AST101: Our Corner of the Universe
Lab 4: Planetary Orbits

Name:

Student number (SUID):

Lab section number:

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1 Introduction

Objectives

The Planetary Orbits Lab reviews used the Planetary Orbit Simulator to review Kepler's laws of planetary motion.

Materials

Links to the simulation required for this lab are available at

`https://walterfreeman.github.io/ast101/lab4.html`

2 Background Material

Answer the following questions after reviewing the background page "Kepler's Laws and Planetary Motion."

We didn't give a precise definition of eccentricity in class; we said only that a more eccentric ellipse is "more stretched out" than a less eccentric one. Several of the items in this lab ask you to work with number values, though, so we need to define exactly what the eccentricity is.

The eccentricity of an ellipse is given by

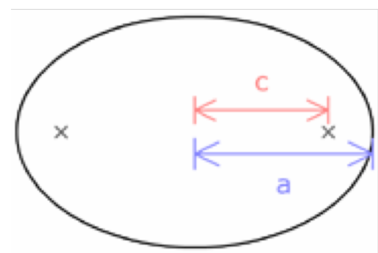
$$\text{(distance from center to focus)} \times \text{(semimajor axis)}$$

You can explore this in the *eccentricity demonstrator*, at `http://astro.unl.edu/naap/pos/animations/ellipsedemo.swf`.

Question 1. Draw an arrow connecting each law on the left with a consequence of that law on the right.

Kepler's 1st Law	Planets move faster when closer to the Sun
Kepler's 2nd Law	Planets with large orbits take a long time to orbit the Sun
Kepler's 3rd Law	Planets orbit the sun on elliptical paths

Question 2. The ellipse to the right has an eccentricity of about



(a) 0.25
(b) 0.5
(c) 0.75
(d) 0.9

Question 3. For a planet in an elliptical orbit to "sweep out equal areas in equal amounts of time" it must

(a) move slowest when near the sun
(b) move fastest when near the sun
(c) move at the same speed at all times
(d) have a perfectly circular orbit

Question 4. Which of the following is not part of Kepler's contribution to planetary orbits?

(a) shapes of the orbit
(b) speeds of planets in their orbit
(c) orbital period
(d) how gravity determines the way planets orbit

3 Kepler's First Law

If you have not already done so, launch the NAAP Planetary Orbit Simulator.

- Open the Keplers 1st Law tab if it is not already (its open by default).
- Enable all 5 check boxes.
- The white dot is the "simulated planet." One can click on it and drag it around.
- Change the size of the orbit with the semimajor axis slider. Note how the background grid indicates change in scale while the displayed orbit size remains the same.
- Change the eccentricity and note how it affects the shape of the orbit.
- You can change the value of a slider by clicking on the slider bar or by entering a number in the value box.

Be aware that the ranges of several parameters are limited by practical issues that occur when creating a simulator rather than any true physical limitations. We have limited the semi-major axis to 50 AU since that covers most of the objects in which we are interested in our solar system and have limited eccentricity to 0.7 since the ellipses would be hard to fit on the screen for larger values. Note that the semi-major axis is aligned horizontally for all elliptical orbits created in this simulator, where they are randomly aligned in our solar system.

- Animate the simulated planet. You may need to increase the animation rate for very large orbits or decrease it for small ones.
- The planetary presets set the simulated planets parameters to those like our solar systems planets. Explore these options.

Question 5. For what eccentricity is the secondary focus (which is usually empty) also located at the sun? What is the shape of this orbit?

Question 6. Create an orbit with $a = 20$ AU and $e = 0$. Drag the planet first to the far left of the ellipse and then to the far right. What are the values of r_1 and r_2 at these locations?

	r_1 AU	r_2 AU
Far Left		
Far Right		

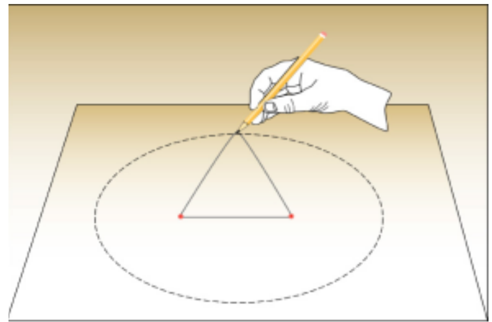
Question 7. Create an orbit with $a = 20$ AU and $e = 0.5$. Drag the planet first to the far left of the ellipse and then to the far right. What are the values of r_1 and r_2 at these locations?

	r_1 AU	r_2 AU
Far Left		
Far Right		

Question 8. For the orbit with $a = 20$ AU and $e = 0.5$, can you find a point in the orbit where r_1 and r_2 are equal? Sketch the ellipse, the location of this point, and r_1 and r_2 in the space below.

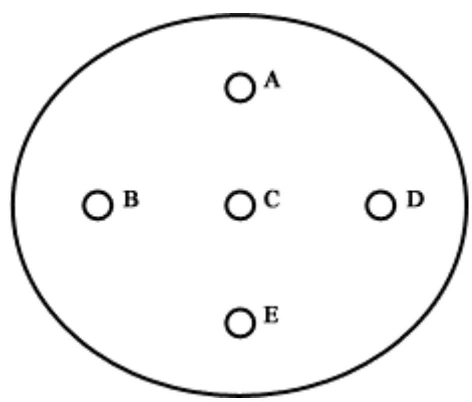
Question 9. What is the value of the sum of r_1 and r_2 and how does it relate to the ellipse properties? Is this true for all ellipses?

Question 10. As we saw in class, you can create an ellipse using a loop of string and two thumbtacks, replacing my string and magnets on the whiteboard. The string is first stretched over the thumbtacks which act as foci. The string is then pulled tight using the pencil which can then trace out the ellipse. Assume that you wish to draw an ellipse with a semi-major axis of $a = 20$ cm and $e = 0.5$. Using what you have learned earlier in this lab, what would be the appropriate distances for a) the separation of the thumbtacks and b) the length of the string? Please fully explain how you determine these values. This will require drawing a diagram of your ellipse and some careful diagram-drawing and length-labelling.



Question 11. Which point or points in the figure to the right is a focus of the ellipse?

(a) A, E
(b) C
(c) B, D
(d) B, C, D
(e) A, C, E



4 Kepler's Second Law

- Use the "clear optional features" button to remove the 1st Law features.
- Open the Kepler's 2nd Law tab.
- Press the "start sweeping" button. Adjust the semimajor axis and animation rate so that the planet moves at a reasonable speed.
- Adjust the size of the sweep using the "adjust size" slider.
- Click and drag the sweep segment around. Note how the shape of the sweep segment changes, but the area does not.
- Add more sweeps. Erase all sweeps with the "erase sweeps" button.
- The "sweep continuously" check box will cause sweeps to be created continuously when sweeping. Test this option.

Question 12. Erase all sweeps and create an ellipse with $a = 1$ AU and $e = 0$. Set the fractional sweep size to one-twelfth of the period. Drag the sweep segment around. Does its size or shape change?

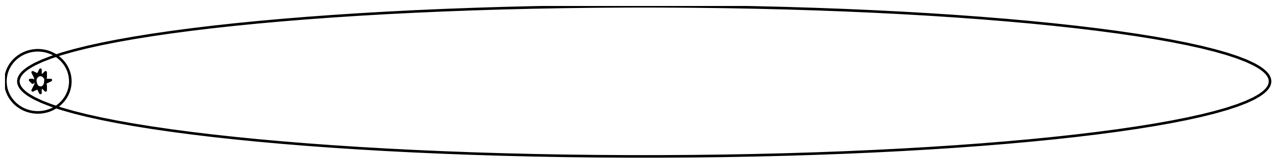
Question 13. Leave the semi-major axis at $a = 1$ AU and change the eccentricity to $e = 0.5$. Drag the sweep segment around and note that its size and shape change. What do you notice about the speed of the planet when the sweep segment the "skinniest?" What do you notice about the speed of the planet when the sweep is the "fattest?" Where is the planet located relative to the sun when it is sweeping out each of these segments?

Question 14. What eccentricity in the simulator gives the greatest variation of sweep segment shape?

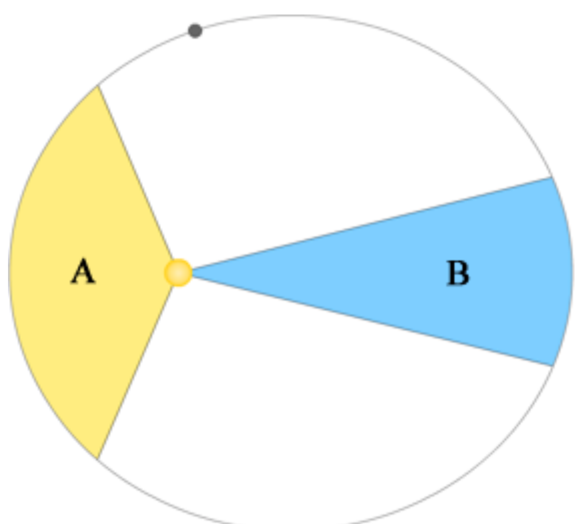
Question 15. The speed of a planet in orbit is

(a) constant
(b) always speeding up, but barely noticeable
(c) always slowing down, but barely noticeable
(d) sometimes speeding up and sometimes slowing down

Question 16. Halley's comet has a semimajor axis of about 18.5 AU, a period of 76 years, and an eccentricity of about 0.97 (so Halley's orbit cannot be shown in this simulator.) The orbit of Halley's comet, the Earth's orbit, and the Sun are shown in the diagram below (not exactly to scale). Based upon what you know about Kepler's 2nd Law, and the fact that Halley's comet must be near the Sun to be seen, explain why we can only see the comet for about 6 months every orbit (76 years)?



Question 17. The areas in regions A and B are equal in size. Which of the following statements are true?



(a) The orbital path length subtended by region A is longer than that given by region B. Therefore it will take the planet longer to move through region A.
(b) The planet will cover the distances subtended by regions A and B in equal amounts of time because the planet moves faster through region A than region B.
(c) The planet will take longer to move through region B because it is moving slower in region B than it is in region A.

5 Kepler's Third Law

- Use the "clear optional features" button to remove the 2nd Law features.
- Open the Kepler's 3rd Law tab.

Question 18. Use the simulator to complete the table below.

Object	P (years)	a (AU)	e	P^2	a^3
Earth		1.00			
Mars		1.52			
Ceres		2.77	0.08		
Chiron	50.7		0.38		

Question 19. As the size of a planets orbit increases, what happens to its period?

Question 20. Start with the Earth's orbit and change the eccentricity to 0.6. Does changing the eccentricity change the period of the planet?

Question 21. If a planet has an orbital radius four times Earth's, what will its period be?

(a) half as large
(b) the same
(c) four times as much
(d) eight times as much
(e) none of the above