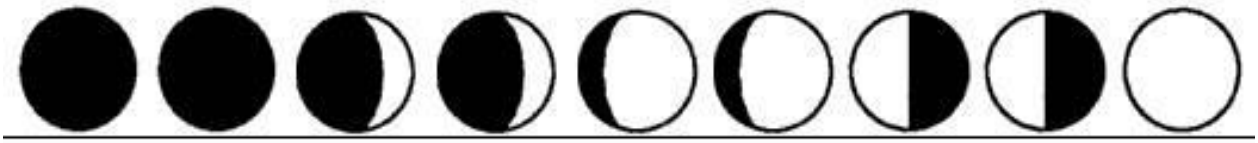
PHASES, ROTATION, DISTANCES, AND LIBRATIONS OF THE MOON

**Lunar Phases:** As we watch the moon go through its phases, we are witnessing the moon revolving around the Earth while it progresses through its day and night cycle (Memorize this fact). This cycle is equivalent to about one month and will be derived more precisely in the exercise that follows. As the moon changes its shape, there are seven phase words that are important: waxing, waning, crescent, gibbous, full, new, and quarter. Waxing means to grow; the light of the moon is on the right. Waning is when the moon is decreasing in brightness, and its illumination is on the left. Crescent means horned, like a croissant, and gibbous comes from the Latin, humped. With its two "b's" think about the moon **b**ulging outward on **b**oth sides. As we are viewing Luna in a gibbous phase, more than half of its surface is illuminated by the sun. When the moon is full, the hemisphere facing the Earth is completely filled with sunlight; it is opposite to the sun with the Earth between them. When the moon is new, it is in the same direction as the sun, and the hemisphere facing Earth is in complete darkness. The opposite hemisphere called the far side is in a full phase. This hemisphere has been mistakenly called the dark side of the moon even though all parts of the moon go through a day and night cycle. It is the quarter moon where some confusion arises because the moon appears to be half illuminated. A first quarter moon, half on—half off, is a waxing moon presenting the right half of its disk in sunlight. The dividing line between day and night, the terminator is a straight line. The moon has completed the first quarter of its phase cycle, and hence, it is called a first quarter moon. At last quarter, half on—half off, it is the left half of the waning moon that is observed. A last quarter moon has proceeded through three-quarters of its phase cycle and can also be called a third quarter moon. I prefer last quarter since the **l**ight of a **l**ast quarter moon is on the **l**eft (the three L's). Sometimes students will refer to a full moon as the second quarter, but this term is not accepted by anyone. With your lunar phase vocabulary refreshed, at your first opportunity, watch Luna progressing from a thin waxing crescent to a first quarter moon. It will still be only about 10 percent as bright as a full moon. Examine as Luna changes its position in the sky as it revolves around the Earth. The big change in the moon's brilliance explodes during the three days following first quarter and culminates in the full moon which is bright enough for some individuals to see color or read a newspaper by its light. Can you put the following phases of the moon in their correct order? See "The Moon on a Stick" exercise.



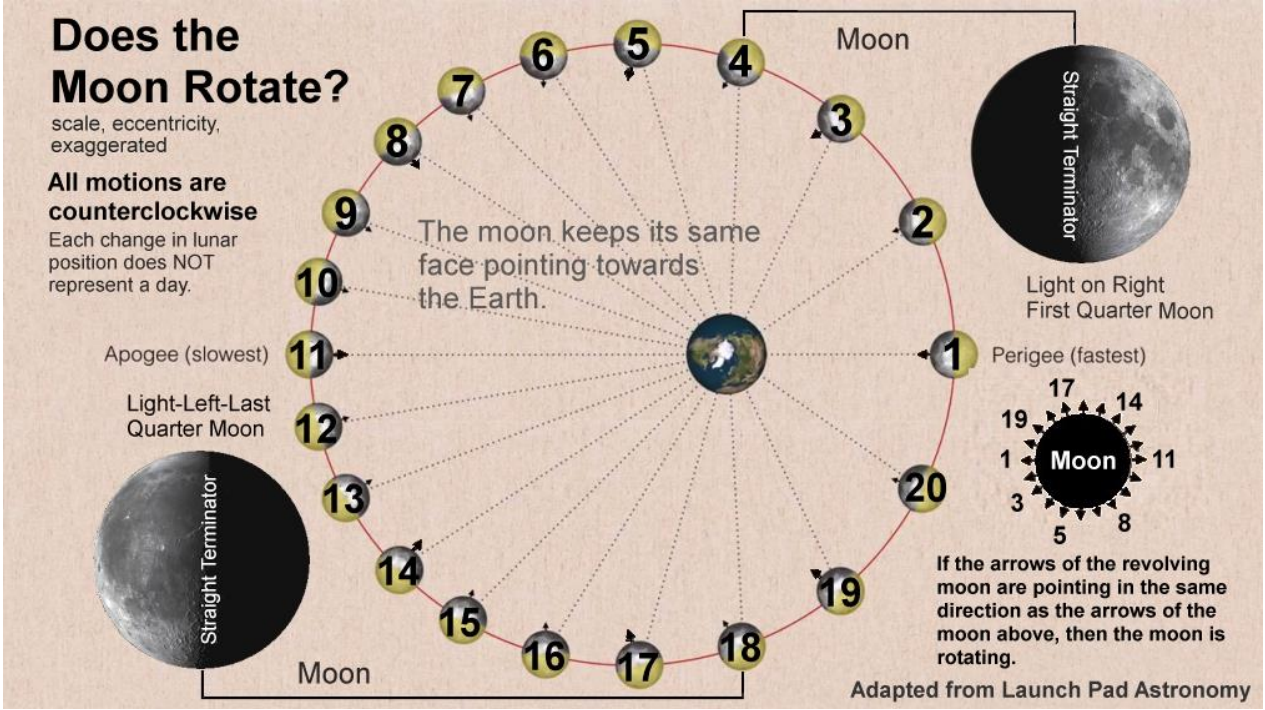
**The Harvest Moon and other Moon Names:** The moon that is closest to the autumnal equinox is called the Harvest Moon. It is at this time of the year that the moon's orbital path is closest to being parallel with the eastern horizon. Accordingly, the moon's orbital motion around the Earth does not carry it very far below the horizon during the course of a day. For several nights the nearly full moon rises well before twilight ends. Before electric lights, farmers in Europe and America could continue harvesting their crops well into the night. The term "Harvest Moon" first originated in Europe where the change in time between moonrises near its full phase was only 10-20 minutes around the autumnal equinox. At our latitude of 40 degrees north, the change is 25-30 minutes on average. You may be surprised to learn that the full moons of other months also have names. Here they are:

**January**—Old Moon, or Moon After Yule; **February**—Snow Moon, Hunger Moon, or Wolf Moon; **March**—Sap Moon, Crow Moon, or Lenten Moon; **April**—Grass Moon or Egg Moon; **May**—Planting Moon or Milk Moon; **June**—Rose Moon, Flower Moon, or Strawberry Moon; **July**—Thunder Moon or Hay Moon; **August**—Green Corn Moon or Grain Moon; **September**—Harvest Moon or Fruit Moon; **October**—Hunter's Moon; **November**—Frosty Moon or Beaver Moon; **December**—Moon Before Yule or Long Night Moon. The next time the moon is full, you may see it in a new light or at least call it by its rightful name.

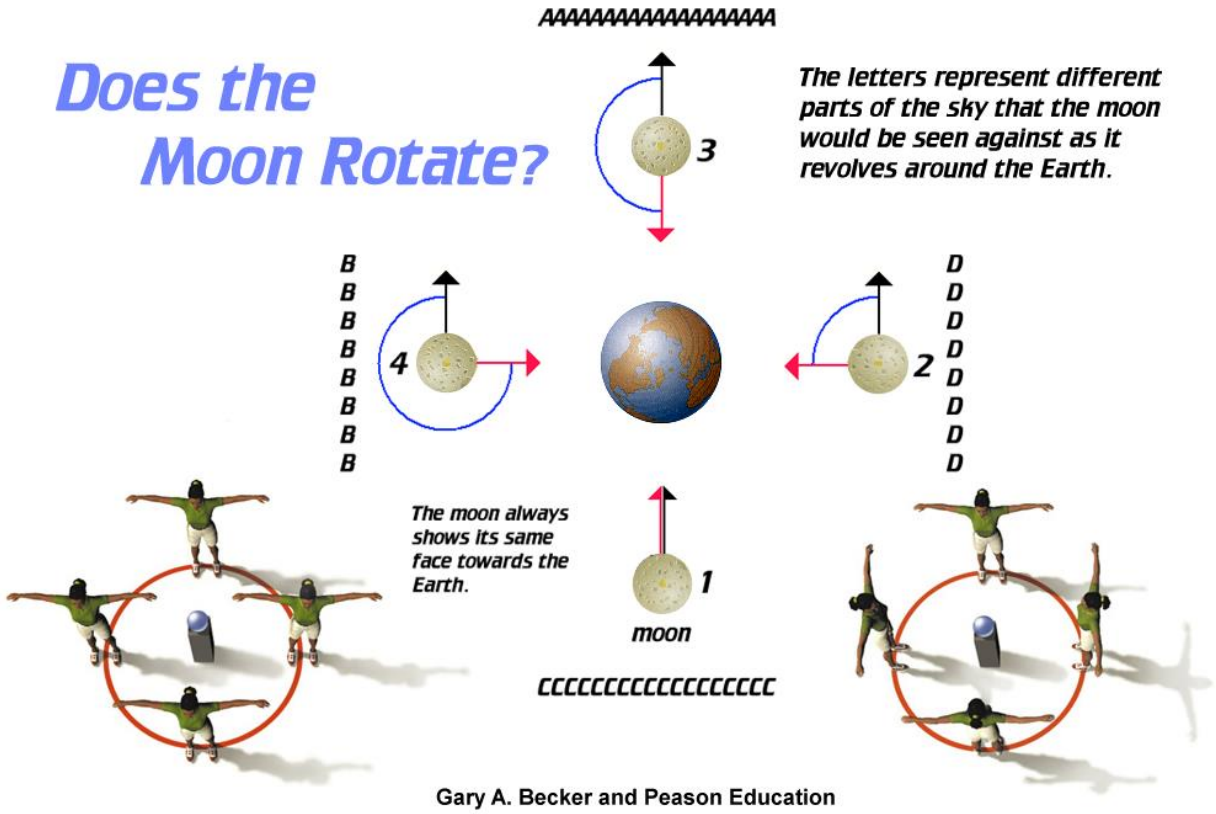
**Summersaulting Moon:** When the moon is full or near its full phase, try this little experiment. It will require you to view the moon shortly after it rises in the east, and then again near its setting location, around dawn or around bedtime—midnight to 1:00 a.m. The observations need not occur on the same night, but they should take place around the time of the full moon, which makes this phenomenon easier to detect. Notice the maria, the dark, waterless regions where most of the lunar landings took place. At moonrise they will appear to be pointed upward; by midnight, they will be more horizontal; and by moonset they are slanted downward. This curious movement is not a motion at all, but merely a consequence of Earth's rotation carrying astronomical bodies across an arcuate (curved) path in the sky. Understand the tilt of the moon, and you will come to realize that most movie footage of the moon is taken in the early evening, even if the scene is supposed to be occurring in the early hours of the morning. Constellations follow the same convention as the American poet Robert Frost noted in the "Star-Splitter." "You know Orion always comes up sideways. Throwing a leg up over our fence of mountains…" When Orion sets, it's like he has just tripped and is falling face forward against the Earth—splat! If you didn't catch it, that last sentence was not Frost's.

**Rotation of the Moon:** The moon keeps its same face pointing towards the Earth at all times. This means that the moon does or does not rotate on its axis? Think about this. Examine the following picture. Note the numbers associated with the moon in its orbital path and with the smaller circle on the right with the many arrows pointing from it. The same numbers and arrow directions on the moon wheel correspond to the numbers on the moon's orbital path around the Earth. If the object makes a complete spin then the moon rotates.

Does the moon rotate? Yes or No. Circle the answer which you believe to be correct after examining the two pictures which follow this exercise.




Here is another way of looking at whether the moon rotates. In the slide, position marked one, the observer looks in the direction of AAAAAAA. In position two he/she looks in the direction of BBBBBBB, etc. If the moon keeps its same face or hemisphere pointed towards the Earth, then it must complete one spin on its axis. Does the moon rotate?

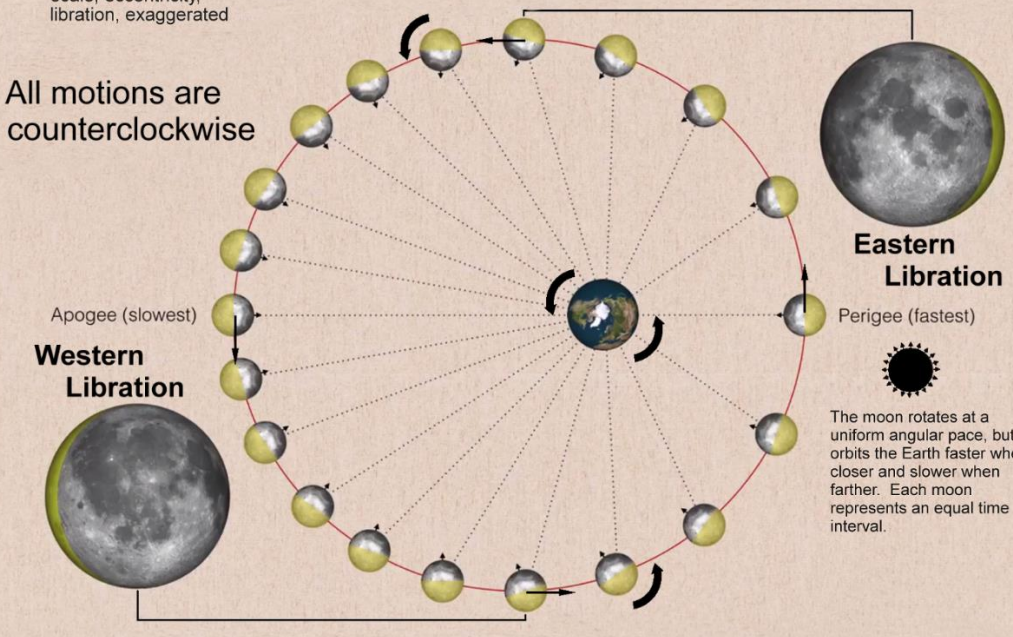


**Lunar Librations:** I had a rough night's sleep. When counting asteroids and melatonin didn't work, my wife asked what was bothering me. I said, Lunar librations… I'm trying to visualize them in my mind." Her response was, "Why are you just picturing them? Place an order at the State Store." "Not libations," I responded, becoming even more alert, "librations, the wobbling effects that the moon goes through as it orbits the Earth." "Can't help you there," she responded, falling back to sleep. There are three of them, two in longitude (east-west) and one in latitude (north-south). Over a 30-year period, they allow astronomers to view 59 percent of the lunar surface, not just the normal 50 percent that most individuals believe can be observed. The never before seen 41 percent of the far side of the moon was first imaged by the former Soviet Union's Luna 3 in 1959. The moon keeps its same face pointing towards Earth, a synchronous dance that allows Luna to complete one rotation (spin) in exactly the same interval of time that it needs to complete one revolution (orbit) around the Earth. The moon's rotation takes place at a uniform (angular) rate. While the moon is acting very consistent in its rotation, it is also revolving around the Earth in an elliptically-shaped (oval) orbit, moving towards and away from our planet, continually changing its orbital speed. When the moon is nearest at perigee and farthest at apogee, Luna basically has no longitudinal librations. At perigee the moon is orbiting at its greatest velocity. As the moon begins to move away from perigee, Luna's angular change due to rotation lags behind the more rapid angular change due to its orbital motion, and we get to peek around the eastern limb of the moon. By the time the moon reaches apogee, its farthest distance from Earth, we basically see it face on again with almost no libration in longitude. Here the moon is moving at its slowest orbital motion, but it continues to rotate at an even angular rate slowly outpacing its orbital motion. We now get to peek around the western limb (side) of the moon. Another smaller diurnal (daily) libration in longitude is at its maximum when the moon rises and sets. When Luna rises, our terrestrial position is "higher" than the moon's location, and we get a little peek over the eastern boundary, similar to being on the summit of a high mountain and being able to look over the curvature of the Earth. Likewise, when the moon sets, we look a little beyond its western limb. Those are the two geometrical librations in longitude, but what about the libration in latitude which is a north-south oscillation? The moon's axis which always points in the same direction as it orbits the Earth is tilted about 1.5 degrees to the perpendicular of its orbital plane, but the plane of the moon's orbit is also tilted by about 5.2 degrees to the plane of Earth's orbit (the ecliptic), causing the moon to have a total tilt of about 6.7 degrees in latitude as viewed from the Earth. Again, think of yourself being on a mountain. When the moon is located below the ecliptic, we have a view beyond the lunar north pole, but when the moon is above the ecliptic, we now get a peek past the lunar south pole. Keep in mind that while these librations are occurring the moon is moving closer and farther from the Earth as well as above and below the ecliptic plane, exaggerating the wobbling motions. Here is are links to many years' worth of lunar librations compiled by NASA's Lunar Reconnaissance Orbiter, https://astronomy.org/moravian/index.html#6. Two images modified from ***Launch Pad Astronomy's*** video on eclipses (below), should help explain the major lunar librations in a more visual sense. Having now been able to envision these three librations in my mind and write descriptively about them, I feel the need to celebrate, taking my wife's advice, with a libation. Cheers!

# Libration in Longitude

scale, eccentricity,
libration, exaggerated

All motions are
counterclockwise

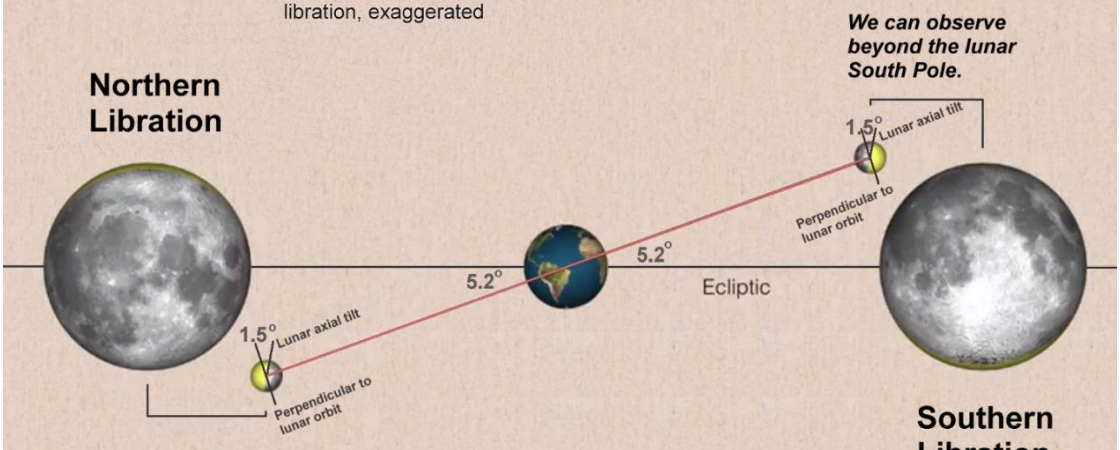



The moon rotates at a uniform angular pace, but orbits the Earth faster when closer and slower when farther. Each moon represents an equal time interval.

Adapted from Launch Pad Astronomy

# Libration in Latitude

scale, inclinations,
libration, exaggerated




*We see beyond the lunar North Pole.*

The total monthly libration in latitude is equal to 6.7 degrees, the sum of the lunar axial tilt plus the inclination of the moon's orbit to the plane of the ecliptic.

Adapted from Launch Pad Astronomy

Name _____ Date_____ Moravian University

SYNODIC, SIDEREAL, AND ANOMALISTIC LUNAR PERIODS
(Phase, Orbit, and Distance)

**Introduction:** Examine the PowerPoint on lunar phases found here, https://astronomy.org/moravian/C02-Misconceptions.pdf and go to the slides which show the moon progressing through an 99-day and a 110-day sequence of phases, librations, and distances. From these slides and a YouTube video found in the same section, you will be able to gain a better appreciation for the:

1. **Phase Period of the Moon:** This is called the synodic period, the time it takes the moon to complete a full series of phases, important for the time period of the month, how early humans established calendars, and the prediction of eclipses and their saros cycles.
2. **Orbital Period of the Moon around the Earth:** This is termed the sidereal period and can be determined by the moon's passage by the First Point of Aries, a reference position in the sky.
3. **Perigee to Perigee and Apogee and Apogee Periods of the Moon:** Called the anomalistic month, it is the time it takes the moon to travel from closest to closest positions to the Earth (perigee to perigee) and farthest to farthest positions from the Earth (apogee to apogee).

**Procedure for Determining the Synodic (phase) Period of the Moon:**

1. **The major phases of the moon**—New Moon, First Quarter, Full Moon, and Last Quarter are shown at the end of this laboratory exercise.
2. In the 99 and 110-slide PowerPoint sequences found in the *Popular Misconceptions* section, https://astronomy.org/moravian/C02-Misconceptions.pdf, determine the day of the New Moon, First Quarter, Full Moon, and Last Quarter moons. The day counts are indicated in the upper left of each slide.
3. Proceed through all of the slides in the Misconceptions PowerPoint and list the days when these phases occurred in the first table.
4. State the interval of time between the repetition of like major phases as well as the average length of time for each phase type in the left column. Keep in mind each picture represents the phase of the moon at 12:01 a.m., whether the moon was visible or not from Bethlehem, PA. Note that the phase series composed of 99 slides was completed near Earth aphelion (farthest position to the sun), while the second series of 110 slides was completed near Earth perihelion (closest location to the sun).

**Additional Recommendations:** Watch the YouTube videos on lunar phases at https://astronomy.org/moravian/C02-Misconceptions.pdf, then complete the exercise "Know the Phases of the Moon or Die" in the "Misconceptions" chapter. Submit this to your instructor for a grade. Take the lunar phase practice quiz https://astronomy.org/moravian/C02-Misconceptions.pdf. Know the phase that comes before and after the one that is pictured in the sample quiz.

**PHASE PERIOD OF THE MOON**

This phase series was completed near aphelion, when Earth's orbital speed was slowest.

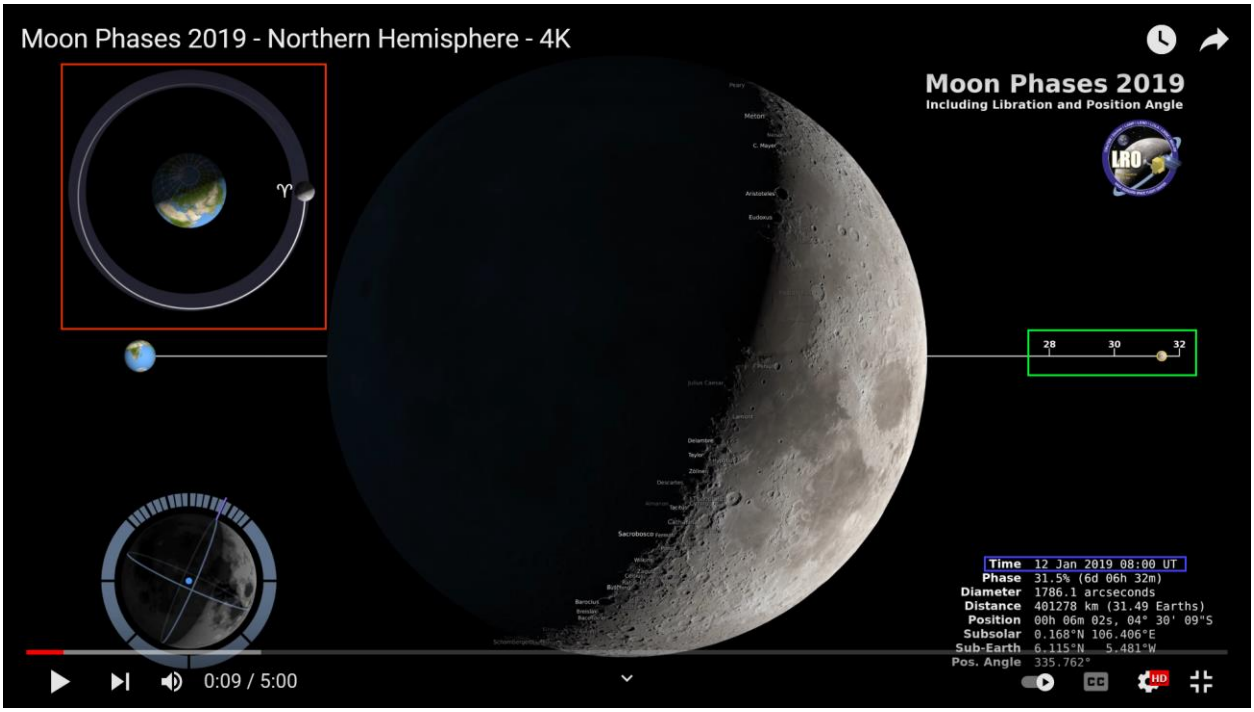
| **Lunar Phase** **Completed near Earth Aphelion (Earth farthest from the sun)** | **Day** | **Days Between Similar Phases** | **Day** Arrow: move same number from top to bottom. | **Days Between Similar Phases** | **Day** Arrow: move same number from top to bottom. | **Average No. of Days Between Similar Phases** |
|---|---|---|---|---|---|---|
| New Moon | 7 | | | | | |
| First Quarter | | | | | | |
| Full Moon | | | | | | |
| Last Quarter | | | | | | |
| New Moon | | | | | | |
| Average of All Averages | ----- ----- | ---------- ---------- | ----- ----- | ---------- ---------- | ----- ----- | |

This phase series was completed near perihelion, when Earth's orbital speed was at its greatest.

| **Lunar Phase** **Completed near Earth Perihelion (Earth closest to the sun)** | **Day** | **Days Between Similar Phases** | **Day** Arrow: move same number from top to bottom. | **Days Between Similar Phases** | **Day** Arrow: move same number from top to bottom. | **Average No. of Days Between Similar Phases** |
|---|---|---|---|---|---|---|
| New Moon | | | | | | |
| First Quarter | | | | | | |
| Full Moon | | | | | | |
| Last Quarter | 135 | | | | | |
| New Moon | | | | | | |
| Average of All Averages | ----- ----- | ---------- ---------- | ----- ----- | ---------- ---------- | ----- ----- | |

**Orbital (Sidereal) Period of the Moon:** In this exercise we are going to use NASA's ***Lunar Reconnaissance Orbiter*** data to determine the orbital period of the moon around the Earth. You can go to https://astronomy.org/moravian/index.html#6 to find the necessary YouTube videos of LRO data. On the following picture, the red box (upper left) marks the orbital period of the moon. Luna is next to the first point of Aries ♈, the location of the sun on the first day of spring (Vernal Equinox). That will be your reference point for determining how long the moon takes to orbit the Earth. Stop the video and note only the day of this passage. That datum can be found in the lower right-hand part of the video noted in the blue rectangle. Start in January and

complete the passages of the moon past the First Point of Aries for that year. Find the number of days between each passage and take the average of those day for each row. Take the last column and average all of the averages for that column and place your answer in the bottom right box. You may pick any **L**unar ***R****econnaissance* ***O****rbiter* year you choose,




1. **<u>Here are the number of days each month contains:</u>**
   J-31, F-28 (29 in 2016 and 2020), M-31, A-30, M-31, J-30, J-31, A-31, S-30, O-31, N-30, D-31
2. **<u>Arithmetic</u>:** What are the number of days between April 4 and May 27? Find the difference between the remaining days in April by subtracting 4 from 30 than adding the number of days in May. 30 – 4 = 26 + 27 = 53. There are 53 days between April 4 and May 27.

**PERIOD OF REVOLUTION OF THE MOON AROUND EARTH**

| ♈ | Day | Difference in Days | Day | Difference in Days | Day | Difference in Days | Day | Average In Days |
|---|---|---|---|---|---|---|---|---|
| **Passing the First Point of Aries ♈** | **Jan.** | | **Feb.** | | **Mar.** | | **Apr.** | |
| **Passing the First Point of Aries ♈** | **Apr.** | | **May 1** | | **May.** | | **Jun.** | |
| **Passing the First Point of Aries ♈** | **Jun.** | | **Jul.** | | **Aug.** | | **Sept.** | |
| **Passing the First Point of Aries ♈** | **Sept.** | | **Oct.** | | **Nov.** | | **Dec.** | |
| Average | ------ | ------ | ----- | ------ | ------ | ------ | ------ | |

**Procedure for Calculating the Anomalistic Period of the Moon:**

The moon revolves around the Earth in an elliptical orbit getter closer and farther from Earth. The time it takes the moon to orbit the Earth from its closest position, perigee to the next perigee, or from its farthest location, apogee to the next apogee, is called the anomalistic period. It is an important interval related to the prediction of similar solar eclipses. Its period may surprise you.

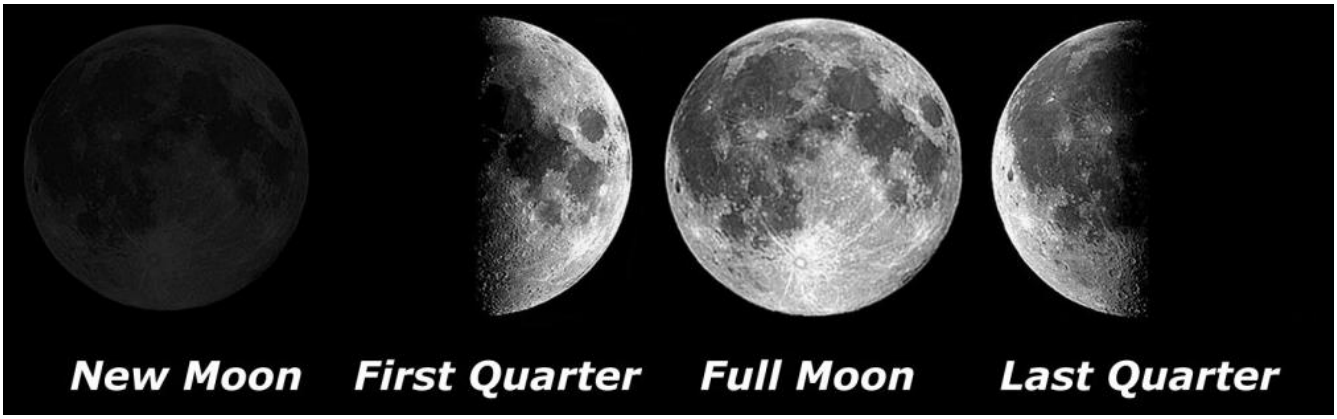
1. By scrolling through the PowerPoint slides rapidly, or better yet watching one of the ***L**unar **R**econnaissance **O**rbiter videos* you will see the changing angular diameter (size) of the moon in the sky, a function of the moon's changing distance from the Earth.
2. Go to https://astronomy.org/moravian/index.html#6 and use one of the compilations created by NASA's Lunar Reconnaissance Orbiter. You will get the most accurate results if you incorporate the difference in time between events, including the fraction of a day between perigees (largest moon) or apogees (smallest moon). **Your instructor will tell you whether he wants you to achieve this better accuracy or simply a day count.**
3. Note in the table when the moon will be at its perigee position, closest to Earth and largest in the sky and at its apogee location, farthest from Earth and smallest in the sky. You can accomplish this by observing the movement of the small ball located at the right center of the screen marked by the green rectangle in the picture found on the previous page. The ball will move between the numbers 28 and 32. Those number represent the moon's distance in Earth diameters. Earth is approximately 8000 miles in diameter.
4. At the point of largest or smallest lunar size, stop the video and note the month and the day. **Only indicate the hour if your professor requests this additional information.**
5. Calculate the days between perigee to the next perigee and apogee to the next apogee.
6. Take the average of your findings to discover the perigee to perigee and apogee to apogee time intervals more accurately. Place these in the last column. Finally, take the average of all periods in the last column and place your answer at the bottom right of the table.
7. **Hints:** Maximize your screen brightness. Slow the video down and increase the resolution of the image in the settings section. You can go as high as 4K. Observe the ball moving back and forth (center right of your screen—green rectangle) giving the Earth-moon distance in Earth diameters.
8. **Here are the number of days each month contains:**
   J-31, F-28 (29 in 2016 and 2020), M-31, A-30, M-31, J-30, J-31, A-31, S-30, O-31, N-30, D-31
9. **Arithmetic:** What are the number of days between July 27 and August 23? Find the difference between the remaining days in July by subtracting 27 from 31 than add the number of days in August. 31 – 27 = 4 + 23 = 27. There are 27 days between July 27 and August 23.

   **Use this method if your teacher asks you to include the day plus hour counts.**
10. **Arithmetic:** Find the difference in time between May 15, 05 hours and June 10, 17 hours. May has 31 days or 30 days, 24 hours.
    (May) 30 days, 24 hours – (May) 15 days, 05 hours = 15 days, 19 hours + (June) 10 days 17 hours = 25 days 36 hours = 26 days 12 hours, or 26 days + 12/24 day = 26.5 days. To decimalize your answer, please see below. Got it, Good!
11. **Decimalize the day in the DIFFERENCE Columns to the nearest 1/10 of a day:** If the final difference between two perigee or apogee positions comes to 28-14/24 days, the 14/24 is equivalent to 0.58 day which would round up to 0.6 day or 28.6 days for your final answer. Divide the 24 into the 14 to get this fraction then round up.

## ANOMALISTIC PERIOD OF THE MOON
# (day count or days plus hours)

| | Day/Hr. | Difference Days/Hr. | Day/Hr. | Difference | Day/Hr. | Difference Days/Hr. | Day/Hr. | Average Days/Hr. |
|---|---|---|---|---|---|---|---|---|
| **Perigee** Moon Largest | **Jan.** hours | Decimalize Days | **Feb.** hours | Decimalize Days | **Mar.** hours | Decimalize Days | **Apr.** hour | |
| | **Apr.** hours | Decimalize Days | **May** hours | Decimalize Days | **Jun.** hours | Decimalize Days | **Jul.** hour | |
| | **Jul.** hours | Decimalize Days | **Aug.** hours | Decimalize Days | **Sept.** hours | Decimalize Days | **Oct.** hour | |
| | **Oct.** hours | Decimalize Days | **Nov.** hours | Decimalize Days | **Dec.** hours | ---------- | ---------- - | |
| **Apogee** Moon Smallest | **Jan.** hours | Decimalize Days | **Feb**. hours | Decimalize Days | **Mar.** hours | Decimalize Days | **Apr.** hours | |
| | **Apr.** hours | Decimalize Days | **May** hours | Decimalize Days | **Jun.** hours | Decimalize Days | **Jul.** hours | |
| | **Jul.** hours | Decimalize Days | **Aug.** hours | Decimalize Days | **Sept.** hours | Decimalize Days | **Oct.** hours | |
| | **Oct.** hours | Decimalize Days | **Nov.** hours | Decimalize Days | **Dec.** hours | ---------- | ---------- | |
| **Super Average** | **-----** | **----------** | **-----** | **----------** | **-----** | **----------** | **-----** | |

## MAJOR PHASES OF THE MOON




**January 27, 2023**