| **Introduction to Astronomy** | **Laboratory Exercise #2** |
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| Name ____________________________ | Date _______________ |
| Partners __________________________ | Section _____________ |

# Kepler's Laws

**Purpose:**
To develop familiarity with orbital paths as described by Kepler's Laws.

**Equipment:**

Scales Scissors Calculator

**Kepler's Laws**

**Law #1:**

Planets move in elliptical orbits with the Sun at one focus of the ellipse.

**Law #2:**

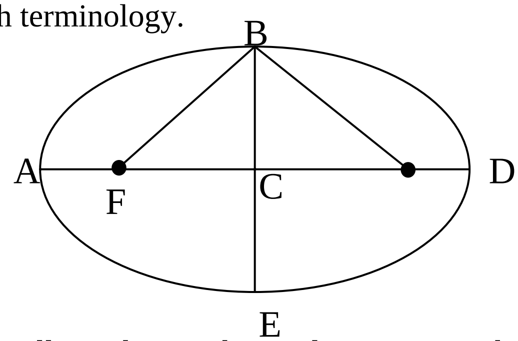
The orbital speed changes so that the planet sweeps out equal areas for equal time periods.

**Law #3:**

The time to make one orbit squared is equal to the semi-major axis cubed if the time is given in years and the semi-major axis is given in astronomical units.

These laws apply not only to planets, but also to any object that orbits another. This includes moons and satellites orbiting a planet.

This part of the exercise is to get you familiar with ellipses and the parameters that describe them. We will begin with terminology.




**Focus –** A pair of points within the ellipse that can be used to construct the ellipse. If a string is attached at the two focal points, an ellipse can be draw by stretching the string with a pencil and moving the pencil back and forth while keeping the string stretched.

**Major Axis –** The widest portion of the ellipse forms the major axis. In the diagram above it would be the line between points *A* and *D*. Half of this distance is the **semi-major axis**, which will be represented by the variable '*a*'.

**Minor Axis –** The narrowest portion of the ellipse forms the minor axis. In the diagram above it would be the line between points *B* and *E*. Half of this distance is the **semi-minor axis**, which will be represented by the variable '*b*'.

**Focal distance –** This is the distance from the center of the ellipse to the focal point along the major axis. In the diagram above it would be the line between points *C* and *F*. This distance will be represented by the variable '*c*'.

**Eccentricity –** This is a value used to indicate the flatness of the ellipse. It is the ratio *c/a*. For a perfect circle the two focal points are at the center of the circle. Therefore, $c = 0$ and the eccentricity is *0*. At the other extreme, the value of *c* could be nearly, but not quite equal to *a*. In this case the eccentricity is just a little less than *1*.

**Exercise:**
Attached to this lab are two plots of a fictitious asteroid named Cedarville-α. Its path around the sun was tracked and plotted at 10 day intervals. Answer the following questions.

1. From the graph determine the following values.

   **Semi-Major Axis:** **a = _________.**

   **Semi-Minor Axis:** **b = _________.**

   **Focal Distance:** **c = _________.**

   **Eccentricity:** **e = _________.**

2. For ellipses there is a relationship between *a*, *b* and *c*. It is given as follows

$$c^2 = a^2 - b^2$$

   Percent difference is given by the formula

$$\%diff = \left( \frac{c_{meas} - c_{calc}}{(c_{meas} + c_{calc})/2} \right) \times 100\%$$

   Calculate the value for *c* and compare to the measured value of *c* from question 1.

   **Calculated Value:** **c = _______________.**

   **Percent Difference:** **%diff = ___________.**

3. Verify Kepler's 2nd Law.

Take the second plot of the asteroid's path and detach it from the lab. Choose one position of the asteroid and connect it to the Sun by drawing a straight line. Choose a second position which is 30 days later in the orbit and connect it to the sun. Shade in the area and count the squares. Repeat this 3 more times at other locations within the ellipse. Record the number of squares below.

**$A_1$ = ________. $A_2$ = _______. $A_3$ = _______. $A_4$ = _______.**

An alternate means of comparing the area is to cut out the areas and measure their mass on a scales. For each of the areas shaded in above cut them out and measure the mass of the piece of paper.

**$A_1$ = ________. $A_2$ = _______. $A_3$ = _______. $A_4$ = _______.**

**Question: Are the areas measured by the two methods the same? Which method do you feel is more accurate and why?**

4. Verify Kepler's 3rd Law.

From the plot of the asteroid determine the orbital period. Convert this period into years.

**Period in days:** **P = _________.**

**Period in years:** **P = _________.**

Each square on the grid has a side length of $1.25 \times 10^{10}$ m. Determine the length of the semi-major axis in terms of meters and in terms of astronomical units.

$$1 \text{ AU} = 1.5 \times 10^{11} \text{ m}$$

**Semi-major Axis in meters** **a = ________________.**

**Semi-major Axis in AU's** **a = ________________.**

Calculate $P^2$ and $a^3$ and compare the results.

**Period squared** **$P^2$ = ________.**

**Semi-major cubed** **$a^3$ = ________.**

**Question: Did this calculation verify Kepler's 3$^{rd}$ Law? What is the percentage difference between your two values? (Use the formula for percentage difference given previously in the lab.)**

5. Asteroid collision.

   Using the first plot of the asteroid's path, draw the path the earth would take around the sun. For this exercise assume the earth's orbit is circular and use a compass.

   **Question: Does the earth have to worry about a collision with this asteroid? If so, the chances of collision would be very low. What things can you think of would affect how probable a collision would be?**