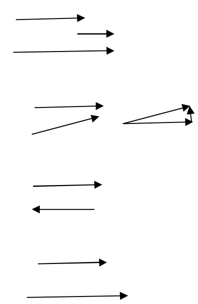
Newton's Laws of Motion

- What is the reason for Kepler's three descriptive laws?
- Newton's Law of Gravity
- Modern view of Kepler's Laws
  - 1 & 3 can be derived from Newton's laws of motion
  - Emmy Noether: 2 can be derived from fact that laws of physics do not depend on direction.
- **Announcements**
- **E-mail must have "ISP205" in the subject so your email does not look like spam.**

Newton's Second Law

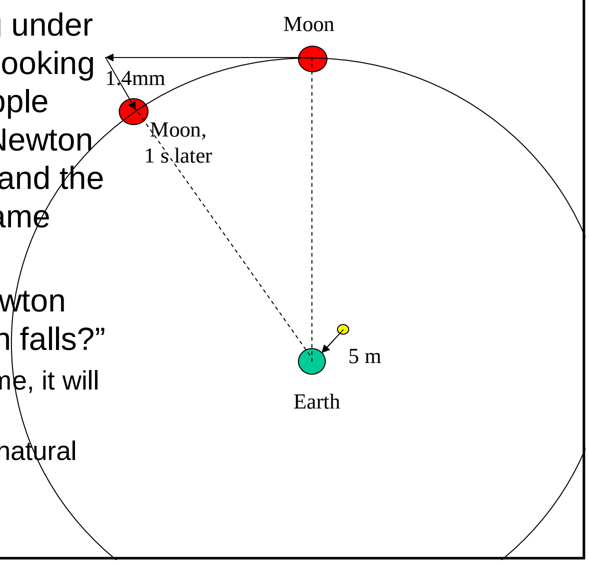
- Newton's First Law: In the absence of a force, an object moves at the same speed in the same direction.
- Newton's Second Law tells how to find the motion if there is a force.
  - *Force* **=** *mass x acceleration*
    F **=** *m x a*
  - **Acceleration is change in velocity divided by amount of time—how much velocity changes every second.**
- Q5 The velocity changed in
  a. Case A only
  b. Case B only
  c. Neither cases A nor B
  d. Both cases A and B
- Q1 The acceleration is greatest for which case? A, B, C, or D

- Case A
  - Velocity at start
  - Velocity after 1 s
- Case B
  - Velocity at start
  - Velocity after 1 s
- Case C
  - Velocity at start
  - Velocity after 1 s
- Case D
  - Velocity at start
  - Velocity after 2 s



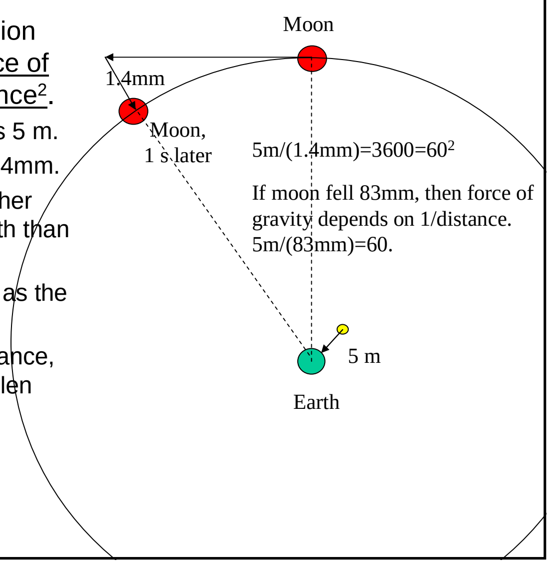
Newton discovers the law of gravity

- Newton was sitting under an apple tree and looking at the moon. An apple falls on his head. Newton realizes the moon and the apple fall for the same reason.
- Q2: What does Newton mean by "the moon falls?"
  a. After a very long time, it will hit the earth.
  b. It is falling from its natural path.



Newton discovers the law of gravity

- Newton realizes the moon and the apple fall for the same reason. He does a calculation and concludes that the <u>force of gravity depends as 1/distance^2</u>.
  - In 1 second, an apple falls 5 m.
  - In 1 second, moon falls 1.4mm.
  - The moon is 60 times farther from the center of the earth than the apple.
  - Moon falls 1/60^2 as much as the apple.
  - If force depends on 1/distance, then moon would have fallen 83mm.



Newton's Law of Gravity

- Force between sun and earth

  Force = G $mass_{Sun}$ $mass_{Earth}$/ $Distance^2$
  - Force decreases with square of distance.
  - This is a universal law. Law applies to all. Two planets pull on each other.
  - This law is reciprocal: Sun pulls on the Earth; Earth pulls on the sun.
- Earth's natural motion is motion at constant speed in a straight line. How does sun make Earth deviate from its natural motion?
  - Force on earth = $mass_{Earth} \times$ acceleration (Newton 2nd)
  - G $mass_{Sun}$ $mass_{Earth}$/ $Distance^2$ = $mass_{Earth}$ acceleration
  - acceleration = G $mass_{Sun}$ / $Distance^2$
  - Acceleration (how much the velocity changes in 1 s) is proportional to the mass of the sun and inversely to the square of the distance.

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- Q3: If a giant hand suddenly swapped the sun for a black hole of the same mass, the earth would
  a. spiral into the black hole.
  b. orbit faster.
  c. Keep the same path & period.
- Q4: Does Mars slightly affect Earth's motion?
  a. Yes
  b. No

Newton Derives Kepler's 3rd Law

- Quick & dirty derivation: Assume orbit is a circle of radius R. Ignore numerical constants such as π or 2.
  - From Newton's 2nd Law, F=ma, and Newton's law of gravity, $F=GMm/R^2$ we found

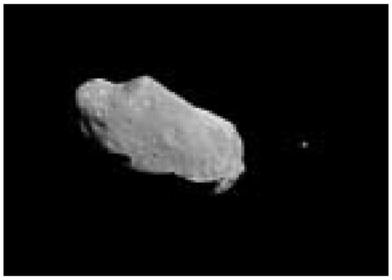
    acceleration = G $mass_{Sun}$ / $Distance^2$

    $a = G\ m / R^2$.
  - Velocity, distance/time, is approximately $2\pi R/P$, where P is period.
  - Acceleration, change in velocity/time, is approximately (R/P)/P.
  - $R/P^2 = a = G\ m / R^2$.
  - $P^2 = R^3/(G\ M)$
- Accurate derivation
  - $P^2 = 4\pi^2/G\ R^3/(M_{sun}+M_{planet})$
  - $P^2= R^3/M$ if P is in years (not seconds), R in astronomical units (not m or ft), and M is mass of star and planet measured in solar mass (not kg).

Newton Derives Kepler's 3rd Law

- $P^2 = R^3/M$, if P is in years, R in astronomical units, and M is mass of sun & planet in solar mass. (Mass planet is usually negligible.)
- Kepler's 3rd Law depends on the mass of the star.
- The laws of motion are universal. We can use K's 3rd Law to measure mass of stars, planets, galaxies, & asteroids.

- Q3 Astronomers measured orbit of Dactyl. If Dactyl takes a short time to orbit Ida, then
  a. mass of Ida is big.
  b. mass of Ida is small.
  c. mass of Dactyl is small.
  d. mass of Dactyl is big.



Asteroid Ida & little Dactyl

Kepler's Law of Equal Areas
Conservation of Angular Momentum

- Why does Jenna speed up when she brings her arms in?
- Angular momentum is L=mvr
  - L=mass × component of velocity perp. to radius × radius
- Why does Jenna…?
  - The rotating stool is not causing Jenna to twist, angular momentum stays the same.
  - The radius of the dumbells decreases. To keep L same, v increases. Smaller r ➔ larger v
- Kepler's 2nd Law.
  - Since the sun is not causing the planet to twist, L stays the same.
  - mvr = constant
  - smaller r ➔ larger v
  - Planet speeds up when closer to sun
- Emmy Noether (about 1910) showed
  - Laws of physics are the same regardless of direction implies conservation of angular momentum

Kepler2 simulation