7.2: The Phases of Venus

Our next activity is taking another page from Galileo's book – literally! In 1609, after inventing the telescope, Galileo chose three objects for his first investigations: the Moon, Jupiter, and Venus. The Moon proved to be a rugged place, full of mountains, craters with their rays, and large dark seas of frozen lava. Jupiter was a beautiful world with colorful cloud bands and four brilliant moons of its own.

Although these discoveries contradicted Aristotle's geocentric theory (the moons of Jupiter didn't circle the Earth and Aristotle's moon was supposed to be smooth and flat), they didn't actually contradict Aristotle's central idea – that the Earth, and not the Sun, was the center of the solar system. Galileo's quest to prove the Sun-centered theory of Copernicus correct was not satisfied by his observations of the Moon and Jupiter.

Galileo's observations of Venus were the final piece to the heliocentric puzzle. Observations of Venus through the telescope showed beautiful phases just as our Moon does. A little investigation and thought showed that this was only possible with a heliocentric system such as the one proposed by Copernicus – more importantly, phases of Venus were ***impossible in Aristotle's Earth-centered system***.

This activity will allow us to recreate the observations of Galileo using ping-pong balls as planetary models and prove that Galileo and Copernicus were right about the sun-centered theory of the solar system.

Academic Standards

Science and Engineering Practices

- Asking questions and defining problems.
- Developing and using models.
- Planning and carrying out investigations.
- Analyzing and interpreting data.
- Constructing explanations.
- Argument from evidence.

Crosscutting Concepts

- Patterns in nature.
- Cause and effect.
- Systems and system models.

Next Generation Science Standards

- Space systems (K-5, 6-8, 9-12).
- Structure and function (K-5, 6-8, 9-12).

- Waves and electromagnetic radiation (6-8, 9-12).
- Gravitation and orbits (6-8, 9-12).

For the Educator

Facts you need to know

1. Venus is the closest planet to Earth, and almost the same size, mass, and density as our planet; in fact, if you only consider size and mass, Venus could be Earth's twin.
2. Venus (and Mercury) are closer to the Sun than Earth is; this fact will be critical in order for students to understand this activity.
3. When we observe planets with a telescope, planets ***closer to the Sun*** than Earth appear markedly different from planets that are farther away from the Sun than Earth is. Closer planets are called ***inferior planets,*** while those planets farther from the Sun than Earth are called ***superior planets.***
4. Inferior planets ***always show phases*** when you observe them, superior planets never do. This is only possible in a ***heliocentric solar system***.

Teaching and Pedagogy

Planets which are closer to the Sun than the Earth (Venus and Mercury) are called ***inferior planets***; those planets which are farther from the Sun than we are (Mars, Jupiter and the rest) are called ***superior planets.*** Galileo quickly noted that whenever he observed an inferior planet – it always shows phases – but the superior planets never do. Experimenting with models like the one you have just built in your classroom convinced Galileo that only the sun-centered system would make this possible!

Unlike the moons around Jupiter and the rugged surface of the Moon, the phases of Venus went right to the heart of Aristotle's geocentric system. Try as he might, there was no way Galileo could arrange the geocentric model to recreate these observations – but they occurred quite naturally and easily with a heliocentric model!

For your students, once you show them the phases of Venus with the Sun in the center of the model, challenge them to find the same thing with the Earth in the center. (In Aristotle's model, Earth is in the center, then the Moon, the Sun, Venus is farther out from Earth than either the Sun or Moon.) Try as they might, Aristotle's model will never produce the phases of Venus we see in a telescope.

Galileo's book ***Dialogues Concerning the Two Chief World Systems***, showed people how to experiment with models very similar to the ones your students have just built. This showed everyone who cared to look that the old Earth-centered system just didn't work, and the new heliocentric system of Copernicus ***did***.

Student Outcomes

What will the student discover?

1. Different models make different predictions about what we will observe in Nature. The two models we are dealing with – the heliocentric (Sun-centered) and the geocentric (Earth-centered) models, give very different predictions about what we will observe when we look at Venus.
2. If you were to take care and move each model, observing how Venus appears every 15 days, the geocentric (Earth-centered) model would show you only small changes, and Venus never shows a crescent or half-lit appearance.
3. The heliocentric (Sun-centered) model is different. Here Venus moves smoothly from a thin crescent, to a half-lit phase, and finally a gibbous phase. We do not see Venus in new phase or full phase because these line up Venus with the Sun and make observing the planet impossible.
4. On the face of it, either theory seems possible. However when we observe Venus with a telescope, it becomes clear which theory successfully predicts the performance and appearance of Nature.

What will your students learn about science?

1. Once again, different models make different predictions about what we will observe in Nature. Many theories or hypotheses are possible, but unless a theory makes a ***unique prediction about Nature***, the theory is unprovable and therefore valueless.
2. Testing theories with experiments, or with models, can help us decide when we are on the right track in understanding how the Universe works.
3. Our emotional attachment or fondness for one theory or another cannot be a deciding factor in our experiments. Scientists propose theories, but ultimately, Nature is the way it is and wishing will not make it different.

4. Polls don't count in science. When Galileo was building his telescope and using it to show that Copernicus' heliocentric theory was actually correct (and Aristotle's ideas were in fact wrong), 99.9% of the learned scientific minds of the day believed Aristotle was correct. Belief and polls aside, Galileo was right and everyone else was wrong.

Conducting the Activity

Materials

1. Four ping-pong balls
2. Four poker chips (you can substitute sports-drink caps if you like)
3. A can of bright yellow spray paint
4. A can of flat black spray paint
5. A roll of 2-inch wide masking tape
6. A tube of silicone glue
7. Markers or classroom paints
8. A can of clear acrylic or art fixative spray (optional)
9. Three white ping-pong balls per student group – $2
10. Six poker chips per group (you can substitute sports-drink caps if you like)
11. One set of 6-10 powerful magnets (for the teacher's model) – $4
12. Wooden or plastic ruler (actually, almost any sturdy stick will do.)

Building the Model of Venus' Phases

1. Begin by using silicone glue to attach one of the ping-pong balls to a poker chip or bottle cap – this will be the Sun.
    - Note: Even if you use bottle caps as bases for the students, the teacher's model should use poker chips – it makes it much easier to attach magnets to the bottom of the teacher's model which will allow you to display the model on any white board for everyone to see!
2. **[Teacher]** After the glue has cured at least 24 hours, set the Sun models out on some newspaper. Use the yellow spray paint to decorate the Sun models. Shake the can well and spray the paint on in thin coats, just a spritz at a time. You will need several coats of paint, and allow at least 30 minutes between coats.  Be sure you use plenty of newspaper as you will be spraying from all sides. Space the models well apart and only paint in a well ventilated area. An empty garage (preferably with the door at least partly open) works very well. Leave the room immediately when you are done spraying to avoid exposure to fumes and allow the paint to dry completely (30 min or so) between coats.
3. **[Teacher]** The other three ping-pong balls must be colored half-black, and half left unpainted white; the black side will represent night, the white side will be the daytime side of the moon or planet. There are two fundamental ways to do this: one at a time (very neat and precise), or in batches of a dozen or so at a time (less precise, but saves a great deal of time.) Both methods begin the same way, by taping off half the ping-pong ball with masking tape. Look for the seam, like an equator running around the ball. Tear off a length of tape and carefully apply the edge to the seam and work your way around making sure the tape is well sealed to the ball. You should now have half a ping-pong ball sticking up from a 2-inch tube of masking tape as you can see below.
4. If you are painting the balls one at a time, place the ball on the end of a ruler (the masking tape will help it stay secure). Hold the ball at arm's length and spray it with flat black paint. Remember, use thin coats and work in a well ventilated area!

    If you are painting in batches, put a dozen or so balls into a cardboard box (a copy paper box works very well). Stand them up carefully on their masking tape tubes toward the center of the box and not too close together. Spray the black paint into the box – don't forget newspapers underneath – particles of paint will float up out of the box and may drift a bit!

    When the paint dries, carefully remove the tape and you should have perfect ping-pong balls – half black and half white!

5. Now it is time to decorate the Earth and Jupiter using markers. There are two approaches to this, the accurate and the creative – you must decide which will work best for your students!  For an accurate model, use photos or maps of the Earth and draw in continents, oceans, mountain ridges, green prairies, islands, etc. You can even use a bit of white paint (or correction fluid!) to add storms and clouds to your model of Earth. Jupiter has alternating dark and light bands – dark bands are dark brown or grey, light bands are tan or yellow. Start with a light band around the equator and alternate as you go toward the poles. Add a red spot on one of the lighter southern cloud bands!

For a creative Earth model, have students draw continents, islands, oceans any way they wish. You can even have them name their planet creations.

Venus is the easiest of all – it needs no decorating! Venus is covered in thick, white clouds that never part or reveal the surface underneath. For our purposes, a half-black, half-white ping-pong ball will work perfectly!

When you are done decorating, glue the planets and moons to their bases with silicone glue. After they are dry (24 hours!), a quick coat of clear art sealer will not go amiss (old-fashioned lacquer hair spray works well for this if you can find it!) – it often helps keep marker from coming off again on your student's hands!

6. Your model is now ready to play with and explore!

Exploring the Model of Venus' Phases Model

1. Set up your models on a desktop with the Sun in the center, then Venus a bit farther out, and then Earth. Set Jupiter aside for later!
2. The trick with these models is to remember how they should be displayed. Ask your students why one side of the planet models are colored black? The answer of course, is that this is the nighttime side of the planet, the decorated side is daytime. The daytime side of the planets ***must always face the Sun.*** This will seem obvious to you when you think about it for a moment!
3. Begin with Sun, Venus, and Earth all in a line. Have your students put their eye down at tabletop level and look at Venus ***from the position of the Earth***. Ask them to draw what they see! If their eye is right above the planet Earth, they will see that Venus is in new phase – only the dark side faces the Earth. (Venus is invisible to us in this position – the Sun's glare blocks it from view!)
4. Now advance Venus about 45-degrees in a counter clockwise direction around the Sun. Make sure the bright white side stays facing the Sun at all times! Ask the students to make another observation and draw what they see – they will see a crescent phase!
5. Continue to advance the Venus model 45 degrees at a time and the students will see all the phases; new, crescent, half, gibbous, full, etc. If you have older students who have smart phones, ask them to place their phone just behind the Earth model and take a photo of Venus – these photos show the phases off beautifully!
6. Now that your students have seen the phases of Venus – let's try Jupiter! Set your Sun, Earth, and Jupiter models up on a tabletop or on the floor (this one takes more room!) Place Earth just 5-inches from the Sun, and Jupiter 25-inches away – we do this because giant Jupiter is five times farther away from the Sun than we are! Make sure the bright sides of the planets face the Sun at all times!
7. Once again, have students put their eye down near the Earth and look at Jupiter. We see a full disk (no phases.) Move Jupiter around the Sun in a circle and make a drawing every 45-degrees just as you did for Venus – be sure the decorated side of Jupiter

always faces the Sun. (You may want a piece of string or a yardstick to help you keep Jupiter at the right distance!) Your students will quickly notice that Jupiter never shows us any phases – it always looks full and round!

Discussion Questions

1. How does this new discovery of the phases of Venus challenge Aristotle's theory?
   - **Answer:** The phases of Venus can only occur if the Sun is in the center of the model. There is no way to arrange the model with the Earth in the center and still create this effect.
2. How is this activity different from the previous one?
   - **Answer:** The moons of Jupiter only challenge the idea that ***everything orbits Earth***. The phases of Venus make it impossible to believe in anything except a ***Sun-centered model.***
3. Why do you think that so many people got mad at Galileo and even charged him with crimes when he showed that Aristotle's ideas about the solar system were wrong?
   - **Answer:** People become emotionally attached to ideas, just as they do with cherished friends. Being told that you are wrong is never a comfortable experience. Being told that ***everyone else is wrong*** usually provokes a very negative response from people!

Supplemental Materials

Going Deeper

Try this model again with the Earth in the center, the Sun orbiting close to Earth, and Venus farther away. Venus should be several times farther from Earth than the Sun is. Can you make Venus appear in phases? In fact, the Earth-centered system fails dramatically here – Venus never appears to show phases when the Earth is in the center.

There is the additional problem of why Mercury and Venus show phases, but Mars, Jupiter, and Saturn do not. (People in Galileo's time did not know of any planets beyond Saturn!) In the Earth-centered model, all of the planets are farther away from Earth than the Sun is. There is no reason for them to appear different from one another in a telescope.

In the heliocentric model however, Earth is just the third planet – one of many! Planets closer to the Sun than Earth appear different from those which are farther away from the Sun than we are. The heliocentric model of Copernicus and Galileo easily explains things that the geocentric model cannot.

Being an Astronomer

This one is obvious – it's time to go observe Jupiter and Venus! If your school does not have a telescope available, try contacting your local astronomy club for help. You can even ask parents through a newsletter or your PTA – you will be surprised how easily you can find someone with a telescope to share!

Venus is sometimes called the ***Evening Star*** because it is brilliant white – the brightest object in the sky after the Moon – and appears in the sky just after sunset (or just before dawn.) Looking at brilliant Venus, even with a pair of binoculars, will easily show that it has phases! This is a very unexpected thing and surprises and delights young and old the first time they see it. If you find when Venus is visible in the morning, you may be able to bring a pair of binoculars to school and allow all the students to have a look at it first thing in the morning!

Observing Jupiter can be done with an 8x or higher power pair of binoculars, but it is far better done with a telescope. The good news is that almost any telescope will do the job, even a very small one such as those you see on sale at holiday time in department stores. If you do not have access to a telescope or binoculars, this is a great time to check the internet and see if there is an amateur astronomy club near your town. Astronomy clubs often do outreach, and if you explain to them that you and your students want a chance to observe the planets, they will almost certainly help out. Some clubs have regular observing nights or ***star parties*** that students and parents would be welcome to attend; some clubs will even be willing to bring their telescopes and equipment to your school for an evening of observing the planets and the Moon!

Being a Scientist

If you have access to a telescope, observing and recording the changing phases of Venus can be a fun and challenging exercise. Venus appears as a ***morning star*** for a period of weeks during most school years. While Venus is visible in the morning skies, you and your students can observe and record the changes you see by looking at Venus at least once per week.

As you observe Venus and sketch the shape of the phase you see each week, you can also pay attention to how large Venus appears in the eyepiece of the telescope by observing how much of the field of view Venus takes up. You will notice that some phases (the crescent phases) appear quite large. Other phases (particularly the gibbous phases) will appear quite small in the eyepiece.

If you pay close attention, you may also notice that the large crescent phases make Venus appear noticeably brighter in the morning sky, while the small gibbous phases make Venus appear dimmer.

How do we explain this? Have your students go back to their model and see where Earth and Venus are located for the crescent and gibbous phases. You students will quickly notice that crescent Venus is ***much closer to Earth*** than the gibbous phase.

Having Venus more than 100 million miles closer to Earth during crescent phase makes the planet look both larger – and brighter!

Following Up

Galileo's famous book ***Dialogues Concerning the Two Chief World Systems*** was actually written as a play! There are three main characters: ***Salviati*** is a scientist and astronomer who believes that Copernicus' sun-centered system is correct. ***Simplicio*** is a traditional scientist who supports Aristotle and the earth-centered system. ***Sagredo*** is an intelligent fellow who has asked these two famous men to debate so that he might decide which theory is correct.

Have your students do a presentation to the class where someone takes each part. You can even do this as a group project with ***Team Salviati*** and ***Team Simplicio*** doing the debating and ***Team Sagredo*** asking both teams to answer questions. Have your actors use the ping-pong models to demonstrate their points and show why the evidence favors their theory.

Of course, the outcome of our little debate is more predetermined than a pro-wrestling match! Salviati (and Galileo!) will win the day, but having children take the parts and present the evidence can be both fun and enlightening!
