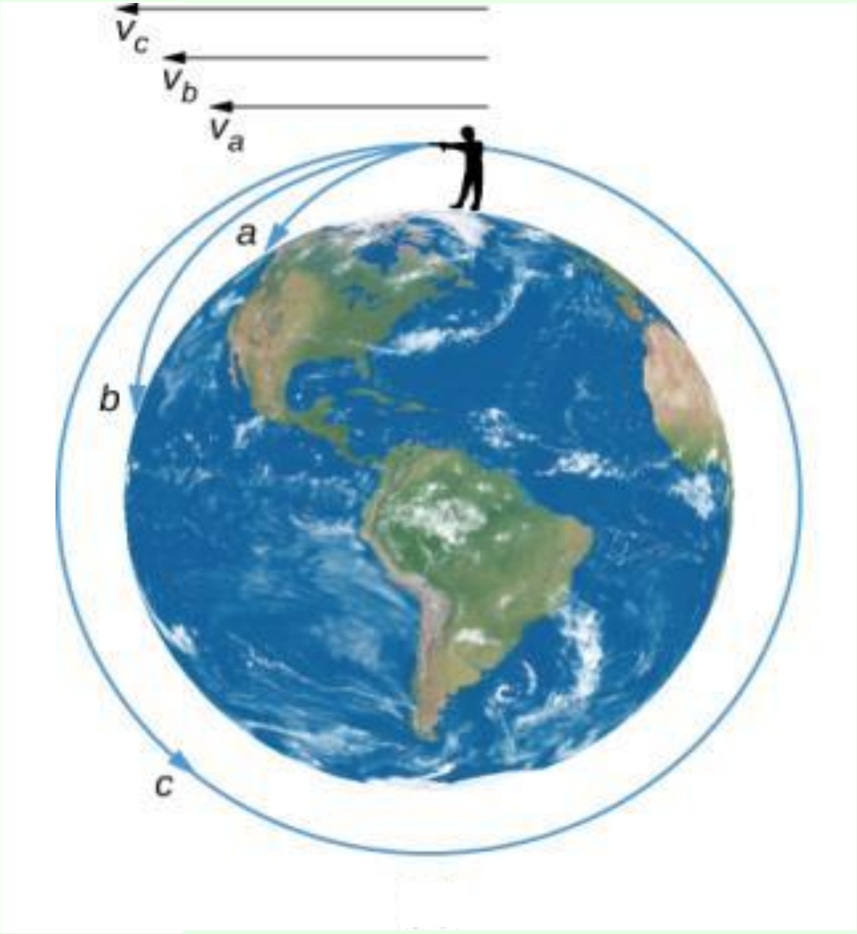


[OpenStax: Astronomy]

Paths a & b: Initial speeds are weak enough that Earth's gravity pulls the projectile back to the surface.

Path c: Initial speed is strong enough that Earth's gravity never pulls the projectile back to the surface.

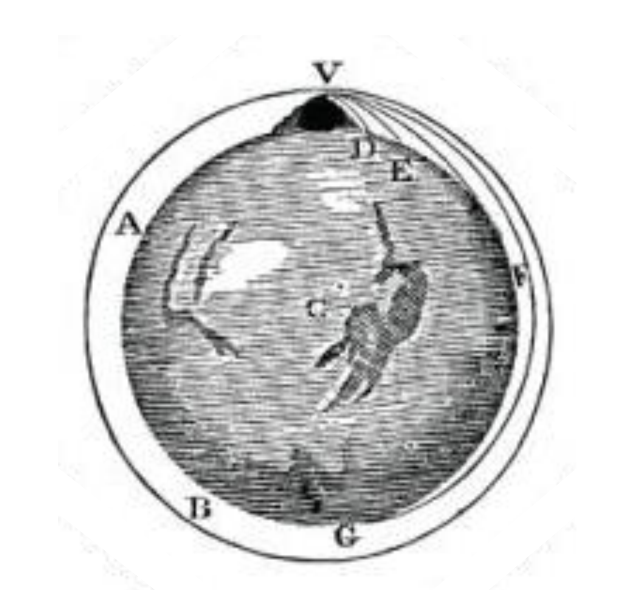
Orbiting is free falling while missing Earth



[OpenStax: Astronomy]

Paths a & b: Initial speeds are weak enough that Earth's gravity pulls the projectile back to the surface.

Path c: Initial speed is strong enough that Earth's gravity never pulls the projectile back to the surface.



[Adapted from *De Mundi Systemate*, Newton (1731)] orbiting

"The knack of flying is learning how to throw yourself at the ground and miss"

- Hitchhikers Guide to the Galaxy

Weightless in Orbit

Clockwise from top left: Tracy Caldwell Dyson (NASA), Naoko Yamzaki (JAXA), Dorothy Metcalf-Lindenburger (NASA), and Stephanie Wilson (NASA). (credit: NASA)

Astronauts in Free Fall: While in space, astronauts are falling freely, so they experience “weightlessness.”

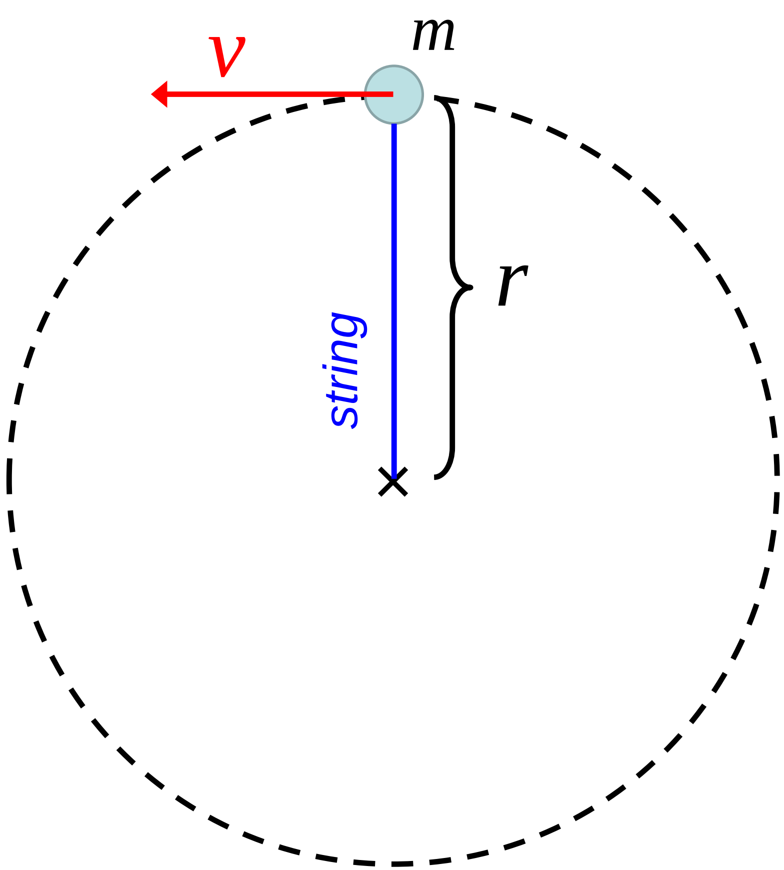
Circular Motion

Recall

acceleration = **change** in velocity over time

speed & direction

Rotation is a type of acceleration where the velocity **direction changes**, but speed is constant.



"ball on a string"

Circular Motion

Recall

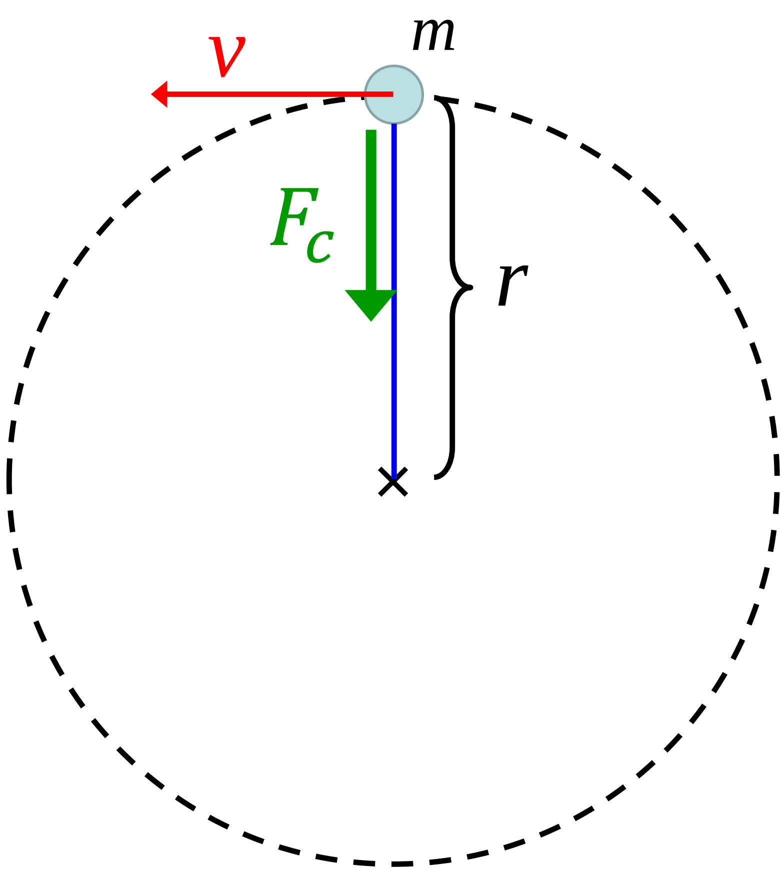
acceleration = **change** in velocity over time

speed & direction

Rotation is a type of acceleration where the velocity **direction changes**, but speed is constant.

Acceleration: $a_c = \frac{v^2}{r}$

Centripetal Force: $F_c = \frac{mv^2}{r}$



"ball on a string"

Circular Motion Example: Earth's orbit of Sun

Newton's version of Kepler's 3rd Law

$$T^2 = \frac{4\pi^2}{G(M_1 + M_2)} a^3$$

Formula is in SI units

T = orbital period in seconds

a = semimajor axis in meters

$M_{1,2}$ =Mass of orbiting objects in Kg

G = 6.6743×10^{-11} $m^3/Kg.s^2$