**Kepler’s Laws & Retrograde Motion**

**AP Physics**

1. State Kepler’s 1st Law.
2. Find the eccentricities of Neptune’s and Pluto’s orbits. Use the ellipse eccentricity animation to visualize the shape of the orbit of each planet. Explain why the two orbits might intersect.
3. The varying distance from the Earth to the Sun could potentially be why we have seasons, but in fact the seasons are due to the tilt of the Earth’s rotation axis. One reason it cannot be due to the ellipticity of Earth’s orbit is that summer and winter do not occur at the perihelion and aphelion. Also Earth’s orbit is too circular to produce much of an effect. Can you think of a third reason why the seasons cannot be due to the changing Earth-Sun distance?
4. Go to <http://www.walter-fendt.de/ph14e/keplerlaw1.htm> for the final applet on the Kepler’s 1st Law page that traces out the orbits of the planets (the actual link on the page is disengaged but this is the correct applet). Turn on the “Elliptical Orbit” button, and trace the orbit of Mercury. Write down the ellipticity and the distances from the Sun at the perihelion and aphelion. Now do the same for Venus. How does the ellipticity relate to the variation between the perihelion and aphelion distances?
5. State Kepler’s 2nd Law.

Explore using the applet for Kepler’s 2nd Law. You can also use following link to explore the 2nd Law:

[http://highered.mcgraw-hill.com/sites/0072482621/student\_view0/interactives.html#](http://highered.mcgraw-hill.com/sites/0072482621/student_view0/interactives.html)

Scroll down to find Kepler’s 2nd Law. This site also has many other interactives which may be helpful during this activity.

1. State Kepler’s 3rd Law.
2. Kepler’s 3rd Law can be written in the following simple form:

**P2 = a3**

where P is in years and “a” is in a.u. This equation only works for objects which are orbiting the Sun.

Using the above formula and the information from the table you printed, calculate the semi-major axes of the two asteroids Pallas and Ceres.

Their orbits are thus between the orbits of which planets? (This is where almost all asteroids are – in the Asteroid Belt)

1. Now calculate the cubes of the semi-major axes and the squares of the orbital periods of the planets listed in the table and fill in those spaces in the table.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Object Name | Semi-major Axis (a.u.) | Orbital Period (years) | a3 | P2 |
| Mercury | 0.39 | 0.24 |  |  |
| Earth | 1 | 1 |  |  |
| Jupiter | 5.2 | 11.88 |  |  |
| Neptune | 30.06 | 164.82 |  |  |

1. Using Excel plot P2 on the x-axis and a3 on the y-axis for the planets in the table above. Describe the general trend of the points you plotted. Does this plot demonstrate a linear relationship? (Turn this graph in with your lab on Monday)
2. This question uses the 1st applet on the Kepler’s 3rd Law page. Set the orbits tab to “All Orbits” and chose the 3 month time increment. Now find out how many orbits Jupiter completes in the time it takes Saturn to do one orbit. What did you find? Does your answer make sense given the above table?
3. Using the same applet, play with the viewing angle and zoom until you can clearly see the tilts of the orbits for all bodies from Mercury to Eris. Which two bodies in the applet have the greatest tilts?
4. An important application of Newton’s generalization of Kepler’s 3rd law is being able to determine the mass of a central body based on the motion of a satellite around that body. In order to apply the following equation, the mass of the central body has to be much greater than whatever is orbiting it (this makes sense – think about the masses of the planets vs. the Sun’s mass).

M = a3/P2

Remember that “a” still has to be in AU, P in years, and then the mass, M, comes out in units of the Sun’s mass, or solar masses.

One of Jupiter’s moons, Europa, orbits Jupiter with a period of 3.6 days (0.01 years) with a semi-major axis of 0.004 a.u. Calculate the mass of the central body using the above equation (remember your units):

Now look at the mass you calculated. Does this seem plausible?

1. A current topic of great interest in astronomy is the search for extra-solar planets. There are now more extra-solar planets known than there are planets in our Solar System! We will use the semi-major axes and periods of some extra-solar planets to determine the masses of their parent stars.

Go to the following link and look at the values for the extrasolar planets around the stars 51 Peg and 47 UMa.

<http://exoplanet.eu/catalog-all.php>

Calculate the masses of the stars, 51 Peg and 47 UMa the same way you calculated the mass of Jupiter above.

How do the masses of these stars compare to the mass of the Sun?

1. What is the definition of retrograde motion?
2. Why does Mars sometimes appear to move westward in the sky relative to the stars?
3. Explain how retrograde motion is the reason we refer to Venus sometimes as “the morning star” and sometimes as “the evening star” (although it’s not a star)? The retrograde motion applet might help (try viewing Venus from Earth with the Sun turned on).
4. Compared to Mars, how big a retrograde loop would you expect Neptune to exhibit?