SESSION FIVE: SOLAR AND LUNAR ECLIPSES

THE GREAT ECLIPSE CHASE

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Murphy's Laws have built in corollaries for virtually every situation and profession. For astronomers there seems to be a direct relationship with the desire to observe a particular celestial event and the number of pitfalls and disasters that nature can produce to thwart the event. In essence, when you are sure everything will proceed in a smooth and orderly fashion, Murphy is hiding just behind that next rock ready to make you stumble and laugh as you fall. This time, happily, it was Murphy that fumbled.

My little odyssey began when friends, Ernie Andrews (minister), Charlie Takacs (planetarium director), and Carlson R. Chambliss (Ph D astronomer) traveled to Richmond, Virginia to view a broken annular eclipse. The solar event was being sponsored by nature herself, but the ground expedition was hosted by the Virginia Science Center's Universe Planetarium. On May 30, 1984 the moon was to rendezvous with the sun along an extremely narrow path, only four miles wide in the location where we would be situated.

The eclipse path stretched from the Gulf of Mexico to the Virginia coast. Positioning was everything. Unlike total solar eclipses where the moon completely covers the sun and the sky darkens rapidly, this eclipse would feature a ring of sunlight surrounding Sol because the moon would be just a smidgen too far away, and therefore, too small to cover the sun completely. What would make this eclipse unique, however, was that the apparent size of the moon was so close to the apparent size of the sun, that when the ring phenomenon occurred, mountains jutting from the rugged limb of the moon would break the perimeter of the sun into a circle of sparkling, flickering light called Baily's Beads. Normally in a total solar eclipse, Baily's Beads would be visible just a moment or two before second contact. With a broken annular, such as the one that we would witness, Baily's Beads might be visible for up to 30 seconds or more as the center of the moon passed in front of the center of the sun.

Our plan was to view the eclipse along the banks of the James River at Berkeley Plantation, 40 miles east of Richmond. There would be extensive network media coverage, as well as hundreds of participating observers as this celestial courtship of the sun and the moon passed over the plantation around noon. The eclipse would also provide, as Charlie noted, "an exceptional opportunity to record the many varied methods for viewing the sun's disk." Since at all times the sun's bright and dangerous photosphere and chromosphere would be visible, this eclipse could not be viewed directly with the unaided eye. Filtration or projection methods would have to be employed.

Murphy's plan was a classic in its simplicity. It was to provide as much cloud cover and precipitation over as wide an area as possible, then render everyone immobile by duping as many meteorologists as possible into thinking that the skies would eventually clear.

Our crowded compact station wagon, lent to us by Kutztown University departed in a downpour which did not abate to any real extent during our six hour trek to Richmond. By the time we were comfortably settled into our Holiday Inn, we were already contemplating chasing the eclipse further south the following morning. Only Ernie Andrews, with his direct hotline to God, remained confident that we would have any chance of seeing the event through broken or clear skies. However, even he had to bow to Murphy's wishes when we and about 100 other eclipse enthusiasts assembled, early that evening, in the ultramodern Universe Planetarium and heard the morning's forecast for the eclipse—that simplest of four-lettered words which is the bane of all astronomical observations—RAIN!!!

Our soggy walk back to the motel brought us to the realization that it was up to us to find that elusive hole in the sky so that we could bathe in the near umbra of the moon. Carlson miraculously produced a bottle of cheap peach brandy from his suitcase, and we were off to my room to plan strategy for the next day. With maps and charts spread over the bed and our glasses filled with ice to smooth the cutting bite of the liquor, we decided to rouse ourselves at 5:30 a.m. for a final weather assessment and then make our move.

The 11 p.m. Weather Channel satellite photo showed a long, narrow tongue of clear sky about 200 miles to the west of Richmond, followed by another region of clouds farther west paralleling the Appalachians. Atlanta, Georgia, along the centerline of annularity, would be clear and dry tomorrow, but eastward towards Greenville, South Carolina, the prediction for a successful view dwindled to only 50 percent. Our more restricted driving range appeared to limit us to Greensboro, North Carolina, about 200 miles away, which held almost no prospects of clearing by eclipse time. Still we thought that we had to give it a go. We had come too far already to simply pack it in and admit defeat. One thing was certain; Berkeley Plantation, as well as the entire Eastern Seaboard, was doomed to be damp and soggy on eclipse day. We were on our own.

I was awakened by the clock radio which Charlie had set for 5 a.m. and to his voice saying, "It's 'puddling' outside." The rain had not stopped. We quickly dressed, assembled our gear, and ran it down to the wagon. Shortly after six, we were driving past the glitzy planetarium where others from our group would be assembling at 8 a.m. for a continental breakfast, and then the bleak drive to Berkeley Plantation.

By 8:30 a.m., we were nearing the border between Virginia and North Carolina, and conditions had not improved to any great extent. We gassed up and breakfasted at a local truck stop where the southern drawl of the waitress and the twang of the country music were thicker than the ketchup which Ernie used to smooth over the bland taste of his grits. It was a fortunate stop, however, for there we met another party of eclipse chasers. They had a small road map of the Carolinas and had plotted the centerline of annularity through these two states. We were able to jot on a napkin the few towns as markers which lay along the eclipse path.

A half-hour later we were procuring "official" North Carolina road maps at a tourist hospitality center. Luckily, they were large and detailed, containing whole degrees of latitude and longitude, essential to my plan of plotting the northern and southern limits of the eclipse path. The race was now on for a site. Charlie was driving well above the 55 mph speed limit. Carlson was scanning the highway with binoculars for state police. Ernie adamantly maintained that we were going to see the sun. Damn you Murphy—it was still pouring outside.

To obtain a detailed plot of the path of annularity, I constructed a makeshift ruler from the printed lines of the map text. Then I used this measuring device to locate as accurately as possible the northern and southern limits of the eclipse path. Precise latitude and longitude positions were obtained from the U.S. Naval Observatory's Bulletin 166 which thankfully we had taken along. It was tedious work on a bumpy highway traveling at 70 mph; but within a half hour, numerous points were positioned, connected, and then double checked. I quickly concluded the centerline computed by the observers back at breakfast was wrong. They would be about five miles too far north and would miss the most spectacular part of the eclipse, the sun completely surrounded by Baily's Beads.

From our information two sites were chosen, one northeast of Greensboro, in a small town called Osceola, an important railroad depot during the Civil War; and the other, about 40 miles to the southwest on the banks of the Yadkin River, just north of a small community called Reeds. Our decision was narrowed down considerably when a radio bulletin noted that the banks of the Yadkin no longer existed. The river had flooded Reeds. Our decision was irreversible—onward to Osceola despite the fact that it was still raining.

It was in this moment of deepest despair that Murphy began to falter. The rain suddenly stopped and the scudding gray clouds that had plagued our entire trip, thinned and rapidly lifted. Ahead of us lay a small patch of barely blue sky. Charlie nearly pushed the accelerator pedal to the floor as we reveled in our excitement over the improving weather conditions. As we approached our turquoise oasis, others miraculously began to appear. A flash of sunlight suddenly scalded our white vehicle, and then another, as our screaming station wagon rolled under clear skies.

In our euphoria we exited from the main highway too early, and without very much help from our road map, had to slice our way through Burlington, NC, a city of about 40,000. We had been traveling along Interstate 85 which paralleled the eclipse path for several hundred miles and which remained our best hope for an easy access to a centerline position. The few clouds which remained had become puffy white cumulus against a fresh clean sky. A left turn at Glen Raven, on through Elon College, and then a question mark at Gibsonville. Our map did not indicate a route number to Osceola, and the road divided up ahead. At this point in our journey, there was no margin for error. Our destination lay somewhere 10 miles in front of us, and the moon was scheduled to make first contact with the sun in less than 15 minutes.

Luckily, we found the local municipal building. I must have had an urgent look on my face as I briskly opened the double glass doors and immediately approached a secretary. "Osceola," she sighed. "Why I've heard of it, but I've never been there. One moment, please..." She sashayed into an official looking office, then disappeared around a corner. What seemed like an eternity later, the chief of police appeared, with a Boss Hog attitude straight from Dukes of Hazard, but smoking a pipe rather than the classic long cigar. "Where you all headed," he drawled. He had the kind of expression that you wouldn't want to encounter if pulled over for a traffic violation. "Osceola!" I snapped, perhaps a bit too tersely. "There's an eclipse about to happen and we're late." He relaxed somewhat, his badge catching the reflected glint from the fluorescent lights above his head. Then after a couple of short puffs on his pipe, he directed me to follow Route 61 north for another 10 miles.

That may have been the longest ribbon of macadamized roadway that I ever traversed—past sprouting tobacco fields drying in the spring breeze and ramshackled homes that looked as if they hadn't been repaired since the War Between the States. Up ahead lay a couple of scattered buildings, a whitewashed, dilapidated-looking general store, and a rusty old bullet-pocked sign proclaiming that we had finally arrived in OSCEOLA.

With only minutes to spare, it was now quite evident that we were not going catch first contact, the beginning of the eclipse. We had to secure a place to observe without arousing the suspicions of the locals and then assemble all of our equipment. I ran down a road, one of only two in town, towards what looked like some inviting tobacco fields.

The location was not ideal; the ground was wet in places and telephone wires split the sky, but still it would do quite nicely. Across the road a young, bearded man rested on his front stoop. I introduced myself, and then got straight to the point. No, he did not own the field across the road, but he knew who did. He probably wouldn't mind if we observed there, but then it would be best to secure his permission. His number was in the phone book. “Better call to make sure,” he quipped.

Oh God, another 10 minutes of fumbling. More wasted time... Where were my dimes? My mind screamed at him in desperation. Man, don't you know there's an eclipse about to happen? Damn it, we don't have time for civility. I wanted to blast him right where he sat and take over his "ranch."

"Thank you," I calmly tried to reply and started to turn up the road again. My lips, quivered. We eyed each other for just an instant more—a critical moment in both of our lives where he must have realized that there was something terribly out of sync—at least in my world. His facial expression turned to a smile, and he motioned over to his left to a lush grassy plot that was just perfect for our group. "You're free to use it," he nodded. My "thank you" this time was more ecstatic.

Daryl Rumley, his wife, and three small children could not have been more congenial partners in our eclipse adventure. They viewed the sun with us, provided us with soft drinks, and allowed our aching bladders blessed relief. It had been a long drive from Richmond. The kindnesses shown to our group by that family were truly appreciated, and they will be remembered as one of the high points in our drama to view this eclipse.

The Rumley homestead was also right on target—ground zero—as we were soon to discover. The next 10 minutes were spent in intense activity as tripods, cameras, solar filters, telescopes, video and audio recorders were rapidly unloaded, unfolded, mounted, switched on, screwed in, assembled, adjusted, and pointed towards the sun. "Where's the masking tape?" "Does anyone have a wrench?" "What time is it?" were the familiar chattering heard during those first harried moments. These exclamations were punctuated against the varied tapestry of precise time beats from my shortwave radio, keeping us ever vigilant of the disappearing sun. Within a dozen minutes of our arrival at the Rumley farm, the first pictures were snapped, and we were beginning to settle into our observing routine.

There is no other natural phenomenon which can quite duplicate the subtle shades of colors or the sudden dimming of light which befalls a landscape in or near a total solar eclipse. The effect is one of contrasts because the sky is clear, yet the intensity of sunlight dwindles well below the threshold of that which would be expected on even a cloudy day. In total solar eclipses, the approach of the moon's shadow can produce a blackening sky similar to the look of an approaching thunderstorm, and then a rapid dimming of daylight until the illumination of the landscape is equivalent to the brightness of several full moons. Because this eclipse was a broken annular, the sun's intensity was reduced to only $^{1}/_{250}$th of its normal brilliance. Still, the effects were startling and spectacular.

As annularity approached, we appeared to be immersed in a gray fog. God turned down his giant rheostat, and the landscape darkened in obedience. Colors lost their vividness and became metallic blues and greens, browns and yellows. Shadows became less distinct as the sky grayed into denim blue, yet the sun remained painfully vivid.

There was a brief and glorious moment as I peered through my camera with its filtered lens when the entire moon was engulfed by a broken ring of jeweled solar iridescence, sparkling and flashing as streamers of sunlight poured its radiance from the depths of lunar valleys gliding past the limb of the sun. The ground pulsated as if being pummeled by distant lightning, but in this case the flashes were being created by the collective flashes and diminutions of the beaded ring.

I managed to snap four images during the brief, broken annular portion of the eclipse. A solar filter was used at all times to ensure safety. After each frame was recorded and the film advanced, I needed to wait a second or so while watching the sun through my camera’s viewfinder for tripod and camera vibrations to be naturally dampened. Using a cable release so I would not have to physically touch the camera to trigger the next exposure, was just as important. This period of waiting is perhaps the most difficult aspect of successful eclipse imaging which photographers have to master, and it needs to be practiced well in advance so that it becomes an instinctive aspect of photographing the event. I had good training because 11 years earlier, I had successfully recorded a total solar eclipse from the deck of a moving ship. That eclipse photography was considerably more complicated.

The abrupt fading of the diamonds on the eastern limb of the sun and their enhancement on the opposite side signaled the final curtain call of this broken annular eclipse. About eight or ten brightening beads blended, melted, and consumed each other to reform the razor thin solar crescent. We had just witnessed one of nature's rarest and shortest of spectacles. The entire broken annular event had lasted only seven seconds.

We stuck it out for the duration until the moon had completely retreated from the sun, and by the time we packed and said our goodbyes to the Rumley family, it was three o'clock. Ahead of us lay 600 miles of concrete and macadam roadway to be traversed as rapidly as the law would permit. Three of us had teaching assignments the following morning. But we really didn't care. When I arrived home by 3:00 a.m. my adrenalin was still pumping, and sleep came with great difficulty.

Just how lucky we had been was revealed to us by the satellite photos that Charlie obtained a few days later from the National Weather Service. Murphy had been defeated by our small, stalwart group, but he lurked just a few dozen miles away in an approaching cloud bank that we had seen moving towards us from the west near the time of fourth contact. The entire East Coast had also been prevented from viewing the eclipse by either rain or cloudy conditions.

We had defeated Murphy this time and had recorded the May 30, 1984 broken annular eclipse, but next time, who could tell? For the moment, we savored a deserved triumph which lasted right through the working hours of the next day. That Friday evening, I had one of the deepest and most relaxing sleeps of my life.

Written in June of 1984/revised in Februrary of 2007

NOTES

Name _________________________________ Date ____________________ Moravian College

QUESTIONS ABOUT THE *GREAT ECLIPSE CHASE*

1. Based upon the information given in the first paragraph, define what is meant by Murphy's Law. If it can

   ____.

2. _________________ Is an annular eclipse a solar or lunar eclipse? Base your answer on what is being covered or what is hiding, Sol or Luna.

3. ____ What is the main characteristic of an annular eclipse?

4. _____________________ The effect produced by the last part of the sun to be covered, as mountains near the edge (limb) of the moon hide the last remaining visible part of the sun, are known as… ….

5. ____________________ Was there any time that this eclipse was safe to view without filters?

6. ____________________ Give a synonym for the word "umbra."

7. ____________________ Was Atlanta, Georgia located in the correct position to see the eclipse if the weather was clear?

8. ____ What would happen if our observing location was too far north or south of the northern or southern limit of the eclipse?

9. ____ Why was Osceola, North Carolina the only choice for our location for observing the eclipse?

10. What are some of the visual effects (sky color, shadow intensity) that can be seen during a solar eclipse?

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NOTES

A. Some basic information about eclipses

1. **Definitions/Concepts/Nomenclature**
   a. **Eclipse:** It means to either hide or to cover
   b. **Lunar or Solar eclipse?** An eclipse gets its name from the object that is being hidden or covered.
      1) **Solar eclipse:** Sol is Latin for the sun. The moon hides the sun.
      2) **Lunar eclipse:** Luna is Latin for the moon. The moon hides in the shadow of the Earth.
   c. **Umbra:** The primary shadow of the Earth or the moon.
      1) **Total solar eclipse:** When the observer on Earth is completely in the moon's umbra. The sun is totally hidden by the moon.
      2) **Total lunar eclipse:** When the moon is in the Earth's umbra, it is completely eclipsed by the Earth's shadow.
   d. **Penumbra:** The secondary shadow of the Earth or the moon.
      1) **Solar eclipse:** Part of the sun is being covered by part of the moon as witnessed by an observer on the Earth.
      2) **Lunar eclipse:** The sunlight reflecting from the moon is being partially blocked by the Earth. An observer on the moon would see part of the Earth blocking part of the sun.

2. **Different types of eclipses**
   a. **Total:** **sun and moon**
      1) Solar: The moon totally covers the sun
      2) Lunar: The moon moves completely into the shadow of the Earth.
   b. **Partial:** **sun and moon**
      1) Solar: Part of the moon is covering part of the sun.
      2) Lunar: Part of the moon is within Earth's main shadow, the umbra.
   c. **Annular:** **sun only.** The moon angular size appears to be too small in the sky to cover the sun as it passes centrally in front of it. A ring or annulus of the sun is seen around the moon.
   d. **Penumbral:** **moon only.** The moon passes into the secondary shadow of the Earth called the penumbra, but no part of the moon passes into Earth's main shadow.

3. **Angular diameter:** The sizes or separations of astronomical objects seen in the sky are measured as angles or fractions of angles of the sky which they obscure.

4. The apparent size or **angular diameters** of the sun and moon in the sky are about the same. The sun is about 389 times farther away than the moon is from the Earth, but the sun is about 400 times the diameter of the moon. This makes their angular diameters similar. Both the sun and moon appear to be the same size in the sky to the human eye.

5. **Changing Distances:** The Earth revolves around the sun and the moon revolves around the Earth in oval-shaped or elliptical orbits causing slight changes in each object's angular diameter.

Object	Distance	Angular Diameter
a. Earth-Moon distance		
1) Perigee:	221,000 miles (356,000 km)	33' 30"
2) Average:	239,000 miles (385,000 km)	
3) Apogee:	252,000 miles (406,000 km)	29' 31"
b. Earth-Sun distance		
1) Perihelion:	91.5 million miles (147 million km)	32' 30"
2) Average:	92.6 million miles (149 million km)	
3) Aphelion:	94.5 million miles (152 million km)	31' 28"

peri = near, apo = away from, helion = Helios = sun, ge = geo = Earth (Greek)

6. Ratio of Earth to sun distance, Earth to moon distance:
Ratio of Sun's diameter to Moon's diameter:

$$\frac{\text{Sun to Earth distance}}{\text{Earth to moon distance}} = \frac{92{,}960{,}000 \text{ miles}}{238{,}900 \text{ miles}} = \frac{389}{1}$$ Moon is about 400 times closer to Earth than the sun

$$\frac{\text{Diameter of sun}}{\text{Diameter of moon}} = \frac{864{,}300 \text{ miles}}{2{,}160 \text{ miles}} = \frac{400}{1}$$ Sun is 400 times bigger than the moon

If the Earth is two feet in diameter and the moon is six inches in diameter a ratio of 4:1 exists, 8000:2000 miles which is very close to reality 7,917.5:2160 miles in actuality 3.67:1.00 (equatorial diameter = 7926, polar diameter = 7900 miles).
The distance of the moon from the Earth expressed in Earth diameters (8,000 miles) = 240,000 miles/8,000 miles = 30 Earth diameter x 2 feet/Earth diameter is equal to 60 feet (30.1). Sixty feet x 389 Earth-moon distance to sun = 23,000 feet = 4.4 miles to the sun.

7. **The changing distances of the moon from the Earth and the Earth from the sun** does make a difference and creates the conditions that allow a central solar eclipse to be either total or annular. A **central solar eclipse** occurs when observers can see the center of the moon passing in front of the center of the sun. Since the moon spends more time at a distance greater than its average distance from Earth (apogee) a central solar eclipse has a greater chance of being annular than total, about 48/49 total solar eclipses to 51/52 annular eclipses.

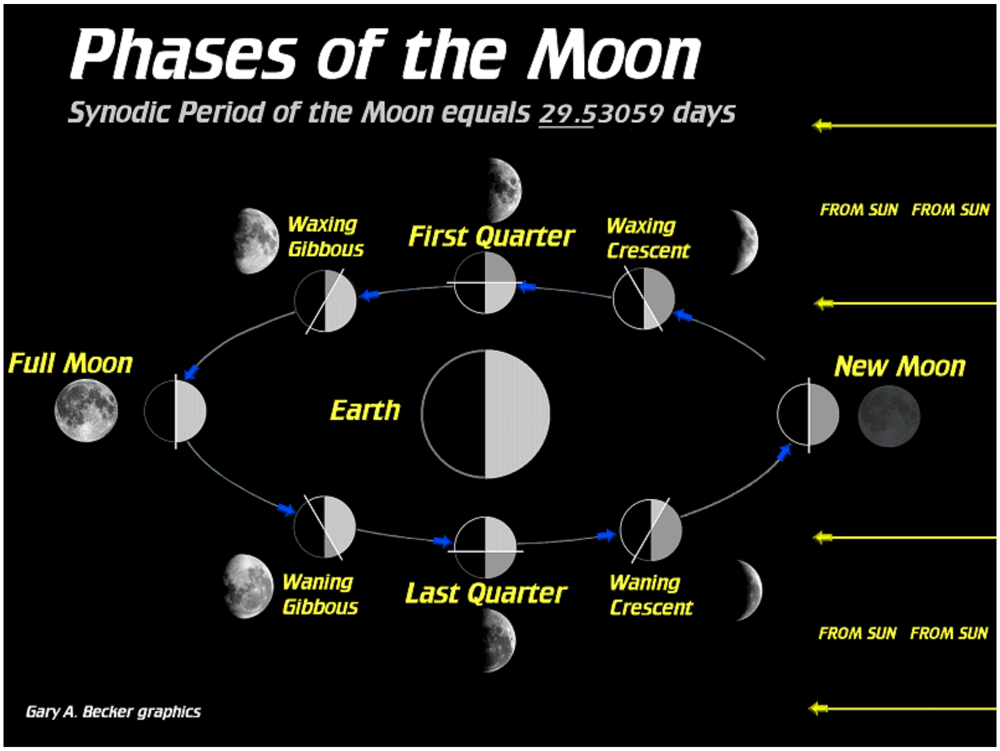
8. **Necessary conditions to create an eclipse:**
   a. The **moon** must be either **new or full**. See the diagram showing lunar phases.
   b. The **moon** must be **near or at a node**, one of its two crossing positions on the ecliptic, in order for a lunar or a solar eclipse to occur. The word **node** is a general term that is used to express the intersection of two planes in space.
   c. There are two crossing position, the ascending node where the moon moves from below to above the eclipse, and the descending node, where the moon travel from above to below the ecliptic.

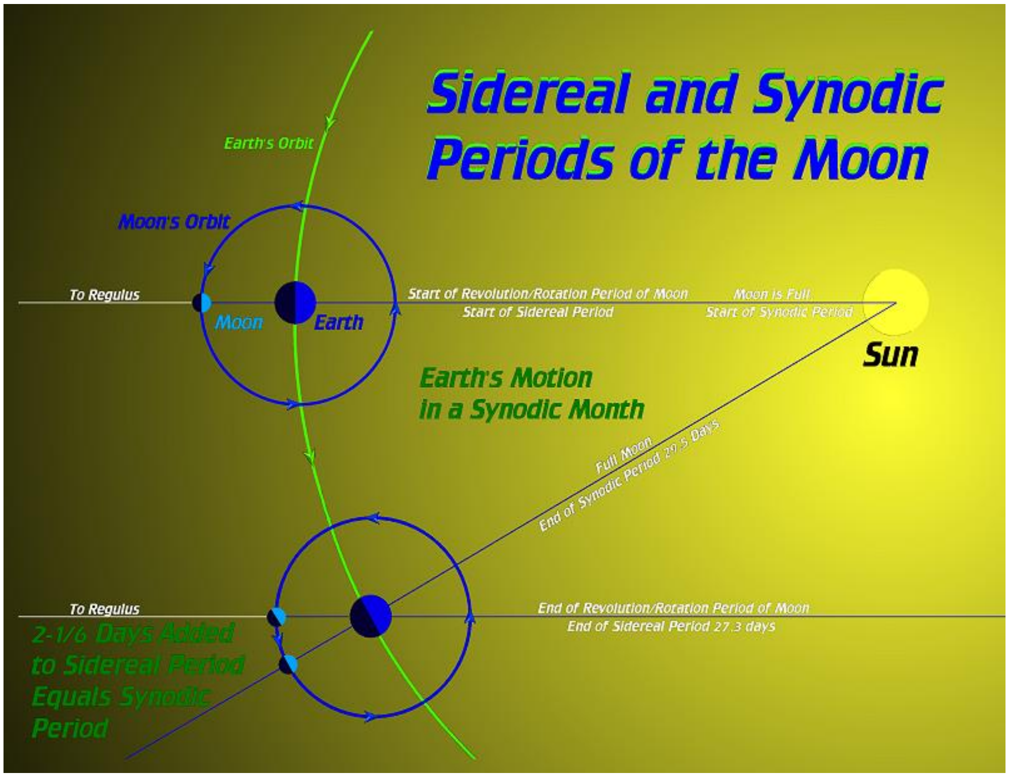
9. **Circumstances governing the repetition of eclipses:** Consider the repetition of eclipses like two different but steady drumbeats. When the drumsticks strike the drum at exactly the same instant, an eclipse occurs. The beats are in phase. The next series of beats are out of phase and no eclipse occurs. Eventually the cycle of beats will become in phase and another eclipse will occur. The different beats are represented by different lunar cycles: the synodic month, the nodical month, and the anomalistic month.

   a. **For an eclipse to occur, the moon's phase must be full or new.** The interval of time it takes the moon to complete its series of phases is called its **synodic period,** and averages **29.5**3059 days. This is the **MAJOR DRUM BEAT** driving the repetition of any solar or lunar eclipse.

      1) **Sidereal period of the moon: 27.3**2166 days. It is the period of revolution of the moon around the Earth. The sidereal period of the moon is not one of the beats that create the repetition of eclipses, but it must be thoroughly understood to comprehend the other necessary beats.

      2) **The Synodic (phase) period of the moon: 29.5**3059 days. It is different than the lunar sidereal period. After one revolution of the moon around the Earth, the Earth has completed approximately $^{1}/_{12}$th of its orbital circuit around the sun. Because of the change in position of the Earth due to it orbital motion, the Earth, moon, and sun are no longer in the same phase alignment. To repeat the same phase alignment, of Earth, moon, and sun, the moon must continue in its orbit on average for another 2.2 (2-1/6) days. When this interval is added to the sidereal period of 27.3 (27-1/3) days, the synodic period of 29.5 days results.





b. **<u>For an eclipse to occur the moon must be at or near one of its nodes</u>.** This is called the **nodical or** nodal **period** and it is the interval of time it takes the moon to make two successive crossings of the same node, either the **ascending** or **descending** node. At the **ascending node** the moon crosses the ecliptic **moving in a northerly direction**. Just the opposite is true for the **descending node** where the moon crosses the ecliptic **moving southward**.

1) **<u>Nodical period</u>: <u>27.2</u>**1222 days. This period is shorter than the lunar sidereal period because the nodes move westward in the sky, in the opposite direction of the eastward moving moon.

2) **<u>The nodes move westward</u>.** Each successive time that the moon returns to the same node, it will cross at a position slightly west of its original location. This westward motion of the nodes along the ecliptic plane is referred to as the **regression of the moon's nodes,** and it is why the nodical period is shorter than the sidereal period. Remember, the moon is moving eastward amongst the stars because of its orbital motion. At the same time the nodes are moving westward, in the opposite direction of the moon's motion. The moon must first return to the node before completing one orbit around the Earth. A complete **nodical regression cycle takes 18.61 years.**

3) **<u>Why do the nodes regress</u>?** The regression of the moon's nodes results from the sun's gravity trying to pull the orbital plane of the moon into the plane of the ecliptic. The result of this force acts at a right angle to it, thus causing the moon's orbit to wobble (regress or precess) to the west completing a full cycle in 18.61 years. Since the moon’s orbit wobbles from east to west we see the node moving in the opposite direction,

westward, for the exact same reason that the sun moves westward in the sky over the time period of a day.

c. **<u>In order for the repetition of an eclipse to occur, the same number of days must occur within the time frame of two different positive integral numbers of synodic and nodical months</u>. Integers** are whole or counting numbers such as -2, -1, 0, 1, 2, etc.

47 synodic months = 51 nodical months
47 x <u>29.5</u>3059 days **= 51 x <u>27.2</u>**1222 days **= ECLIPSE**
1387.938 days 1387.823 days **REPETITION**

The numbers 47 and 51 are integers while the number of whole days within 47 synodic months equals the same number of days in 51 nodical months. This period of time is equivalent to **3.8 years** (3 years 291 or 292 days) and represents an eclipse cycle that does not necessarily result in the repetition of similar eclipses or at similar latitudes. A cycle of similar eclipses would represent a series of eclipses of the same type, i.e., total, annular, or partial eclipses. The 3.8 years corresponds to a period of 3 years 291 or 292 days. The difference of one day results because there may be no or one leap year occurring during that period of time.

d. **<u>Eclipses occur more frequently than once every 3.8 years</u>** because there are many different cycles that are running concurrently.
   1) **<u>Minimum number of eclipses</u>:** There must be at least **two solar eclipses and two lunar eclipses** (including penumbral) **happening in any given year.** This results because there are two nodes.
   2) **<u>Maximum number of eclipses</u>:** There can be as many as **seven eclipses taking place within a one-year** period with the maximum number of any one type equaling five. Therefore, if seven eclipses occurred during a year's time, and five of them were solar, then only two could be lunar. Because of the westward regression of the moon's nodes, the time interval between eclipse seasons is shorter than half a year, 173.31 days versus 182.12 days. Because of the shallow inclination of the moon's orbit to the ecliptic an eclipse season can last anywhere from 31-37 days allowing two eclipses of the same type to occur before and after the node. In between, an eclipse of the other type would happen.

10. **<u>Circumstances for the repetition of similar eclipses</u>:** These criteria are used mainly for solar eclipses but they are also applicable for lunar eclipses.
   a. The **moon** must return to the **same phase,** new or full.
   b. The **moon** must be **at or near a node.**
   c. The **moon** must be at a **similar distance from the Earth.** This creates the repetition of the same type of solar or lunar eclipse.
      1) **Line of apsides** (ap-seeds): It is a synonym for the **major axis** of the moon's elliptical orbit. It is the longest line segment that can be placed within the boundary of an elliptical orbit. For the moon, the line of apsides completes one revolution around the sky in a period of 8.85 years. It **revolves eastward** in the plane of the moon's orbit and in the direction

of the moon's motion, therefore on successive perigee or apogee passes, the moon must catch up to this position making the anomalistic month longer than the sidereal month.

2) **Anomalistic month:** 27.55455 days, (**27.6** days). It is the time interval between two successive **perigee (closest)** or two successive **apogee (farthest)** passages of the moon.

3) The **Anomalistic month is longer than the sidereal month**: Since the line of apsides makes one complete revolution in a period of 8.85 years, the perigee and apogee positions are continuously changing their direction in the sky. The motion is towards the east, in the same direction that the moon is revolving around the Earth. Therefore, each successive perigee or apogee position is slightly ahead of its last location, and the moon must complete one full revolution (sidereal period) around the Earth plus travel the additional distance that the apsis (major axis) has moved during the period of time that the moon need to reach its perigee location once again. It must take the moon a longer interval of time to complete this cycle than the sidereal month.

4) The revolution of the line of apsides results from solar tidal forces (differential gravitation) which act to slow down and speed up the moon in various parts of its orbit, thus causing the major axis to revolve.

d. **Saros:** To meet the conditions of a similar eclipse, different positive integral numbers of synodic, nodical, and anomalistic months must contain the same number of whole days. The result is the period of time called the **saros,** an interval of **18 years** 9, **10, 11,** or 12 **days** in which an eclipse with similar circumstances will repeat itself. The difference in the day count results from the number of leap years which can occur during that interval.

1) **223 synodic months** x = **29.5**3059 days	**=** 6585.3216 days	**SIMILAR**		
2) **242 nodical months** x = **27.2**1222 days	**=** 6585.3524 days	**ECLIPSE**	**=**	**Saros**
3) **239 anomalistic months** x = 27.55455 days	= 6585.5375 days	**REPETITION**		

e. The **Babylonians** discovered the **saros** about 200-400 BC.

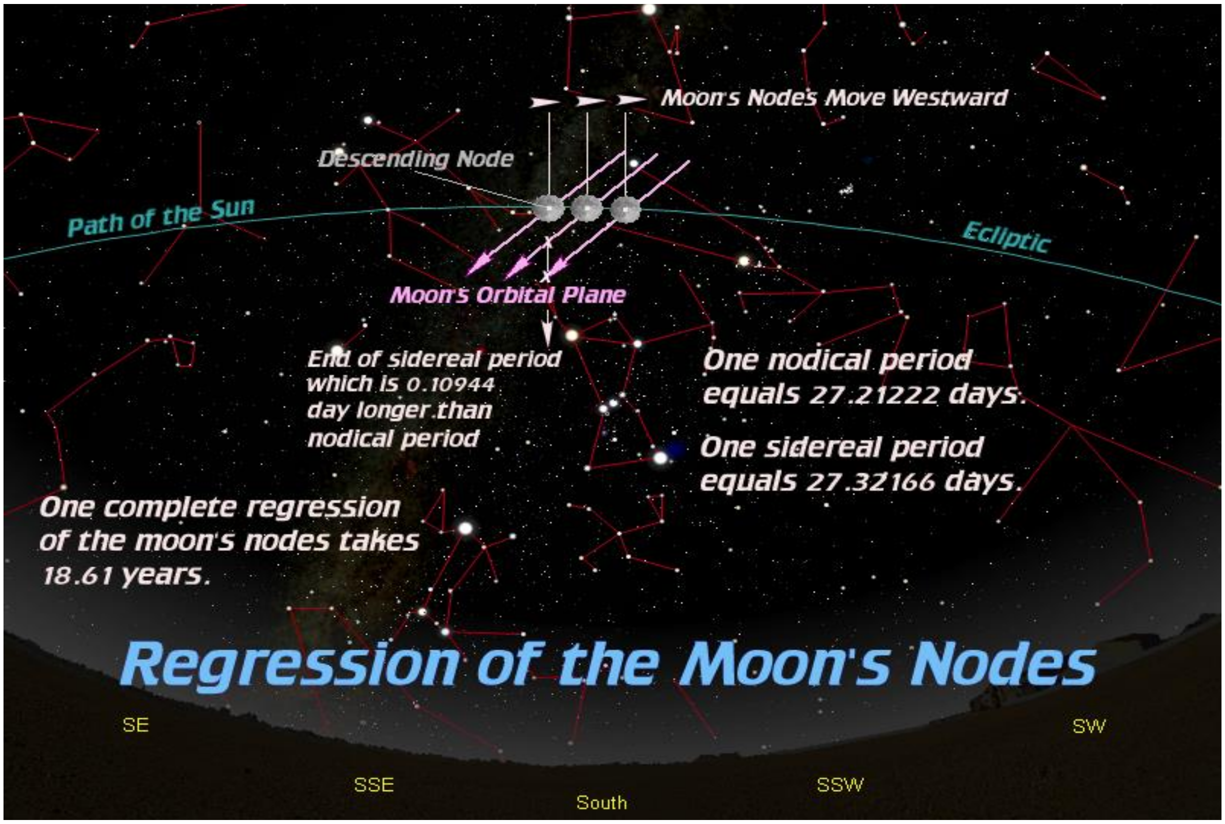
f. Remember, the **major beat of the saros** is represented by the **synodic month.** Similar eclipses will repeat themselves in intervals of 6585 days. Because of the decimal, 0.3216 day, the occurrence of the eclipse will be about $^{1}/_{3}$rd of a day later. Because of the Earth's rotation, the path of totality in a solar eclipse will be shifted about 120 degrees to the west of its previous path.

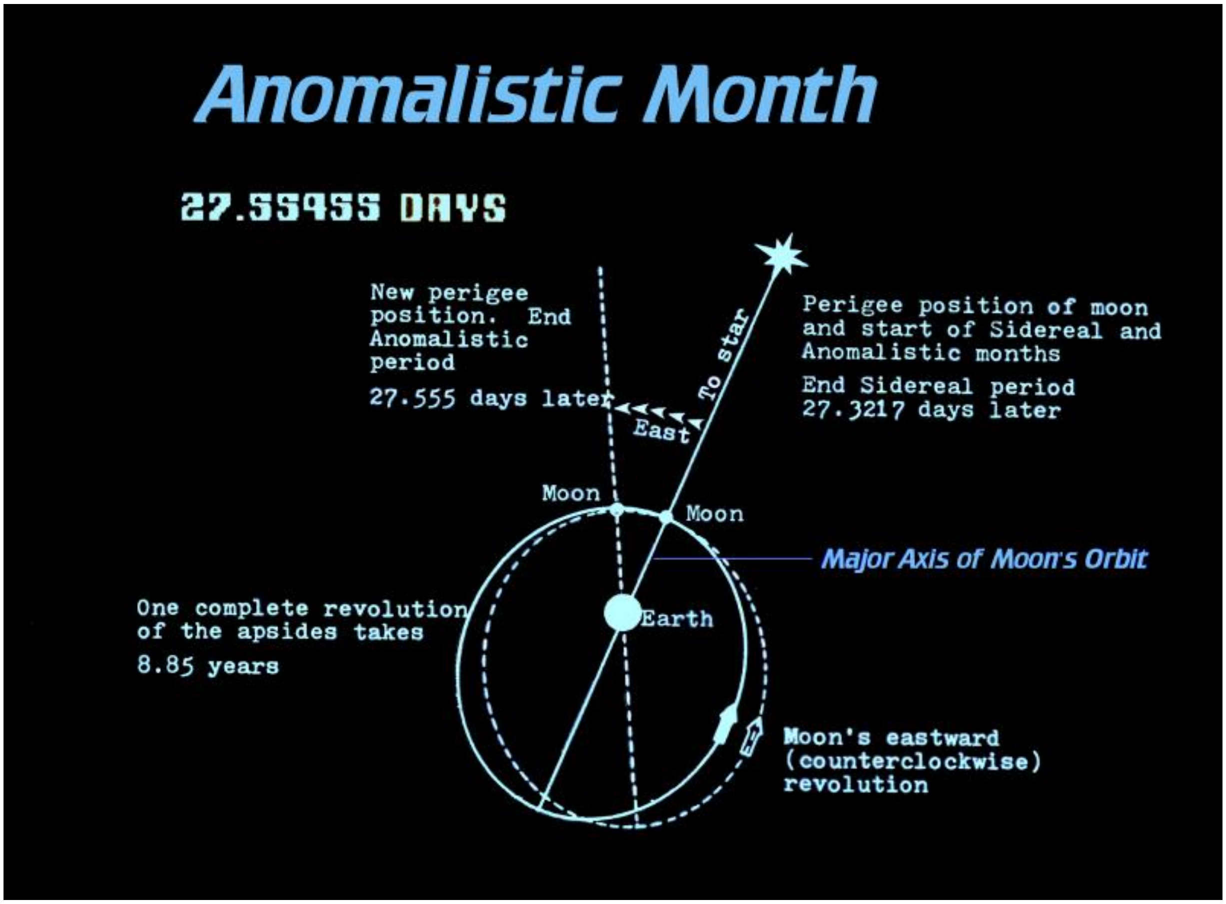
*g. The difference between the synodic and nodical periods, which equals 0.0308 day, will cause the position of the node to shift with respect to the location of the sun or the shadow of the Earth. This will cause an eclipse path to slowly change with respect to latitude. With solar eclipses, the saros cycle begins with partial eclipses occurring at one of the poles. Gradually over the period of the saros, eclipse paths migrate towards the opposite pole, ending a particular series when the misalignments become too great. In lunar eclipses, this difference shifts the moon with respect to the shadow of the Earth causing eclipse types to gradually change.

*h. The residual in the anomalistic period when compared to the synodic period (0.2159 day) will cause a gradual shift in the distance of the moon from the Earth during a saros cycle. For solar eclipses this change will affect the type of eclipses that will transpire during the entire saros period. Annular eclipses may blend into annular-total solar eclipses, then total solar eclipses. The cycle will then reverse itself as the saros continues to completion. The anomalistic period has little effect on lunar eclipses.

B. Solar and Lunar Eclipses of the Future

1. Lehigh Valley: Future total solar eclipses visible through 2444
   a. May 01, 2079—occurs at sunrise
   b. October 26, 2144
   c. April 14, 2200
   d. June 07, 2263—occurs at sunset
   e. September 12, 2444
2. Major North American solar eclipses visible in the US through 2024
   a. April 08, 2024—total, across U.S. (Mexico, Texas to Maine). Passes through Erie, PA only 300 miles from the Lehigh Valley.
   b. August 23, 2044—total from central/eastern Montana to western North Dakota, sunset eclipse
   c. August 12, 2045—total across the US from northern California to northern Florida
3. East Coast/Lehigh Valley: Total Lunar Eclipses through 2025
   a. November 19, 2021—virtually total, deepest ingress into the umbra 4:05 a.m.
   b. May 16, 2022—late evening through early morning.
   c. November 8, 2022—early morning near dawn.
   d. March 14, 2025—from midnight through 4 a.m.


Moon's Nodes Move Westward
Descending Node
Path of the Sun
Ecliptic
Moon's Orbital Plane
End of sidereal period which is 0.10944 day longer than nodical period
One nodical period equals 27.21222 days.
One sidereal period equals 27.32166 days.
One complete regression of the moon's nodes takes 18.61 years.
Regression of the Moon's Nodes
SE
SSE
South
SSW
SW


Anomalistic Month
27.55455 DAYS
New perigee position. End Anomalistic period
27.555 days later
East
To star
Perigee position of moon and start of Sidereal and Anomalistic months
End Sidereal period 27.3217 days later
Moon
Moon
Major Axis of Moon's Orbit
Earth
One complete revolution of the apsides takes
8.85 years
Moon's eastward (counterclockwise) revolution

C. **Visual aspects of solar and lunar eclipses**

1. **Partial Solar Eclipse**—A Solar filter is needed at all times for viewing.
   a. First Contact: The eclipse starts as the black disk of the moon begins to cover the sun. Technically, the moon is tangent to the sun's disk at first and second contact.
   b. Maximum Eclipse: This marks the greatest penetration of the moon's disk over the sun's disk. It is given as a percentage. It occurs at the time of maximum coverage which marks the percentage of the area of the sun's disk that is obscured by the moon. Maximum coverage is also given as a percentage.
   c. Second Contact: This ends the partial eclipse as the moon moves off the sun's disk.

2. **Total Solar Eclipse**—A Solar filter is needed at all times when the photosphere of the sun is visible.
   a. First Contact: The partial eclipse begins. A solar filter is needed. About 20 minutes before second contact, the landscape begins to look metallic gray. Objects appear to have more contrast. The air feels cooler as temperatures drop because of the diminution of sunlight.
   b. Second Contact: The eclipse becomes total. Noticeable darkening of the landscape occurs during the minutes preceding totality with shadow bands visible to the unaided eye as pulsating light. The brighter planets may become visible several minutes prior to totality. The diamond ring, Baily's beads, the corona, and prominences all becomes visible in a matter of 10 to 20 seconds preceding totality as day rapidly changes into night. The effect is emotionally overwhelming. During totality some of the brighter stars may become visible. The landscape is illuminated with a brightness equivalent to three to six full moons. The horizons have an eerie peach-colored hue created by the regions around the moon's umbra which are receiving the last light from the cooler limb-darkened sun. This twilight zone bordering the elliptically-shaped umbra is nearly in totality. The light at the limb of the sun is shifted to the red end of the visual spectrum which creates this peach-colored, sunset like appearance. During totality, the eclipsed sun can be viewed safely with the unaided eye or with unfiltered binoculars or telescopes.
   c. Third Contact: Totality ends. The same sequence of events occurs after totality only in the opposite order, but most observers are less aware or unaware of them because of the majesty of the event that they have just witnessed. Almost everyone, however, sees the diamond ring. The landscape has a bluish/purplish grey look to it to until about 20 minutes after third contact. A solar filter is needed to observe the sun except at the very onset of the diamond ring.
   d. Fourth Contact: The solar eclipse ends. The moon's limb is tangent to the sun's limb.

3. **Annular Eclipse/Broken Annular Eclipse**—They are solar only. A solar filter is needed throughout the entire eclipse.
   a. First Contact: The partial eclipse begins. The landscape looks metallic gray and subdued in brightness, 10-15 minutes before second contact.
   b. Second Contact-normal annular: This is the annular or ringed portion of the eclipse which begins at this point. Baily's beads can be seen through telescopes

properly filtered for solar viewing. The landscape looks metallic gray. Objects appear to have more contrast.

c. Broken Annular: At the time of annularity, if on the centerline, the limb of the moon breaks up into Baily's bead for several second as projecting mountains on the lunar limb hide the sun, and sunlight still continues to shine through the valleys between these mountains. This is the rarest form of solar eclipse and may occur when the umbra is not quite long enough to reach the surface of the Earth or during a hybrid eclipse. In a hybrid eclipse, the shadow of the moon sweeps across the Earth producing an annular eclipse for part of its path. The Earth's curvature causes the moon's umbra to eventually reach Earth's surface creating a short duration total solar eclipse for a portion of the path. At the point(s) on the centerline where the eclipse moves from being annular to total, a broken annular eclipse will occur.

d. Third Contact: The annular portion of the eclipse ends. The landscape appears somewhat subdued in brightness and metallic grey in color for 10-15 minutes after annularity.

e. Fourth Contact: The partial eclipse ends with the moon being tangent to the sun's limb.

4. **Partial Lunar Eclipse:** Since the full moon can be viewed without using filters, the moon going into the Earth's shadow can be viewed safely without filtration or with any type of optical aid like binoculars or telescopes.

a. First Contact: The moon enters Earth's primary shadow, the umbra. As the moon in the penumbra of Earth's shadow approaches the umbra, the portion of the moon closest to the umbra appears dimmer because it is immersed into the deepest region of the penumbral shadow.

b. Maximum Eclipse: This is the deepest invasion of the moon into the Earth's shadow and is measured as a percentage. The eclipsed portion of the moon may appear slightly reddened if the moon is almost completely immersed into the Earth's umbra.

c. Second Contact: The moon leaves Earth's primary shadow. The part of the moon closest to the umbra continues to appear dusky because it is still deep within the penumbral shadow of Earth.

5. **Total Lunar Eclipse**—It is safe to view in all of its aspects.

a. First Contact: The moon enters Earth's primary shadow, the umbra. Before first contact, the portion of the moon deepest into the penumbra, appears subdued in light intensity. The moon's surface that is eclipsed, gradually appears to redden as the moon approaches second contact. The sky appears darker and fainter stars become visible.

b. Second Contact: Totality begins at this point with the moon completely immersed into Earth's umbra. The sky appears to have the same transparency that it would have if the moon were new. This is especially beautiful if viewed in a rural locale. The moon may take on various hues of browns, reds, oranges, and yellows, depending upon how deep the moon progresses into the umbra and the transparency of the Earth's atmosphere around its circumference. At the circumference of the Earth, an observer on the moon would be witnessing simultaneously all of the possible sunsets occurring around the world, hence the reddened color on the surface of the moon. Shorter wavelengths of light are filtered (scattered) by the Earth's atmosphere, near or at sunset producing the reddened hue. If the Earth's atmosphere is dusty from volcanic eruptions, light bent (refracted) into the Earth's shadow by its atmosphere may be absorbed completely by the dust. The moon may appear to be so dark that it disappears from view during totality, but this is rare. Generally, the moon's surface appears brightest at the point closest to the umbra-penumbra boundary, but again not always. One final note. Sometimes at the onset of lunar totality, the limb of the moon may appear to have a blue hue when photographed.

c. Third Contact: The moon begins to leave Earth's primary shadow. The surface of the moon that is eclipsed gradually decreases in its colored hues and fainter stars disappear.

d. Fourth Contact: Luna exits the umbra with the region of the moon closest to the umbra appearing dusky to the unaided eye for perhaps 20 minutes, longer if the moon is being photographed.

6. **Penumbral Eclipses/Partial Penumbral Eclipses:** They are lunar only.

a. The moon enters either partially or wholly into the secondary shadow of the Earth.

b. The limb of the moon nearest to the umbra may appear dusky, but many times these eclipses go unnoticed.

NOTES

Name ______________________________ Date ________________ Moravian College

DISTILL THE DEFINITION TO ITS BASIC MEANING

Instructions: Take the word on the left and find the most important information, words, or numbers associated with it to complete a shortened definition on the right. The full definitions of these words can be found elsewhere in Session Five. **You may not use anymore than six words for your core definition**. **Abbreviations will count as words,** such as mi./sec., equals miles/second, equals two words. Numbers, symbols, and punctuation will not count as words unless used incorrectly. Here is an example. "2 b or not 2 b" will mean "To be or not to be," and will have six words, not four. The grammar police will also be arresting you! The word or a similar word may **NOT** be used in the definition unless there is an asterisk. The asterisk is only good for the word directly next to it. In Broken Eclipse* only "Eclipse" applies to this situation.

WORD	DEFINITION: NO MORE THAN SIX WORDS MAX.
Angular* Diameter	
Annular Eclipse*	
Annulus	
Anomalistic Month	
Aphelion	
Apogee	
Ascending Node	
Baily's Beads*	
Broken Eclipse*	
Centerline	
Central Eclipse*	
Chromosphere	
Corona	
Descending Node	
Diamond Ring	
Eclipse	
Eclipse* Chaser	
Eclipse* Season	
Eclipse* Year	
Ecliptic	
First Contact	
Fourth Contact	
Full Moon*	
Great Eclipse*	
Greatest Eclipse	
Limb	

WORD	DEFINITION: NO MORE THAN SIX WORDS MAX.
Limb Darkening	
Line of Apsides	
Lunar Eclipse	
Major Axis	
Negative Shadow	
New Moon*	
Node	
Nodical* Period	
Northern* Limit	
Partial* Eclipse	
Penumbral Eclipse	
Penumbra	
Perigee	
Perihelion	
Pinhole Projector*	
Prominence	
Regression of Nodes	
Revolution	
Revolution of Apsides	
Saros	
Second Contact	
Shadow Bands	
Shadow* Cone	
Sidereal Period*	
Similar Eclipses*	
Solar Eclipse	
Solar Filter	
Solar Projection*	
Southern* Limit	
Sunspots	
Synodic Period	
Third Contact	
Total Eclipse	
Totality	
Umbra	

WORD LIST FOR ECLIPSES

1. **<u>Angular Diameter</u>:** The angle subtended by an astronomical body against the sky.
2. **<u>Annular Eclipse</u>:** A central solar eclipse in which the angular diameter of the moon is too small to cover the sun. With proper filtration the moon appears to have a ring of sun surrounding it.
3. **<u>Annulus</u>:** It is Latin for ring.
4. **<u>Anomalistic Month</u>:** The amount of time it takes the moon to complete two perigee or apogee passages. Its period is 27.55455 days.
5. **<u>Aphelion</u>:** The farthest position to the sun of an astronomical body in an elliptical orbit around the sun.
6. **<u>Apogee</u>:** The farthest point to the Earth in the moon's elliptical orbit around the Earth.
7. **<u>Ascending Node</u>:** With respect to eclipses, it is the location where the moon's orbital plane passes from below the ecliptic plane to above the ecliptic plane.
8. **<u>Baily's Beads</u>:** The light phenomenon which occurs just moments before second contact or moments after third contact in a central solar eclipse. Sunlight shining through lunar valleys on the moon's limb gives the sun a beaded texture. They were discovered by the English astronomer, Francis Bailey, during the May 15, 1836 total solar eclipse.
9. **<u>Broken Annular Eclipse</u>:** A central solar eclipse in which the angular diameter of the moon is just small enough in comparison to the sun to cause the entire limb of the sun to be broken into a Baily's Beads structure during the moment of annularity. It is the rarest of solar eclipses.
10. **<u>Centerline</u>:** The line across the surface of the Earth where the apex of the moon's umbra points.
11. **<u>Central Eclipse</u>:** A total solar or an annular eclipse…
12. **<u>Chromosphere</u>:** The thin layer of solar atmosphere that lies between the photosphere and the corona which is visible as a pinkish hue just before totality. Its color is due to hydrogen emission.
13. **<u>Corona</u>:** Crown… The tenuous outermost atmosphere of the sun visible to the unaided eye during a total solar eclipse.
14. **<u>Descending Node</u>:** With respect to eclipses, it is the location where the moon's orbital plane passes from above the ecliptic plane to below the ecliptic plane.
15. **<u>Diamond Ring</u>:** The visual appearance of the sun about 10-15 seconds before or after a total solar eclipse. The diamond is created by the photosphere or chromosphere, and the ring by the corona.
16. **<u>Eclipse</u>:** It is from the Greek word, "ekleipsis," and it means to hide or cover.
17. **<u>Eclipse Chaser</u>:** A person who travels to see a total solar or annular eclipse.
18. **<u>Eclipse Season</u>:** The time when the moon is either new or full and also at a node. The time interval between two eclipse seasons is 173.3 days.
19. **<u>Eclipse Year</u>:** The time interval between two eclipse seasons occurring at the same node—346.6 days.
20. **<u>Ecliptic</u>:** The plane of the Earth's orbit projected into space. The motion of the sun against the starry background resulting from Earth's orbital motion around the sun.
21. **<u>First Contact</u>:** The first moment of tangency of the moon's limb with the sun's limb in a partial or central solar eclipse. The first moment of tangency of the moon with the Earth's umbral shadow in a partial or a total lunar eclipse.

22. **<u>Fourth Contact</u>:** The last moment of tangency of the moon's limb with the sun's limb in a central solar eclipse. The last moment of tangency of the moon with the Earth's umbral shadow in a total lunar eclipse.
23. **<u>Full Moon</u>:** The lunar phase which occurs when the moon is opposite to the sun and its entire nearside is completely illuminated.
24. **<u>Great Eclipse</u>:** A total solar eclipse in which the length of totality is equal to or greater than five minutes.
25. **<u>Greatest Eclipse</u>:** The moment when the moon's shadow passes closest to the center of the Earth.
26. **<u>Hybrid Eclipse</u>:** A solar eclipse which has a portion of its path seen as an annular eclipse and part of it path viewed as a total solar eclipse. At the point where the eclipse changes from annular to total, a broken annular eclipse will be seen.
27. **<u>Limb</u>:** The apparent boundary of the sun, moon, or any astronomical object which has a true angular diameter in the sky.
28. **<u>Limb Darkening</u>:** The decrease in the amount of light intensity from the center to the limb of the sun, due to a decrease in the depth of the penetration into the photosphere towards the limb. The photosphere becomes hotter with depth.
29. **<u>Line of Apsides</u>:** In the case of eclipses, the major axis of the moon's elliptical orbit.
30. **<u>Lunar Eclipse</u>:** An astronomical event in which the moon is totally or partially hidden by the Earth's umbral or penumbral shadows.
31. **<u>Major Axis</u>:** The longest axis of an ellipse. In an elliptical orbit, the major axis interests the foci of the ellipse, the center of the ellipse, and the closest and farthest positions of the orbiting body.
32. **<u>Negative Shadow Zone</u>:** The area within the path of a central solar eclipse where the eclipse appears to be ringed.
33. **<u>New Moon</u>:** The phase of the moon in which the hemisphere of the moon facing Earth is in darkness. A condition where the elongation of the moon equals zero.
34. **<u>Node</u>:** The intersection point of two orbital planes.
35. **<u>Nodical/Draconic Period</u>:** With respect to eclipses, the period of time necessary for the moon to complete two successive crossings of the same node.
36. **<u>Northern Limit</u>:** The northernmost boundary along the path of a central solar eclipse where the eclipse appears total or annular.
37. **<u>Partial Eclipse</u>:** It is the portion of a solar eclipse where only a portion of the moon is covering the sun. It is the portion of a lunar eclipse where only part of the moon is immersed within Earth's umbra.
38. **<u>Partial Penumbral Eclipse</u>:** A lunar eclipse in which the moon only partly enters the penumbral shadow of the Earth.
39. **<u>Penumbra</u>:** The secondary shadow of a body created when it is only partially blocking a light source.
40. **<u>Perigee</u>:** The closest point from the Earth along the path of the moon's elliptical orbit.
41. **<u>Perihelion</u>:** The closest position of a body to the sun in its elliptical orbit around the sun.
42. **<u>Pinhole Projector</u>:** A brute force solar projection device in which a small hole, usually made by a pin, acts like a lens projecting an image of the sun to the opposite end of an enclosed tube or long box.
43. **<u>Prominence</u>:** A long lasting coronal event related to magnetic fields in which large amounts of plasma are made to condense and glow. Magnetically induced plasma bubble within the sun's corona.

44. **Regression of the Moon's Nodes:** The westward motion of the moon's orbital intersection points with the ecliptic. The moon's nodes regress completely around the heavens in a period of 18.61 years. The regression of the moon's nodes results from the sun's gravitational force trying to pull the orbital plane of the moon into the plane of the ecliptic.
45. **Revolution:** The period of time it takes for an object of lesser mass to orbit around a body of greater mass.
46. **Revolution of the Moon's Apsides:** The period of time necessary for the major axis of the moon's elliptical orbit to complete one full cycle through the heavens and return to its starting position. Its duration is equal to 8.85 years.
47. **Saros:** The 18 year, 9, 10, 11, or 12 day period between the repetitions of similar solar or lunar eclipses. The time interval varies as a consequence of the number of leap years occurring during this interval.
48. **Second Contact:** In a central solar/lunar eclipse, it is the time when totality or annularity begins. In a partial solar eclipse, it is the instant when the moon is tangent to the sun's disk for the second and last time. In a partial lunar eclipse, it is the time when the moon is tangent to the primary shadow cone of the Earth for the second time, marking the end of the eclipse.
49. **Shadow Bands:** Faint ripples of low contrast light that can undulate across a landscape a minute or so before and after a total solar eclipse. They result from the narrow slit of sunlight shining through a turbulent atmosphere.
50. **Shadow Cone:** The primary or umbral shadow cone of the moon or the Earth.
51. **Sidereal Period of the Moon:** The amount of time it takes the moon to complete one revolution around the Earth, 27.321661 days.
52. **Similar Eclipses**: Eclipses of a particular saros cycle which have nearly the same characteristics.
53. **Solar Eclipse:** An astronomical event in which part of the moon or the entire moon hides the sun.
54. **Solar Filter:** An optical device for safely dimming the sun's brightness to a level where it can be viewed with the human eye. Solar filters should never be used at the eyepiece end of a telescope. They should reduce the sun's intensity prior to its light entering the telescope.
55. **Solar Projection:** A safe solar observing technique where the sun's image is projected through the eyepiece of an unfiltered telescope onto a white screen.
56. **Southern Limit:** The southernmost position along the path of a central solar eclipse where the eclipse appears total or annular.
57. **Sunspots:** Darker, cooler regions in the sun's photosphere where an area of intense magnetic field is preventing the sun from cooling at its normal rate.
58. **Synodic Period of Moon:** The amount of time it takes the moon to complete one phase cycle, 29.5306 days.
59. **Third Contact:** The moment when totality or annularity is over.
60. **Total Eclipse:** An astronomical event where the moon completely covers the photosphere of the sun or the moon is completely immersed in the primary shadow of the Earth.
61. **Totality:** The portion of a solar or lunar eclipse in which the moon completely hides the sun or the moon is entirely immersed within the shadow of the Earth.
61. **Umbra:** The primary shadow cone of an astronomical body. From within this location the eclipse appears to be total.

NOTES

Packet No. ______

Name ____________________________ Date ____________________________

Name ____________________________ Name ____________________________

Name ____________________________ Name ____________________________

ECLIPSE WORD SCRAMBLE QUIZ

(10 points)

Instructions for the Scramble Quiz: You will receive a packet of papers. One color will have the definitions, while the other colored paper will contain the vocabulary words. Complete the quiz by matching the vocabulary word with the correct definition.

Grading: Since students are working in groups, and since this is more of a matching exercise where students need to recognize the correct definition rather than stating it in writing, each mistake will count as a half point deduction. As an example, a team that misses two words will receive a score of 9/10.

Consider the Following Suggestions:

1. **Mandatory:** Write the first and last name of each team member and note the date. Failure to do so will result in the loss of one point for each team member. Each team member will receive the same grade.
2. **Note the Packet Number** on this paper. Without a packet number I will not know which group of words to correct.
3. **Don’t panic! Work as a team.** Keep focused on the problem at hand, not on what the other teams are doing.
4. **First separate** the colors into two packs.
5. **Arrange the vocabulary words in alphabetical order on the left**. Students studied the words in alphabetical order and this will help with remembering the definitions, and particularly words with definitions that are similar. The **vocabulary words are centered** on the page. The **definitions are left justified**. Assemble the packet so that I see the word to be defined first, followed by the definition.
6. **Keep all words and definitions visible on the table** so that all answer possibilities remain viable. Words which are related have definitions which may sound similar. If an incorrect word/definition association is made, and that word/definition is pulled from the table, there will probably be another incorrect word/definition association chosen for the other similar word.
7. **Teams will have about 15 minutes** to complete this exercise. Although this a timed exercise, extra time (one or two minutes) will be given if needed.

NOTES

CAN YOU ANSWER THE FOLLOWING QUESTIONS/STATEMENTS ABOUT SOLAR AND LUNAR ECLIPSES?

GENERAL CONSIDERATIONS

1. The classic configuration (arrangement) of the three bodies which will produce a lunar eclipse is as follows: ________________, ________________, ________________.

2. The alignment that produces a solar eclipse is as follows: ________________, ________________, ________________.

3. Solar eclipses are visible in the DAY/NIGHT (circle one) while lunar eclipses can only be seen AT NIGHT/DURING THE DAY (circle one).

4. A lunar eclipse can only occur when the moon is in the ________________ phase.

5. A solar eclipse can only happen when the moon is in the ________________ phase.

6. The length of time it takes the moon to complete one cycle of phases is equal to ________________ days. This is called the moon's ________________ period.

7. The length of time it takes the moon to make one revolution around the Earth is equal to ________________ days. This is called the moon's ________________ period.

8. The difference between these two periods, about 2-1/6 days, is a result of the Earth's ____ ____.

9. Of the two general types of eclipses mentioned in the last several questions, the partial phases of a ________________ eclipse can be very dangerous to view with the unprotected eye.

10. The primary shadow of the moon is termed the ________________, while the secondary shadow of the moon is called the _______________.

11. The primary shadow of the Earth is called the ________________, while the secondary shadow of the Earth is given the name ________________. Both words are derived from the Latin.

12. During a solar eclipse the color of the moon is ________________, while during a lunar eclipse the moon may appear to be ________________ in color.

13. The atmosphere of the sun, which is visible during a solar eclipse, is called the ________________. Its brightness is equivalent to approximately six full moons.

14. There can be as many as ________________ solar and lunar eclipses occurring during the course of a year.

15. Every year, however, there must be at least ________________ lunar eclipses and a minimum of ________________ solar eclipses.

ECLIPSE TYPES

16. Name the three different types of solar eclipses.
________________, ________________, ________________

17. Name the three different types of lunar eclipses.
________________, ________________, ________________

18. An eclipse in which observers, somewhere on the Earth, would experience the umbra of the moon sweep past their position is called a ________________________________.

19. If an observer on the surface of the Earth views a ring of sun completely surrounding the moon, the eclipse is said to be ________________________________.

20. If the moon sweeps completely into the shadow of Earth, the event can be said to be a ________________________________.

21. The moon enters the secondary shadow of Earth, but no part of its surface is occulted by the primary shadow. The eclipse is termed a ________________________________.

22. An eclipse occurs, but no portion of the world has the opportunity of being enveloped by the moon's primary shadow. This type of eclipse is called a ________________________________.

23. If part of the moon sweeps through part of the Earth's primary shadow, the eclipse is said to be a ________________________________.

24. Name the two different types of central solar eclipses.
________________, ________________

25. A total lunar eclipse viewed from the Earth would appear to an astronaut, standing on the near side of the moon, to be a ________________________________.

PREDICTING ECLIPSES

26. The moon revolves around the Earth and the Earth orbits the sun in a type of orbital path termed an ________________.

27. The sun and moon appear to change their apparent sizes in the sky because
a. ____
b. ____

28. The average distance of the moon from the Earth is ______________________.

29. The average distance of the sun from the Earth is ____________________.

30. When the Earth is closest to the sun it is at a position called _____________________ (91.5 million miles or 147.5 million km).

31. The moon, on the other hand, recedes to its farthest position from Earth at __________________ (253,000 miles or 407,000 km).

32. At its closest location to the Earth, the moon is said to be at the position of __________________ (221,000 miles or 356,000 km).

33. When the Earth is at its greatest distance from the sun it is said to be at the position of __________________ (94.5 million miles or 152.5 million km).

34. It is the longest line segment of an ellipse, connecting the extremes of distance, the foci, and the center. The line segment is termed the ____________________.

35. Referring to an ellipse, the velocity of a body in orbit is fastest when _______________ to the attracting body and _______________ when farthest from the attracting body.

36. An object in an elliptical orbit lingers for a longer period of time at a distance GREATER/LESSER (circle one) than its average distance.

37. Because the moon is 400 times closer to the Earth, but the sun is 400 times larger in diameter, the sun and moon appear to be the _______________ apparent size in the sky. This size is about _______________ degree.

38. If a body is closer, it will appear to be _______________, while if it is farther away, it will appear to be _______________.

39. Since the ovalness (eccentricity) of the lunar orbit is greater than the eccentricity of the Earth's orbit, and the moon is closer to the Earth than the Earth is to the sun, the MOON/SUN (circle one) will vary in size to the greater extent.

40. Since both the moon and the sun are approximately the same apparent size, and it is known that a body in an elliptical orbit will spend more time at a distance farther from its primary than its average distance, the moon normally WILL/WILL NOT (circle one) be large enough to cover the sun's disk completely.

41. Based upon the preceding question, which type of central solar eclipse will be more common: total solar eclipses or annular eclipses? _________________________

42. Which is larger, the Earth's diameter or the diameter of the Earth's shadow cone at the moon's distance? ____________________

43. Between the two major classifications of central solar eclipses and total lunar eclipses, ____________________ are by far the more common.

44. Why is it that if a poll were taken, more people would say that they had observed a total lunar eclipse than a central solar eclipse?
____
____

45. The _______________ is the plane of the Earth's orbit projected into space.

46. To create a solar and a lunar eclipse each month, the moon would have to orbit the Earth ____.

47. Since this is not the case, the moon must orbit the Earth in a different _________________ than the Earth orbits the sun.

48. The moon's orbit intersects the Earth's orbit at an angle of approximately ____________________.

49. The intersection positions are called _________________.

50. The position where the moon travels from below the ecliptic to above the ecliptic is referred to as the ____________________. Opposite this location is the position of the ____________________.

51. Most of the time when the moon is new or full it is either above or below the ecliptic and _______________________________________. (Hint: answer this question with respect to eclipses.)

52. An eclipse can occur when two conditions are met. Please note these situations below:
a. ____
b. ____

53. However, things are not all that simple. There is a problem with the nodes. Their location on the ecliptic is continually changing so that in a period of ________________ years they make one revolution around the sky. This is referred to as the _______________ of the moon's nodes.

54. Since the moon's nodes are moving in a _______________ direction along the ecliptic, but the moon, due to its orbital motion around the Earth, is moving eastward, the moon intersects its nodal point before it has had a chance to complete a full _______________ period.

55. Therefore, the nodical period is LONGER/SHORTER (circle one) than the sidereal period.

56. The sidereal period of the moon is approximately _______________ days, while the nodical period (sometimes referred to as the draconic month) is approximately _______________ days.

57. If an eclipse will be occurring today, one can predict the time of the next eclipse by multiplying the nodical and _______________ periods of the moon by integral numbers which will produce products which possess the same number of _______________.

58. If this is done, one will discover that the next eclipse in this cycle will happen 3.8 years into the future. However, it is known that each year there must be at least ________________ solar eclipses and at least _______________ lunar eclipses occurring. The inescapable conclusion is that there must be ____
____.

59. There is one other problem we have not considered. We have simply predicted the next eclipse in a series. We don't know if this eclipse will be _________________ to the last eclipse in type.

60. In order to include this parameter, we must now consider the distance of the _________________ from the Earth.

61. If the eclipses are to be of the same type, than three considerations must be synchronized. These are as follows:
    a. ____
    b. ____
    c. ____

62. If the moon is new, at a node, and at perigee one can definitely say that a ____________________ eclipse will occur.

63. However, in 3.8 years when the moon is new and again at a node, it MAY/MAY NOT (circle one) be at perigee.

64. This is the result of the major axis of the moon's orbit _______________ its orientation in space. The major axis connects the closest distance and farthest distance that a body in an _______________ orbit can be found from its primary. A line drawn through these positions is called the ____________________.

65. The change in the direction of the major axis of the moon's orbit is referred to as the _____________________________________. One complete revolution takes 8.85 years.

66. The period of time it takes the moon to cross its perigee or apogee locations twice is referred to as the _______________ month or period.

67. Since this change is towards the east, in the same direction that the moon revolves, the perigee to perigee time period is LONGER/SHORTER (circle one) than the sidereal period of the moon.

68. The perigee to perigee or apogee to apogee time period for the moon is approximately _____________ days as compared to the sidereal period which is _____________ days.

69. The length of time between similar solar eclipses is the product of the integers of the _______________ month, _______________ month, and the _______________ month which produce a common number of days.

70. The amount of time referred to in the last problem is 18 years, 10 or 11 days and is referred to as the _______________.

71. Therefore, if a total solar eclipse were to occur on the date of March 7, 1970, one could automatically predict that the next similar eclipse would happen on **March ,19** or **March ,19 .**

DURATION OF A SOLAR ECLIPSE

72. The Earth rotates from _______________ to _______________, and the moon revolves around the Earth towards the direction of _______________. These motions are in DIFFERENT/THE SAME direction (circle one).

73. The velocity of the lunar shadow, due to its orbital motion, is approximately 2000 miles per hour. Since one's ground speed can vary from zero mph at the _______________ to over 1000 mph at the _______________, this can have a drastic effect on the relative velocity of the lunar shadow as it sweeps across the Earth's surface.

74. What latitude would offer the possibility of the longest duration in a solar eclipse? _________________

75. The longest duration of totality for a solar eclipse is about 7½ minutes. State three factors which would facilitate such an occurrence, assuming that the observer would be located along the center of the of the lunar umbra.
a. ____
b. ____
c. ____

76. Because the path of totality of a solar eclipse is so narrow, the most critical factor as to whether one sees totality at all is one's _________________ on the Earth's surface.

MISCELLANEOUS INFORMATION

77. In a total solar eclipse, first contact occurs when ____.

78. In a total solar eclipse, second contact occurs when ____.

79. In a total solar eclipse, third contact occurs when ____.

80. In a total solar eclipse, fourth contact occurs when ____.

81. In a total solar eclipse, the event is completely safe to view with the naked eye between ____________________________ contacts, but unsafe at any other time.

82. In an eclipse about to become total, the ____________________ occurs just moments before second contact.

83. In a total lunar eclipse, first contact occurs when ____.

84. In a total lunar eclipse, second contact occurs when ____.

85. In a total lunar eclipse, third contact occurs when ____.

86. In a total lunar eclipse, fourth contact occurs when ____.

87. It is safe to observe a total lunar eclipse from ______________ contact to ______________ contact.

88. The next total lunar eclipse which will be visible to residents of the Lehigh Valley occurs in (month, year) ___________________.

89. The next easily accessible total solar eclipse in the United States happens on __________________.

NOTES

ANSWERS TO SESSION FIVE QUESTIONS

GENERAL CONSIDERATIONS

1. sun-Earth-moon
2. sun-moon-Earth
3. DAY, NIGHT
4. full
5. new
6. 29.5, synodic
7. 27.3, sidereal
8. revolution around the sun which necessitates additional time above the orbital period to facilitate the same alignment.
9. solar
10. umbra, penumbra
11. umbra, penumbra
12. black, reddish
13. corona
14. seven
15. two, two

ECLIPSE TYPES

16. total, partial, annular
17. total, partial, penumbral
18. total solar eclipse
19. annular
20. total lunar eclipse
21. penumbral eclipse
22. partial solar eclipse
23. partial lunar eclipse
24. total, annular
25. total solar eclipse

PREDICTING ECLIPSES

26. ellipse
27. the Earth changes its distance from the sun.
    the moon changes its distance from the Earth.
28. 239,000 miles (384,00 km)
29. 93,000,000 miles (150,000,000 km)
30. perihelion
31. apogee
32. perigee
33. aphelion
34. major axis (line of apsides)
35. closest, slowest
36. GREATER
37. same, ½

38. larger, smaller
39. moon
40. WILL NOT
41. annular
42. Earth's diameter
43. central solar eclipses
44. More than half of the Earth is exposed to the lunar eclipse, while the path of a total solar or annular eclipse is very limited.
45. ecliptic
46. in the plane of the ecliptic.
47. plane
48. five degrees
49. nodes
50. ascending node, descending node
51. no eclipse will take place
52. the moon is new or full, the moon is at or near a node
53. 18.6, regression
54. westward, sidereal or revolutionary
55. SHORTER
56. 27.3, 27.2
57. synodic, days
58. two, two, more than one cycle occurring simultaneously
59. similar
60. moon
61. a. the moon must be new or full
    b. the moon must be at or near a node
    c. the moon must be at the same distance from the Earth
62. total solar
63. MAY NOT
64. changing, elliptical, line of apsides
65. revolution of the apsides of the moon
66. anomalistic
67. LONGER
68. 27.6, 27.3
69. synodic, nodical, anomalistic
70. saros
71. March 17, 1988, March 18, 1988

DURATION OF A SOLAR ECLIPSE

72. west, east, east, THE SAME
73. poles, equator
74. equator (in actuality the position lies between the equator and the Tropic of Cancer)

75. a. moon at perigee
    b. Earth at aphelion
    c. eclipse path crosses (a little to the north of) the equator (at noon)
76. location

MISCELLANEOUS INFORMATION

77. the approaching lunar disk first makes contact with the sun
78. totality begins
79. totality ends
80. the lunar disk leaves the disk of the sun
81. second and third
82. diamond ring
83. the approaching lunar disk is tangent to Earth's umbra
84. totality begins
85. totality ends
86. the receding lunar disk is tangent to the Earth's umbra
87. first, fourth
88. A total lunar eclipse is visible on Sunday into Monday, May 15/16, 2022. It promises to be an interesting eclipse because the moon goes fairly deep into the umbra. Mid-eclipse occurs just after midnight on May 16 (12:34 a.m.).
89. April 8, 2024. The path of totality passes through central Mexico, central Texas (Dallas), NW Arkansas, SE Missouri, southern Illinois (Carbondale), and Indiana (Indianapolis); northern Ohio (Cleveland), NW Pennsylvania (Erie); northern New York (Rochester), Vermont, New Hampshire, and Maine; and New Brunswick in Canada.

NOTES