

## 13.1: Modeling a Solar Eclipse

Solar eclipses are wonderful events, but it is quite rare to see one. The eclipse is only total along a very narrow line called the **path of totality**. If you are not on this narrow line at exactly the correct time and the weather is not clear – you will miss your total eclipse. Partial eclipses are easier, but they do not visit any particular continent or region very often – you may wait decades between opportunities, or have to travel thousands of miles to see one.

Since we cannot expect the Sun and Moon to cooperate and give you a wonderful solar eclipse of your own (and conveniently during school hours, too!) we must do the next best thing by modeling the solar eclipse in our classroom.

This activity will take our Earth-Moon system model to new levels of detail. In order to do this, we are going to have to make a new model on a different scale. Like so many scientific models in astronomy, this one will fib a little bit when it comes to the real scale of the solar system. As we've seen in Activity #3 (Making a Scale Model of the Earth-Moon System), the distance to the Moon is very large, and that would make our model rather impractical for us.

Students will do better with this activity if we confine our model to a desktop, so that they can see all the parts working together properly. We won't put the Sun in this model either, it is sufficient that we know where the Sun is supposed to be and in which direction the sunlight is shining (this tells us which way the shadows must go!) We can accomplish this simply by putting a construction paper arrow on the desk to indicate the direction of the sunlight!

### 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 Earth and the Moon cast shadows just as any object on Earth does when it lies in direct sunlight. These shadows stretch many thousands of miles off into space but are not visible to us unless a sunlit object passes through them.
2. Because the Earth is roughly 4x larger than the Moon, its shadow is four times wider and four times longer than the lunar shadow. This larger shadow is easier to hit, so to speak, which is one of the reasons why a lunar eclipse is much more common than a solar eclipse.
3. The Moon's orbit is tilted by just over 5°. This may not seem like much, but over the large distance from the Earth to the Moon, it becomes quite significant. Because of the tilt of the Moon's orbit, the Earth and Moon dance now above, now below these shadows in space and prevent an eclipse from happening. Only when Earth, Moon, and Sun are perfectly aligned on a level plane can we have an eclipse!

## Teaching and Pedagogy

This is an interesting exercise in solid geometry! Students working with their models will tend to make several mistakes, let's look at them one at a time. Your students may want to tilt the shadow rather than keeping it perfectly horizontal. This doesn't work in real life, the Sun is so far away that the shadow always points perfectly horizontally (in the plane of the solar system.) Remind your students what we learned using the solar clock and calendar – the angle of the shadow always points back to the Sun!

Some students may want to point the shadow in the wrong direction; the shadow must always point in the same direction as our sunlight arrow. This is really just another version of the same problem. Shadows are stubborn things, they always point directly away from the light source, and once again our experiences with the solar clock and calendar point this out to the student.

The real solution, as you see in the photo below, is to rotate the Earth-Moon model so that the Earth, orbit ring, and the Sun all line up precisely. If you think about that tilted orbit of the Moon, there are only two places where the orbit actually crosses in front of the Earth instead of being either above or below it. These points are called **nodes**; when the Moon is on a node – and that node lies directly between the Earth and the Sun – then an eclipse is possible.

Did you notice that for this model to work, you had to position the Moon between the Earth and the Sun? This is the **new moon phase** when the entire near side of the Moon is in darkness. If you wish, you can draw a new moon on the lunar orbit ring in this position with a marker and draw a full moon on the orbit ring on the opposite side of the Earth! It can be fun to have the children fill in the phases on the orbital ring to refresh them on the lunar phases again!

You will also notice that only the point of the shadow touches the Earth! In reality, this shadow point is never more than 50 miles wide! The combined rotation of the Earth and the orbital motion of the Moon during an eclipse cause the shadow to draw a thin, gracefully curving line hundreds of miles long across the Earth's surface. Combine this with the fact that the **total eclipse** lasts only a few minutes, and you will see why a total eclipse is such a rare event! To see this celestial wonder, you must be precisely on that thin line (and looking up!) at the exact time of day when the eclipse occurs. The relatively tiny size of the shadow, the motions of Earth and Moon, and the precise geometry required in space make this one of the rarest observational events!

**Safety Note:** Staring at the Sun is **NEVER** a safe activity! You can damage your vision permanently without realizing it (the eye has no pain receptors!) If you have the opportunity to observe a solar eclipse, get in touch with a local astronomy group – they can show you many safe and fun ways to observe this wonderful celestial event! See Activity #29 below for more information on this!

## Student Outcomes

### What will the student discover?

1. Solar and lunar eclipses are diverse and delightful events. Solar eclipses are visible only in precise places on Earth and for just a few minutes at a time, and only on the day of the new moon. The next solar eclipse visible across much (but not all!) of North America occurs April 8<sup>th</sup> of 2024. Only those lucky few who stand along the **line of totality** will see the full solar eclipse in all its glory.
2. Lunar eclipses are visible to at least  $\frac{3}{4}$  of the globe when they happen, they are the 'people's eclipses', so to speak. These events occur on full-moon nights, and you don't need a telescope or a binocular to enjoy them, just a lawn chair and a thermos of hot chocolate to keep you warm as you watch the celestial show!
3. The explanation for how eclipses happen is deeply embedded in the ideas of a moving Earth and Moon, revolving in their respective orbits. It is only when we understand how the moons and planets function in their orbits that we can understand the theory that explains how these events happen.

### What will your students learn about science?

Once again we will see the wonderful interplay between theory, prediction, and experimental data. This is the drama of modern science in action! We have developed a marvelous scientific model that explains the Earth-Moon system; it features a heliocentric system with the Earth as a planet rotating on a tilted axis as it orbits the Sun. Our model also includes a lop-sided Moon that forever turns one face to the Earth and keeps the other side hidden, along with changing phases and an elliptical orbit.

When we see an eclipse, this rare event begs to be explained! Can we adjust our model and add new features that will explain these rare and beautiful events without destroying the usefulness of our existing explanations? This is the challenge of the scientist in a nutshell, and we will take up that challenge together as we pursue this activity, and the next!

## Conducting the Activity

### Materials

1. One rubber T-ball
2. One large marble
3. 24-inch square of foam-core board
4. Sharp hobby knife
5. 4 wire coat hangers & sturdy wire cutters or 4 15-inch pieces of sturdy piano wire (a craft or hobby store should be able to help you with this.)
6. An empty soup can
7. Poster putty
8. Hot glue
9. Sheets of black (any dark color) and yellow (any bright color) poster paper
10. Can of light blue spray paint
11. Markers, tape, etc.

### Building the Solar Eclipse Model

1. Spray paint your rubber T-ball blue, and set on the soup can to dry. You can actually set the ball on the soup can and spray it over a sheet of newspaper, allow it to dry and rotate it between coats to be sure that the color is even.
2. When the ball is completely dry, have the students use markers to make this into an Earth model as we did with the ping-pong balls. As before, the exact shape and placement of continents and ocean won't matter much for our demonstration, so don't worry about making a perfectly accurate map!
3. **[Teacher]** Use a string compass and draw two circles on the foam core board. The first circle should be as large as the board itself, the second should be about 2-inches smaller. Trim the outer circle with the hobby knife, (have some cardboard beneath your project to keep from scratching the table!) Trim the inner circle next, this should leave you with a 2-inch wide ring, 2-ft in diameter. The exact width of the ring isn't important, but making it too thin will make it fragile.
4. **[Teacher]** The four wires must now be inserted perpendicularly along the equator of the Earth model, so they form a neat cross the same size as our foam core ring. It is usually easier to puncture the ball with the hobby knife first, and then insert the wire into the ball (you may wish to wear gardening or work gloves when you do this step to protect your hands.)
5. **[Teacher]** Once you have all the wires inserted and you are sure they are correctly in place so as to match the size of your foam core ring, a drop of super glue will help hold them firmly in place. Next use hot glue to firmly attach the wires to the foam core ring; it is often helpful to set the Earth model on the soup can (North Pole down!) while you do this to keep it from rolling around! When the hot glue has cooled completely, flip your model over – it is now ready to use.
6. Cut out a large arrow from yellow construction paper (use the whole length of the paper!) Draw and label a smiling sun at the base of the arrow, and label the pointed end 'Sunlight'. Tape this arrow to your desktop.
7. Set the empty soup can on the center of your sunlight arrow and set the Earth model on top of it. Adjust the position of the Earth so the Moon's orbit (foam core ring) is tipped a bit. The ring should be tipped enough so that the highest point of the ring is well above the top of the t-ball Earth. Secure the rubber ball Earth model in place on the can with some hot glue or a bit of duct tape.
8. Use some poster putty on the marble so that you can put it on the ring and make it stay put. Attach this carefully so that you don't damage the ring! Try moving the marble moon around the ring orbit, notice that the Moon is sometimes above the Earth, and sometimes below it.

### Exploring the Solar Eclipse Model

1. Now it is time to model the Moon's shadow. Use black construction paper to make a cone shape. Its widest point should be the size of the moon marble, and it should be just long enough to reach from the orbit ring to the t-ball Earth model. This will take a little bit of practice and adjusting! When you get it just right, tape the cone together and secure it to the marble moon with some silicone glue.
2. It is finally time to make a solar eclipse! The rules are simple:
  - You can turn the soup can around, but you cannot adjust the angle of the foam ring – it must stay tilted as it is. (This is why we secured the Earth model to the soup can!)
  - The Moon's shadow must remain horizontal, and point in the direction of the sunlight arrow.
  - When you find a place that allows the Moon's shadow to touch the Earth – you've done it! Use your poster putty to secure the Moon and its shadow in place!

### Discussion Questions

1. What does the black paper cone represent in our model?
  - **Answer:** The shadow of the Moon being projected onto the surface of the Earth.
2. Why do we need to be in such an exact location to observe a total solar eclipse?
  - **Answer:** Because the size of the lunar shadow is very small by the time it reaches Earth. This shadow is seldom more than 50 miles wide and you must stand directly in its path to see the total eclipse.
3. Why don't we have a total solar eclipse every time there is a new moon?
  - **Answer:** The Moon's orbit is tilted – most of the time, the Moon is either above or below the Earth during a new moon.

### Supplemental Materials

#### Going Deeper

The prediction of eclipses requires complex mathematics – far beyond the scope of your class whether you teach 1<sup>st</sup> or 12<sup>th</sup> grade! Even so, there are a number of excellent video resources that will help your students to picture, and imagine what happens during a solar eclipse. One of the most interesting of these are a series of short videos taken from the International Space Station looking down upon the Earth as the Great American Eclipse of 2017 happened in real time.

#### Being an Astronomer

In spite of dire warnings to the contrary, **it is possible** to observe the Sun safely as long as you do not look directly at it. While this may seem like a contradiction in terms, allow me to assure you that it is not. We have examined three methods in our previous unit of observing the Sun, one using cardboard boxes that fits in nicely with our low-cost science program, the second requires a pair of binoculars; the third requires only a convenient tree, all of these are easy and fun!

#### Being a Scientist

Being a scientist and observing a solar eclipse is difficult because the solar eclipse is such a rare phenomenon. Still, if you get a chance in your lifetime to observe a total solar eclipse – I urge you to take advantage of it!

#### Following Up

Use the internet and search for the next upcoming eclipses. Even if the eclipse is too distant for you to travel to and observe, there is often live video available from scientists who have made the journey to observe and record this magnificent event.

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