13.3: Why are Eclipses so Rare?

With our two shadow models, we have seen the mechanics of the solar and lunar eclipse. Your students should now be able to explain to someone ***how eclipses work,*** and why both light and shadow are needed to create one. But why are eclipses so rare? Most people have never seen a lunar eclipse although they are fairly common and occur in bunches of three to four events spread out over 18-24 months. These eclipse clusters occur every few years, there are many on-line almanacs that can help you find the next lunar eclipse visible from your area.

Only relatively few people have ever seen a total solar eclipse. These fleeting events last only minutes, and one has to be in a very exact position to observe them. Adventurers, astronomers, and wealthy tourists take trips to exotic locations, people even charter cruise ships to travel to a particular point in the ocean and drift motionless while those on board observe the fleeting event! The model we created seems to suggest that an eclipse should be possible every full and new moon – so why are they so infrequent?

In order to understand this last piece of the eclipse puzzle, we will create yet another model using ping-pong balls again, and our ping-pong Sun model, too. We are going to make a new ping-pong Earth model, this time with the Moon's tilted orbit attached to it!

Academic Standards

Science and Engineering Practices

- Developing and using models.
- Using mathematics.
- Constructing explanations.
- Argument from evidence.

Crosscutting Concepts

- Patterns in nature.
- Cause and effect.
- Systems and system models.
- Structure and function.
- Stability and change.

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).
- The Earth-Moon system (6-8, 9-12).

For the Educator

Facts you need to know

1. The Moon's orbit is tilted 5.5 degrees with respect to the Earth's orbital plane around the Sun.
2. A five degree orbital tilt seems very small, but this small angle carried over 380,000 kilometers often places the Moon far above, or below, the plane of the Earth's orbit.
3. In order to have an eclipse of any kind, the Earth, Moon, and Sun must be precisely aligned in space. It is the tilt of the Moon's orbit which interferes with this alignment.

Teaching and Pedagogy

You will remember that in Activity #30, we used a toy gyroscope to show students that a spinning object's axis is stable in space, no matter how we move it around. The Moon in its orbit is not a solid ring like the metal ring of the gyroscope, or a solid ball of stone like the Earth, but as it spins it acts in much the same way. Spin the gyroscope up and balance it on your finger, push it over so it is tilted a bit just as the Earth's axis and the Moon's orbit are tilted. Students will be quick to notice that it stays upright, but it also wobbles a bit. As with our toy gyroscope, so goes both the Earth and the Moon – this 'toy' is an excellent scientific model!

The lunar orbit, like the Earth's axis, stays pointed in the same orientation as the Earth-Moon system orbits the Sun. In other words, if the highest point on your model's lunar orbit faces north, it must remain facing north as you move the model around the Sun. It may also help to have your model from Activity #34 handy to help illustrate what is happening on a larger scale!

Student Outcomes

What will the student discover?

1. Once again, the scale of distances in our solar system comes into play. Although the tilt of the Moon's orbit is relatively small, the great distances between Earth and Moon make this small angle very significant!
2. The interplay of light and shadow is a magnificent thing. The precise path of light through our solar system, and the shadows created by planets and moons create beautiful phenomena such as eclipses.
3. The design of the solar system is simple, but the many moving bodies and the differences in speed, distance, orbital tilt and position mean that the sky is always changing. As astronomers, we must look when phenomena are available – some of the things we see may never again be visible in our lifetimes!

What will your students learn about science?

This model is the capstone of our exploration of the Earth-Moon system (but not the end of our adventures!) You and your students have seen how models begin with patterns and time keeping, and advance by creatively playing with these models to see what predictions they make, and then testing these predictions with observations and experiments. Instead of reading about science in a book, you and your students have actually engaged in it; building the models, discovering the predictions, and putting them to the test for yourselves. Science is a verb! Science is an adventure! Science is the joy of discovery!

Along the way, we have seen how a single model of the Earth-Moon system could not creditably demonstrate everything we know about the size, scale, motions, and interactions of the Earth, Moon, and Sun. Like real scientists, we have used a variety of models to demonstrate, or rather highlight, different features of the Earth-Moon system that we have discovered. Your students have also seen how we sometimes exaggerate, or deemphasize features of our models by changing size, speed, and distance to suit our own program of investigation and discovery.

Your students have also discovered that science is neither perfect, nor unchanging. Sometimes scientific models and theories must be changed a bit, modified extensively, even tossed out completely. There is no such thing in science as an emotional attachment to a pet theory, or loyalty to an idea which has been demonstrated to be incorrect.

Scientists do not change their minds about a theory lightly, it takes data to drive these changes; but in the face of mounting evidence, any good scientist will go humbly wherever the evidence of nature leads. For all of our magnificent technology, gleaming electronics and massive telescopes, science is a very human activity. It is driven by our curiosity about the universe around us, and our desire to understand the world we live in. Scientists are all children at heart, creative explorers lured on by some interesting pattern that they have glimpsed while at play, delighted by the prospect of learning something new and sharing it with everyone else.

Conducting the Activity

Materials

1. One ping-pong ball
2. A manila file folder or similar stiff card stock
3. Four 3-5 mm beads (grey is preferred, but any color will do)
4. A golf tee
5. A piece of wood or ball of modeling clay for a stand
6. Ping-pong Sun model (See Activity #20)
7. A toy gyroscope (for a teacher demonstration)
8. Markers, glue, poster putty, etc.

Building the Rare Eclipse Model

1. Use markers to decorate a model Earth – your students should be getting good at this by now! You will see why we need a new Earth after we add the lunar orbit to our model!

2. Use silicone glue to attach the South Pole of your model to the golf tee and set it in a ball of clay to stand and dry. Remember that silicone glue needs 24 hours to cure properly. Hot glue can be used to speed up the process if you wish.
3. On the file folder, use a compass to draw and cut out a 5-inch circle. Then cut out a 4.0 cm wide circle from the center of this to create your lunar orbit. If you have done things properly, you should have a lunar orbit ring that will fit nicely over your ping-pong ball. You may use markers to color this black or dark grey if you wish, but do not use crayons, the waxy finish will interfere with attaching our little moon beads to our model later!
4. Place your lunar orbit on the ping-pong Earth model. Be sure the orbit it tilted enough so that the ends of the orbit are well above and below the level of the Earth itself. When you are satisfied that you have everything in the correct position, go ahead and secure your orbital ring with a couple of drops of white glue or super glue. With this large and tilted orbit attached, you can see why we needed to put our Earth model on a stand such as a golf tee! Remind your students that the real lunar orbit is 60x the size of the Earth, we have cheated a bit with a lunar orbit just 5x as wide as the Earth to keep the size of our model manageable.
5. Use some poster putty to attach your four moon beads. One each should go at the highest and lowest position on the orbit, and at the ***nodes*** where the orbit crosses the Earth's equator. Younger children might find four moons a bit confusing, in that case simply keep one bead on the orbital ring and move it about as you need to. You must be careful to treat the lunar orbit ring carefully lest you bend it up and damage the model! In any case, with your moon bead now attached, your model is ready to use.

Exploring the Rare Eclipse Model

1. Have your students begin with the moon bead at one of the node positions. Adjust your model so that the Earth is directly between the Moon and the Sun – this is the correct position for a lunar eclipse with the Moon on the node and the node pointed directly at the Sun.
2. Now advance the Earth 90-degrees anti-clockwise (keep the orbit ring oriented in the same direction!), and advance the Moon bead the same 90-degrees anti-clockwise around its orbit ring. Remind your students that this represents three months of time (¼ of a year!) The Moon is now between the Earth and Sun again, but it is either too high above or too far below the Earth for its shadow to create an eclipse!
3. Continue to advance the Earth and Moon 90-degrees at a time and observer the results. You will quickly see that there are only two times per year, six months apart, when an eclipse is possible. These are called ***eclipse seasons***. For an eclipse to occur, the Moon must be precisely on a node on exactly the correct day when the node is pointed at the Sun. No wonder the eclipses are so rare!

Discussion Questions

1. What factors make eclipses so rare?
    - **Answer:** The large size of the lunar orbit.
    - **Answer:** The tilt of the lunar orbit that prevents the shadows from striking Earth or Moon most months.
    - **Answer:** The small size of the Moon compared to the Earth.
2. What compromises have we made with this model of the Earth-Moon system?
    - **Answer:** We have shown the Moon much closer to the Earth than it really is. The diameter of the Moon's orbit is 30x the Earth's diameter; and orbit this large would make our model difficulty to construct and operate.

Supplemental Materials

Being an Astronomer:

Did you know that you can see eclipses happening on other planets? The Galilean moons of Jupiter are large enough that it is possible to observe, and even photograph these moons and their shadows as they pass in front of their planet Jupiter.

Observing such events requires a relatively large telescope; either a refractor of 100 mm aperture or greater, or a reflector of at least 8-inch aperture, preferably 12-inches or even larger. Once again, your local astronomy club may come to your aid. Most clubs have at least one member with a large reflector telescope of the type required to see the shadow of a moon cross the face of Jupiter.

Observing such an event takes planning! These events can be predicted months in advance, just as eclipses on Earth can, but they do not always happen in the early evening when it would be convenient for students and parents to participate. Meet with your club at the beginning of the school year and see if you can plan an effective observation schedule!

Being a Scientist:

If you have a chance to observe an eclipse on Jupiter, you may be able to set up a live video feed for all of your students to look at. If the eclipse happens at an inconvenient time, you may find that your astronomy club may be able to provide you with a video of the event for your class to look at in the comfort of your classroom.

Scientists observe events making careful note of ***first contact, time of totality,*** and ***last contact.*** You can observe these events either live, or from a video. It can be interesting to compare eclipse events from the different Galilean moons (Io, Europa, Calisto, and Ganymede.) Because of their different distances from Jupiter, each of the Galilean moons travels at a different speed in orbit. This can greatly affect the time of totality as the moon's shadow crosses the face of Jupiter.

Following Up

Predicting eclipses is a very difficult endeavor! Looking at modern calculations of past eclipses that were visible over the Mediterranean and Middle East from 100 BC to 1000 AD, we find that some solar eclipses were just 18 months apart, other times the next solar eclipse might be 400 months apart – that's more than 33 years separating two solar eclipses.

To predict a solar eclipse, you must know the shape of the Moon's orbit precisely, and determine how the Earth and Moon speed up and slow down in their orbits. The Greeks reached this level of sophistication in the first century BC, and the Chinese astronomers reached that level of knowledge about 300 AD. There are rumors that Maya or Inca astronomers may have reached that level of knowledge, but much of their mathematical literature was destroyed by their Spanish conquerors in the early 1500's, so it is unlikely that we will ever know how far these new world astronomers had progressed.
