Reading: Chap. 3, Sect. 3.4 - 3.5
Web-based article on orbits for Thursday
Homework 4: Due Thursday for early grading or Mon./Fri.
Exam 1: Next Tuesday, Oct. 1, see schedule on website.
- Essay provided in lecture this Thursday

Last time: **Kepler to Newton**

- Kepler's Laws
  - Empirical: based on data alone w/o physical bias
  - #1: ellipses; #2: planets move faster when close; #3: $P^2 = a^3$
- Newton!
  - gravity as the physical law - orbits are continual falls

Today: more **Newton**

- Physical Laws and definitions of force, velocity, acceleration
- #1: Inertia; #2: Forces (F=ma); #3: Action/Reaction
- Newton's Law of Universal Gravitation
  - gravity as a central, universal, cosmic force

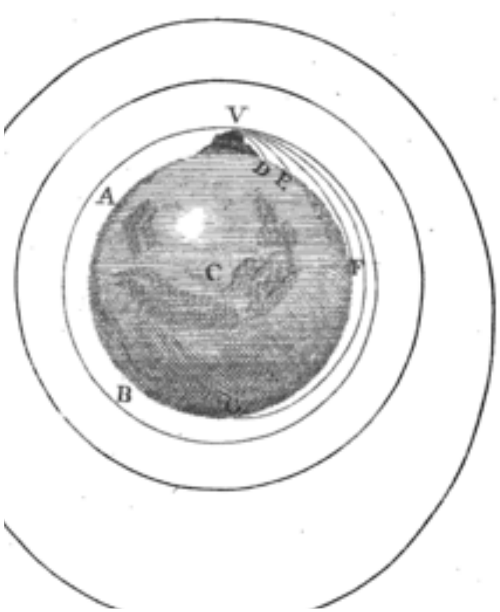
1666: Isaac Newton (1643-1727)

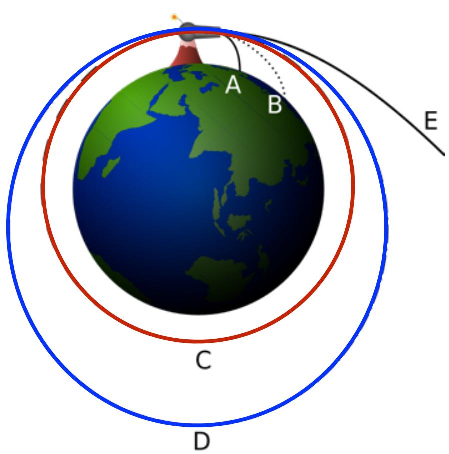
mathematician: Invented calculus as a youth . . .

SYNTHESIZED:
Galileo's Experiments
+
Kepler's Laws
+
Calculus
into Physical Laws;
the basis of Modern Science

Apple falls -> Earth and apple attract each other
Moon and Earth attract each other, too

If moon moves sideways as it falls, it could forever circle the Earth...





Newton's Synthesis

- **Mathematics** - Calculus
  - How to define/formulate/calculate motion & acceleration
- **Physics** - definitions / laws
  - energy of interaction between masses
  - momentum - resistance to change in motion
  - *correspondence with mathematical definitions*
- **Universal Gravitation**
  - dependence of gravitational force on mass & distance
  - connecting Galileo's experiments & Kepler's Laws
  - successful synthesis of earthly & cosmic behavior
  - blueprint for modern physics

Newton's Laws:

Newton #1: **The Law of Inertia**

A body moves at a constant velocity unless an unbalanced force acts on it

- Velocity: speed and direction
  - example: 65 mph southbound
- Force: something that changes a body's velocity
  - something that changes body's speed and/or direction
  - an external "push" or "pull"
- Inertia: *resistance* to change in velocity

Newton's Laws:

Newton #2: **The Law of Force**

Force = mass x acceleration

- Acceleration:
  - (rate of) change in velocity
    = (rate of) change in speed and/or direction
  - examples:
    - 0mph to 60 mph in 12 seconds (accel.)
    - 60 to 0 in 10 seconds (decel.)
    - turning left at the light (change in direction)
- Inertia: **a=F/m**
  - bigger mass: smaller accel. for same force
  - inertia: resistance to acceleration by a force
    - example: linebackers are big, wide receivers are small
    - example: shot put vs. golf ball

mass vs. weight

mass <–> inertia

weight <–> force

Newton's Laws:

Newton #3: **Law of Action and Reaction**

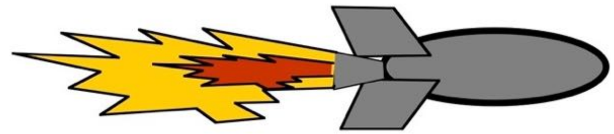
When one body exerts a force on a second body, the second body exerts an equal force, in the opposite direction, on the first.

Newton's Laws:

Newton #3: **Law of Action and Reaction**

When one body exerts a force on a second body, the second body exerts an equal force, in the opposite direction, on the first.

- Example: a rocket



Body 1: expanding gas jet

<–*F*   *F* –>

Body 2: rocket

Newton's Law of Universal Gravitation

Gravity is

- a **central** force: strength drops with distance^2
- a **universal** force: same form everywhere
- a **cosmic** force: inherent property of matter

Apple falls -> Earth and apple attract each other
Moon and Earth attract each other, too

If moon moves sideways as it falls, it could forever circle the Earth...

- **Force of gravity pulls planets towards Sun**
  (Newton's 2nd law)
- **without gravity, planets would fly away in straight lines**
  (Newton's 1st law)

Newton's Derivation of Kepler #3

- Gravitational force pulling planets toward sun

$$F_{\rm toward} = \frac{GMm}{a^2}$$ (Newton's law of Universal Gravitation)

- centrifugal "force" pulling planets away from sun

$$F_{\rm away} = \frac{mv^2}{a}$$ or, since $v = \frac{2\pi a}{P}$

$$F_{\rm away} = \frac{m4\pi^2 a}{P^2}$$

- If forces equal, then distance between doesn't change!

$$\frac{GMm}{a^2} = \frac{m4\pi^2 a}{P^2}$$ ... or ... $$P^2 = a^3 \times \left(\frac{4\pi^2}{GM}\right)$$ ← a constant

this is Kepler's Third Law!

Newton's Legacy

- **Force of Gravity pulls planets towards Sun**
  - without gravity, planets would fly away in straight lines
- Newton's theory of gravity explains -simply- the orbits of the planets

> Understanding motions of the planets was the principal discovery of astronomy from prehistory through 1700.

- Improved observations ("technology") demanded more precise models of the Solar System
- This precision was
  - approached by complex models (epicycles, etc.) but
  - achieved by discovery of the underlying simplicity: **Gravity**