Topic 4: Motions of Earth, Moon, and Sun

Topic 4 Section 1

Overview: without streetlights to dim and hide the moon and planets, most cultures of the past made calculations that predicted their motions. The moon especially became a major tool for timekeeping. Technically, the Earth and Moon are a binary planetary system, but they will be treated as satellites; the Earth is a satellite of the Sun and the Moon is a satellite of the Earth.

Apparent motions of celestial objects

- In 8th grade, you learned that motion occurs relative to a reference point
  - Most observers will naturally choose themselves as a reference point but doing so can lead to misconceptions
    - If you are sitting in a car, you may notice that the car next to you begins to move ahead of your position, but then the driver of your car hits the brake and it becomes clear that the other car was the one that was stationary and your car was the one that was moving
      - Had it actually been the other car moving, your perception of the motions of the two cars would have been real
      - But in this case, your perception of the motions of the two cars was an illusion
    - Observations of celestial objects suffer from the same perceptions; they may be real or illusions
      - For example, each day we observe the Sun going around us and the Earth from east to west but this *apparent motion* is an illusion; the Earth is rotating, a *real motion,* causing us to move from west to east
- Daily motion and stars
  - Most of the celestial objects observed from Earth are stars which appear to rise in the east and set in the west
    - Paths of stars near Polaris will form a complete circle in 24 hours
    - Paths of stars farther from Polaris and in a shorter time will form a part of a circle called an arc
    - All *daily motion* (movement of celestial objects over a 24-hour period) occurs at a constant rate of 15° per hour

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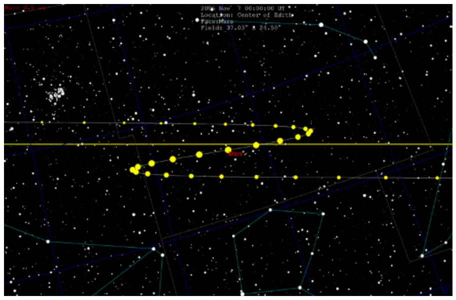
- Apparent motions of the planets
  - Planets also show daily motion similar to that of the stars
  - However, in addition to daily motion, over long period of time (weeks to months), planets also appear to change position relative to background stars
    - Planet – from Greek, planan or wanderer, and Greek planētēs
  - This motion would be similar each year but with a different star background
  - This apparent motion results from all the planets orbiting the Sun at different speeds



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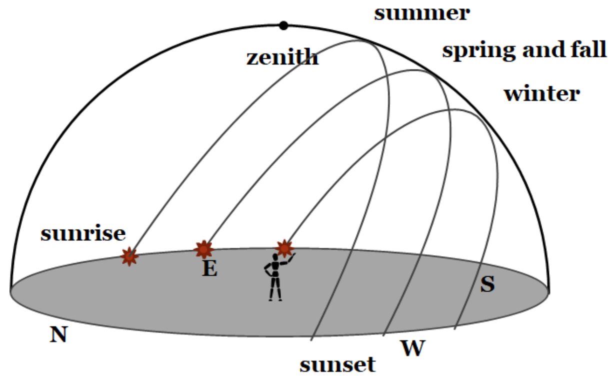
Apparent motions of Earth's moon
- The moon also appears to move east to west each night, but it appears to rise about 50 minutes later each night and appears to shift eastward compared to the background stars

Apparent Sun motions in northern mid-latitudes
- The Sun also appears to move from east to west across the sky each day forming an arc across the southern sky
  - The position of the arc formed by the Sun's path appears to shift north and south based on the season
    - As the Sun's path shifts northward, the path will be longer and there will be more hours of daylight, the longest day occurs on summer solstice
    - As the Sun's path shifts southward, the path will be shorter and there will be fewer hours of daylight, the shortest day occurs on winter solstice



    - On both the vernal (spring) equinox and the autumnal (fall) equinox, the Sun will appear to rise due east and set due west with equal hours of sunlight and night
    - Notice on the figure above that the altitude of the Sun changes throughout the year
      - The Sun always reaches the highest point in the sky at local noon
      - The only places on Earth where the Sun can reach the zenith (directly overhead) are between the latitudes of 23½°N (Tropic of Cancer) and 23½°S (Tropic of Capricorn)

Topic 4 Section 2

Models that help explain apparent celestial motions

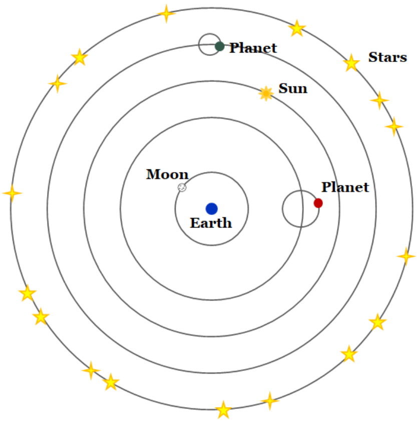
Geocentric models

Most early cultures were under the misconception that since we don't feel like we're moving, the Earth must be stationary in space

Until about the 16th century, most cultures explained the motions of stars and planets using a *geocentric* or Earth centered model

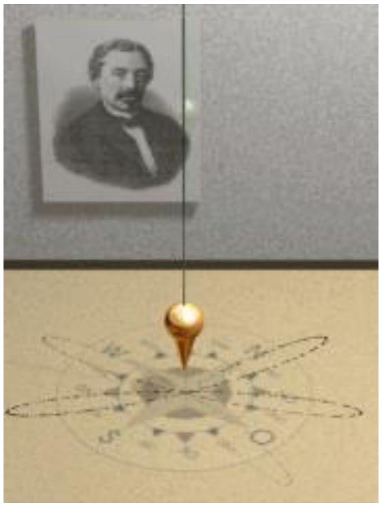
A stationary Earth is placed in the center of this model and circular rings are added to account for the moon, planets, sun, and stars

Notice that since the stars always seemed to be in the same relative positions, they were thought to be on the same sphere in space



Problems with the geocentric model:

- does not explain a Foucault pendulum (freely swinging pendulum)
- does not correctly predict planetary positions



Dominique Toussaint -- Foucault pendulum
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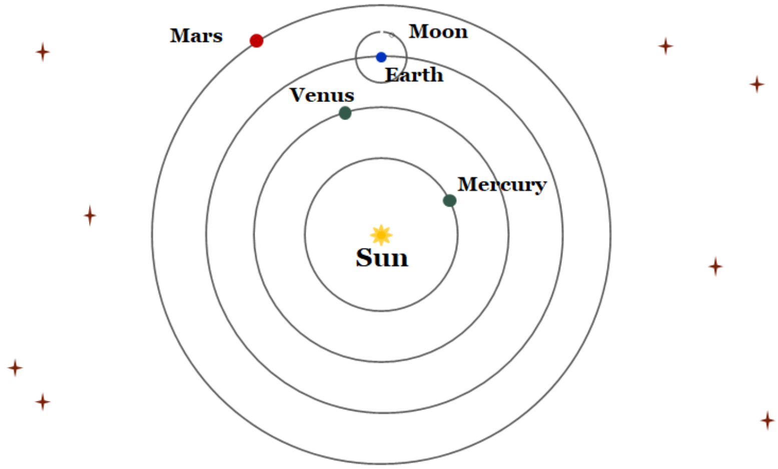
Heliocentric model

Some ancient cultures and most modern cultures use a heliocentric (Sun centered) model to explain the motions of celestial objects



The Sun is placed in the center of our solar system in this model:

- planets are placed on circular rings so that they orbit the Sun
- the moon revolves around the Earth as the Earth revolves around the Sun
- the apparent motions of the Sun and stars are explained by the daily rotation of the Earth on a tilted axis
- the stars are at different distances from the Earth
- predicting the positions of the planets was no better than that using the geocentric model until elliptical orbits with varying orbital speeds for the planets was used

Topic 4 Section 3

Actual Earth motions

Earth is in motion in many ways:

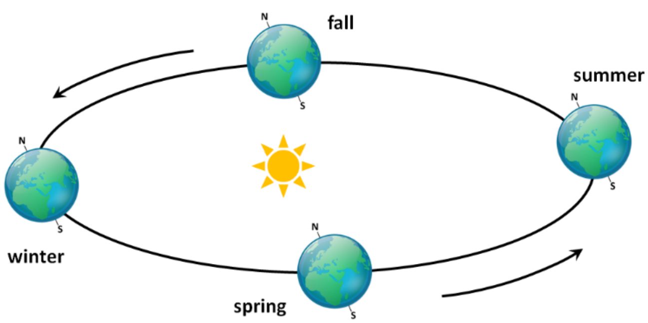
- it moves with the Milky Way as our galaxy expands in the universe
- it orbits the center of the Milky Way every 225 million years like a horse on a merry-go-round
- it revolves around the Sun
- it rotates on its axis

Rotation – Earth is spinning on its own *axis*

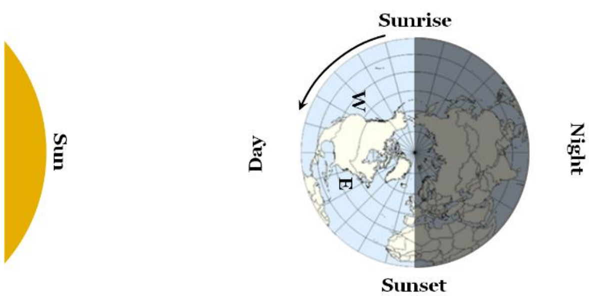
Axis – the imaginary line extending from the North Pole to the South Pole

Earth's axis is tilted 23½° relative to a line perpendicular to the plane of the Earth's orbit of the Sun

As the Earth orbits the Sun, its axis remains pointing very near the North Star or Polaris



Earth rotates about 360° from west to east in a 24-hour period or 15° per hour



Evidence for Earth's rotation

Because there are no reference points near Earth's surface and because Earth's motions are very smooth, we do not notice that we are moving

So how do we know Earth is rotating?

- evidence from people on space stations or on the moon
- satellites detect our rotation

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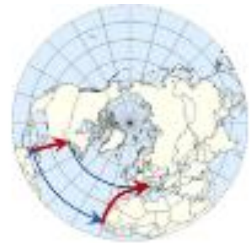
Evidence of Earth's rotating prior to space flight:



- the Foucault pendulum
- the Coriolis effect

Foucault pendulum: a freely swinging pendulum moving in a north – south direction will appear to change direction; after 6 hours it will swing east – west

As viewed from space one observes that the pendulum has not changed the direction of its swing but rather that the Earth has rotated under the pendulum

Coriolis effect: tendency of particles moving at the Earth's surface to deflect to the right in the Northern Hemisphere (and to the left in the Southern Hemisphere)

Due to Earth's rotation, a particle in the Northern Hemisphere moving north will be moving eastward faster than the surface of the Earth and will deflect to the right or eastward and a particle moving south will be moving eastward slower than the surface of the surface of the Earth and deflect to the right or westward.

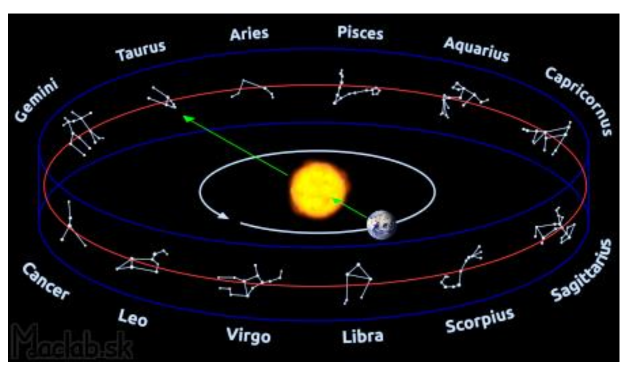
A particle moving with the Earth in the Northern Hemisphere will move along the circle of its latitude and therefore has a centripetal acceleration; increasing its speed east will cause the particle to rise and gravity will pull it toward the center of the Earth or to the right toward the south. Particles going westward will decrease rotational speed and will drop toward the ground but the surface of the Earth is tilted relative to the plane tangent to the surface of Earth which will force the particle to the right or toward the north.

Evidence for Earth's revolution around the Sun

Earth revolves around the Sun counterclockwise, as viewed from Polaris, in a slightly eccentric orbit at a rate of about 1˚ per day (360 ˚ in 365.25 days)

So how do we know the Earth revolves around the Sun?

- parallelism of Earth's rotation axis and the seasons because if the Sun orbits Earth then the season would not change
- the change in which constellation of the Zodiac appears due south at midnight
- Earth's slightly eccentric orbit causes the apparent diameter of the Sun to become slightly larger and slightly smaller once a year
- the doppler shift of stars change from red shifted to blue shifted every six months



Topic 4 Section 4

Earth and moon motions and time

- the year is based on one revolution of the Earth around the Sun
- the month is based on the phases of the moon
- the day is based on one rotation of Earth

Local time

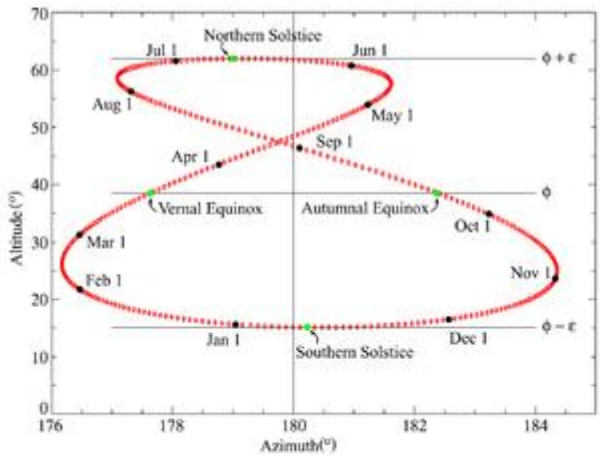
Time based on the rotation of the Earth is *local time*

All places on the same meridian (or longitude) have the same local time

Places slightly east or west of a meridian have different local times

Local solar time is based on the apparent position of the Sun or *sundial time*

Because Earth's orbit is eccentric and its axis is tilted to the plane of the ecliptic, the time of solar noon varies from day to day throughout the year



In fact, the length of a solar day varies from day to day throughout the year

Mean solar time is based on the average length of a solar day (the *mean solar day*) which is then divided into 24 equal hours

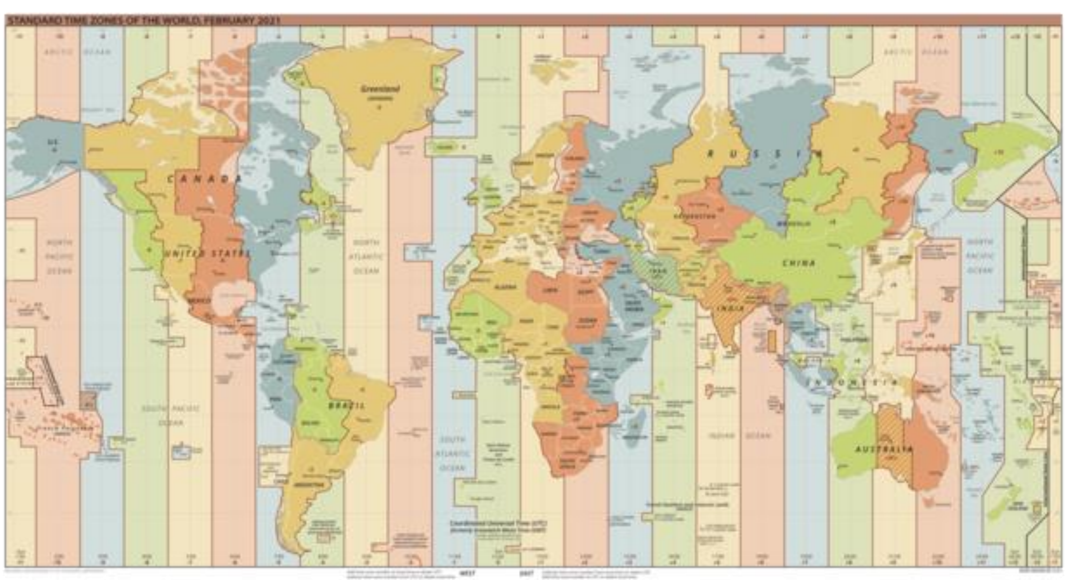
Mean solar time makes it much easier to make watches and clocks

Time zone or standard time

Because a circle has 360°, each hour on earth requires 15° of latitude

Each degree of longitude will differ by 4 minutes of mean solar time

Time zones (15° longitude regions) are marked on the Earth's surface so that people living near one another will all have the same time

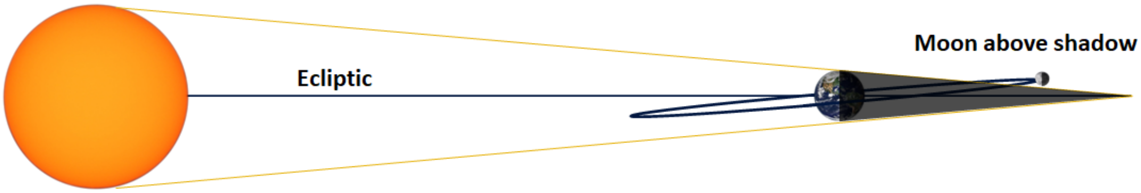


Topic 4 Section 5

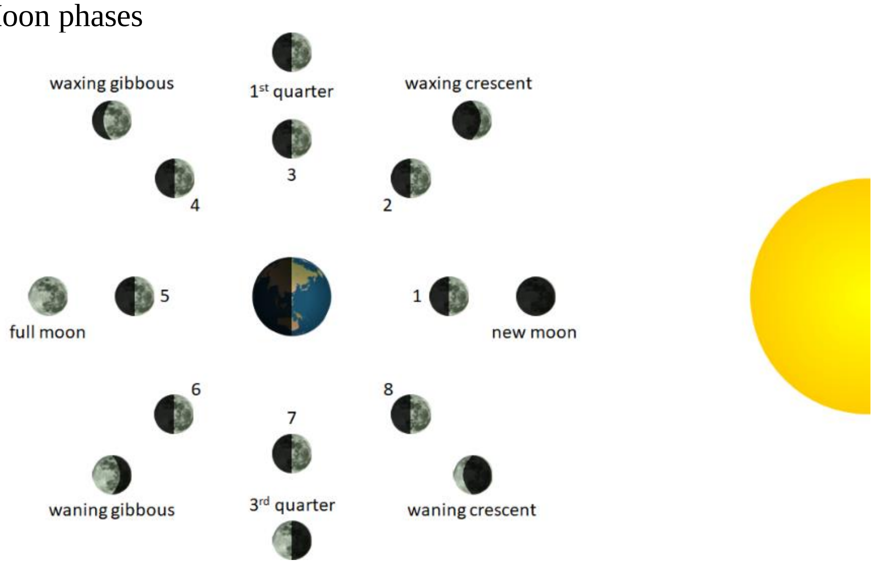
Actual motions of Earth's moon

- the moon's orbit is elliptical
- the moon's orbit is tilted 5° to the plane of the ecliptic (Earth's orbit around the Sun)
- the moon shows phases every 29½ days
- the period of the moon's orbit is 27⅓ days
- the moon rotates every 27⅓ days (always keeps the same face toward the Earth)

Moon's orbit tilted 5° to the ecliptic



Moon phases

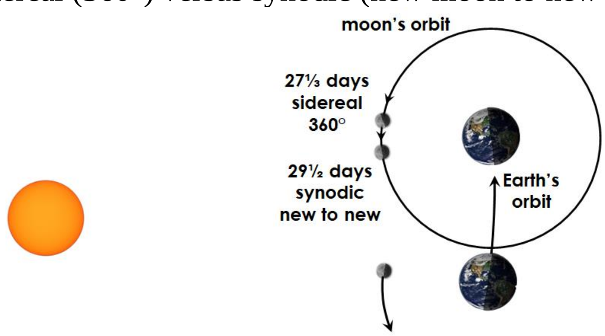


Only half the moon receives light from the Sun

As the moon orbits the Earth, we see different amounts of the light on the side of the moon that faces us

The result is the eight phases of the moon (see diagram above)

Sidereal (360°) versus synodic (new moon to new moon) lunar month



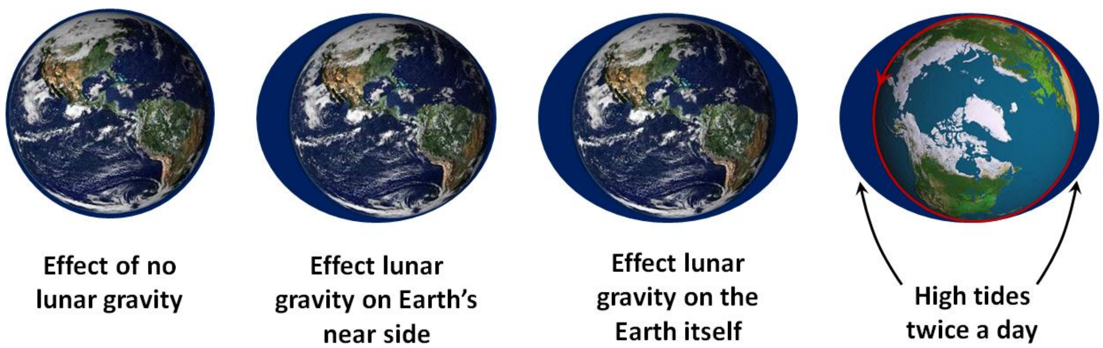
Because Earth travels around the Sun, the moon must orbit a bit more than 360° to reach the next new moon phase

Tides

Tides are caused by the difference between the gravitational pull on the near and far sides of the Earth caused by the Sun and the moon

The force of gravity from the Sun is 223 times greater than the force of gravity from the moon but the difference in gravity from the near and far side of the Sun is 0.017% and the difference from the near and far side of the moon is 6.7% which means the effect from the Sun is only 0.038 times as much as the effect from the moon

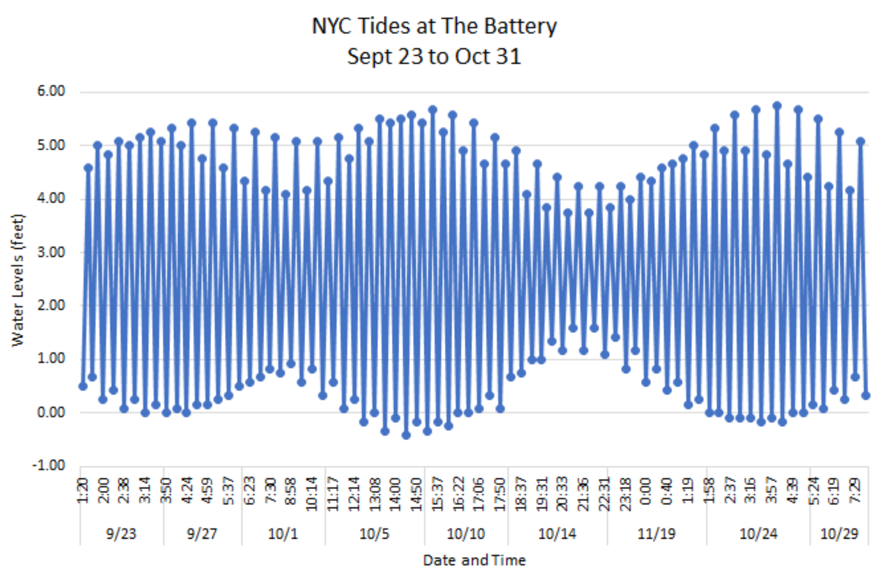
The moon causes two tidal bulges on the Earth

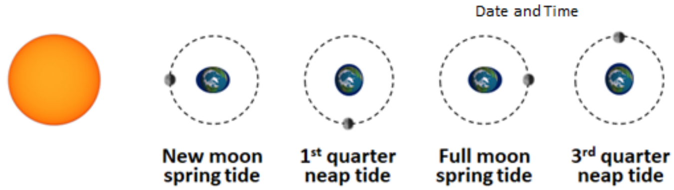


As the Earth rotates, a place on Earth will pass through a higher tidal bulge on the side toward the moon, then through a low tide, then through a lower tidal bulge on the side away from the moon, and finally through a second lower tide.

Because the moon orbits the Earth, each group of two high and two low tides will take about 24 hour and 50 minutes

The Sun also causes a smaller tide that can either add to the lunar tide (a *spring tide* with higher high tides and lower low tides) or can detract from the lunar tide (a *neap tide* with lower high tides and higher low tides)





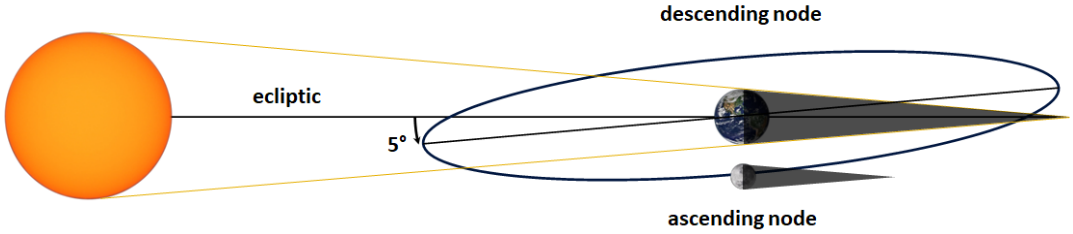
Eclipses

When a celestial object passes entirely or partially into the shadow of another celestial object

Lunar eclipse – occurs when the moon passes into Earth's shadow

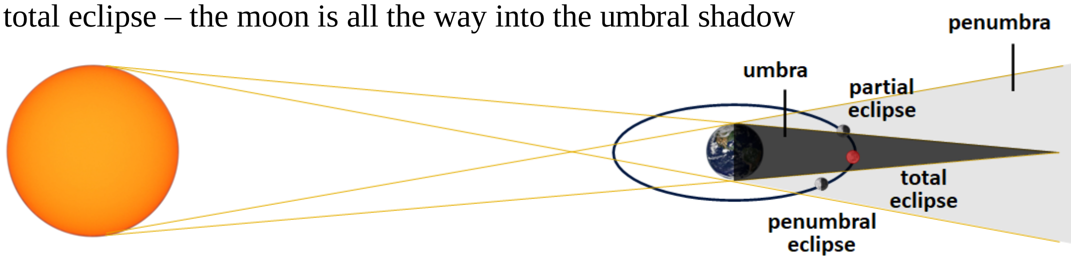
Lunar eclipses can only occur when:

- the moon is in its full moon phase
- the moon is near either its ascending node or its descending node



Types of lunar eclipses:

- penumbral eclipse – the moon is in the penumbral shadow only (not really visible to the human perception)
- partial eclipse – the moon is only part way into the umbral shadow
- total eclipse – the moon is all the way into the umbral shadow



Solar eclipse – occurs when the moon passes between the Earth and the Sun

Solar eclipses can only occur:

- during a new moon phase
- when the moon is near either its ascending node or its descending node

Types of solar eclipses:

- partial eclipse – the moon blocks only part of the Sun
- total eclipse – the moon blocks all the Sun
- annular eclipse – the moon is near its farthest point from Earth in its orbit so that its angular size is smaller than the Sun and a ring of the Sun shows all the way around the moon (the umbral shadow comes to a point above the surface of the Earth)