

Kepler's Laws

Learning Objectives:

- Understand the shapes of orbits and their dependence on eccentricity.
- Compare the shape of the Earth's orbit with that of other planets of the Solar System.
- Understand how planets move differently in different orbits.

Prerequisites:

- Read Chapter 3.3 of The Cosmic Perspective textbook carefully.

Lab Questions

These questions should be answered on D2L by selecting the "Kepler's Laws Lab Questions" quiz. They are worth 50% of the lab grade.

Part I - Kepler's 1st Law: "The orbit of a planet is an ellipse with the Sun at one of the two foci"

- If you have not already done so, launch the NAAP Planetary Orbit Simulator at:

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

- Open Kepler's 1st Law tab if it is not already open.
 - The white dot is the "simulated planet", the yellow dot represents the Sun. You can click on the planet and drag it around its orbit.
 - Change the eccentricity of the orbit by moving the slider around. Start with eccentricity = 0
1. Fill in the blanks: When the orbital eccentricity is 0, the shape of the orbit is a _____ and the sun is located at _____ of the orbit [1pt]
 2. Describe what happens to the shape of the orbit, and to the position of the Sun, when you increase the eccentricity. Does the Sun remain in the center of the orbit as the eccentricity increases? If not, then where is it located? [1pt]
- Using the presets in the upper right corner, select Mercury's orbit, and click OK. Mercury's eccentricity ($e=0.206$) is the largest of all the planets of the solar system.
3. How would you describe the shape of Mercury's orbit, by eye? Is it circular, close to circular, slightly elliptical, very elliptical? [1pt]
- Click "show center", "show empty focus" and "show radial lines". Then, move Mercury around its orbit, and notice how r_1 and r_2 change.

4. Fill in the blanks: r_1 is defined as the distance between _____ and _____. r_2 is defined as the distance between _____ and _____. [1pt]
- Start Mercury along its orbit by pressing “start animation”, and observe what happens to the value of r_1 .
5. How much does r_1 change over one orbital period? What is its minimum and maximum value? [1pt]

We call the position where the planet is furthest from the Sun (and r_1 therefore is at its maximum value) the **aphelion**, and the position where the planet is closest to the Sun (and r_1 is at a minimum) the **perihelion**.

6. Calculate the percentage difference between the distance at perihelion and aphelion for Mercury. Show your work. Based on your calculation, do you think this change in distance is significant? If so, in what way(s) do you think it might affect Mercury ? [W 2pts]

Hint: If you need help calculating percentage differences, see here: <https://www.mathsisfun.com/percentage-difference.html>

- Now, change the preset to **Earth**, and click OK.
7. How would you describe the shape of Earth's orbit, by eye? Is it circular, close to circular, slightly elliptical, very elliptical? [1pt]
 - Start Earth along its orbit by pressing “start animation”, and observe what happens to the value of r_1 .
 8. How much does r_1 change over one orbital period for the Earth? What is the Earth's distance at perihelion and aphelion? [1pt]
 9. Calculate the percentage difference between the perihelion and aphelion distance for the Earth. Show your work. Based on your calculation, do you think this change in distance will affect our planet? [W 2pts]

All planets in our solar system have orbits that are fairly close to circular. This is not always the case for exoplanets, planets orbiting other stars. From the systems we've discovered so far, eccentricities as high as $e=0.7$ seem common.

- Make a planet with a semi major axis of 1 AU and an eccentricity $=0.7$.
10. How far is this planet from its star at **perihelion**? [1pt]
 11. How far is this planet from its star at **aphelion**? [1pt]
 12. To an alien species living on such a planet, how much larger on the sky will the Sun appear at perihelion than at aphelion? Be quantitative, and justify your answer. [W 2pts]

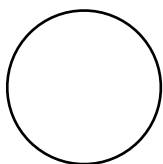
Part II - Kepler's 2nd Law: "A line segment joining a planet and the Sun sweeps out equal areas during equal intervals of time"

- Press the "reset" button on the upper right hand corner, and open the "Kepler's 2nd Law" tab.
 - This simulator lets you visualize the area a planet sweeps out as it orbits. Each different colored sweep corresponds to the same amount of time. You can adjust the time interval per sweep to be whatever you like.
 - For now, let's set the sweep time to one-twelfth of the planet's period, and let's slow the animation rate down to 0.083 yrs/s.
 - Change the eccentricity of the orbit back to 0. Click "sweep continuously", "use sound effect", and then click start sweeping and observe and listen carefully to what happens.
13. How many seconds does the planet take to sweep out each one of these triangles, approximately? [1pt]
- Pause the animation, "erase sweeps" and increase the eccentricity all the way to 0.7, but keep the semi-major axis equal to 1 AU. Then click "start sweeping" again.
14. The sweeps should now all look very different from before and also from each other, but some things have stayed the same. As the planet orbits around the star, what changes and what stays the same? [2pt]
15. Where is the planet relative to the Sun when the sweep segment is the "skinniest"? [1pt]
16. Where is the planet relative to the Sun when the sweep segment is the "fattest"? [1pt]
17. [W] As the sweeps get "fatter", does the planet speed up, slow down, or move at the same speed? Why is this, according to Kepler?

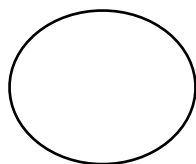
There are 17 questions in this lab. Answers to all 17 should be submitted through the D2L quiz.

Lab Exit Quiz

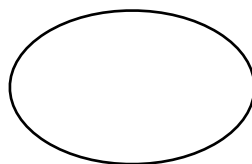
These questions need to be **answered separately** on D2L by clicking on "Kepler's Laws Lab Exit Quiz". They are worth 50% of your lab grade.



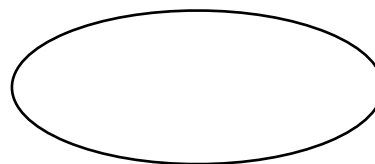
A



B



C



D

1. Consider four theoretical planets orbiting the Sun with the above shapes. Which planet will show the least variation in orbital speed as it revolves around the Sun?
2. Which of the orbits above (ABC or D) is most like the Earth's?
3. If the swept-out areas shown are equal, which segment of the orbit did the planet take the longest time to cover?

- (a) A
- (b) B
- (c) C
- (d) they all took the same time

4. During which of these segments was the planet slowing down the entire time (assume the planet is orbiting counter-clockwise)?

- (a) A
- (b) B
- (c) C
- (d) none
- (e) more than one

5. In chapter 2 you learned that the Earth is actually closest to the Sun when it is winter in the Northern Hemisphere. During which of these months will the Earth be moving the slowest?

- (a) April
- (b) July
- (c) October
- (d) January

