

1 Earth & Moon

The relative positions of Earth, Sun and Moon produce the most noticeable events in the nighttime (and daytime) skies.





Fact: The angular diameter of Moon is approximately 0.5°

Fact: The angular diameter of Sun is approximately 0.5°

These angular measurements are dependent on the distance from Earth. The Sun is approximately 400 times larger than Moon, but Sun is approximately 400 times further away.

	Moon	Sun	X
Minimum Distance (km)	363, 300	147, 100, 000	404
Maximum Distance (km)	405, 500	152, 100, 000	375
Average Distance (km)	384, 400	149, 579, 000	389
	Moon	Sun	X
Diameter (km)	3476	1, 391, 980	400



1.1 Lunar Phases

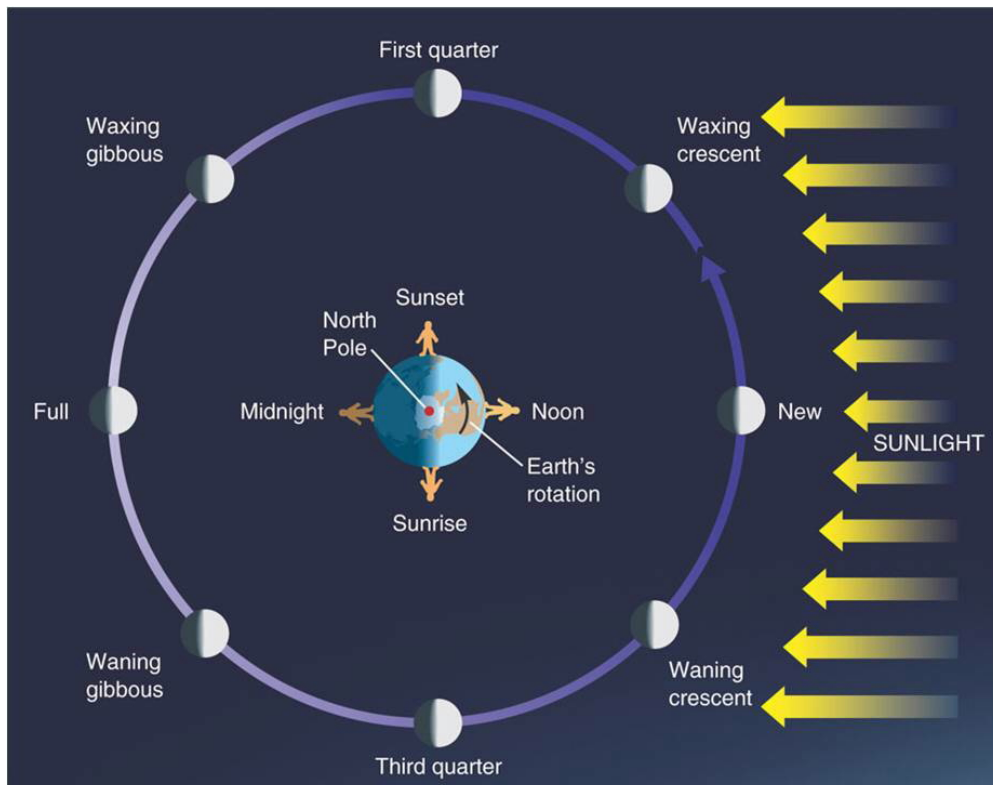
Sidereal Period The time it takes Moon to return to the same point in the sky.

27.321661 days

Synodic Period The time it takes Moon to go from full moon to the next full moon.

29.5305882 days

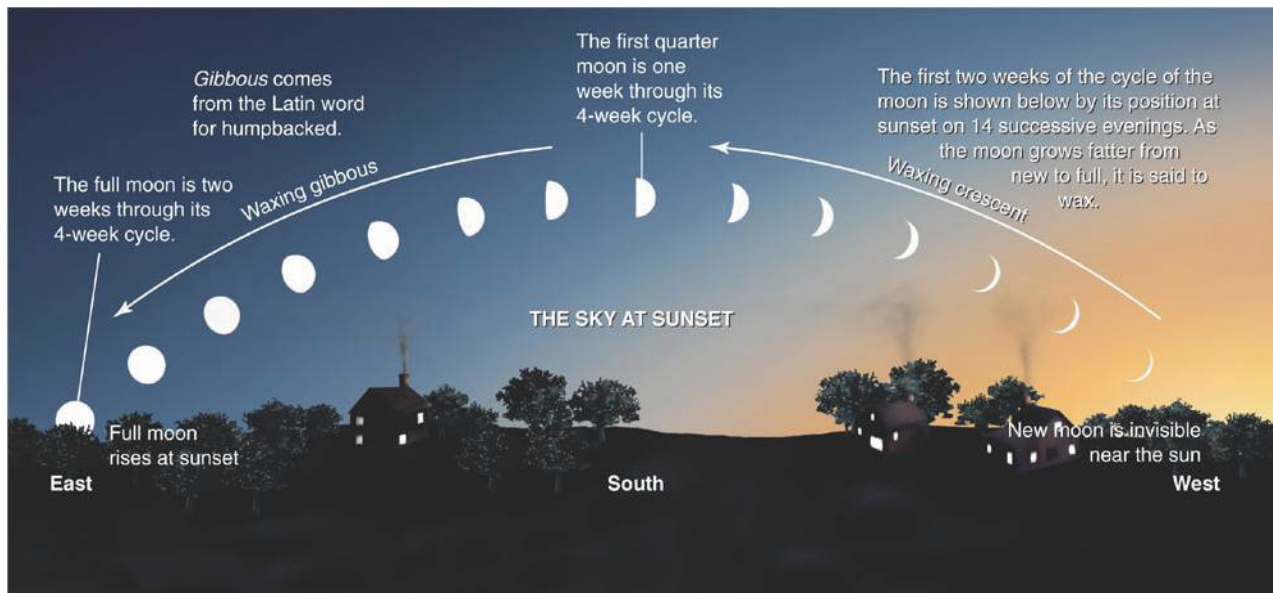
This is longer than the sidereal since Earth is also moving in its orbit around Sun. Moon must travel further in its orbit to reach the same phase.



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1.1.1 Phases

- New Moon
- Waxing Crescent
- First Quarter
- Waxing Gibbous
- Full Moon
- Waning Gibbous
- Third Quarter
- Waning Crescent
- New Moon

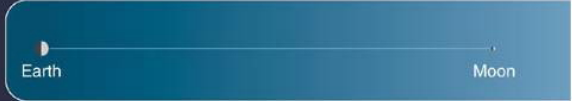


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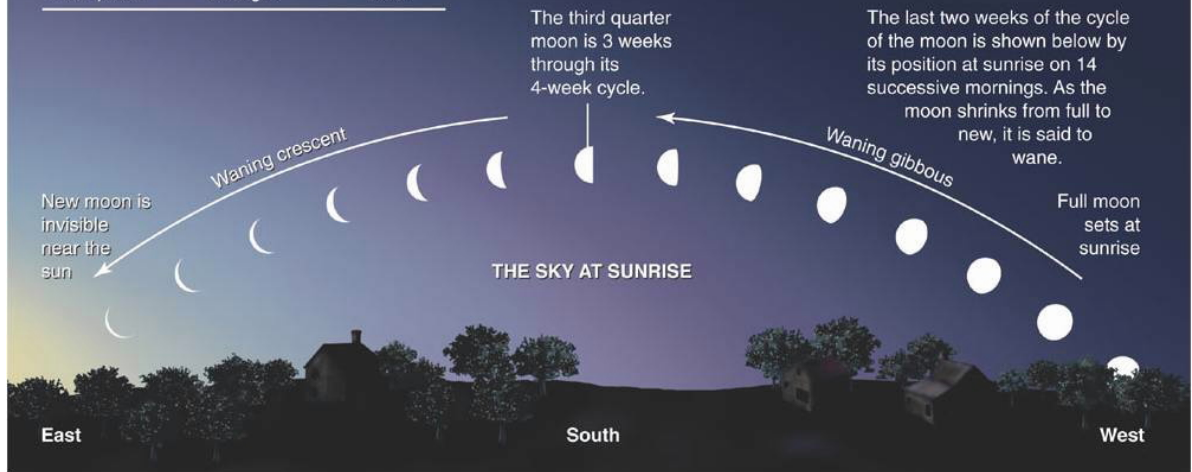
Rise and Set Times When does First Quarter Moon rise?
 When does Full Moon set?
 Etc.

You can use the diagram on the opposite page to determine when the moon rises and sets at different phases.

TIMES OF MOONRISE AND MOONSET		
Phase	Moonrise	Moonset
New	Dawn	Sunset
First quarter	Noon	Midnight
Full	Sunset	Dawn
Third quarter	Midnight	Noon



This diagram is to scale. The moon's orbit is about 30 Earth diameters in radius. Because the orbit is slightly elliptical, the moon's angular diameter in the sky can vary by plus or minus 6 percent. Because the orbit is tipped a bit over 5 degrees, the moon does not follow the ecliptic exactly.

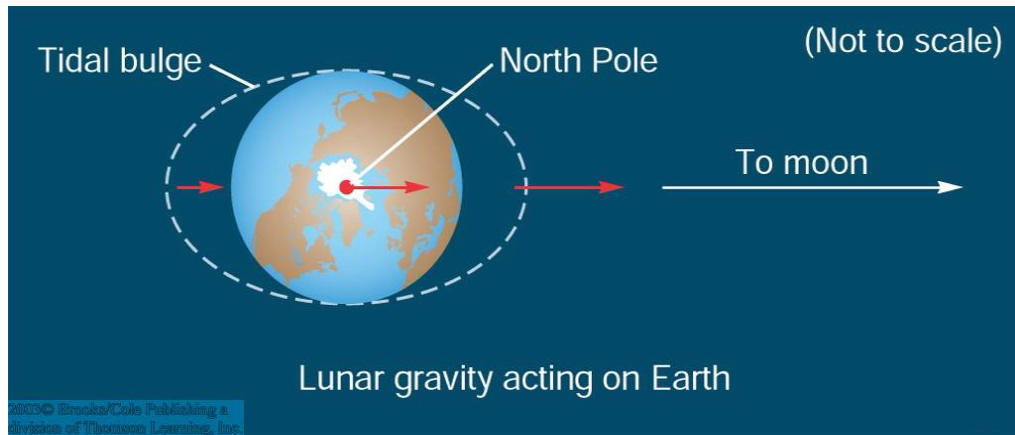


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1.2 Tides

The gravitational attraction by Moon on Earth's ocean creates a bulge toward Moon.

The gravitational attraction by Moon on the center of mass of Earth creates another bulge on the other side of Earth. Hence, two high tides per day and two low tides.

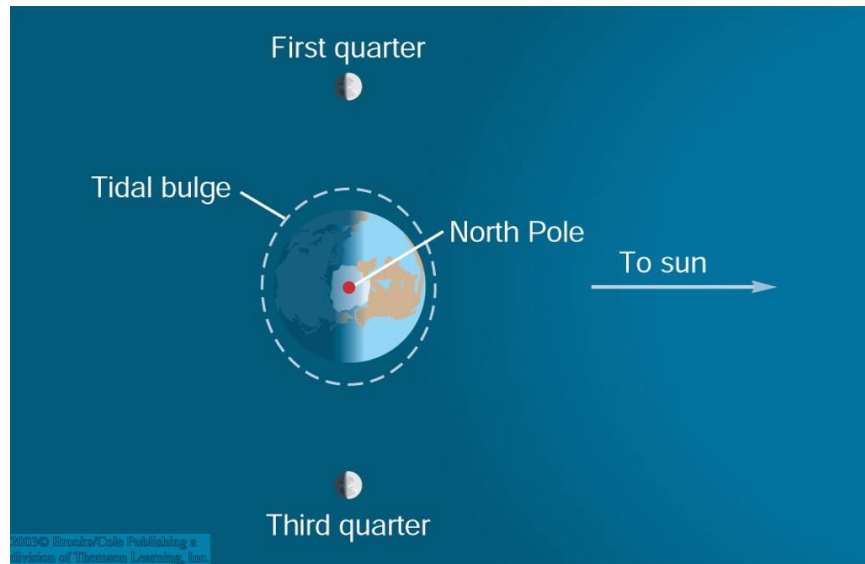


Sun also affects tides.

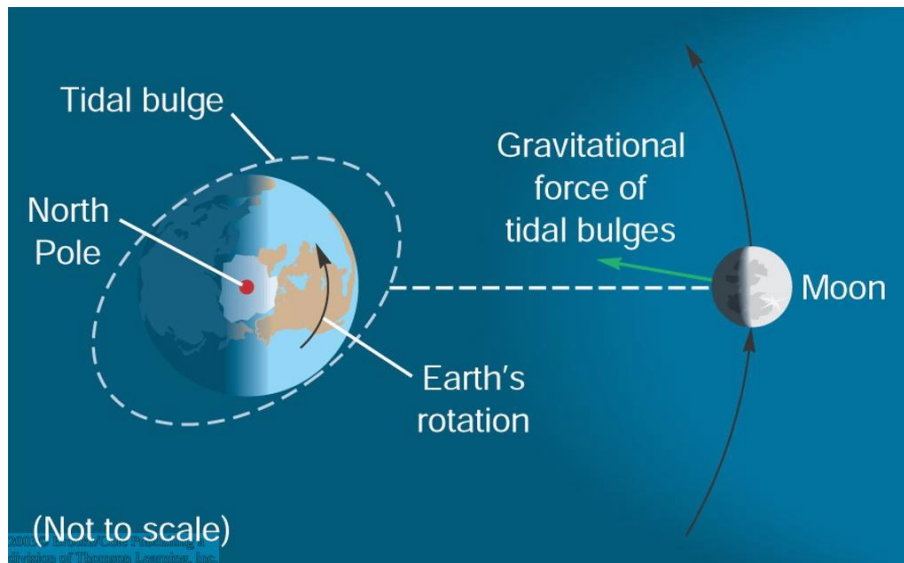
Spring Tides Occur near full and new moons. Sun and Moon add together to produce larger tidal swings.



Neap Tides Occur near first and third quarter. Sun and Moon are more perpendicular.

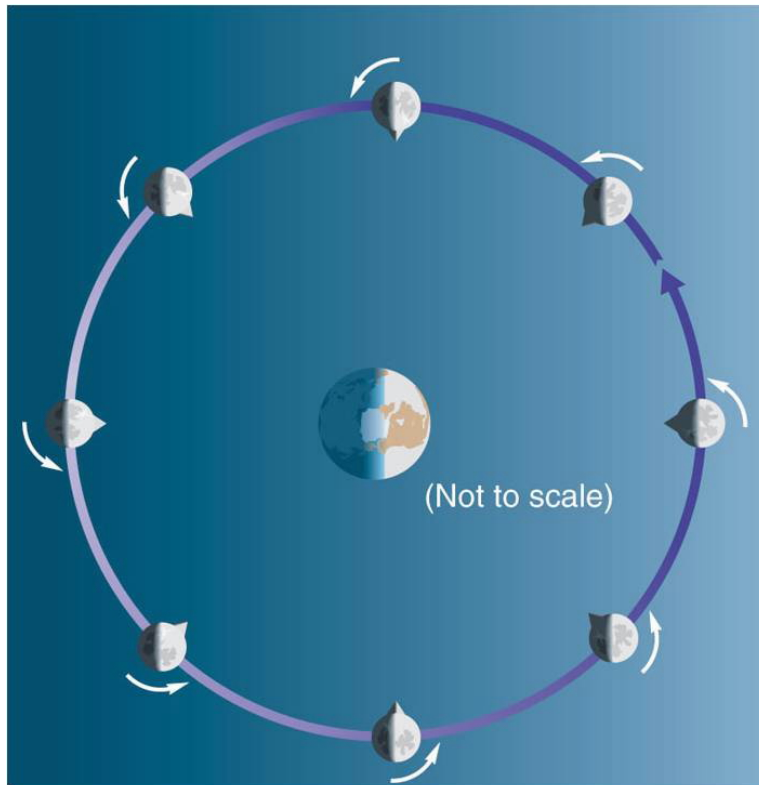


Actually, the bulge is not directed directly at Moon but leads Moon by a little bit.



Tidal Effects Slows the rotation of Earth. Frictional force between the water in the oceans and the surface of Earth. Earth is slowing by 0.001 seconds per century.

Same side of Moon always faces Earth.



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Moon's orbit is also getting bigger. Moon is pulled forward in its orbit causing it to move faster and be flung into a higher orbit. Moon's is moving away from Earth at a rate of 3 cm/y.

1.2.1 Lunar Eclipses

Occur at full moon phases only

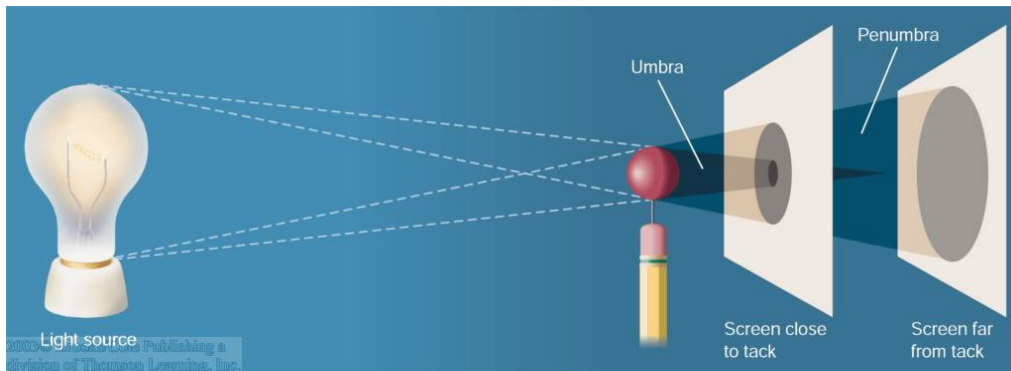
Moon enters Earth's shadow

Doesn't happen each month. Moon's orbit is inclined to the ecliptic by $5^{\circ}9'$.

Earth's shadow is about 1.4 million kilometers long and is 9000 kilometers wide at Moon's distance from Earth. Moon's diameter is 3476 kilometers.

Penumbral shadow

Umbral shadow - dark



■ **Table 3-1 | Total and Partial Eclipses of the Moon, 2006 to 2013**

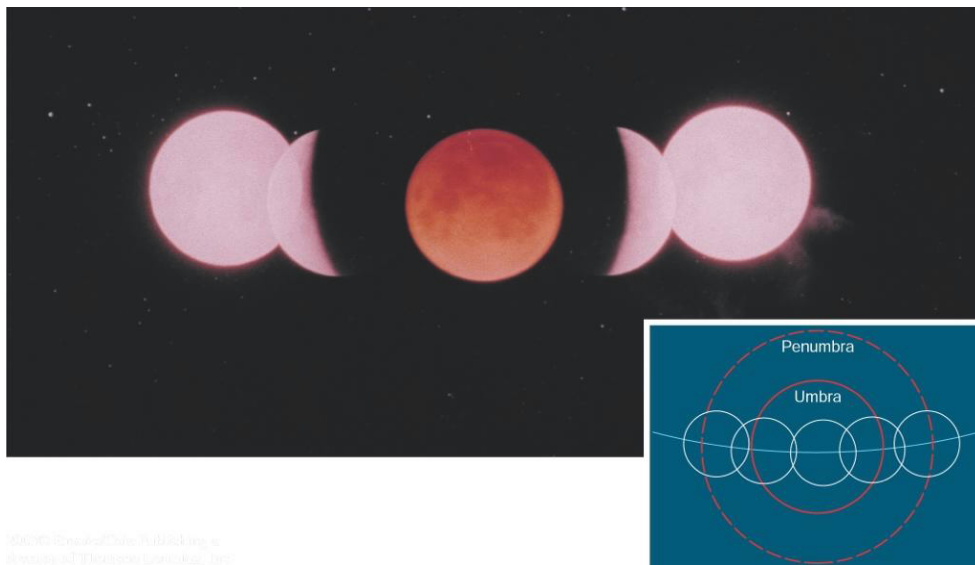
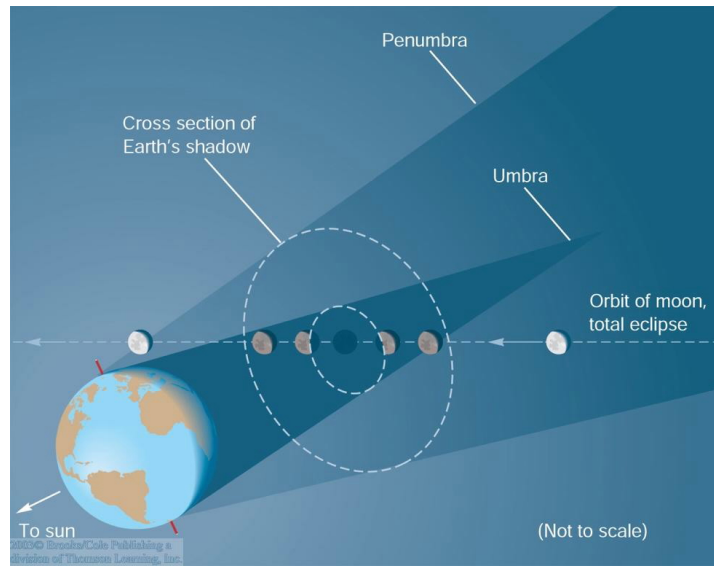
Year	Time* of Mideclipse (GMT)	Length of Totality (Hr:Min)	Length of Eclipse [†] (Hr:Min)
2006 Sept. 7	18:52	Partial	1:30
2007 Mar. 3	23:22	1:14	3:40
2007 Aug. 28	10:38	1:30	3:32
2008 Feb. 21	3:27	0:50	3:24
2008 Aug. 16	21:11	Partial	3:08
2009 Dec. 31	19:24	Partial	1:00
2010 June 26	11:40	Partial	2:42
2010 Dec. 21	8:18	1:12	3:28
2011 June 15	20:13	1:40	3:38
2011 Dec. 10	14:33	0:50	3:32
2012 June 4	11:03	Partial	2:08

*Times are Greenwich Mean Time. Subtract 5 hours for Eastern Standard Time, 6 hours for Central Standard Time, 7 hours for Mountain Standard Time, and 8 hours for Pacific Standard Time. From your time zone, lunar eclipses that occur between sunset and sunrise will be visible, and those at midnight will be best placed.

[†]Does not include penumbral phase.

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Total lunar eclipse Occurs when Moon moves completely inside the umbral shadow of Earth. Will glow coppery red due to the light being bent around Earth by its atmosphere.

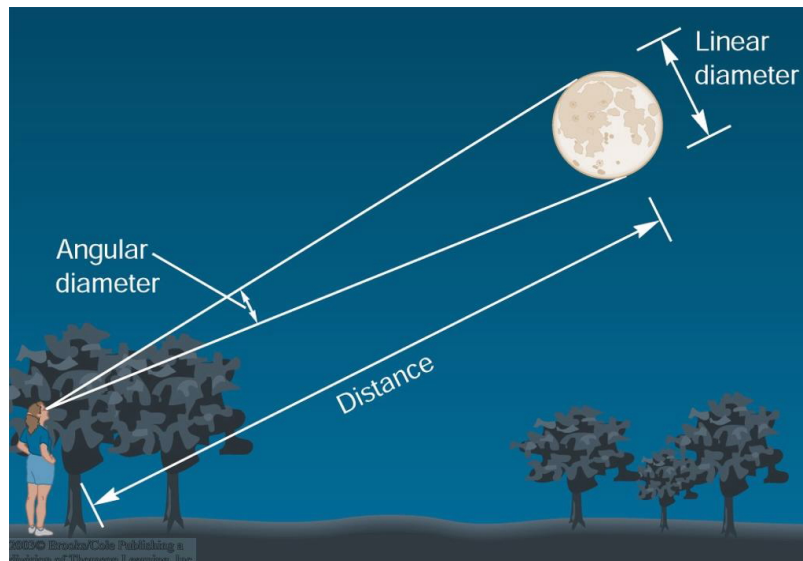




Partial lunar eclipse Moon enters the umbra only partially.

Penumbral lunar eclipse Moon does not enter the umbra at all but enters the penumbra. Results in only a partial dimming and is difficult to detect.

Angular Diameter



Small-Angle Formula

$$\frac{\text{angular diameter}}{206,265''} = \frac{\text{linear diameter}}{\text{distance}}$$

The number 206,265'' is the number of seconds of arc in one radian. For Moon

$$\frac{\text{angular diameter}}{206,265} = \frac{3476 \text{ km}}{384,000 \text{ km}}$$

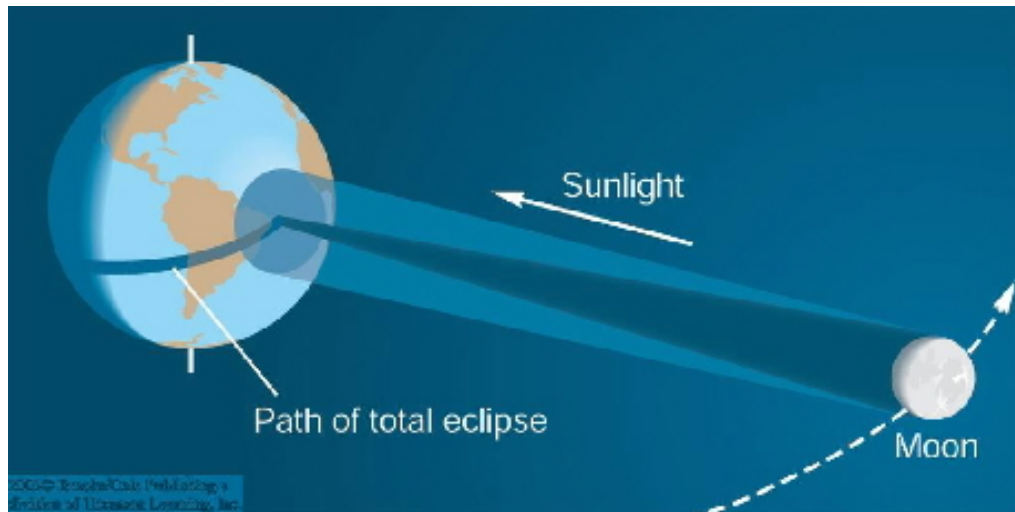
The angular diameter of Moon in the sky is 1870 seconds of arc or 31 minutes of arc, which is approximately 0.5° .

1.3 Solar Eclipses

Occur at new moon

Moon passes between Earth and Sun

Moon's shadow at the distance to Earth can be up to about 200 miles wide.



A Total Solar Eclipse



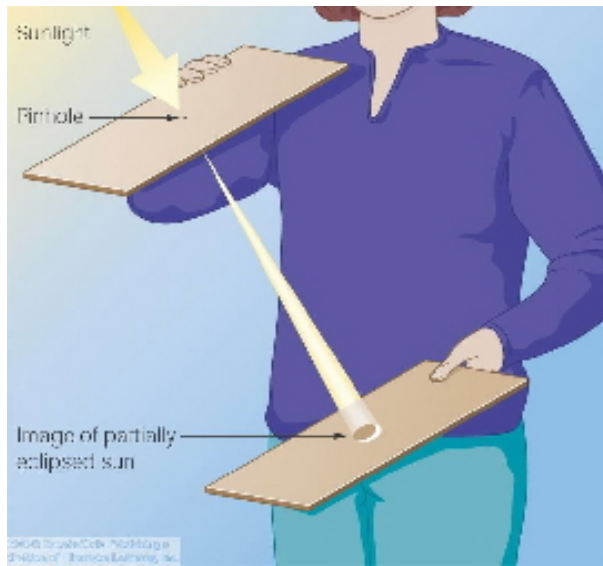
Total Solar Eclipse Can be viewed safely with the naked eye
Photosphere is totally covered



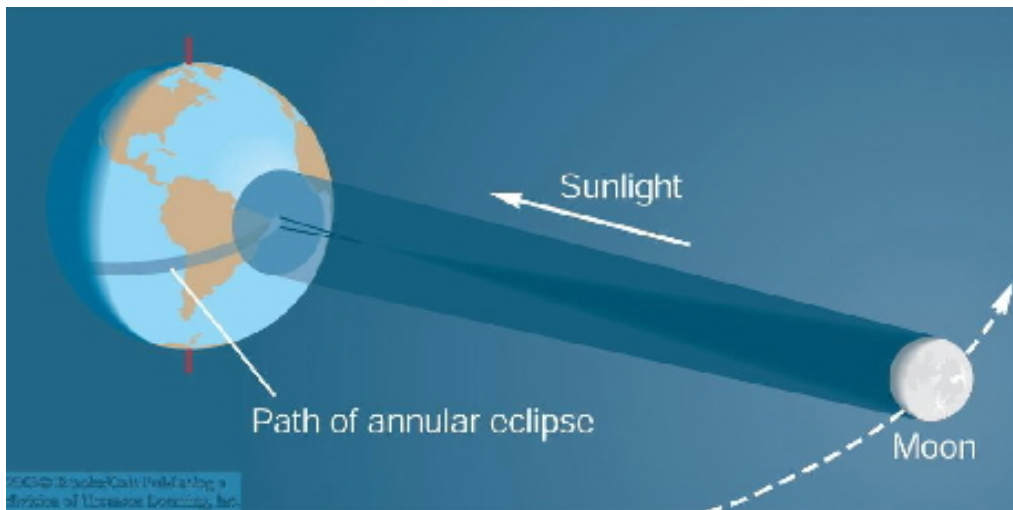
Just before and after totality, the sun's light shines through the valleys of Moon and produces the diamond ring effect.

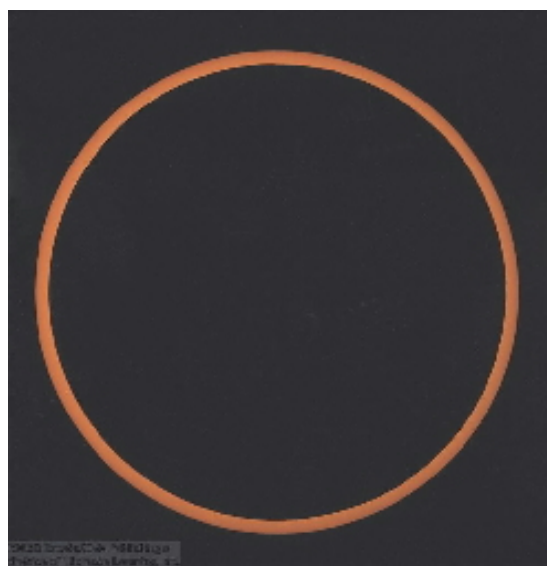


Partial Solar Eclipse Not safe to look at with the naked eye
Pinhole projection is easy and safe



Annular Eclipse
Not safe to view with the naked eye
When Moon is near its aphelion point in its orbit, further from Earth, smaller angular diameter





■ **Table 3-2 | Total and Annular Eclipses of the Sun, 2006 to 2016****

Date	Total/Annular (T/A)	Time of Mid-eclipse* (GMT)	Maximum Length of Total or Annular Phase (Min:Sec)	Area of Visibility
2006 Mar. 29	T	10 ^h	4:07	Atlantic, Africa, Turkey
2006 Sept. 22	A	12 ^h	7:09	N.E. of S. America, Atlantic
2008 Feb. 7	A	4 ^h	2:14	S. Pacific, Antarctica
2008 Aug. 1	T	10 ^h	2:28	Canada, Arctic, Siberia
2009 Jan. 26	A	8 ^h	7:56	S. Atlantic, Indian Ocean
2009 July 22	T	3 ^h	6:40	Asia, Pacific
2010 Jan. 15	A	7 ^h	11:10	Africa, Indian Ocean
2010 July 11	T	20 ^h	5:20	Pacific, S. America
2012 May 20	A	23 ^h	5:46	Japan, N. Pacific, W. U.S.
2012 Nov. 13	T	22 ^h	4:02	Australia, S. Pacific
2013 May 10	A	0 ^h	6:04	Australia, Pacific
2013 Nov. 3	AT	13 ^h	1:40	Atlantic, Africa
2015 March 20	T	10 ^h	2:47	N. Atlantic, Arctic
2016 March 9	T	2 ^h	4:10	Borneo, Pacific
2016 Sept. 1	A	9 ^h	3:06	Atlantic, Africa, Indian Oc.

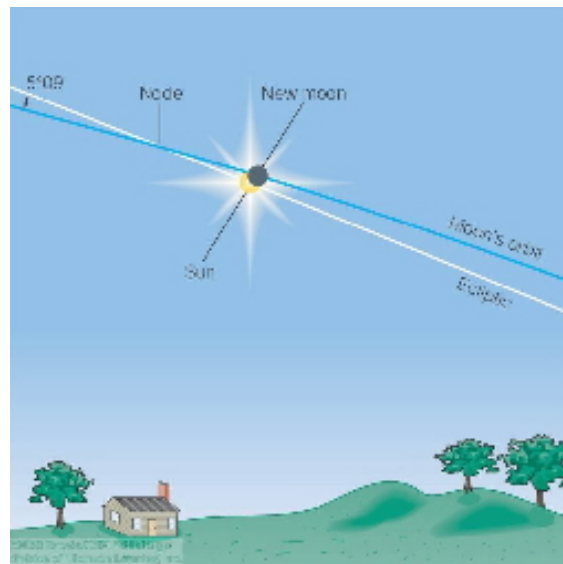
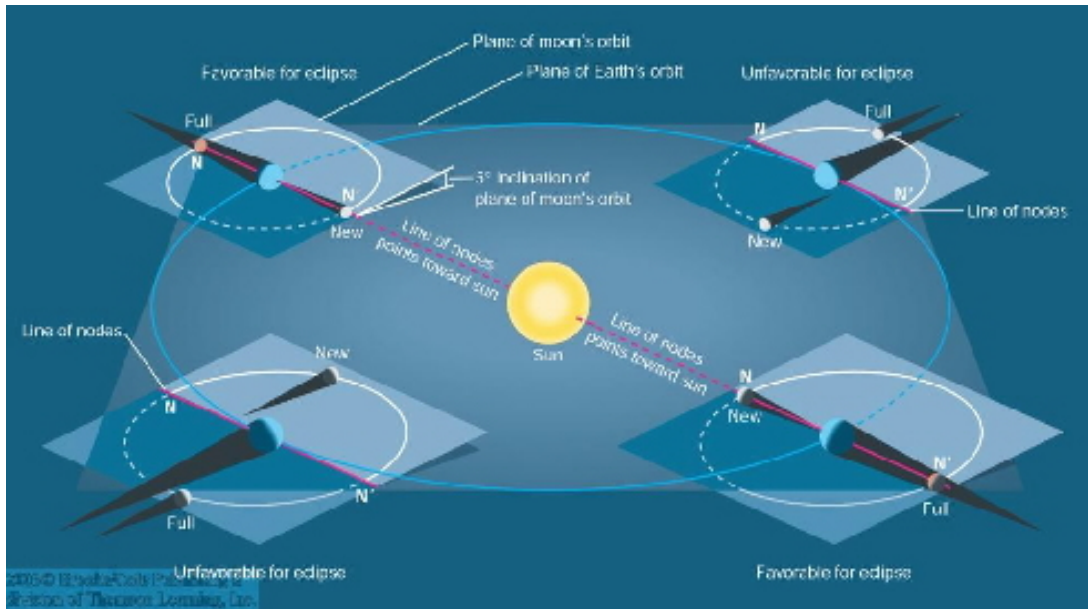
The next major total solar eclipse visible from the United States will occur on August 21, 2017.

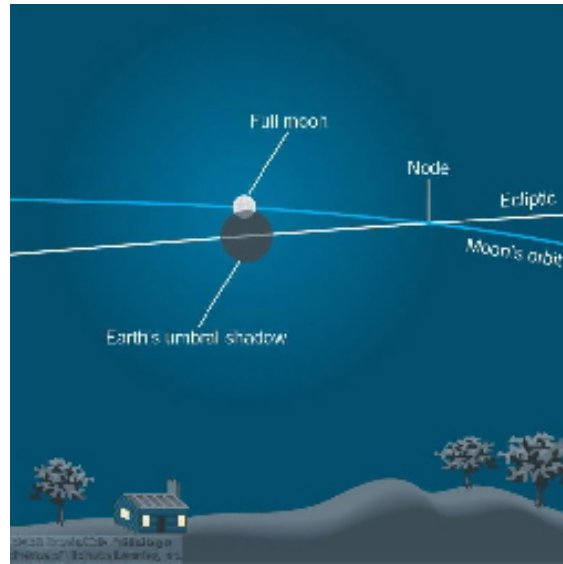
*Times are Greenwich Mean Time. Subtract 5 hours for Eastern Standard Time, 6 hours for Central Standard Time, 7 hours for Mountain Standard Time, and 8 hours for Pacific Standard Time.

^hhours.

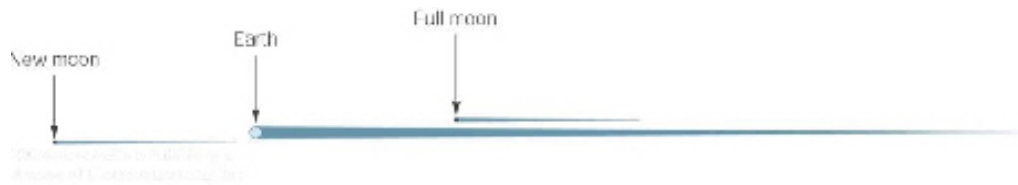
**There are no total or annular eclipses of the sun during 2014.

Line of Nodes Both lunar and solar eclipses can occur when the line of nodes of Moon's orbit points in the direction of Sun.





When the nodes point away from Sun



Saros Cycle 18 years, $11\frac{1}{3}$ days (6585.321 days)

Known in ancient times

After 3 Saros cycles, eclipses repeat in the same part of the world

