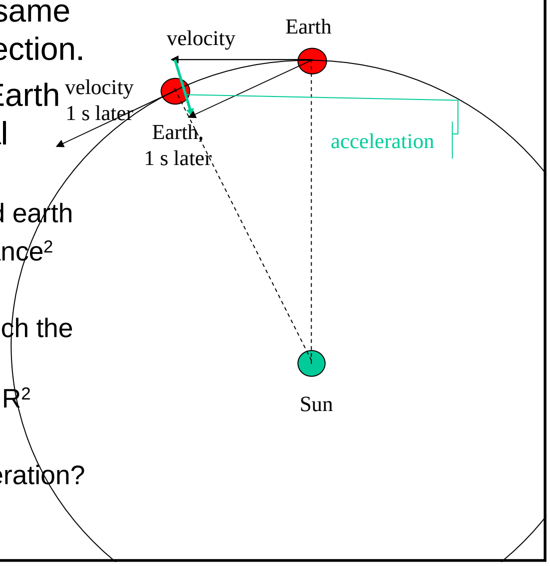
Newton explains Kepler's Laws—27 Jan

- First test is Thurs, Feb 5.
  - Click on Study Guide & 2005 Test on Syllabus.
    - Material covered on Q2, 3, & 28 from 2005 will not be on the test.
  - Missouri (Show me) Club
    - Tues, Feb 3, 7:00-8:00pm, room 1415.
  - Covers material through today.
  - About 30 multiple choice questions
    - Some require working with models such as phases of Venus & zodiac (Fig 2.12).
  - How to study
    - Identify Big Ideas
    - Practice models & examples
    - Do 2005 test
    - Go over homework & clicker questions
- Topics for today
  - Newton derives Kepler's 3rd Law
  - Kepler's 1st Law is derived from Newton's Laws in Phy 321.
  - Emmy Noether showed Kepler's law of equal areas can be derived from the idea that laws of nature do not depend on rotation.
  - Light

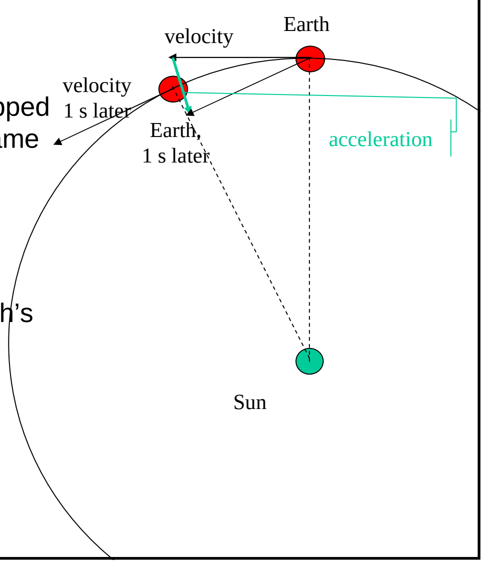
How sun affects earth's motion

- The natural motion of the earth is motion at the same speed in the same direction.
- How does sun make Earth deviate from its natural motion?
  - Force between sun and earth $F = G\, m_{Sun}\, m_{Earth} / \text{Distance}^2$
  - $F = m_{Earth}\,\text{acceleration}$
  - Acceleration is how much the velocity changes in 1 s.
  - $m_{Earth} a = G\, m_{Sun}\, m_{Earth} / R^2$
  - $a = G\, m_{Sun} / R^2$
  - What affects the acceleration?



How sun affects earth's motion

- How does sun make Earth deviate from its natural motion?
  - $a = G\ m_{Sun} / R^2$
  - What affects the acceleration?
- Q: 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.
- Q: 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

    $\text{acceleration} = G\ \text{mass}_{Sun} / R^2$

    $a = G\ m / R^2$.
  - 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.

- Q 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

Light, Thermal Radiation—27 Jan

- What can we learn by analyzing light?
  - Example of globular cluster
- Thermal radiation
  - Radiation of warm bodies

Light

- Almost all we know about astronomy comes from analyzing light.
- Example: globular clusters
  - Around 1915, Harlow Shapley figured out the distances to the Milky Way's globular clusters.
  - What do you notice about the light of the globular cluster M10?

Globular Cluster M10

Light

- Almost all we about astronomy comes from analyzing light.
- What do you notice about the light of the globular cluster M10?
  - Color: Red stars are brighter than blue stars ⇒ Red stars are giants, about the size of the earth's orbit.
  - Spectra show M10 has much less oxygen (and other elements heavier than Li) than sun ⇒ M10 is very old, one of the first systems to have formed
  - Spectra shows the speed of M10 is very fast compared to that of stars near the sun ⇒ orbits of globular clusters are long & thin, whereas sun's is almost circular

Globular Cluster M10

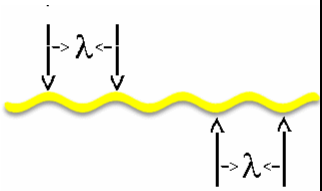
Wavelength, Frequency

- Wavelength λ = distance between successive crests.

  m meter

  nm nanometer (10^{-9}m)

  Å angstrom (10^{-10}m)
- Wave moves at speed of light c.
- Frequency is rate at which crests pass.
  - $f = c/\lambda$
  - Cycles/second; Hertz

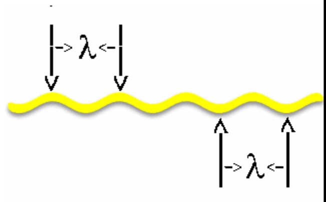


Light is quantized

- A photon is a quantum, the smallest amount, of light.
- A photon carries energy

  $E = h\,f = h\,c\,/\,\lambda$ (h is Planck's constant)
  - A photon can do an amount of work E
    - Give an electron its energy
    - Make an electron move faster
- A photon carries momentum

  $p = h\,f\,/c = h\,/\,\lambda$
  - A photon can give a push
    - Push an electron against pull of gravity



The E-M wave in action link

Thermal radiation

(Blackbody Radiation)

- Any object that absorbs light also emits light.
- Do people emit light?
  - People emit light in the "thermal infrared" part of the spectrum.
  - Your eyes cannot see infrared radiation. 8000 λ<12000nm
  - You can see visible light
    - Blue 440nm
    - Green 550nm
    - Red 620nm
- A perfect absorber (perfectly black) emits a characteristic spectrum of light. (Called thermal or black-body radiation.)
  - Intensity depends only on
    - Temperature
    - Area
- A non-perfect absorber (grey body) with emissivity ε absorbs a fraction ε and reflects a fraction (1-ε).
  - Intensity is ε that of thermal radiation.

Picture taken with an infrared camera
ornitorinko.org:8080/.../portrait-bits.jpg

Infrared camera—Seeing with infrared eyes

- A perfect absorber (perfectly black) emits a characteristic spectrum of light. (Called thermal or black-body radiation.)
  - Intensity depends only on
    - Temperature
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- A non-perfect absorber (grey body) with emissivity ε absorbs a fraction ε and reflects a fraction $(1-\varepsilon)$.
  - Intensity is ε that of thermal radiation.
- Thermal infrared
  - Wavelength is 8,000-12,000 nm
  - An object with a temperature of 300K emits most of its light in the thermal infrared.
  - Does infrared light show the same thing as visible light?

- Q As viewed with an infrared camera, why is the man's hair darker than his cheeks?
  A. His hair has less area than his cheeks.
  B. His hair has less emissivity.
  C. His hair is cooler.
  D. His hair is dark, and his skin is light.