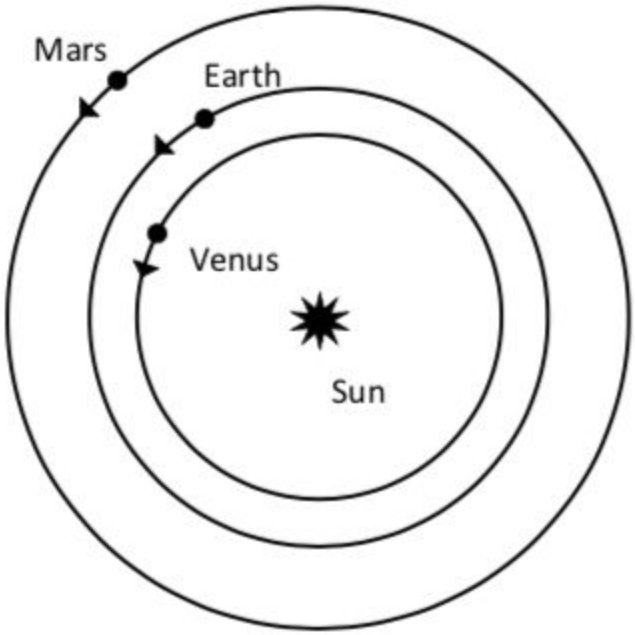
Gravity and Orbits: How Does Changing the Mass and Velocity of a Satellite and the Mass of the Object That It Revolves Around Affect the Nature of the Satellite's Orbit?

Introduction

The motion of an object is the result of all the different *forces* that act on it. If you pull on a door, the door will move in the direction that you pulled it. If you push on a marble that is resting on a table, the marble will move in the direction you pushed it. Pulling on a door and pushing on a marble are examples of a *contact force*, which is a force that is applied to an object through direct contact. There are other types of forces that can push or pull on an object without touching it. A magnet, for example, can pull or push on another magnet without touching it. Static electricity, which is the buildup of electrical charge on an object, can also pull or push on an object. Magnetic and electrical forces are therefore called *non-contact forces* because they act at a distance. **Perhaps the most common non-contact force is *gravity*. Gravity is a force of attraction between two objects; the force due to gravity always works to bring objects closer together.**

Any two objects, as long as they have some mass, will have a gravitational force of attraction between them. The strength or magnitude of the gravitational force that exists between any two objects is influenced by the masses of those two objects and the distance between them. **The magnitude of gravitational attraction increases with greater mass.** This means that the gravitational force that exists between Earth and a car is greater than the gravitational force that exists between Earth and a marble. The magnitude of gravitational attraction, however, decreases as the distance between any two objects increases. The magnitude of the gravitational force that exists between Earth and an object that is moving away from it will therefore get weaker and weaker as the object moves farther and farther away from Earth.

The orbits of Venus, Earth, and Mars as they would appear to an observer located above our solar system (the diagram is not to scale)



The force of gravity keeps planets orbiting a star and moons orbiting planets. An *orbit* is a regular, repeating path that one object in space takes around another one. An object in an orbit is called a *satellite*. A satellite can be natural, like planets, moons, and comets, or it can be something that was created by engineers and scientists, such as the International Space Station or the Hubble Space Telescope.

All orbits are *elliptical,* which means that the satellite follows a path that is round but can range in shape from a perfect circle to a long, thin oval. The shape of the orbit that most of the inner planets of our solar system follow, for example, is nearly circular. The figure to the left shows the orbits of Venus, Earth, and Mars. Notice that these orbits look almost like perfect circles. The orbits of comets and some of the outer dwarf plants have a very different shape. They are highly *eccentric*. In other words, their orbits look like a squashed circle.

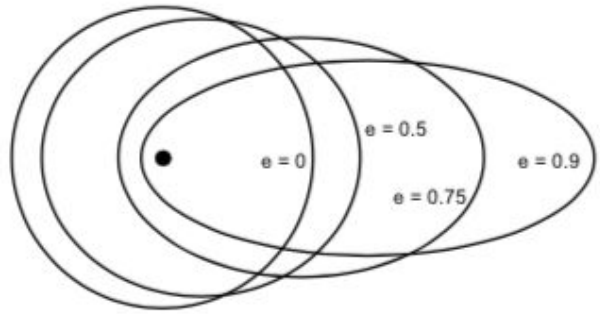
One way to describe the shape of an orbit is to calculate its *eccentricity*. Eccentricity is a way to quantify how much an orbit differs from a perfect circle. It is a value that ranges from 0 to 1. An

orbit with an eccentricity of 0 is a perfect circle. The figure to the right illustrates orbits with eccentricity values of 0., 0.5, 0.75, and 0.9.

Another way to describe the orbit of a satellite is to measure its orbital distance(s). Satellites do not always stay the same distance from the star or planet that they are orbiting because their orbits are elliptical. Sometimes they are closer and sometimes they are further away from the star or planet.

The third, and final, way to describe the orbit of a satellite is to measure the time it takes to make one full orbit. The amount of time required to complete an orbit is called the orbital period. Earth, for example, has an orbital period of one year.

Orbits with different eccentricities



In this investigation, you will have an opportunity to use an online simulation to explore how three different factors affect the shape, distance, and period of a satellite's orbit.

1. The first factor is the **mass of the satellite**.
2. The second factor is its **initial velocity** (speed in a given direction).
3. The third factor is the **mass of the object that it is orbiting**.

Your goal in this investigation is to determine how all three factors are related to each other so you can better understand and predict the shape, distance, and period of a satellite's orbit.

Your Task

Use what you know about gravity; scale, proportion, and quantity; and the role of models in science to design and carry out an investigation that will allow you to determine how these three different factors affect the shape, distance, and period of a satellite's orbit. The three factors you will explore are the mass of the satellite, the initial velocity of the satellite, and the mass of the object that the satellite is orbiting.

The guiding question of this investigation is: ***How does changing the mass and velocity of a satellite and the mass of the object that it revolves around affect the nature of the satellite's orbit?***

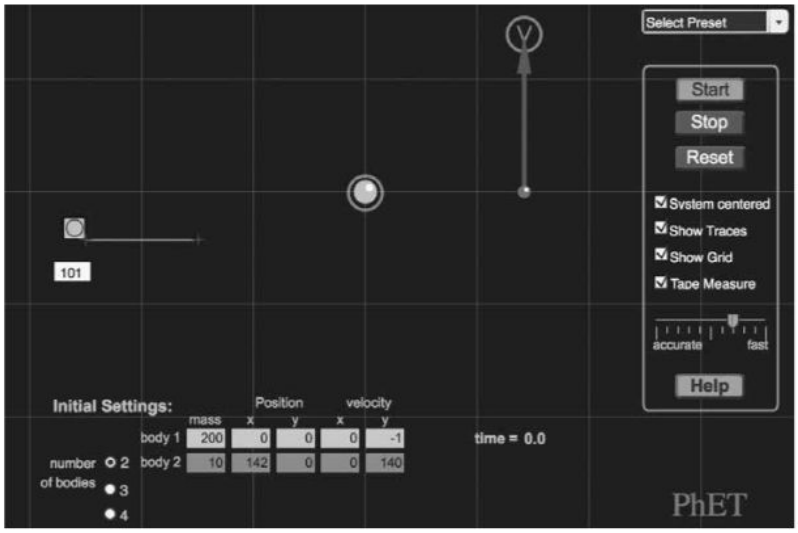
Materials

- You will use an online simulation called ***My Solar System*** to conduct your investigation; the simulation is available at *https://phet.colorado.edu/en/simulation/legacy/my-solar-system*.

Getting Started

The ***My Solar System*** simulation (see figure to the right) enables you to observe the orbit of a planet as it orbits around a star. It also allows you to change the mass and velocity of the planet and the mass of the star to see how changes in velocity and mass affects the shape, distance, and period of the planet's orbit. You can also change the

A screenshot from the *My Solar System* simulation



initial velocity of any object that is orbiting the star.
To use this simulation, start by making sure that the boxes next to System Centered, Show Traces, Show Grid, and Tape Measure in the control panel on the right side of the screen are all checked. This will make it easier for you to take the measurements. The mass, initial position, and initial velocity of each body in the solar system can also be changed by typing in new values for each factor using the text boxes at the bottom of the simulation. This simulation is useful because it allows you to see the path a planet takes as it orbits a star, and perhaps more importantly, it provides a way for you to design and carry out controlled experiments. This is important because you must be able to manipulate variables during a controlled experiment, and many of the variables that we are interested in here, such as the mass of a star, the mass of a planet, or the initial velocity of a planet, cannot be changed in the real world.

You will need to design and carry out three different experiments using the *My Solar System* simulation to determine the relationship between these factors and the nature of a satellite's orbit. Remember, any object in an orbit is called a satellite. A satellite can be natural, like planets and moons, or a satellite can be something that is manufactured and sent into space. You will need to conduct three different experiments because you will need to be able to answer three specific questions before you will be able to develop an answer to the guiding question for this lab:

- How does changing the **mass of the star** affect the way a planet orbits around it?
- How does changing the **mass of a planet** affect the way it orbits around a star?
- How does changing the **velocity of a planet** affect the way it orbits around a star?

It will be important for you to determine what type of data you need to collect, how you will collect the data, and how you will analyze the data for each experiment because each experiment is slightly different.

To determine *what type of data you need to collect*, think about the following questions:

- What are the components of this system and how do they interact?
- How can you describe the components of the system quantitatively?
- What information will you need to determine the perihelion and aphelion (or perigee and apogee) of an orbit during each experiment?
- What information will you need to calculate the eccentricity of an orbit during each experiment?
- What information will you need to determine an orbital period during each experiment?

To determine *how you will collect your data*, think about the following questions:

- What will serve as your independent and dependent variable for each experiment?
- How will you vary the independent variable during each experiment?
- What will you do to hold the other variables constant during each experiment?
- When will you need to take measurements or observations during each experiment?
- What scale or scales should you use when you take your measurements?
- What types of comparisons will you need to make using the simulation?
- How will you keep track of the data you collect and how will you organize it?

To determine *how you will analyze your data*, think about the following questions:

- How will you compare the perihelion and aphelion (or perigee and apogee) of an orbit?
- How will you calculate the eccentricity of an orbit?
- How will you compare the eccentricities of several different orbits?
- How will you determine an orbital period?
- How will you compare the periods of several different orbits?
- What potential proportional relationships can you find in the data?

Example data table for your investigation (you will need **three** total data tables):

Effect of Mass of the Star on the Orbit of a Satellite

	Trial 1	Trial 2	Trial 3
Mass of Star			
Mass of Satellite			
Velocity of Satellite			
Eccentricity of Orbit (difference between closest and farthest distance)			
Period of Orbit (time)			

*You will need three total data tables, to change three different variables:

1. Mass of the star
2. Mass of the satellite
3. Velocity of the satellite

Once you have carried out all your different experiments, you will need to develop an answer to the guiding question for this investigation. To be sufficient, your answer must explain how the mass of the satellite, the velocity of the satellite, AND the mass of the object that the satellite is orbiting (the sun) affect the eccentricity, the distance, and the period of an orbit. For it to be valid and acceptable, your answer will also need to be consistent with your findings from all experiments.

Report

Once you have completed your research, you will need to prepare an investigation report that consists of four sections (be sure to have section headings):

1. Introduction: Give some background information on the topic. Explain what question you were trying to answer and include a hypothesis. (Background info, research question and hypothesis)
2. Procedure: What did you do during your investigation and why did you conduct your investigation in this way? (How you collected and analyzed data)
3. Data: Include a data table and/or graph to show your results. Be sure to include a title for your table or graph with labels for the variables. Be sure to include numerical data (qualitative data) for each variable that you test.
4. Conclusion: What is your argument? (Claim - Evidence - Reasoning)
    a. Your **claim** should be the answer to your investigative question.
    b. Your **evidence** should include qualitative data (actual numbers) that you have collected during your investigation that helps support your claim.
    c. Your **reasoning** should include assumptions about gravity and satellite orbits that help support your claim .

Your report should answer these questions in two pages or less. The report must be typed, and any diagrams, figures, or tables should be embedded into the document. Type your report on Google Docs (12 point font, double-spaced) and share it with your teacher. Your report will be graded based on the rubric in the class syllabus.