

## Satellite Motion Labs

Purpose:

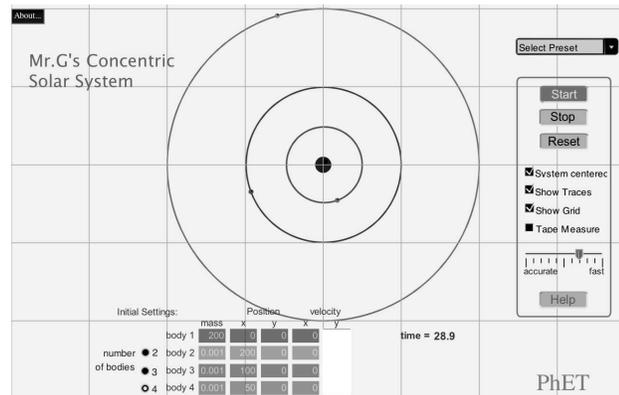
- To experiment with satellite motion using an interactive simulation.
- To gain understanding of Kepler's Laws of Satellite Motion and Newton's Synthesis.

Expectations:

- You are to create your own individual solar system. Do not use the work of others. You need the experiences gained in the experiments to understand the physics.
- Use the Internet to research Kepler's Laws and Newton's Synthesis.
- This lab should take at least an hour to complete out of class.

Materials:

- Computer with Internet access.  
Passes to the library can be requested.
- The applet needed can found at:  
[http://phet.colorado.edu/sims/my-solar-system/my-solar-system\\_en.html](http://phet.colorado.edu/sims/my-solar-system/my-solar-system_en.html)
- Google *phet "my-solar-system"* to save typing the link.



1. Circular Orbits: follow directions!
  - 1.1. Launch the my-solar-system applet.
  - 1.2. Select the show grid option.
  - 1.3. Set the number of bodies to four.
  - 1.4. Leave the mass of the central body at 200 units. Set the masses of the other bodies to 0.001. This will prevent the satellites from perturbing the orbits of other satellites too much.
  - 1.5. Adjust the radius of the outermost satellite so that is at the convenient intersection of a grid line.
  - 1.6. Adjust the parameters of the largest radius satellite until its orbit is as perfect a circle as possible. The grid will help you decide if the orbit is circular in all directions with respect to the central body. Use trial and error, but be systematic and observant about how changing the parameters affects the shape of ellipse. Random thoughtless guessing will waste too much time. There are patterns; find them and discuss them.
  - 1.7. Leave the other satellites alone for now.
  - 1.8. Take a screenshot for your lab book to document your work. Using Paint or Preview (PC or Mac) to title your work before final printing. Inverting the screenshot can save much ink or toner.
  - 1.9. Discuss how orbital velocity changes in an elliptical orbit and compare it with the velocities in a circular orbit. Connect your observations with Kepler's Second Law of Areas.
2. Determine the Universal Gravitational Constant (G)
  - 2.1. In the real world, G is  $6.67 \times 10^{-11} \text{ Nm}^2/\text{kg}^2$ . The programmer of this applet did not use this number. Computers are much quicker at computing with integers than very small numbers like G. To control this program and calculate orbits, the number the program uses for G in the simulation will have to be measured. This can be done using Newton's Synthesis.
  - 2.2. To solve Newton's Synthesis, start by setting the equation for force centripetal equal to the force of gravity equation:  $F_c = F_G$ . Substitute the respective formulas and solve the equation for G. Label one mass *star* and the other *planet*. It could also be planet with moons, or planet with satellites. Think carefully about which one cancels in the equation (if you are wrong, it will become apparent when your solar system does not work).
  - 2.3. Substitute your values from the *previous* circular orbit into the equation. If your orbit were perfectly circular, your result for G would come to an integer. Most likely, it will be close to an integer since you did not make your orbit perfect. Round to a whole integer for best results.

3. Testing G
  - 3.1. If your value for G is correct then you can control this simulated solar system. Start by solving Newton's Synthesis for velocity instead of G.
  - 3.2. Use the orbit equation to calculate the velocity the second satellite needs to have a circular orbit. Use the simulation value for G you previously calculated, not real G.
  - 3.3. Enter your calculated velocity for the second satellite into the simulation. If you are correct, the orbit should be perfectly circular on your first try. If not, find the error.
  
4. Create a solar system
  - 4.1. *Calculate* the circular orbital speed for the remaining satellite. Use the same method as in the previous experiment. No trial and error, it would take too long.
  - 4.2. Try out your solar system. It should produce three concentric orbits – like a bull's-eye. If not, something is wrong with your value of G or your calculations. Correct the mistake.
  - 4.3. Make adjustments to your system until you have stable concentric orbits. Print a titled screenshot for your lab report.
  
5. Kepler's Third Law: The Law of Harmony.
  - 5.1. Use the time counter in the applet to measure the period of each planet in your concentric circular solar system. Do your best to get as close to one orbit as possible. Report your percent uncertainty.
  - 5.2. Plot a graph of T vs. r using Graphical Analysis. Remove the connecting lines, and find a simple curve that fits the data.
  - 5.3. Kepler's Third Law states that the period squared is proportional to the radius cubed for a satellite. This means that if you square each period (create a new calculated column) and cube each radius (another new calculated column), the graph of  $T^2$  vs.  $r^3$  should be proportional and linear. Your data table should have four columns.
  - 5.4. Create a graph of period squared versus radius cubed. Calculate the slope of the linear trend.
  - 5.5. Discuss how the Law of Harmony is supported by your model solar system. Connect these observations to the graphs you made.
  
6. Perturbation
  - 6.1. In your earlier model, your working solar system had planets with masses of 0.001. This made the mass of the central star \_\_\_\_\_ times larger than any planet. Why did the instructions call for such tiny planets?
  - 6.2. What happens when one of planets is given a whole integer mass? Try increasing the mass of one of your planets until there are differences. Make observations and explanations.
  - 6.3. How does this experiment relate the orbits of the real planets in the solar system? How does it relate to the discovery of planet Neptune?
  
7. A-Level work (optional):
  - 7.1. There are a number of preset simulations that go beyond simple orbits. Choose an interesting one and make connections between it and real-life analogs of that simulation.

Write up the lab as five short sections. Make sure there is a conclusion for each section.