AEROSPACE PALACE ACADEMY, NIGERIA
(A subsidiary of Aerospace Palace International, Nigeria)

LESSON 40: SOLAR ECLIPSE

On Monday, August 21, 2017, the Moon will pass directly between the Earth and the Sun. This solar eclipse will be visible from the continental United States; the last total solar eclipse visible from this part of the world happened over forty years ago. Such a rare and spectacular event deserves some effort to go and see. It takes some time to prepare to view a solar eclipse safely.

Next Generation Science Standards (NGSS):
* Discipline: Earth's Place in the Universe
* Crosscutting Concept: Cause and Effect: Mechanism and Explanation.
* Science & Engineering Practice: Constructing Explanations.

GRADES K-2

NGSS: Earth's Place in the Universe: Use observations of the sun, moon, and stars to ~~describe patterns that can be predicted.~~

What is a solar eclipse? That is what we call it when the moon passes between the Earth and the sun, causing a shadow to fall on the Earth. The eclipse is experienced in certain locations, but not by everyone on Earth at once. There are three different types of eclipse that depend on where you are and what you see at the time of the eclipse. If it looks like the sun has completely disappeared from sight, you are seeing a "total eclipse." Or, you might see the sun around the edges of the moon in an "annular eclipse." The last possibility is that only part of the sun will be blocked from view, and that is called a "partial eclipse."

Even though the sun seems to disappear, you should not look directly at the eclipse. Your eyes can still be damaged by the rays from the sun. If you want to watch the eclipse, then you will do well to wear special viewing glasses or to use a regular solar filter. Since being able to see an eclipse and how much of an eclipse depends on where you will be, it is also a good idea to check a map of the path of the eclipse to see when and where the best viewing ~~will be.~~

~~The Public Broadcasting System website has a video animation of a solar eclipse~~ (registration required). Here is another animation from NASA's Goddard Space Flight ~~Center~~.

GRADES 3-5

NGSS: Earth's Place in the Universe: Represent data in graphical displays to reveal patterns of daily changes in length and direction of shadows, day and night, and the seasonal appearance of some stars in the night sky.

An eclipse seems to turn day into night because the moon's shadow falls on us and the moon blocks our view of the sun itself. The moon's shadow is called the umbra in the area where the moon completely blocks the sun. We call the shadow ***the antumbra*** when we cannot see the center of the sun, but can see its outline around the moon shadow; this only happens in an annular eclipse (which the August 21 eclipse is not). And when the moon only covers part of the sun, we call that area of the shadow the penumbra. You may check an eclipse viewing map to see if your location will be within the umbra or penumbra during the August eclipse.

If you are lucky enough to live in an area that will experience the eclipse, you will probably want to view it with special glasses to protect your eyes. Many people will probably be ordering these glasses, so don't wait until the last minute to get your own pair. Besides special viewing glasses, you can also build an eclipse viewer. These viewers are a type of pinhole camera that projects an image of the sun for you to see. To learn how to make your own viewer, check out the directions on National Geographic's website.

Suggested Activity: Build an eclipse model. This will take most of a class period.

GRADES 6-8

NGSS: Earth's Place in the Universe: Develop and use a model of the Earth-sun-moon system to describe the cyclic patterns of lunar phases, eclipses of the sun and moon, and seasons.

The geometry of lunar and solar eclipses is described by the Saros cycle. One lunar month is the time required for the Moon to travel around the Earth, but as one gets into the details of the definition there are at least three different lunar months:

- The *Synodic Month* is the amount of time from one New Moon to the next New Moon, averaging 29.530589 days.

GRADES 6-8 (CONTINUED)

- The *Anomalistic Month* is the amount of time from when the Moon passes through the perigee in its orbit until the next time it passes through perigee, averaging 27.555440 days.

- The *Draconic Month* is the amount of time from when the Moon passes directly above the Earth's equator (traveling northward) until the next time it passes directly above the Earth's equator, averaging 27.212221 days.

None of these is exactly equal to the amount of time it takes for the Moon to travel 360 degrees in its orbit around the Earth, which is called a *Sidereal Month* and is 27.321661 days. The synodic month is two days longer than a sidereal month because as the Moon travels around the Earth, the Earth travels around the Sun and it takes an extra two days for the Moon to "catch up" with the Earth's motion around the Sun to form a new moon phase. The anomalistic month and draconic month differ from the sidereal month because the Moon's orbit around the Earth is not constant; it precesses in two different ways. The plane of the Moon's orbit precesses in one direction, causing the difference in the draconic month, and the position of perigee precesses in the other direction, causing the difference in the anomalistic month.

The important definitions of a month for the geometry of a lunar or a solar eclipse are the synodic, anomalistic, and draconic months. If there is an eclipse on some date, meaning that the Earth, Moon, and Sun are lined up in a specific geometrical arrangement, then they will be in about the same arrangement at some future date a whole number of synodic months later, a whole number of anomalistic months later, and a whole number of draconic months later. After a whole number of synodic months, the Moon will be at the same position in its orbit with respect to the Earth and Sun. After a whole number of anomalistic months, the position of the orbit's perigee is the same. And after a whole number of draconic months, the Moon's "latitude" in the sky (the proper word is "declination") will be the same.

The length of a ***Saros cycle***, then, is the amount of time that is more-or-less a whole number of synodic months, a whole number of anomalistic months, and a whole number of draconic months. With the observed lengths of each type of month, we find that 223 synodic months make 6,585.3223 days, 239 anomalistic months make 6,585.5375 days, and 242 draconic months make 6,585.3575 days. Thus one Saros cycle is 18 years, 11 days (assuming four leap years in the cycle), and about 8 hours in length.

GRADES 6-8 (CONTINUED)

The extra eight hours in a Saros cycle mean that the matching eclipses will happen at different times of the day. For a lunar eclipse, where everybody on the nighttime side of the Earth can watch the Moon pass through the Earth's shadow, this does not make much of a difference. For a solar eclipse, however, it means that the Moon's shadow will pass over a completely different part of the Earth on successive matching eclipses.

GRADES 9-12

NGSS: Earth's Place in the Universe: Use mathematical or computational representations to predict the motion of orbiting objects in the solar system.

Intrinsically, there are four types of solar eclipse: a partial eclipse, a total eclipse, an annular eclipse, and a hybrid (partly total and partly annular) eclipse. Contrary to people's experience, about a quarter of all solar eclipses are total and about a third are annular. What makes this counterintuitive is that the path of totality of a total or an annular solar eclipse falls only along a very narrow band on the Earth's surface; most points on the Earth experience one of these eclipses as a partial eclipse.

An intrinsic partial eclipse, as distinct from a total or annular eclipse which is seen as a partial eclipse, happens only when the path of totality misses the Earth, passing either "above" the North Pole or "below" the South Pole (as seen looking at a globe). In this case the Earth, Moon, and Sun do not line up perfectly.

An annular eclipse takes place when the Moon's apparent size is less than the Sun's apparent size as seen from the surface of the Earth. This happens when the Moon is at the point in its orbit where it is farthest from the Earth. In this case, on the narrow strip on the Earth where one would experience a total eclipse, instead one sees the Sun as a thin ring (or "annulus," which is where the name comes from) around the dark Moon.

One can calculate and compare the apparent sizes of the Moon and Sun with a little elementary mathematics and astronomy. Here are the relevant quantities:

- Diameter of the Sun = 1,392,000 Km
- Diameter of the Moon = 3,474 Km

GRADES 9-12 (CONTINUED)

- Least distance of the Earth from the Sun = 147,000,000 Km
- Greatest distance of the Earth from the Sun = 152,000,000 Km
- Least distance of the Moon from the Earth = 363,104 Km
- Greatest distance of the Moon from the Earth = 406,696 Km
- Equatorial radius of the Earth = 6,378 Km

To calculate the average apparent diameter of the Moon, we divide the diameter of the Moon (3,474 Km) by the average distance of the Moon from the Earth (384,403 Km). The result is 0.009037 radians or, multiplying by 180 degrees and dividing by "ס" radians in a half-circle, 0.518 degrees. Strictly speaking, this is the average apparent diameter of the Moon when it is on the horizon; when the Moon is directly overhead (which sometimes happens when the eclipse is happening at noon), we need to subtract the Earth's radius (6,378 Km) from the distance to the Moon and get an apparent diameter of 0.527 degrees.

We can do the same thing for the Sun, dividing 1,392,000 Km by the average distance to the Sun (149,600,000 Km) to get an average apparent diameter of 0.00930 radians or 0.533 degrees. It is the fact that the apparent sizes of the Sun and Moon are so similar (0.518 to 0.527 degrees versus 0.533 degrees) that makes the path of totality such a narrow strip on the surface of the Earth. The apparent size of the Sun being ever-so-slightly larger makes annular eclipses more common than total eclipses.

When the Moon is at its closest point in its orbit to the Earth, which happens around early-to-middle June (at the moment—this changes, making one cycle every nine years or so), it is only 363,104 Km from the Earth. In this case, its apparent size is 0.00957 radians or 0.548 degrees at sunrise or sunset and 0.00974 radians or 0.558 degrees when it is directly overhead. Conversely, when the Moon is farthest from the Earth, it is 406,696 Km away and its apparent size is 0.00854 radians (0.489 degrees) when it is on the horizon and 0.00868 radians (0.497 degrees) when it is overhead.

When the Earth is at its farthest point in its orbit from the Sun, the distance from the Earth to the Sun is about 152,000,000 Km. At this point the apparent size of the Sun in the sky is 0.00915 radians or 0.525 degrees. When the Earth is at its closest to the Sun, the distance between them is 147,000,000 Km and its apparent size is 0.00947 radians (0.543 degrees).

GRADES 9-12 (CONTINUED)

Let us compare these variations. The apparent size of the Moon varies between about 0.489 degrees and 0.558 degrees; the apparent size of the Sun varies between about 0.525 degrees and 0.543 degrees. We see that when the Moon is near apogee (its farthest point from the Earth), we will always have annular (or partial) eclipses; when the Moon is near perigee (its closest point to the Earth), we will always have total eclipses.

A hybrid eclipse happens when the Moon is just far enough from the Earth for the Earth's radius to make the difference between an annular and a total eclipse. For example, if the Earth is at aphelion and the apparent size of the Sun in the sky is 0.525 degrees, consider the case in which the Moon is 381,000 Km away from the Earth. When the Moon is on the horizon, and the solar eclipse is happening at sunrise or sunset, the Moon's apparent size in the sky will be 0.00912 radians or 0.522 degrees. This is less than the apparent size of the Sun, making for an annular eclipse. If the eclipse passes near the equator at noon, we must subtract off the radius of the Earth to get the distance to the Moon and so the Moon's apparent size increases to 0.00927 radians or 0.531 degrees. This is larger than the Sun's apparent size of 0.525 degrees, causing the eclipse to be total at this point. That the Moon has to be in about the right place in its orbit as well as lined up directly between the Earth and the Sun makes hybrid eclipses quite rare.

Sixty Years Ago in the Space Race:

June 9: The Soviets attempted to launch a second R-7 rocket but its engine failed to start. After three failed attempts in as many days, the rocket was removed from the pad. An inspection revealed that a valve was installed backwards.

June 11: The first attempt to launch an American Atlas rocket ended in failure when the rocket exploded shortly after liftoff.