Gravity and Kepler's Laws

PSC 203

Overview

- In this section:
  - What is gravity and how does it work?
  - How do objects move in the solar system?
- Pre-lecture questions …

Gravity

Theory of Gravity

- Gravity is the force of attraction between any two masses
- Sir Isaac Newton
- Albert Einstein

Law of Gravity

- Force is:
- directly proportional to product of masses
- inversely proportional to distance squared

$$F_G = \frac{Gm_1 m_2}{r^2}$$

Qualitative relationships

- Mass
  - More mass, more force
  - Less mass, less force
- Distance
  - Large distance, less force
  - Small distance, more force

G

- Universal Gravitational Constant
- found by experiment
- assumed constant throughout universe

$$G = 6.7x10^{-11} \frac{Nm^2}{kg^2}$$

- Don't need to memorize this number

Qualitative Example

$$F_A = \frac{G\, m_A\, m_2}{r^2} \qquad F_B = \frac{G\,(2m_A)\,m_2}{r^2}$$

$$F_B = 2F_A$$

Example 2

$$F_A = \frac{G\, m_1 m_2}{r^2} \qquad F_B = \frac{G\, m_1 m_2}{(3r)^2}$$

$$F_B = \frac{1}{9} F_A$$

Qualitative relationships

- Need to look at full equation
- You need to make sure that your units are the standard mks (meters, kilograms, and seconds)
- Then it is just plugging into the calculator
- For astronomy, masses and distances are often found in the tables in the book

Example: Earth and Moon

$$F_G = \frac{(6.7x10^{-11}\frac{Nm^2}{kg^2})(6x10^{24}kg)(7x10^{22}kg)}{(4x10^8 m)^2}$$

$$F_G = 1.75x10^{20} N$$

Surface Gravity

Surface Gravity

- Measures the affect of gravity at the surface of an object
- Depends on mass and radius of planet

$$g = \frac{GM}{R^2}$$

Qualitative relationships

- Mass
  - More mass, more gravity
  - Less mass, less gravity
- Radius
  - Large radius, less gravity
  - Small radius, more gravity

Give and take

- The jovian planets have more mass than terrestrials
- But they also have a larger radius…
- So what is the result?
  - Table from other textbook

Example questions

- From concept tests…

Kepler's 1st Law

Kepler

- Johannes Kepler (1571-1630)
- was trying to understand how planets moved
- used very precise data from Tycho Brahe

1st observation

- converted observations of positions of planets against background stars to positions relative to sun
- didn't fall on perfect circles as had been assumed

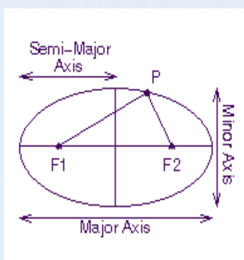
Kepler's 1st Law

"Each planet moves in an elliptical orbit with the sun at one focus of the ellipse."

Ellipse

- oval shape
- 2 focus points
- mathematical equation

$$\frac{x^2}{a^2}+\frac{y^2}{b^2}=1$$



Eccentricity

- eccentricity - a measure of the flattening of an ellipse
- $e = 0$ is circle
- $e > 0$ means flattened
- higher e means more flattened

Eccentricity of objects

- most planets have low eccentricity ($e < 0.1$)
- comets have high eccentricity
- applet

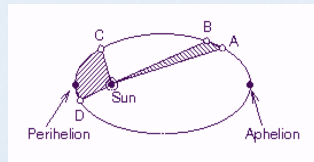
Kepler's 2nd Law

2nd observation

- Planets didn't move at a constant speed
- moved faster when closer to sun
- moved slower when further from sun

Kepler's 2nd Law

- "The line from the sun to any planet sweeps out equal areas in equal time intervals."



Animation

- Links to animation applets are on course website
- applet

Kepler's 3rd Law

3rd observation

- planets did not orbit around sun at same speed
- closest to sun orbited faster
- further out from sun orbited slower

Kepler's 3rd Law

- "The squares of the periods of the planets are proportional to the cubes of the average distances from the sun."

$P^2 \sim a^3$

Animations

- Links to animation applets are on course website
- applet

Using the equation

- Most often use the ratio form of the equation

$$\frac{P_1^2}{P_2^2} = \frac{a_1^3}{a_2^3}$$

Example: Planets around Sun

- For Earth:
  - P_2 = 1 year
  - a_2 = 1 AU
- For any other object:

$$P = \sqrt{(a*a*a)}$$

- P in years, a in AU

Example: Planets around Sun

- For an object at, a = 2AU

$$a^3 = (2)^3 = 2*2*2 = 8$$

$$P = \sqrt{8} = 2.83$$

Example question

- From concept tests….