Lab Handout

Lab 3. 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.

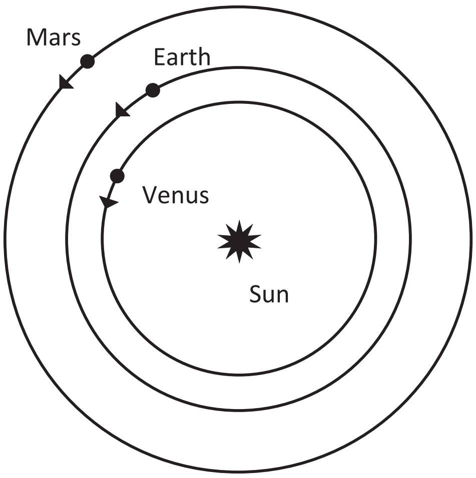
Any two objects, as long as they have some mass, will have a gravitational force of attraction between them. The strength or magnitude of the gravitational force that exists between any two objects is influenced by the masses of those two objects and the distance between them. The magnitude of gravitational 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 objects moves farther and farther away from Earth.

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. Figure L3.1 (p. 90) 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.

FIGURE L3.1

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)



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. Figure L3.2 illustrates orbits with eccentricity values of 0., 0.5, 0.75, and 0.9. The formula used to calculate eccentricity is

$$e = (\sqrt{a^2 - b^2}) / a$$

where e is the eccentricity of the ellipse, a = is the major axis of the ellipse, and b = is the minor axis of the ellipse. Figure L3.3 shows how to calculate the eccentricity of an orbit. In this example, the major axis of the ellipse (a) is 7 units long and the minor axis (b) is 5 units long. Substituting these values into the formula gives a value of 0.7. This elliptical orbit would be considered highly eccentric.

FIGURE L3.2

Orbits with different eccentricities

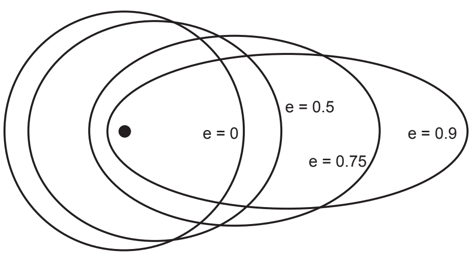
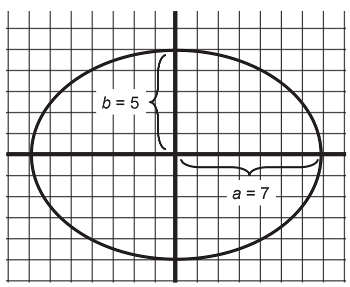


FIGURE L3.3

How to calculate the eccentricity of an orbit



$$e = (\sqrt{a^2 - b^2}) / a$$

$$e = (\sqrt{7^2 - 5^2}) / 7$$

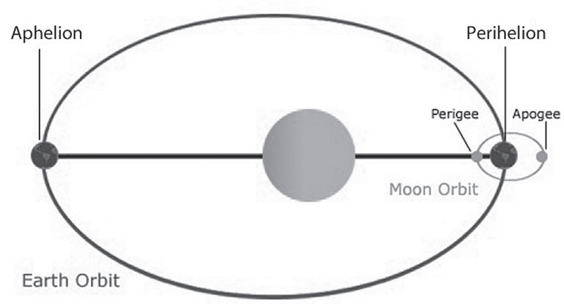
$$e = 0.7$$

Another way to describe the orbit of a satellite is to measure its orbital distance. Satellites, however, do not always stay the same distance from the star or planet that they orbiting because their orbits are elliptical. For planets, like Earth, the point in their orbit when they are closest to the Sun is called the perihelion (see Figure L3.4). The point where a planet is farthest from the Sun is called the aphelion. The closest point the Moon or a manufactured satellite comes to Earth is called its perigee, and the farthest point is the apogee. Earth reaches its aphelion during July and its perihelion in January. 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.

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. The first factor is the mass of the satellite. The second factor is its initial velocity (speed in a given direction). The third factor is the mass of the object that it is orbiting. This type of investigation can be difficult because identifying the exact nature of the relationship that exists between multiple factors is challenging. Take mass as an example. There are many potential ways that the mass of a satellite or the mass of the object it is orbiting could influence the satellite's orbit. The shape, distance, and period of the orbit may depend on the mass of the larger object and/or the mass of the smaller object. The mass of the satellite and the mass of the object it is orbiting could also change these three aspects of a satellite's orbit in different ways.

FIGURE L3.4

Illustration of the orbit of Earth around the Sun and of the Moon around Earth showing the aphelion, perihelion, perigee, and apogee. (The orbits of the Earth and the Moon are not as eccentric as they appear in this image.)



In addition to mass, there are many different ways that an orbit might change due to a change in the initial velocity of a satellite. The eccentricity of an orbit may either increase or decrease as the initial velocity increases. The initial velocity may also affect the orbital period but may not change the distance of its perigee and apogee (or perihelion and aphelion if the satellite is a planet). All of these different relationships are possible, as well as many others. 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 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.*

Safety Precautions

Follow all normal lab safety rules.

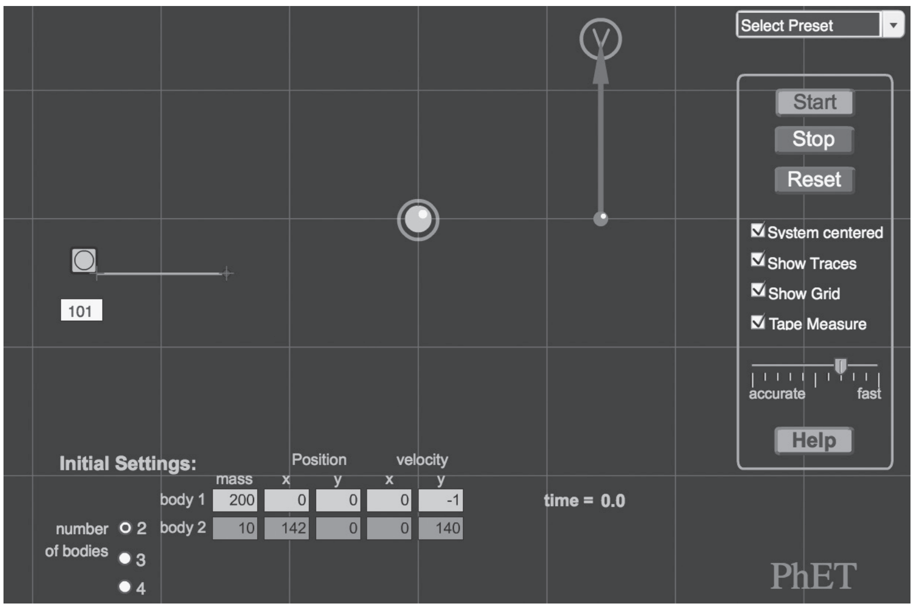
Investigation Proposal Required? ☐ Yes ☐ No

Getting Started

The *My Solar System* simulation (see Figure L3.5) enables you to observe the orbit of a planet as it orbits around a star. It also allows you to change the mass of the planet and the star to see how changes in mass affects the shape, distance, and period of the planet's orbit. You can also add additional bodies to the solar system and change the initial velocity of any object that is orbiting the star.

FIGURE L3.5

A screenshot from the *My Solar System* simulation



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. You can add or remove bodies from the solar system by clicking on the radio buttons in the lower left corner. 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 see the path a planet takes as it orbits a star, and perhaps more important, 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 at least three different experiments using the *My Solar System* simulation to determine the relationship between the three 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 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 the 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 the 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?

Once you have carried out all your different experiments, your group 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 initial velocity of the satellite, and the mass of the object that the satellite is orbiting affect the eccentricity, the perihelion and aphelion, 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 three experiments.

Connections to the Nature of Scientific Knowledge and Scientific Inquiry

As you work through your investigation, be sure to think about

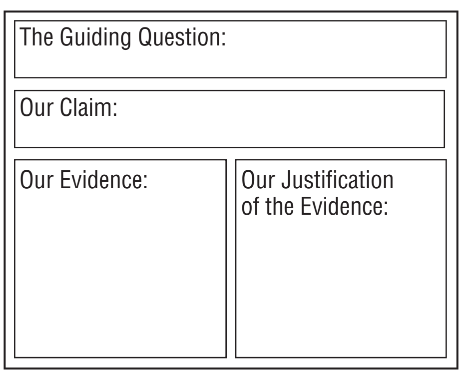
- the difference between laws and theories in science, and
- the assumptions made by scientists about order and consistency in nature.

Initial Argument

Once your group has finished collecting and analyzing your data, your group will need to develop an initial argument. Your initial argument needs to include a claim, evidence to support your claim, and a justification of the evidence. The claim is your group's answer to the guiding question. The evidence is an analysis and interpretation of your data. Finally, the justification of the evidence is why your group thinks the evidence matters. The justification of the evidence is important because scientists can use different kinds of evidence to support their claims. Your group will create your initial argument on a whiteboard. Your whiteboard should include all the information shown in Figure L3.6.

FIGURE L3.6

Argument presentation on a whiteboard



Argumentation Session

The argumentation session allows all of the groups to share their arguments. One or two members of each group will stay at the lab station to share that group's argument, while the other members of the group go to the other lab stations to listen to and critique the other arguments. This is similar to what scientists do when they propose, support, evaluate, and refine new ideas during a poster session at a conference. If you are presenting your group's argument, your goal is to share your ideas and answer questions. You should also keep a record of the critiques and suggestions made by your classmates so you can use this feedback to make your initial argument stronger. You can keep track of specific critiques and suggestions for improvement that your classmates mention in the space below.

Critiques of our initial argument and suggestions for improvement:

If you are critiquing your classmates' arguments, your goal is to look for mistakes in their arguments and offer suggestions for improvement so these mistakes can be fixed. You should look for ways to make your initial argument stronger by looking for things that the other groups did well. You can keep track of interesting ideas that you see and hear during the argumentation in the space below. You can also use this space to keep track of any questions that you will need to discuss with your team.

Interesting ideas from other groups or questions to take back to my group:

Once the argumentation session is complete, you will have a chance to meet with your group and revise your initial argument. Your group might need to gather more data or design a way to test one or more alternative claims as part of this process. Remember, your goal at this stage of the investigation is to develop the best argument possible.

Report

Once you have completed your research, you will need to prepare an investigation report that consists of three sections. Each section should provide an answer for the following questions:

1. What question were you trying to answer and why?
2. What did you do to answer your question and why?
3. What is your argument?

Your report should answer these questions in two pages or less. You should write your report using a word processing application (such as Word, Pages, or Google Docs), if possible, to make it easier for you to edit and revise it later. You should embed any diagrams, figures, or tables into the document. Be sure to write in a persuasive style; you are trying to convince others that your claim is acceptable or valid.