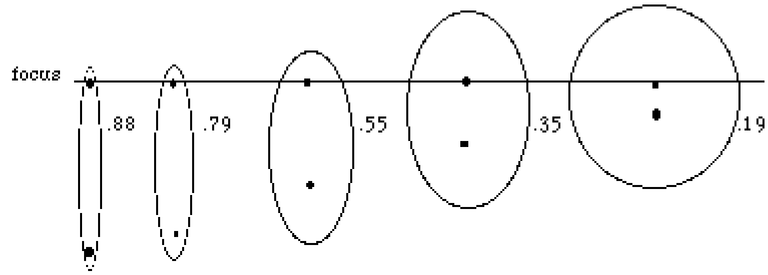
Honors Physics | Construct Planetary Orbits Around the Sun | Spring 2010

Kepler Activity 2

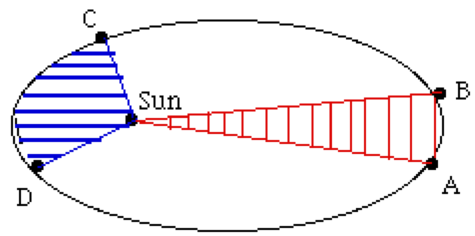
Name: ____________________

The eccentricity of an ellipse is a measure of its flatness. Numerically, it is the distance between the foci divided by the length of the major axis. The following is a series of ellipses having the same major axis but different eccentricities:



As the eccentricity approaches 1, the ellipse approaches a straight line. As the eccentricity approaches 0, the foci come closer together and the ellipse becomes more circular. A circle has an eccentricity of zero.

Kepler's second law states that a line from the planet to the Sun sweeps over equal areas in equal amounts of time. These areas in the ellipse are called sectors. In the following diagram, as the planet moves from point A to point B along its orbit, a long, skinny sector is created.



If we wanted to create a sector of equal area at points closer to the Sun (points C and D), the result is a short, fat sector. According to Kepler, the time it takes for the planet to get from A to B is equal to the time it takes the planet to get from C to D. This means that a planet orbits slower as it moves further from the Sun (conservation of angular momentum).

Kepler's third law deals with the length of time a planet takes to orbit the Sun, called the period of revolution. The law states that the square of the period of revolution is proportional to the cube of the planet's average distance to the sun:

$$\mathbf{T^2} \text{ (in Earth years) } \mathbf{= a^3} \text{ (in AU)}.$$

Because of the way a planet moves along its orbit, its average distance from the Sun is half of the long diameter of the elliptical orbit (the semimajor axis.) The period, **P**, is measured in years and the semimajor axis, **a**, is measured in astronomical units (AU), the average distance from the Earth to the Sun.

An example for using this formula would be to calculate how long it takes the near-Earth asteroid called Eros to orbit the Sun. The closest distance to the Sun that Eros orbits is 1.13 AU, and the farthest away from the Sun that it orbits is 1.78 AU. So, the average distance from Eros to the Sun, the semimajor axis, is (1.13 + 1.78)/2 = 1.46 AU. Substituting this in for **a** in the formula

T^2 and solving for **P** we see that it takes Eros about 1.76 years to orbit the Sun.

Kepler Activity 2

Materials:

Thumbtacks or pins, string, cardboard (21.5 cm x 28 cm), metric ruler, pencil, paper, calculator, and Java Applet.

Purpose:

In this activity student will learn how to make an ellipse using string and how varying the length of the string alters the shape of the ellipse. Students will also learn how characteristics of an ellipse relate to the orbits of the planets.

Procedure:

Part A

1. Place a blank sheet of paper on top of the cardboard and place two thumbtacks or pins about 3 cm apart.
2. Tie the string into a circle with a circumference of 15 to 20 cm. Loop the string around the thumbtacks. With someone holding the tacks or pins, place a pencil inside the loop and pull it taut.
3. Move the pen or pencil around the tacks, keeping the string taut, until you have completed a smooth, closed curve or an ellipse.
4. Repeat Steps 1 though 3 several times. First vary the distance between the tacks and then vary the circumference of the string. However, change only one of these each time. Note the effect on the size and shape of the ellipse with each of these changes.
5. Orbits are usually described in terms of eccentricity (e) The eccentricity of any ellipse is determined by dividing the distance (d) between the foci or tacks by the length of the major axis (L). Measure and record (d) and (L) for each ellipse you created.
6. Calculate and record the eccentricity of the ellipses that you constructed.

Part B

1. Refer to the chart of eccentricities of planetary orbits to construct an ellipse with the same eccentricity as Earth's orbit. Repeat Step 1 with the orbit of Pluto and Mercury.
2. Use Java applet, i.e. on-line

- Select proper eccentricity
- Select “start” and “area” to trace-out areas
- Stop and print-out
- Title: “which planet”
- Label the Sun, perihelion, and aphelion.
- Highlight and measure “L”. Calculate d and label the two foci.
- Attach all graphs

Data and Observations

Record Information from Part A:

Planet	Eccentricity
Mercury	0.21
Venus	0.01
Earth	0.02
Mars	0.09
Jupiter	0.05
Saturn	0.06
Uranus	0.05
Neptune	0.01
Pluto	0.25

Constructed ellipse	d (cm)	L (cm)	e (d/L)
#1			
#2			
#3			
Earth's orbit			
Mercury's orbit			
Pluto's orbit			

Analyze:

1. What effect does a change in the length of the string or the distance between the tacks have on the shape of the ellipse?

2. What must be done to the string or placement of tacks to decrease the eccentricity of the constructed ellipse?

Conclude and Apply

1) Describe the shape of Earth's orbit. Where is the Sun located within the orbit?

2) Name the planets that have the most eccentric orbits.

3) Using Kepler's third law and the (L) from your chart for Earth, Mercury, and Pluto. Calculate the period of revolution for these three planets. (Note: values are based (not scaled) on your measurements and not actual planetary data.)

4) Explain how perihelion and aphelion apply to the conservation of angular momentum.

5) If a planet has a semi-major axis *a* and eccentricity *e*, then the following hold for perihelion and aphelion: ph = $a(1-e)$ and ah = $a(1 + e)$

a) What would be the perihelion and aphelion positions of a theoretical planet that has a semi-major axis of 400 million km and an eccentricity of 0.5?

b) What is the average *a* value in km? If 150 million km = 1 AU, what is *a* in AU's?

c) Calculate the period, T for this planet to make 1-orbit around the Sun in years.

d) Given the following data: Neptune (a = 30.07 AU, T = 163.7 yr, e = 0.009) and Pluto (a = 39.48 AU, T = 248.0 yr, e = 0.249) show that Pluto is closer to the Sun at perihelion than Neptune is at any point in its orbit. This was a major factor in demoting Pluto from the status of "planet."