

## Astro 18-- Planets and Planetary Systems – Spring 2007

### Homework 2: Gravity, Kepler's Laws, Newton's Laws

*Due Thursday April 12th before class.*

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This Homework is based on Chapter 4 of Bennett.

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*Homework Policy:* Homeworks count as 30% of your final grade. Homeworks turned in one class period late will be graded with a grade reduction of 1/2. Homeworks more than one class period late will not be accepted. Your one lowest-graded homework assignment will not count toward your final grade. For each problem, in addition to giving the numerical answer you must show your reasoning (what steps you went through to arrive at your answers, with words and drawings as well as numbers) and state what units you are using.

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1) *Understanding Acceleration:*

- a) What do we mean by *acceleration*? State your answer both in words and in an equation. What is the *acceleration of gravity*? Explain what we mean when we state an acceleration in units of meters / sec<sup>2</sup>.
- b) It's wintertime in the Sierras and you have gone to the local snowy hill to go sledding. You and your sled accelerate downhill at the rate of 2 meters / sec<sup>2</sup>. How fast will you be going after 5 seconds? After 10 seconds?
- c) You are driving along the freeway (for example Route 17) at a speed of 60 miles per hour when you see a deer crossing the road. You slam on your breaks to stop. Your brakes make your car *decelerate*. (Deceleration is simply negative acceleration.) If your rate of deceleration is 20 miles per hour per second, how long will it take you to come to a stop?

2) *Testing Kepler's third law:* We can test Kepler's third law,  $p^2/a^3 = \text{constant}$ , for the classical and dwarf planets in our own Solar System. Use Appendix E in Bennett, or use one of the planetary science web links listed on our class web page to fill in the second, third, and fourth columns of the following Table. Use three decimal places throughout the Table.

“Classical Planets”

Planet	a = Semimajor axis of orbit (AU)	p = Period (years)	Test Kepler's Law $p^2/a^3$ (years <sup>2</sup> /AU <sup>3</sup> )
Mercury			
Venus			
Earth			
Mars			
Jupiter			
Saturn			
Uranus			
Neptune			

Do the same for some new “dwarf planets” (get information on orbits from <http://www.gps.caltech.edu/~mbrown/planetlila/>)

Dwarf Planet	a = Semimajor axis of orbit (AU). Use average of closest and furthest approach to Sun	p = Period (years)	Test Kepler's Law $p^2/a^3$ (years <sup>2</sup> /AU <sup>3</sup> )
Eris			
2003 EL61			
2005 FY9			

What conclusion can you draw from this exercise? Is  $p^2/a^3$  really constant? If  $p^2/a^3$  is not exactly constant, over what percent difference from unity does it range?

3) *New Comet:* A new comet is discovered and studies of its motion indicate that it orbits the Sun with a period of 100 years. a) Use Kepler's third law in its original form to find

the comet's average distance from the Sun (i.e. find the semi-major axis of the comet's orbit). Be sure to include units in your answer. b) Use Appendix E in Bennett or one of the planetary science web links listed on our class web page to place this new comet in the context of the planets in our Solar System: between which two planets' orbits does the new comet's mean distance from the Sun lie?

4) *Newton's Law of Universal Gravitation*: Use Newton's Law of Universal Gravitation to answer each of the following questions:

a) How does tripling the distance between two objects affect the gravitational force between them?

b) Compare the gravitational force between the Earth and the Sun to that between Jupiter and the Sun. (Use Appendix E in Bennett or one of the planetary science web pages to look up characteristics you need to know.)

c) Suppose the Sun were magically replaced by a star with twice as much mass. What would happen to the gravitational force between the Earth and the Sun?

5) *Understanding Kepler's third law*: Use Newton's version of Kepler's third law to answer the following questions. (*Hint*: The numerical calculations for this problem are so simple that you will not need a calculator.)

a) Imagine another solar system, with a star of the same mass as the Sun. Suppose there is a planet in that solar system with a mass twice that of Earth, orbiting at a distance of 1 AU from the star. What is the orbital period of the planet? Explain.

b) Suppose a solar system has a star that is four times as massive as our Sun. If that solar system has a planet the same size and mass as Earth orbiting at a distance of 1 AU, what is the orbital period of the planet? Explain.

6) *Measuring Masses*. Use Newton's version of Kepler's third law to answer each of the following questions. In each case show how you reached your conclusion.

a) The Moon orbits the Earth in an average of 27.3 days at an average distance of 384,000 kilometers. Use these facts to determine the mass of the Earth. You may

neglect the mass of the Moon and assume  $M_{\text{Earth}} + M_{\text{Moon}} \sim M_{\text{Earth}}$ . (The Moon's mass is about 1/80 of Earth's.)

b) Jupiter's moon Io orbits Jupiter every 42.5 hours at an average distance of 422,000 kilometers from the center of Jupiter. Calculate the mass of Jupiter. (Io's mass is very small compared to Jupiter's.)

c) Calculate the orbital period of the Space Shuttle in an orbit 300 kilometers above the Earth's surface. (Hint: you will need to know the radius of the Earth.)

d) Pluto's moon Charon orbits Pluto every 6.4 days with a semimajor axis of 19,700 kilometers. Calculate the combined mass of Pluto and Charon. Compare this combined mass to the mass of the Earth.