

Lab 3 – Kepler's Laws of Planetary Motion

ASTR 1010

Name:

Overview

In this activity you will investigate Kepler's three laws of planetary motion using the planets in the Solar System. You will also calculate orbital information about a comet.

Objectives

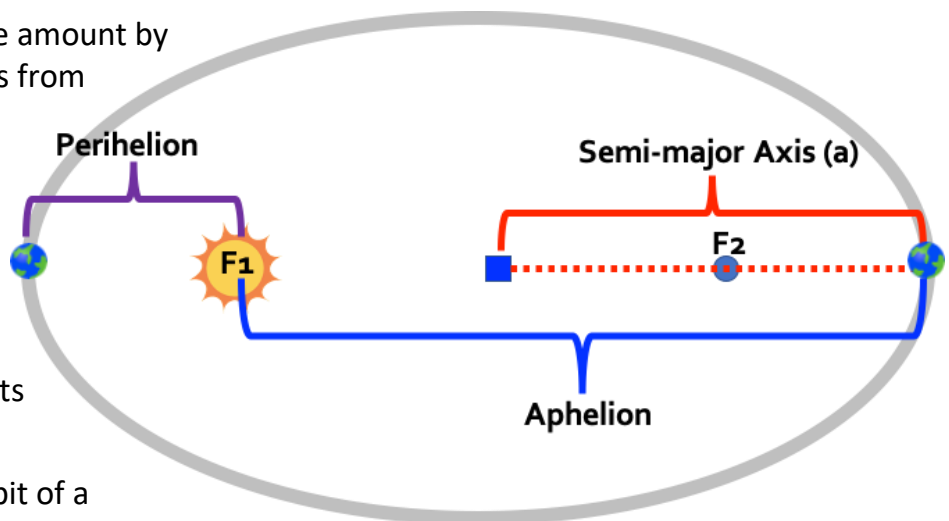
After completing this activity students will be able to:

- Describe how eccentricity influences the shape of an orbit.
- Investigate the orbital parameters of planets in the Solar System.
- Calculate the orbital periods of bodies in the Solar System.

Definitions

Here are some terms from lecture that we will be using today in lab:

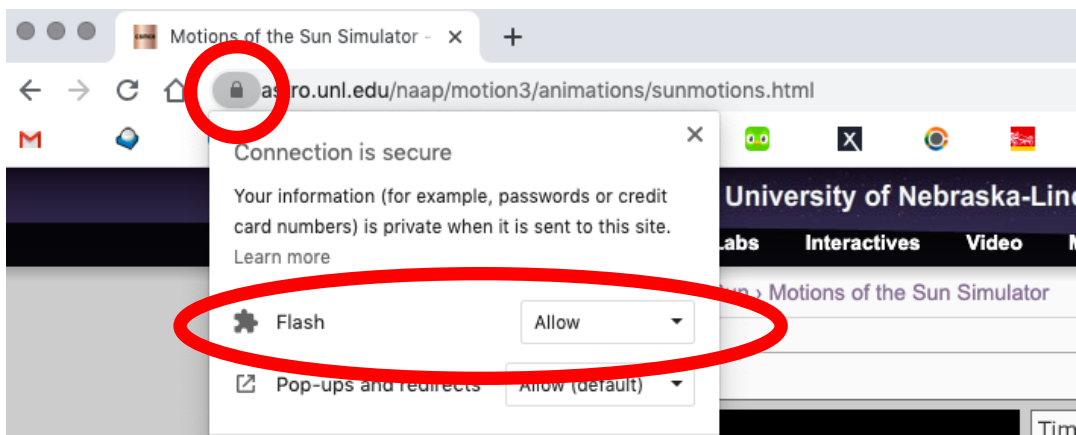
- **Kepler's First Law** – the orbit of each planet is an ellipse with the Sun at one focus.
- **Kepler's Second Law** – a line joining the planet and the Sun sweeps out equal areas during equal intervals of time → equal area = equal time.
- **Kepler's Third Law** – The square of the orbital period of a planet (P) in years is directly proportional to the cube of the semimajor axis (a) in AU of its orbit → $P^2 = a^3$
- **Eccentricity (e)** - measure of the amount by which an elliptical orbit deviates from a circle (e=0 is a perfect circle).
- **Semi-major axis (a)** - half of the major-axis length of an ellipse or elliptical orbit. Often given in units of AU or km. Approximately the same as the distance from the Sun for planets in the Solar System.
- **Perihelion** – the point in the orbit of a planet, asteroid, or comet at which it is closest to the Sun.
- **Aphelion** - the point in the orbit of a planet, asteroid, or comet at which it is furthest from the Sun.
- **Astronomical Unit (AU)** – mean distance between the Sun and the Earth. $1 \text{ AU} = 1.5 \times 10^8 \text{ km}$



For this activity you will be using the Planetary Orbits simulator from the University of Nebraska – Lincoln. The simulator shows an animation of a planet orbiting the Sun. You can adjust the parameters of the orbit yourself or use pre-set parameters for the planets in the Solar System. There are also various tools to help you understand Kepler’s laws. The simulator can be found here:

<https://astro.unl.edu/naap/pos/animations/kepler.html>

If the applet is not loading, please check that your Flash settings are set to “Allow”. In Chrome, you do this by clicking on the lock icon on your web browser’s address bar.



Note. Allowing Flash will vary depending on your web browser. If you are using a browser that is not Chrome, ask Google how to allow flash for your browser.

Part 1. Kepler’s First Law

The orbit of each planet is an ellipse with the Sun at one focus.

Applet setup: Click the “start animation” button and then click on the tab labeled “Kepler’s 1st Law” in the lower left of the window. Click on “show empty focus,” “show center,” and “show semimajor axis.” You can adjust the orbit’s eccentricity by sliding the “eccentricity” bar on the right side of the window.

1. Describe what happens to the shape of the ellipse when eccentricity gets larger.

2. Describe what happens when the eccentricity gets smaller.

3. Change the value of eccentricity until the orbit becomes circular in shape. What is the eccentricity of a circular orbit?

Let's examine the orbits of the planets. Be sure that the empty focus, center, and semi-major axis boxes are still turned on and then click "set parameters for" in the upper-right corner to select each planet in the Solar System. You must click "OK" to update the parameters.

Complete the eccentricity and semi-major axis columns in Table 1 below. You will need to click each planet one at a time to view their orbits. Note that the orbital periods will be calculated later in the lab activity. (Hint. It might be a good idea to put this info into an Excel sheet...)

Table 1. Planet eccentricities and semi-major axes

Planet	Eccentricity	Semi-major Axis (AU)
Mercury		
Venus		
Earth		
Mars		
Jupiter		
Saturn		
Uranus		
Neptune		

4. Which planet has the most circular orbit?

5. Which planet has the most elliptical orbit?

During Kepler's lifetime in the early 17th-century, only Mercury, Venus, Earth, Mars, Jupiter and Saturn were known planets. Tycho Brahe told Kepler that the data for the position of Mars were the most difficult to match using a circular orbit. Based on this information Kepler selected the orbit of Mars as the starting point to developing his first law of planetary motion.

6. Briefly discuss why the orbit of Mars was so difficult to reconcile with a circular orbit?

Before proceeding to the next part, click the “reset” button near the top right corner of the app to refresh the simulation display.

Part 2. Kepler’s Second Law

A line joining the planet and the Sun sweeps out equal areas during equal intervals of time.

Applet setup: Click “Kepler’s 2nd Law.” Notice that you can control how long a sweep lasts by adjusting the fractional sweep bar. The default value is a sweep for 1/16 of the orbital period. Click “start animation” and observe how the speed of the planet changes.

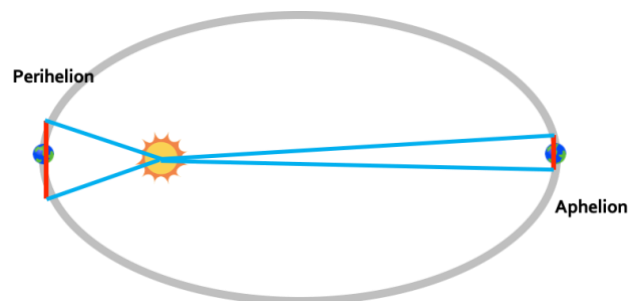
7. Describe how the orbital speed of the planet changes when it is near aphelion (which is the farthest point from the Sun).

8. Describe how the speed changes when it is near perihelion (which is the closest point to the Sun).

As you observe the planet approaching perihelion click the sweep button and the simulation will show you the area swept out by the line connecting the Sun to the planet (1/16 of the orbital period). Repeat this procedure when the planet approaches aphelion. Now sweep a random area as the third one.

9. Are these three areas the same or is one larger than others?

10. How does the shape of the area at perihelion compare to the shape of the area at aphelion? (Example using this cartoon orbit, compare the bases of the triangle (in red) and the legs connecting to the Sun (in blue). Now do this with the figure in the simulator!)



Before proceeding to the next part, click the “reset” button near the top right corner of the app to refresh the simulation display.

Part 3. Kepler’s Third Law

The square of the orbital period of a planet is directly proportional to the cube of the semimajor axis of its orbit.

The third law states that the amount of time it takes a planet to orbit the Sun is related to the planet’s average distance from the Sun. Mathematically, it can be approximated as

$$P^2 = a^3 \quad (\text{Equation 1})$$

Where P is the orbital period of the object **in years** and a is the semi-major axis of the object **in AU**.

Using Equation 1 and the semi-major axis values from Table 1, calculate the orbital period of each planet in Table 2. (Hint. Did you pick up on the first hint?)

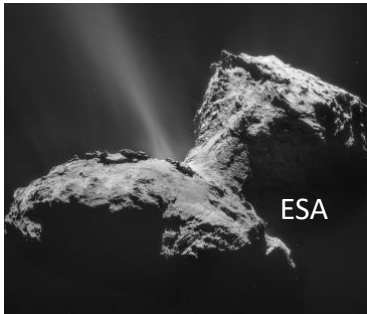
Table 2. Orbital Period of Planets

Planet	Orbital Period (years)
Mercury	
Venus	
Earth	
Mars	
Jupiter	
Saturn	
Uranus	
Neptune	

Part 4. Comet Orbits

Planets aren’t the only Solar System objects that follow Kepler’s Laws. Comets do too! Using what you have learned from Parts 1 and 3, let’s explore the orbits of two comets!

The first comet is 1P/Halley, aka Halley's Comet. The first confirmed recording of this comet was by Chinese astronomers in 240 BCE. It has an orbital eccentricity of 0.967 and a semi-major axis of 17.94 AU



The second comet is 67P/Churyumov-Gerasimenko. It was visited by the ESA spacecraft Rosetta and Philae (Rosetta's lander) became the first spacecraft to land on a comet's surface in November 2014! It has an orbital eccentricity of 0.632 and a semi-major axis of 3.51 AU.

11. Comparing the eccentricities of the comet, which comet has a higher eccentricity? Describe what the shape of that comet's orbit would look like.

12. Using Equation 1 and the semi-major axis values given above, calculate the orbital periods of the two comets:

1P/Halley

67P/Churyumov-Gerasimenko

13. Halley's Comet was last at perihelion in 1986. As a 'naked-eye' comet, when at perihelion it can be seen without the use of a telescope or any other instrument (which is awesome!). Using your answer from Question 12, what year do we expect the next opportunity to see Halley's comet with our unaided eye?