NAME: ___________________________________ Date: _______________

LAB: KEPLER'S LAWS OF PLANETARY MOTION

Purpose: To understand Kepler's Laws describing the movements of planets in the solar system.

Background: In the 1500s, **Nicolaus Copernicus** challenged the **GEOCENTRIC** (earth-centered) model of the solar system that had been promoted and accepted by philosophers and astronomers such as Aristotle and Ptolemy for almost 2000 years. Copernicus described a **HELIOCENTRIC** (sun-centered) model of the solar system, which placed Earth and the other planets in circular orbits around the Sun. He proposed that all planets orbit in the same direction, but each planet orbits at a different speed and distance from the Sun. **Galileo Galilei's** observations made with his telescope in the early 1600s and the work of other astronomers eventually confirmed Copernicus' model.

Tycho Brahe, a 16th Century Danish astronomer, spent his life making detailed, precise observations of the positions of stars and planets. His apprentice, **Johannes Kepler**, explained Brahe's observations in mathematical terms and developed three laws of planetary motion. **Kepler's laws**, together with **Newton's Laws** of Inertia and Universal Gravitation, explain most planetary motion.

KEPLER'S FIRST LAW

Kepler's First Law, the **"Law of Ellipses"** states that all objects that orbit the Sun, including planets, asteroids and comets, follow elliptical paths. An ellipse is an oval-shaped geometric figure whose shape is determined by two points within the figure. Each point is called a "focus" (plural: foci). In the solar system, the Sun is at one focus of the orbit of each planet; the second focus is empty.

You will examine this by drawing 3 ellipses with foci that are different distances apart. (0.5 cm, 2 cm, and 4 cm)

Hypothesis:

Which ellipse will be most eccentric? ____________________________________

Why? ____

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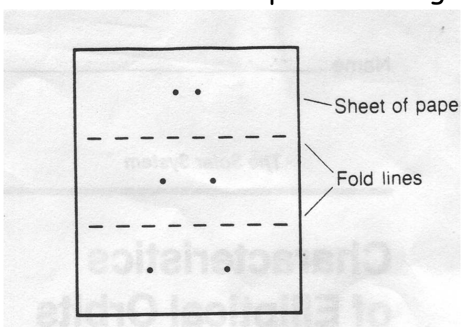
Procedure

1) If needed,tie the ends of the string into a loop about 6 - 7 cm across.

2) Fold the "drawings" paper in thirds, than flatten it out. The folds divide the paper into spaces where you will draw and compare 3 ellipses. Measure and mark two dots 0.5 cm apart in the center of the top third, mark two more 2 cm apart in the middle third, and in the bottom third, make two dots 4 cm. apart. See Figure 2.



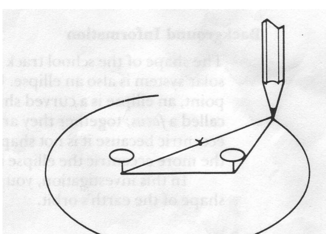


Figure 3

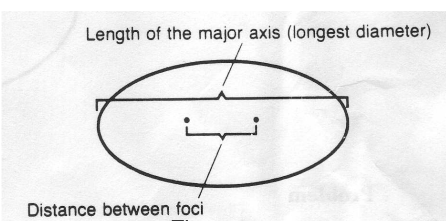


Figure 4

3) Put the paper over the cardboard, and push the thumbtacks into one set of points, far enough to be firm, but not flat against the paper. These are the ellipses foci. Put the string around the thumbtacks, and use the pencil inside it like a drawing pencil to draw an ellipse around the foci, pulling the string tight against the tacks. See Figure 4. Have one partner hold the tacks steady if needed.

4) Repeat step 3 for the other two sets of foci. It is OK if an ellipse goes off the paper at the top and bottom, as long as the major axis (across the tacks) is on the paper. Put some scrap paper down so you don't draw on the desk :)

5) Calculate Eccentricity ("out-of-roundness")
ECCENTRICITY is the amount of flattening of an ellipse, or how much the shape of the ellipse deviates from a perfect circle. A circle, which has only one central focus) has an eccentricity of 0. The greater the eccentricity, the less circular the ellipse.

a) Measure the distance between the thumbtacks for each ellipse. Put the data in the chart below. (a)

b) Draw a line across the foci to the edges of the ellipse. This is the major axis. Measure that. (b)

c) Calculate the eccentricity. (c) Eccentricity (e) = F ÷ A   It should be between 0 and 1. SHOW WORK IN THE DATA TABLE!

Why does elliptical eccentricity have no unit?

____

Ellipse	(a) Distance between foci (mm)	(b) Length of major axis (mm)	(c) Eccentricity: a/b SHOW WORK!	Which is roundest? Least round?
A				
B				
C				

6) Look at the Planet Data Table in your notes.

Which planet has the most elliptical orbit? ______________________________

Which planet has the most circular orbit? ______________________________

7) Because a planet's orbit is elliptical, its distance from the Sun varies throughout its "year" (one revolution around the Sun). Look up the following terms in your textbook (p. 29 of blue textbooks in the room or p.668 yellow textbook) and write their definitions in the spaces provided.

PERIHELION ____

APHELION ____

LABEL the points that represent perihelion and aphelion on the ellipse diagram on the front of this page.

8) Look up the following information in your notes/textbook and fill in the blanks.

Earth is at perihelion on __________________________; on that date, Earth is

approximately __________________________ km from the Sun.

Earth is at aphelion on __________________________; on that date, Earth is

approximately __________________________ km from the Sun.

9) Based on your understanding of Kepler's First Law, explain why the distance from a planet to the Sun is typically given as an <u>average distance</u>.

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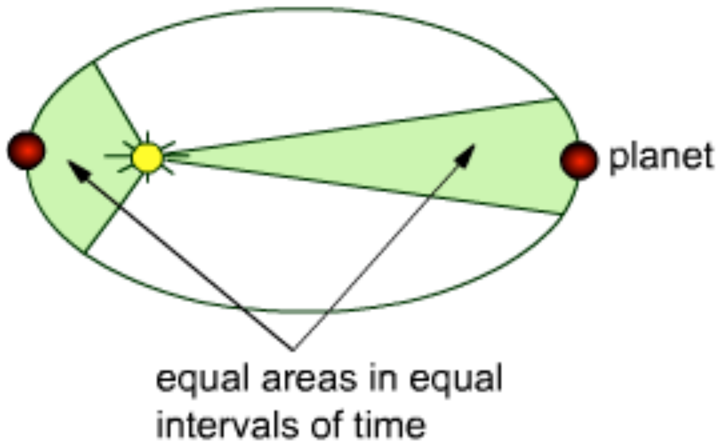
KEPLER'S SECOND LAW

Kepler's Second Law, the "Law of Equal Areas" states that a line drawn from the Sun to a planet sweeps equal areas in equal time, as illustrated on the diagram on the next page. A planet's orbital velocity (the speed at which it travels around the Sun) changes as its position in its orbit changes. Its velocity is fastest when it is closest to the Sun and slowest when it is farthest from the sun.



http://library.thinkquest.org/03oct/02144/pics/basics/kepler2.png

1) If Area X = Area Y on the diagram above, what can be inferred about the orbital velocities as the planet travels along its orbit through Area X compared to Area Y? (Which is faster?)

____

____

2) A planet's orbital velocity is fastest at the position it its orbit called ___________________ (perihelion/aphelion). Look back to your notes for the date when Earth is at this position. During what season (in the Northern Hemisphere) is Earth at this position? ____________________________

Therefore, Earth moves _________________________ (faster/slower) in summer than in winter, so summer in the Northern Hemisphere must be ____________________________ (longer/shorter) than winter.

3) Isaac Newton later determined that the force of GRAVITY holds the planets in orbit around the Sun. When a planet is closer to the Sun, the force of the Sun's gravitational attraction on the planet is __________________________ (stronger/weaker) than when the planet is farther from the Sun.

KEPLER'S THIRD LAW

Kepler's Third Law, the "Law of Periods" relates a planet's period of revolution (the time it takes to complete one orbit of the Sun) to its average distance from the Sun. Kepler determined the mathematical relationship between period and distance and concluded that the square of a planet's period is proportional to the cube of its mean distance from the Sun. The formula used to determine this relationship for any planet is: $T^2 = R^3$, where T is the planet's period in Earth years and R is the planet's mean distance from the Sun in astronomical units (AU, where 1 AU equals the mean distance from the Earth to the Sun = 150 million km).

Sample Problem: Planet X has an average distance from the Sun of 1.76 AU.
What is the planet's period of revolution, in Earth years?

$T^2 = R^3$

$T^2 = (1.76)^3 = 5.45$

$T = \sqrt{5.45} = 2.33$ Earth years

1) Calculate the period of revolution of each of the following planets.

Planet	Mean Distance to Sun (AU)	Period of Revolution (Earth years)
Mercury	0.387	
Mars	1.524	
Saturn	9.539	
Pluto	39.440	

2) Haley's comet has an average distance of 17.91 AU from the Sun. Calculate the period of Haley's comet. SHOW YOUR WORK BELOW!

3) Draw a graph that shows the relationship between a planet's period of revolution in Earth years (some planets will need to be converted from days to years) and its average distance from the Sun (in AU). Look up the data on the Planet Data Table in your notes. Plot period on the x-axis and distance on the y-axis. Label each planet on the graph. Be sure to label the axes and include a title.
Describe the graph. What is the relationship between period and distance from the Sun?