Name________________________________ Section____________ Date__________

CONCEPTUAL PHYSICS: Hewitt/Baird | **Tech Lab**

Projectile and Satellite Motion | Orbital Mechanics Simulation

Worlds of Wonder

Purpose
To use a simulation to study the orbital mechanics of a simplified solar system

Apparatus
computer
PhET simulation: "My Solar System" (available at http://phet.colorado.edu)

Discussion
Lab activities involving stars and planets are difficult to conduct inside a classroom or laboratory. Since we cannot create stars and planets to experiment with in the classroom, we will use a computer simulation that uses the laws of gravity to show the behavior of large objects at great distances from one another.

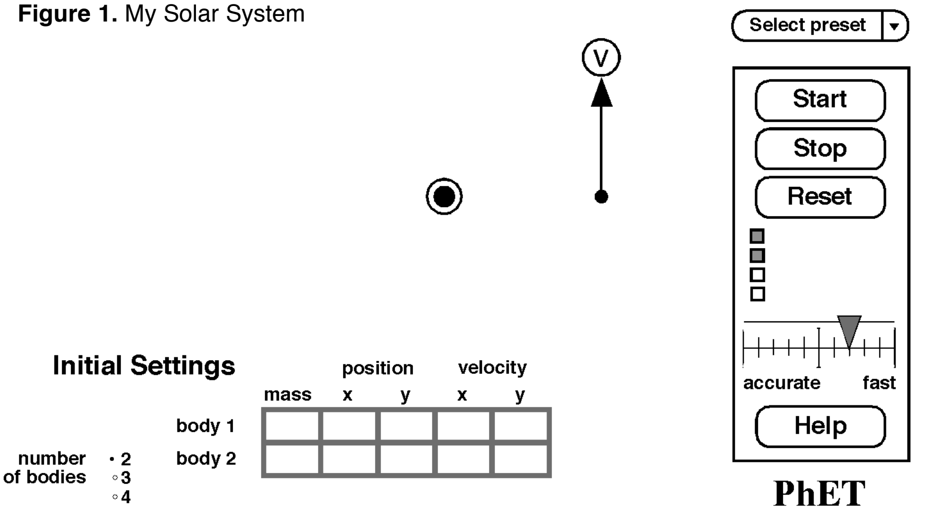
Procedure

SETUP
Step 1: Start the computer and let it complete its start-up process.

Step 2: Open the PhET simulation, "My Solar System." If you're not sure how to do this, ask your instructor for assistance.

Step 3: When the simulation opens, the screen should resemble the figure below.

Figure 1. My Solar System



PART A: NEWTON'S CANNON
Isaac Newton explained that universal gravitation accounted for both the fall of an apple and the orbit of the Moon. At the time, this was hard for people to understand. Newton used a thought experiment to how the same force could explain free fall and orbital motion. In this activity, you will simulate "Newton's Cannon."

Step 1: In the control panel on the right side of the screen, the checkboxes for System Centered and Show Tracks should be checked. Set the “accurate/fast” slider to the midpoint. Set the Initial Settings for Body 1 (yellow Sun) and Body 2 (pink planet) as follows.

a. **Body 1: mass = 200, position x = 0, position y = 0, velocity x = 0, velocity y = 0.**

b. **Body 2: mass = 1, position x = 0, position y = 100, velocity x = 0, velocity y = 0.**

Step 2: Click the on-screen Start button and record your observation .

Step 3: Click the on-screen Reset button to stop the simulation and restore the initial position and velocity settings.

Step 4: Change the initial **Velocity x** of Body 2 (the pink planet) to 40. Click the on-screen Start button and record your observation of what happens. How is it different from your previous observation?

Step 5: Click the on-screen Reset button to stop the simulation and restore the initial position and velocity settings. Change the initial **Velocity x** of the pink planet to 80. Click the on-screen Start button and record your observation.

Step 6: Click the on-screen Reset button. Change the initial **Velocity x** of the pink planet to 160. Click the on-screen Start button and record your observation of what happens. How is it different from your previous observation?

Step 7: Click the on-screen Reset button. Through trial and error, determine the minimum initial Velocity x that will allow the pink planet to orbit the yellow Sun. From your previous investigations, you know a speed of 40 is too small and an initial speed of 80 is more than enough. So your result will be between 40 and 80. Don’t worry if the animation shows the planet moving through the Sun. What is the minimum initial Velocity x that will allow the pink planet to orbit the yellow Sun at least ten times without crashing?

Step 8: Click the on-screen Reset button. On the control panel, click the Show Grid checkbox. Through trial and error, determine the correct initial Velocity x that will allow the pink planet to orbit the yellow Sun in a **circular** orbit. If the initial speed is too high or too low, the orbit will be elliptical. What speed is just right to allow a **circular** orbit?

PART B: HARMONY OF THE WORLDS

There is a mathematical relationship between the orbital radius and orbital speed of planets circling the Sun. German mathematician Johannes Kepler discovered this relationship. He started with volumes of astronomical data, worked through hundreds of pages of calculations, and spent approximately 30 years pursuing the discovery. In this activity, we'll use the simulation to generate data that will allow us to make the discovery in much less time.

Step 1: Find circular orbits for planets at various distances from the Sun. Start by setting the Position y of the pink planet at a distance of 50. This sets the orbital radius to 50.

Step 2: On the control panel, click to activate the Tape Measure.

Step 3: Click and drag the tape measure box icon until its crosshairs (+) are on the pink planet. Now click and drag the other end of the tape measure vertically downward, across the Sun, until it measures a distance of 100. Since you set the orbital radius to 50, the orbital diameter is 100. So the tape measure represents the diameter of the orbit.

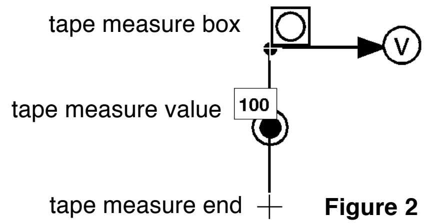


Figure 2

Step 4: Set the Velocity x of the pink planet to 150. Click the on-screen Start button and observe the orbit. Since the trace of the pink planet doesn't pass through the far end of the tape measure, the orbit is not circular.

Step 5: Click the on-screen Reset button. Try a different Velocity x for the pink planet. Through trial and error, keep trying until you find the speed that results in a circular orbit. The trace of the pink planet will pass through the far end of the tape measure when the orbit is circular. Record the Velocity x on the data table.

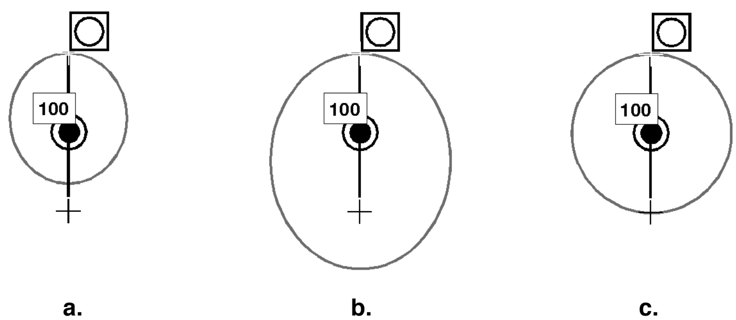


Figure 3

a. and b. Non-circular elliptical orbits c. Circular orbit

Step 6: Find circular orbits when the orbital radius is 100, 150, and 200 to complete the data table.

Data Table

Orbital Radius R (Position y)	Orbital Speed v (Velocity x)
50	
100	
150	
200	

More curriculum can be found in Pearson Addison Wesley's **Conceptual Physics Laboratory Manual: Activities · Experiments · Demonstrations · Tech Labs** by Paul G. Hewitt and Dean Baird. ISBN: 0321732480

Summing Up

PART A: NEWTON'S CANNON

1. A cannonball dropped from a cliff will fall straight down and hit the surface of the Earth. How could the cannonball be made to orbit the Earth, instead?

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2. Based on your experience with the simulation, which do you think is more common: *circular* orbits or non-circular *elliptical* orbits? Defend your answer.

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PART B: HARMONY OF THE WORLDS

3. Use the following method to determine the relationship between the orbital radius of a planet and the orbital speed of its circular orbit. For this activity, we'll limit our investigation to three possible relationships. They are as follows:

   Orbital radius is inversely proportional to orbital speed: $R \sim 1/v$.

   Orbital radius is inversely proportional to the square of orbital speed: $R \sim 1/v^2$.

   Orbital radius is inversely proportional to the square root of orbital speed: $R \sim 1/\sqrt{v}$.

   a. To see the pattern in the data, we need to simplify and process our data. First rewrite the orbital data on the table below.

R	v	R*	v*	1/v*	$1/v^{*2}$	$1/\sqrt{v^*}$
50		1.00	1.00	1.00	1.00	1.00
100		2.00				
150						
200						

   b. Divide each value in the Orbital Radius column by the first value in the Orbital Radius column (50). Record the results in the R* column of the table above. That is, the values in the R* column will be the results of the quotients 50/50, 100/50, 150/50, and 200/50.

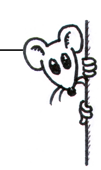
   c. Repeat this process using the Orbital Speed data to determine values of v*. That is, divide all values of Orbital Speed by the first value of orbital speed.

   d. Now complete the last three columns by performing the appropriate mathematical operations on the values in the v* column.

4. Select the column that best matches the R* column. Is it ___$1/v^*$, ___$1/v^{*2}$, or ___$1/\sqrt{v^*}$?

5. Complete the statement: Orbital radius is inversely proportional to the

____



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