

## My Solar System

Name \_\_\_\_\_ Period \_\_\_\_\_

**Introduction:** Every physics student has had a lot of experience with the force of gravity. Unfortunately, this experience is limited to the interaction between a very large object, the Earth, and much smaller objects that are very close to it. This is a very limited range of the possibilities. Software simulations of gravity allow physics students to explore a variety of other gravitational interactions between objects. These activities are designed to be used with the JAVA applet My Solar System that can be found on the Physics Education Technology (PhET) website at the University of Colorado at Boulder.

**Directions:** Go to the My Solar System simulation on the PhET website and carefully follow the instructions for each activity. Answer the questions and record your results before going on to the next activity. The simulation can be found at this URL:

<http://phet.colorado.edu/sims/my-solar-system/my-solar-system.swf>

**Activity 1:** Look over the start screen. The simulations controls and settings are on the right and simulation inputs are at the bottom. Click on Start to see the outputs in the center and lower right. The paths of the objects in the simulation are displayed along with elapsed time. Click Stop and move the cursor over each object. Its current position and velocity are displayed under the time. Click Start again and write down at least 2 observations about this simulation below.

**Activity 2:** Click the Show Grid box and make sure that System Centered and Show Traces are checked too. Drag the slider bar all the way to the left for the most accuracy. Click Reset, then change Body 1's mass to 500 and its x and y position and velocity to 0. Change Body 2's mass to 30, its x position to 200, and y position and x and y velocity to zero. Reset must always be clicked before changing position and velocity of the current simulation. Write down your prediction for the motion of both Bodies below before clicking Start to find out.

Body 1 (Yellow) motion:

Body 2 (Purple) motion:

Q1: Were your predictions correct? How many distance units does one square of the grid represent? Click and drag on the lower right corner of the window to make it 10 grids wide.

Q2: Change Body 2's mass to 0.001. Click Start again. What is different about the result? Why do you think this is?

Q3: What should be the direction of Body 2's initial velocity so that it doesn't ever hit Body 1?

Q4: Increase Body 2's y velocity by increments of 10 until it doesn't touch Body 1. At what velocity does this first happen? What is the shape of the resulting orbit?

Q5: Continue to increase Body 2's velocity until the orbit has a circular shape. Using the grid, adjust it by increments of 1 until it is as close to a perfect circle as you can get. What velocity resulted in a circle? Is the speed of Body 2 constant? Stop it as it crosses the grid on the opposite side and place the cursor over it to verify.

Q6: Is the velocity of Body 2 constant? Explain.

Activity 3: Draw a free-body diagram of Body 2 in its circular orbit below. Using Newton's Second Law, the Law of Gravity, and the equation for centripetal acceleration, derive an expression for the Universal Gravitational Constant, G. Using the values from the simulation, solve for the value of G used in the simulation. Show ALL of your work below. Verify your result with your teacher before going on. Note: This computer simulation does not use metric units. It uses units created by the programmer. Because of this it is acceptable to leave units off your answers for this lab.

G = \_\_\_\_\_

Q7: Use your equation from above to derive an equation for the speed of an object in a circular orbit. Using this equation and your value for G, solve for the speed required for a third body to be in a circular orbit with a radius of 100. Show all of your work and your final answer below.

Activity 4: Change the number of bodies to 3. Notice that the position and velocity for Body 1 and Body 2 changed when you clicked by the 3. Change them back, then set Body 3's mass to 0.001, its x position to 100, its y velocity to your value from Q7, and its y position and x velocity to 0. Using your equation from Q7, the fact that speed is the distance over time, and the equation for the circumference of a circle, derive an equation for the period of an object in a circular orbit. Show all of your work below.

Q8: Using your equation for period from above, predict the ratio of Body 2's period to Body 3's period? Use the simulation to verify your result. Show all of your work below. It is easier to measure the period if you click Stop just as a Body completes an orbit.

Activity 5: Add velocity to Body 3 in increments of 10 until it reaches a maximum radius of about 400 on the left side of its orbit. Change the velocity in increments of 1 until it is as close to 400 as you can get it. Write the velocity that achieved 400 below.

Q9: Click Reset and then Start and observe Body 3 carefully during the first half of its orbit. What happens to its distance from Body 1 as it travels this part of the orbit? What happens to its speed?

Q10: Click Reset and then Start and observe Body 3 carefully during the last half of its orbit. What happens to its distance from Body 1 (the Star) as it travels this part of the orbit? What happens to its speed?

Q11: The closest point in an orbit to the central body is known as the periapsis, the farthest is the apoapsis. Write down P (periapsis), A (apoapsis), or SAME for the location of each quantity listed below for body 3 in an elliptical orbit.

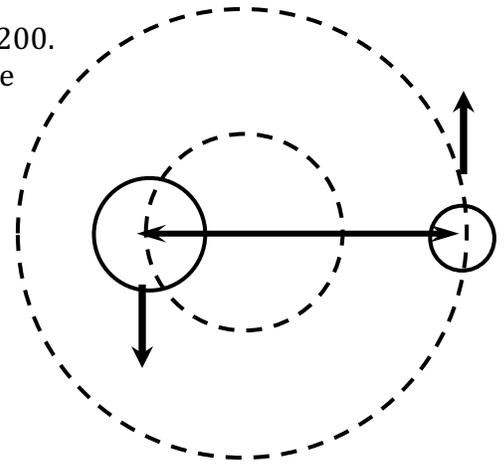
Max Velocity\_\_\_\_\_ Max Kinetic Energy\_\_\_\_\_ Max Potential Energy\_\_\_\_\_

Max Force\_\_\_\_\_ Max Angular Momentum\_\_\_\_\_ Max Total Energy\_\_\_\_\_

Q12: Use conservation of angular momentum and the equation for the angular momentum of a particle to predict the speed of Body 3 at apoapsis. Show all of your work below. Verify your prediction with the simulation by clicking Stop at apoapsis and placing the cursor over Body 3.

Activity 6: Select the "Sun and Planet" preset from the drop-down menu in the upper right. Click Start and observe the motion of Body 1. In this system the mass of the small body is not insignificant relative to the larger body. Both bodies orbit their common center of mass. In this activity we will set up a new 2-body system where each body orbits in a circle about the center of mass as shown in the figure at the top of the next page. The radius of each orbit is equal to the distance of that body to the center of mass. Body 1 will have a mass of 400 ( $m_1$ ) and Body 2 will

have a mass of 100 ( $m_2$ ). They will be separated by a distance of 200. Calculate the distance  $m_1$  is from the center of mass. This distance will be the radius of the smaller circular orbit shown at right. What is the radius of the larger orbit? Show all of your work below.



Q13: Each body will have the same circular orbit period. Knowing this, which body will have the greatest speed? Which body will have the greatest angular speed? Explain.

Draw a free-body diagram of  $m_1$  in its circular orbit below. Using Newton's Second Law, the Law of Gravity, and the equation for centripetal acceleration, derive an expression for the speed of  $m_1$ . Use your equation to calculate the speed of  $m_1$ . Show all of your work below. Hint: The quantity  $r$  used in the gravity equation is the distance between the 2 objects. The quantity  $r$  in the centripetal acceleration equation is the radius of the circle. These two quantities are NOT the same when the mass of body 2 is not insignificant.

Derive an equation for the speed of  $m_2$  using the same method used for  $m_1$ . Using this equation, calculate  $m_2$ 's speed. Show all of your work below. Set up this 2-body simulation using your center of mass and velocity calculations to verify your calculations. Refer to the figure at the top of the page.

Activity 7: Set body 1 mass to 500 and its x position to -400. Set y position and x and y velocity to 0. Set body 2 mass to .001 and its x position to -385 so it is just on the surface of body 1. Set its y position and y velocity to zero. Set its x velocity to 700. Write down your prediction for the motion of body 2 below before you click Start.

Q14: Was your prediction correct? Increase its x velocity in increments of 25. At what velocity does body 2 leave the screen?

There is a minimum velocity that will result in body 2 never returning. This is called escape velocity. Using the fact that an object on an escape trajectory has zero total energy, use conservation of energy to derive an equation for escape velocity for an initially stationary object. Use your equation to determine its x velocity so that it escapes body 1. Show your work below.

Activity 8: Conservation of energy can be used to predict the maximum separation of 2 objects moving apart with some initial velocity. Set body 1's mass to 500, its x position to 50, and its x velocity to 210. Set its y position and y velocity to zero. Set body 2's mass to 500, its x position to -50, and its x velocity to -210. Set its y position and y velocity to zero. Use conservation of energy to predict their greatest separation. Verify your prediction by clicking Start. Click Stop when body 1 and body 2 stop at their greatest separation. Use the cursor to read their x position. Show all of your work below.

Q15: What happens when body 1 and body 2 collide at the end of the simulation? What other (not energy) conservation principle explains this? Change body 1's mass to 550. Use this conservation principle to predict the velocity after body 1 and body 2 collide. **After un-checking the System Centered box**, use the simulation to verify your prediction. Show all of your work below.