Name: _____

Planetary Orbit Simulator – Student Guide

Background Material

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

Question 1: Draw a line connecting each law on the left with a description of it on the right.

(Kepler's 1ˢᵗ Law)

(only a force acting on an object can change its motion)

(Kepler's 2ⁿᵈ Law)

(planets move faster when close to the sun)

(Kepler's 3ʳᵈ Law)

(planets orbit the sun in elliptical paths)

(Newton's 1ˢᵗ Law)

(planets with large orbits take a long time to complete an orbit)

Question 2: When written as $P^2 = a^3$ Kepler's 3rd Law (with P in years and a in AU) is applicable to …

   a) any object orbiting our sun.

   b) any object orbiting any star.

   c) any object orbiting any other object.

Question 3: The ellipse to the right has an eccentricity of about …

   a) 0.25

   b) 0.5

   c) 0.75

   d) 0.9
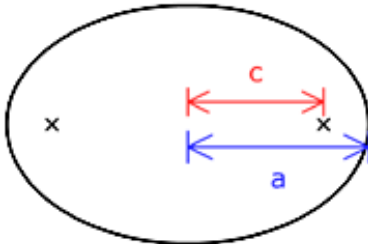
Question 4: For a planet in an elliptical orbit to "sweep out equal areas in equal amounts of time" it must …

   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 5: If a planet is twice as far from the sun at aphelion than at perihelion, then the strength of the gravitational force at aphelion will be _____ as it is at perihelion.

    a) four times as much

    b) twice as much

    c) the same

    d) one half as much

    e) one quarter as much

Kepler's 1st Law

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

- Open the Kepler's 1st Law tab if it is not already (it's open by default).

- Enable all 5 check boxes.

- The white dot is the "simulated planet". One can click on it and drag it around.

> **Tip:** You can change the value of a slider by clicking on the slider bar or by entering a number in the value box.

- 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.

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 planet's parameters to those like our solar system's planets. Explore these options.

Question 6: For what eccentricity is the secondary focus (which is usually empty) located at the sun? What is the shape of this orbit? _____

_____

Question 7: 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 8: 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 9: For the ellipse 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 10: 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 11: It is easy to create an ellipse using a loop of string and two thumbtacks. 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.
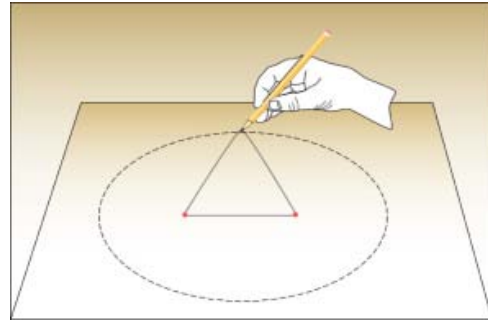
Assume that you wish to draw an ellipse with a semi-major axis of a = 20 cm and e = 0.5. Using what you have learned earlier in this lab, what would be the appropriate distances for a) the separation of the thumbtacks and b) the length of the string? Please fully explain how you determine these values.

_____

_____

_____

_____

_____

Kepler's 2nd 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. Where is
the sweep segment the "skinniest"? Where is it the "fattest"? Where is the planet when it
is sweeping out each of these segments? (What names do astronomers use for these
positions?) _____

_____

_____

_____

_____

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

_____

Question 15: 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, explain why we can only see the comet for about 6 months every orbit (76 years)?

_____

_____

_____

_____

_____
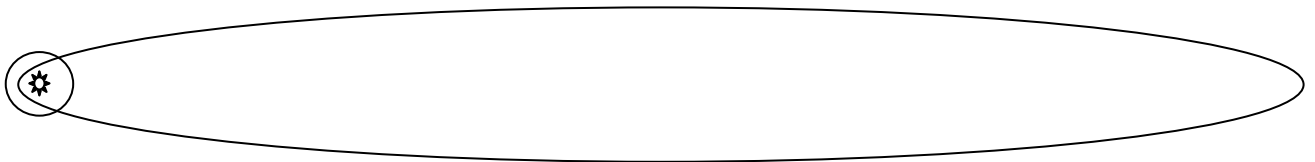
Kepler's 3rd Law

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

Question 16: 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 17: As the size of a planet's orbit increases, what happens to its period?_____

Question 18: Start with the Earth's orbit and change the eccentricity to 0.6.   Does changing the eccentricity change the period of the planet?_____

Newtonian Features

- **Important:** Use the "clear optional features" button to remove other features.
- Open the Newtonian features tab.
- Click both show vector boxes to show both the velocity and the acceleration of the planet.   Observe the direction and length of the arrows. The length is proportional to the values of the vector in the plot.

Question 19: The acceleration vector is always pointing towards what object in the simulator? _____

Question 20: Create an ellipse with a = 5 AU and e = 0.5. For each marked location on the plot below indicate a) whether the velocity is increasing or decreasing at the point in

the orbit (by circling the appropriate arrow) and b) the angle θ between the velocity and acceleration vectors. Note that one is completed for you.

| (↑) ↓ | θ = 61° |

| ↑ ↓ | θ = |

| ↑ ↓ | θ = |

| ↑ ↓ | θ = |

| ↑ ↓ | θ = |

| ↑ ↓ | θ = |

| ↑ ↓ | θ = |

| ↑ ↓ | θ = |
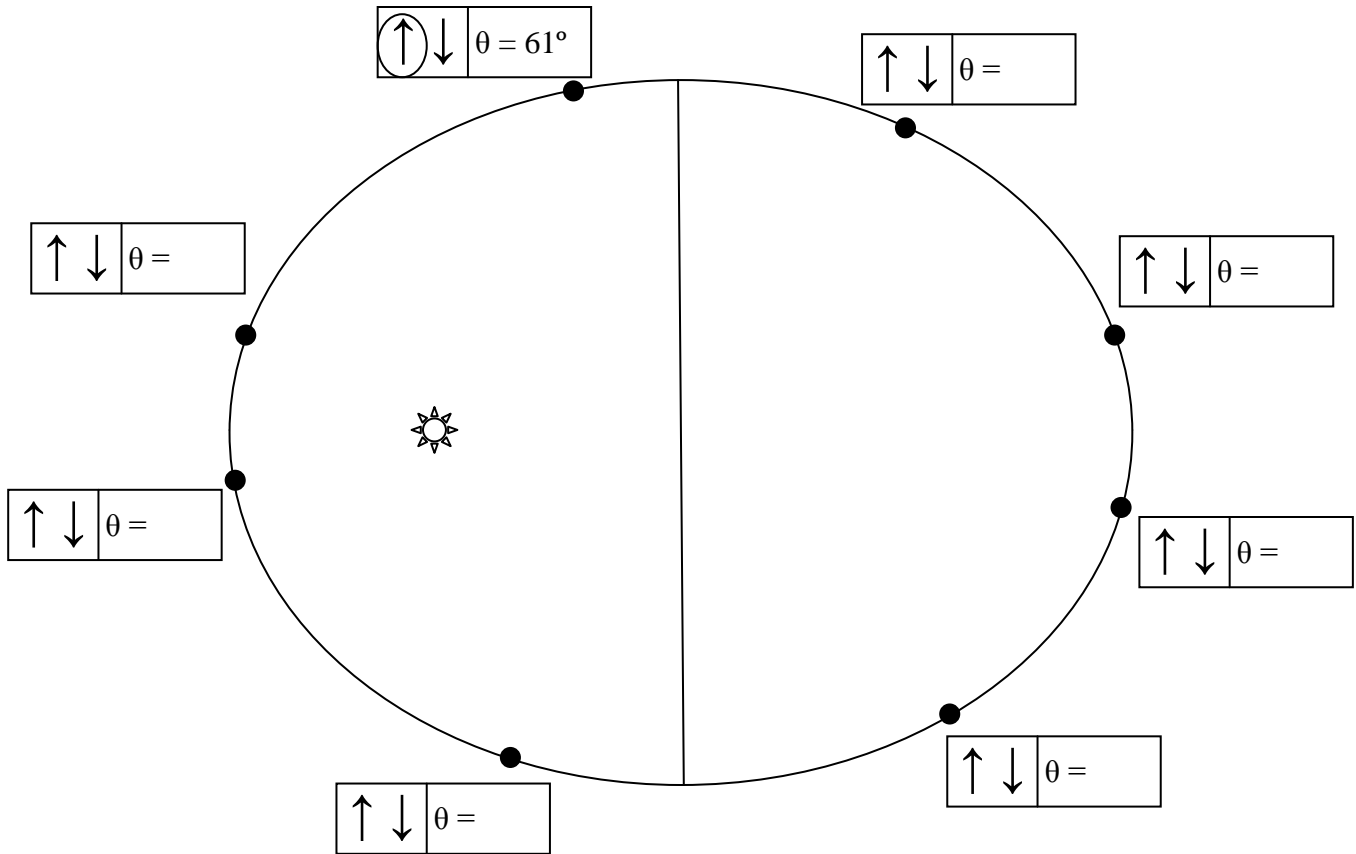
Question 21: Where do the maximum and minimum values of velocity occur in the orbit?

_____

_____

Question 22: Can you describe a general rule which identifies where in the orbit velocity is increasing and where it is decreasing? What is the angle between the velocity and acceleration vectors at these times? _____

_____

_____

_____

_____

Astronomers refer to planets in their orbits as "forever falling into the sun". There is an attractive gravitational force between the sun and a planet. By Newton's 3rd law it is equal in magnitude for both objects. However, because the planet is so much less massive than the sun, the resulting acceleration (from Newton's 2nd law) is much larger.

Acceleration is defined as the change in velocity – both of which are vector quantities. Thus, acceleration continually changes the magnitude and direction of velocity. As long as the angle between acceleration and velocity is less than 90°, the magnitude of velocity will increase. While Kepler's laws are largely descriptive of what planet's do, Newton's laws allow us to describe the nature of an orbit in fundamental physical laws!