Kepler’s Laws of Planetary Motion

Purpose:
The purpose of this activity is to become more familiar with Kepler’s Laws of Planetary Motion. This activity has been modified from the Genesis Mission Search for Origins Education series.

Materials:
• Cardboard
• Pencil
• 2 Push Pins
• Cotton Twine
• Ruler
• Plain paper

Part 1: Drawing and Ellipse and Calculating Eccentricity: Kepler’s First Law of Planetary Motion

1. Gather a piece of cardboard, two push pins, and a piece of string about 25 centimeters long. Tie your string in a loop.

2. Place your paper on the cardboard and put your push pins in the middle of the page length wise. The push pins should be about 10 centimeters apart. (Each partner must do this)

3. Put your loop of string over the ends of the push pins. Draw the loop tight with the tip of your pencil and form a triangle with your string. Keep the loop tight and draw an ellipse.

4. Remove the string and push pins from your paper.

5. Label each hole made by the push pins “focus 1” and “focus 2”.

6. Chose one of the foci and label it “Sun.” Choose a place on the outline of your ellipse and place a dot there. label the dot with a planet name of your choice.

7. Find the point on the outline of the ellipse that is closest to the dot that you made the Sun. Label this point “Perihelion.”

8. Find the point on the outline of the ellipse that is farthest from the dot that you made the Sun. Label this point “Aphelion.”

9. Put an “X” directly in the center of our ellipse exactly half way between the two foci.

10. Draw a line from the x to the dot that you denoted as the sun. Label this line as “c.”

11. Draw another line from the “X” through the focus that does not denote the Sun and all the way to the point that you denoted “Aphelion.” Label this line as “a.” In math, we call this line the “semi-major axis.” It is similar to the radius of a circle.

12. **Eccentricity** is the measurement of how stretched out an ellipse is. It ranges from zero to one. Zero is the eccentricity of a circle and one is the eccentricity of a straight line. Calculate the value of the eccentricity for the ellipse you drew by measuring the length of line “c” and measuring the length of line “a.” Calculate the eccentricity of the ellipse by taking “c” and dividing it by “a” using the following formula: \( e = \frac{c}{a} \). Show your work on your ellipse drawing.
13. On this same page, write down what you think this suggests about Kepler’s First Law.

14. Put this paper in your science notebook.

**Part 2: Calculating the Eccentricity of Planet Orbits**

1. Calculate the eccentricity of each planet by using the formula \( e = \frac{c}{a} \). Recreate this table in your notebook and fill in the values for \( e \).

<table>
<thead>
<tr>
<th>Planet</th>
<th>Distance from center of ellipse to focus in Astronomical Units (c)</th>
<th>Semi-Major Axis in Astronomical Units (a)</th>
<th>Eccentricity (e)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mercury</td>
<td>0.080</td>
<td>0.387</td>
<td></td>
</tr>
<tr>
<td>Venus</td>
<td>0.005</td>
<td>0.723</td>
<td></td>
</tr>
<tr>
<td>Earth</td>
<td>0.017</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>Mars</td>
<td>0.142</td>
<td>1.524</td>
<td></td>
</tr>
<tr>
<td>Jupiter</td>
<td>0.250</td>
<td>5.203</td>
<td></td>
</tr>
<tr>
<td>Saturn</td>
<td>0.534</td>
<td>9.540</td>
<td></td>
</tr>
<tr>
<td>Uranus</td>
<td>0.901</td>
<td>19.180</td>
<td></td>
</tr>
<tr>
<td>Neptune</td>
<td>0.271</td>
<td>30.060</td>
<td></td>
</tr>
<tr>
<td>Pluto (Dwarf Planet)</td>
<td>9.821</td>
<td>39.440</td>
<td></td>
</tr>
</tbody>
</table>

*Answer the following questions in complete sentences in your science notebook.*

2. Which of the planet’s orbits is the most eccentric? Assume that Pluto is still a planet for this question.

3. Which of the planet’s orbits is the least eccentric (closest to a circle’s eccentricity of zero)? Assume that Pluto is still a planet for this question.

4. Which two planets have the most similar eccentricity.

5. Which planet has an eccentricity most similar to Earth’s eccentricity?

6. The average eccentricity of the Moon’s orbit around the earth is 0.054900489. Would you say the eccentricity of the Moon’s orbit is low, medium, or high with respect to most of the planets’ orbits around the Sun?

7. How could the eccentricity of a planet’s orbit affect the amount of solar radiation it receives from the sun?

**Part 3: Kepler’s Second Law of Planetary Motion**

1. Look at the animation at the front of the classroom. How does the speed of all three planets’ orbits at perihelion compare to the speed of the planet’s orbit at aphelion? In your answer use the words “perihelion” and “aphelion” while answering in a complete sentences.
2. Look at the diagram below. Count the number of squares in sector 1 and in sector 2, then place this diagram and your count in your notebook.

Squares in Sector 1: ______________

Squares in Sector 2: ______________

3. What can you say about the number of squares in Sector 1 compared to the number of squares in Sector 2? What does the number of squares imply about each sector’s area?

4. If it takes the same amount of time for a planet to move from point A to point B as it does for a planet to move from point C to point D, then what must a planet do in terms of its speed in each sector? Speed equals distance over time. Note that the distance between A and B is shorter than the distance between C and D.

5. Based on what you have seen here, Kepler’s Second Law says that planets sweep out equal __________ in equal __________. To do this, planets __________ __________ when closer to the Sun and they __________ __________ when further from the Sun.

6. Earth’s perihelion is in January and its aphelion is in July. Why is this not the reason for the season on Earth? If it was, the Northern Hemisphere on Earth would be hotter in January and colder in July. Think about it.

**Part 4: Kepler’s Third Law of Planetary Motion**

<table>
<thead>
<tr>
<th>Planet</th>
<th>Mean Orbital Velocity and Mean Distance to the Sun</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean Orbit Velocity in km/s</td>
</tr>
<tr>
<td>Mean Orbit Velocity in km/s</td>
<td></td>
</tr>
<tr>
<td>Mean Distance to the Sun (a) in Astronomical Units (AU)</td>
<td></td>
</tr>
</tbody>
</table>

1. How does the distance from the Sun of a planet affect the planet’s orbital velocity? In other words, do planets that are farther from the Sun travel faster or do they travel slower?

2. Based on your response to number 1, what do you think Kepler’s Third Law of Planetary Motion say?