

CELESTIAL
SHADOW PLAY
TOTAL LUNAR ECLIPSE
SEPTEMBER 7-8, 2025

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TV VENKATESWARAN

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Celestial shadow play: Total Lunar Eclipse

by T. V. Venkateswaran

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FOREWORD

A rare celestial event, a total lunar eclipse is to take place on the night of September 7, 2025. A cosmic wonder, it is sure to excite everyone.

Unfortunately, especially in India, even after we know so much about the eclipse, many still advocate that eclipse is an inauspicious time. Scaremongers have field day making people huddled inside while one of nature's wonder takes place.

Several scientific studies have indeed been conducted. During the total solar eclipse of 1980 and later microbiological studies were conducted to find if cooked food becomes contaminated during the eclipse. Obviously, no such contamination was found. Several Indian astronomers like Āryabhaṭa, Varāhamihira, Prthūdakasvāmin, Lallacharya and others have categorically stated that eclipse are shadow play caused by Moon entering Earth's shadow or Sun being obstructed by the Moon. Yet obscurantists come in force, create a situation of scare and make ordinary people confused.

This small booklet is to explain the phenomena of eclipses, how & why they occur as well as teach some simple safe viewing techniques that one can easily follow.

Hopefully, this booklet would contribute in a small way in making people come out in large numbers and safely watch the annular solar eclipse.

Gratitude is due to Shri Biman Basu, Ms Anshumala, Shri C Taposh, activists of Tamil Nadu Science Forum, Tamil Nadu Astronomy and Science Society, and All India Peoples Science Network and my colleagues at IISER Mohali for support and encouragement provided.

T. V. Venkateswaran
IISER Mohali

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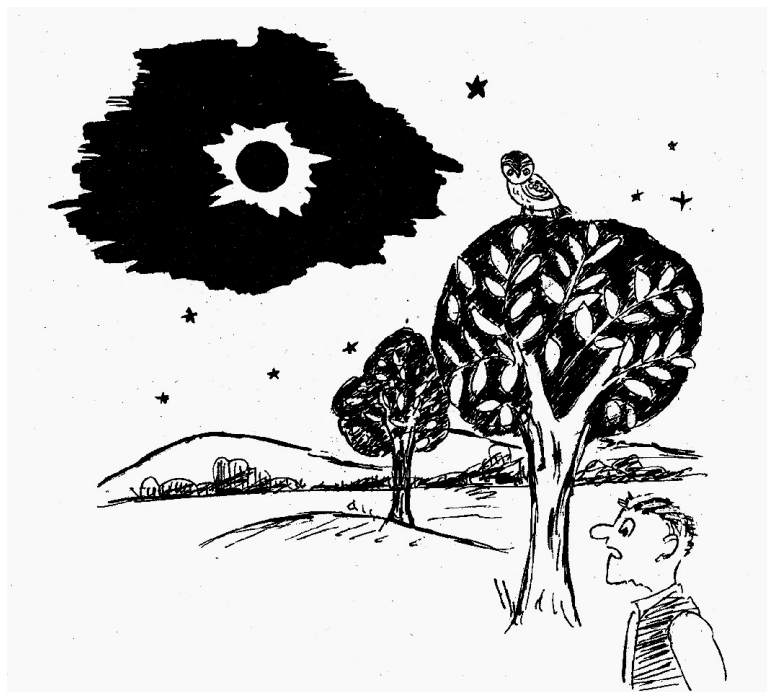
Mesmerising cosmic shows

We live in a fascinating world, where so many strange things keep happening! Consider the changes in the phase of the Moon over a month, how enchanting! Look at the shooting stars, or the Aurora Borealis; or the solar and lunar eclipses. They are captivating. During a total solar eclipse, the sky becomes dark like night for some time during the day. If we come to think of it, each of these phenomena is fascinating. Let us have a look at one of these fascinating phenomena.

Who has not lost his/her heart at seeing a full Moon on a cloudless night? Poets for ages have been enamoured by the Moon – its changing phases as well as its dazzling full moon phase. While Poornima and



Amavasya is predictable, and occur regularly, on rare occasions, a comet becomes visible with its long tail. At times we can see what look like 'falling' or 'shooting' stars, which astronomers call meteor showers. About once in a few centuries, we can see a magnificent explosion of a star – called a supernova. While the star is exploding, it may become so brilliant that it becomes visible even during the daytime. Last time humanity was able to witness such an event was in 1987 when for weeks, a supernova was visible to even naked eye in the southern sky. However, it was not bright enough to be visible during the day.



*Total solar eclipse is bewildering;
Sky above evokes wonder!*

Another class of cosmic events that enchants us are the solar and lunar eclipses. During a solar eclipse, as the Moon gradually covers the face of the Sun, we see the Sun look like crescent Moon. At the time of totality, when the Moon fully covers the Sun, it becomes suddenly

so dark that it seems like night even during the day. Stars shine in the sky and the beautiful corona – the upper atmosphere of Sun not visible otherwise – comes into view like a silvery halo around a dark Sun.

At times, the Moon is far from Earth, and hence small, while the Sun is closer to Earth and thus large. Therefore, the disc of the Moon cannot completely cover the face of the Sun. Then you have an incredible cosmic event—annular solar eclipse, popularly known as “ring of fire eclipse”. The Moon obstructs the central part of the disc of the Sun; the unobstructed edge appears like a ring of fire. We witnessed such a fantastic event in India on June 21st, 2020.

Another spectacular event is a total lunar eclipse, which occurs on full moon days when the Moon enters the Earth's shadow and becomes dark. Unlike a total solar eclipse, the Moon will not become entirely invisible but will seem dim and reddish.

We have an excellent opportunity to see this cosmic spectacle on the night of September 7-8, 2025, when a total lunar eclipse occurs. The lunar eclipse will be visible in Asia, Europe, Africa, and Australia. In India, the eclipse will commence around 11:00 PM IST on September 7th and terminate around 12:22 AM IST on September 8th. The maximum eclipse, in which the moon is closest to the centre of the Earth's shadow, will take place on September 7th at 11:41 PM IST.

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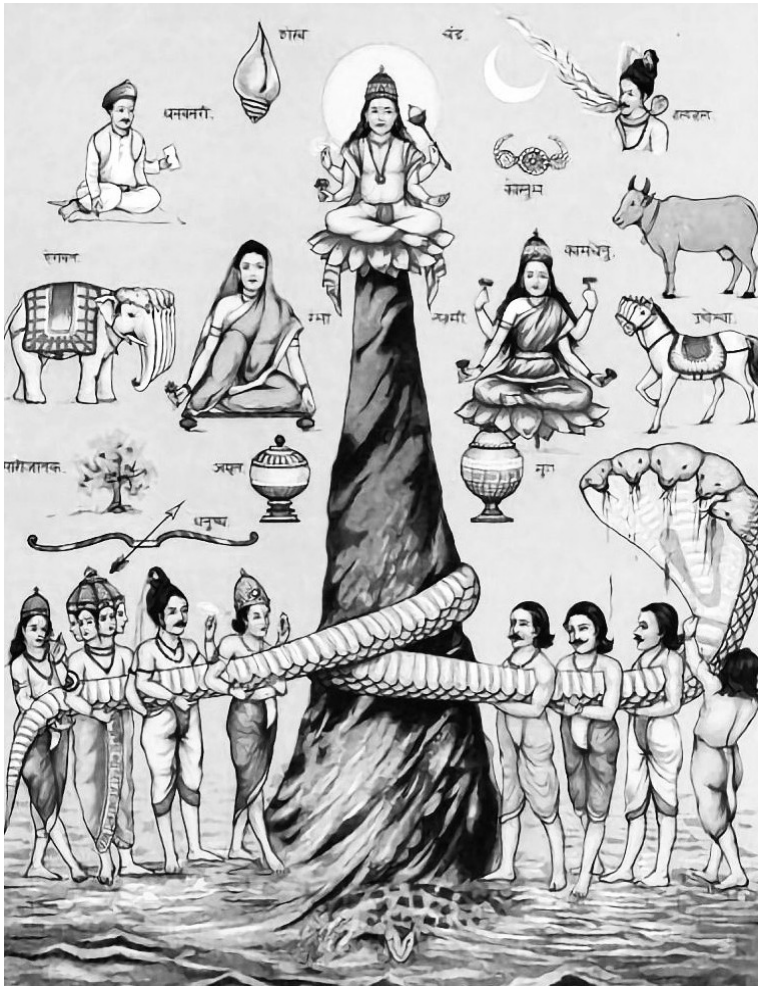
The Puranic myth of eclipses

Eclipses, in particular total solar eclipses, are spectacular celestial phenomena that have got historical and scientific importance. Of all the astronomical events visible from Earth, eclipses are the most awesome.

But for *Jyotishis* an eclipse is an *apshakun* (inauspicious event). A *Jyotishi* is likely to say “It is all the play of *Rahu*. You know, the head of the demon (*asura*) *Rahu* is taking revenge and eating away the Sun. We people in Earth depend upon Sun for our sustenance. Eclipse is ominous. We should be afraid; due to the bad ‘*doshas*’ (evil eye), food will be contaminated and polluted. We should not eat anything. We should gratify the wretched asura *Rahu* so that he is satisfied and leaves the Sun unharmed.” In fact, in Sanskrit, the eclipse is called ‘*grahana*’ meaning held forcibly or to seize or afflicted because of being captured. It also means to absorb or swallow.

Puranas like the *Vishnu Purana*, *Bhagavatha Purana*, etc., narrate a fantastic story of how the Sun and the Moon came to be eclipsed regularly. Long long ago, the Earth was covered by a flash flood. Many precious things were lost in flood. *Amrita* (or *soma*) - the nectar of immortality was one that got lost in the process. It was clear that the ocean had to be churned so that these precious materials could be recovered. The gods decided that they would need the help of the demons (*asuras*) in the churning of the ocean of milk, which would bring forth these treasures. They offered them an equal share of the *amrita*. However, they could never afford to give the demons the strength provided by the *amrita*, which would have made them even more potent than the gods.

The demons agreed to the proposal and first helped the gods to tear up the Mount Mandara for use as a churning stick. The serpent



Samudra Manthan

Vasuki was brought from his underwater abode to be used as a churning rope. Through a trick of *Vishnu*, the gods took the tail end and the demons pulled from the head. As the churning progressed, *Vasuki*'s breath grew very hot and the demons almost suffocated.

While the ocean was churned up, a deadly poison, *halahala*, was also churned up. Lord Shiva drank this, to save humanity, with a

consequence that his throat became coloured blue – and he is therefore also called Neelkantha. As the churning progressed, Mount *Mandara* began to sink into the ocean bed, and something had to be done to prop it up. Thereupon, Vishnu assumed the form of his tortoise avatar – *Koorma* - and dived to the bottom of the ocean. He let them use his back as a pivot upon which the churning stick/mount could turn.

The ocean produced *Lakshmi*, *Sura*, goddess of wine, *Chandra* or the Moon, *Rambha* the nymph, *Uchchaisravas* the white horse, *Kaustubha* a jewel, *Parijata* the celestial wishing tree, *Surabhi* the cow of plenty, *Airavata* a white elephant, *Sankha* a conch shell, *Dhanus* a mighty bow and *Visha* the poison. And at last, the ocean also produced the *amrit*, carried by *Dhanwantri*. Both gods and demons immediately tried to seize it, but the demons were first. While they were quarrelling over who should drink it first, *Vishnu* assumed the form of *Mohini*, a beautiful woman. Through sleight of hand, she gave the demons *varuni*, or liquor, while the gods were served the *amrit*.



Rahu is beheaded by Vishnu as Mohini.

One of the demons – *asura* called *Rahu*, however, caught on to the deception and sought a portion of the *amrit*. He camouflaged himself as a *Devta* and found his share. While he was drinking his portion of *amrit*, he was exposed by Sun and Moon to be an *asura*. *Vishnu* used his *Sudarshana Chakra* and beheaded *Rahu*.

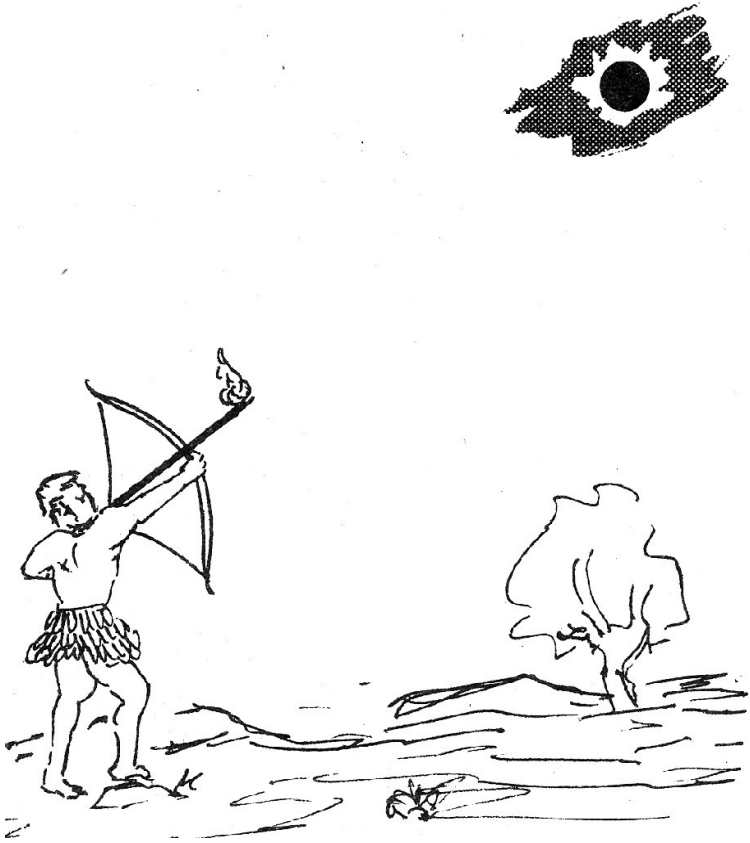
But since *Rahu* had already swallowed the divine nectar, he, that is both the trunk-less head and the headless body, became immortal. Since that day *Rahu* is trying to take revenge on Sun and Moon. Every now and then he gobbles up the Sun and Moon causing eclipses. The trunk-less head is known as *Rahu*. The headless trunk of the demon *Rahu* is known as *Ketu*. Since *Rahu/Ketu* had swallowed the divine nectar and became immortal, they were given a place in the heavens.

People who believe the *Puranas* to be true stories consider that eclipses are inauspicious and recommend the observance of fast during the period of the eclipse and do not cook food. Offerings are made to mollify and appease *Rahu* so that the *grahan* is over and the Sun is released from his captivity. If the solar eclipse ends after sunset, then the people fast during the night and consume food only next morning after sunrise. People take a bath as the eclipse begins and also after the eclipse is over. During the period of eclipse, they perform rituals like prayer, *tarpana*, *sraddha*, *homa*, *dana* (charity). *Tulsi* (Basil) leaves are used as a remedy and placed on all the items like milk, curd, pickles and stored water during the eclipse. Pregnant women are not allowed to move out during the eclipse and are asked to stay indoors where no sunlight enters the room. Generally, people are not allowed to watch the eclipse. Even temples are closed during the duration of the eclipse and opened after the eclipse is over, after performing special puja and rituals. In fact, people avoid even sleeping and attending to nature's calls during an eclipse!

In ancient times not only in India but all over the world, far-fetched stories were made up to explain eclipses. In China, it was believed that a dragon gobbles up the Sun/Moon and causes an eclipse. To scare away the dragon people sounded the gong and beat their drums

ANNULAR SOLAR ECLIPSE

during an eclipse. Many civilisations have very similar myths associated with the eclipse. But these are ancient myths – not truths.



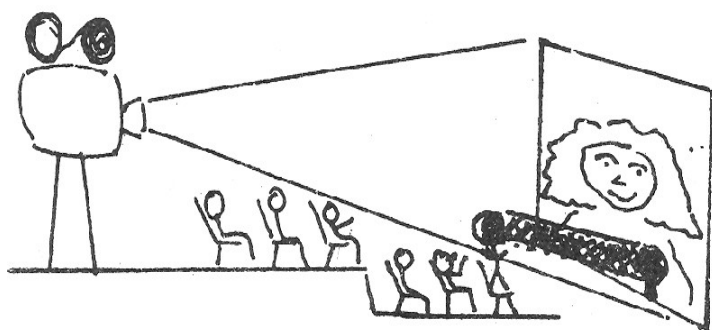
Eclipses in ancient times induced fear

Different cultures have unique myths about lunar eclipses: Egyptians believed a pig swallowed the moon; Mayans thought it was a jaguar; the Chinese imagined a three-legged toad. India's Gond tribe saw eclipses as joyful events symbolising the sun and moon creating new worlds. In some African tribes, people feared the sun had been extinguished and tried to relight it with flaming arrows. Eskimos likened eclipses to human illness, believing the sun and moon occasionally fall sick.

3

Rational explanations

In India for long time eclipses were seen as something to be feared and as bad omens. The earliest mention is in the Rigveda which states that the asura Svarbhanu pierces the Sun with darkness, who is then rescued by the sage Atri. Later, Svarbhanu is identified with Rahu and in the famous story of the churning of nectar, Svarbhanu is beheaded, and the bodyless head, Rahu, causes the eclipses. Ketu was earlier used to denote comets and meteors, and it is only in much later texts that Ketu is identified with the head-less body of Svarbhanu.

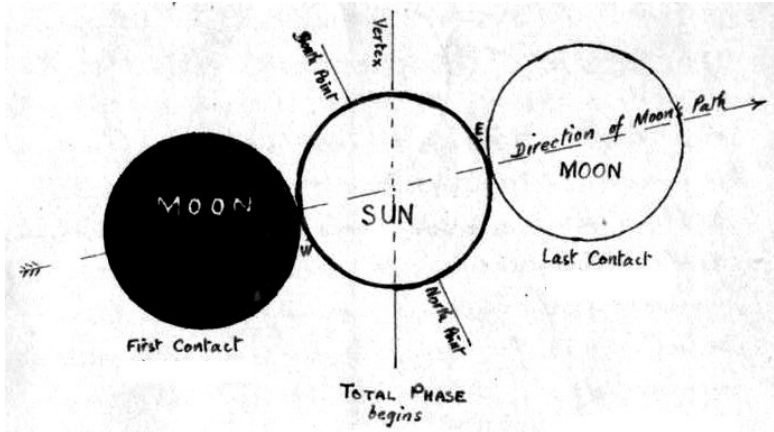


Like the shadow of the head seen on the cinema screen, during solar eclipse, shadow of the Moon falls on the Earth.

Indian astronomy was revolutionised with the arrival of Aryabhata. Born in 476 C.E. in present day Patna, during the Gupta period, he shook the world of astronomy and maths. In the fourth part of his only surviving work, the Aryabhatiya, he made some astonishing claims for its day. He states that the earth is spherical in shape and rotates about its axis once a day. Notably, Aryabhata dispenses with Rahu and Ketu, explains eclipses as due to shadows of the earth and the Moon, and describes how to calculate their timing and their size.

He was not afraid of refuting traditional wisdom if it did not agree with reality. Aryabhatiyam, Golapadah, Chapter 4, Shloka 37 says *chādayati śaśi sūryam śaśinām mahatī ca bhucchāyā ||*, which essentially means ‘the moon covers the sun (during a solar eclipse) and the great shadow of the earth covers moon (during a lunar eclipse)’.

Varahamihira demolishes the idea of puranic entity Rahu/Ketu being the cause of the eclipses. He wrote, *bhūcchāyām svagrahaṇe bhāskaramarkagrahe praviśatinduḥ. pragrahaṇamataḥ paścānnendorbhānośca pūrvārdhāt*, meaning “the truth is that in her own eclipse, the moon enters the shadow of the earth, and in that of the sun, the solar disc. Hence, the lunar eclipse does not commence at the western limb nor the solar at the eastern limb”.



Varahamihira knew that solar eclipse will commence from the western limb of the Sun.

The invariance in direction eclipse phases, east to west for lunar; west to east for solar, is caused by Moon's orbit, which is from west to east around the Earth. If a demon were truly responsible for these phenomena, one would not expect such predictability. Eclipses, for example, are calculated well in advance, indicating that the motion of Rahu follows fixed patterns. This raises questions about how the actions attributed to a deity could be predetermined. Additionally, it is unclear why Rahu and Ketu do not obscure both the Sun and Moon simultaneously.

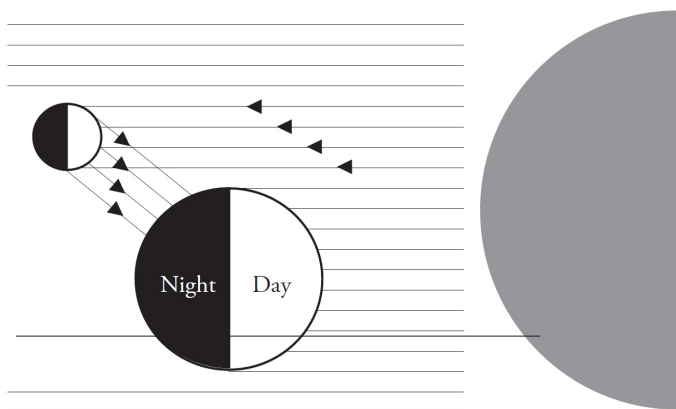
Lalla circa 720 C.E. C.E.) who resided in present day Gujarat was one of the few astronomers who refuted the Rahu/Ketu theory of eclipses. In his work *Śiṣyadhīvaṛddhida* tantra, chapter XX, is titled 'false notions'. He says "if you are of the opinion that an artful demon (Rahu) is always the cause of an eclipse by swallowing (the Sun or Moon), then how is it that an eclipse can be determined by means of calculation. Moreover, why is there not an eclipse on a day other than the day of New or Full Moon." A more compelling argument presented by Lalla is that, while the Sun may appear eclipsed at a particular location on Earth, there are other regions where it remains fully visible. If Rahu were truly responsible for swallowing the Sun during a solar eclipse, the Sun would be obscured everywhere on the planet simultaneously. In his work Lalla says "In a solar eclipse, people at different parts (of the earth) see different portions of the Sun eclipsed. Some do not see (the eclipse) at all. Knowing this, who can maintain that an eclipse is caused by Rahu?"

Like Aryabhata, scientifically inclined scholars in India have clearly asserted that eclipses occur due to the shadow of the Moon falling on the Earth, and the Earth's shadow being cast on the Moon. In *Bṛhat-saṃhitā*, Varahamihira, says 'the moon, moving from the west, hides the solar disc from below just like a cloud'. In a cinema hall, when a person gets up on his seat and blocks light from the projector, the film is 'eclipsed'- that is, the shadow of the man's head falls on the screen. Solar and lunar eclipses are merely such shadow plays – though a magnificent and gorgeous one.

4

How and when eclipses occur

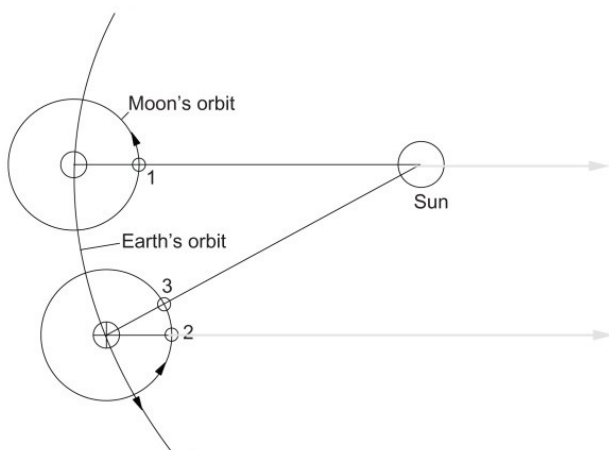
In our solar system, only the Sun shines by its own light. The Moon, planets and other solar system objects reflect sunlight; they have no source of light. That is why we see the phases of the Moon. As the Moon goes around the Earth, the orientation of the Moon with respect to Sun changes. When Moon is precisely on the same side as the Sun, it is called 'conjunction'. Now the portion of Moon that is illuminated by Sun - day side of Moon - is facing away from Earth, and the 'night' part of the Moon is all that is visible from Earth. Therefore, Moon will not be visible from Earth - we have new Moon or Amavasya. But when the Moon is exactly opposite to the Sun, a situation called 'opposition', precisely the opposite happens. Now the face of Moon, lit by sunlight faces the Earth and its night side is facing away from Earth. Therefore, we see a full Moon – or Poornima. During the intervening period, we see the different phases of the Moon.



One half of Earth and Moon always are sunlit and other half dark. The proportion of the 'day' and 'night' side visible from Earth makes the Moon appear as crescent

As the Moon goes around the Earth, the angle between Sun, Earth and Moon changes. The changing position with respect to the Sun causes our natural satellite, Moon, to cycle through a series of phases. New Moon > New Crescent > the First Quarter > Waxing Gibbous > Full Moon > Waning Gibbous > Last Quarter > Old Crescent > New Moon. The phase known as the new Moon cannot be actually seen because the illuminated side of the Moon is then pointed away from Earth. The rest of the phases are familiar to all of us as the Moon cycles through them month after month.

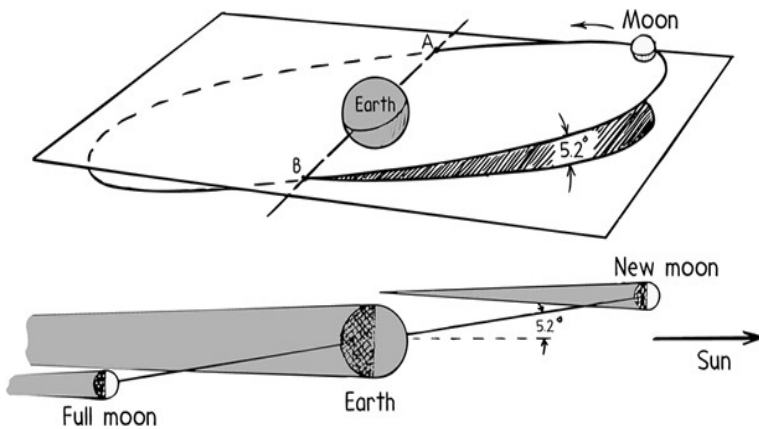
The Moon goes around Earth once in 27.3 days, but it takes 29.53 days to go from one new Moon to the next new Moon or from one full Moon to the next one. Moon returning to the 'same star' (or a particular point in space) means the plane containing the centre of Earth and centre of Moon point towards that specific star. While the full Moon phase implies the centre of Sun, the centre of Earth and centre of Moon are in the same plane. Moon orbits the Earth and Earth revolve around the Sun. By the time the Moon makes one orbit and comes back to the



1. The Sun, the Moon and Earth are aligned in a plane. We have new moon. The Earth -Moon line is aligned to a distant star.
2. After about 27.3 days Earth-Moon line is aligned to the same star. However, the Moon is not in the same direction as the Sun.
3. After about 29.5 days the Earth, the Moon and the Sun are in the same plane, the next new moon.

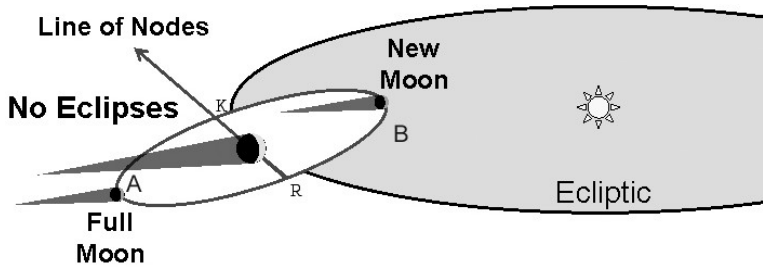
same point in space, and aligned to a specific star, the Earth would have moved ahead in its orbit. Therefore, it takes an additional 2.2 days for the Moon to reach opposition or conjunction with the Sun.

Usually, the Moon comes between the Sun and Earth on every new Moon, but we don't have a solar eclipse on every new Moon. A solar eclipse can occur only when the centres of Sun, Moon and Earth are nearly in a straight line. Only then the shadow of the Moon falls on Earth (like the head of a cinema viewer that comes between the projector and the screen). During a normal full Moon day, the centres of these three celestial objects in the same plane and not on the same line. This is the crucial difference.



As the plane of the orbit of the Moon is inclined, although the Earth, the Moon and the Sun are in the same plane, they are not in the same line. The Moon is above or below the line joining Earth and Sun, that is the ecliptic plane.

But why do we then have eclipse at all? To understand this, we need to know another exciting feature of Moon's orbit. We all know that Earth goes around the Sun in an elliptical orbit. The plane on which Earth revolves around the Sun is called the ecliptic plane. Where does the Moon's orbit lie? Is it on the same plane as that of Earth's revolution around the Sun – the ecliptic plane? The answer is: NO. In fact, the orbit of Moon is inclined to ecliptic plane at about 5 degrees.

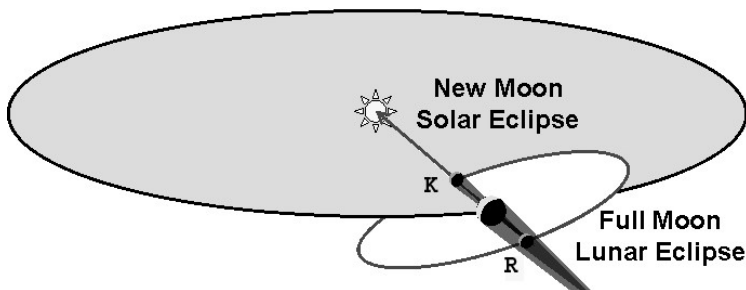


When the new moon or full moon occurs the Moon is above or below the ecliptic plane, and therefore eclipses do not occur. The Moon is not on any of the nodes.

As a result, the Moon's orbital plane intersects the Earth's orbital plane at two points, called nodes. One of these two points is called the ascending node – where the Moon moves from 'below' the ecliptic plane to above (marked R). The other is called the descending node – where the Moon moves from above the ecliptic plane to below it (K in the illustration).

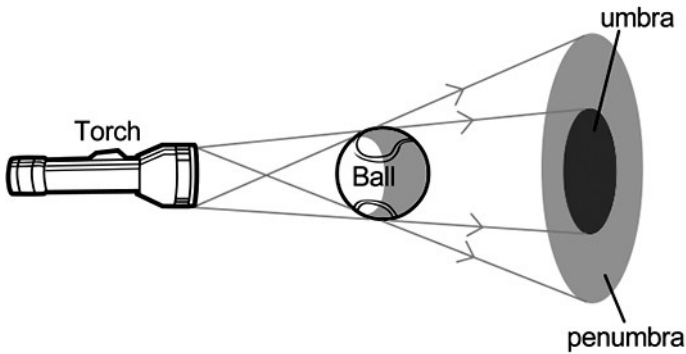
Most of the time, Moon is either 'above' or 'below' the ecliptic plane. If the Moon is above (or below) the ecliptic plane and is on the same side of Sun as Earth, we will have a normal new Moon, but no eclipse will occur. The centres of the three objects will be on a plane but not on a straight line. However, if the Moon happens to be on the same side of the Sun and also at either of the nodes, what will result? Imagine.

In such a situation, Earth, Moon and the Sun will lie precisely on a straight line. If the Moon is on the same side as the Sun; that is,



When the Moon is on the plane of the ecliptic, it is in either of the node. When the new moon or full moon takes place, then it would cause eclipses.

in conjunction, then it will be new Moon or Amavasya. And since the three cosmic bodies are perfectly aligned, the Moon will obstruct the view of Sun. We know, any object placed in the path of light, will cast a shadow. A tree in the open, under sunlight, will cast a shadow. A table near a burning candle will cast a shadow. In the present case, the Moon will cast a shadow that will fall on the surface of the Earth, causing an eclipse of the Sun.



An object obstructing a light source will produce darker umbra and lighter penumbra shadows.

Similarly, if the Moon is at one of its nodes and at opposition with the Sun, the centres of the three objects will form a straight line. Now the shadow of the Earth will fall on the Moon, causing a lunar eclipse. From this it is clear that a lunar eclipse will occur only on a Full Moon or Poornima.

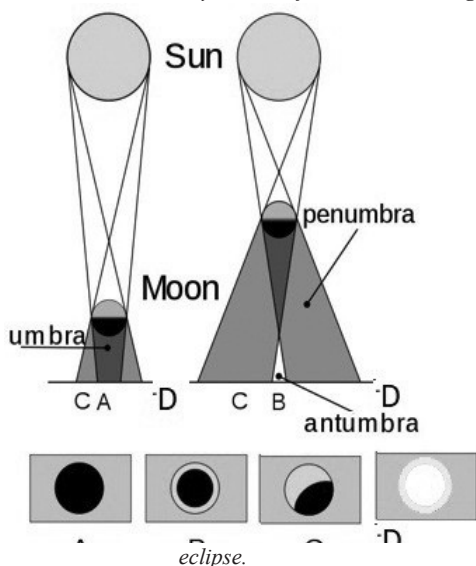
So, we can see, although we have a conjunction of Moon with the Sun on every new Moon, it is not a lunar eclipse. The opposition of the Moon with the Sun occurs on every full moon. Yet, we do not have eclipses every fortnightly because the three cosmic bodies do not come in a straight line every fortnight. It is only on those rare occasions when the Moon is at one of the nodes and in conjunction with Sun, that an eclipse would occur.

5

Solar Eclipse

We now know that eclipses are neither dragons eating the Sun, nor Rahu taking revenge. They are just a play of shadows. Shadows, which are nothing but the absence of light, have its own physics. In candlelight, one can observe that a spherical shadow is cast around the candle and candle stand. The shadow will have two concentric regions, the first one - with a darker, sharp shadow and a second one with a lighter, diffused shadow. The same can be observed on

At the location A the Sun will be covered by the disc of the Moon resulting in Total solar



As the Moon is relatively far from Earth, it will appear small and will not be able to cover the whole disc of the Sun. At the location B the Sun will appear like a ring of fire causing annular, annular solar eclipse.

At the location C on Earth, only part of the Sun is covered by the Moon, hence partial eclipse.

At location D, no part of the Sun is covered and hence no eclipse.

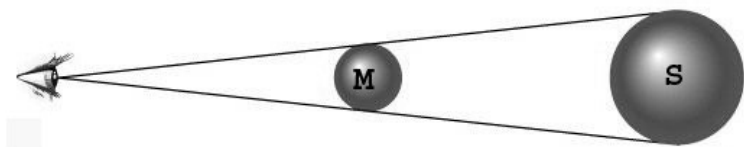
The head of the man blocking the light from the projector would appear sharp at the centre surrounding which a diffused shadow in the shape of a magnified head would also appear. The darker region is called the umbra, and the diffused shadow region is known as the penumbra. For a person standing in the umbra region, the source of light would be totally cut off, whereas for a person in the penumbra, the source would be partially obstructed.

In a total eclipse, the Sun is the source of light, and the Moon is the obstruction causing the shadow. In this case, too, there will be two concentric regions of shadow - umbra and penumbra. When the shadow falls on Earth, for those watching the eclipse from the umbral area (A), the Sun would be blocked entirely. In case of the annular solar eclipse those in the region of antumbra (B) central portion of the Sun will be obstructed and they can witness the ring eclipse. On the other hand, for those who watch it from the penumbral region (C), only part of the Sun would appear obstructed. We can say, a 'total solar eclipse' occurs at the area of umbra and a partial eclipse at the penumbral region. Typically, the totality can be seen from only a small region under the umbra. In contrast, most places will witness a partial eclipse. Those who are outside the region of the shadows (D) no eclipse would be visible.

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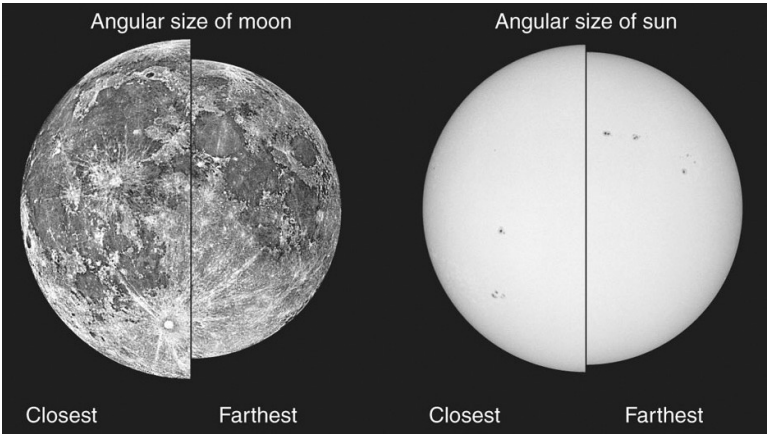
Of being the right size

On a scale model, if Sun is represented as a football, then Earth would be only of the size of a grain of moong dal and the Moon a mere grain of sand. Yet, due to some queer are such from Earth the Sun and Moon appear to be deceptively identical in size. The Sun is about 400 times bigger than Moon, but it is also about 400 times further away from Earth. Hence, from Earth, the Sun and Moon appear to be of the same size (1800 arc seconds or $\frac{1}{2}$ degree), making possible total solar eclipses. If the size of the Sun or Moon or the relative distances were different from what they are now, then there would be no total solar eclipses at all!



The Moon and the Sun appear almost same size from Earth.

One should hasten to add, the apparent size of the Moon and Sun does not always remain the same. As Earth revolves around the Sun in an elliptical path, at times, the Earth may be closer to the Sun and at times may be farther away. As a result, the apparent size of the Sun would vary. When the Earth goes around the Sun in an elliptical orbit, it is at the nearest position (called Perihelion) on January 4 every year. Earth reaches the farthest point (Aphelion) on July 4 every year. On July 4 when Earth is farthest from Sun, the apparent size would be 1891 arc seconds. On January 4, when Earth is the nearest to Sun, the



As the orbits of the Moon and Earth are elliptical, the apparent size of the Moon and the Sun changes every day.

apparent size of Sun would be around 1955 arc seconds. [One degree has 60 arc minutes and each arc minutes has 60 arc seconds].

The mean angular size of Sun is 1800 arc seconds (that is, ½ degree). As the variation in apparent size is only 3%, it is not perceptible to naked eye. The Moon, likewise, goes round the Earth in an elliptical path. Hence the angular size of Moon varies between 1764 arc seconds and 2012 arc seconds. Again, the average visible size turns out to be almost equal to the angular size of Sun - 1800 arc seconds. Yet the insignificant difference is responsible for the different kinds of solar eclipses.

Size	Minimum	Average	Maximum
	(arc seconds)		
The Sun	1886.4	1918.8	1951.2
Moon on the horizon	1760.4	1879.2	2012.4
Moon when overhead	1789.2	1908.0	2048.9
Moon at point of maximum eclipse	1764.0	1911.6	2044.8

(the apparent size of the Sun does not change appreciably from horizon to overhead, due to the immense distance)

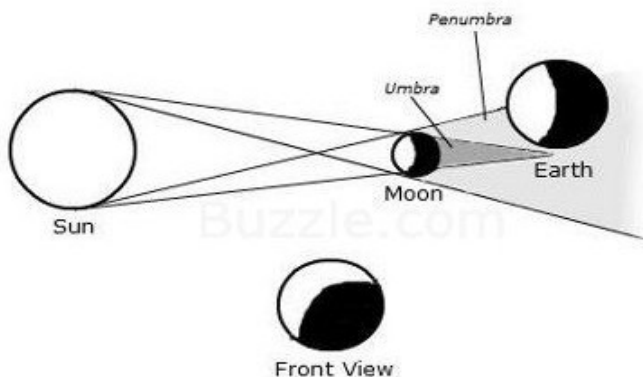
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Types of solar eclipses

There are three types of solar eclipses: annular, total or partial. An eclipse can also be partly total and partly annular when it is called a 'hybrid eclipse'. Let us look at a situation when the Moon is at one of the nodes, but not precisely aligned to Sun. The Moon will not cover the whole of the Sun's disk, but only a part of it would be covered. This phenomenon is called a 'partial solar eclipse'.

A total solar eclipse occurs only when the apparent size of the Moon is the same or more than the apparent size of the Sun. In other words, the Earth-Moon distance should be less than the average. Needless to say, the position of the Moon in the space must be at one of the nodes or very close to it. Under these circumstances, the Moon's disc is seen centred against that of Sun, and the umbra of Moon's shadow falls on Earth. The total solar eclipse is seen from the umbral region.

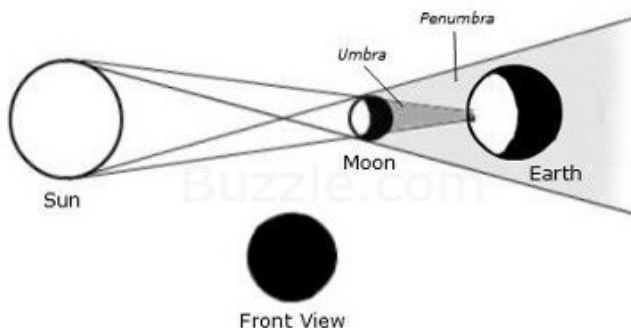
Partial Solar Eclipse



From the penumbral area, only partial eclipse is seen.

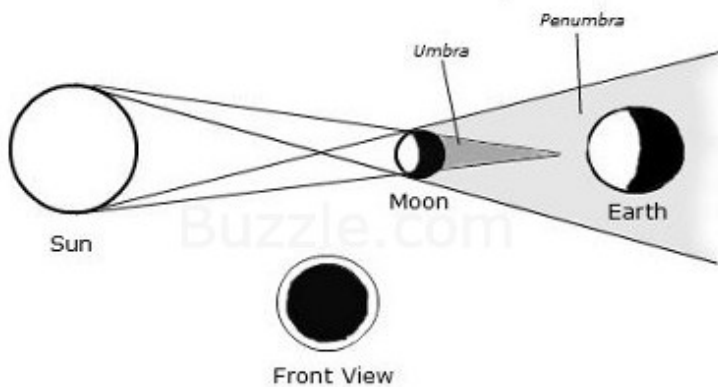
When the Moon is not at the exact node, but very close to it, only part of the Sun is covered, and we have partial solar eclipse.

Total Solar Eclipse



When the Moon is very very close to the node and the apparent size of the Moon is bigger than that of Sun, we have total solar eclipse.

Annular Solar Eclipse

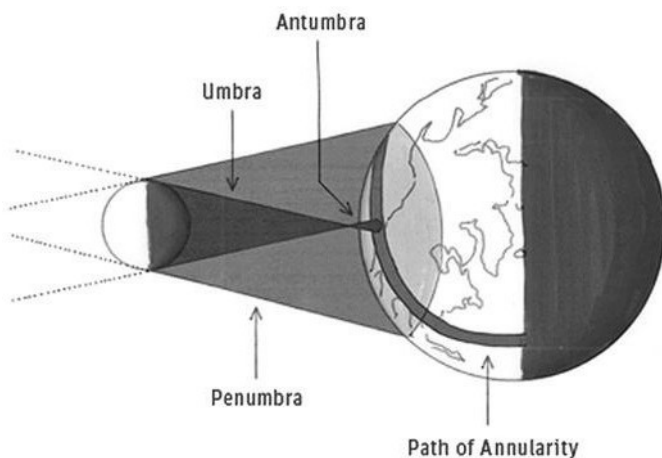


The Moon is very very near to the node, but the apparent size of the Moon is smaller than that of Sun, we have annular solar eclipse.

On a rarest of a rare occasion, the Moon may be at a node and aligned with the Sun and Earth, but the apparent size of the Moon might be smaller than the apparent size of the Sun. Sun may be near the Perihelion, making it appear bigger. Or the Moon might be near its farthest point, making it appear smaller than the average. In such a situation the Moon's disc would not be able to completely cover Sun's

disc. When the centre of the Moon and the centre of the Sun's disc are aligned, only the central part is obstructed. The edges of the Sun are visible beyond the Moon's disc like a ring of fire. Sun will give the appearance of a bangle or a bracelet. This incredible phenomenon is known as an annular solar eclipse.

Sometimes, the visible sizes of the Sun and Moon are so close that a total or an annular eclipse is seen depending on the observer's location. Such an eclipse is known as a 'hybrid solar eclipse'. The apparent size of the Moon and the Sun is so close that the position of the Moon in the sky makes all the difference. Later we will explain how the Moon overhead appears slightly bigger compared to Moon seen at the horizon. Hence the eclipse starts as annular, changes to a total eclipse, then changes back to an annular eclipse again before the end. The totality path will be very narrow, and the totality would be for a very short duration. The rare annular eclipse is ordinarily visible only over a small area on Earth. Still, a partial solar eclipse would be visible over a large part of the world. The last hybrid solar eclipse occurred on April 20, 2023, and the next one is on November 14, 2031.



During the duration of the eclipse, Earth rotates, and the Moon revolves. Therefore, the shadow spot falling on the face of Earth moves across.

We know that annularity occurs only where the antumbra of the Moon falls on the Earth's surface. Likewise, the total solar eclipse is visible where the umbra of the shadow falls. But Earth and Moon are not stationary. Hence the shadow falling on the surface of the Earth also does not remain fixed. The Moon moves eastward in its orbit with respect to the Sun at an average speed of 3,400 km an hour. Meanwhile, the Earth rotates eastward at about 1,670 km an hour (at the equator). So, over a period of time, the shadow of the Moon sweeps across the Earth's surface. The antumbra/umbra of the Moon's shadow sweeps along a thin band across the Earth's surface. The phase of the annularity/totality of the eclipse is observed successively along this path. The path across the Earth's surface within which an annular/total solar eclipse is visible - in other words, where the antumbra/umbra of Moon falls - is called the 'path of annularity/totality'. The path of annularity/totality covers less than 1% of Earth's surface area. To see the ring of fire eclipse, or total eclipse you must be somewhere within the narrow path of annularity/totality. The path of an annular/total eclipse can cross any part of the Earth. Even the North and South Poles get an total/annual eclipse sooner or later.

8

Duration of a solar eclipse

We know that the average visible size of Sun and Moon in the sky is 1800 arc seconds or $\frac{1}{2}$ degree. We know that it takes Moon 29.5 days, or let us say, 30 days to move from one new Moon (or full Moon) to the next one. Therefore, in one day, it covers $360 / 30 =$ about 12 degrees in the sky. That is, it moves 12 degrees in 24 hrs. Consequently, it moves $\frac{1}{2}$ degree in about 1 hour. Here we are not talking of the apparent daily movement of the Moon, but the movement of the Moon amongst the background stars.

Likewise, as Earth moves around the Sun, the apparent position of the Sun with respect to the stars also keeps changing, about 1 degree eastward per day. Hence, the Sun will move 150 arc seconds in one hour. During an annular eclipse, the apparent disc of Sun is bigger than usual.

Therefore, for the Moon to move about $\frac{1}{2}$ degree (apparent size of the Sun) eastward from the first contact to second contact (beginning of annularity/totality), it will take about $1\frac{1}{2}$ hour. Likewise, for the Moon to fully uncover the Sun (from the third contact to the fourth contact), it will take about $1\frac{1}{2}$ hour. That is, the partial phase of the eclipse will last for about three hours. However, it these will depend on the daily mean motion of Moon and Sun also the distance between the Earth Sun and Moon. Therefore, the duration and totality of eclipse can vary from one eclipse to another. The longest annular solar eclipse of the 21st century took place on January 15, 2010, with a duration of 11 minutes and 7.8 seconds. The shortest possible annular solar eclipse occurred on March 18, 1950, as well as April 29, 2014. the annularity was less than 0.5 seconds.

8

Lunar Eclipse

Just as we observe trees, buildings, people and even clouds casting shadows during daytime, our Earth too casts a shadow in sunlight, extending in the direction opposite to the Sun. While we can easily see shadows falling on the ground around us, Earth's shadow in space remains invisible as there is no surface for it to fall upon. However, this hidden shadow reveals itself dramatically during a lunar eclipse, when the Moon moves into Earth's shadow and we witness our planet's dark silhouette gradually covering the lunar disc.

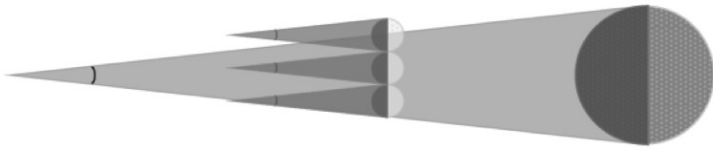
A lunar eclipse occurs precisely when the Moon passes through Earth's shadow. This celestial alignment requires the Sun, Earth and Moon to lie in the same plane, allowing Earth's shadow to fall directly on the Moon. Since this perfect alignment happens only during a Full Moon, when the Moon is positioned exactly opposite the Sun with Earth in between, lunar eclipses can occur exclusively on Full Moon nights. The phenomenon beautifully demonstrates how ordinary shadow-play scales up to cosmic proportions when celestial bodies align.

Earth's shadow consists of two distinct regions, the umbra and penumbra. The umbra represents the zone of complete shadow where the Sun is entirely hidden behind Earth. If you were positioned within this region in space, you would witness a total blackout of the Sun, with no portion of its disc visible. The penumbra, on the other hand, forms a transitional area of partial shadow where only part of the Sun's disc remains obscured. Here, sunlight appears dimmed but not completely blocked, creating a twilight-like effect as portions of the Sun peek around Earth's edges.

The umbral shadow extends over three times beyond the Moon's average orbital distance, always pointing directly opposite to the Sun. At the Moon's distance, this cone of darkness appears approximately 2.5

TYPES OF SOLAR ECLIPSES

times wider than the Moon itself when projected on an imaginary screen. The penumbra forms a much larger, fainter shadow circle about 4.6 times the lunar diameter. This substantial size difference means the Moon has ample space to become fully immersed when its orbital path takes it through the umbra during a total lunar eclipse, while still allowing for partial eclipses when it grazes only the penumbral regions.



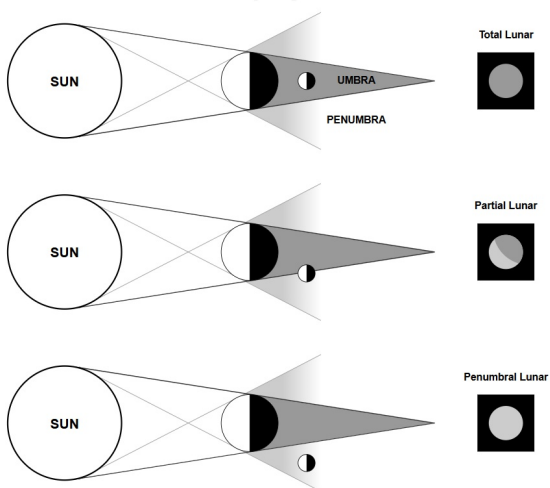
At Moon's distance the size of the Earth's shadow is nearly 2.5 times the Moon's disc

A lunar eclipse occurs when the Moon moves through Earth's shadow, causing it to darken noticeably. When the Moon passes completely into the umbra, the region of total shadow, without any part remaining in the partially lit penumbra, we witness the spectacular phenomenon of a total lunar eclipse.

However, not every lunar eclipse reaches totality. The Moon's orbit tilts about 5° relative to Earth's orbital plane, which means it doesn't always pass centrally through the umbra. If the Full Moon ventures too far north or south of the shadow's centre, only a portion enters the umbra, creating a partial lunar eclipse. These events, while interesting, lack the dramatic beauty of total eclipses. The stark contrast between the brightly lit section outside the umbra and the darkened portion within often overwhelms the subtle red glow of the shadowed area, unless the Moon nearly completes its entry into the umbra. However, depending on the magnitude of the eclipse, the shadowed portion of the lunar surface may appear a dark red or rust colour, simply a charcoal grey because of the sharp contrast between it and the brilliant part of the Moon that remains outside the umbra. Similar effect may be expected during the partial phase before and after total lunar eclipse.

ANNULAR SOLAR ECLIPSE

In cases where the Moon's path takes it completely outside the umbra, passing only through the faint penumbral shadow, the resulting penumbral eclipse shows barely noticeable dimming. Most casual observers would not be able to spot any difference from a normal Full Moon. Indeed unless at least half of the Moon enters penumbra, the



eclipse may prove undetectable.

Types of lunar eclipse

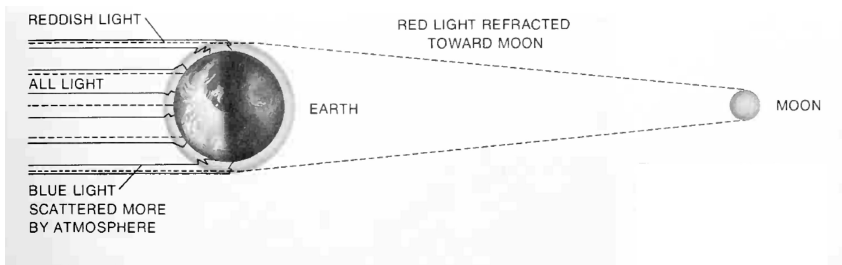
Regardless of type, lunar eclipses remain fascinating celestial events that are remarkably easy to observe. Visible from anywhere on Earth's night side during the eclipse, these occurrences happen when the Full Moon intersects Earth's shadow, though most Full Moons pass above or below the shadow cone entirely. Typically, we see one or two lunar eclipses each year, making them relatively frequent opportunities to witness our planet's shadow dancing across the lunar surface.

Unlike solar eclipses which are visible only from a narrow path on Earth's day side and appear differently based on the observer's location, lunar eclipses offer a more democratic celestial show. The entire night side of our planet (weather permitting, of course) gets to witness the same spectacular event simultaneously, with the eclipse appearing identical to all viewers across Earth's darkened hemisphere. Whether you are watching from Mumbai, Melbourne, or Mexico City, the eclipse will

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appear identical across Earth's darkened hemisphere, making it one of astronomy's most accessible wonders.

The visibility of these lunar spectacles depends entirely on Earth's rotation. Take for instance the total lunar eclipse of March 13-14, 2025, its totality phase occurred between 06:26 and 07:31 UTC (11:56 to 13:01 IST). Since this timing fell during daylight hours in India, skywatchers here missed the show, while observers across the Western Hemisphere, including North and South America, enjoyed prime viewing. Conversely, the September 7-8, 2025, total lunar eclipse will grace our skies from 17:30 to 18:52 UTC (23:00 to 00:24 IST), making it perfectly visible across India's night skies, while leaving viewers in the Americas out of luck as the Moon will be below their horizon during these hours.



Earth's atmosphere refracts the red portion of the visible spectrum, casting a reddish hue over the eclipsed Moon.

A striking difference exists between total solar and lunar eclipses. Unlike the Sun which completely disappears during a solar eclipse, the Moon never fully vanishes during its total eclipse. Even at peak totality, a small amount of sunlight is bent, or refracted, through our atmosphere and into Earth's shadow. Our atmosphere acts like a cosmic prism, scattering blue light while allowing red wavelengths to pass through. This atmospheric filtering paints Earth's shadow with a reddish hue, which in turn bathes the eclipsed Moon in dramatic crimson tones. Imagine standing on the Moon during totality: you would witness Earth completely blocking the Sun, but our planet's atmosphere would glow with a breathtaking 360° sunset, its red light illuminating the lunar surface.

Each lunar eclipse creates a unique celestial display. The umbral shadow's colour varies dramatically, painting the disc of Moon in shades

of vibrant red-orange, other times as a deep coppery red or even a muted brownish grey. This was noticed by Indian astronomers, and Āryabhaṭa in his *Aryabhatiyam* (4.46) says “At the beginning and end of its eclipse, the Moon (i.e., the obscured part of the Moon) is smoky; when half obscured, it is black; when (just) totally obscured, (i.e. at immersion or emersion), it is tawny; when far inside the Shadow, it is copper-coloured with blackish tinge.”

This colour variation depends entirely on Earth's atmospheric conditions; thus, no two lunar eclipse looks the same. The eclipse's darkness is influenced by several factors: cloud cover along the atmospheric rim that refracts sunlight, volcanic dust particles suspended in our atmosphere, and the Moon's precise path through the umbra. Also, total lunar eclipses tend to be darkest when the moon's orbit carries it through the centre of the umbra.

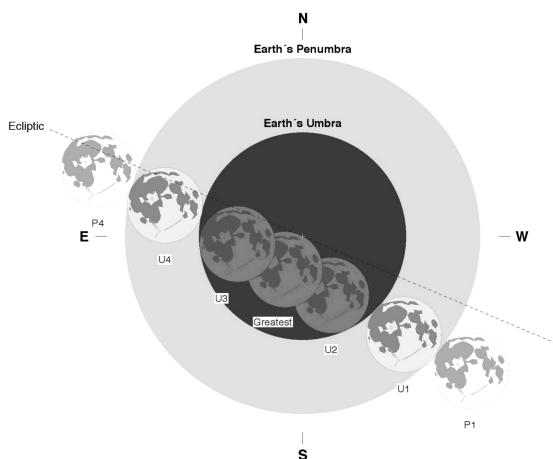
As the Moon first enters Earth's penumbral shadow, the dimming is so subtle that casual skywatchers might not notice anything unusual. Over the next hour, as it moves deeper into the penumbra, the gradual darkening becomes more apparent. The real spectacle begins when the Moon starts entering the umbra, a distinct dark "bite" appears to creep across the lunar surface. Since the Moon moves through space at roughly one lunar diameter per hour, this dramatic partial phase lasts about an hour before totality begins, when the entire Moon is immersed in Earth's shadow.

Stages of total lunar eclipse

Before the eclipse begins, the Moon appears as a regular full moon, shining brightly in the night sky.

First Contact (Penumbral Eclipse Begins): The eclipse officially starts when the Moon first enters Earth's faint penumbral shadow. At this stage, the change is subtle, and most observers will not notice anything unusual. Only when more than half of the Moon's disc moves into the penumbra does a slight smoky dimming become visible.

Second Contact (Partial Eclipse Begins): The real transformation begins when the Moon's edge touches Earth's dark umbral shadow. This marks the start of the partial eclipse. Within moments, a distinct "bite" appears on the Moon's surface, as if a dark shadow is slowly consuming it. Over the next hour, the umbra spreads across the Moon, making it appear as though it is waning rapidly.



The timings of the phases of the eclipse on September 7-8, 2025, are as follows.

<i>Penumbral eclipse begins:</i>	<i>20:58:21 on 7 Sep IST (15:28:21 UT)</i>
<i>Partial eclipse begins:</i>	<i>21:57:02 on 7 Sep IST (16:27:02 UT)</i>
<i>Total eclipse begins:</i>	<i>23:00:41 on 7 Sep IST (17:30:41 UT)</i>
<i>Maximum eclipse:</i>	<i>23:41:43 on 7 Sep IST (18:11:43 UT)</i>
<i>Total eclipse ends:</i>	<i>00:22:47 on 8 Sep IST (18:52:47 UT)</i>
<i>Partial eclipse ends:</i>	<i>01:26:26 on 8 Sep IST (19:56:26 UT)</i>
<i>Penumbral eclipse ends:</i>	<i>02:25:00 on 8 Sep IST (20:55:00 UT)</i>

Third Contact (Total Eclipse Begins): The Moon is now completely within Earth's umbra, marking the start of totality. Instead of disappearing, the Moon takes on an eerie, coppery-red glow, a result of sunlight filtering through Earth's atmosphere. The exact shade varies, ranging from deep red to orange or even dusky brown, depending on atmospheric conditions. Keep watch of over the change in colour. At this stage, the Moon looks unlike its usual bright self, glowing faintly in the darkened sky.

Fourth Contact (Total Eclipse Ends): As the Moon begins to exit the umbra, the total eclipse phase ends. A bright crescent slowly reappears on one edge, growing steadily over the next hour. The Moon seems to "wax" back to fullness as the shadow recedes.

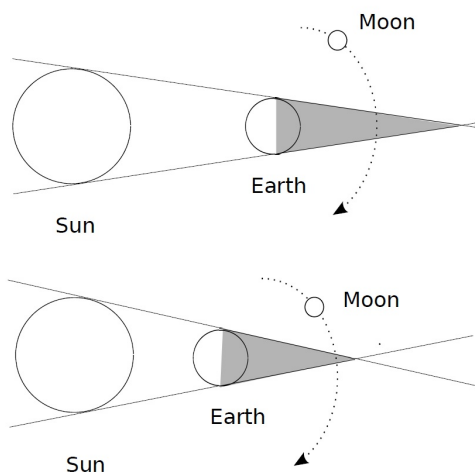
Fifth Contact (Partial Eclipse Ends): The Moon fully leaves the umbra, ending the partial eclipse. Though it looks nearly full again, a faint penumbral shading remains, making it slightly dimmer than usual. Most casual observers won't detect this subtle darkening.

Sixth Contact (Penumbral Eclipse Ends): Finally, the Moon completely exits Earth's penumbra, marking the official end of the eclipse. It returns to its usual brilliant full moon appearance, as if nothing extraordinary had happened.

9

Duration of lunar eclipse

The exact duration of a lunar eclipse depends on where the moon crosses Earth's shadow. The moon spends about an hour crossing the penumbra, and then another hour entering the darker umbra. Totality can last as long as 1 hour 40 minutes followed by the emergence of the moon into the penumbra plus another hour as it emerges into full sunlight. A total lunar eclipse can take nearly six hours from start to finish.



Variations in the distances of the moon and sun from the earth influence the duration of the lunar eclipse.

The diameter of Earth's shadow at the distance of the moon is approximately 9,000 kilometres or about 2.6 times the diameter of the moon. The Moon orbits the Earth at an average speed of about 1.03 km/s. Thus, one can compute that the total lunar eclipse will last nearly $9000/1.03 \sim 145$ minutes. But this would be grossly in error.

Variations in the distances of the moon and sun from the earth influence the duration of the lunar eclipse. First, while the Moon moves from west to east, the shadow of Earth moves from east to west, due to Earth's orbit around the Sun. Thus, the duration will be reduced from the above computation. Further Earth goes around the Sun in elliptical orbit, at times near the Sun, at times far away from the Sun. When the Earth is near to sun, the shadow will be larger. Likewise, the due to elliptical orbit of the Moon its disc size will also change. Further the speed of Earth around the Sun and Moon around the Earth also vary depending upon the distances. All these variations make the eclipse hide and seek more dramatic. The apparent sizes of the disks of the moon and the shadow are affected by small periodic changes in the geocentric distances of the moon and the sun. When the moon is farther from the earth, its disk looks smaller and so does the cross-section of the shadow cone where it intersects the moon's orbit. When the sun is closer to the earth, the earth's shadow cone is shorter, which also decreases the size of the shadow disk that the moon passes through.

Earth's rotation determines when an observer is on the night side of the planet and can see the eclipse. However, the speed of Earth's rotation does not change the duration of the eclipse itself. Primarily the Moon's orbit around the Earth dictates how long it takes to pass through the Earth's shadow. This orbital path and speed are the primary factors determining the overall eclipse duration. While the Moon's distance from Earth can affect the duration of totality (longer for apogee, shorter for perigee), this is a factor of the Moon's orbit and applies equally to all observers during that specific eclipse.

When the Moon is overhead, you are closer to it, because you're on the side of the Earth facing it; hence you are closer by up to the radius of the Earth, depending on how close to overhead it

is. Because the Moon is very close to the Earth (compared to the planets and the Sun), this makes a measurable difference to its apparent size. Since any eclipse involves the Moon, this means that the Moon will be larger in the middle of an eclipse than at the start and end. Thus, the angular diameter of the Moon at maximum eclipse is on average 0.531° , and ranges from 0.490° (7.8% smaller than average), to 0.568° (7.0% larger than average).

The longest duration of totality for a lunar eclipse is 107 minutes. This can happen when the moon crosses through the middle of Earth's shadow, when the moon is at or very near apogee, the farthest point in its orbit from Earth. When the moon is near apogee, it is moving more slowly and needs more time to cross our planet's shadow.

If many parameters coincide the duration of the totality of lunar eclipse will be longer. Earth's shadow must be largest; Moon must be moving slowest. Thus, Moon's disc will be the smallest, The total lunar eclipse of July 16, 2000 — which was visible in the Pacific Ocean, eastern Asia and Australia — was one of the longest on record, lasting 106 minutes, 25 seconds. Before that on Aug. 13, 1859, totality lasted three seconds longer. It will take thousands of years, until Aug. 19, 4753, for there to be a longer total eclipse, which will last 106 minutes, 35 seconds

The full moon on the night of July 27-28, 2018, presents the longest total lunar eclipse of the 21st century (2001 to 2100). The total phase of the eclipse – called the totality – spans 1 hour 42 minutes and 57 seconds. That's in contrast to the shortest total lunar eclipse of this century, which occurred on April 4, 2015, and lasted 4 minutes and 48 seconds.

Like how we describe solar eclipses by their magnitude (the fraction of the Sun's disk covered), lunar eclipses are also characterized by their umbral magnitude. This value indicates how much of the Moon's diameter falls within Earth's dark umbral shadow. A greater umbral magnitude signifies a more profound

eclipse. For instance, the total lunar eclipse on September 7-8, 2025, will have an umbral magnitude of 1.3638, meaning Earth's umbra will cover 1.3638 times the Moon's diameter. At maximum eclipse, the Moon's centre will pass 11.7 arcminutes south of the umbra's central axis.

This celestial event will occur 2.7 days before the Moon reaches perigee (its closest approach to Earth on September 10, 12:11 UTC or 17:41 IST), making it appear about 3.2% larger than average. During the eclipse, the Moon's angular size will range between 0.538° and 0.548° . The angular size of Earth's umbral (darkest) shadow at the Moon's distance will be 1.48 degrees and the umbral+ penumbral (fainter outer shadow) radius is 2.53 degrees. These favourable conditions, the substantial umbral magnitude combined with the slightly enlarged lunar disk, will create an extended totality lasting 82 minutes and partial phase 209 minutes.

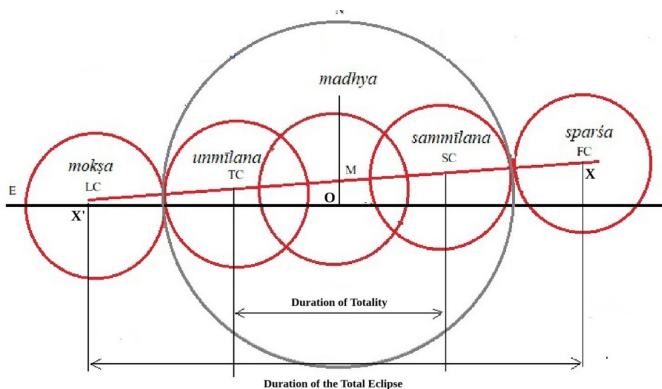
Earlier texts like the *Vāsiṣṭha Siddhānta* (from Varāhamihira's *Pañca-siddhāntikā*) detail mathematical calculations for lunar eclipses, including first and last contact points. Solar eclipses, however, are discussed in other *siddhāntas* like the *Pauliśa*, *Romaka*, and *Saura*, believed to predate *Āryabhaṭa*'s work. Nonetheless *Āryabhaṭa* (476–550 CE) stands among India's earliest astronomers to provide a scientifically rigorous explanation for eclipses. In the *Aryabhatiyam* (4.37), he states: *chādayati śaśi sūryam śaśinām mahaṭi ca bhucchāyā* ("The Moon covers the Sun, and Earth's vast shadow eclipses the Moon"). Here, he correctly identified eclipses as shadows resulting from precise alignments of the Sun, Earth, and Moon. He further elaborated that lunar eclipses occur when the Moon enters Earth's shadow during full moon, while solar eclipses happen when the Moon obscures the Sun during new moon. In verse 4.38, he specifies that "When at the end of a lunar month, the Moon, lying near a node (of the Moon), enters the Sun, or, at the end of a lunar fortnight, enters the Earth's Shadow, it is more or less the middle of an eclipse, (solar eclipse in the former case and lunar eclipse in the latter case)"

Varāhamihira (c. 505 CE) further demystified eclipses in his *Bṛhatsaṃhitā*, rejecting mythological explanations. He asserts: *bhucchayām svagrahaṇe bhāskaram arkagrahe praviśati induḥ* ("During a lunar eclipse, the Moon enters Earth's shadow; during a solar eclipse, it covers the Sun") and dismisses the demon *Rāhu* as a cause, firmly rejecting mythological explanations involving the demon *Rāhu*. He states *rāhurakāraṇam asmin niyuktah* (the scientific fact is that (the demon) *Rāhu* is not at all the cause of eclipse) (*Bṛhatsaṃhitā* 5.8, 5.13).

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Indian astronomers developed sophisticated computational methods to predict various eclipse parameters including timing, visibility regions, eclipse type (partial, total, or annular), and duration. The seventh-century mathematician-astronomer Brahmagupta, in his *Brāhmasphuṭasiddhānta*, enumerated fourteen precise parameters for lunar eclipses, covering aspects like contact times (*sparśa* and *mokṣa*), totality duration (*vimarda*), and magnitude of obscuration (*grāsa*). For total eclipses, they particularly tracked five key phases: initial contact (*sparśa*), beginning (*sanmilana*) and end (*unmilana*) of totality, mid-eclipse (*madhya*), and final release (*mokṣa*).

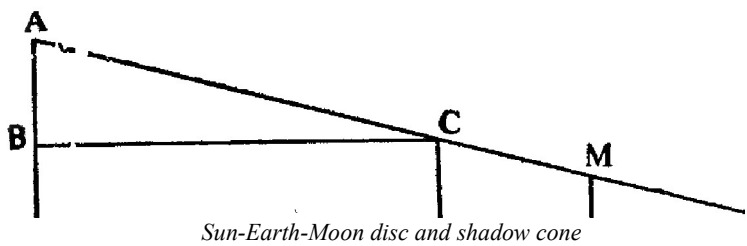
The *Aryabhatiyam* stands as one of the earliest texts detailing computational methods for eclipse prediction. Verses 39 and 40 specifically describe the calculation of lunar eclipse durations. During a total lunar eclipse, the phenomenon begins when the Moon's eastern edge first contacts the western boundary of Earth's umbral shadow (*sparśa*). As the Moon progresses deeper into the shadow, complete totality occurs, followed by its gradual emergence from the shadow's eastern side until final separation (*mokṣa*). Traditional Indian astronomy considers only the umbral phase, measuring the eclipse duration strictly between first and last contacts.



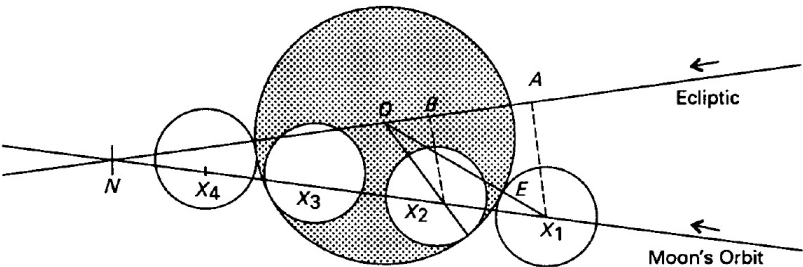
The computational approach involves analysing the motion of the Moon's centre (X) from first contact (FC) to mid-eclipse (M).

The 'half-duration' (*sparśa sthiti*) represents the time taken for X to traverse from FC to M, while the subsequent half (*mokṣa sthiti*) covers M to last contact (LC). The total duration equals *sparśa sthiti* +

mokṣa sthiti. Geometrically, the FC-to-LC distance equals the sum of Earth's shadow diameter (Bhūbhā = $2S_e$) and lunar diameter ($2S_m$). With the Moon's apparent velocity (v) across the shadow, the half-duration becomes $(S_e + S_m)/v$, requiring determination of three key parameters: shadow size, lunar disc diameter, and relative velocity.



The shadow geometry derives from similar triangles in the Sun-Earth-Moon system. Let S and E represent the Sun's and Earth's centres with semi-diameters AS and CE respectively. The shadow cone's vertex (V) forms where solar and terrestrial rays converge. Aryabhata's verse 39 states: Earth's shadow length (EV) = $(SE \times 2CE)/(2AS - 2CE)$, where SE is the Sun-Earth distance. This follows from triangle similarity (CEV ~ ABC), yielding $EV = (SE \times CE)/(AS - CE)$. Verse 40 then calculates the shadow diameter at lunar distance (MD): Tamas = $[(EV - ED) \times 2CE]/EV$, where ED is the Earth-Moon distance, derived from triangle similarity (MDV ~ CEV). Thus, one can easily compute the shadow size and lunar disc diameter.



In the above image X_1 is the position of centre of Moon at first contact. 'A' is a point on the ecliptic, which is the latitude of the Moon at that instant. Thus, the triangle OAX_1 is a right triangle. The

line $X_1 X_2 X_3 X_4$ is the orbit of the Moon, indicating its inclination with respect to the ecliptic.

When the Moon's centre (X_1 at first contact) lies at latitude AX_1 ; which is determined by the perpendicular AX_1 from the ecliptic. The progress of Moon's disc's perpendicular from A to the shadow centre (O) determines half-duration.

The perpendicular distance OA relates to the contact geometry through $OA^2 = OX_1^2 - AX_1^2$; also, from the illustration we know that $OX_1 = S_e + S_m$ (semi-diameter of the disc of Earth's shadow and Moon) and AX_1 is the Moon's latitude (Vikṣepa) at the instance of first contact. The relative velocity is 'candragati - ravigati'.

Thus, $sparśa\ sthiti\ T_1 = \sqrt{[(S_e + S_m)^2 - Vikṣepa^2]} / (\text{candragati} - \text{ravigati})$, accounting for the relative Moon-Sun motion. The duration $mokṣa\ sthiti\ (T_2)$ may differ due to velocity variations, which can be computed similar to the above. Thus, the total duration of the lunar eclipse is $T_1 + T_2$.

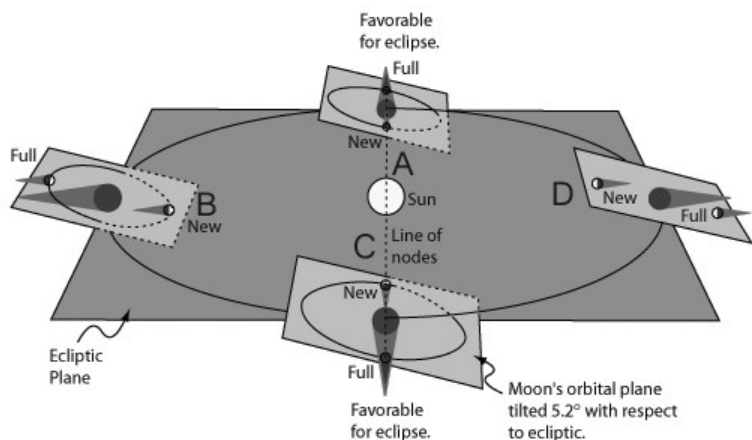
Aryabhata's verse 42 encapsulates this: half-totality equals $\sqrt{[(S_e - S_m)^2 - \text{latitude}^2]} / (\text{candragati} - \text{ravigati})$, emphasizing the dependence on apparent disk sizes and lunar latitude. The apparent diameters ($\approx 32'$ for Sun/Moon, $\approx 81'$ for shadow) vary with celestial distances - lunar proximity increases its apparent size while solar proximity shortens the shadow cone. These dimensional fluctuations, combined with the Moon's elliptical orbit (changing angular velocity from 0.489° to 0.559°), create the characteristic "hide-and-seek" dynamics of eclipses.

11

Eclipse pattern

The orbital plane of Moon is inclined to Earth's orbital plane—ecliptic plane— by about 5.2 degrees. Therefore, at times, the Moon is above the ecliptic plane or below it. There are only two points on which the orbit of the Moon and the ecliptic plane intersect. These are called nodes. Every month, as the Moon goes around the Earth, it passes through these points.

Now, look at the line joining these two nodes. The line of nodes points towards the Sun, only two times a year. Rest of the time it is pointed elsewhere. In the above illustration, it is readily apparent that when the Earth is at the position A&C, the line of nodes is pointing towards the Sun. In other cases, such as B&D, the line of nodes are not pointing towards the Sun.



Conditions are favourable for eclipses when the Moon is on the line of intersection of the Moon's orbit and the plane of the Earth's orbit.

Also notice when the Earth is at A&C position, the new Moon (and full Moon) occur while the Moon is at one of the nodes. In the case of B&D, the new Moon and full Moon occurs at a point different from the nodes.

At all times, the illuminated by Sun, the Moon and Earth are casting a shadow. While the Earth is at B&D, the shadows of the Moon and Earth does not fall on each other even when they are between the Sun and one another. The Moon is either above or below the ecliptic plane. Hence, on a new moon day, the Moon can be in between Earth and Sun, still not obstruct the view of the Sun, resulting in eclipse.

However, as seen earlier two times a year, the line of nodes is pointed towards the Sun. It is during such times that the eclipses occur. When the Moon is in a node, and it is a new moon phase, we have a solar eclipse. If the Moon is at the node and it is a full moon, then we have a lunar eclipse.

This implies, every six months, the nodes are aligned with the Sun and Earth. A solar and lunar eclipse occurs during such time. Hence, they are called as eclipse season. After an eclipse season, about six months later the next season occurs.

Look at this pattern: -

26 Dec 2019 Solar eclipse (Annular)

10-11 Jan 2020 Lunar Eclipse (Penumbral)

5-6 Jun 2020 Lunar Eclipse (Penumbral)

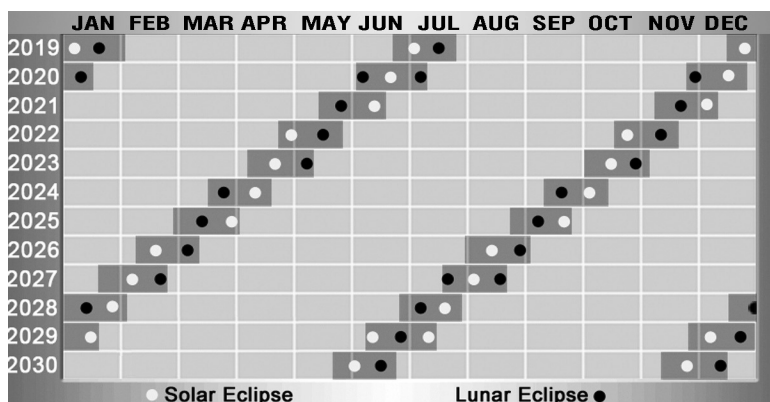
21 June 2020 Solar Eclipse (Annular)

4-5 Jul 2020 Lunar Eclipse (Penumbral)

29-30 Nov 2020 Lunar Eclipse (Penumbral)

14 Dec 2020 Solar Eclipse (Total)

Can you notice after every solar eclipse (Amavasya), the next Poornima is a lunar eclipse? When the line of nodes is pointing towards the Sun, lunar and solar eclipse occur in pair. Also, notice after nearly six months of a solar eclipse there is another solar eclipse. The Earth has gone from A to C (or from C to A).



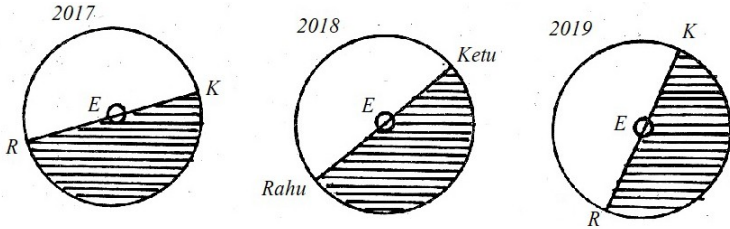
Observe the pattern of the solar and lunar eclipses, year after year. They occur just short of six months, the line joining the nodes point towards the Sun.

Does that mean eclipses recur every six months? Almost, but not quite. As the Earth and Moon rotate and revolves regularly, there is a pattern to the occurrence of the eclipses. However, the line joining the nodes is not pointed to one single direction in the celestial sphere. The line itself is rotating - or precessing. The lunar nodes slowly regress westward by 19.3° per year. Therefore, every year the eclipses do not occur on the same dates. As the position of the nodes keeps changing every year, the potential points on Earth's orbit (or dates) when an eclipse takes place also shift. In fact, the mean time between two eclipse season is 173.3 days.

Form careful observations and comparing records in ancient times a far deeper pattern was discovered in the solar eclipses, Saros cycle. The periodicity and recurrence of eclipses are governed by the Saros cycle, a period of approximately 6,585.3 days (18 years 11 days 8 hours). It was known to the Chaldeans as a period when lunar eclipses seem to repeat themselves. Still, the cycle applies to solar eclipses as well.

The line joining the nodes completes one rotation in 6585.3 days (about 18.6 years). The Chaldean astronomers in about 400 BCE discovered that eclipses occur in regular succession at an interval of 18 years and $11\frac{1}{3}$ days. This cycle is known as the 'Chaldean Saros'. Saros

comes from a Greek word for “repetition”. The exact interval is 223 lunar months of 29.53 days or 6,585.3 days. The Saros cycle provides a simple method of predicting eclipses. But though an eclipse repeat



The line joining the node rotates, and therefore every year the direction it points in space changes.

itself during every Saros cycle, it is not visible from the same place on Earth. Since the period is one-third of a day longer than 18 years and 11 days when the eclipse recurs, the Earth will have spun one-third of a rotation farther east. The eclipse will occur to the west of where it did earlier.

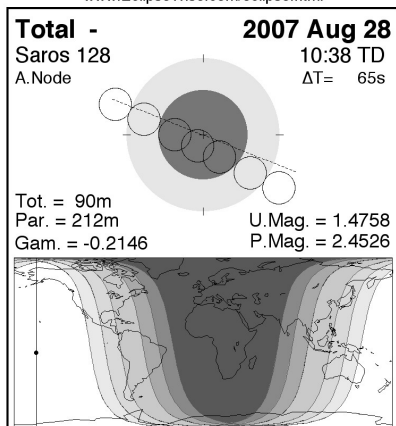
We know that Moon takes 29.53059 days (29d 12h 44m) from a New Moon to another New Moon. This period is called a ‘Synodic Month’. However, if we calculate its motion from ascending node (or descending node) again to ascending node (or descending node), it will complete the revolution in just 27.21222 days (27d 05h 06m). This period is called a ‘Draconic Month’. The Moon takes a little longer, 27.55455 days (27d 13h 19m) to travel from its farthest point in orbit again to the same point in the orbit. This period is called an ‘Anomalistic Month’.

Now we know that Moon must be at the node and also at the new Moon phase for it to cause an eclipse of the Sun. Further, for different eclipses, if the Moon happens to be at the same point in its orbit, then the time of totality in all of them will be the same. One can see that 223 synodic months, 242 draconic months, and 239 anomalistic months are also equal (to within a couple of hours). This period is called one Saros period, equivalent to about 6,585.3 days (18 years, 11 days 8

hours). That is, if an eclipse occurs today, then after 18 years, 11 days and 8 hours another eclipse will occur, which will have about the same geometry.

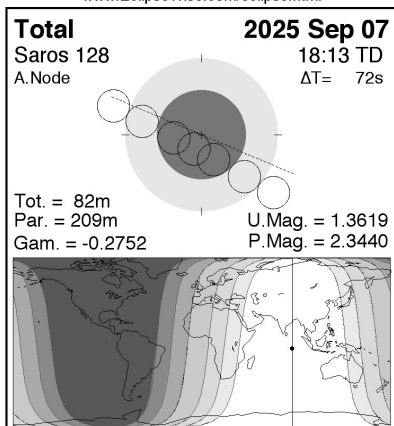
The total lunar eclipse taking place on September 7, 2025, is said to be part of the Solar Saros cycle 128, which is 18 years 11 days before the last eclipse of this series occurred on August 28, 2007, and the next one that will take place on September 19, 2043.

www.EclipseWise.com/eclipse.html



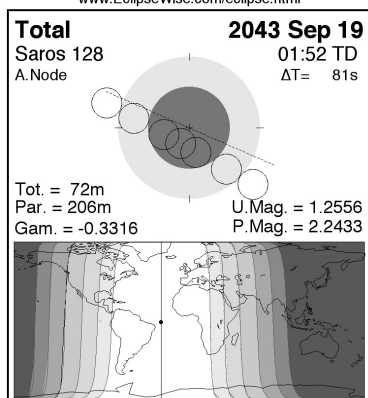
Thousand Year Canon of Lunar Eclipses
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Thousand Year Canon of Lunar Eclipses
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The past, present and the future solar eclipses belonging to Saros 128. Observe the path of the eclipse shift westward.

Compare the position of the path of annularity of these three eclipses. Can you observe the path appears to have shifted westwards as compared to an earlier occasion?

Any two eclipses separated by one Saros cycle share very similar geometries. They occur at the same node with the Moon at nearly the same distance from Earth and at the same time of the year. However, because the Saros period is not equal to a whole number of days, its biggest drawback is that subsequent eclipses are visible from different parts of the globe. The extra $\frac{1}{3}$ day displacement means that Earth must rotate an additional ~ 8 hours or $\sim 120^\circ$ with each cycle. For solar eclipses, this results in the shifting of each successive eclipse path by $\sim 120^\circ$ westward. Thus, a Saros series returns to about the same geographic region every three Saros periods (54 years and 34 days).

A Saros series does not last indefinitely due to delicate motions of the Moon. In particular, the Moon's node shifts eastward by about 0.5° with each cycle. Therefore, after a point, the node is not aligned with Sun and Earth, and hence an eclipse will not occur. Due to the ellipticity of the orbits of the Earth and Moon, the exact duration and number of eclipses in a complete Saros is not constant. A series may last between 1,226 and 1,550 years and is comprised of 69 to 87 eclipses.

Saros cycle number

Solar eclipses that take place near the Moon's ascending node have odd Saros numbers. On the other hand, solar eclipses occurring near the Moon's descending node have even Saros numbers. The numbering system used for the Saros series was introduced by the Dutch Astronomer G. van den Bergh. He assigned the number 1 to a pair of solar and lunar eclipses that were in progress during the second millennium BCE. At present, 180 cycles in 5,000 years (2000 BCE to 3000 CE) are numbered.

A typical lunar eclipse Saros series begins when a Full Moon occurs $\sim 17^\circ$ east of a node. The Saros cycle begins with a subtle celestial dance, the Moon barely skims the northern edge of Earth's penumbral shadow, creating a faint penumbral eclipse. As the celestial rhythm continues (one Saros period later), the Moon's path shifts slightly southward, dipping deeper into the penumbra, resulting in a more noticeable penumbral eclipse. After about 10 such events, the lunar spectacle intensifies as the Moon's southern edge first brushes against the umbral shadow, marking the series' first partial lunar eclipse. Over the next 20 cycles, each occurring at 18.031-year intervals, the Moon penetrates further into the umbra with every pass, gradually increasing the eclipse magnitude. The celestial show reaches its climax when the Moon fully enters the umbra, producing the series' first total eclipse. For about two centuries, this pattern continues; every Saros period brings another total eclipse as the Moon marches steadily southward through Earth's shadow. Midway through the series when the Moon passes through the umbra's centre, most dramatic long duration total eclipses occur. After approximately 13 spectacular total eclipses, the Moon begins its exit from the umbral region, transitioning back through another 20 partial eclipses. The grand finale comes with about 10 fading penumbral eclipses, ending with a barely perceptible event where the Moon just kisses the southern edge of the penumbra. From first to final act, this typical Saros series spans about 1,300 years, presenting nearly 73 eclipses. The Saros cycle 128, lunar eclipse series, began with a faint penumbral eclipse on June 18, 1304, when the Moon barely grazed the northern edge of Earth's penumbral shadow, and conclude with the a final penumbral eclipse touching the southern fringe of the penumbra on August 2, 2566. Over a period of 1,262.11 years, this Saros series includes 71 separate lunar eclipses. Interestingly, all eclipses in this series occur when the Moon crosses the ascending node of its orbit, the point where Moon transitions from the southern to northern hemisphere of Earth's orbital plane.

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Frequency of lunar eclipses

Between 2001 and 2100, there will be a total of 228 lunar eclipses, comprising 86 penumbral, 57 partial, and 85 total events. Within this century, there are six years—2009, 2020, 2031, 2038, 2056, and 2085—that will each feature four lunar eclipses. Additionally, sixteen years will experience three lunar eclipses, while the remaining seventy-eight years will have two eclipses each. The longest total lunar eclipse of the century occurred on July 27, 2018, with a duration of 1 hour, 42 minutes, and 57 seconds; the shortest took place on April 4, 2015, lasting just 4 minutes and 43 seconds.

The total lunar eclipse, September 7-8, 2025:

Time	Phase	Event	Direction	Altitude
8:58 pm <i>Sun, Sep 7</i>		<i>Penumbral Eclipse begins</i> The Earth's penumbra start touching the Moon's face.	 123°	 42.1°
9:57 pm <i>Sun, Sep 7</i>		<i>Partial Eclipse begins</i> Partial moon eclipse starts - moon is getting red.	 138°	 52.3°
11:00 pm <i>Sun, Sep 7</i>		<i>Total Eclipse begins</i> Total moon eclipse starts - completely red moon.	 163°	 59.6°
11:41 pm <i>Sun, Sep 7</i>		<i>Maximum Eclipse</i> Moon is closest to the center of the shadow.	 183°	 60.9°
12:22 am <i>Mon, Sep 8</i>		<i>Total Eclipse ends</i> Total moon eclipse ends.	 203°	 58.9°
1:26 am <i>Mon, Sep 8</i>		<i>Partial Eclipse ends</i> Partial moon eclipse ends.	 226°	 50.8°
2:25 am <i>Mon, Sep 8</i>		<i>Penumbral Eclipse ends</i> The Earth's penumbra ends.	 240°	 40.3°

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The scientific significance of an eclipse

The lunar eclipse has been an object of curiosity for commoners and a rare opportunity for astronomers for scientific study.

History is replete with instances of the eclipse being feared as beckoning evil by various cultures. However, eclipses have also assisted in several scientific predictions. Ancient astronomers like Aryabhata carefully observed that during lunar eclipses, Earth's shadow cast on the Moon always appeared perfectly circular, regardless of the eclipse's timing or the observer's location. He reasoned that only a spherical object can produce a round shadow from any angle when illuminated by sunlight. If Earth were flat, as the puranic view suggested, its shadow would appear elongated or change shape during different eclipses, while other shapes like cylinders would create varying shadow patterns. The uniformity of this circular shadow, visible across different geographical locations from Greece to India, provided irrefutable evidence that Earth must be curved in all directions equally. Aryabhata, in his seminal work *Aryabhatiyam*, took this observation further by calculating Earth's approximate size based on how long the Moon took to traverse this shadow.

Before it was discovered on Earth, Helium was first detected in the solar corona during a solar eclipse, which occurred on August 18, 1868, over Guntur, India. Einstein's theory of relativity received corroboration from the observations of the bending of the starlight observed during the total solar eclipse of 1919. Einstein had predicted that light travelling near a massive object should bend due to curvature in the space-time. You can observe if and how much the starlight bend when passing close to the Sun. However, the brightness of the Sun does not permit viewing the stars.

Nevertheless, during the brief time of a total solar eclipse, when the disc of the Sun is completely covered by the Moon, the stars will

be visible during the daytime. One can take a photograph of the stars during the total solar eclipse and compare its position against the star maps to see the shift in the coordinates. If starlight had bent near the Sun, one should observe the change in the apparent coordinates of the stars. An expedition was arranged to South America during the solar eclipse of 1919 to obtain observational confirmation. The result matched prediction and corroborated the theory of general relativity. It is also noteworthy that Indian physicist Meghnad Saha discovered a relation between unknown lines in the solar spectrum and highly ionised state of matter by studying the spectrum of the corona of the Sun, prominently visible during total solar eclipses.

The width of the path of totality depends upon the sizes of Moon and Sun, which is a proxy for their distances. Now with modern technology, we can know the range of the Moon, the size of the Moon and range of the Sun very accurately. By accurately measuring the width of the path of totality, one can estimate the size of the Sun. In fact, this effort is one of the significant activities in the total solar eclipses in the recent past.

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Tips for safe watching

It is perfectly safe to watch a lunar eclipse with the naked eye. Unlike solar eclipses, lunar eclipses do not require any special eye protection. You can safely observe a lunar eclipse with your naked eyes, binoculars, or a telescope without any risk of eye damage. No mysterious rays emanate from the Sun or Moon during solar or lunar eclipses. Such claims are not based on scientific facts. An eclipse is nothing but a shadow play – cosmic hide-and-seek between Sun and Moon. No physical change takes place on the Sun during an eclipse, and therefore no new rays emanate from Sun.

The case of solar eclipse is distinct. Sun is a bright source of light. Usually, we do not stare at it directly. However, on the day of an eclipse, we may wish to observe the partial phases and enjoy, and this is what makes watching a solar eclipse dangerous.



Always use a safe solar filter to observe the Sun.

During the partial eclipse, Sun would be still very bright to cause eye damage and retina-burning. So, never look at the Sun, even partially eclipsed, without proper eye protection. However, during

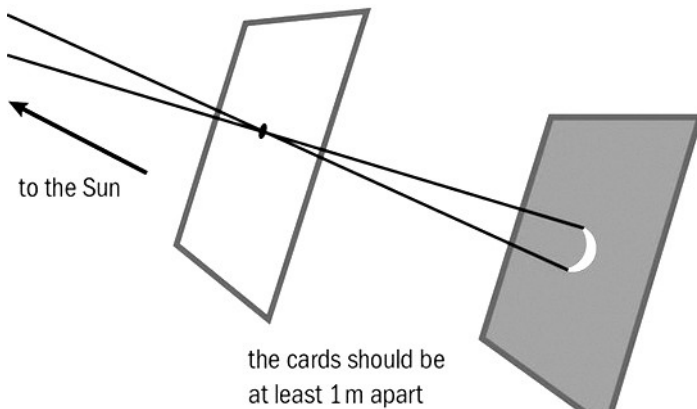
ANNULAR SOLAR ECLIPSE

totality, it is safe to look at the Sun directly, taking care to quickly move the eyes away from the Sun as soon as Bailey's beads appear. In the darkness, during totality, the pupils of our eyes will dilate, and exposure to sudden brightness as the Sun reappears from behind the Moon may cause damage to the eye.

There are many secure methods for safe watching of the solar eclipse.

Do not use colour film negatives or underexposed B&W photo-film negatives.

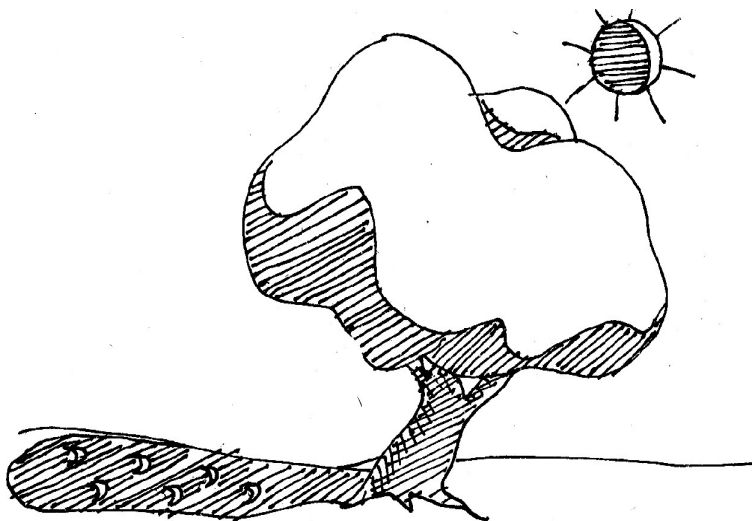
One can also use Mylar sheets or welder's glass (No. 14) for safe watching. Ensure that there are no scratches in any kind of filters being used for viewing Sun. One can fabricate a pin-hole camera to view the eclipsed Sun's image. One can project the image of the Sun onto a wall using a simple mirror conveniently positioned. Solar filters are also available with several science-popularising agencies, Vigyan Prasar and State Councils for Science and Technology. They are safe and handy.



Make your pinhole camera and project the image of the Sun on a screen.

A safer method is to observe the image projected on a wall/screen. One can make a pin-hole camera with a screen to project the image. Do not use the pin-hole camera to observe the Sun directly. A

ball mirror projection is a useful tool for not only watching the eclipse but also for conducting various studies on the motion of the Sun and Earth. Visit <https://www.youtube.com/watch?v=9FHT6R-Hm4Y> to know how to make ball mirror projection. You can also view 'daytime astronomy' videos of Vigyan Prasar in the YouTube (and VP website) to



learn various activities and projects that you can undertake.

Trees with dense leaves act as a natural pinhole and one can observe wonderful images of the crescent Sun during the partial phase.

It would be an exciting sight to look at hundreds of crescents-shaped Sun cast by a tree. In fact, the tiny holes between the leafy canopy act as a pinhole camera and project the image of the Sun. An eclipse is a lifetime opportunity. Do it for no miss. It is for (safe) watching and enjoying, not for avoiding.

