Name: ____________________

Date: ____________________

Section: ____________________

Astron 104 Laboratory #4
Gravity and Orbital Motion
Section 5.5, 5.6

Introduction

No astronomical object can stand still — gravity makes certain of this. Newton's Law of Universal Gravitation tells us that any two bodies attract each other by their mutual gravitational force. Every object in the Universe moves in response to the pull of gravity: moons orbit planets, planets and comets orbit stars, stars follow orbits through their galaxy, galaxies orbit each other in giant galaxy clusters. In this lab, you will use a gravity simulator to investigate orbital motion and Kepler's Laws.

Learning Objectives

At the completion of this lab, you should be able to:

1. Explain what we mean by "down" in terms of gravity
2. Describe the role of mass in gravitational acceleration
3. Describe the variations in orbital speed with position in the orbit
4. Describe the patter of orbital speed with semimajor axis length
5. Construct a plot comparing speed and semimajor axis for an orbit

Gravity [30 pts total]

Open the PhET *My Solar System* program[1] and verify that the following boxes are checked:

- System Centered

[1] Available at `http://phet.colorado.edu/sims/my-solar-system/my-solar-system_en.html`.

- Show Traces
- Show Grid

Set the slider to the middle (between Accurate and Fast). Set the number of bodies to 2. Set the masses to "200" for Body 1 and "1" for Body 2. Place Body 1 at $(x, y) = (0, 0)$ and Body 2 at $(200, 0)$. Now we're ready to test it out!

1. What do you predict will happen if we just release Body 2 from rest (set all velocities to 0 in both x and y directions? [**5 pts**]

2. Test your prediction by setting the velocities to 0 for both Bodies and pressing *Start*. Briefly describe the motions of the Bodies. [**5 pts**]

3. Reset the mass of Body 1 to "20" and repeat the experiment. Try it again with the mass of Body 1 set to "2." Describe the motions of the two bodies in these tests. Do both objects move? Do they move the same amount? [**5 pts**]

4. Compare these three tests. As you change the mass of Body 1, what changes about the motion of the two bodies? Does the strength of the gravitational attraction between the bodies depend on their masses? [**5 pts**]

5. Predict what would happen if you repeat the experiment, but increase the mass of Body 2 while leaving Body 1 at 200. Test your prediction! [**5 pts**]

6. If you think about it, you have performed this experiment in real life: releasing a small object (a ball, for example) at rest near a large object (Earth!). Usually we call this "dropping" something.
   Set Body 1 at mass 500 (Earth), Body 2 at mass 0.01 (ball) and 0 velocity for both. You can use the mouse to drag the ball around the grid. Try a few experiments placing the ball at different locations and release it by pressing *Start*. Based on your experiments, what direction does a ball fall if we "drop" it? (In other words, how does gravity influence what we mean by "down?") **[5 pts]**

Orbiting [30 pts total]

We could imagine a scenario where the two bodies are a star and a planet. Typically, the mass of the star s much larger, so let's use 200 for the star and 1 for the planet. Let's start with the star at $(x, y) = (0, 0)$ and the planet at $(100, 0)$.

1. Clearly from your earlier experiments, a motionless planet will fall toward a star. What if the planet is in motion: will it still fall? Try adding a positive velocity in the x direction, say 150 units, and press *Start*. Describe the resulting motion of the planet. **[5 pts]**

2. Will adding enough velocity in the x direction eventually make the planet simply leave? Try it, and describe what happens. **[5 pts]**

3. The other way to avoid falling into a star is **orbiting** the star. Set the planet's x velocity to 0 and the y velocity to 10. What happens? **[5 pts]**

4. Increase the y velocity, multiplying by two each time, until the planet misses the star. Now you have an orbit! What is the minimum y velocity you need? Describe the shape of the orbit. [**5 pts**]

5. Now, keep increasing the y velocity until the planet follows a circular orbit (you can tell from the grid: the planet should pass through the the point $(-100, 0)$ on the other side of the star). What y velocity gives a circular orbit? [**10 pts**]

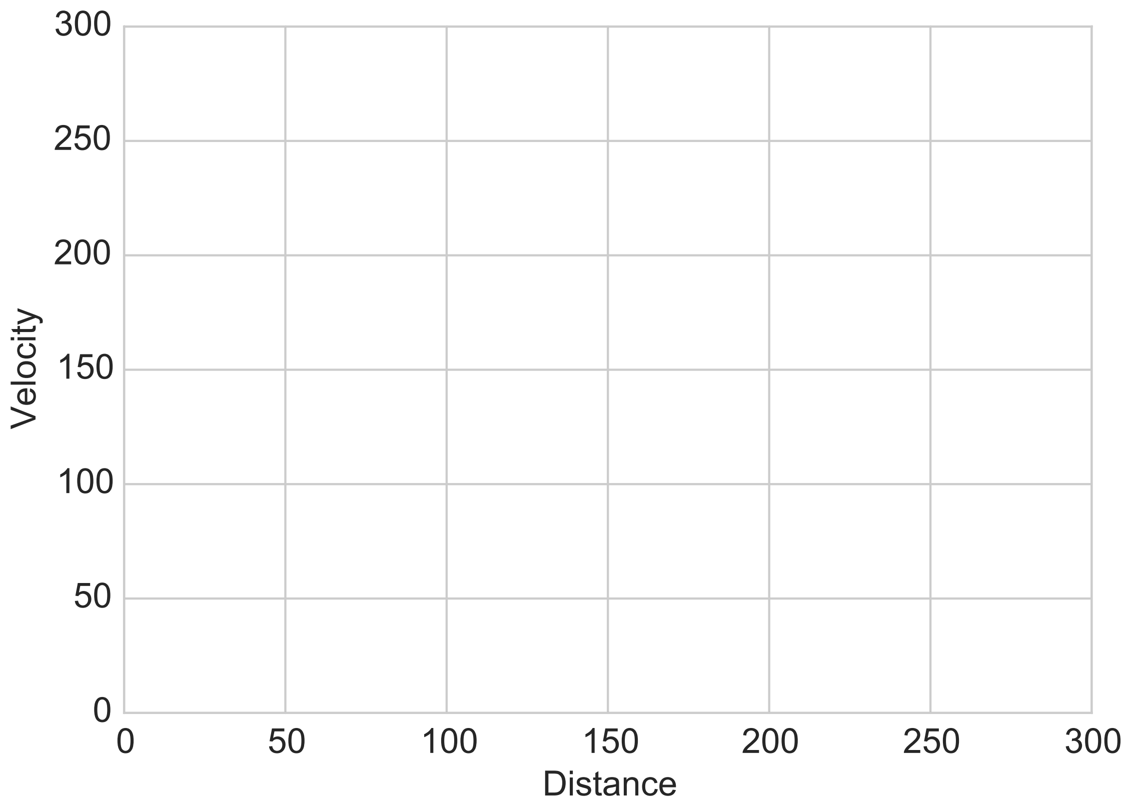
Orbit Speed: Kepler's Third Law [60 pts total]

1. Set the (x, y) position back to $(100, 0)$ and set the y velocity for a circular orbit. Record the values you found in the table below. The **period** of the orbit is the time required to complete one "lap." Measure the period of the orbit using the timer in the program. You can get good precision by counting out several orbits (5–10) and noting the total time required. Then divide the total time by the number of orbits to get the period of one orbit. Record the value in the table.

   Repeat these steps for the other x positions in the table. For the positions between the grid lines, use the *Tape Measure* feature in the program to make sure your orbits are circular. [**20 pts**]

x **position**	y **velocity of circular orbit**	**Period of circular orbit**
50		
100		
150		
200		
250		

2. Now, plot the velocity against hte distance from the star for your orbits:



Connect the points with a line and describe the relationship between distance from the star and the planet's speed in a circular orbit. [**10 pts**]

3. Use your plot to predict the velocity required for a circular orbit at $x = 125$. Test your prediction: did you get it right? [**5 pts**]

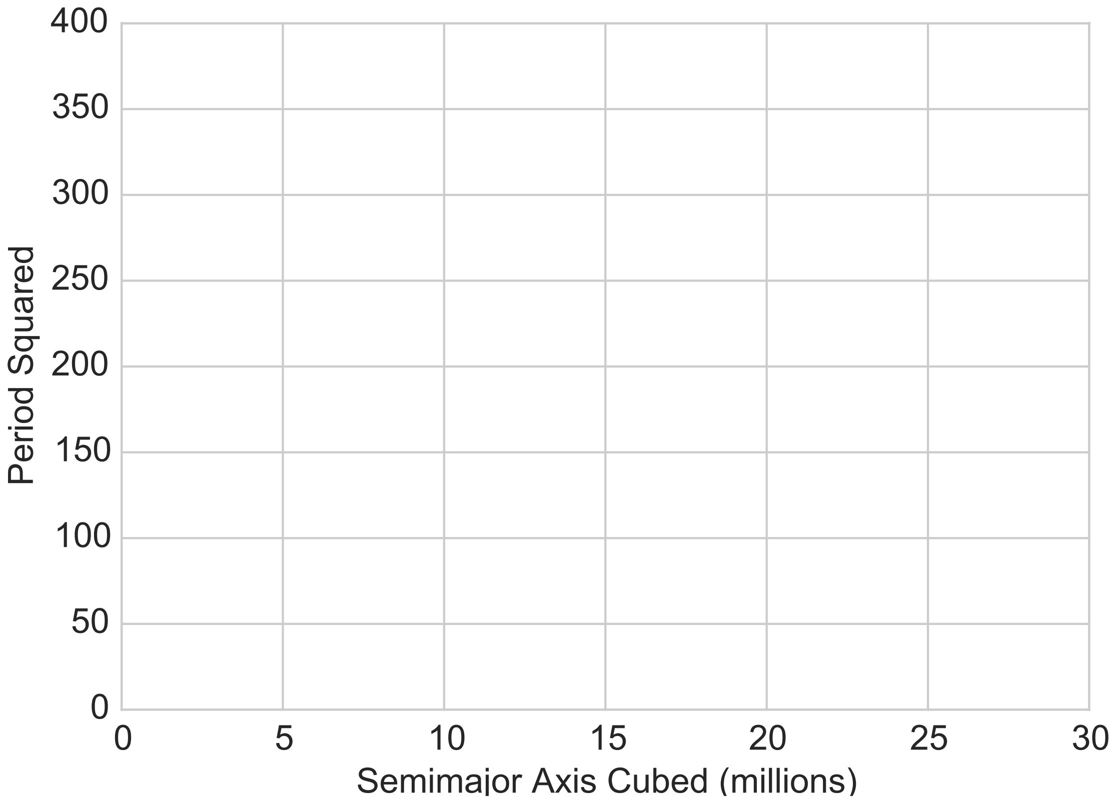
4. Kepler's Third Law tells us that for orbital motion, the period squared is proportional to the semimajor axis cubed: $P^2 \propto a^3$. In other words, $P^2 = Ka^3$ where K is some constant. For a circular orbit, the semimajor axis a is equal to the distance to the star. Use the table below to record your values [**10 pts**]:

x **position**	**(Semimajor axis)**^{3}	**(Period)**^{2}
50		
100		
150		
200		
250		

5. The general equation for a straight line is $y = Kx + b$. Make substitutions to show that Kepler's Third Law has the form of the equation of a straight line. What is y? What is x? [**5 pts**]

6. Kepler's Third Law predicts that a plot of P^2 versus a^3 should lead to data points that all fall along a straight line. You can test this prediction using your data from *My Solar System*.

Plot your (period)^2 and (semimajor axis)^3 on the plot below:



Based on your plot, does Kepler's Third Law corectly predict the orbital motions in your data? How can you tell? [**10 pts**]