# THE MOON (http://en.wikipedia.org/wiki/Moon)

The **Moon** is Earth's only natural satellite and is the fifth largest satellite in the Solar System. It is the largest natural satellite in the Solar System relative to the size of its planet, a quarter the diameter of Earth and 1/81 its mass, and is the second densest satellite after Io. It is in synchronous rotation with Earth, always showing the same face; the near side is marked with dark volcanic mariaamong the bright ancient crustal highlands and prominent impact craters. Despite being the brightest object in the sky after the Sun, its surface is actually very dark, with a similar reflectance to coal. Its prominence in the sky and its regular cycle of phases have since ancient times made the Moon an important cultural influence on language, the calendar, art and mythology. The Moon's gravitational influence produces the ocean tides and the minute lengthening of the day. The Moon's current orbital distance, about thirty times the diameter of the Earth, causes it to be the same size in the sky as the Sun – allowing the Moon to cover the Sun precisely in totalsolar eclipses.

The Moon is the only celestial body on which human beings have made a manned landing. While the Soviet Union's Luna programmewas the first to reach the Moon with unmanned spacecraft, the United States' NASA Apollo program achieved the only manned missions to date, beginning with the first manned lunar orbiting mission by Apollo 8 in 1968, and six manned lunar landings between 1969 and 1972 – the first being Apollo 11 in 1969. These missions returned over 380 kg of lunar rocks, which have been used to develop a detailed geological understanding of the Moon's origins (it is thought to have formed some 4.5 billion years ago in a giant impact), the formation of its internal structure, and its subsequent history.

Since the Apollo 17 mission in 1972, the Moon has been visited only by unmanned spacecraft. Since 2004, Japan, China, India, the United States, and the European Space Agency have each sent lunar orbiters. These spacecraft have confirmed the discovery of lunar water ice in permanently shadowed craters at the poles and bound into the lunar regolith. Future manned missions to the Moon are planned but not yet underway; the Moon remains, under the Outer Space Treaty, free to all nations to explore for peaceful purposes.

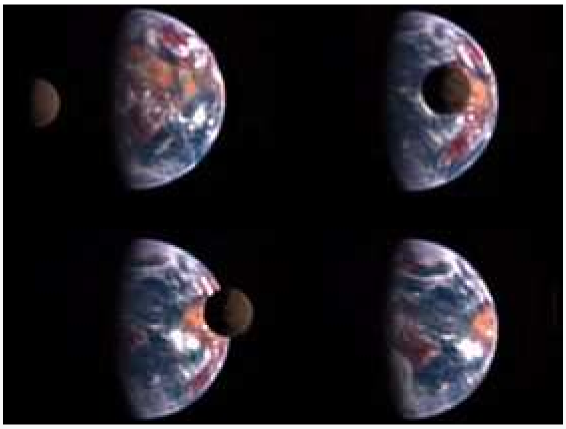
| Orbital characteristics | |
|---|---|
| **Perigee** | 363,104 km (0.0024 AU) |
| **Apogee** | 405,696 km (0.0027 AU) |
| **Semi-major axis** | 384,399 km (0.002 57 AU)[1] |
| **Eccentricity** | 0.0549[1] |
| **Orbital period** | 27.321 582 d (27 d 7 h 43.1 min[1]) |
| **Synodic period** | 29.530 589 d (29 d 12 h 44 min 2.9 s) |
| **Average orbital speed** | 1.022 km/s |
| **Inclination** | 5.145° to the ecliptic[1] (between 18.29° and 28.58° to Earth's equator) |
| **Longitude of ascending node** | regressing by one revolution in 18.6 years |
| **Argument of perigee** | progressing by one revolution in 8.85 years |
| **Satellite of** | Earth |

| Physical characteristics | |
|---|---|
| **Mean radius** | 1,737.10 km (0.273 Earths)[1][2] |
| **Equatorial radius** | 1,738.14 km (0.273 Earths)[2] |
| **Polar radius** | 1,735.97 km (0.273 Earths)[2] |
| **Flattening** | 0.001 25 |
| **Circumference** | 10,921 km (equatorial) |
| **Surface area** | $3.793 \times 10^{7}$ $km^2$ (0.074 Earths) |
| **Volume** | $2.1958 \times 10^{10}$ $km^3$ (0.020 Earths) |
| **Mass** | $7.3477 \times 10^{22}$ kg (0.0123 Earths[1]) |
| **Mean density** | 3,346.4 $kg/m^3$[1] |
| **Equatorial surface gravity** | 1.622 $m/s^2$ (0.165 4 g) |
| **Escape velocity** | 2.38 km/s |
| **Sidereal rotation period** | 27.321582 d (synchronous) |
| **Equatorial rotation velocity** | 4.627 m/s |
| **Axial tilt** | 1.5424° (to ecliptic) 6.687° (to orbit plane) |

| | | | | |
|---|---|---|---|---|
| **Albedo** | 0.136[3] | | | |
| **Surface temp.** | | min | mean | max |
| equator | | 100 K | 220 K | 390 K |
| 85°N[4] | | 70 K | 130 K | 230 K |
| **Apparent magnitude** | −2.5 to −12.9[nb 1] −12.74 (mean full Moon)[2] | | | |
| **Angular diameter** | 29.3 to 34.1 arcminutes[2][nb 2] | | | |
| **Atmosphere[5][nb 3]** | | | | |
| **Surface pressure** | $10^{-7}$ Pa (day) | | | |

The proper English name for Earth's natural satellite is, simply, the Moon (capitalized as a proper noun).[6][7] *Moon* is a Germanic word, related to the Latin *mensis*[8] and Ancient Greek *μήνας* (mēnas) both meaning month, and to *Μήνη* (Mēnē), the alternate name for *σελήνη* (Selēnē), the Ancient Greek name for the Moon.[9][10] It is ultimately a derivative of the Proto-Indo-European root *me-*, also represented in *measure*[8] (time), with reminders of its importance in measuring time in words derived from it like *Monday*, *month* and*menstrual*. The related adjective is *lunar*, after the Latin name *Luna*, as well as an adjectival prefix *seleno-* and suffix *-selene*, from the Ancient Greek name.[11] In English, the word *moon* exclusively meant "the Moon" until 1665, when it was extended to refer to the recently discovered natural satellites of other planets.[8] Subsequently, these objects were given distinct names to avoid confusion.[7]The Moon is sometimes referred to by its Latin name *Luna*, primarily in science fiction.

## Physical characteristics



Comparative sizes of the Earth and the Moon, as seen from Deep Impact, 50 million km distant

The Moon is exceptionally large relative to the Earth: a quarter the diameter of the planet and 1/81 its mass.[12] It is the largest moon in the solar system relative to the size of its planet (although Charon is larger relative to the dwarf planet Pluto).[13] The Moon's surface area is less than one-tenth that of the Earth; about a quarter of the Earth's land area. However, the Earth and Moon are still considered a planet–satellite system, rather than a double-planet system, as their barycentre, the common centre of mass, is located about 1,700 km (about a quarter of the Earth's radius) beneath the surface of the Earth.[14]

### Formation

*Main article: Giant impact hypothesis*

Several mechanisms have been proposed for the Moon's formation 4.527 ± 0.010 billion years ago,[nb 4] some 30–50 million years after the origin of the Solar System.[15] These include the fission of the Moon from the Earth's crust through centrifugal forces,[16] which would require too great an initial spin of the Earth,[17] the gravitational capture of a pre-formed Moon,[18] which would require an unfeasibly extended atmosphere of the Earth to dissipate the energy of the passing Moon,[17] and the co-formation of the Earth and the Moon together in the primordial accretion disk, which does not explain the depletion of metallic iron in the Moon.[17] These hypotheses also cannot account for the high angular momentum of the Earth–Moon system.[19]

The prevailing hypothesis today is that the Earth–Moon system formed as a result of a giant impact: a Mars-sized body hit the nearly formed proto-Earth, blasting material into orbit around the proto-Earth, which accreted to form the Moon.[20] Giant impacts are thought to have been common in the early Solar System. Computer simulations modelling a giant impact are consistent with measurements of the angular momentum of the Earth–Moon system, and the small size of the lunar core; they also show that most of the Moon came from the impactor, not from the proto-Earth.[21] However, meteorites show that other inner Solar System bodies such as Mars andVesta have very different oxygen and tungsten isotopic compositions to the Earth, while the Earth and Moon have near-identical isotopic compositions. Post-impact mixing of the vaporized material between the forming Earth and Moon could have equalized their isotopic compositions,[22] although this is debated.[23]

The large amount of energy released in the giant impact event and the subsequent reaccretion of material in Earth orbit would have melted the outer shell of the Earth, forming a magma ocean.[24][25] The newly formed Moon would also have had its own lunar magma ocean; estimates for its depth range from about 500 km to the entire radius of the Moon.[24]

### Internal structure

*Main article: Internal structure of the Moon*

| Chemical composition of the lunar surface regolith (derived from crustal rocks)[26] | | | |
|---|---|---|---|
| Compound | Formula | Composition (wt %) | |
| | | Maria | Highlands |
| silica | $SiO_2$ | 45.4% | 45.5% |
| alumina | $Al_2O_3$ | 14.9% | 24.0% |

| | | | |
|---|---|---|---|
| lime | CaO | 11.8% | 15.9% |
| iron(II) oxide | FeO | 14.1% | 5.9% |
| magnesia | MgO | 9.2% | 7.5% |
| titanium dioxide | $TiO_2$ | 3.9% | 0.6% |
| sodium oxide | $Na_2O$ | 0.6% | 0.6% |
| **Total** | | **99.9%** | **100.0%** |

The Moon is a differentiated body: it has a geochemically distinct crust, mantle, and core. This structure is thought to have developed through the fractional crystallization of a global magma ocean shortly after the Moon's formation 4.5 billion years ago.[27]Crystallization of this magma ocean would have created a mafic mantle from the precipitation and sinking of the minerals olivine,clinopyroxene, and orthopyroxene; after about three-quarters of the magma ocean had crystallised, lower-density plagioclaseminerals could form and float into a crust on top.[28] The final liquids to crystallise would have been initially sandwiched between the crust and mantle, with a high abundance of incompatible and heat-producing elements.[1] Consistent with this, geochemical mapping from orbit shows the crust is mostly anorthosite,[5] and moon rock samples of the flood lavas erupted on the surface from partial melting in the mantle confirm the mafic mantle composition, which is more iron rich than that of Earth.[1] Geophysical techniques suggest that the crust is on average ~50 km thick.[1]

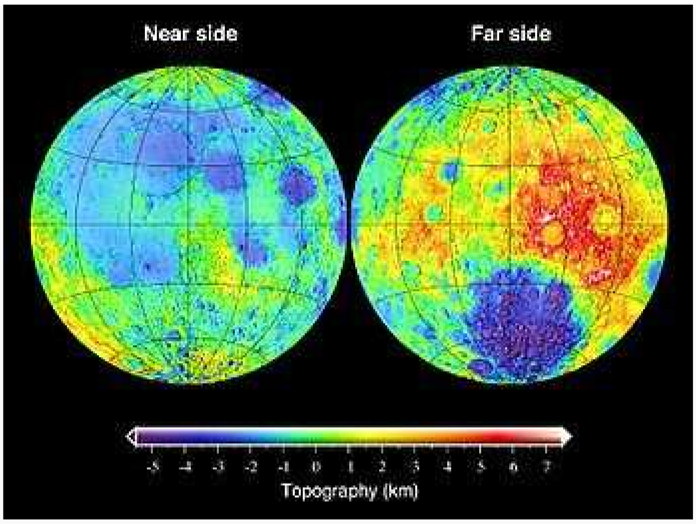
The Moon is the second densest satellite in the Solar System after Io.[29] However, the core of the Moon is small, with a radius of about 350 km or less:[1] this is only ~20% the size of the Moon, in contrast to the ~50% of most other terrestrial bodies. Its composition is not well constrained, but it is probably metallic iron alloyed with a small amount of sulfur and nickel; analyses of the Moon's time-variable rotation indicate that it is at least partly molten.[30]

### Surface geology

*Main articles: Geology of the Moon and Moon rocks*
*See also: Topography of the Moon and List of features on the Moon*

Near side of the Moon

Far side of the Moon. Note the lack of dark maria.[31]




Topography of the Moon, referenced to the lunar geoid.

The Moon is in synchronous rotation: it rotates about its axis in about the same time it takes to orbit the Earth. This results in it nearly always keeping the same face turned towards the Earth. The Moon used to rotate at a faster rate, but early in its history, its rotation slowed and became locked in this orientation as a result of frictional effects associated with tidaldeformations caused by the Earth.[32] The side of the Moon that faces Earth is called the near side, and the opposite side the far side. The far side is often inaccurately called the "dark side," but in fact, it is illuminated exactly as often as the near side: once per lunar day, during the new Moon phase we observe on Earth when the near side is dark.[33]

The topography of the Moon has been measured with laser altimetry and stereo image analysis.[34] The most visible topographic feature is the giant far side South Pole – Aitken basin, some 2,240 km in diameter, the largest crater on the Moon and the largest known crater in the Solar System.[35][36] At 13 km deep, its floor is the lowest elevation on the Moon.[35][37] The highest elevations are found just to its north-east, and it has been suggested that this area might have been thickened by the oblique formation impact of South Pole – Aitken.[38] Other large impact basins, such as Imbrium,Serenitatis, Crisium, Smythii, and Orientale, also possess regionally low elevations and elevated rims.[35] The lunar far side is on average about 1.9 km higher than the near side.[1]

**Volcanic features**

*Main article: Lunar mare*

The dark and relatively featureless lunar plains which can clearly be seen with the naked eye are called *maria* (Latin for "seas"; singular *mare*), since they were believed by ancient astronomers to be filled with water.[39] They are now known to be vast solidified pools of ancient basaltic lava. While similar to terrestrial basalts, the mare basalts have much higher abundances of iron and are completely lacking in minerals altered by water.[40][41] The majority of these lavas erupted or flowed into the depressions associated with impact basins. Several geologic provinces containing shield volcanoes and volcanic domes are found within the near side maria.[42]

Maria are found almost exclusively on the near side of the Moon, covering 31% of the surface on the near side,[12]compared with a few scattered patches on the far side covering only 2%.[43] This is thought to be due to a concentration of heat-producing elements under the crust on the near side, seen on geochemical maps obtained by *Lunar Prospector'*s gamma-ray spectrometer, which would have caused the underlying mantle to heat up, partially melt, rise to the surface and erupt.[44][28][45] Most of the Moon's mare basalts erupted during the Imbrian period, 3.0–3.5 billion years ago, although some radiometrically dated samples are as old as 4.2 billion years,[46] and the youngest eruptions, dated by crater counting, appear to have been only 1.2 billion years ago.[47]

The lighter-coloured regions of the Moon are called *terrae*, or more commonly *highlands*, since they are higher than most maria. They have been radiometrically dated as forming 4.4 billion years ago, and may represent plagioclase cumulates of the lunar magma ocean.[46][47] In contrast to the Earth, no major lunar mountains are believed to have formed as a result of tectonic events.[48]

**Impact topography**

*See also: List of craters on the Moon*

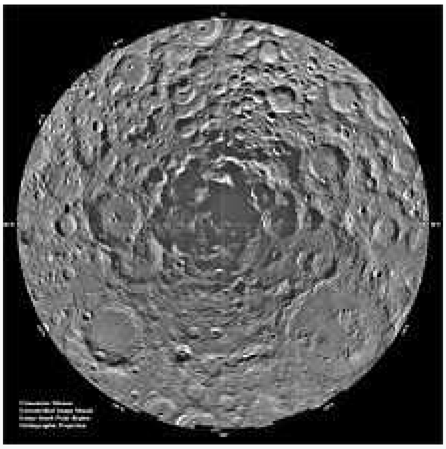
Lunar crater Daedalus on the Moon's far side

The other major geologic process that has affected the Moon's surface is impact cratering,[49] with craters formed when asteroids and comets collide with the lunar surface. There are estimated to be roughly 300,000 craters wider than 1 km on the Moon's near side alone.[50] These arenamed for scholars, scientists, artists and explorers.[51] The lunar geologic timescale is based on the most prominent impact events, includingNectaris, Imbrium, and Orientale, structures characterised by multiple rings of uplifted material, typically hundreds to thousands of kilometres in diameter and associated with a broad apron of ejecta deposits that form a regional stratigraphic horizon.[52] The lack of an atmosphere, weather and recent geological processes mean that many of these craters are well-preserved. While only a few multi-ring basins have been definitively dated, they are useful for assigning relative ages. Since impact craters accumulate at a nearly constant rate, counting the number of craters per unit area can be used to estimate the age of the surface.[52] The radiometric ages of impact-melted rocks collected during the Apollo missionscluster between 3.8 and 4.1 billion years old: this has been used to propose a Late Heavy Bombardment of impacts.[53]

Blanketed on top of the Moon's crust is a highly comminuted (broken into ever smaller particles) and impact gardened surface layer calledregolith, formed by impact processes. The finer regolith, the lunar soil of silicon dioxide glass, has a texture like snow and smell like spentgunpowder.[54] The regolith of older surfaces is generally thicker than for younger surfaces: it varies in thickness from 10–20 m in the highlands and 3–5 m in the maria.[55] Beneath the finely comminuted regolith layer is the *megaregolith*, a layer of highly fractured bedrock many kilometres thick.[56]

**Presence of water**

*Main article: Lunar water*



Lunar south pole as imaged byClementine: note permanent polar shadow.

Although liquid water cannot persist at the Moon's surface, and water vapour is quickly decomposed by sunlight and lost to space, scientists have thought since the 1960s that water ice, deposited by impacting comets or produced by the reaction of oxygen-rich lunar rocks and hydrogen in the solar wind, could survive in the cold, permanently shadowed craters at the Moon's poles.[57] These craters have been in shadow for the past two billion years,[58] and computer simulations suggest that up to 14,000 km$^2$ might be in permanent shadow.[59] The presence of usable quantities of water on the Moon is an important factor in rendering lunar habitation cost-effective, since transporting from Earth would be prohibitively expensive.[60]

Many different signatures of lunar water have since been found.[61] In 1994, *Clementine* 's bistatic radar experiment found indications of small, frozen pockets of water close to the surface (though later Arecibo radar observations suggested these might be rocks ejected from young impact craters);[62] *Lunar Prospector'*s neutron spectrometer indicated in 1998 that high concentrations of hydrogen are present in the upper metre of the regolith near the polar regions;[63] in 2008, new analysis found small amounts of water in the interior of volcanic lava beads brought to Earth by Apollo 15.[64] In September 2009, *Chandrayaan-1*, the first Indian lunar mission, detected water and hydroxyl absorption lines in reflected sunlight using NASA's Moon Mineralogy Mapper instrument, evidence of large quantities of water on the Moon's surface, possibly as high as

1,000ppm.[65] Weeks later, NASA's *LCROSS* mission flew its 2300 kg impactor into a permanently shadowed polar crater, and detected at least 100 kg of water in the plume of ejected material.[66][67]

**Gravity and magnetic fields**

*Main articles: Gravity of the Moon and Magnetic field of the Moon*

The gravitational field of the Moon has been measured through tracking the Doppler shift of radio signals emitted by orbiting spacecraft. The main lunar gravity features are mascons, large positive gravitational anomalies associated with some of the giant impact basins, partly caused by the dense mare basaltic lava flows that fill these basins.[68] These anomalies greatly influence the orbit of spacecraft about the Moon. There are some puzzles: lava flows by themselves cannot explain all of the gravitational signature, and some mascons exist that are not linked to mare volcanism.[69]

The Moon has an external magnetic field of the order of one to a hundred nanoteslas, less than one-hundredth that of the Earth. It does not currently have a global dipolar magnetic field, as would be generated by a liquid metal core geodynamo, and only has crustal magnetization, probably acquired early in lunar history when a geodynamo was still operating.[70][71]Alternatively, some of the remnant magnetization may be from transient magnetic fields generated during large impact events, through the expansion of an impact-generated plasma cloud in the presence of an ambient magnetic field—this is supported by the apparent location of the largest crustal magnetizations near the antipodes of the giant impact basins.[72]

**Atmosphere**

*Main article: Atmosphere of the Moon*

The Moon has an atmosphere so tenuous as to be nearly vacuum, with a total mass of less than 10 metric tons.[73] The surface pressure of this small mass is around $3 \times 10^{-15}$ atm (0.3nPa); it varies with the lunar day. Its sources include outgassing and sputtering, the release of atoms from the bombardment of lunar soil by solar wind ions.[5][74] Elements that have been detected include sodium and potassium, produced by sputtering, which are also found in the atmospheres of Mercury and Io; helium-4 from the solar wind; and argon-40, radon-222, andpolonium-210, outgassed after their creation by radioactive decay within the crust and mantle.[75][76] The absence of such neutral species (atoms or molecules) as oxygen, nitrogen,carbon, hydrogen and magnesium, which are present in the regolith, is not understood.[75] Water vapor has been detected by Chandrayan-1 and found to vary with latitude, with a maximum at ~60-70 degrees; it is possibly generated from the sublimation of water ice in the regolith.[77] These gases can either return into the regolith due to the Moon's gravity, or be lost to space: either through solar radiation pressure, or if they are ionised, by being swept away by the solar wind's magnetic field.[75]

Orbit and relationship to Earth

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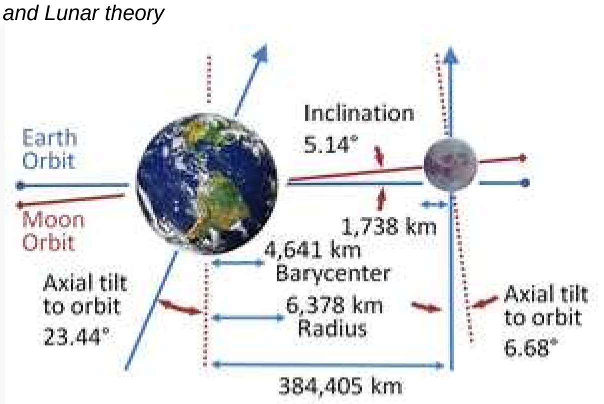
*Main articles: Orbit of the Moon and Lunar theory*




The Earth-Moon system, *not* drawn to scale.[78] Both individual radii and the barycenter radii are given.[79]

The Moon makes a complete orbit around the Earth with respect to the fixed stars about once every 27.3 days[nb 5] (its sidereal period). However, since the Earth is moving in its orbit about the Sun at the same time, it takes slightly longer for the Moon to show the same phase to Earth, which is about 29.5 days[nb 6] (its synodic period).[12] Unlike most satellites of other planets, the Moon orbits near the ecliptic and not the Earth's equatorial plane.

There are several known near-Earth asteroids that have unusual Earth-associated horseshoe orbits: 3753 Cruithne, 54509 YORP,(85770) 1998 UP1 and 2002 AA29.[80] They are co-orbital with the Earth, so that their orbits bring them close to Earth for periods of time but then alter in the long term, and they are not natural satellites of Earth.[81]

**Seasons**

Although the Moon's minute axial tilt (1.54 degrees) means that seasonal variation is minimal, it is just enough to create a 3-degree variation in the Sun's elevation at the poles, resulting in a very slight "summer" and "winter".[82] From images taken by *Clementine*in 1994, it appears that four mountainous regions on the rim of Peary crater at the Moon's north pole remain illuminated for the entire lunar day, creating peaks of eternal light. No such regions exist at the south pole. Similarly, there are places that remain in permanent shadow at the bottoms of many polar craters,[59] and these dark craters are extremely cold: *Lunar Reconnaissance Orbiter* measured the lowest summer temperatures in craters at the southern pole at 35 K (−238 ℃),[83] and just 26 K close to the winter solstice in north polar Hermite Crater. This is the coldest temperature in the Solar System ever measured by a spacecraft, colder even than the surface of Pluto.[82]

**Tidal effects**

*Main articles: Tidal force, Tidal acceleration, Tide, and Theory of tides*

The tides on the Earth are mostly generated by the gradient in intensity of the Moon's gravitational pull from one side of the Earth to the other, the tidal forces. This forms two tidal bulges on the Earth, which are most clearly seen in elevated sea level as ocean tides.[84] Since the Earth spins about 27 times faster than the Moon moves around it, the bulges are dragged along with the Earth's surface faster than the Moon moves, rotating around the Earth once a day as it spins on its axis.[84] The ocean tides are magnified by other effects: frictional coupling of water to Earth's rotation through the ocean floors, the inertia of water's movement, ocean basins that get shallower near land, and oscillations between different ocean basins.[85] The gravitational attraction of the Sun on the Earth's oceans is almost half that of the Moon, and their gravitational interplay is responsible for spring and neap tides.[84]

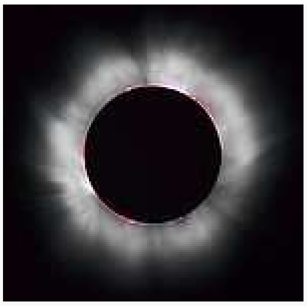
The libration of the Moon over a single lunar month.

Gravitational coupling between the Moon and the bulge nearest the Moon acts as a torque on the Earth's rotation, draining angular momentumand rotational kinetic energy from the Earth's spin.[84][86] In turn, angular momentum is added to the Moon's orbit, accelerating it, which lifts the Moon into a higher orbit with a longer period. As a result, the distance between the Earth and Moon is increasing, and the Earth's spin slowing down.[86] Measurements from lunar ranging experiments with laser reflectors left during the Apollo missions have found that the Moon's distance to the Earth increases by 38 mm per year[87] (though this is only 0.10 ppb/year of the radius of the Moon's orbit). Atomic clocks also show that the Earth's day lengthens by about 15 microseconds every year,[88] requiring the occasional addition of a leap second to the calendar. This tidal drag will continue until the spin of the Earth has slowed to match the orbital period of the Moon; however, long before this could happen, the Sun will have become a red giant, engulfing the Earth.[89][90]

The lunar surface also experiences tides of amplitude ~10 cm over 27 days, with two components: a fixed one due to the Earth, as they are insynchronous rotation, and a varying component from the Sun.[86] The Earth-induced component arises from libration, a result of the Moon's orbital eccentricity; if the Moon's orbit were perfectly circular, there would only be solar tides.[86] Libration also changes the angle from which the Moon is seen, allowing about 59% of its surface to be seen from the Earth (but only half at any instant).[12]

### Eclipses

*Main articles: Solar eclipse and Lunar eclipse*



The 1999 solar eclipse

The Moon passing in front of the Sun, from the STEREO-B spacecraft.[91] From the Earth, the Moon and Sun appear the same size. From a satellite in an Earth-trailing orbit, the Moon appears smaller than the Sun.

Eclipses can only occur when the Sun, Earth, and Moon are all in a straight line. Solar eclipses occur near a new Moon, when the Moon is between the Sun and Earth. In contrast, lunar eclipses occur near a full Moon, when the Earth is between the Sun and Moon. The angular diameters of the Moon and the Sun as seen from Earth overlap in their variation, so that both total and annular solar eclipses are possible.[92] In a total eclipse, the Moon completely covers the disc of the Sun and the solar corona becomes visible to the naked eye. Since the distance between the Moon and the Earth is very slowly increasing over time,[84] the angular diameter of the Moon is decreasing. This means that hundreds of millions of years ago the Moon would always completely cover the Sun on solar eclipses, and no annular eclipses were possible. Likewise, about 600 million years from now (if the angular diameter of the Sun does not change), the Moon will no longer cover the Sun completely, and only annular eclipses will occur.[93]

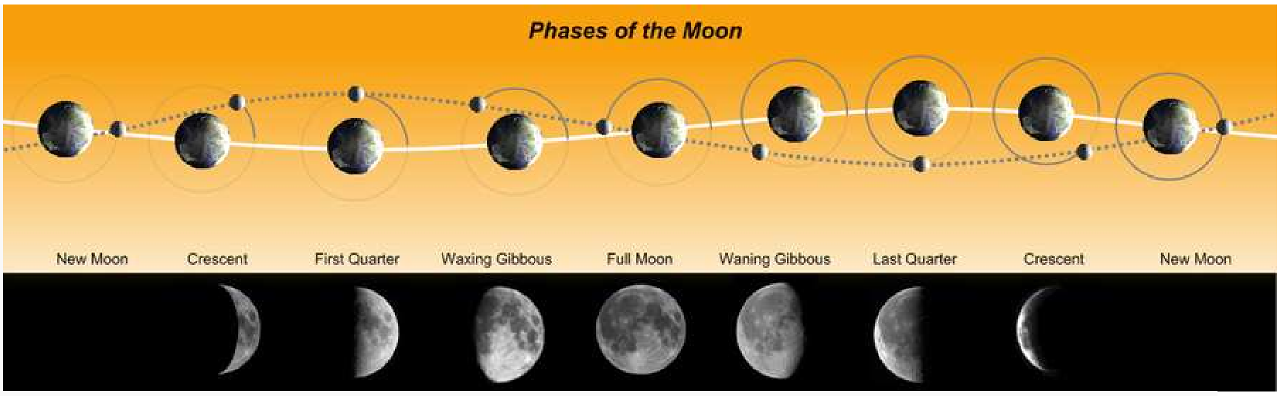
Because the Moon's orbit around the Earth is inclined by about 5° to the orbit of the Earth around the Sun, eclipses do not occur at every full and new Moon. For an eclipse to occur, the Moon must be near the intersection of the two orbital planes.[93] The periodicity and recurrence of eclipses of the Sun by the Moon, and of the Moon by the Earth, is described by the saros cycle, which has a period of approximately 18 years.[94]

As the Moon is continuously blocking our view of a half-degree-wide circular area of the sky,[nb 7][95] the related phenomenon ofoccultation occurs when a bright star or planet passes behind the Moon and is occulted: hidden from view. In this way, a solar eclipse is an occultation of the Sun. Because the Moon is comparatively close to the Earth, occultations of individual stars are not visible everywhere on the planet, nor at the same time. Because of the precession of the lunar orbit, each year different stars are occulted.[96]

## Appearance from Earth

*See also: Lunar phase, Earthshine, and Observing the Moon*

The Moon has an exceptionally low albedo, giving it a similar reflectance to coal. Despite this, it is the second brightest object in the sky after the Sun.[12][nb 8] This is partly due to the brightness enhancement of the opposition effect; at quarter phase, the Moon is only one-tenth as bright, rather than half as bright, as at full Moon.[97] Additionally, colour constancy in thevisual system recalibrates the relations between the colours of an object and its surroundings, and since the surrounding sky is comparatively dark, the sunlit Moon is perceived as a bright object. The edges of the full Moon seem as bright as the centre, with no limb darkening, due to the reflective properties of lunar soil, which reflects more light back towards the Sun than in other directions. The Moon does appear larger when close to the horizon, but this is a purely psychological effect, known as the Moon illusion, first described in 1021 by the Islamic physicist Alhacen in the *Book of Optics*.[98]




The phases of the Moon in their order of appearance: New Moon through Crescent, First Quarter, and Gibbous to reach Full Moon. This is followed by Gibbous, Last Quarter and Crescent to complete full circle at the New Moon again.

The highest altitude of the Moon in the sky varies: while it has nearly the same limit as the Sun, it alters with the lunar phase and with the season of the year, with the full Moon highest during winter. The 18.6 year nodes cycle also has an influence: when the ascending node of the lunar orbit is in the vernal equinox, the lunar declination can go as far as 28° each month. This means the Moon can go overhead at latitudes up to 28° fro m the equator, instead of only 18°. The orientation of the Moon's crescent also depends on the latitude of the observation site: close to the equator, an observer can see a *boat* Moon.[99]

There has been historical controversy over whether features on the Moon's surface change over time. Today, many of these claims are thought to be illusory, resulting from observation under different lighting conditions, poor astronomical seeing, or inadequate drawings. However, outgassing does occasionally occur, and could be responsible for a minor percentage of the reported lunar transient phenomena. Recently, it has been suggested that a roughly 3 km diameter region of the lunar surface was modified by a gas release event about a million years ago.[100][101] The Moon's appearance, like that of the Sun, can be affected by Earth's atmosphere: common effects are a 22° halo ring formed when the Moon's light is ref racted through the ice crystals of high cirrostratus cloud, and smaller coronal rings when the Moon is seen through thin clouds.[102]

## Study and exploration

*See also: Robotic exploration of the Moon, List of current and future lunar missions, Colonization of the Moon, and List of man-made objects on the Moon*

Map of the Moon by Johannes Heveliusfrom his Selenographia (1647), the first map to include the libration zones.

### Early studies

*Main articles: Exploration of the Moon: Early history, Selenography, and Lunar theory*

Understanding of the Moon's cycles was an early development of astronomy: by the 5th century BC, Babylonian astronomers had recorded the 18-year Saros cycle of lunar eclipses,[103] and Indian astronomers had described the Moon's monthly elongation.[104] The Chinese astronomerShi Shen (fl. 4th century BC) gave instructions for predicting solar and lunar eclipses.[105] Later, the physical form of the Moon and the cause ofmoonlight became understood. The ancient Greek philosopher Anaxagoras (d. 428 BC) reasoned that the Sun and Moon were both giant spherical rocks, and that the latter reflected the light of the former.[106][107] Although the Chinese of the Han Dynasty believed the Moon to be energy equated to *qi*, their 'radiating influence' theory also recognized that the light of the Moon was merely a reflection of the Sun, and Jing Fang(78–37 BC) noted the sphericity of the Moon.[108] In 499 AD, the Indian astronomer Aryabhata mentioned in his *Aryabhatiya* that reflected sunlight is the cause of the shining of the Moon;[109] this was later proved through experimentation by the Islamic astronomer and physicist,Alhazen (965–1039), who found that sunlight was not reflected from the Moon as by a mirror, as had been thought, but that the Moon "emits light from those portions of its surface which the sun's light strikes."[110] Shen Kuo (1031–1095) of the Song Dynasty created an allegory equating the waxing and waning of the Moon to a round ball of reflective silver that, when doused with white powder and viewed from the side, would appear to be a crescent.[111]

In Aristotle's (384–322 BC) description of the universe, the Moon marked the boundary between the spheres of the mutable elements (earth, water, air and fire), and the imperishable stars of aether, an influential philosophy that would dominate for centuries.[112] However, in the 2nd century BC, Seleucus of Seleucia correctly theorized that tides were due to the attraction of the Moon, and that their height depends on the Moon's position relative to the Sun.[113] In the same century, Aristarchus computed the size and distance of the Moon from Earth, obtaining a value of about twenty times the Earth radius for the distance. These figures were greatly improved by Ptolemy (90-168 AD): his values of a mean distance of 59 times the Earth's radius and a diameter of 0.292 Earth diameters were close to the correct values of about 60 and 0.273 respectively.[114]

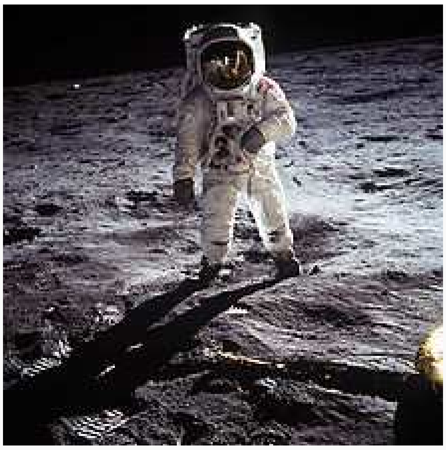
During the Middle Ages, before the invention of the telescope, the Moon was increasingly recognised as a sphere, though many believed that it was "perfectly smooth".[115] In 1609, Galileo Galilei drew one of the first telescopic drawings of the Moon in his book *Sidereus Nuncius* and noted that it was not smooth but had mountains and craters. Telescopic mapping of the Moon followed: later in the 17th century, the efforts of Giovanni Battista Riccioli and Francesco Maria Grimaldi led to the system of naming of lunar features in use today. The more exact 1834-6 *Mappa Selenographica* of Wilhelm Beer and Johann Heinrich Mädler, and their associated 1837 book *Der Mond*, the first trigonometrically accurate study of lunar features, included the heights of more than a thousand mountains, and introduced the study of the Moon at accuracies possible in earthly geography.[116] Lunar craters, first noted by Galileo, were thought to be volcanic until the 1870s proposal of Richard Proctor that they were formed by collisions.[12] This view gained support in 1892 from the experimentation of geologist Grove Karl Gilbert, and from comparative studies from 1920 to the 1940s,[117] leading to the development of lunar stratigraphy, which by the 1950s was becoming a new and growing branch of astrogeology.[12]

**First direct exploration: 1959–1980s**

*Main articles: Apollo program and Moon landing*

Earth as viewed from the Moon during the Apollo 8 mission, Christmas Eve, 1968. Africa is at the sunset terminator, both Americas are under cloud, and Antarctica is at the left end of the terminator.

The Cold War-inspired space race between the Soviet Union and the U.S. led to an acceleration of interest in exploration of the Moon. Once launchers had the necessary capabilities, these nations sent unmanned probes on both flyby and impact/lander missions. Spacecraft from the Soviet Union's *Luna* program were the first to accomplish a number of goals: following three unnamed, failed missions in 1958,[118] the first man-made object to escape Earth's gravity and pass near the Moon was *Luna 1*; the first man-made object to impact the lunar surface was *Luna 2*, and the first photographs of the normally occluded far side of the Moon were made by *Luna 3*, all in 1959. The first spacecraft to perform a successful lunar soft landing was *Luna 9* and the first unmanned vehicle to orbit the Moon was *Luna 10*, both in 1966.[12] Rock and soil sampleswere brought back to Earth by three *Luna* sample return missions (*Luna 16*, *20*, and *24*), which returned 0.3 kg total.[119]



Astronaut Buzz Aldrin photographed byNeil Armstrong during the first Moon landingon July 20, 1969

American lunar exploration began with robotic missions aimed at developing understanding of the lunar surface for an eventual manned landing: the Jet Propulsion Laboratory's *Surveyor* program landed its first spacecraft four months after *Luna 9*. NASA's manned Apollo program was developed in parallel; after a series of unmanned and manned tests of the Apollo spacecraft in Earth orbit, and spurred on by a potential Soviet lunar flight, in 1968 Apollo 8 made the first crewed mission to lunar orbit. The subsequent landing of the first humans on the Moon in 1969 is seen by many as the culmination of the space race.[120] Neil Armstrong became the first person to walk on the Moon as the commander of the American mission Apollo 11 by first setting foot on the Moon at 02:56 UTC on July 21, 1969.[121] The Apollo missions 11 to 17 (except Apollo 13, which aborted its planned lunar landing) returned 382 kg of lunar rock and soil in 2,196 separate samples.[122] The American Moon landing and return was enabled by considerable technological advances in the early 1960s, in domains such as ablation chemistry, software engineering andatmospheric re-entry technology, and by highly competent management of the enormous technical undertaking.[123][124]

Scientific instrument packages were installed on the lunar surface during all the Apollo missions. Long-lived instrument stations, including heat flow probes, seismometers, and magnetometers, were installed at the Apollo 12, 14, 15, 16, and 17 landing sites. Direct transmission of data to Earth concluded in late 1977 due to budgetary considerations,[125][126] but as the stations' lunar laser ranging corner-cube retroreflector arrays are passive instruments, they are still being used. Ranging to the stations is routinely performed from earth-based stations with an accuracy of a few centimetres, and data from this experiment are being used to place constraints on the size of the lunar core.[127]

**Current era: 1990–present**

Post-Apollo and *Luna*, many more countries have become involved in direct exploration of the Moon. In 1990, Japan orbited the Moon with the*Hiten* spacecraft, becoming the third country to place a spacecraft into lunar orbit. The spacecraft released a smaller probe, *Hagoromo*, in lunar orbit, but the transmitter failed, preventing further scientific use of the mission.[128] In 1994, the U.S. sent the joint Defense Department/NASA spacecraft *Clementine* to lunar orbit. This mission obtained the first near-global topographic map of the Moon, and the first global multispectralimages of the lunar surface.[129] This was followed in 1998 by the *Lunar Prospector* mission, whose instruments indicated the presence of excess hydrogen at the lunar poles, which is likely to have been caused by the presence of water ice in the upper few meters of the regolith within permanently shadowed craters.[130]

The European spacecraft *Smart 1*, the second ion-propelled spacecraft, was in lunar orbit from November 15, 2004 until its lunar impact on September 3, 2006, and made the first detailed survey of chemical elements on the lunar surface.[131] China has expressed ambitious plans for exploring the Moon, and successfully orbited its first spacecraft, *Chang'e-1*, from November 5, 2007 until its lunar impact on March 1, 2008.[132] In its sixteen-month mission, it obtained a full image map of the Moon. Between October 4, 2007 and June 10, 2009, the Japan Aerospace Exploration Agency's *Kaguya (Selene)* mission, a lunar orbiter fitted with a high-definition video camera, and two small radio-transmitter satellites, obtained lunar geophysics data and took the first high-definition movies from beyond Earth orbit.[133][134] India's first lunar mission,*Chandrayaan I*, orbited from 8 November 2008 until loss of contact on August 27, 2009, creating a high resolution chemical, mineralogical and photo-geological map of the lunar surface.[135]The country plans to launch *Chandrayaan II* in 2013, which is slated to include a Russian robotic lunar rover.[136][137] The U.S. co-launched the *Lunar Reconnaissance Orbiter* (LRO) and the *LCROSS* impactor and follow-up observation orbiter on June 18, 2009; *LCROSS* completed its mission by making a planned and widely observed impact in the crater Cabeus on October 9, 2009,[138] while *LRO* is currently in operation, obtaining precise lunar altimetry and high-resolution imagery.

Other upcoming lunar missions include Russia's *Luna-Glob*: an unmanned lander, set of seismometers, and an orbiter based on its Martian *Phobos-Grunt* mission, which is slated to launch in 2012.[139][140] Privately funded lunar exploration has been promoted by the Google Lunar X Prize, announced September 13, 2007, which offers US$20 million to anyone who can land a robotic rover on the Moon and meet other specified criteria.[141]

NASA began to plan to resume manned missions following the call by U.S. President George W. Bush on January 14, 2004 for a mission to the Moon by 2020.[142] The Constellation program was funded and construction and testing begun on a manned spacecraft and launch vehicle,[143] and design studies for a lunar base.[144] However, that program has been placed in jeopardy by the proposed 2011 budget, which will cancel Constellation in favor of NASA pursuing space technology and heavy-lift rocketry research.[145] India has also expressed its hope for a manned mission to the Moon by 2020.[146]

## Legal status

*Main article: Space law*

Although *Luna* landers scattered pennants of the Soviet Union on the Moon, and U.S. flags were symbolically planted at their landing sites by the Apollo astronauts, no nation currently claims ownership of any part of the Moon's surface.[147] Russia and the U.S. are party to the 1967 Outer Space Treaty,[148] which defines the Moon and all outer space as the "province of all mankind".[147] This treaty also restricts the use of the Moon to peaceful purposes, explicitly banning military installations and weapons of mass destruction.[149] The 1979 Moon Agreement was created to restrict the exploitation of the Moon's resources by any single nation, but it has not been signed by any of the space-faring nations.[150] While several individuals have made claims to the Moon in whole or in part, none of these are considered credible.[151][152][153]

## In culture

*See also: Moon in fiction, Lunar calendar, Lunar deity, Lunar effect, and Blue moon*

The Moon's regular phases make it a very convenient timepiece, and the periods of its waxing and waning form the basis of many of the oldest calendars. An eagle-bone tally stick, found near the village of Le Placard in France and dated to 13,000 years ago, is believed by many to mark the phases of the Moon.[154] The month, a word derived from "Moon", is a rough approximation of the lunar cycle adapted to the modern solar calendar.[155] The Moon has been the subject of many works of art and literature and the inspiration for countless others. It is a motif in the visual arts, the performing arts, poetry, prose and music. A 5,000-year-old rock carving at Knowth, Ireland may represent the Moon, which would be the earliest depiction discovered.[156] In many prehistoric and ancient cultures, the Moon was thought to be a deity or other supernatural phenomenon, and astrological views of the Moon continue to be propagated today. The contrast between the brighter highlands and darker maria create the patterns seen by different cultures as the Man in the Moon, the rabbit and the buffalo, among others. The Moon has a long association with insanity and irrationality; the words *lunacy* and *loony* are derived from the Latin name for the Moon, *Luna*. Philosophers such as Aristotle andPliny the Elder argued that the full Moon induced insanity in susceptible individuals, believing that the brain, which is mostly water, must be affected by the Moon and its power over the tides, but the Moon's gravity is too slight to affect any single person.[157] Even today, people insist that admissions to psychiatric hospitals, traffic accidents, homicides or suicides increase during a full Moon, although there is no scientific evidence to support such claims.[157]

## Notes

1. **^** The *maximum value* is given based on scaling of the brightness from the value of −12.74 given for an equator to Moon-centre distance of 378 000 km in the NASA factsheet reference to the minimum Earth-Moon distance given there, after the latter is corrected for the Earth's equatorial radius of 6 378 km, giving 350 600 km. The *minimum value* (for a distant new Moon) is based on a similar scaling using the maximum Earth-Moon distance of 407 000 km (given in the factsheet) and by calculating the brightness of the earthshine onto such a new Moon. The brightness of the earthshine is [ Earth albedo × (Earth radius / Radius of Moon's orbit)$^2$ ] relative to the direct solar illumination that occurs for a full Moon. (Earth albedo = 0.367; Earth radius = (polar radius × equatorial radius)$^{½}$ = 6 367 km).
2. **^** The range of angular size values given are based on simple scaling of the following values given in the fact sheet reference: at an Earth-equator to Moon-centre distance of 378 000 km, the angular size is 1896arcseconds. The same fact sheet gives extreme Earth-Moon distances of 407 000 km and 357 000 km. For the maximum angular size, the minimum distance has to be corrected for the Earth's equatorial radius of 6 378 km, giving 350 600 km.
3. **^** Lucey *et al.* (2006) give $10^7$ particles cm$^{-3}$ by day and $10^5$ particles cm$^{-3}$ by night. Along with equatorial surface temperatures of 390 K by day and 100 K by night, the ideal gas law yields the pressures given in the infobox (rounded to the nearest order of magnitude; $10^{-7}$ Pa by day and $10^{-10}$ Pa by night.
4. **^** This age is calculated from isotope dating of lunar rocks.
5. **^** More accurately, the Moon's mean sidereal period (fixed star to fixed star) is 27.321661 days (27d 07h 43m 11.5s), and its mean tropical orbital period (from equinox to equinox) is 27.321582 days (27d 07h 43m 04.7s) (*Explanatory Supplement to the Astronomical Ephemeris*, 1961, at p.107).
6. **^** More accurately, the Moon's mean synodic period (between mean solar conjunctions) is 29.530589 days (29d 12h 44m 02.9s) (*Explanatory Supplement to the Astronomical Ephemeris*, 1961, at p.107).
7. **^** On average, the Moon covers an area of 0.21078 square degrees on the night sky.
8. **^** The Sun's apparent magnitude is −26.7) and the full Moon's apparent magnitude is −12.7.

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