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# Earth

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*This article is about the planet. For other uses, see*[*Earth (disambiguation)*](https://en.wikipedia.org/wiki/Earth_(disambiguation))*.*

|  |  |
| --- | --- |
| **Earth [Astronomical symbol of Earth](https://en.wikipedia.org/wiki/File:Earth_symbol.svg)** | |
| ["The Blue Marble" photograph of Earth, taken by the Apollo 17 lunar mission. The Arabian peninsula, Africa and Madagascar lie in the upper half of the disc, whereas Antarctica is at the bottom.](https://en.wikipedia.org/wiki/File:The_Earth_seen_from_Apollo_17.jpg)  "[The Blue Marble](https://en.wikipedia.org/wiki/The_Blue_Marble)" photograph of Earth, taken during the [*Apollo 17*](https://en.wikipedia.org/wiki/Apollo_17) lunar mission in 1972 | |
| [**Orbital characteristics**](https://en.wikipedia.org/wiki/Osculating_orbit) | |
| [Epoch](https://en.wikipedia.org/wiki/Epoch_(astronomy)) [J2000](https://en.wikipedia.org/wiki/J2000.0)[[n 1]](https://en.wikipedia.org/wiki/Earth#cite_note-epoch-1) | |
| [**Aphelion**](https://en.wikipedia.org/wiki/Aphelion) | 152,100,000 km (94,500,000 mi) (1.01673 [AU](https://en.wikipedia.org/wiki/Astronomical_unit)) [[n 2]](https://en.wikipedia.org/wiki/Earth#cite_note-apsis-2) |
| [**Perihelion**](https://en.wikipedia.org/wiki/Perihelion) | 147,095,000 km (91,401,000 mi) (0.9832687 AU) [[n 2]](https://en.wikipedia.org/wiki/Earth#cite_note-apsis-2) |
| [**Semi-major axis**](https://en.wikipedia.org/wiki/Semi-major_axis) | 149,598,023 km (92,955,902 mi) (1.000001018 AU) [[1]](https://en.wikipedia.org/wiki/Earth#cite_note-VSOP87-3) |
| [**Eccentricity**](https://en.wikipedia.org/wiki/Orbital_eccentricity) | 0.0167086[[1]](https://en.wikipedia.org/wiki/Earth#cite_note-VSOP87-3) |
| [**Orbital period**](https://en.wikipedia.org/wiki/Orbital_period) | 365.256363004 d [[2]](https://en.wikipedia.org/wiki/Earth#cite_note-IERS-4) (1.00001742096 [yr](https://en.wikipedia.org/wiki/Julian_year_(astronomy))) |
| **Average**[**orbital speed**](https://en.wikipedia.org/wiki/Orbital_speed) | 29.78 km/s (18.50 mi/s)[[3]](https://en.wikipedia.org/wiki/Earth#cite_note-earth_fact_sheet-5) (107,200 km/h (66,600 mph)) |
| [**Mean anomaly**](https://en.wikipedia.org/wiki/Mean_anomaly) | 358.617° |
| [**Inclination**](https://en.wikipedia.org/wiki/Orbital_inclination) | * 7.155° to the [Sun](https://en.wikipedia.org/wiki/Sun)'s [equator](https://en.wikipedia.org/wiki/Equator); * 1.57869°[[4]](https://en.wikipedia.org/wiki/Earth#cite_note-Allen294-6) to [invariable plane](https://en.wikipedia.org/wiki/Invariable_plane); * 0.00005° to J2000 [ecliptic](https://en.wikipedia.org/wiki/Ecliptic) |
| [**Longitude of ascending node**](https://en.wikipedia.org/wiki/Longitude_of_the_ascending_node) | −11.26064°[[3]](https://en.wikipedia.org/wiki/Earth#cite_note-earth_fact_sheet-5) to J2000 ecliptic |
| [**Argument of perihelion**](https://en.wikipedia.org/wiki/Argument_of_periapsis) | 114.20783°[[3]](https://en.wikipedia.org/wiki/Earth#cite_note-earth_fact_sheet-5) |
| [**Satellites**](https://en.wikipedia.org/wiki/Natural_satellite) | * [One natural satellite](https://en.wikipedia.org/wiki/Moon); * >1381 operational [artificial satellites](https://en.wikipedia.org/wiki/Artificial_satellite)[[5]](https://en.wikipedia.org/wiki/Earth#cite_note-ucs-7)[[n 3]](https://en.wikipedia.org/wiki/Earth#cite_note-space_debris-8) |
| **Physical characteristics** | |
| **Mean radius** | 6,371.0 km (3,958.8 mi)[[6]](https://en.wikipedia.org/wiki/Earth#cite_note-hbcp2000-9) |
| [**Equatorial**](https://en.wikipedia.org/wiki/Equator)**radius** | 6,378.1 km (3,963.2 mi)[[7]](https://en.wikipedia.org/wiki/Earth#cite_note-usno-10)[[8]](https://en.wikipedia.org/wiki/Earth#cite_note-WGS-84-11) |
| [**Polar**](https://en.wikipedia.org/wiki/Geographical_pole)**radius** | 6,356.8 km (3,949.9 mi)[[9]](https://en.wikipedia.org/wiki/Earth#cite_note-cazenave_ahrens1995-12) |
| [**Flattening**](https://en.wikipedia.org/wiki/Flattening) | 0.0033528[[10]](https://en.wikipedia.org/wiki/Earth#cite_note-IERS2004-13) 1/298.257222101 ([ETRS89](https://en.wikipedia.org/wiki/ETRS89)) |
| **Circumference** | * 40,075.017 km (24,901.461 mi) ([equatorial](https://en.wikipedia.org/wiki/Equator)) [[8]](https://en.wikipedia.org/wiki/Earth#cite_note-WGS-84-11) * 40,007.86 km (24,859.73 mi) ([meridional](https://en.wikipedia.org/wiki/Meridional)) [[11]](https://en.wikipedia.org/wiki/Earth#cite_note-WGS-84-2-14)[[12]](https://en.wikipedia.org/wiki/Earth#cite_note-circ-15) |
| [**Surface area**](https://en.wikipedia.org/wiki/Spheroid#Surface_area) | * 510,072,000 km2 (196,940,000 sq mi)[[13]](https://en.wikipedia.org/wiki/Earth#cite_note-Pidwirny_2006_8-16)[[14]](https://en.wikipedia.org/wiki/Earth#cite_note-cia-17)[[n 4]](https://en.wikipedia.org/wiki/Earth#cite_note-surfacecover-18) * (148,940,000 km2 (57,510,000 sq mi) (29.2%) land * 361,132,000 km2 (139,434,000 sq mi) (70.8%) water) |
| [**Volume**](https://en.wikipedia.org/wiki/Volume) | [1.08321×1012 km3](https://en.wikipedia.org/wiki/Volume_of_the_Earth) (2.59876×1011 cu mi)[[3]](https://en.wikipedia.org/wiki/Earth#cite_note-earth_fact_sheet-5) |
| [**Mass**](https://en.wikipedia.org/wiki/Mass) | 5.97237×1024 kg (1.31668×1025 lb)[[15]](https://en.wikipedia.org/wiki/Earth#cite_note-Luzum2011-19) (3.0×10−6 [*M*☉](https://en.wikipedia.org/wiki/Solar_mass)) |
| **Mean**[**density**](https://en.wikipedia.org/wiki/Density) | 5.514 g/cm3 (0.1992 lb/cu in)[[3]](https://en.wikipedia.org/wiki/Earth#cite_note-earth_fact_sheet-5) |
| [**Surface gravity**](https://en.wikipedia.org/wiki/Surface_gravity) | 9.807 m/s2 (32.18 ft/s2)[[16]](https://en.wikipedia.org/wiki/Earth#cite_note-NIST2008-20) ([1 *g*](https://en.wikipedia.org/wiki/Gravity_of_Earth)) |
| [**Moment of inertia factor**](https://en.wikipedia.org/wiki/Moment_of_inertia_factor) | 0.3307[[17]](https://en.wikipedia.org/wiki/Earth#cite_note-Williams1994-21) |
| [**Escape velocity**](https://en.wikipedia.org/wiki/Escape_velocity) | 11.186 km/s (6.951 mi/s)[[3]](https://en.wikipedia.org/wiki/Earth#cite_note-earth_fact_sheet-5) |
| **Sidereal**[**rotation period**](https://en.wikipedia.org/wiki/Rotation_period) | 0.99726968 d[[18]](https://en.wikipedia.org/wiki/Earth#cite_note-Allen296-22) (23h 56m 4.100s) |
| **Equatorial rotation velocity** | 1,674.4 km/h (1,040.4 mph)[[19]](https://en.wikipedia.org/wiki/Earth#cite_note-Cox2000-23) |
| [**Axial tilt**](https://en.wikipedia.org/wiki/Axial_tilt) | 23.4392811°[[2]](https://en.wikipedia.org/wiki/Earth#cite_note-IERS-4) |
| [**Albedo**](https://en.wikipedia.org/wiki/Albedo) | * 0.367 [geometric](https://en.wikipedia.org/wiki/Geometric_albedo)[[3]](https://en.wikipedia.org/wiki/Earth#cite_note-earth_fact_sheet-5) * 0.306 [Bond](https://en.wikipedia.org/wiki/Bond_albedo)[[3]](https://en.wikipedia.org/wiki/Earth#cite_note-earth_fact_sheet-5) |
| |  |  |  |  | | --- | --- | --- | --- | | **Surface**[**temp.**](https://en.wikipedia.org/wiki/Temperature) | **min** | **mean** | **max** | | [**Kelvin**](https://en.wikipedia.org/wiki/Kelvin) | 184 K[[20]](https://en.wikipedia.org/wiki/Earth#cite_note-asu_lowest_temp-24) | 288 K[[21]](https://en.wikipedia.org/wiki/Earth#cite_note-kinver20091210-25) | 330 K[[22]](https://en.wikipedia.org/wiki/Earth#cite_note-asu_highest_temp-26) | | **Celsius** | −89.2 °C | 15 °C | 56.7 °C | | **Fahrenheit** | −128.5 °F | 59 °F | 134 °F | | |
| **Atmosphere** | |
| **Surface**[**pressure**](https://en.wikipedia.org/wiki/Atmospheric_pressure) | 101.325 [kPa](https://en.wikipedia.org/wiki/Pascal_(unit)) (at [MSL](https://en.wikipedia.org/wiki/Sea_level)) |
| [**Composition by volume**](https://en.wikipedia.org/wiki/Atmospheric_chemistry#Atmospheric_composition) | * 78.08% [nitrogen](https://en.wikipedia.org/wiki/Nitrogen) (N2)[[3]](https://en.wikipedia.org/wiki/Earth#cite_note-earth_fact_sheet-5) (dry air) * 20.95% [oxygen](https://en.wikipedia.org/wiki/Oxygen) (O2) * 0.930% [argon](https://en.wikipedia.org/wiki/Argon) * 0.039% [carbon dioxide](https://en.wikipedia.org/wiki/Carbon_dioxide)[[23]](https://en.wikipedia.org/wiki/Earth#cite_note-NOAA-27) * ~ 1% [water vapor](https://en.wikipedia.org/wiki/Water_vapor) ([climate](https://en.wikipedia.org/wiki/Climate)-variable) |

**Earth** (otherwise known as **the world**,[[n 5]](https://en.wikipedia.org/wiki/Earth#cite_note-29) in [Greek](https://en.wikipedia.org/wiki/Greek_language): **Γαῖα** *Gaia*,[[n 6]](https://en.wikipedia.org/wiki/Earth#cite_note-31) or in [Latin](https://en.wikipedia.org/wiki/Latin): **Terra**[[26]](https://en.wikipedia.org/wiki/Earth#cite_note-32)) is the third planet from the [Sun](https://en.wikipedia.org/wiki/Sun), the densest planet in the [Solar System](https://en.wikipedia.org/wiki/Solar_System), the largest of the Solar System's four[terrestrial planets](https://en.wikipedia.org/wiki/Terrestrial_planet), and the only [astronomical object](https://en.wikipedia.org/wiki/Astronomical_object) known to harbor [life](https://en.wikipedia.org/wiki/Life).

According to [radiometric dating](https://en.wikipedia.org/wiki/Radiometric_dating) and other sources of evidence, Earth formed about 4.54 billion years ago.[[27]](https://en.wikipedia.org/wiki/Earth#cite_note-USGS1997-33)[[28]](https://en.wikipedia.org/wiki/Earth#cite_note-34)[[29]](https://en.wikipedia.org/wiki/Earth#cite_note-35) Earth [gravitationally](https://en.wikipedia.org/wiki/Gravity) interacts with other objects in space, especially the Sun and the [Moon](https://en.wikipedia.org/wiki/Moon). During one orbit around the Sun, Earth rotates about its own axis 366.26 times, creating 365.26 [solar days](https://en.wikipedia.org/wiki/Solar_time) or one [sidereal year](https://en.wikipedia.org/wiki/Sidereal_year).[[n 7]](https://en.wikipedia.org/wiki/Earth#cite_note-sidereal_solar-36) Earth's axis of rotation is tilted 23.4° away from the perpendicular of its [orbital plane](https://en.wikipedia.org/wiki/Orbital_plane_(astronomy)), producing seasonal variations on the planet's surface within a period of one [tropical year](https://en.wikipedia.org/wiki/Tropical_year) (365.24 solar days).[[30]](https://en.wikipedia.org/wiki/Earth#cite_note-yoder1995-37) The Moon, Earth's only permanent [natural satellite](https://en.wikipedia.org/wiki/Natural_satellite), by its gravitational relationship with Earth, causes ocean tides, stabilizes the orientation of Earth's rotational axis, and gradually slows Earth's rotational rate.[[31]](https://en.wikipedia.org/wiki/Earth#cite_note-aaa428_261-38)

Earth's [lithosphere](https://en.wikipedia.org/wiki/Lithosphere) is divided into several rigid [tectonic plates](https://en.wikipedia.org/wiki/Plate_tectonics) that migrate across the surface over periods of many millions of years. 71% of Earth's surface is covered with water.[[32]](https://en.wikipedia.org/wiki/Earth#cite_note-39) The remaining 29% is land mass—consisting of continents and islands—that together has many lakes, rivers, and other sources of water that contribute to the [hydrosphere](https://en.wikipedia.org/wiki/Hydrosphere). The majority of Earth's [polar regions](https://en.wikipedia.org/wiki/Polar_regions_of_Earth) are covered in ice, including the [Antarctic ice sheet](https://en.wikipedia.org/wiki/Antarctic_ice_sheet) and the sea ice of the Arctic ice pack. Earth's interior remains active with a solid iron inner core, a liquid outer core that generates the [Earth's magnetic field](https://en.wikipedia.org/wiki/Earth%27s_magnetic_field), and a convecting [mantle](https://en.wikipedia.org/wiki/Mantle_(geology)) that drives plate tectonics.

Within its first billion years,[[33]](https://en.wikipedia.org/wiki/Earth#cite_note-age_earth1-40) life appeared in Earth's oceans, and began to affect the [atmosphere](https://en.wikipedia.org/wiki/Atmosphere_of_Earth) and surface, leading to the proliferation of [aerobic](https://en.wikipedia.org/wiki/Aerobic_organism) and [anaerobic organisms](https://en.wikipedia.org/wiki/Anaerobic_organism). Since then, the combination of Earth's distance from the Sun, physical properties, and [geological history](https://en.wikipedia.org/wiki/Geological_history_of_Earth) have allowed life to evolve and today thrive. The earliest undisputed life on Earth arose at least 3.5 billion years ago. Earlier physical evidence of life includes [biogenic](https://en.wikipedia.org/wiki/Biogenic) [graphite](https://en.wikipedia.org/wiki/Graphite) in 3.7 billion-year-old [metasedimentary rocks](https://en.wikipedia.org/wiki/Metasediment) discovered in southwestern [Greenland](https://en.wikipedia.org/wiki/Greenland), as well as "remains of [biotic life](https://en.wikipedia.org/wiki/Biotic_material)" found in 4.1 billion-year-old rocks in [Western Australia](https://en.wikipedia.org/wiki/Western_Australia).[[34]](https://en.wikipedia.org/wiki/Earth#cite_note-AP-20151019-41)[[35]](https://en.wikipedia.org/wiki/Earth#cite_note-PNAS-20151014-pdf-42) Except when interrupted by [mass extinction events](https://en.wikipedia.org/wiki/Extinction_event), Earth's [biodiversity](https://en.wikipedia.org/wiki/Biodiversity) has continually expanded.[[36]](https://en.wikipedia.org/wiki/Earth#cite_note-SahneyBentonFerry2010-43) Although scholars estimate that over 99% of all species of life (over five billion)[[37]](https://en.wikipedia.org/wiki/Earth#cite_note-Book-Biology-44) that ever lived on Earth are today [extinct](https://en.wikipedia.org/wiki/Extinction),[[38]](https://en.wikipedia.org/wiki/Earth#cite_note-StearnsStearns2000-45)[[39]](https://en.wikipedia.org/wiki/Earth#cite_note-NYT-20141108-MJN-46) there are an estimated 10–14 million species still in existence,[[40]](https://en.wikipedia.org/wiki/Earth#cite_note-science_241_4872_1441-47)[[41]](https://en.wikipedia.org/wiki/Earth#cite_note-MillerSpoolman2012-48) of which about 1.2 million have been documented and over 86% have not yet been described.[[42]](https://en.wikipedia.org/wiki/Earth#cite_note-PLoS-20110823-49) More recently, in May 2016, scientists reported that 1 trillion species are estimated to be on Earth currently with only one-thousandth of one percent described.[[43]](https://en.wikipedia.org/wiki/Earth#cite_note-NSF-2016002-50) Over 7.3 billion [humans](https://en.wikipedia.org/wiki/Homo_sapiens)[[44]](https://en.wikipedia.org/wiki/Earth#cite_note-PopCounter-51) live on Earth and depend on its [biosphere](https://en.wikipedia.org/wiki/Biosphere) and [minerals](https://en.wikipedia.org/wiki/Mineral) for their survival. Earth's human population is divided among about 200 sovereign[states](https://en.wikipedia.org/wiki/State_(polity)) that interact through diplomacy, conflict, travel, trade, and communication media.

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  + [2.1Formation](https://en.wikipedia.org/wiki/Earth#Formation)
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## Name and etymology

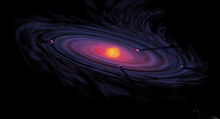
The modern English word *Earth* developed from a wide variety of [Middle English](https://en.wikipedia.org/wiki/Middle_English) forms,[[n 8]](https://en.wikipedia.org/wiki/Earth#cite_note-53) which derived from an [Old English](https://en.wikipedia.org/wiki/Old_English) noun most often spelled [*eorðe*](https://en.wiktionary.org/wiki/eor%C3%B0e).[[45]](https://en.wikipedia.org/wiki/Earth#cite_note-oedearth-52) It has cognates in every [Germanic language](https://en.wikipedia.org/wiki/Germanic_languages), and their [proto-Germanic](https://en.wikipedia.org/wiki/Proto-Germanic) root has been reconstructed as [\**erþō*](https://en.wiktionary.org/wiki/Appendix:Proto-Germanic/er%C3%BE%C5%8D). In its earliest appearances, *eorðe* was already being used to translate the many senses of [Latin](https://en.wikipedia.org/wiki/Latin_language) [*terra*](https://en.wiktionary.org/wiki/terra) and [Greek](https://en.wikipedia.org/wiki/Ancient_Greek_language) [γῆ](https://en.wiktionary.org/wiki/%CE%B3%E1%BF%86) (*gē*): the ground,[[n 9]](https://en.wikipedia.org/wiki/Earth#cite_note-55) its soil,[[n 10]](https://en.wikipedia.org/wiki/Earth#cite_note-57) dry land,[[n 11]](https://en.wikipedia.org/wiki/Earth#cite_note-60) the human world,[[n 12]](https://en.wikipedia.org/wiki/Earth#cite_note-62) the surface of the world (including the sea),[[n 13]](https://en.wikipedia.org/wiki/Earth#cite_note-65) and the globe itself.[[n 14]](https://en.wikipedia.org/wiki/Earth#cite_note-67) As with [Terra](https://en.wikipedia.org/wiki/Terra_(goddess)) and [Gaia](https://en.wikipedia.org/wiki/Gaia_(goddess)), Earth was a [personified goddess](https://en.wikipedia.org/wiki/Earth_goddess) in[Germanic paganism](https://en.wikipedia.org/wiki/Germanic_paganism): the [Angles](https://en.wikipedia.org/wiki/Angles) were listed by [Tacitus](https://en.wikipedia.org/wiki/Tacitus) as among the [devotees](https://en.wikipedia.org/wiki/Anglo-Saxon_paganism) of [Nerthus](https://en.wikipedia.org/wiki/Nerthus),[[54]](https://en.wikipedia.org/wiki/Earth#cite_note-68) and later [Norse mythology](https://en.wikipedia.org/wiki/Norse_mythology) included [Jörð](https://en.wikipedia.org/wiki/J%C3%B6r%C3%B0), a giantess often given as the mother of [Thor](https://en.wikipedia.org/wiki/Thor).[[55]](https://en.wikipedia.org/wiki/Earth#cite_note-SIMEK179-69)

Originally, *earth* was written in lowercase, and from [early Middle English](https://en.wikipedia.org/wiki/Early_Middle_English), its [definite](https://en.wikipedia.org/wiki/Definite) sense as "the globe" was expressed as [*the*](https://en.wikipedia.org/wiki/Definite_article)*earth*. By [early Modern English](https://en.wikipedia.org/wiki/Early_Modern_English), many nouns were capitalized, and *the earth* became (and often remained) *the Earth*, particularly when referenced along with other heavenly bodies. More recently, the name is sometimes simply given as *Earth*, by analogy with the names of the [other planets](https://en.wikipedia.org/wiki/Solar_System).[[45]](https://en.wikipedia.org/wiki/Earth#cite_note-oedearth-52) [House styles](https://en.wikipedia.org/wiki/Style_guide) now vary: [Oxford spelling](https://en.wikipedia.org/wiki/Oxford_spelling) recognizes the lowercase form as the most common, with the capitalized form an acceptable variant. Another convention capitalizes "Earth" when appearing as a name (e.g. "Earth's atmosphere") but writes it in lowercase when preceded by *the* (e.g. "the atmosphere of the earth"). It almost always appears in lowercase in colloquial expressions such as "what on earth are you doing?"[[56]](https://en.wikipedia.org/wiki/Earth#cite_note-oxford-70)

## Chronology

*Main article:*[*History of Earth*](https://en.wikipedia.org/wiki/History_of_Earth)

### Formation

[](https://en.wikipedia.org/wiki/File:Protoplanetary-disk.jpg)

Artist's impression of the early Solar System's planetary disk

The earliest material found in the [Solar System](https://en.wikipedia.org/wiki/Solar_System) is dated to 4.5672±0.0006 [billion years ago](https://en.wikipedia.org/wiki/Billion_years_ago) (Gya).[[57]](https://en.wikipedia.org/wiki/Earth#cite_note-bowring_housch1995-71) By 4.54±0.04 Gya[[33]](https://en.wikipedia.org/wiki/Earth#cite_note-age_earth1-40) the primordial Earth had formed. The [formation and evolution of the Solar System](https://en.wikipedia.org/wiki/Formation_and_evolution_of_the_Solar_System) bodies occurred along with those of the Sun. In theory, a [solar nebula](https://en.wikipedia.org/wiki/Solar_nebula) partitions a volume out of a [molecular cloud](https://en.wikipedia.org/wiki/Molecular_cloud) by gravitational collapse, which begins to spin and flatten into a [circumstellar disk](https://en.wikipedia.org/wiki/Circumstellar_disk), and then the planets grow out of that disk along with the Sun. A nebula contains gas, ice grains, and [dust](https://en.wikipedia.org/wiki/Cosmic_dust) (including [primordial nuclides](https://en.wikipedia.org/wiki/Primordial_nuclide)). In [nebular theory](https://en.wikipedia.org/wiki/Nebular_theory), [planetesimals](https://en.wikipedia.org/wiki/Planetesimal) form by [accretion](https://en.wikipedia.org/wiki/Accretion_(astrophysics)). The assembly of the primordial Earth proceeded for 10–20 Ma.[[58]](https://en.wikipedia.org/wiki/Earth#cite_note-nature418_6901_949-72)

The process that led to the formation of the Moon approximately 4.53 billion years ago[[59]](https://en.wikipedia.org/wiki/Earth#cite_note-science310_5754_1671-73) is the subject of ongoing research. The [working hypothesis](https://en.wikipedia.org/wiki/Working_hypothesis) is that it formed by accretion from material loosed from Earth after a [Mars](https://en.wikipedia.org/wiki/Mars)-sized object, named [Theia](https://en.wikipedia.org/wiki/Theia_(planet)), [impacted](https://en.wikipedia.org/wiki/Giant_impact_hypothesis) Earth.[[60]](https://en.wikipedia.org/wiki/Earth#cite_note-reilly20091022-74) In this scenario, the mass of Theia was approximately 10% of that of Earth,[[61]](https://en.wikipedia.org/wiki/Earth#cite_note-canup_asphaug2001a-75) it impacted Earth with a glancing blow,[[62]](https://en.wikipedia.org/wiki/Earth#cite_note-canup_asphaug2001b-76) and some of its mass merged with Earth. Between approximately 4.1 and 3.8 Gya, numerous [asteroid](https://en.wikipedia.org/wiki/Asteroid) impacts during the [Late Heavy Bombardment](https://en.wikipedia.org/wiki/Late_Heavy_Bombardment) caused significant changes to the greater surface environment of the Moon, and by inference, to that of Earth.

### Geological history

*Main article:*[*Geological history of Earth*](https://en.wikipedia.org/wiki/Geological_history_of_Earth)

Earth's atmosphere and oceans formed by [volcanic](https://en.wikipedia.org/wiki/Volcano) activity and [outgassing](https://en.wikipedia.org/wiki/Outgassing) that included water vapor. The [origin of the world's oceans](https://en.wikipedia.org/wiki/Origin_of_the_world%27s_oceans) was condensation augmented by water and ice delivered by asteroids, [protoplanets](https://en.wikipedia.org/wiki/Protoplanet), and [comets](https://en.wikipedia.org/wiki/Comet).[[63]](https://en.wikipedia.org/wiki/Earth#cite_note-watersource-77) In [this model](https://en.wikipedia.org/wiki/Faint_young_Sun_paradox), atmospheric "greenhouse gases" kept the oceans from freezing when the newly forming Sun had only 70% of its [current luminosity](https://en.wikipedia.org/wiki/Solar_luminosity).[[64]](https://en.wikipedia.org/wiki/Earth#cite_note-asp2002-78) By 3.5 Gya, Earth's magnetic field was established, which helped prevent the atmosphere from being stripped away by the solar wind.[[65]](https://en.wikipedia.org/wiki/Earth#cite_note-physorg20100304-79)

A crust formed when the molten outer layer of Earth cooled [to form](https://en.wikipedia.org/wiki/Phase_transition) a solid as the accumulated water vapor began to act in the atmosphere. The two models[[66]](https://en.wikipedia.org/wiki/Earth#cite_note-williams_santosh2004-80) that explain land mass propose either a steady growth to the present-day forms[[67]](https://en.wikipedia.org/wiki/Earth#cite_note-science164_1229-81) or, more likely, a rapid growth[[68]](https://en.wikipedia.org/wiki/Earth#cite_note-tp322_19-82) early in Earth history[[69]](https://en.wikipedia.org/wiki/Earth#cite_note-rg6_175-83) followed by a long-term steady continental area.[[70]](https://en.wikipedia.org/wiki/Earth#cite_note-science310_5756_1947-84)[[71]](https://en.wikipedia.org/wiki/Earth#cite_note-jaes23_799-85)[[72]](https://en.wikipedia.org/wiki/Earth#cite_note-ajes38_613-86) Continents formed by [plate tectonics](https://en.wikipedia.org/wiki/Plate_tectonics), a process ultimately driven by the continuous loss of heat from Earth's interior. On [time scales](https://en.wikipedia.org/wiki/Geologic_time_scale) lasting hundreds of millions of years, the[supercontinents](https://en.wikipedia.org/wiki/Supercontinent) have formed and broken up three times. Roughly 750 mya (million years ago), one of the earliest known supercontinents, [Rodinia](https://en.wikipedia.org/wiki/Rodinia), began to break apart. The continents later recombined to form [Pannotia](https://en.wikipedia.org/wiki/Pannotia), 600–540 mya, then finally [Pangaea](https://en.wikipedia.org/wiki/Pangaea), which also broke apart 180 mya.[[73]](https://en.wikipedia.org/wiki/Earth#cite_note-as92_324-87)

The present pattern of [ice ages](https://en.wikipedia.org/wiki/Ice_age) began about 40 mya and then intensified during the [Pleistocene](https://en.wikipedia.org/wiki/Pleistocene) about 3 mya. High-[latitude](https://en.wikipedia.org/wiki/Latitude) regions have since undergone repeated cycles of glaciation and thaw, repeating every 40–100000 years. The last continental glaciation ended 10,000 years ago.[[74]](https://en.wikipedia.org/wiki/Earth#cite_note-psc-88)

### Evolution of life

[**Life timeline**](https://en.wikipedia.org/wiki/Timeline_of_life)

[view](https://en.wikipedia.org/wiki/Template:Life_timeline) • [discuss](https://en.wikipedia.org/wiki/Template_talk:Life_timeline) • [edit](https://en.wikipedia.org/w/index.php?title=Template:Life_timeline&action=edit)

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[***water***](https://en.wikipedia.org/wiki/Water)

[**Simple life**](https://en.wikipedia.org/wiki/Unicellular_life)

[***photosynthesis***](https://en.wikipedia.org/wiki/Evolution_of_photosynthesis)

[**Eukaryotes**](https://en.wikipedia.org/wiki/Eukaryote)

[**Multicellular organisms**](https://en.wikipedia.org/wiki/Multicellular_organism)

[**Land life**](https://en.wikipedia.org/wiki/Silurian#Flora_and_fauna)

[**Dinosaurs**](https://en.wikipedia.org/wiki/Dinosaur)

[**Mammals**](https://en.wikipedia.org/wiki/Mammal)

[**Flowers**](https://en.wikipedia.org/wiki/Flowering_plant)

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[Earliest Earth](https://en.wikipedia.org/wiki/Age_of_the_Earth)

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[Earliest water](https://en.wikipedia.org/wiki/Origin_of_water_on_Earth#Water_in_the_development_of_Earth)

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[Earliest life  
(-4100)](https://en.wikipedia.org/wiki/Abiogenesis)

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[Meteorite bombardment](https://en.wikipedia.org/wiki/Late_Heavy_Bombardment)

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[Earliest oxygen](https://en.wikipedia.org/wiki/Geological_history_of_oxygen)

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[Atmospheric oxygen](https://en.wikipedia.org/wiki/Geological_history_of_oxygen)

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[Oxygen Crisis](https://en.wikipedia.org/wiki/Great_Oxygenation_Event)

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[Earliest sexual reproduction](https://en.wikipedia.org/wiki/Evolution_of_sexual_reproduction#Origin_of_sexual_reproduction)

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[Cambrian explosion](https://en.wikipedia.org/wiki/Cambrian_explosion)

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[Earliest humans](https://en.wikipedia.org/wiki/Human)

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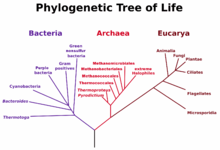
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[Axis scale](https://en.wikipedia.org/wiki/Cartesian_coordinate_system#Two_dimensions): [millions of years](https://en.wikipedia.org/wiki/Geologic_time_scale).  
*also see {*[*{Human timeline}*](https://en.wikipedia.org/wiki/Template:Human_timeline)*} and {*[*{Nature timeline}*](https://en.wikipedia.org/wiki/Template:Nature_timeline)*}*

*Main article:*[*Evolutionary history of life*](https://en.wikipedia.org/wiki/Evolutionary_history_of_life)

Highly energetic [chemical reactions](https://en.wikipedia.org/wiki/Chemical_reaction) are thought to have produced self–replicating molecules around four billion years ago. This was followed a half billion years later by the [last common ancestor of all life](https://en.wikipedia.org/wiki/Last_universal_common_ancestor).[[75]](https://en.wikipedia.org/wiki/Earth#cite_note-sa282_6_90-89) The development of [photosynthesis](https://en.wikipedia.org/wiki/Photosynthesis) allowed the Sun's energy to be harvested directly by life forms; the resultant [molecular oxygen](https://en.wikipedia.org/wiki/Molecular_oxygen) (O2) accumulated in the atmosphere and due to interaction with ultraviolet solar radiation, formed a protective [ozone layer](https://en.wikipedia.org/wiki/Ozone_layer) (O3) in the upper atmosphere.[[76]](https://en.wikipedia.org/wiki/Earth#cite_note-NYT-20131003-90) The incorporation of smaller cells within larger ones resulted in the [development of complex cells](https://en.wikipedia.org/wiki/Endosymbiotic_theory) called [eukaryotes](https://en.wikipedia.org/wiki/Eukaryotes).[[77]](https://en.wikipedia.org/wiki/Earth#cite_note-jas22_3_225-91) True multicellular organisms formed as cells within [colonies](https://en.wikipedia.org/wiki/Colony_(biology)) became increasingly specialized. Aided by the absorption of harmful [ultraviolet radiation](https://en.wikipedia.org/wiki/Ultraviolet_radiation) by the ozone layer, life colonized Earth's surface.[[78]](https://en.wikipedia.org/wiki/Earth#cite_note-burton20021129-92) The earliest [fossil](https://en.wikipedia.org/wiki/Fossil) evidence for[life](https://en.wikipedia.org/wiki/Life) is [microbial mat](https://en.wikipedia.org/wiki/Microbial_mat) fossils found in 3.48 billion-year-old [sandstone](https://en.wikipedia.org/wiki/Sandstone) in [Western Australia](https://en.wikipedia.org/wiki/Western_Australia),[[79]](https://en.wikipedia.org/wiki/Earth#cite_note-Origin1-93)[[80]](https://en.wikipedia.org/wiki/Earth#cite_note-Origin2-94)[[81]](https://en.wikipedia.org/wiki/Earth#cite_note-RavenJohnson2002-95)[[82]](https://en.wikipedia.org/wiki/Earth#cite_note-AP-20131113-96)[[83]](https://en.wikipedia.org/wiki/Earth#cite_note-AST-20131108-97) [biogenic](https://en.wikipedia.org/wiki/Biogenic_substance) [graphite](https://en.wikipedia.org/wiki/Graphite) found in 3.7 billion-year-old [metasedimentary rocks](https://en.wikipedia.org/wiki/Metasediment) in [Western Greenland](https://en.wikipedia.org/wiki/Western_Greenland),[[84]](https://en.wikipedia.org/wiki/Earth#cite_note-NG-20131208-98) as well as, remains of [biotic material](https://en.wikipedia.org/wiki/Biotic_material) found in 4.1 billion-year-old rocks in Western Australia.[[34]](https://en.wikipedia.org/wiki/Earth#cite_note-AP-20151019-41)[[35]](https://en.wikipedia.org/wiki/Earth#cite_note-PNAS-20151014-pdf-42)

[](https://en.wikipedia.org/wiki/File:PhylogeneticTree,_Woese_1990.PNG)

Speculative [phylogenetic tree](https://en.wikipedia.org/wiki/Phylogenetic_tree) of life on Earth based on [rRNA](https://en.wikipedia.org/wiki/RRNA) analysis

Since the 1960s, it has been hypothesized that severe glacial action between 750 and 580 mya, during the [Neoproterozoic](https://en.wikipedia.org/wiki/Neoproterozoic), covered much of Earth in ice. This hypothesis has been termed "[Snowball Earth](https://en.wikipedia.org/wiki/Snowball_Earth)", and it is of particular interest because it preceded the [Cambrian explosion](https://en.wikipedia.org/wiki/Cambrian_explosion), when multicellular life forms began to proliferate.[[85]](https://en.wikipedia.org/wiki/Earth#cite_note-kirschvink1992-99) Following the Cambrian explosion, about 535 mya, there have been five [major mass extinctions](https://en.wikipedia.org/wiki/Extinction_event).[[86]](https://en.wikipedia.org/wiki/Earth#cite_note-sci215_4539_1501-100) The [most recent such event](https://en.wikipedia.org/wiki/Cretaceous%E2%80%93Tertiary_extinction_event) was 66 mya, when [an asteroid impact](https://en.wikipedia.org/wiki/Chicxulub_impactor) triggered the extinction of the non-[avian](https://en.wikipedia.org/wiki/Bird) [dinosaurs](https://en.wikipedia.org/wiki/Dinosaur) and other large reptiles, but spared some small animals such as [mammals](https://en.wikipedia.org/wiki/Mammal), which then resembled [shrews](https://en.wikipedia.org/wiki/Shrew). Over the past 66 [Ma](https://en.wikipedia.org/wiki/Annum), mammalian life has diversified, and several million years ago an African ape-like animal such as [*Orrorin tugenensis*](https://en.wikipedia.org/wiki/Orrorin_tugenensis) gained the ability to stand upright.[[87]](https://en.wikipedia.org/wiki/Earth#cite_note-gould1994-101) This facilitated tool use and encouraged communication that provided the nutrition and stimulation needed for a larger brain, which allowed the [evolution of the human race](https://en.wikipedia.org/wiki/Human_evolution). The [development of agriculture](https://en.wikipedia.org/wiki/History_of_agriculture), and then [civilization](https://en.wikipedia.org/wiki/List_of_ancient_civilizations), led to humans having an influence on Earth and the nature and quantity of other life forms as no other species ever has.[[88]](https://en.wikipedia.org/wiki/Earth#cite_note-bgsa119_1_140-102)

### Predicted future

*Main article:*[*Future of the Earth*](https://en.wikipedia.org/wiki/Future_of_the_Earth)

*See also:*[*Global catastrophic risk*](https://en.wikipedia.org/wiki/Global_catastrophic_risk)

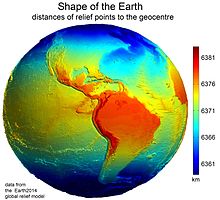
Estimates on how much longer Earth will be able to continue to support life range from 500 million years (Myr), to as long as 2.3 billion years (Ga).[[89]](https://en.wikipedia.org/wiki/Earth#cite_note-britt2000-103)[[90]](https://en.wikipedia.org/wiki/Earth#cite_note-carrington-104)[[91]](https://en.wikipedia.org/wiki/Earth#cite_note-pnas1_24_9576-105) Earth's long-term future is closely tied to that of the Sun. As a result of the steady accumulation of helium at the Sun's core, the [Sun's total luminosity](https://en.wikipedia.org/wiki/Solar_luminosity) will slowly increase. The luminosity of the Sun will grow by 10% over the next 1.1 Ga and by 40% over the next 3.5 Ga.[[92]](https://en.wikipedia.org/wiki/Earth#cite_note-sun_future-106)Climate models indicate that the rise in radiation reaching Earth is likely to have dire consequences, including the loss of the oceans.[[93]](https://en.wikipedia.org/wiki/Earth#cite_note-icarus74_472-107)

Earth's increasing surface temperature will accelerate the [inorganic](https://en.wikipedia.org/wiki/Inorganic) [CO2 cycle](https://en.wikipedia.org/wiki/Carbon_cycle), reducing its concentration to levels lethally low for plants (10 [ppm](https://en.wikipedia.org/wiki/Parts_per_million) for [C4 photosynthesis](https://en.wikipedia.org/wiki/C4_carbon_fixation)) in approximately 500–900 Ma.[[89]](https://en.wikipedia.org/wiki/Earth#cite_note-britt2000-103) The lack of vegetation will result in the loss of oxygen in the atmosphere, so animal life will become extinct within several million more years.[[94]](https://en.wikipedia.org/wiki/Earth#cite_note-ward_brownlee2002-108) After another billion years all surface water will have disappeared[[90]](https://en.wikipedia.org/wiki/Earth#cite_note-carrington-104) and the mean global temperature will reach 70 [°C](https://en.wikipedia.org/wiki/Celsius)[[94]](https://en.wikipedia.org/wiki/Earth#cite_note-ward_brownlee2002-108) (158 [°F](https://en.wikipedia.org/wiki/Fahrenheit)). Earth is expected to be effectively habitable for about another 500 Ma from that point,[[89]](https://en.wikipedia.org/wiki/Earth#cite_note-britt2000-103) although this may be extended up to 2.3 Ga if the nitrogen is removed from the atmosphere.[[91]](https://en.wikipedia.org/wiki/Earth#cite_note-pnas1_24_9576-105) Even if the Sun were eternal and stable, 27% of the water in the modern oceans will descend to the [mantle](https://en.wikipedia.org/wiki/Mantle_(geology)) in one billion years, due to reduced steam venting from mid-ocean ridges.[[95]](https://en.wikipedia.org/wiki/Earth#cite_note-hess5_4_569-109)

The Sun will [evolve](https://en.wikipedia.org/wiki/Stellar_evolution) to become a [red giant](https://en.wikipedia.org/wiki/Red_giant) in about 5 Ga. Models predict that the Sun will expand to roughly 1 AU (150,000,000 km), which is about 250 times its present radius.[[92]](https://en.wikipedia.org/wiki/Earth#cite_note-sun_future-106)[[96]](https://en.wikipedia.org/wiki/Earth#cite_note-sun_future_schroder-110) Earth's fate is less clear. As a red giant, the Sun will lose roughly 30% of its mass, so, without tidal effects, Earth will move to an orbit 1.7 AU (250,000,000 km) from the Sun when it reaches its maximum radius. Earth was, therefore, once expected to escape envelopment by the expanded Sun's outer atmosphere, though most, if not all, remaining life would have been destroyed by the Sun's increased luminosity (peaking at about 5,000 times its present level).[[92]](https://en.wikipedia.org/wiki/Earth#cite_note-sun_future-106) A 2008 simulation indicates that Earth's orbit will decay due to [tidal effects](https://en.wikipedia.org/wiki/Tidal_acceleration) and drag, causing it to enter the red giant Sun's atmosphere and be vaporized.[[96]](https://en.wikipedia.org/wiki/Earth#cite_note-sun_future_schroder-110)

## Physical characteristics

### Shape

[](https://en.wikipedia.org/wiki/File:Earth2014shape_SouthAmerica_small.jpg)

Shape of planet Earth. Shown are distances between surface relief and the geocentre. The South American Andes summits are visible as elevated areas. Data from the [Earth2014](https://en.wikipedia.org/w/index.php?title=Earth2014&action=edit&redlink=1)[[97]](https://en.wikipedia.org/wiki/Earth#cite_note-Earth2014-111)global relief model.

*Main article:*[*Figure of the Earth*](https://en.wikipedia.org/wiki/Figure_of_the_Earth)

The shape of Earth approximates an [oblate spheroid](https://en.wikipedia.org/wiki/Oblate_spheroid), a sphere flattened along the axis from pole to pole such that there is a [bulge](https://en.wikipedia.org/wiki/Equatorial_bulge) around the [equator](https://en.wikipedia.org/wiki/Equator).[[98]](https://en.wikipedia.org/wiki/Earth#cite_note-milbert_smith96-112) This bulge results from the [rotation](https://en.wikipedia.org/wiki/Rotation) of Earth, and causes the diameter at the equator to be 43 kilometres (27 mi) larger than the [pole](https://en.wikipedia.org/wiki/Geographical_pole)-to-pole diameter.[[99]](https://en.wikipedia.org/wiki/Earth#cite_note-ngdc2006-113) Thus the point on the surface farthest from Earth's [center of mass](https://en.wikipedia.org/wiki/Center_of_mass) is the summit of the equatorial [Chimborazo](https://en.wikipedia.org/wiki/Chimborazo_(volcano)) volcano in[Ecuador](https://en.wikipedia.org/wiki/Ecuador).[[100]](https://en.wikipedia.org/wiki/Earth#cite_note-ps20_5_16-114)[[101]](https://en.wikipedia.org/wiki/Earth#cite_note-lancet365_9462_831-115)[[102]](https://en.wikipedia.org/wiki/Earth#cite_note-tall_tales-116)[[103]](https://en.wikipedia.org/wiki/Earth#cite_note-The_.27Highest.27_Spot_on_Earth-117) The average diameter of the reference spheroid is about 12,742 kilometres (7,918 mi), which is approximately (40,000 km)/[π](https://en.wikipedia.org/wiki/Pi), because the [meter](https://en.wikipedia.org/wiki/Meter#Meridional_definition) was originally defined as 1/10,000,000 of the distance from the equator to the [North Pole](https://en.wikipedia.org/wiki/North_Pole) through Paris, France.[[104]](https://en.wikipedia.org/wiki/Earth#cite_note-nist_length2000-118)

Local [topography](https://en.wikipedia.org/wiki/Topography) deviates from this idealized spheroid, although on a global scale these deviations are small compared to Earth's radius: The maximum deviation of only 0.17% is at the [Mariana Trench](https://en.wikipedia.org/wiki/Mariana_Trench) (10,911 metres (35,797 ft) below local sea level), whereas [Mount Everest](https://en.wikipedia.org/wiki/Mount_Everest) (8,848 metres (29,029 ft) above local sea level) represents a deviation of 0.14%. If Earth were shrunk to the size of a [billiard ball](https://en.wikipedia.org/wiki/Billiard_ball), some areas of Earth such as large mountain ranges and oceanic trenches would feel like tiny imperfections, whereas much of the planet, including the [Great Plains](https://en.wikipedia.org/wiki/Great_Plains) and the [abyssal plains](https://en.wikipedia.org/wiki/Abyssal_plain), would feel smoother.[[105]](https://en.wikipedia.org/wiki/Earth#cite_note-119)

### Chemical composition

*See also:*[*Abundance of elements on Earth*](https://en.wikipedia.org/wiki/Abundance_of_elements_on_Earth)

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| --- | --- | --- | --- |
| **Chemical composition of the crust**[[106]](https://en.wikipedia.org/wiki/Earth#cite_note-brown_mussett1981-120) | | | |
| **Compound** | **Formula** | **Composition** | |
| **Continental** | **Oceanic** |
| [silica](https://en.wikipedia.org/wiki/Silica) | SiO2 | 60.2% | 48.6% |
| [alumina](https://en.wikipedia.org/wiki/Aluminum_oxide) | Al2O3 | 15.2% | 16.5% |
| [lime](https://en.wikipedia.org/wiki/Calcium_oxide) | CaO | 5.5% | 12.3% |
| [magnesia](https://en.wikipedia.org/wiki/Magnesium_oxide) | MgO | 3.1% | 6.8% |
| [iron(II) oxide](https://en.wikipedia.org/wiki/Iron(II)_oxide) | FeO | 3.8% | 6.2% |
| [sodium oxide](https://en.wikipedia.org/wiki/Sodium_oxide) | Na2O | 3.0% | 2.6% |
| [potassium oxide](https://en.wikipedia.org/wiki/Potassium_oxide) | K2O | 2.8% | 0.4% |
| [iron(III) oxide](https://en.wikipedia.org/wiki/Iron(III)_oxide) | Fe2O3 | 2.5% | 2.3% |
| [water](https://en.wikipedia.org/wiki/Water_(molecule)) | H2O | 1.4% | 1.1% |
| [carbon dioxide](https://en.wikipedia.org/wiki/Carbon_dioxide) | CO2 | 1.2% | 1.4% |
| [titanium dioxide](https://en.wikipedia.org/wiki/Titanium_dioxide) | TiO2 | 0.7% | 1.4% |
| [phosphorus pentoxide](https://en.wikipedia.org/wiki/Phosphorus_pentoxide) | P2O5 | 0.2% | 0.3% |
| **Total** | | **99.6%** | **99.9%** |

[Earth's mass](https://en.wikipedia.org/wiki/Earth_mass) is approximately 5.97×1024 [kg](https://en.wikipedia.org/wiki/Kilogram) (5,970 [Yg](https://en.wikipedia.org/wiki/Yottagram)). It is composed mostly of [iron](https://en.wikipedia.org/wiki/Iron) (32.1%), [oxygen](https://en.wikipedia.org/wiki/Oxygen) (30.1%), [silicon](https://en.wikipedia.org/wiki/Silicon) (15.1%), [magnesium](https://en.wikipedia.org/wiki/Magnesium) (13.9%), [sulfur](https://en.wikipedia.org/wiki/Sulfur) (2.9%), [nickel](https://en.wikipedia.org/wiki/Nickel) (1.8%), [calcium](https://en.wikipedia.org/wiki/Calcium) (1.5%), and [aluminium](https://en.wikipedia.org/wiki/Aluminium) (1.4%), with the remaining 1.2% consisting of trace amounts of other elements. Due to [mass segregation](https://en.wikipedia.org/wiki/Mass_segregation), the core region is estimated to be primarily composed of iron (88.8%), with smaller amounts of nickel (5.8%), sulfur (4.5%), and less than 1% trace elements.[[107]](https://en.wikipedia.org/wiki/Earth#cite_note-pnas71_12_6973-121)

The geochemist [F. W. Clarke](https://en.wikipedia.org/wiki/Frank_Wigglesworth_Clarke) calculated that a little more than 47% of Earth's [crust](https://en.wikipedia.org/wiki/Crust_(geology)) consists of oxygen. The more common rock constituents of the crust are nearly all oxides: chlorine, sulfur and fluorine are the important exceptions to this and their total amount in any rock is usually much less than 1%. The principal oxides are silica, alumina, iron oxides, lime, magnesia, potash and soda. The silica functions principally as an acid, forming silicates, and all the most common minerals of [igneous rocks](https://en.wikipedia.org/wiki/Igneous_rocks) are of this nature. From a computation based on 1,672 analyses of all kinds of rocks, Clarke deduced that 99.22% was composed of 11 oxides (see the table at right), with the other constituents occurring in minute quantities.[[108]](https://en.wikipedia.org/wiki/Earth#cite_note-122)

### Internal structure

*Main article:*[*Structure of the Earth*](https://en.wikipedia.org/wiki/Structure_of_the_Earth)

Earth's interior, like that of the other terrestrial planets, is divided into layers by their [chemical](https://en.wikipedia.org/wiki/Chemical) or physical ([rheological](https://en.wikipedia.org/wiki/Rheology)) properties, but unlike the other terrestrial planets, it has a distinct outer and inner core. The outer layer is a chemically distinct [silicate](https://en.wikipedia.org/wiki/Silicate_minerals) solid crust, which is underlain by a highly [viscous](https://en.wikipedia.org/wiki/Viscous) solid mantle. The crust is separated from the mantle by the [Mohorovičić discontinuity](https://en.wikipedia.org/wiki/Mohorovi%C4%8Di%C4%87_discontinuity), and the thickness of the crust varies: averaging 6 [km](https://en.wikipedia.org/wiki/Kilometre) (kilometers) under the oceans and 30–50 km on the continents. The crust and the cold, rigid, top of the [upper mantle](https://en.wikipedia.org/wiki/Upper_mantle) are collectively known as the lithosphere, and it is of the lithosphere that the tectonic plates are composed. Beneath the lithosphere is the [asthenosphere](https://en.wikipedia.org/wiki/Asthenosphere), a relatively low-viscosity layer on which the lithosphere rides. Important changes in crystal structure within the mantle occur at 410 and 660 km below the surface, spanning a [transition zone](https://en.wikipedia.org/wiki/Transition_zone_(Earth)) that separates the upper and lower mantle. Beneath the mantle, an extremely low viscosity liquid [outer core](https://en.wikipedia.org/wiki/Outer_core) lies above a solid [inner core](https://en.wikipedia.org/wiki/Inner_core).[[109]](https://en.wikipedia.org/wiki/Earth#cite_note-tanimoto_ahrens1995-123) The inner core may rotate at a slightly higher [angular velocity](https://en.wikipedia.org/wiki/Angular_velocity) than the remainder of the planet, advancing by 0.1–0.5° per year.[[110]](https://en.wikipedia.org/wiki/Earth#cite_note-science309_5739_1313-124) The radius of the inner core is about one fifth of that of Earth.

|  |  |  |  |
| --- | --- | --- | --- |
| **Geologic layers of Earth**[[111]](https://en.wikipedia.org/wiki/Earth#cite_note-pnas76_9_4192-125) | | | |
| **[Earth-cutaway-schematic-english.svg](https://en.wikipedia.org/wiki/File:Earth-cutaway-schematic-english.svg)**  **Earth cutaway from core to exosphere. Not to scale.** | **Depth**[[112]](https://en.wikipedia.org/wiki/Earth#cite_note-robertson2001-126) **km** | **Component Layer** | **Density g/cm3** |
| 0–60 | Lithosphere[[n 15]](https://en.wikipedia.org/wiki/Earth#cite_note-127) | — |
| 0–35 | Crust[[n 16]](https://en.wikipedia.org/wiki/Earth#cite_note-128) | 2.2–2.9 |
| 35–60 | Upper mantle | 3.4–4.4 |
| 35–2890 | Mantle | 3.4–5.6 |
| 100–700 | Asthenosphere | — |
| 2890–5100 | Outer core | 9.9–12.2 |
| 5100–6378 | Inner core | 12.8–13.1 |

### Heat

*Main article:*[*Earth's internal heat budget*](https://en.wikipedia.org/wiki/Earth%27s_internal_heat_budget)

Earth's [internal heat](https://en.wikipedia.org/wiki/Internal_heat) comes from a combination of residual heat from [planetary accretion](https://en.wikipedia.org/wiki/Planetary_accretion) (about 20%) and heat produced through [radioactive decay](https://en.wikipedia.org/wiki/Radioactive_decay) (80%).[[113]](https://en.wikipedia.org/wiki/Earth#cite_note-turcotte-129) The major heat-producing [isotopes](https://en.wikipedia.org/wiki/Isotope) within Earth are [potassium-40](https://en.wikipedia.org/wiki/Potassium), [uranium-238](https://en.wikipedia.org/wiki/Uranium), [uranium-235](https://en.wikipedia.org/wiki/Uranium-235), and[thorium-232](https://en.wikipedia.org/wiki/Thorium).[[114]](https://en.wikipedia.org/wiki/Earth#cite_note-sanders20031210-130) At the center, the temperature may be up to 6,000 °C (10,830 °F),[[115]](https://en.wikipedia.org/wiki/Earth#cite_note-131) and the pressure could reach 360 [GPa](https://en.wikipedia.org/wiki/GPa).[[116]](https://en.wikipedia.org/wiki/Earth#cite_note-ptrsl360_1795_1227-132) Because much of the heat is provided by radioactive decay, scientists postulate that early in Earth's history, before isotopes with short half-lives had been depleted, Earth's heat production would have been much higher. This extra heat production, twice present-day at approximately 3 [Ga](https://en.wikipedia.org/wiki/Year#SI_prefix_multipliers),[[113]](https://en.wikipedia.org/wiki/Earth#cite_note-turcotte-129) would have increased temperature gradients with radius, increasing the rates of [mantle convection](https://en.wikipedia.org/wiki/Mantle_convection) and plate tectonics, and allowing the production of uncommon igneous rocks such as [komatiites](https://en.wikipedia.org/wiki/Komatiites) that are rarely formed today.[[117]](https://en.wikipedia.org/wiki/Earth#cite_note-epsl121_1-133)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Present-day major heat-producing isotopes**[[118]](https://en.wikipedia.org/wiki/Earth#cite_note-T.26S_137-134) | | | | |
| **Isotope** | **Heat release W/kg isotope** | **Half-life years** | **Mean mantle concentration kg isotope/kg mantle** | **Heat release W/kg mantle** |
| 238U | 94.6 × 10−6 | 4.47 × 109 | 30.8 × 10−9 | 2.91 × 10−12 |
| 235U | 569 × 10−6 | 0.704 × 109 | 0.22 × 10−9 | 0.125 × 10−12 |
| 232Th | 26.4 × 10−6 | 14.0 × 109 | 124 × 10−9 | 3.27 × 10−12 |
| 40K | 29.2 × 10−6 | 1.25 × 109 | 36.9 × 10−9 | 1.08 × 10−12 |

The mean heat loss from Earth is 87 mW m−2, for a global heat loss of 4.42 × 1013 W.[[119]](https://en.wikipedia.org/wiki/Earth#cite_note-jg31_3_267-135) A portion of the core's thermal energy is transported toward the crust by [mantle plumes](https://en.wikipedia.org/wiki/Mantle_plume); a form of convection consisting of upwellings of higher-temperature rock. These plumes can produce [hotspots](https://en.wikipedia.org/wiki/Hotspot_(geology)) and [flood basalts](https://en.wikipedia.org/wiki/Flood_basalt).[[120]](https://en.wikipedia.org/wiki/Earth#cite_note-science246_4926_103-136) More of the heat in Earth is lost through plate tectonics, by mantle upwelling associated with [mid-ocean ridges](https://en.wikipedia.org/wiki/Mid-ocean_ridge). The final major mode of heat loss is through conduction through the lithosphere, the majority of which occurs under the oceans because the crust there is much thinner than that of the continents.[[121]](https://en.wikipedia.org/wiki/Earth#cite_note-heat_loss-137)

### Tectonic plates

|  |  |
| --- | --- |
| [**Earth's major plates**](https://en.wikipedia.org/wiki/List_of_tectonic_plates)[[122]](https://en.wikipedia.org/wiki/Earth#cite_note-brown_wohletz2005-138) | |
| [Shows the extent and boundaries of tectonic plates, with superimposed outlines of the continents they support](https://en.wikipedia.org/wiki/File:Tectonic_plates_(empty).svg) | |
| **Plate name** | **Area 106 km2** |
| [Pacific Plate](https://en.wikipedia.org/wiki/Pacific_Plate) | 103.3 |
| [African Plate](https://en.wikipedia.org/wiki/African_Plate)[[n 17]](https://en.wikipedia.org/wiki/Earth#cite_note-jaes41_3_379-139) | 78.0 |
| [North American Plate](https://en.wikipedia.org/wiki/North_American_Plate) | 75.9 |
| [Eurasian Plate](https://en.wikipedia.org/wiki/Eurasian_Plate) | 67.8 |
| [Antarctic Plate](https://en.wikipedia.org/wiki/Antarctic_Plate) | 60.9 |
| [Indo-Australian Plate](https://en.wikipedia.org/wiki/Indo-Australian_Plate) | 47.2 |
| [South American Plate](https://en.wikipedia.org/wiki/South_American_Plate) | 43.6 |

*Main article:*[*Plate tectonics*](https://en.wikipedia.org/wiki/Plate_tectonics)

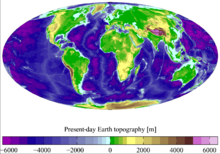
The mechanically rigid outer layer of Earth, the lithosphere, is broken into pieces called tectonic plates. These plates are rigid segments that move in relation to one another at one of three types of plate boundaries: [convergent boundaries](https://en.wikipedia.org/wiki/Convergent_boundary), at which two plates come together, [divergent boundaries](https://en.wikipedia.org/wiki/Divergent_boundary), at which two plates are pulled apart, and [transform boundaries](https://en.wikipedia.org/wiki/Transform_boundary), in which two plates slide past one another laterally. [Earthquakes](https://en.wikipedia.org/wiki/Earthquake), [volcanic activity](https://en.wikipedia.org/wiki/Volcanism), [mountain-building](https://en.wikipedia.org/wiki/Orogeny), and [oceanic trench](https://en.wikipedia.org/wiki/Oceanic_trench) formation can occur along these plate boundaries.[[123]](https://en.wikipedia.org/wiki/Earth#cite_note-kious_tilling1999-140) The tectonic plates ride on top of the asthenosphere, the solid but less-viscous part of the upper mantle that can flow and move along with the plates.[[124]](https://en.wikipedia.org/wiki/Earth#cite_note-seligman2008-141)

As the tectonic plates migrate, the ocean floor is [subducted](https://en.wikipedia.org/wiki/Subduction) under the leading edges of the plates at convergent boundaries. At the same time, the upwelling of mantle material at divergent boundaries creates mid-ocean ridges. The combination of these processes continually recycles the [oceanic crust](https://en.wikipedia.org/wiki/Oceanic_crust) back into the mantle. Due to this recycling, most of the ocean floor is less than 100 Ma old in age. The oldest oceanic crust is located in the Western Pacific, and has an estimated age of about 200 Ma.[[125]](https://en.wikipedia.org/wiki/Earth#cite_note-duennebier1999-142)[[126]](https://en.wikipedia.org/wiki/Earth#cite_note-noaa20070307-143) By comparison, the oldest dated [continental crust](https://en.wikipedia.org/wiki/Continental_crust) is 4030 Ma.[[127]](https://en.wikipedia.org/wiki/Earth#cite_note-cmp134_3-144)

The seven major plates are the [Pacific](https://en.wikipedia.org/wiki/Pacific_Plate), [North American](https://en.wikipedia.org/wiki/North_American_Plate), [Eurasian](https://en.wikipedia.org/wiki/Eurasian_Plate), [African](https://en.wikipedia.org/wiki/African_Plate), [Antarctic](https://en.wikipedia.org/wiki/Antarctic_Plate), [Indo-Australian](https://en.wikipedia.org/wiki/Indo-Australian_Plate), and [South American](https://en.wikipedia.org/wiki/South_American_Plate). Other notable plates include the [Arabian Plate](https://en.wikipedia.org/wiki/Arabian_Plate), the [Caribbean Plate](https://en.wikipedia.org/wiki/Caribbean_Plate), the [Nazca Plate](https://en.wikipedia.org/wiki/Nazca_Plate) off the west coast of South America and the [Scotia Plate](https://en.wikipedia.org/wiki/Scotia_Plate) in the southern Atlantic Ocean. The Australian Plate fused with the Indian Plate between 50 and 55 mya. The fastest-moving plates are the oceanic plates, with the [Cocos Plate](https://en.wikipedia.org/wiki/Cocos_Plate) advancing at a rate of 75 mm/year[[128]](https://en.wikipedia.org/wiki/Earth#cite_note-podp2000-145) and the Pacific Plate moving 52–69 mm/year. At the other extreme, the slowest-moving plate is the Eurasian Plate, progressing at a typical rate of about 21 mm/year.[[129]](https://en.wikipedia.org/wiki/Earth#cite_note-gps_time_series-146)

### Surface

*Main articles:*[*Lithosphere*](https://en.wikipedia.org/wiki/Lithosphere)*,*[*Landform*](https://en.wikipedia.org/wiki/Landform)*, and*[*Extreme points of Earth*](https://en.wikipedia.org/wiki/Extreme_points_of_Earth)

[](https://en.wikipedia.org/wiki/File:AYool_topography_15min.png)

Present-day Earth [altimetry](https://en.wikipedia.org/wiki/Terrain) and[bathymetry](https://en.wikipedia.org/wiki/Bathymetry). Data from the [National Geophysical Data Center](https://en.wikipedia.org/wiki/National_Geophysical_Data_Center).

Earth has a total [surface area](https://en.wikipedia.org/wiki/Spheroid#surface_area) of about 501 million [km2](https://en.wikipedia.org/wiki/Square_kilometre) (197 million sq mi).[[13]](https://en.wikipedia.org/wiki/Earth#cite_note-Pidwirny_2006_8-16) About 70.8%[[13]](https://en.wikipedia.org/wiki/Earth#cite_note-Pidwirny_2006_8-16) of the surface is covered by water, with much of the [continental shelf](https://en.wikipedia.org/wiki/Continental_shelf) below sea level. This equates to 361.13 million [km2](https://en.wikipedia.org/wiki/Square_kilometre) (139.43 million sq mi).[[13]](https://en.wikipedia.org/wiki/Earth#cite_note-Pidwirny_2006_8-16)[[130]](https://en.wikipedia.org/wiki/Earth#cite_note-147) The submerged surface has mountainous features, including a globe-spanning mid-ocean ridge system, as well as undersea volcanoes,[[99]](https://en.wikipedia.org/wiki/Earth#cite_note-ngdc2006-113) oceanic trenches, [submarine canyons](https://en.wikipedia.org/wiki/Submarine_canyon), [oceanic plateaus](https://en.wikipedia.org/wiki/Oceanic_plateau) and abyssal plains. The remaining 29.2% (148.94 million km2, or 57.51 million sq mi) not covered by water has[terrain](https://en.wikipedia.org/wiki/Terrain) that varies greatly from place to place and consists of mountains, deserts, plains, plateaus, and other [landforms](https://en.wikipedia.org/wiki/Landform).

Earth's surface undergoes reshaping over [geological time](https://en.wikipedia.org/wiki/Geological_time) periods due to [tectonics and erosion](https://en.wikipedia.org/wiki/Erosion_and_tectonics). The surface features built up or deformed through plate tectonics are subject to steady[weathering](https://en.wikipedia.org/wiki/Weathering) and [erosion](https://en.wikipedia.org/wiki/Erosion) from [precipitation](https://en.wikipedia.org/wiki/Precipitation_(meteorology)), thermal cycles, and chemical effects. [Glaciation](https://en.wikipedia.org/wiki/Glaciation), [coastal erosion](https://en.wikipedia.org/wiki/Coastal_erosion), the build-up of [coral reefs](https://en.wikipedia.org/wiki/Coral_reef), and large meteorite impacts[[131]](https://en.wikipedia.org/wiki/Earth#cite_note-kring-148) also act to reshape the landscape.

The continental crust consists of lower density material such as the igneous rocks [granite](https://en.wikipedia.org/wiki/Granite) and [andesite](https://en.wikipedia.org/wiki/Andesite). Less common is [basalt](https://en.wikipedia.org/wiki/Basalt), a denser volcanic rock that is the primary constituent of the ocean floors.[[132]](https://en.wikipedia.org/wiki/Earth#cite_note-layers_earth-149) [Sedimentary rock](https://en.wikipedia.org/wiki/Sedimentary_rock) is formed from the accumulation of sediment that becomes buried and [compacted together](https://en.wikipedia.org/wiki/Diagenesis). Nearly 75% of the continental surfaces are covered by sedimentary rocks, although they form about 5% of the crust.[[133]](https://en.wikipedia.org/wiki/Earth#cite_note-jessey-150) The third form of rock material found on Earth is [metamorphic rock](https://en.wikipedia.org/wiki/Metamorphic_rock), which is created from the transformation of pre-existing rock types through high pressures, high temperatures, or both. The most abundant [silicate minerals](https://en.wikipedia.org/wiki/Silicate_mineral) on Earth's surface include [quartz](https://en.wikipedia.org/wiki/Quartz), [feldspars](https://en.wikipedia.org/wiki/Feldspar), [amphibole](https://en.wikipedia.org/wiki/Amphibole), [mica](https://en.wikipedia.org/wiki/Mica), [pyroxene](https://en.wikipedia.org/wiki/Pyroxene) and [olivine](https://en.wikipedia.org/wiki/Olivine).[[134]](https://en.wikipedia.org/wiki/Earth#cite_note-de_pater_lissauer2010-151) Common [carbonate minerals](https://en.wikipedia.org/wiki/Carbonate_mineral) include [calcite](https://en.wikipedia.org/wiki/Calcite) (found in [limestone](https://en.wikipedia.org/wiki/Limestone)) and [dolomite](https://en.wikipedia.org/wiki/Dolomite).[[135]](https://en.wikipedia.org/wiki/Earth#cite_note-wekn_bulakh2004-152)

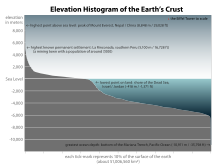
The [pedosphere](https://en.wikipedia.org/wiki/Pedosphere) is the outermost layer of Earth's continental surface and is composed of [soil](https://en.wikipedia.org/wiki/Soil) and subject to [soil formation processes](https://en.wikipedia.org/wiki/Pedogenesis). The total arable land is 10.9% of the land surface, with 1.3% being permanent cropland.[[136]](https://en.wikipedia.org/wiki/Earth#cite_note-153)[[137]](https://en.wikipedia.org/wiki/Earth#cite_note-154) Close to 40% of Earth's land surface is used for cropland and pasture, or an estimated 1.3×107 km2 of cropland and 3.4×107 km2 of pastureland.[[138]](https://en.wikipedia.org/wiki/Earth#cite_note-fao1994-155)

The elevation of the land surface varies from the low point of −418 m at the [Dead Sea](https://en.wikipedia.org/wiki/Dead_Sea), to a 2005-estimated maximum altitude of 8,848 m at the top of Mount Everest. The mean height of land above sea level is 840 m.[[139]](https://en.wikipedia.org/wiki/Earth#cite_note-sverdrup-156)

Besides being described in terms of [Northern](https://en.wikipedia.org/wiki/Northern_Hemisphere) and [Southern](https://en.wikipedia.org/wiki/Southern_Hemisphere) hemispheres centered on the poles, Earth is also often described in terms of [Eastern](https://en.wikipedia.org/wiki/Eastern_Hemisphere) and [Western](https://en.wikipedia.org/wiki/Western_Hemisphere) hemispheres. Earth's surface is traditionally divided into seven continents and various seas.

### Hydrosphere

*Main article:*[*Hydrosphere*](https://en.wikipedia.org/wiki/Hydrosphere)

[](https://en.wikipedia.org/wiki/File:Earth_elevation_histogram_2.svg)

Elevation histogram of Earth's surface

The abundance of water on Earth's surface is a unique feature that distinguishes the "Blue Planet" from other planets in the Solar System. Earth's hydrosphere consists chiefly of the oceans, but technically includes all water surfaces in the world, including inland seas, lakes, rivers, and underground waters down to a depth of 2,000 m. The deepest underwater location is [Challenger Deep](https://en.wikipedia.org/wiki/Challenger_Deep) of the Mariana Trench in the Pacific Ocean with a depth of 10,911.4 m.[[n 18]](https://en.wikipedia.org/wiki/Earth#cite_note-trench_depth-157)[[140]](https://en.wikipedia.org/wiki/Earth#cite_note-kaiko7000-158)

The mass of the oceans is approximately 1.35×1018 [metric tons](https://en.wikipedia.org/wiki/Metric_ton), or about 1/4400 of Earth's total mass. The oceans cover an area of 3.618×108 km2 with a mean depth of 3682 m, resulting in an estimated volume of1.332×109 km3.[[141]](https://en.wikipedia.org/wiki/Earth#cite_note-ocean23_2_112-159) If all of Earth's crustal surface was at the same elevation as a smooth sphere, the depth of the resulting world ocean would be 2.7 to 2.8 km.[[142]](https://en.wikipedia.org/wiki/Earth#cite_note-160)[[143]](https://en.wikipedia.org/wiki/Earth#cite_note-161)

About 97.5% of the water is saline; the remaining 2.5% is fresh water. Most fresh water, about 68.7%, is present as ice in [ice caps](https://en.wikipedia.org/wiki/Ice_cap) and [glaciers](https://en.wikipedia.org/wiki/Glacier).[[144]](https://en.wikipedia.org/wiki/Earth#cite_note-162)

The average [salinity](https://en.wikipedia.org/wiki/Salinity) of Earth's oceans is about 35 grams of salt per kilogram of sea water (3.5% salt).[[145]](https://en.wikipedia.org/wiki/Earth#cite_note-kennish2001-163) Most of this salt was released from volcanic activity or extracted from cool igneous rocks.[[146]](https://en.wikipedia.org/wiki/Earth#cite_note-mullen2002-164) The oceans are also a reservoir of dissolved atmospheric gases, which are essential for the survival of many aquatic life forms.[[147]](https://en.wikipedia.org/wiki/Earth#cite_note-natsci_oxy4-165) Sea water has an important influence on the world's climate, with the oceans acting as a large [heat reservoir](https://en.wikipedia.org/wiki/Heat_reservoir).[[148]](https://en.wikipedia.org/wiki/Earth#cite_note-michon2006-166)Shifts in the oceanic temperature distribution can cause significant weather shifts, such as the [El Niño-Southern Oscillation](https://en.wikipedia.org/wiki/El_Ni%C3%B1o-Southern_Oscillation).[[149]](https://en.wikipedia.org/wiki/Earth#cite_note-sample2005-167)

### Atmosphere

*Main article:*[*Atmosphere of Earth*](https://en.wikipedia.org/wiki/Atmosphere_of_Earth)

[](https://en.wikipedia.org/wiki/File:ISS-40_Typhoon_Halong.jpg)

A typhoon as seen from low Earth orbit

The [atmospheric pressure](https://en.wikipedia.org/wiki/Atmospheric_pressure) on Earth's surface averages 101.325 [kPa](https://en.wikipedia.org/wiki/KPa), with a [scale height](https://en.wikipedia.org/wiki/Scale_height) of about 8.5 km.[[3]](https://en.wikipedia.org/wiki/Earth#cite_note-earth_fact_sheet-5) It has a composition of 78% [nitrogen](https://en.wikipedia.org/wiki/Nitrogen) and 21% oxygen, with trace amounts of [water vapor](https://en.wikipedia.org/wiki/Water_vapor), [carbon dioxide](https://en.wikipedia.org/wiki/Carbon_dioxide) and other gaseous molecules. The height of the [troposphere](https://en.wikipedia.org/wiki/Troposphere) varies with latitude, ranging between 8 km at the poles to 17 km at the equator, with some variation resulting from weather and seasonal factors.[[150]](https://en.wikipedia.org/wiki/Earth#cite_note-geerts_linacre97-168)

Earth's [biosphere](https://en.wikipedia.org/wiki/Biosphere) has significantly altered its [atmosphere](https://en.wikipedia.org/wiki/Atmosphere_of_Earth). [Oxygenic photosynthesis](https://en.wikipedia.org/wiki/Oxygen_evolution#Oxygen_evolution_in_nature) evolved 2.7 Gya, [forming](https://en.wikipedia.org/wiki/Oxygen_catastrophe) the primarily nitrogen–oxygen atmosphere of today.[[76]](https://en.wikipedia.org/wiki/Earth#cite_note-NYT-20131003-90) This change enabled the proliferation of [aerobic organisms](https://en.wikipedia.org/wiki/Aerobic_organisms)and, indirectly, the formation of the [ozone layer](https://en.wikipedia.org/wiki/Ozone_layer) due to the subsequent [conversion of atmospheric O2 into O3](https://en.wikipedia.org/wiki/Ozone%E2%80%93oxygen_cycle). The ozone layer blocks [ultraviolet](https://en.wikipedia.org/wiki/Ultraviolet) [solar radiation](https://en.wikipedia.org/wiki/Solar_radiation), permitting life on land.[[151]](https://en.wikipedia.org/wiki/Earth#cite_note-Harrison_2002-169) Other atmospheric functions important to life include transporting water vapor, providing useful gases, causing small [meteors](https://en.wikipedia.org/wiki/Meteor) to burn up before they strike the surface, and moderating temperature.[[152]](https://en.wikipedia.org/wiki/Earth#cite_note-atmosphere-170) This last phenomenon is known as the [greenhouse effect](https://en.wikipedia.org/wiki/Greenhouse_effect): trace molecules within the atmosphere serve to capture [thermal energy](https://en.wikipedia.org/wiki/Thermal_energy) emitted from the ground, thereby raising the average temperature. Water vapor, carbon dioxide, [methane](https://en.wikipedia.org/wiki/Methane) and [ozone](https://en.wikipedia.org/wiki/Ozone) are the primary [greenhouse gases](https://en.wikipedia.org/wiki/Greenhouse_gas) in the atmosphere. Without this heat-retention effect, the average surface temperature would be −18 °C, in contrast to the current +15 °C, and life would likely not exist.[[153]](https://en.wikipedia.org/wiki/Earth#cite_note-Pidwirny2006_7-171)

#### Weather and climate

*Main articles:*[*Weather*](https://en.wikipedia.org/wiki/Weather)*and*[*Climate*](https://en.wikipedia.org/wiki/Climate)

[](https://en.wikipedia.org/wiki/File:MODIS_Map.jpg)

Satellite image of Earth [cloud cover](https://en.wikipedia.org/wiki/Cloud_cover)using [NASA](https://en.wikipedia.org/wiki/NASA)'s [Moderate-Resolution Imaging Spectroradiometer](https://en.wikipedia.org/wiki/Moderate-Resolution_Imaging_Spectroradiometer)

Earth's atmosphere has no definite boundary, slowly becoming thinner and fading into outer space. Three-quarters of the atmosphere's mass is contained within the first 11 km of the surface. This lowest layer is called the troposphere. Energy from the Sun heats this layer, and the surface below, causing expansion of the air. This lower-density air then rises, and is replaced by cooler, higher-density air. The result is [atmospheric circulation](https://en.wikipedia.org/wiki/Atmospheric_circulation) that drives the weather and climate through redistribution of thermal energy.[[154]](https://en.wikipedia.org/wiki/Earth#cite_note-moran2005-172)

The primary atmospheric circulation bands consist of the [trade winds](https://en.wikipedia.org/wiki/Trade_winds) in the equatorial region below 30° latitude and the [westerlies](https://en.wikipedia.org/wiki/Westerlies) in the mid-latitudes between 30° and 60°.[[155]](https://en.wikipedia.org/wiki/Earth#cite_note-berger2002-173) [Ocean currents](https://en.wikipedia.org/wiki/Ocean_current) are also important factors in determining climate, particularly the [thermohaline circulation](https://en.wikipedia.org/wiki/Thermohaline_circulation) that distributes thermal energy from the equatorial oceans to the polar regions.[[156]](https://en.wikipedia.org/wiki/Earth#cite_note-rahmstorf2003-174)

Water vapor generated through surface evaporation is transported by circulatory patterns in the atmosphere. When atmospheric conditions permit an uplift of warm, humid air, this water condenses and falls to the surface as precipitation.[[154]](https://en.wikipedia.org/wiki/Earth#cite_note-moran2005-172) Most of the water is then transported to lower elevations by river systems and usually returned to the oceans or deposited into lakes. This [water cycle](https://en.wikipedia.org/wiki/Water_cycle) is a vital mechanism for supporting life on land, and is a primary factor in the erosion of surface features over geological periods. Precipitation patterns vary widely, ranging from several meters of water per year to less than a millimeter. Atmospheric circulation, topographic features and temperature differences determine the average precipitation that falls in each region.[[157]](https://en.wikipedia.org/wiki/Earth#cite_note-hydrologic_cycle-175)

The amount of solar energy reaching Earth's surface decreases with increasing latitude. At higher latitudes the sunlight reaches the surface at lower angles and it must pass through thicker columns of the atmosphere. As a result, the mean annual air temperature at sea level decreases by about 0.4 °C (0.7 °F) per degree of latitude from the equator.[[158]](https://en.wikipedia.org/wiki/Earth#cite_note-sadava_heller2006-176) Earth's surface can be subdivided into specific latitudinal belts of approximately homogeneous climate. Ranging from the equator to the polar regions, these are the [tropical](https://en.wikipedia.org/wiki/Tropics) (or equatorial), [subtropical](https://en.wikipedia.org/wiki/Subtropics), [temperate](https://en.wikipedia.org/wiki/Temperate) and [polar](https://en.wikipedia.org/wiki/Polar_region) climates.[[159]](https://en.wikipedia.org/wiki/Earth#cite_note-climate_zones-177) Climate can also be classified based on the temperature and precipitation, with the climate regions characterized by fairly uniform air masses. The commonly used [Köppen climate classification](https://en.wikipedia.org/wiki/K%C3%B6ppen_climate_classification) system (as modified by [Wladimir Köppen](https://en.wikipedia.org/wiki/Wladimir_K%C3%B6ppen)'s student Rudolph Geiger) has five broad groups ([humid tropics](https://en.wikipedia.org/wiki/Tropical_climate), [arid](https://en.wikipedia.org/wiki/Desert), [humid middle latitudes](https://en.wikipedia.org/wiki/Humid_subtropical_climate), [continental](https://en.wikipedia.org/wiki/Continental_climate) and cold [polar](https://en.wikipedia.org/wiki/Polar_climate)), which are further divided into more specific subtypes.[[155]](https://en.wikipedia.org/wiki/Earth#cite_note-berger2002-173)

Climate on Earth has latitudinal anomalies, namely the habitability of the Scandinavian peninsula very far north in sharp contrast to the polar climates of northern Canada as well as the cool summers expected at low latitudes in the Southern Hemisphere (for example on the west coast of South America). Another anomaly is the impact of landmass on temperature, manifested by the fact that Earth is much warmer at [aphelion](https://en.wikipedia.org/wiki/Aphelion), where the planet is at a more distant position from the Sun.[[160]](https://en.wikipedia.org/wiki/Earth#cite_note-Earth_at_Aphelion-178) When the Northern hemisphere is turned towards the sunlight even the increased distance to it does not hinder temperatures to be 2.3 °C (4 °F) warmer than at [perihelion](https://en.wikipedia.org/wiki/Perihelion)—when the marine southern hemisphere is turned towards the Sun.[[160]](https://en.wikipedia.org/wiki/Earth#cite_note-Earth_at_Aphelion-178)

At high latitudes, the western sides of continents tend to be milder than the eastern sides—for example seen in North America and Western Europe where rough continental climates appear on the east coast on parallels with mild climates on the other side of the ocean.[[161]](https://en.wikipedia.org/wiki/Earth#cite_note-179)

The highest air temperature ever measured on Earth was 56.7 °C (134.1 °F) in [Furnace Creek, California](https://en.wikipedia.org/wiki/Furnace_Creek,_California), in [Death Valley](https://en.wikipedia.org/wiki/Death_Valley_National_Park), in 1913.[[162]](https://en.wikipedia.org/wiki/Earth#cite_note-180) The lowest air temperature ever directly measured on Earth was −89.2 °C (−128.6 °F) at [Vostok Station](https://en.wikipedia.org/wiki/Vostok_Station) in 1983,[[163]](https://en.wikipedia.org/wiki/Earth#cite_note-181) but satellites have used remote sensing to measure temperatures as low as −94.7 °C (−138.5 °F) in [East Antarctica](https://en.wikipedia.org/wiki/East_Antarctica).[[164]](https://en.wikipedia.org/wiki/Earth#cite_note-182) These temperature records are only measurements made with modern instruments from the 20th century onwards and likely do not reflect the full range of temperature on Earth.

#### Upper atmosphere

[](https://en.wikipedia.org/wiki/File:Full_moon_partially_obscured_by_atmosphere.jpg)

This view from orbit shows the full Moon partially obscured by Earth's atmosphere. [*NASA*](https://en.wikipedia.org/wiki/NASA)*image*

Above the troposphere, the atmosphere is usually divided into the [stratosphere](https://en.wikipedia.org/wiki/Stratosphere), [mesosphere](https://en.wikipedia.org/wiki/Mesosphere), and [thermosphere](https://en.wikipedia.org/wiki/Thermosphere).[[152]](https://en.wikipedia.org/wiki/Earth#cite_note-atmosphere-170) Each layer has a different [lapse rate](https://en.wikipedia.org/wiki/Lapse_rate), defining the rate of change in temperature with height. Beyond these, the [exosphere](https://en.wikipedia.org/wiki/Exosphere) thins out into the [magnetosphere](https://en.wikipedia.org/wiki/Magnetosphere), where the geomagnetic fields interact with the [solar wind](https://en.wikipedia.org/wiki/Solar_wind).[[165]](https://en.wikipedia.org/wiki/Earth#cite_note-sciweek2004-183) Within the stratosphere is the ozone layer, a component that partially shields the surface from ultraviolet light and thus is important for life on Earth. The [Kármán line](https://en.wikipedia.org/wiki/K%C3%A1rm%C3%A1n_line), defined as 100 km above Earth's surface, is a working definition for the boundary between the atmosphere and [outer space](https://en.wikipedia.org/wiki/Outer_space).[[166]](https://en.wikipedia.org/wiki/Earth#cite_note-cordoba2004-184)

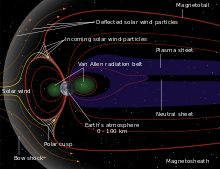
Thermal energy causes some of the molecules at the outer edge of the atmosphere to increase their velocity to the point where they can escape from Earth's gravity. This causes a slow but steady [leakage of the atmosphere into space](https://en.wikipedia.org/wiki/Atmospheric_escape). Because unfixed [hydrogen](https://en.wikipedia.org/wiki/Hydrogen) has a low [molecular mass](https://en.wikipedia.org/wiki/Molecular_mass), it can achieve [escape velocity](https://en.wikipedia.org/wiki/Escape_velocity) more readily and it leaks into outer space at a greater rate than other gases.[[167]](https://en.wikipedia.org/wiki/Earth#cite_note-jas31_4_1118-185) The leakage of hydrogen into space contributes to the shifting of Earth's atmosphere and surface from an initially [reducing](https://en.wikipedia.org/wiki/Redox) state to its current [oxidizing](https://en.wikipedia.org/wiki/Redox) one. Photosynthesis provided a source of free oxygen, but the loss of reducing agents such as hydrogen is thought to have been a necessary precondition for the widespread accumulation of oxygen in the atmosphere.[[168]](https://en.wikipedia.org/wiki/Earth#cite_note-sci293_5531_839-186) Hence the ability of hydrogen to escape from the atmosphere may have influenced the nature of life that developed on Earth.[[169]](https://en.wikipedia.org/wiki/Earth#cite_note-abedon1997-187) In the current, oxygen-rich atmosphere most hydrogen is converted into water before it has an opportunity to escape. Instead, most of the hydrogen loss comes from the destruction of methane in the upper atmosphere.[[170]](https://en.wikipedia.org/wiki/Earth#cite_note-arwps4_265-188)

### Magnetic field

*Main article:*[*Earth's magnetic field*](https://en.wikipedia.org/wiki/Earth%27s_magnetic_field)

The main part of [Earth's magnetic field](https://en.wikipedia.org/wiki/Earth%27s_magnetic_field) is generated in the core, the site of a [dynamo](https://en.wikipedia.org/wiki/Dynamo) process that converts kinetic energy of fluid convective motion into electrical and magnetic field energy. The field extends outwards from the core, through the mantle, and up to Earth's surface, where it is, to rough approximation, a [dipole](https://en.wikipedia.org/wiki/Dipole). The poles of the dipole are located close to Earth's geographic poles. At the equator of the magnetic field, the magnetic-field strength at the surface is 3.05 × 10−5 [T](https://en.wikipedia.org/wiki/Tesla_(unit)), with global [magnetic dipole moment](https://en.wikipedia.org/wiki/Magnetic_dipole_moment) of7.91 × 1015 T m3.[[171]](https://en.wikipedia.org/wiki/Earth#cite_note-lang2003-189) The convection movements in the core are chaotic; the magnetic poles drift and periodically change alignment. This causes [field reversals](https://en.wikipedia.org/wiki/Geomagnetic_reversal) at irregular intervals averaging a few times every million years. The most recent reversal occurred approximately 700,000 years ago.[[172]](https://en.wikipedia.org/wiki/Earth#cite_note-fitzpatrick2006-190)[[173]](https://en.wikipedia.org/wiki/Earth#cite_note-campbelwh-191)

### Magnetosphere

[](https://en.wikipedia.org/wiki/File:Structure_of_the_magnetosphere-en.svg)

Schematic of Earth's magnetosphere. The solar wind flows from left to right

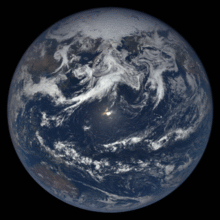
The extent of Earth's magnetic field in space defines the magnetosphere. Ions and electrons of the solar wind are deflected by the magnetosphere; solar wind pressure compresses the dayside of the magnetosphere, to about 10 Earth radii, and extends the nightside magnetosphere into a long tail. Because the velocity of the solar wind is greater than the speed at which wave propagate through the solar wind, a supersonic bowshock precedes the dayside magnetosphere within the solar wind. [Charged particles](https://en.wikipedia.org/wiki/Charged_particles) are contained within the magnetosphere; the plasmasphere is defined by low-energy particles that essentially follow magnetic field lines as Earth rotates; the ring current is defined by medium-energy particles that drift relative to the geomagnetic field, but with paths that are still dominated by the magnetic field, and the [Van Allen radiation belt](https://en.wikipedia.org/wiki/Van_Allen_radiation_belt) are formed by high-energy particles whose motion is essentially random, but otherwise contained by the magnetosphere.

During a magnetic storm, charged particles can be deflected from the outer magnetosphere, directed along field lines into Earth's ionosphere, where atmospheric atoms can be excited and ionized, causing the [aurora](https://en.wikipedia.org/wiki/Aurora_(astronomy)).[[174]](https://en.wikipedia.org/wiki/Earth#cite_note-stern2005-192)

## Orbit and rotation

### Rotation

*Main article:*[*Earth's rotation*](https://en.wikipedia.org/wiki/Earth%27s_rotation)

[](https://en.wikipedia.org/wiki/File:EpicEarth-Globespin(2016May29).gif)

Earth rotation imaged by [DSCOVR EPIC](https://en.wikipedia.org/wiki/Deep_Space_Climate_Observatory) on May 29, 2016, a few weeks before the solstice

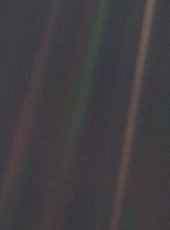
Earth's rotation period relative to the Sun—its mean solar day—is 86,400 seconds of mean solar time (86,400.0025 [SI](https://en.wikipedia.org/wiki/SI) seconds).[[175]](https://en.wikipedia.org/wiki/Earth#cite_note-aj136_5_1906-193) Because Earth's solar day is now slightly longer than it was during the 19th century due to[tidal deceleration](https://en.wikipedia.org/wiki/Tidal_acceleration), each day varies between 0 and 2 SI [ms](https://en.wikipedia.org/wiki/Milliseconds) longer.[[176]](https://en.wikipedia.org/wiki/Earth#cite_note-USNO_TSD-194)[[177]](https://en.wikipedia.org/wiki/Earth#cite_note-195)

Earth's rotation period relative to the [fixed stars](https://en.wikipedia.org/wiki/Fixed_star), called its *stellar day* by the [International Earth Rotation and Reference Systems Service](https://en.wikipedia.org/wiki/International_Earth_Rotation_and_Reference_Systems_Service) (IERS), is 86,164.098903691 seconds of mean solar time (UT1), or23h 56m 4.098903691s.[[2]](https://en.wikipedia.org/wiki/Earth#cite_note-IERS-4)[[n 19]](https://en.wikipedia.org/wiki/Earth#cite_note-Aoki-196) Earth's rotation period relative to the [precessing](https://en.wikipedia.org/wiki/Precession_(astronomy)) or moving mean [vernal equinox](https://en.wikipedia.org/wiki/Vernal_equinox), misnamed its [*sidereal day*](https://en.wikipedia.org/wiki/Sidereal_day), is 86,164.09053083288 seconds of mean solar time (UT1) (23h 56m 4.09053083288s)as of 1982.[[2]](https://en.wikipedia.org/wiki/Earth#cite_note-IERS-4) Thus the sidereal day is shorter than the stellar day by about 8.4 ms.[[178]](https://en.wikipedia.org/wiki/Earth#cite_note-seidelmann1992-197) The length of the mean solar day in SI seconds is available from the IERS for the periods 1623–2005[[179]](https://en.wikipedia.org/wiki/Earth#cite_note-iers1623-198) and 1962–2005.[[180]](https://en.wikipedia.org/wiki/Earth#cite_note-iers1962-199)

Apart from meteors within the atmosphere and low-orbiting satellites, the main apparent motion of celestial bodies in Earth's sky is to the west at a rate of 15°/h = 15'/min. For bodies near the [celestial equator](https://en.wikipedia.org/wiki/Celestial_equator), this is equivalent to an apparent diameter of the Sun or the Moon every two minutes; from Earth's surface, the apparent sizes of the Sun and the Moon are approximately the same.[[181]](https://en.wikipedia.org/wiki/Earth#cite_note-zeilik1998-200)[[182]](https://en.wikipedia.org/wiki/Earth#cite_note-angular-201)

### Orbit

*Main article:*[*Earth's orbit*](https://en.wikipedia.org/wiki/Earth%27s_orbit)

[](https://en.wikipedia.org/wiki/File:Pale_Blue_Dot.png)

The historic [Pale Blue Dot](https://en.wikipedia.org/wiki/Pale_Blue_Dot)photo taken in 1990 by the[*Voyager 1*](https://en.wikipedia.org/wiki/Voyager_1) spacecraft showing Earth (center right) from nearly 6.4 billion kilometers (4×109 mi) away

Earth orbits the Sun at an average distance of about 150 million kilometres (93,000,000 mi) every 365.2564 mean solar days, or one [sidereal year](https://en.wikipedia.org/wiki/Sidereal_year). This gives an apparent movement of the Sun eastward with respect to the stars at a rate of about 1°/day, which is one apparent Sun or Moon diameter every 12 hours. Due to this motion, on average it takes 24 hours—a [solar day](https://en.wikipedia.org/wiki/Solar_time)—for Earth to complete a full rotation about its axis so that the Sun returns to the [meridian](https://en.wikipedia.org/wiki/Meridian_(astronomy)). The orbital speed of Earth averages about 29.8 km/s (107,000 km/h), which is fast enough to travel a distance equal to Earth's diameter, about 12,742 km (7,918 mi), in seven minutes, and the distance to the Moon, 384,000 km (239,000 mi), in about 3.5 hours.[[3]](https://en.wikipedia.org/wiki/Earth#cite_note-earth_fact_sheet-5)

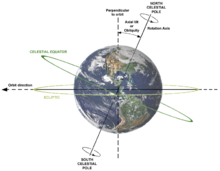
The Moon and Earth orbit a common [barycenter](https://en.wikipedia.org/wiki/Barycenter) every 27.32 days relative to the background stars. When combined with the Earth–Moon system's common orbit around the Sun, the period of the [synodic month](https://en.wikipedia.org/wiki/Synodic_month), from new moon to new moon, is 29.53 days. Viewed from the [celestial north pole](https://en.wikipedia.org/wiki/Celestial_pole), the motion of Earth, the Moon, and their axial rotations are all [counterclockwise](https://en.wikipedia.org/wiki/Counterclockwise). Viewed from a vantage point above the north poles of both the Sun and Earth, Earth orbits in a counterclockwise direction about the Sun. The orbital and axial planes are not precisely aligned: Earth's [axis is tilted](https://en.wikipedia.org/wiki/Axial_tilt) some 23.4 degrees from the perpendicular to the Earth–Sun plane (the [ecliptic](https://en.wikipedia.org/wiki/Ecliptic)), and the Earth–Moon plane is tilted up to ±5.1 degrees against the Earth–Sun plane. Without this tilt, there would be an eclipse every two weeks, alternating between [lunar eclipses](https://en.wikipedia.org/wiki/Lunar_eclipse) and [solar eclipses](https://en.wikipedia.org/wiki/Solar_eclipse).[[3]](https://en.wikipedia.org/wiki/Earth#cite_note-earth_fact_sheet-5)[[183]](https://en.wikipedia.org/wiki/Earth#cite_note-moon_fact_sheet-202)

The [Hill sphere](https://en.wikipedia.org/wiki/Hill_sphere), or [gravitational](https://en.wikipedia.org/wiki/Gravity) sphere of influence, of Earth is about 1.5 million kilometres (930,000 mi) in radius.[[184]](https://en.wikipedia.org/wiki/Earth#cite_note-vazquez_etal2006-203)[[n 20]](https://en.wikipedia.org/wiki/Earth#cite_note-hill_radius-204) This is the maximum distance at which the Earth's gravitational influence is stronger than the more distant Sun and planets. Objects must orbit Earth within this radius, or they can become unbound by the gravitational perturbation of the Sun.

Earth, along with the Solar System, is situated in the [Milky Way](https://en.wikipedia.org/wiki/Milky_Way) and orbits about 28,000 [light-years](https://en.wikipedia.org/wiki/Light-year) from its center. It is about 20 light-years above the [galactic plane](https://en.wikipedia.org/wiki/Galactic_plane) in the [Orion Arm](https://en.wikipedia.org/wiki/Orion_Arm).[[185]](https://en.wikipedia.org/wiki/Earth#cite_note-nasa20051201-205)

### Axial tilt and seasons

*Main article:*[*Axial tilt § Earth*](https://en.wikipedia.org/wiki/Axial_tilt#Earth)

[](https://en.wikipedia.org/wiki/File:AxialTiltObliquity.png)

Earth's axial tilt (or [obliquity](https://en.wikipedia.org/wiki/Obliquity)) and its relation to the [rotation axis](https://en.wikipedia.org/wiki/Rotation) and [plane of orbit](https://en.wikipedia.org/wiki/Orbital_plane_(astronomy))

The axial tilt of the Earth is approximately 23.439281°.[[2]](https://en.wikipedia.org/wiki/Earth#cite_note-IERS-4) Due to Earth's axial tilt, the amount of sunlight reaching any given point on the surface varies over the course of the year. This causes seasonal change in climate, with [summer](https://en.wikipedia.org/wiki/Summer) in the [northern hemisphere](https://en.wikipedia.org/wiki/Northern_hemisphere) occurring when the North Pole is pointing toward the Sun, and [winter](https://en.wikipedia.org/wiki/Winter) taking place when the pole is pointed away. During the summer, the day lasts longer and the Sun climbs higher in the sky. In winter, the climate becomes generally cooler and the days shorter. In northern temperate latitudes, the Sun rises north of true east during the summer solstice, and sets north of true west, reversing in the winter. The Sun rises south of true east in the summer for the southern temperate zone, and sets south of true west.

Above the [Arctic Circle](https://en.wikipedia.org/wiki/Arctic_Circle), an extreme case is reached where there is no daylight at all for part of the year, up to six months at the North Pole itself, a [polar night](https://en.wikipedia.org/wiki/Polar_night). In the [southern hemisphere](https://en.wikipedia.org/wiki/Southern_hemisphere) the situation is exactly reversed, with the [South Pole](https://en.wikipedia.org/wiki/South_Pole) oriented opposite the direction of the North Pole. Six months later, this pole will experience a [midnight sun](https://en.wikipedia.org/wiki/Midnight_sun), a day of 24 hours, again reversing with the South Pole.

By astronomical convention, the four seasons can be determined by the [solstices](https://en.wikipedia.org/wiki/Solstice) — the points in the orbit of maximum axial tilt toward or away from the Sun — and the [equinoxes](https://en.wikipedia.org/wiki/Equinox), when the direction of the tilt and the direction to the Sun are perpendicular. In the northern hemisphere, [winter solstice](https://en.wikipedia.org/wiki/Winter_solstice) currently occurs around 21 December, [summer solstice](https://en.wikipedia.org/wiki/Summer_solstice) is near 21 June, [spring equinox](https://en.wikipedia.org/wiki/Spring_equinox) is around 20 March and [autumnal equinox](https://en.wikipedia.org/wiki/Autumnal_equinox) is about 22 or 23 September. In the southern hemisphere, the situation is reversed, with the summer and winter solstices exchanged and the spring and autumnal equinox dates swapped.[[186]](https://en.wikipedia.org/wiki/Earth#cite_note-bromberg2008-206)

The angle of Earth's axial tilt is relatively stable over long periods of time. Its axial tilt does undergo [nutation](https://en.wikipedia.org/wiki/Nutation); a slight, irregular motion with a main period of 18.6 years.[[187]](https://en.wikipedia.org/wiki/Earth#cite_note-lin2006-207) The orientation (rather than the angle) of Earth's axis also changes over time, [precessing](https://en.wikipedia.org/wiki/Precession) around in a complete circle over each 25,800 year cycle; this precession is the reason for the difference between a sidereal year and a [tropical year](https://en.wikipedia.org/wiki/Tropical_year). Both of these motions are caused by the varying attraction of the Sun and the Moon on Earth's equatorial bulge. The poles also migrate a few meters across Earth's surface. This [polar motion](https://en.wikipedia.org/wiki/Polar_motion) has multiple, cyclical components, which collectively are termed [quasiperiodic motion](https://en.wikipedia.org/wiki/Quasiperiodic_motion). In addition to an annual component to this motion, there is a 14-month cycle called the [Chandler wobble](https://en.wikipedia.org/wiki/Chandler_wobble). Earth's rotational velocity also varies in a phenomenon known as length-of-day variation.[[188]](https://en.wikipedia.org/wiki/Earth#cite_note-fisher19960205-208)

In modern times, Earth's [perihelion](https://en.wikipedia.org/wiki/Perihelion) occurs around 3 January, and its [aphelion](https://en.wikipedia.org/wiki/Aphelion) around 4 July. These dates change over time due to precession and other orbital factors, which follow cyclical patterns known as [Milankovitch cycles](https://en.wikipedia.org/wiki/Milankovitch_cycles). The changing Earth–Sun distance causes an increase of about 6.9%[[n 21]](https://en.wikipedia.org/wiki/Earth#cite_note-solar_energy-209) in solar energy reaching Earth at perihelion relative to aphelion. Because the southern hemisphere is tilted toward the Sun at about the same time that Earth reaches the closest approach to the Sun, the southern hemisphere receives slightly more energy from the Sun than does the northern over the course of a year. This effect is much less significant than the total energy change due to the axial tilt, and most of the excess energy is absorbed by the higher proportion of water in the southern hemisphere.[[189]](https://en.wikipedia.org/wiki/Earth#cite_note-williams20051230-210)

## Habitability

A planet that can sustain life is termed [habitable](https://en.wikipedia.org/wiki/Planetary_habitability), even if life did not originate there. Earth provides liquid water—an environment where complex [organic molecules](https://en.wikipedia.org/wiki/Organic_compound) can assemble and interact, and sufficient energy to sustain [metabolism](https://en.wikipedia.org/wiki/Metabolism).[[190]](https://en.wikipedia.org/wiki/Earth#cite_note-ab2003-211) The distance of Earth from the Sun, as well as its orbital eccentricity, rate of rotation, axial tilt, geological history, sustaining atmosphere and protective magnetic field all contribute to the current climatic conditions at the surface.[[191]](https://en.wikipedia.org/wiki/Earth#cite_note-dole1970-212)

### Biosphere

*Main article:*[*Biosphere*](https://en.wikipedia.org/wiki/Biosphere)

A planet's life forms inhabit ecosystems, whose total is sometimes said to form a "biosphere". Earth's biosphere is thought to have begun [evolving](https://en.wikipedia.org/wiki/Evolution) about 3.5 Gya.[[76]](https://en.wikipedia.org/wiki/Earth#cite_note-NYT-20131003-90) The biosphere is divided into a number of [biomes](https://en.wikipedia.org/wiki/Biome), inhabited by broadly similar plants and animals. On land, biomes are separated primarily by differences in latitude, [height above sea level](https://en.wikipedia.org/wiki/Elevation) and [humidity](https://en.wikipedia.org/wiki/Humidity). Terrestrial [biomes](https://en.wikipedia.org/wiki/Tundra) lying within the Arctic or [Antarctic Circles](https://en.wikipedia.org/wiki/Antarctic_Circle), at [high altitudes](https://en.wikipedia.org/wiki/Alpine_tundra) or in [extremely arid areas](https://en.wikipedia.org/wiki/Desert) are relatively barren of plant and animal life; [species diversity](https://en.wikipedia.org/wiki/Latitudinal_gradients_in_species_diversity) reaches a peak in [humid lowlands at equatorial latitudes](https://en.wikipedia.org/wiki/Tropical_rainforest).[[192]](https://en.wikipedia.org/wiki/Earth#cite_note-amnat163_2_192-213)

### Natural resources and land use

*Main articles:*[*Natural resource*](https://en.wikipedia.org/wiki/Natural_resource)*and*[*Land use*](https://en.wikipedia.org/wiki/Land_use)

|  |  |
| --- | --- |
| **Estimated human land use, 2000**[[193]](https://en.wikipedia.org/wiki/Earth#cite_note-Lambin2011-214) | |
| **Land use** | **Mha** |
| Cropland | 1,510–1,611 |
| Pastures | 2,500–3,410 |
| Natural forests | 3,143–3,871 |
| Planted forests | 126–215 |
| Urban areas | 66–351 |
| Unused, productive land | 356–445 |

Earth has resources that have been exploited by humans. Those termed [non-renewable resources](https://en.wikipedia.org/wiki/Non-renewable_resources), such as [fossil fuels](https://en.wikipedia.org/wiki/Fossil_fuel), only renew over geological timescales.

Large deposits of fossil fuels are obtained from Earth's crust, consisting of [coal](https://en.wikipedia.org/wiki/Coal), [petroleum](https://en.wikipedia.org/wiki/Petroleum), and [natural gas](https://en.wikipedia.org/wiki/Natural_gas). These deposits are used by humans both for energy production and as feedstock for chemical production. Mineral [ore](https://en.wikipedia.org/wiki/Ore) bodies have also been formed within the crust through a process of [ore genesis](https://en.wikipedia.org/wiki/Ore_genesis), resulting from actions of [magmatism](https://en.wikipedia.org/wiki/Magma), erosion and plate tectonics.[[194]](https://en.wikipedia.org/wiki/Earth#cite_note-Ramdohr-215) These bodies form concentrated sources for many metals and other useful [elements](https://en.wikipedia.org/wiki/Chemical_element).

Earth's biosphere produces many useful biological products for humans, including food, [wood](https://en.wikipedia.org/wiki/Wood), [pharmaceuticals](https://en.wikipedia.org/wiki/Pharmaceutical), oxygen, and the recycling of many organic wastes. The land-based [ecosystem](https://en.wikipedia.org/wiki/Ecosystem) depends upon [topsoil](https://en.wikipedia.org/wiki/Topsoil) and fresh water, and the oceanic ecosystem depends upon dissolved nutrients washed down from the land.[[195]](https://en.wikipedia.org/wiki/Earth#cite_note-science299_5607_673-216) In 1980, 5,053 [Mha](https://en.wikipedia.org/wiki/Hectare) (50.53 million km2) of Earth's land surface consisted of forest and woodlands, 6,788 Mha (67.88 million km2) was grasslands and pasture, and 1,501 Mha (15.01 million km2) was cultivated as croplands.[[196]](https://en.wikipedia.org/wiki/Earth#cite_note-Turner1990-217) The estimated amount of [irrigated land](https://en.wikipedia.org/wiki/Irrigated_land) in 1993 was 2,481,250 square kilometres (958,020 sq mi).[[14]](https://en.wikipedia.org/wiki/Earth#cite_note-cia-17)Humans also live on the land by using [building materials](https://en.wikipedia.org/wiki/Building_material) to construct shelters.

### Natural and environmental hazards

[](https://en.wikipedia.org/wiki/File:Pavlof2014iss.jpg)

A volcano injecting hot ash into the atmosphere

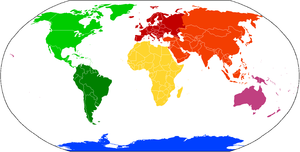
Large areas of Earth's surface are subject to extreme weather such as tropical [cyclones](https://en.wikipedia.org/wiki/Cyclone), [hurricanes](https://en.wikipedia.org/wiki/Hurricane), or [typhoons](https://en.wikipedia.org/wiki/Typhoon) that dominate life in those areas. From 1980 to 2000, these events caused an average of 11,800 human deaths per year.[[197]](https://en.wikipedia.org/wiki/Earth#cite_note-walsh2008-218) Many places are subject to earthquakes, [landslides](https://en.wikipedia.org/wiki/Landslide), [tsunamis](https://en.wikipedia.org/wiki/Tsunami), [volcanic eruptions](https://en.wikipedia.org/wiki/Volcano), [tornadoes](https://en.wikipedia.org/wiki/Tornado), [sinkholes](https://en.wikipedia.org/wiki/Sinkhole), [blizzards](https://en.wikipedia.org/wiki/Blizzard), floods, droughts, [wildfires](https://en.wikipedia.org/wiki/Wildfire), and other calamities and disasters.

Many localized areas are subject to human-made [pollution](https://en.wikipedia.org/wiki/Pollution) of the air and water, [acid rain](https://en.wikipedia.org/wiki/Acid_rain) and toxic substances, loss of vegetation ([overgrazing](https://en.wikipedia.org/wiki/Overgrazing), [deforestation](https://en.wikipedia.org/wiki/Deforestation), [desertification](https://en.wikipedia.org/wiki/Desertification)), loss of wildlife, species [extinction](https://en.wikipedia.org/wiki/Extinction), [soil degradation](https://en.wikipedia.org/wiki/Soils_retrogression_and_degradation),[soil depletion](https://en.wikipedia.org/wiki/Soil_depletion) and [erosion](https://en.wikipedia.org/wiki/Erosion).

According to the United Nations, a scientific consensus exists linking human activities to [global warming](https://en.wikipedia.org/wiki/Global_warming) due to industrial carbon dioxide emissions. This is predicted to produce changes such as the melting of glaciers and ice sheets, more extreme temperature ranges, significant changes in weather and a [global rise in average sea levels](https://en.wikipedia.org/wiki/Sea_level_rise).[[198]](https://en.wikipedia.org/wiki/Earth#cite_note-un20070202-219)

### Human geography

*Main articles:*[*Human geography*](https://en.wikipedia.org/wiki/Human_geography)*and*[*World*](https://en.wikipedia.org/wiki/World)

[](https://en.wikipedia.org/wiki/File:Continents_vide_couleurs.png)

**The seven**[**continents**](https://en.wikipedia.org/wiki/Continent)**of Earth**[[199]](https://en.wikipedia.org/wiki/Earth#cite_note-NatlGeo-220)

|  |  |  |
| --- | --- | --- |
| * [North America](https://en.wikipedia.org/wiki/North_America) * [South America](https://en.wikipedia.org/wiki/South_America) * [Antarctica](https://en.wikipedia.org/wiki/Antarctica) | * [Europe](https://en.wikipedia.org/wiki/Europe) * [Africa](https://en.wikipedia.org/wiki/Africa) | * [Asia](https://en.wikipedia.org/wiki/Asia) * [Oceania](https://en.wikipedia.org/wiki/Oceania) * [v](https://en.wikipedia.org/wiki/Template:World_map_indicating_continents) * [t](https://en.wikipedia.org/wiki/Template_talk:World_map_indicating_continents) * [e](https://en.wikipedia.org/w/index.php?title=Template:World_map_indicating_continents&action=edit) |

[Cartography](https://en.wikipedia.org/wiki/Cartography), the study and practice of map-making, and [geography](https://en.wikipedia.org/wiki/Geography), the study of the lands, features, inhabitants and phenomena on Earth, have historically been the disciplines devoted to depicting Earth.[Surveying](https://en.wikipedia.org/wiki/Surveying), the determination of locations and distances, and to a lesser extent [navigation](https://en.wikipedia.org/wiki/Navigation), the determination of position and direction, have developed alongside cartography and geography, providing and suitably quantifying the requisite information.

Earth's human population reached approximately seven billion on 31 October 2011.[[200]](https://en.wikipedia.org/wiki/Earth#cite_note-221) Projections indicate that the [world's human population](https://en.wikipedia.org/wiki/World_population) will reach 9.2 billion in 2050.[[201]](https://en.wikipedia.org/wiki/Earth#cite_note-un2006-222) Most of the growth is expected to take place in [developing nations](https://en.wikipedia.org/wiki/Developing_nations). [Human population density](https://en.wikipedia.org/wiki/Population_density#Human_population_density) varies widely around the world, but a majority live in Asia. By 2020, 60% of the world's population is expected to be living in urban, rather than rural, areas.[[202]](https://en.wikipedia.org/wiki/Earth#cite_note-prb2007-223)

It is estimated that one-eighth of Earth's surface is suitable for humans to live on – three-quarters of Earth's surface is covered by oceans, leaving one quarter as land. Half of that land area is desert (14%),[[203]](https://en.wikipedia.org/wiki/Earth#cite_note-hessd4_439-224) high mountains (27%),[[204]](https://en.wikipedia.org/wiki/Earth#cite_note-biodiv-225) or other unsuitable terrain. The northernmost permanent settlement in the world is [Alert](https://en.wikipedia.org/wiki/Alert,_Nunavut), on [Ellesmere Island](https://en.wikipedia.org/wiki/Ellesmere_Island) in [Nunavut](https://en.wikipedia.org/wiki/Nunavut), Canada.[[205]](https://en.wikipedia.org/wiki/Earth#cite_note-cfsa2006-226) (82°28′N) The southernmost is the [Amundsen–Scott South Pole Station](https://en.wikipedia.org/wiki/Amundsen%E2%80%93Scott_South_Pole_Station), in Antarctica, almost exactly at the South Pole. (90°S)

Independent sovereign nations claim the planet's entire land surface, except for some parts of Antarctica, a few [land parcels along the Danube](https://en.wikipedia.org/wiki/Croatia%E2%80%93Serbia_border_dispute) river's western bank, and the odd [unclaimed area](https://en.wikipedia.org/wiki/Terra_nullius) of [Bir Tawil](https://en.wikipedia.org/wiki/Bir_Tawil)between Egypt and Sudan. As of 2015, there are 193 [sovereign states](https://en.wikipedia.org/wiki/List_of_sovereign_states) that are [member states of the United Nations](https://en.wikipedia.org/wiki/Member_states_of_the_United_Nations), plus two [observer states](https://en.wikipedia.org/wiki/United_Nations_General_Assembly_observers) and 72 [dependent territories](https://en.wikipedia.org/wiki/Dependent_territory) and [states with limited recognition](https://en.wikipedia.org/wiki/List_of_states_with_limited_recognition).[[14]](https://en.wikipedia.org/wiki/Earth#cite_note-cia-17)Historically, Earth has never had a [sovereign](https://en.wikipedia.org/wiki/Sovereignty) government with authority over the entire globe although a number of nation-states have striven for [world domination](https://en.wikipedia.org/wiki/Hyperpower) and failed.[[206]](https://en.wikipedia.org/wiki/Earth#cite_note-kennedy1989-227)

The [United Nations](https://en.wikipedia.org/wiki/United_Nations) is a worldwide [intergovernmental organization](https://en.wikipedia.org/wiki/International_organization) that was created with the goal of intervening in the disputes between nations, thereby avoiding armed conflict.[[207]](https://en.wikipedia.org/wiki/Earth#cite_note-uncharter-228) The U.N. serves primarily as a forum for international diplomacy and [international law](https://en.wikipedia.org/wiki/International_law). When the consensus of the membership permits, it provides a mechanism for armed intervention.[[208]](https://en.wikipedia.org/wiki/Earth#cite_note-un_int_law-229)

The first human to orbit Earth was [Yuri Gagarin](https://en.wikipedia.org/wiki/Yuri_Gagarin) on 12 April 1961.[[209]](https://en.wikipedia.org/wiki/Earth#cite_note-kuhn2006-230) In total, about 487 people have visited outer space and reached orbit as of 30 July 2010, and, of these, [twelve](https://en.wikipedia.org/wiki/Apollo_program) have walked on the Moon.[[210]](https://en.wikipedia.org/wiki/Earth#cite_note-ellis2004-231)[[211]](https://en.wikipedia.org/wiki/Earth#cite_note-shayler_vis2005-232)[[212]](https://en.wikipedia.org/wiki/Earth#cite_note-wade2008-233) Normally, the only humans in space are those on the [International Space Station](https://en.wikipedia.org/wiki/International_Space_Station). The station's [crew](https://en.wikipedia.org/wiki/List_of_International_Space_Station_expeditions), made up of six people, is usually replaced every six months.[[213]](https://en.wikipedia.org/wiki/Earth#cite_note-nasa_rg_iss2007-234) The farthest that humans have travelled from Earth is 400,171 km, achieved during the [Apollo 13](https://en.wikipedia.org/wiki/Apollo_13) mission in 1970.[[214]](https://en.wikipedia.org/wiki/Earth#cite_note-Apollo13History-235)

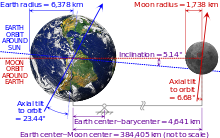
## Moon

|  |  |
| --- | --- |
| **Characteristics** | |
| [Full moon as seen from Earth's Northern Hemisphere](https://en.wikipedia.org/wiki/File:FullMoon2010.jpg) | |
| **Diameter** | 3,474.8 km |
| **Mass** | 7.349×1022 kg |
| [**Semi-major axis**](https://en.wikipedia.org/wiki/Semi-major_axis) | 384,400 km |
| **Orbital period** | 27 d 7 h 43.7 m |

*Main article:*[*Moon*](https://en.wikipedia.org/wiki/Moon)

The Moon is a relatively large, [terrestrial](https://en.wikipedia.org/wiki/Terrestrial_planet), planet-like [natural satellite](https://en.wikipedia.org/wiki/Natural_satellite), with a diameter about one-quarter of Earth's. It is the largest moon in the Solar System relative to the size of its planet, although [Charon](https://en.wikipedia.org/wiki/Charon_(moon)) is larger relative to the [dwarf planet](https://en.wikipedia.org/wiki/Dwarf_planet) [Pluto](https://en.wikipedia.org/wiki/Pluto). The natural satellites of other planets are also referred to as "moons", after Earth's.

The gravitational attraction between Earth and the Moon causes [tides](https://en.wikipedia.org/wiki/Tides) on Earth. The same effect on the Moon has led to its [tidal locking](https://en.wikipedia.org/wiki/Tidal_locking): its rotation period is the same as the time it takes to orbit Earth. As a result, it always presents the same face to the planet. As the Moon orbits Earth, different parts of its face are illuminated by the Sun, leading to the [lunar phases](https://en.wikipedia.org/wiki/Lunar_phase); the dark part of the face is separated from the light part by the [solar terminator](https://en.wikipedia.org/wiki/Terminator_(solar)).

[](https://en.wikipedia.org/wiki/File:Earth-Moon.svg)

Details of the Earth–Moon system, showing the radius of each object and the Earth–Moon [barycenter](https://en.wikipedia.org/wiki/Barycenter). The Moon's axis is located by [Cassini's third law](https://en.wikipedia.org/wiki/Cassini%27s_laws).

Due to their [tidal interaction](https://en.wikipedia.org/wiki/Tidal_acceleration), the Moon recedes from Earth at the rate of approximately 38 mm/yr. Over millions of years, these tiny modifications—and the lengthening of Earth's day by about 23 [µs](https://en.wikipedia.org/wiki/Microsecond)/yr—add up to significant changes.[[215]](https://en.wikipedia.org/wiki/Earth#cite_note-espenak_meeus20070207-236) During the [Devonian](https://en.wikipedia.org/wiki/Devonian) period, for example, (approximately 410 mya) there were 400 days in a year, with each day lasting 21.8 hours.[[216]](https://en.wikipedia.org/wiki/Earth#cite_note-hannu_poropudas19911216-237)

The Moon may have dramatically affected the development of life by moderating the planet's climate. [Paleontological](https://en.wikipedia.org/wiki/Paleontology) evidence and computer simulations show that Earth's axial tilt is stabilized by tidal interactions with the Moon.[[31]](https://en.wikipedia.org/wiki/Earth#cite_note-aaa428_261-38) Some theorists think that without this stabilization against the [torques](https://en.wikipedia.org/wiki/Torque) applied by the Sun and planets to Earth's equatorial bulge, the rotational axis might be chaotically unstable, exhibiting chaotic changes over millions of years, as appears to be the case for Mars.[[217]](https://en.wikipedia.org/wiki/Earth#cite_note-nature410_6830_773-238)

Viewed from Earth, the Moon is just far enough away to have almost the same apparent-sized disk as the Sun. The [angular size](https://en.wikipedia.org/wiki/Angular_size) (or [solid angle](https://en.wikipedia.org/wiki/Solid_angle)) of these two bodies match because, although the Sun's diameter is about 400 times as large as the Moon's, it is also 400 times more distant.[[182]](https://en.wikipedia.org/wiki/Earth#cite_note-angular-201) This allows total and annular solar eclipses to occur on Earth.

The most widely accepted theory of the Moon's origin, the [giant impact theory](https://en.wikipedia.org/wiki/Giant_impact_hypothesis), states that it formed from the collision of a Mars-size protoplanet called Theia with the early Earth. This hypothesis explains (among other things) the Moon's relative lack of iron and volatile elements, and the fact that its composition is nearly identical to that of Earth's crust.[[218]](https://en.wikipedia.org/wiki/Earth#cite_note-nature412_708-239)

## Asteroids and artificial satellites

[](https://en.wikipedia.org/wiki/File:STS-133_International_Space_Station_after_undocking_9.jpg)

The [International Space Station](https://en.wikipedia.org/wiki/International_Space_Station) is an artificial satellite in orbit around Earth.

Earth has at least five [co-orbital asteroids](https://en.wikipedia.org/wiki/Quasi-satellite), including [3753 Cruithne](https://en.wikipedia.org/wiki/3753_Cruithne) and [2002 AA29](https://en.wikipedia.org/wiki/2002_AA29).[[219]](https://en.wikipedia.org/wiki/Earth#cite_note-whitehouse20021021-240)[[220]](https://en.wikipedia.org/wiki/Earth#cite_note-christou_asher2011-241) A [trojan asteroid](https://en.wikipedia.org/wiki/Earth_trojan) companion, [2010 TK7](https://en.wikipedia.org/wiki/2010_TK7), is librating around the leading [Lagrange triangular point](https://en.wikipedia.org/wiki/Lagrange_point), L4, in the [Earth's orbit](https://en.wikipedia.org/wiki/Earth%27s_orbit) around the[Sun](https://en.wikipedia.org/wiki/Sun).[[221]](https://en.wikipedia.org/wiki/Earth#cite_note-Connors-242)[[222]](https://en.wikipedia.org/wiki/Earth#cite_note-Choi-243)

The tiny [near-Earth asteroid](https://en.wikipedia.org/wiki/Near-Earth_asteroid) [2006 RH120](https://en.wikipedia.org/wiki/2006_RH120) makes close approaches to the Earth–Moon system roughly every twenty years. During these approaches, it can orbit Earth for brief periods of time.[[223]](https://en.wikipedia.org/wiki/Earth#cite_note-244)

As of September 2015, there were 1,305 operational, human-made [satellites](https://en.wikipedia.org/wiki/Satellite) orbiting Earth.[[5]](https://en.wikipedia.org/wiki/Earth#cite_note-ucs-7) There are also inoperative satellites, including [Vanguard 1](https://en.wikipedia.org/wiki/Vanguard_1), the oldest satellite currently in orbit, and over 300,000 pieces of [space debris](https://en.wikipedia.org/wiki/Space_debris). Earth's largest artificial satellite is the International Space Station.

## Cultural and historical viewpoint

*Main article:*[*Earth in culture*](https://en.wikipedia.org/wiki/Earth_in_culture)

[](https://en.wikipedia.org/wiki/File:NASA-Apollo8-Dec24-Earthrise.jpg)

"[Earthrise](https://en.wikipedia.org/wiki/Earthrise)", the first photograph of Earth as a celestial body, taken by astronauts on board [Apollo 8](https://en.wikipedia.org/wiki/Apollo_8).

The standard astronomical symbol of Earth consists of a cross circumscribed by a circle, [Earth symbol.svg](https://en.wikipedia.org/wiki/File:Earth_symbol.svg),[[224]](https://en.wikipedia.org/wiki/Earth#cite_note-liungman2004-245) representing the [four quadrants of the world](https://en.wikipedia.org/wiki/Four_corners_of_the_world_(disambiguation)).

[Human cultures](https://en.wikipedia.org/wiki/Culture) have developed many views of the planet. Earth is sometimes [personified](https://en.wikipedia.org/wiki/Anthropomorphism) as a [deity](https://en.wikipedia.org/wiki/Deity). In many cultures it is a [mother goddess](https://en.wikipedia.org/wiki/Mother_goddess) that is also the primary [fertility deity](https://en.wikipedia.org/wiki/Fertility_deity),[[225]](https://en.wikipedia.org/wiki/Earth#cite_note-:0-246) and by the mid-20th century the [Gaia Principle](https://en.wikipedia.org/wiki/Gaia_hypothesis) compared Earth's environments and life as a single self-regulating organism leading to broad stabilization of the conditions of habitability.[[226]](https://en.wikipedia.org/wiki/Earth#cite_note-vanishing255-247)[[227]](https://en.wikipedia.org/wiki/Earth#cite_note-J1972-248)[[228]](https://en.wikipedia.org/wiki/Earth#cite_note-lovelock1974-249) [Creation myths](https://en.wikipedia.org/wiki/Creation_myth) in many religions involve the creation of Earth by a supernatural deity or deities.[[225]](https://en.wikipedia.org/wiki/Earth#cite_note-:0-246)

Scientific investigation has resulted in several culturally transformative shifts in our view of the planet. In the West, belief in a [flat Earth](https://en.wikipedia.org/wiki/Flat_Earth)[[229]](https://en.wikipedia.org/wiki/Earth#cite_note-russell1997-250) was displaced by the idea of [spherical Earth](https://en.wikipedia.org/wiki/Spherical_Earth), credited to [Pythagoras](https://en.wikipedia.org/wiki/Pythagoras) in the 6th century BC.[[230]](https://en.wikipedia.org/wiki/Earth#cite_note-251) Earth was further believed to be [the center of the universe](https://en.wikipedia.org/wiki/Geocentric_model) until the 16th century, when scientists first theorized that it was [a moving object](https://en.wikipedia.org/wiki/Heliocentrism), comparable to the other planets in the Solar System.[[231]](https://en.wikipedia.org/wiki/Earth#cite_note-arnett20060716-252) Due to the efforts of influential Christian scholars and clerics such as [James Ussher](https://en.wikipedia.org/wiki/James_Ussher), who sought to determine the age of Earth through analysis of genealogies in Scripture, Westerners prior to the 19th century generally believed Earth to be a few thousand years old at most. It was only during the 19th century that geologists realized [Earth's age](https://en.wikipedia.org/wiki/Earth%27s_age) was at least many millions of years.[[232]](https://en.wikipedia.org/wiki/Earth#cite_note-253) [Lord Kelvin](https://en.wikipedia.org/wiki/William_Thomson,_1st_Baron_Kelvin) used [thermodynamics](https://en.wikipedia.org/wiki/Thermodynamics) to estimate the age of Earth to be between 20 million and 400 million years in 1864, sparking a vigorous debate on the subject; it was only when radioactivity and [radioactive dating](https://en.wikipedia.org/wiki/Radiometric_dating) were discovered in the late 19th and early 20th centuries that a reliable mechanism for determining Earth's age was established, proving the planet to be billions of years old.[[233]](https://en.wikipedia.org/wiki/Earth#cite_note-254)[[234]](https://en.wikipedia.org/wiki/Earth#cite_note-255) The perception of Earth shifted again in the 20th century when humans first viewed it from orbit, and especially with photographs of Earth returned by the [Apollo program](https://en.wikipedia.org/wiki/Apollo_program).[[235]](https://en.wikipedia.org/wiki/Earth#cite_note-256)

## See also

* [Celestial sphere](https://en.wikipedia.org/wiki/Celestial_sphere)
* [Earth physical characteristics tables](https://en.wikipedia.org/wiki/Earth_physical_characteristics_tables)
* [Earth science](https://en.wikipedia.org/wiki/Earth_science)
* [Earth system science](https://en.wikipedia.org/wiki/Earth_system_science)
* [Timeline of the far future](https://en.wikipedia.org/wiki/Timeline_of_the_far_future)

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| |  | | --- | | * [icon](https://en.wikipedia.org/wiki/File:Issoria_lathonia.jpg)[**Biology portal**](https://en.wikipedia.org/wiki/Portal:Biology)      * https://upload.wikimedia.org/wikipedia/commons/thumb/4/43/The_Earth_seen_from_Apollo_17_with_transparent_background.png/21px-The_Earth_seen_from_Apollo_17_with_transparent_background.png[**Earth sciences portal**](https://en.wikipedia.org/wiki/Portal:Earth_sciences)      * https://upload.wikimedia.org/wikipedia/commons/thumb/6/6a/Earth_Day_Flag.png/24px-Earth_Day_Flag.png[**Ecology portal**](https://en.wikipedia.org/wiki/Portal:Ecology)      * [icon](https://en.wikipedia.org/wiki/File:Terrestrial_globe.svg)[**Geography portal**](https://en.wikipedia.org/wiki/Portal:Geography)      * [icon](https://en.wikipedia.org/wiki/File:Moon-Mdf-2005.jpg)[**Moon portal**](https://en.wikipedia.org/wiki/Portal:Moon)      * https://upload.wikimedia.org/wikipedia/commons/thumb/8/83/Solar_system.jpg/17px-Solar_system.jpg[**Solar System portal**](https://en.wikipedia.org/wiki/Portal:Solar_System)      * [icon](https://en.wikipedia.org/wiki/File:Cumulus_clouds_in_fair_weather.jpeg)[**Weather portal**](https://en.wikipedia.org/wiki/Portal:Weather) | |

## Notes

* 1. [**Jump up^**](https://en.wikipedia.org/wiki/Earth#cite_ref-epoch_1-0) All astronomical quantities vary, both [secularly](https://en.wikipedia.org/wiki/Secular_phenomena) and [periodically](https://en.wikipedia.org/wiki/Frequency). The quantities given are the values at the instant [J2000.0](https://en.wikipedia.org/wiki/J2000.0) of the secular variation, ignoring all periodic variations.
  2. ^ [Jump up to:***a***](https://en.wikipedia.org/wiki/Earth#cite_ref-apsis_2-0) [***b***](https://en.wikipedia.org/wiki/Earth#cite_ref-apsis_2-1) aphelion = *a* × (1 + *e*); perihelion = *a* × (1 – *e*), where *a* is the semi-major axis and *e* is the eccentricity. The difference between Earth's perihelion and aphelion is 5 million kilometers.
  3. [**Jump up^**](https://en.wikipedia.org/wiki/Earth#cite_ref-space_debris_8-0) United States Strategic Command tracks about 15,000 other artificial objects, mostly debris. See: [*"USSTRATCOM Space Control and Space Surveillance"*](https://www.stratcom.mil/factsheets/11/Space_Control_and_Space_Surveillance). January 2014*. Retrieved17 July 2015*.
  4. [**Jump up^**](https://en.wikipedia.org/wiki/Earth#cite_ref-surfacecover_18-0) Due to natural fluctuations, ambiguities surrounding [ice shelves](https://en.wikipedia.org/wiki/Ice_shelf), and mapping conventions for [vertical datums](https://en.wikipedia.org/wiki/Vertical_datum), exact values for land and ocean coverage are not meaningful. Based on data from the [Vector Map](https://en.wikipedia.org/wiki/Vector_Map) and [Global Landcover](http://www.landcover.org/) datasets, extreme values for coverage of lakes and streams are 0.6% and 1.0% of Earth's surface. The ice shields of [Antarctica](https://en.wikipedia.org/wiki/Antarctica) and[Greenland](https://en.wikipedia.org/wiki/Greenland) are counted as land, even though much of the rock that supports them lies below sea level.
  5. [**Jump up^**](https://en.wikipedia.org/wiki/Earth#cite_ref-29) Particularly as the setting for human [civilization](https://en.wikipedia.org/wiki/Civilization) and experience.[[24]](https://en.wikipedia.org/wiki/Earth#cite_note-28)
  6. [**Jump up^**](https://en.wikipedia.org/wiki/Earth#cite_ref-31) From the name of the [Greek earth goddess](https://en.wikipedia.org/wiki/Gaia_(goddess)), but now particularly used for the global [ecosystem](https://en.wikipedia.org/wiki/Ecosystem).[[25]](https://en.wikipedia.org/wiki/Earth#cite_note-30)
  7. [**Jump up^**](https://en.wikipedia.org/wiki/Earth#cite_ref-sidereal_solar_36-0) The number of solar days is one less than the number of[sidereal days](https://en.wikipedia.org/wiki/Sidereal_day) because the orbital motion of Earth around the Sun causes one additional revolution of the planet about its axis.
  8. [**Jump up^**](https://en.wikipedia.org/wiki/Earth#cite_ref-53) Including *eorþe*, *erþe*, *erde*, and *erthe*.[[45]](https://en.wikipedia.org/wiki/Earth#cite_note-oedearth-52)
  9. [**Jump up^**](https://en.wikipedia.org/wiki/Earth#cite_ref-55) As in [*Beowulf*](https://en.wikipedia.org/wiki/Beowulf) (1531–33):  
     *Wearp ða wundelmæl   wrættum gebunden  
     yrre oretta,   þæt hit on****eorðan****læg,  
     stið ond stylecg.*[[45]](https://en.wikipedia.org/wiki/Earth#cite_note-oedearth-52)[[46]](https://en.wikipedia.org/wiki/Earth#cite_note-beo-54)  
     "He threw the artfully-wound sword so that it lay upon the **earth**, firm and sharp-edged."[[46]](https://en.wikipedia.org/wiki/Earth#cite_note-beo-54)
  10. [**Jump up^**](https://en.wikipedia.org/wiki/Earth#cite_ref-57) As in the Old English glosses of the [*Lindisfarne Gospels*](https://en.wikipedia.org/wiki/Lindisfarne_Gospels) ([Luke 13](https://en.wikipedia.org/wiki/Luke_13):7):  
      Succidite ergo illam ut quid etiam **terram** occupat: *hrendas* uel*scearfað forðon ðailca* uel *hia to huon uutedlice****eorðo****gionetað*uel *gemerras.*[[45]](https://en.wikipedia.org/wiki/Earth#cite_note-oedearth-52)  
      "Remove it. Why should it use up the **soil**?"[[47]](https://en.wikipedia.org/wiki/Earth#cite_note-56)
  11. [**Jump up^**](https://en.wikipedia.org/wiki/Earth#cite_ref-60) As in [Ælfric](https://en.wikipedia.org/wiki/%C3%86lfric_of_Eynsham)'s [*Heptateuch*](https://en.wikipedia.org/wiki/Heptateuch) ([Gen. 1](https://en.wikipedia.org/wiki/Book_of_Genesis):10):  
      *Ond God gecygde ða drignysse****eorðan****ond ðære wætera gegaderunge he het sæ*.[[45]](https://en.wikipedia.org/wiki/Earth#cite_note-oedearth-52)[[48]](https://en.wikipedia.org/wiki/Earth#cite_note-58)  
      "And God called the dry land **Earth**; and the gathering together of the waters called he Seas."[[49]](https://en.wikipedia.org/wiki/Earth#cite_note-59)
  12. [**Jump up^**](https://en.wikipedia.org/wiki/Earth#cite_ref-62) As in the [Wessex Gospels](https://en.wikipedia.org/wiki/Wessex_Gospels) ([Matt. 28](https://en.wikipedia.org/wiki/Matthew_28):18):  
      *Me is geseald ælc anweald on heofonan & on****eorðan***.[[45]](https://en.wikipedia.org/wiki/Earth#cite_note-oedearth-52)  
      "All authority in heaven and on **earth** has been given to me."[[50]](https://en.wikipedia.org/wiki/Earth#cite_note-61)
  13. [**Jump up^**](https://en.wikipedia.org/wiki/Earth#cite_ref-65) As in the [Codex Junius](https://en.wikipedia.org/wiki/Codex_Junius)'s [*Genesis*](https://en.wikipedia.org/wiki/Genesis_A) (112–16):  
      *her ærest gesceop   ece drihten,  
      helm eallwihta,   heofon and****eorðan****,  
      rodor arærde   and þis rume land  
      gestaþelode   strangum mihtum,  
      frea ælmihtig.*[[45]](https://en.wikipedia.org/wiki/Earth#cite_note-oedearth-52)[[51]](https://en.wikipedia.org/wiki/Earth#cite_note-63)  
      "Here first with mighty power the Everlasting Lord, the Helm of all created things, Almighty King, made **earth** and heaven, raised up the sky and founded the spacious land."[[52]](https://en.wikipedia.org/wiki/Earth#cite_note-64)
  14. [**Jump up^**](https://en.wikipedia.org/wiki/Earth#cite_ref-67) As in [Ælfric](https://en.wikipedia.org/wiki/%C3%86lfric_of_Eynsham)'s *On the Seasons of the Year* (Ch. 6, §9):  
      *Seo****eorðe****stent on gelicnysse anre pinnhnyte, & seo sunne glit onbutan be Godes gesetnysse.*[[45]](https://en.wikipedia.org/wiki/Earth#cite_note-oedearth-52)  
      "The **earth** can be compared to a pine cone, and the Sun glides around it by God's decree.[[53]](https://en.wikipedia.org/wiki/Earth#cite_note-66)
  15. [**Jump up^**](https://en.wikipedia.org/wiki/Earth#cite_ref-127) Locally varies between 5 and 200 km.
  16. [**Jump up^**](https://en.wikipedia.org/wiki/Earth#cite_ref-128) Locally varies between 5 and 70 km.
  17. [**Jump up^**](https://en.wikipedia.org/wiki/Earth#cite_ref-jaes41_3_379_139-0) Including the [Somali Plate](https://en.wikipedia.org/wiki/Somali_Plate), which is being formed out of the African Plate. See: Chorowicz, Jean (October 2005). "The East African rift system".[*Journal of African Earth Sciences*](https://en.wikipedia.org/wiki/Journal_of_African_Earth_Sciences)**43**(1–3): 379–410.[*Bibcode*](https://en.wikipedia.org/wiki/Bibcode):[*2005JAfES..43..379C*](http://adsabs.harvard.edu/abs/2005JAfES..43..379C).[*doi*](https://en.wikipedia.org/wiki/Digital_object_identifier):[*10.1016/j.jafrearsci.2005.07.019*](https://dx.doi.org/10.1016%2Fj.jafrearsci.2005.07.019).
  18. [**Jump up^**](https://en.wikipedia.org/wiki/Earth#cite_ref-trench_depth_157-0) This is the measurement taken by the vessel [*Kaikō*](https://en.wikipedia.org/wiki/Kaik%C5%8D) in March 1995 and is considered the most accurate measurement to date. See the [Challenger Deep](https://en.wikipedia.org/wiki/Challenger_Deep) article for more details.
  19. [**Jump up^**](https://en.wikipedia.org/wiki/Earth#cite_ref-Aoki_196-0) The ultimate source of these figures, uses the term "seconds of UT1" instead of "seconds of mean solar time".—Aoki, S.; Kinoshita, H.; Guinot, B.; Kaplan, G. H.; McCarthy, D. D.; Seidelmann, P. K. (1982). "The new definition of universal time".Astronomy and Astrophysics**105**(2): 359–61.[*Bibcode*](https://en.wikipedia.org/wiki/Bibcode):[*1982A&A...105..359A*](http://adsabs.harvard.edu/abs/1982A&A...105..359A).
  20. [**Jump up^**](https://en.wikipedia.org/wiki/Earth#cite_ref-hill_radius_204-0) For Earth, the [Hill radius](https://en.wikipedia.org/wiki/Hill_radius) is {\displaystyle R\_{H}=a\left({\frac {m}{3M}}\right)^{\frac {1}{3}}}, where *m* is the mass of Earth, *a* is an astronomical unit, and *M* is the mass of the Sun. So the radius in AU is about {\displaystyle \left({\frac {1}{3\cdot 332,946}}\right)^{\frac {1}{3}}=0.01}.
  21. [**Jump up^**](https://en.wikipedia.org/wiki/Earth#cite_ref-solar_energy_209-0) Aphelion is 103.4% of the distance to perihelion. Due to the inverse square law, the radiation at perihelion is about 106.9% the energy at aphelion.

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  8. ^ [Jump up to:***a***](https://en.wikipedia.org/wiki/Earth#cite_ref-WGS-84_11-0) [***b***](https://en.wikipedia.org/wiki/Earth#cite_ref-WGS-84_11-1) [World Geodetic System](https://en.wikipedia.org/wiki/World_Geodetic_System) (*WGS-84*). [Available online](http://earth-info.nga.mil/GandG/wgs84/) from [National Geospatial-Intelligence Agency](https://en.wikipedia.org/wiki/National_Geospatial-Intelligence_Agency).
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  12. [**Jump up^**](https://en.wikipedia.org/wiki/Earth#cite_ref-circ_15-0) Earth's [circumference](https://en.wikipedia.org/wiki/Circumference) is almost exactly 40,000 km because the metre was calibrated on this measurement—more specifically, 1/10-millionth of the distance between the poles and the equator.
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| [**Spectral classification**](https://en.wikipedia.org/wiki/Spectral_classification) | G2V[[2]](https://en.wikipedia.org/wiki/Sun#cite_note-2) |
| [**Metallicity**](https://en.wikipedia.org/wiki/Metallicity) | *Z* = 0.0122[[3]](https://en.wikipedia.org/wiki/Sun#cite_note-3) |
| [**Angular size**](https://en.wikipedia.org/wiki/Angular_size) | 31.6–32.7 [minutes of arc](https://en.wikipedia.org/wiki/Minutes_of_arc)[[4]](https://en.wikipedia.org/wiki/Sun#cite_note-4) |
| **Adjectives** | Solar |
| [**Orbital**](https://en.wikipedia.org/wiki/Orbit)**characteristics** | |
| **Mean distance from**[**Milky Way**](https://en.wikipedia.org/wiki/Milky_Way)**core** | ≈ 2.7×1017 km 27,200 [light-years](https://en.wikipedia.org/wiki/Light-years) |
| [**Galactic period**](https://en.wikipedia.org/wiki/Galactic_year) | (2.25–2.50)×108 [yr](https://en.wikipedia.org/wiki/Julian_year_(astronomy)) |
| [**Velocity**](https://en.wikipedia.org/wiki/Velocity) | ≈ 220 km/s (orbit around the center of the Milky Way) ≈ 20 km/s (relative to average velocity of other stars in stellar neighborhood) ≈ 370 km/s[[5]](https://en.wikipedia.org/wiki/Sun#cite_note-5) (relative to the [cosmic microwave background](https://en.wikipedia.org/wiki/Cosmic_microwave_background_radiation#CMBR_dipole_anisotropy)) |
| **Physical characteristics** | |
| **Equatorial**[**radius**](https://en.wikipedia.org/wiki/Radius) | [695,700](https://en.wikipedia.org/wiki/Solar_radius) km[[6]](https://en.wikipedia.org/wiki/Sun#cite_note-IAU2015resB3-6) 109 × Earth[[7]](https://en.wikipedia.org/wiki/Sun#cite_note-sse-7) |
| **Equatorial**[**circumference**](https://en.wikipedia.org/wiki/Circumference) | 4.379×106 km[[7]](https://en.wikipedia.org/wiki/Sun#cite_note-sse-7) 109 × Earth[[7]](https://en.wikipedia.org/wiki/Sun#cite_note-sse-7) |
| [**Flattening**](https://en.wikipedia.org/wiki/Flattening) | 9×10−6 |
| [**Surface area**](https://en.wikipedia.org/wiki/Surface_area) | 6.09×1012 km2[[7]](https://en.wikipedia.org/wiki/Sun#cite_note-sse-7) 12,000 × Earth[[7]](https://en.wikipedia.org/wiki/Sun#cite_note-sse-7) |
| [**Volume**](https://en.wikipedia.org/wiki/Volume) | 1.41×1018 km3[[7]](https://en.wikipedia.org/wiki/Sun#cite_note-sse-7) 1,300,000 × Earth |
| [**Mass**](https://en.wikipedia.org/wiki/Mass) | (1.98855±0.00025)×1030 kg[[1]](https://en.wikipedia.org/wiki/Sun#cite_note-nssdc-1) 333,000 × Earth[[1]](https://en.wikipedia.org/wiki/Sun#cite_note-nssdc-1) |
| **Average**[**density**](https://en.wikipedia.org/wiki/Density) | 1.408 g/cm3[[1]](https://en.wikipedia.org/wiki/Sun#cite_note-nssdc-1)[[7]](https://en.wikipedia.org/wiki/Sun#cite_note-sse-7)[[8]](https://en.wikipedia.org/wiki/Sun#cite_note-8) 0.255 × Earth[[1]](https://en.wikipedia.org/wiki/Sun#cite_note-nssdc-1)[[7]](https://en.wikipedia.org/wiki/Sun#cite_note-sse-7) |
| **Center**[**density**](https://en.wikipedia.org/wiki/Density)**(modeled)** | 162.2 g/cm3[[1]](https://en.wikipedia.org/wiki/Sun#cite_note-nssdc-1) 12.4 × Earth |
| **Equatorial**[**surface gravity**](https://en.wikipedia.org/wiki/Surface_gravity) | 274.0 m/s2[[1]](https://en.wikipedia.org/wiki/Sun#cite_note-nssdc-1) 27.94 [*g*](https://en.wikipedia.org/wiki/G-force) 27,542.29 [*cgs*](https://en.wikipedia.org/wiki/Cgs) 28 × Earth[[7]](https://en.wikipedia.org/wiki/Sun#cite_note-sse-7) |
| [**Escape velocity**](https://en.wikipedia.org/wiki/Escape_velocity) **(from the surface)** | 617.7 km/s[[7]](https://en.wikipedia.org/wiki/Sun#cite_note-sse-7) 55 × Earth[[7]](https://en.wikipedia.org/wiki/Sun#cite_note-sse-7) |
| **Temperature** | Center (modeled): 1.57×107 K[[1]](https://en.wikipedia.org/wiki/Sun#cite_note-nssdc-1) [Photosphere](https://en.wikipedia.org/wiki/Photosphere) (effective): 5,772 [K](https://en.wikipedia.org/wiki/Kelvin)[[1]](https://en.wikipedia.org/wiki/Sun#cite_note-nssdc-1) [Corona](https://en.wikipedia.org/wiki/Corona): ≈ 5×106 K |
| [**Luminosity**](https://en.wikipedia.org/wiki/Luminosity)**(Lsol)** | 3.828×1026 [W](https://en.wikipedia.org/wiki/Watt)[[1]](https://en.wikipedia.org/wiki/Sun#cite_note-nssdc-1) ≈ 3.75×1028 [lm](https://en.wikipedia.org/wiki/Lumen_(unit)) ≈ 98 lm/W [efficacy](https://en.wikipedia.org/wiki/Luminous_efficacy) |
| **Mean**[**radiance**](https://en.wikipedia.org/wiki/Radiance)**(Isol)** | 2.009×107 W·m−2·sr−1 |
| **Age** | ≈ 4.6 billion years[[9]](https://en.wikipedia.org/wiki/Sun#cite_note-Bonanno-9)[[10]](https://en.wikipedia.org/wiki/Sun#cite_note-10) |
| [**Rotation**](https://en.wikipedia.org/wiki/Rotation)**characteristics** | |
| [**Obliquity**](https://en.wikipedia.org/wiki/Axial_tilt) | 7.25°[[1]](https://en.wikipedia.org/wiki/Sun#cite_note-nssdc-1) (to the [ecliptic](https://en.wikipedia.org/wiki/Ecliptic)) 67.23° (to the [galactic plane](https://en.wikipedia.org/wiki/Galactic_plane)) |
| [**Right ascension**](https://en.wikipedia.org/wiki/Right_ascension) **of North pole**[[11]](https://en.wikipedia.org/wiki/Sun#cite_note-iau-iag-11) | 286.13° 19 h 4 min 30 s |
| [**Declination**](https://en.wikipedia.org/wiki/Declination) **of North pole** | +63.87° 63° 52' North |
| **Sidereal**[**rotation period**](https://en.wikipedia.org/wiki/Solar_rotation) **(at equator)** | 25.05 d[[1]](https://en.wikipedia.org/wiki/Sun#cite_note-nssdc-1) |
| **(at 16° latitude)** | 25.38 d[[1]](https://en.wikipedia.org/wiki/Sun#cite_note-nssdc-1) 25 d 9 h 7 min 12 s[[11]](https://en.wikipedia.org/wiki/Sun#cite_note-iau-iag-11) |
| **(at poles)** | 34.4 d[[1]](https://en.wikipedia.org/wiki/Sun#cite_note-nssdc-1) |
| **Rotation velocity (at equator)** | 7.189×103 km/h[[7]](https://en.wikipedia.org/wiki/Sun#cite_note-sse-7) |
| [**Photospheric**](https://en.wikipedia.org/wiki/Photosphere)**composition (by mass)** | |
| [**Hydrogen**](https://en.wikipedia.org/wiki/Hydrogen) | 73.46%[[12]](https://en.wikipedia.org/wiki/Sun#cite_note-12) |
| [**Helium**](https://en.wikipedia.org/wiki/Helium) | 24.85% |
| [**Oxygen**](https://en.wikipedia.org/wiki/Oxygen) | 0.77% |
| [**Carbon**](https://en.wikipedia.org/wiki/Carbon) | 0.29% |
| [**Iron**](https://en.wikipedia.org/wiki/Iron) | 0.16% |
| [**Neon**](https://en.wikipedia.org/wiki/Neon) | 0.12% |
| [**Nitrogen**](https://en.wikipedia.org/wiki/Nitrogen) | 0.09% |
| [**Silicon**](https://en.wikipedia.org/wiki/Silicon) | 0.07% |
| [**Magnesium**](https://en.wikipedia.org/wiki/Magnesium) | 0.05% |
| [**Sulfur**](https://en.wikipedia.org/wiki/Sulfur) | 0.04% |

The **Sun** is the [star](https://en.wikipedia.org/wiki/Star) at the center of the [Solar System](https://en.wikipedia.org/wiki/Solar_System) and is by far the most important source of [energy](https://en.wikipedia.org/wiki/Energy) for life on [Earth](https://en.wikipedia.org/wiki/Earth). It is a nearly perfect sphere of hot [plasma](https://en.wikipedia.org/wiki/Plasma_(physics)),[[13]](https://en.wikipedia.org/wiki/Sun#cite_note-13)[[14]](https://en.wikipedia.org/wiki/Sun#cite_note-14) with internal [convective](https://en.wikipedia.org/wiki/Convection) motion that generates a[magnetic field](https://en.wikipedia.org/wiki/Magnetic_field) via a [dynamo process](https://en.wikipedia.org/wiki/Solar_dynamo).[[15]](https://en.wikipedia.org/wiki/Sun#cite_note-doi10.1146.2Fannurev-astro-081913-040012-15) Its diameter is about 109 times that of Earth, and [its mass](https://en.wikipedia.org/wiki/Solar_mass) is about 330,000 times that of Earth, accounting for about 99.86% of the total mass of the Solar System.[[16]](https://en.wikipedia.org/wiki/Sun#cite_note-Woolfson00-16) About three quarters of the Sun's mass consists of [hydrogen](https://en.wikipedia.org/wiki/Hydrogen); the rest is mostly [helium](https://en.wikipedia.org/wiki/Helium), with much smaller quantities of heavier elements, including [oxygen](https://en.wikipedia.org/wiki/Oxygen), [carbon](https://en.wikipedia.org/wiki/Carbon), [neon](https://en.wikipedia.org/wiki/Neon), and [iron](https://en.wikipedia.org/wiki/Iron).[[17]](https://en.wikipedia.org/wiki/Sun#cite_note-basu2008-17)

The Sun is a [G-type main-sequence star](https://en.wikipedia.org/wiki/G-type_main-sequence_star) (G2V) based on [spectral class](https://en.wikipedia.org/wiki/Stellar_classification) and it is informally referred to as a yellow dwarf. It formed approximately 4.6 billion[[a]](https://en.wikipedia.org/wiki/Sun#cite_note-short-18)[[9]](https://en.wikipedia.org/wiki/Sun#cite_note-Bonanno-9)[[18]](https://en.wikipedia.org/wiki/Sun#cite_note-Connelly2012-19) years ago from the [gravitational collapse](https://en.wikipedia.org/wiki/Gravitational_collapse) of matter within a region of a large [molecular cloud](https://en.wikipedia.org/wiki/Molecular_cloud). Most of this matter gathered in the center, whereas the rest flattened into an orbiting disk that [became the Solar System](https://en.wikipedia.org/wiki/Formation_and_evolution_of_the_Solar_System). The central mass became increasingly hot and dense, eventually initiating [nuclear fusion](https://en.wikipedia.org/wiki/Nuclear_fusion) in [its core](https://en.wikipedia.org/wiki/Solar_core). It is thought that almost all stars [form by this process](https://en.wikipedia.org/wiki/Star_formation).

The Sun is roughly middle-aged and has not changed dramatically for over four billion[[a]](https://en.wikipedia.org/wiki/Sun#cite_note-short-18) years, and will remain fairly stable for more than another five billion years. However, after [hydrogen fusion](https://en.wikipedia.org/wiki/Hydrogen_fusion) in its core has stopped, the Sun will undergo severe changes and become a [red giant](https://en.wikipedia.org/wiki/Red_giant). It is calculated that the Sun will become sufficiently large to engulf the current orbits of [Mercury](https://en.wikipedia.org/wiki/Mercury_(planet)), [Venus](https://en.wikipedia.org/wiki/Venus), and possibly Earth.

The enormous effect of the Sun on Earth has been recognized since [prehistoric times](https://en.wikipedia.org/wiki/Prehistoric_times), and the Sun has been [regarded by some cultures](https://en.wikipedia.org/wiki/The_Sun_in_culture) as a [deity](https://en.wikipedia.org/wiki/Solar_deity). Earth's movement around the Sun is the basis of the [solar calendar](https://en.wikipedia.org/wiki/Solar_calendar), which is the predominant [calendar](https://en.wikipedia.org/wiki/Calendar) in use today.

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## Name and etymology

The English proper noun *Sun* developed from [Old English](https://en.wikipedia.org/wiki/Old_English) *sunne* and may be related to *south*. Cognates to English *sun* appear in other [Germanic languages](https://en.wikipedia.org/wiki/Germanic_languages), including [Old Frisian](https://en.wikipedia.org/wiki/Old_Frisian) *sunne*, *sonne*, [Old Saxon](https://en.wikipedia.org/wiki/Old_Saxon) *sunna*,[Middle Dutch](https://en.wikipedia.org/wiki/Middle_Dutch) *sonne*, modern [Dutch](https://en.wikipedia.org/wiki/Dutch_language) *zon*, [Old High German](https://en.wikipedia.org/wiki/Old_High_German) *sunna*, modern German *Sonne*, [Old Norse](https://en.wikipedia.org/wiki/Old_Norse) *sunna*, and [Gothic](https://en.wikipedia.org/wiki/Gothic_language) *sunnō*. All Germanic terms for the Sun stem from [Proto-Germanic](https://en.wikipedia.org/wiki/Proto-Germanic) \**sunnōn*.[[19]](https://en.wikipedia.org/wiki/Sun#cite_note-BARNHART776-20)[[20]](https://en.wikipedia.org/wiki/Sun#cite_note-MALLORY129-21)

The English weekday name *Sunday* stems from Old English (*Sunnandæg*; "Sun's day", from before 700) and is ultimately a result of a [Germanic interpretation](https://en.wikipedia.org/wiki/Interpretatio_germanica) of Latin *dies solis*, itself a translation of the Greek ἡμέρα ἡλίου (*hēméra hēlíou*).[[21]](https://en.wikipedia.org/wiki/Sun#cite_note-BARNHART778-22) The Latin name for the Sun, *Sol*, is not common in general English language use; the adjectival form is the related word *solar*.[[22]](https://en.wikipedia.org/wiki/Sun#cite_note-23)[[23]](https://en.wikipedia.org/wiki/Sun#cite_note-24) The term *sol* is also used by planetary astronomers to refer to the duration of a [solar day](https://en.wikipedia.org/wiki/Solar_day) on another planet, such as [Mars](https://en.wikipedia.org/wiki/Mars).[[24]](https://en.wikipedia.org/wiki/Sun#cite_note-25) A mean [Earth](https://en.wikipedia.org/wiki/Earth) solar day is approximately 24 hours, whereas a mean Martian 'sol' is 24 hours, 39 minutes, and 35.244 seconds.[[25]](https://en.wikipedia.org/wiki/Sun#cite_note-26)

### Religious aspects

*Main article:*[*Solar deity*](https://en.wikipedia.org/wiki/Solar_deity)

Solar deities and Sun worship can be found throughout most of recorded history in various forms, including the Egyptian [Ra](https://en.wikipedia.org/wiki/Ra), the Hindu [Surya](https://en.wikipedia.org/wiki/Surya), the Japanese [Amaterasu](https://en.wikipedia.org/wiki/Amaterasu), the Germanic [Sól](https://en.wikipedia.org/wiki/S%C3%B3l_(sun)), and the Aztec [Tonatiuh](https://en.wikipedia.org/wiki/Tonatiuh), among others.

From at least the [4th Dynasty](https://en.wikipedia.org/wiki/4th_Dynasty) of [Ancient Egypt](https://en.wikipedia.org/wiki/Ancient_Egypt), the Sun was worshipped as the god [Ra](https://en.wikipedia.org/wiki/Ra), portrayed as a falcon-headed divinity surmounted by the solar disk, and surrounded by a serpent. In the [New Empire](https://en.wikipedia.org/wiki/New_Kingdom_of_Egypt) period, the Sun became identified with the [dung beetle](https://en.wikipedia.org/wiki/Dung_beetle), whose spherical ball of dung was identified with the Sun. In the form of the Sun disc [Aten](https://en.wikipedia.org/wiki/Aten), the Sun had a brief resurgence during the [Amarna Period](https://en.wikipedia.org/wiki/Amarna_Period) when it again became the preeminent, if not only, divinity for the [Pharaoh](https://en.wikipedia.org/wiki/Pharaoh) [Akhenaton](https://en.wikipedia.org/wiki/Akhenaton).[[26]](https://en.wikipedia.org/wiki/Sun#cite_note-27)[[27]](https://en.wikipedia.org/wiki/Sun#cite_note-28)

The Sun is viewed as a goddess in [Germanic paganism](https://en.wikipedia.org/wiki/Germanic_paganism), [Sól/Sunna](https://en.wikipedia.org/wiki/S%C3%B3l_(sun)).[[20]](https://en.wikipedia.org/wiki/Sun#cite_note-MALLORY129-21) Scholars theorize that the Sun, as a Germanic goddess, may represent an extension of an earlier [Proto-Indo-European](https://en.wikipedia.org/wiki/Proto-Indo-Europeans) Sun deity because of[Indo-European linguistic](https://en.wikipedia.org/wiki/Indo-European_languages) connections between Old Norse *Sól*, [Sanskrit](https://en.wikipedia.org/wiki/Sanskrit) [*Surya*](https://en.wikipedia.org/wiki/Surya), [Gaulish](https://en.wikipedia.org/wiki/Gaulish_language) [*Sulis*](https://en.wikipedia.org/wiki/Sulis), [Lithuanian](https://en.wikipedia.org/wiki/Lithuanian_language) [*Saulė*](https://en.wikipedia.org/wiki/Saul%C4%97), and [Slavic](https://en.wikipedia.org/wiki/Slavic_languages) *Solntse*.[[20]](https://en.wikipedia.org/wiki/Sun#cite_note-MALLORY129-21)

In ancient Roman culture, [Sunday](https://en.wikipedia.org/wiki/Sunday) was the day of the Sun god. It was adopted as the [Sabbath](https://en.wikipedia.org/wiki/Sabbath) day by Christians who did not have a Jewish background. The symbol of light was a pagan device adopted by Christians, and perhaps the most important one that did not come from Jewish traditions. In paganism, the Sun was a source of life, giving warmth and illumination to mankind. It was the center of a popular cult among Romans, who would stand at dawn to catch the first rays of sunshine as they prayed. The celebration of the winter solstice (which influenced Christmas) was part of the Roman cult of the unconquered Sun ([Sol Invictus](https://en.wikipedia.org/wiki/Sol_Invictus)). Christian churches were built with an orientation so that the congregation faced toward the sunrise in the East.[[28]](https://en.wikipedia.org/wiki/Sun#cite_note-29)

## Characteristics

The Sun is a [G-type main-sequence star](https://en.wikipedia.org/wiki/G-type_main-sequence_star) that comprises about 99.86% of the mass of the Solar System. The Sun has an [absolute magnitude](https://en.wikipedia.org/wiki/Absolute_magnitude) of +4.83, estimated to be brighter than about 85% of the stars in the [Milky Way](https://en.wikipedia.org/wiki/Milky_Way), most of which are [red dwarfs](https://en.wikipedia.org/wiki/Red_dwarf).[[29]](https://en.wikipedia.org/wiki/Sun#cite_note-30)[[30]](https://en.wikipedia.org/wiki/Sun#cite_note-31) The Sun is a [Population I](https://en.wikipedia.org/wiki/Population_I_stars), or heavy-element-rich,[[b]](https://en.wikipedia.org/wiki/Sun#cite_note-heavy_elements-32) star.[[31]](https://en.wikipedia.org/wiki/Sun#cite_note-zeilik-33) The formation of the Sun may have been triggered by shockwaves from one or more nearby [supernovae](https://en.wikipedia.org/wiki/Supernova).[[32]](https://en.wikipedia.org/wiki/Sun#cite_note-Falk-34) This is suggested by a high [abundance](https://en.wikipedia.org/wiki/Abundance_of_the_chemical_elements) of heavy elements in the Solar System, such as [gold](https://en.wikipedia.org/wiki/Gold) and [uranium](https://en.wikipedia.org/wiki/Uranium), relative to the abundances of these elements in so-called [Population II](https://en.wikipedia.org/wiki/Population_II), heavy-element-poor, stars. These elements could most plausibly have been produced by [endothermic](https://en.wikipedia.org/wiki/Endothermic) nuclear reactions during a supernova, or by [transmutation](https://en.wikipedia.org/wiki/Nuclear_transmutation) through [neutron absorption](https://en.wikipedia.org/wiki/Neutron_absorption) within a massive second-generation star.[[31]](https://en.wikipedia.org/wiki/Sun#cite_note-zeilik-33)

The Sun is by far the brightest object in the sky, with an [apparent magnitude](https://en.wikipedia.org/wiki/Apparent_magnitude) of −26.74.[[33]](https://en.wikipedia.org/wiki/Sun#cite_note-35)[[34]](https://en.wikipedia.org/wiki/Sun#cite_note-36) This is about 13 billion times brighter than the next brightest star, [Sirius](https://en.wikipedia.org/wiki/Sirius), which has an apparent magnitude of −1.46. The mean distance of the Sun's center to Earth's center is approximately 1 [astronomical unit](https://en.wikipedia.org/wiki/Astronomical_unit) (about 150,000,000 km; 93,000,000 mi), though the distance varies as Earth moves from [perihelion](https://en.wikipedia.org/wiki/Perihelion) in January to [aphelion](https://en.wikipedia.org/wiki/Aphelion) in July.[[35]](https://en.wikipedia.org/wiki/Sun#cite_note-USNO-37) At this average distance, light travels from the Sun's horizon to Earth's horizon in about 8 minutes and 19 seconds, while light from the closest points of the Sun and Earth takes about two seconds less. The energy of this [sunlight](https://en.wikipedia.org/wiki/Sunlight) supports almost all life[[c]](https://en.wikipedia.org/wiki/Sun#cite_note-38) on Earth by [photosynthesis](https://en.wikipedia.org/wiki/Photosynthesis),[[36]](https://en.wikipedia.org/wiki/Sun#cite_note-Simon2001-39) and drives [Earth's climate](https://en.wikipedia.org/wiki/Earth%27s_climate) and weather.

The Sun does not have a definite boundary, and in its outer parts its density decreases exponentially with increasing distance from its center.[[37]](https://en.wikipedia.org/wiki/Sun#cite_note-Zirker2002-11-40) For the purpose of measurement, however, the Sun's radius is considered to be the distance from its center to the edge of the [photosphere](https://en.wikipedia.org/wiki/Photosphere), the apparent visible surface of the Sun.[[38]](https://en.wikipedia.org/wiki/Sun#cite_note-Phillips1995-73-41) By this measure, the Sun is a near-perfect sphere with an [oblateness](https://en.wikipedia.org/wiki/Oblateness) estimated at about 9 millionths,[[39]](https://en.wikipedia.org/wiki/Sun#cite_note-Godier-42) which means that its polar diameter differs from its equatorial diameter by only 10 kilometres (6.2 mi).[[40]](https://en.wikipedia.org/wiki/Sun#cite_note-perfect_sphere-43) The tidal effect of the planets is weak and does not significantly affect the shape of the Sun.[[41]](https://en.wikipedia.org/wiki/Sun#cite_note-Schutz2003-44)The Sun rotates faster at its [equator](https://en.wikipedia.org/wiki/Equator) than at its [poles](https://en.wikipedia.org/wiki/Poles_of_astronomical_bodies). This [differential rotation](https://en.wikipedia.org/wiki/Solar_rotation) is caused by [convective motion](https://en.wikipedia.org/wiki/Convection) due to heat transport and the [Coriolis force](https://en.wikipedia.org/wiki/Coriolis_effect) due to the Sun's rotation. In a frame of reference defined by the stars, the rotational period is approximately 25.6 days at the equator and 33.5 days at the poles. Viewed from Earth as it orbits the Sun, the *apparent rotational period* of the Sun at its equator is about 28 days.[[42]](https://en.wikipedia.org/wiki/Sun#cite_note-Phillips1995-78-45)

## Sunlight

*Main article:*[*Sunlight*](https://en.wikipedia.org/wiki/Sunlight)

The [solar constant](https://en.wikipedia.org/wiki/Solar_constant) is the amount of power that the Sun deposits per unit area that is directly exposed to sunlight. The solar constant is equal to approximately 1,368 W/m2 (watts per square meter) at a distance of one[astronomical unit](https://en.wikipedia.org/wiki/Astronomical_unit) (AU) from the Sun (that is, on or near Earth).[[43]](https://en.wikipedia.org/wiki/Sun#cite_note-TSI-46) Sunlight on the surface of Earth is [attenuated](https://en.wikipedia.org/wiki/Attenuation_(electromagnetic_radiation)) by Earth's atmosphere, so that less power arrives at the surface (closer to 1,000 W/m2) in clear conditions when the Sun is near the [zenith](https://en.wikipedia.org/wiki/Zenith).[[44]](https://en.wikipedia.org/wiki/Sun#cite_note-El-Sharkawi2005-47) Sunlight at the top of Earth's atmosphere is composed (by total energy) of about 50% infrared light, 40% visible light, and 10% ultraviolet light.[[45]](https://en.wikipedia.org/wiki/Sun#cite_note-Solar_radiation-48) The atmosphere in particular filters out over 70% of solar ultraviolet, especially at the shorter wavelengths.[[46]](https://en.wikipedia.org/wiki/Sun#cite_note-49) Solar [ultraviolet radiation](https://en.wikipedia.org/wiki/Ultraviolet_radiation) ionizes Earth's dayside upper atmosphere, creating the electrically conducting [ionosphere](https://en.wikipedia.org/wiki/Ionosphere).[[47]](https://en.wikipedia.org/wiki/Sun#cite_note-Phillips1995-50)

The Sun's color is white, with a [CIE](https://en.wikipedia.org/wiki/CIE_1931_color_space) color-space index near (0.3, 0.3), when viewed from space or when the Sun is high in the sky. When measuring all the photons emitted, the Sun is actually emitting more photons in the green portion of the spectrum than any other.[[48]](https://en.wikipedia.org/wiki/Sun#cite_note-51)[[49]](https://en.wikipedia.org/wiki/Sun#cite_note-52) When the Sun is low in the sky, [atmospheric scattering](https://en.wikipedia.org/wiki/Diffuse_sky_radiation) renders the Sun yellow, red, orange, or magenta. Despite its typical whiteness, most people mentally picture the Sun as yellow; the reasons for this are the subject of debate.[[50]](https://en.wikipedia.org/wiki/Sun#cite_note-yellow_sun_paradox-53) The Sun is a [G2V](https://en.wikipedia.org/wiki/G-type_main-sequence_star)star, with *G2* indicating its [surface temperature](https://en.wikipedia.org/wiki/Effective_temperature) of approximately 5,778 K (5,505 °C, 9,941 °F), and *V* that it, like most stars, is a [main-sequence](https://en.wikipedia.org/wiki/Main_sequence) star.[[51]](https://en.wikipedia.org/wiki/Sun#cite_note-Phillips1995-47-54)[[52]](https://en.wikipedia.org/wiki/Sun#cite_note-55) The average [luminance](https://en.wikipedia.org/wiki/Luminance) of the Sun is about 1.88 [giga](https://en.wikipedia.org/wiki/Giga) [candela per square metre](https://en.wikipedia.org/wiki/Candela_per_square_metre), but as viewed through Earth's atmosphere, this is lowered to about 1.44 Gcd/m2.[[d]](https://en.wikipedia.org/wiki/Sun#cite_note-56) However, the luminance is not constant across the disk of the Sun ([limb darkening](https://en.wikipedia.org/wiki/Limb_darkening)).

## Composition

*See also:*[*Molecules in stars*](https://en.wikipedia.org/wiki/Molecules_in_stars)

The Sun is composed primarily of the [chemical elements](https://en.wikipedia.org/wiki/Chemical_element) [hydrogen](https://en.wikipedia.org/wiki/Hydrogen) and [helium](https://en.wikipedia.org/wiki/Helium); they account for 74.9% and 23.8% of the mass of the Sun in the photosphere, respectively.[[53]](https://en.wikipedia.org/wiki/Sun#cite_note-lodders-57) All heavier elements, called [*metals*](https://en.wikipedia.org/wiki/Metallicity) in astronomy, account for less than 2% of the mass, with oxygen (roughly 1% of the Sun's mass), carbon (0.3%), neon (0.2%), and iron (0.2%) being the most abundant.[[54]](https://en.wikipedia.org/wiki/Sun#cite_note-hkt2004-58)

The Sun inherited its chemical composition from the [interstellar medium](https://en.wikipedia.org/wiki/Interstellar_medium) out of which it formed. The hydrogen and helium in the Sun were produced by [Big Bang nucleosynthesis](https://en.wikipedia.org/wiki/Big_Bang_nucleosynthesis), and the heavier elements were produced by [stellar nucleosynthesis](https://en.wikipedia.org/wiki/Stellar_nucleosynthesis) in generations of stars that completed their [stellar evolution](https://en.wikipedia.org/wiki/Stellar_evolution) and returned their material to the interstellar medium before the formation of the Sun.[[55]](https://en.wikipedia.org/wiki/Sun#cite_note-hkt2004_78-59) The chemical composition of the photosphere is normally considered representative of the composition of the primordial Solar System.[[56]](https://en.wikipedia.org/wiki/Sun#cite_note-aller1968-60) However, since the Sun formed, some of the helium and heavy elements have gravitationally settled from the photosphere. Therefore, in today's photosphere the helium fraction is reduced, and the [metallicity](https://en.wikipedia.org/wiki/Metallicity) is only 84% of what it was in the [protostellar](https://en.wikipedia.org/wiki/Protostar)phase (before nuclear fusion in the core started). The protostellar Sun's composition is believed to have been 71.1% hydrogen, 27.4% helium, and 1.5% heavier elements.[[53]](https://en.wikipedia.org/wiki/Sun#cite_note-lodders-57)

Today, nuclear fusion in the Sun's core has modified the composition by converting hydrogen into helium, so the innermost portion of the Sun is now roughly 60% helium, with the abundance of heavier elements unchanged. Because heat is transferred from the Sun's core by radiation rather than by convection (see [Radiative zone](https://en.wikipedia.org/wiki/Sun#Radiative_zone) below), none of the fusion products from the core have risen to the photosphere.[[57]](https://en.wikipedia.org/wiki/Sun#cite_note-hkt2004_9.2.3-61)

The reactive core zone of "hydrogen burning", where hydrogen is converted into helium, is starting to surround an inner core of "helium ash". This development will continue and will eventually cause the Sun to leave the [main sequence](https://en.wikipedia.org/wiki/Main_sequence), to become a [red giant](https://en.wikipedia.org/wiki/Red_giant).[[58]](https://en.wikipedia.org/wiki/Sun#cite_note-62)

The solar heavy-element abundances described above are typically measured both using [spectroscopy](https://en.wikipedia.org/wiki/Astronomical_spectroscopy) of the Sun's photosphere and by measuring abundances in [meteorites](https://en.wikipedia.org/wiki/Meteorites) that have never been heated to melting temperatures. These meteorites are thought to retain the composition of the protostellar Sun and are thus not affected by settling of heavy elements. The two methods generally agree well.[[17]](https://en.wikipedia.org/wiki/Sun#cite_note-basu2008-17)

### Singly ionized iron-group elements

In the 1970s, much research focused on the abundances of [iron-group](https://en.wikipedia.org/wiki/Iron_group) elements in the Sun.[[59]](https://en.wikipedia.org/wiki/Sun#cite_note-biemont1978-63)[[60]](https://en.wikipedia.org/wiki/Sun#cite_note-64) Although significant research was done, until 1978 it was difficult to determine the abundances of some iron-group elements (e.g. [cobalt](https://en.wikipedia.org/wiki/Cobalt) and [manganese](https://en.wikipedia.org/wiki/Manganese)) via[spectrography](https://en.wikipedia.org/wiki/Spectrography) because of their [hyperfine structures](https://en.wikipedia.org/wiki/Hyperfine_structure).[[59]](https://en.wikipedia.org/wiki/Sun#cite_note-biemont1978-63)

The first largely complete set of [oscillator strengths](https://en.wikipedia.org/wiki/Oscillator_strength) of singly ionized iron-group elements were made available in the 1960s,[[61]](https://en.wikipedia.org/wiki/Sun#cite_note-65) and these were subsequently improved.[[62]](https://en.wikipedia.org/wiki/Sun#cite_note-66) In 1978, the abundances of singly ionized elements of the iron group were derived.[[59]](https://en.wikipedia.org/wiki/Sun#cite_note-biemont1978-63)

### Isotopic composition

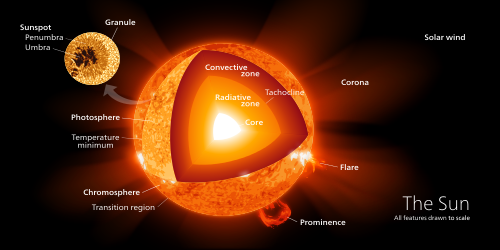
Various authors have considered the existence of a gradient in the isotopic compositions of solar and planetary [noble gases](https://en.wikipedia.org/wiki/Noble_gas),[[63]](https://en.wikipedia.org/wiki/Sun#cite_note-67) e.g. correlations between isotopic compositions of [neon](https://en.wikipedia.org/wiki/Neon) and [xenon](https://en.wikipedia.org/wiki/Xenon) in the Sun and on the planets.[[64]](https://en.wikipedia.org/wiki/Sun#cite_note-68)

Prior to 1983, it was thought that the whole Sun has the same composition as the solar atmosphere.[[65]](https://en.wikipedia.org/wiki/Sun#cite_note-manuel1983-69) In 1983, it was claimed that it was [fractionation](https://en.wikipedia.org/wiki/Fractionation) in the Sun itself that caused the isotopic-composition relationship between the planetary and solar-wind-implanted noble gases.[[65]](https://en.wikipedia.org/wiki/Sun#cite_note-manuel1983-69)

## Structure

### Core

*Main article:*[*Solar core*](https://en.wikipedia.org/wiki/Solar_core)

[](https://en.wikipedia.org/wiki/File:Sun_poster.svg)

The structure of the Sun

The [core](https://en.wikipedia.org/wiki/Solar_core) of the Sun extends from the center to about 20–25% of the solar radius.[[66]](https://en.wikipedia.org/wiki/Sun#cite_note-Garcia2007-70) It has a density of up to 150 g/cm3[[67]](https://en.wikipedia.org/wiki/Sun#cite_note-Basu-71)[[68]](https://en.wikipedia.org/wiki/Sun#cite_note-NASA1-72) (about 150 times the density of water) and a temperature of close to 15.7 million [kelvins](https://en.wikipedia.org/wiki/Kelvin) (K).[[68]](https://en.wikipedia.org/wiki/Sun#cite_note-NASA1-72) By contrast, the Sun's surface temperature is approximately 5,800 K. Recent analysis of [SOHO](https://en.wikipedia.org/wiki/Solar_and_Heliospheric_Observatory) mission data favors a faster rotation rate in the core than in the radiative zone above.[[66]](https://en.wikipedia.org/wiki/Sun#cite_note-Garcia2007-70) Through most of the Sun's life, energy is produced by [nuclear fusion](https://en.wikipedia.org/wiki/Nuclear_fusion) in the core region through a series of steps called the [p–p (proton–proton) chain](https://en.wikipedia.org/wiki/Proton-proton_chain_reaction); this process converts [hydrogen](https://en.wikipedia.org/wiki/Hydrogen) into [helium](https://en.wikipedia.org/wiki/Helium).[[69]](https://en.wikipedia.org/wiki/Sun#cite_note-73) Only 0.8% of the energy generated in the Sun comes from the [CNO cycle](https://en.wikipedia.org/wiki/CNO_cycle), though this proportion is expected to increase as the Sun becomes older.[[70]](https://en.wikipedia.org/wiki/Sun#cite_note-jpcs271_1_012031-74)

The core is the only region in the Sun that produces an appreciable amount of [thermal energy](https://en.wikipedia.org/wiki/Thermal_energy) through fusion; 99% of the power is generated within 24% of the Sun's radius, and by 30% of the radius, fusion has stopped nearly entirely. The remainder of the Sun is heated by this energy as is transferred outwards through many successive layers, finally to the solar photosphere where it escapes into space as sunlight or the [kinetic energy](https://en.wikipedia.org/wiki/Kinetic_energy) of particles.[[51]](https://en.wikipedia.org/wiki/Sun#cite_note-Phillips1995-47-54)[[71]](https://en.wikipedia.org/wiki/Sun#cite_note-Zirker2002-15-75)

The [proton–proton chain](https://en.wikipedia.org/wiki/Proton%E2%80%93proton_chain) occurs around 9.2×1037 times each second in the core, converting about 3.7×1038 protons into [alpha particles](https://en.wikipedia.org/wiki/Alpha_particle) (helium nuclei) every second (out of a total of ~8.9×1056 free protons in the Sun), or about 6.2×1011 kg/s.[[51]](https://en.wikipedia.org/wiki/Sun#cite_note-Phillips1995-47-54) Fusing four free [protons](https://en.wikipedia.org/wiki/Proton) (hydrogen nuclei) into a single [alpha particle](https://en.wikipedia.org/wiki/Alpha_particle) (helium nuclei) releases around 0.7% of the fused mass as energy,[[72]](https://en.wikipedia.org/wiki/Sun#cite_note-76) so the Sun releases energy at the mass–energy conversion rate of 4.26 million metric tons per second, for 384.6 [yottawatts](https://en.wikipedia.org/wiki/Yotta-) (3.846×1026 W),[[1]](https://en.wikipedia.org/wiki/Sun#cite_note-nssdc-1) or 9.192×1010 [megatons](https://en.wikipedia.org/wiki/TNT_equivalent) of [TNT](https://en.wikipedia.org/wiki/Trinitrotoluene) per second. Theoretical models of the Sun's interior indicate a power density of approximately 276.5 W/m3,[[73]](https://en.wikipedia.org/wiki/Sun#cite_note-77) a value that more nearly approximates reptile metabolism than a thermonuclear bomb.[[e]](https://en.wikipedia.org/wiki/Sun#cite_note-power_production_density-78)

The fusion rate in the core is in a self-correcting equilibrium: a slightly higher rate of fusion would cause the core to heat up more and [expand](https://en.wikipedia.org/wiki/Thermal_expansion) slightly against the weight of the outer layers, reducing the density and hence the fusion rate and correcting the [perturbation](https://en.wikipedia.org/wiki/Perturbation_(astronomy)); and a slightly lower rate would cause the core to cool and shrink slightly, increasing the density and increasing the fusion rate and again reverting it to its present rate.[[74]](https://en.wikipedia.org/wiki/Sun#cite_note-79)[[75]](https://en.wikipedia.org/wiki/Sun#cite_note-80)

### Radiative zone

*Main article:*[*Radiative zone*](https://en.wikipedia.org/wiki/Radiative_zone)

From the core out to about 0.7 solar radii, [thermal radiation](https://en.wikipedia.org/wiki/Thermal_radiation) is the primary means of energy transfer.[[76]](https://en.wikipedia.org/wiki/Sun#cite_note-autogenerated1-81) The transfer of energy through this zone is by radiation not by thermal [convection](https://en.wikipedia.org/wiki/Convection). The temperature drops from approximately 7 million to 2 million kelvins with increasing distance from the core.[[68]](https://en.wikipedia.org/wiki/Sun#cite_note-NASA1-72) This [temperature gradient](https://en.wikipedia.org/wiki/Temperature_gradient) is less than the value of the [adiabatic lapse rate](https://en.wikipedia.org/wiki/Adiabatic_lapse_rate) and hence cannot drive convection, hence, energy is transferred by [radiation](https://en.wikipedia.org/wiki/Radiation).[[68]](https://en.wikipedia.org/wiki/Sun#cite_note-NASA1-72) [Ions](https://en.wikipedia.org/wiki/Ions) of [hydrogen](https://en.wikipedia.org/wiki/Hydrogen) and [helium](https://en.wikipedia.org/wiki/Helium) emit [photons](https://en.wikipedia.org/wiki/Photons), which travel only a brief distance before being reabsorbed by other ions.[[76]](https://en.wikipedia.org/wiki/Sun#cite_note-autogenerated1-81) The density drops a hundredfold (from 20 g/cm3 to only 0.2 g/cm3) from 0.25 solar radii to the 0.7 radii, the top of the radiative zone.[[76]](https://en.wikipedia.org/wiki/Sun#cite_note-autogenerated1-81)

### Tachocline

*Main article:*[*Tachocline*](https://en.wikipedia.org/wiki/Tachocline)

The radiative zone and the convective zone are separated by a transition layer, the [tachocline](https://en.wikipedia.org/wiki/Tachocline). This is a region where the sharp regime change between the uniform rotation of the radiative zone and the differential rotation of the convection zone results in a large shear between the two—a condition where successive horizontal layers slide past one another.[[77]](https://en.wikipedia.org/wiki/Sun#cite_note-82) The fluid motion of the convection zone above, slowly disappears from the top of this layer to its bottom where it matches that of the radiative zone. Presently, it is hypothesized (see [Solar dynamo](https://en.wikipedia.org/wiki/Solar_dynamo)) that a magnetic dynamo within this layer generates the Sun's [magnetic field](https://en.wikipedia.org/wiki/Magnetic_field).[[68]](https://en.wikipedia.org/wiki/Sun#cite_note-NASA1-72)

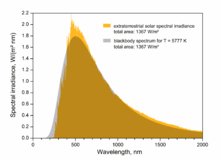
### Convective zone

*Main article:*[*Convection zone*](https://en.wikipedia.org/wiki/Convection_zone)

The Sun's convection zone extends from 0.7 solar radii (200,000 km) to near the surface. In this layer, the temperature is lower than in the radiative zone and heavier atoms are not fully ionized. As a result, radiative heat transport is less effective and convection moves the Sun's energy outward through this layer. The density of the plasma is low enough to allow convective currents to develop. Material heated at the tachocline picks up heat and expands, thereby reducing its density and allowing it to rise. As a result, an orderly motion of the mass develops into [thermal cells](https://en.wikipedia.org/wiki/Thermal) that carry the majority of the heat outward to the Sun's photosphere above. Once the material diffusively and radiatively cools just beneath the photospheric surface, its density increases, and it sinks to the base of the convection zone, where it again picks up heat from the top of the radiative zone and the convective cycle continues. At the photosphere, the temperature has dropped to 5,700 K and the density to only 0.2 g/m3 (about 1/6,000 the density of air at sea level).[[68]](https://en.wikipedia.org/wiki/Sun#cite_note-NASA1-72)

The thermal columns of the convection zone form an imprint on the surface of the Sun giving it a granular appearance called the [solar granulation](https://en.wikipedia.org/wiki/Granule_(solar_physics)) at the smallest scale and [supergranulation](https://en.wikipedia.org/wiki/Supergranulation) at larger scales. Turbulent convection in this outer part of the solar interior sustains "small-scale" dynamo action over the near-surface volume of the Sun.[[68]](https://en.wikipedia.org/wiki/Sun#cite_note-NASA1-72) The Sun's thermal columns are [Bénard cells](https://en.wikipedia.org/wiki/B%C3%A9nard_cells) and take the shape of hexagonal prisms.[[78]](https://en.wikipedia.org/wiki/Sun#cite_note-83)

### Photosphere

[](https://en.wikipedia.org/wiki/File:EffectiveTemperature_300dpi_e.png)

The [effective temperature](https://en.wikipedia.org/wiki/Effective_temperature), or [black body](https://en.wikipedia.org/wiki/Black_body) temperature, of the Sun (5,777 K) is the temperature a black body of the same size must have to yield the same total emissive power.

*Main article:*[*Photosphere*](https://en.wikipedia.org/wiki/Photosphere)

The visible surface of the Sun, the photosphere, is the layer below which the Sun becomes [opaque](https://en.wikipedia.org/wiki/Opacity_(optics)) to visible light.[[79]](https://en.wikipedia.org/wiki/Sun#cite_note-Abhyankar1977-84) Above the photosphere visible sunlight is free to propagate into space, and its energy escapes the Sun entirely. The change in opacity is due to the decreasing amount of [H− ions](https://en.wikipedia.org/wiki/Hydrogen_anion), which absorb visible light easily.[[79]](https://en.wikipedia.org/wiki/Sun#cite_note-Abhyankar1977-84) Conversely, the visible light we see is produced as electrons react with [hydrogen](https://en.wikipedia.org/wiki/Hydrogen) atoms to produce H− ions.[[80]](https://en.wikipedia.org/wiki/Sun#cite_note-Gibson-85)[[81]](https://en.wikipedia.org/wiki/Sun#cite_note-Shu-86)The photosphere is tens to hundreds of kilometers thick, and is slightly less opaque than air on Earth. Because the upper part of the photosphere is cooler than the lower part, an image of the Sun appears brighter in the center than on the edge or *limb* of the solar disk, in a phenomenon known as [limb darkening](https://en.wikipedia.org/wiki/Limb_darkening).[[79]](https://en.wikipedia.org/wiki/Sun#cite_note-Abhyankar1977-84) The spectrum of sunlight has approximately the spectrum of a [black-body](https://en.wikipedia.org/wiki/Black-body) radiating at about 6,000 [K](https://en.wikipedia.org/wiki/Kelvin), interspersed with atomic[absorption lines](https://en.wikipedia.org/wiki/Absorption_line) from the tenuous layers above the photosphere. The photosphere has a particle density of ~1023 m−3 (about 0.37% of the particle number per volume of [Earth's atmosphere](https://en.wikipedia.org/wiki/Earth%27s_atmosphere) at sea level). The photosphere is not fully ionized—the extent of ionization is about 3%, leaving almost all of the hydrogen in atomic form.[[82]](https://en.wikipedia.org/wiki/Sun#cite_note-87)

During early studies of the [optical spectrum](https://en.wikipedia.org/wiki/Optical_spectrum) of the photosphere, some absorption lines were found that did not correspond to any [chemical elements](https://en.wikipedia.org/wiki/Chemical_element) then known on Earth. In 1868, [Norman Lockyer](https://en.wikipedia.org/wiki/Norman_Lockyer) hypothesized that these absorption lines were caused by a new element that he dubbed [*helium*](https://en.wikipedia.org/wiki/Helium), after the Greek Sun god [Helios](https://en.wikipedia.org/wiki/Helios). Twenty-five years later, helium was isolated on Earth.[[83]](https://en.wikipedia.org/wiki/Sun#cite_note-Lockyer-88)

### Atmosphere

*See also:*[*Corona*](https://en.wikipedia.org/wiki/Corona)*and*[*Coronal loop*](https://en.wikipedia.org/wiki/Coronal_loop)

[](https://en.wikipedia.org/wiki/File:Solar_eclipse_1999_4_NR.jpg)

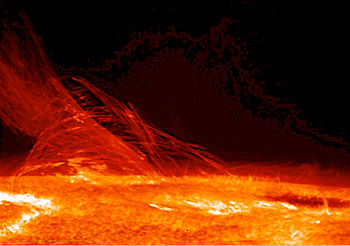
During a total [solar eclipse](https://en.wikipedia.org/wiki/Solar_eclipse), the solar[corona](https://en.wikipedia.org/wiki/Corona) can be seen with the naked eye, during the brief period of totality.

During a total [solar eclipse](https://en.wikipedia.org/wiki/Solar_eclipse), when the disk of the Sun is covered by that of the Moon, parts of the Sun's surrounding atmosphere can be seen. It is composed of four distinct parts: the [chromosphere](https://en.wikipedia.org/wiki/Chromosphere), the [transition region](https://en.wikipedia.org/wiki/Solar_transition_region), the[corona](https://en.wikipedia.org/wiki/Corona) and the [heliosphere](https://en.wikipedia.org/wiki/Heliosphere).

The coolest layer of the Sun is a temperature minimum region extending to about 500 km above the photosphere, and has a temperature of about 4,100 [K](https://en.wikipedia.org/wiki/Kelvin).[[79]](https://en.wikipedia.org/wiki/Sun#cite_note-Abhyankar1977-84) This part of the Sun is cool enough to allow the existence of simple molecules such as [carbon monoxide](https://en.wikipedia.org/wiki/Carbon_monoxide) and water, which can be detected via their absorption spectra.[[84]](https://en.wikipedia.org/wiki/Sun#cite_note-Solanki1994-89)

The chromosphere, transition region, and corona are much hotter than the surface of the Sun.[[79]](https://en.wikipedia.org/wiki/Sun#cite_note-Abhyankar1977-84) The reason is not well understood, but evidence suggests that [Alfvén waves](https://en.wikipedia.org/wiki/Alfv%C3%A9n_wave) may have enough energy to heat the corona.[[85]](https://en.wikipedia.org/wiki/Sun#cite_note-90)

Above the temperature minimum layer is a layer about 2,000 km thick, dominated by a spectrum of emission and absorption lines.[[79]](https://en.wikipedia.org/wiki/Sun#cite_note-Abhyankar1977-84) It is called the *chromosphere* from the Greek root *chroma*, meaning color, because the chromosphere is visible as a colored flash at the beginning and end of total [solar eclipses](https://en.wikipedia.org/wiki/Solar_eclipse).[[76]](https://en.wikipedia.org/wiki/Sun#cite_note-autogenerated1-81) The temperature of the chromosphere increases gradually with altitude, ranging up to around 20,000 K near the top.[[79]](https://en.wikipedia.org/wiki/Sun#cite_note-Abhyankar1977-84) In the upper part of the chromosphere [helium](https://en.wikipedia.org/wiki/Helium) becomes partially [ionized](https://en.wikipedia.org/wiki/Ionization).[[86]](https://en.wikipedia.org/wiki/Sun#cite_note-Hansteen1997-91)

[](https://en.wikipedia.org/wiki/File:171879main_LimbFlareJan12_lg.jpg)

Taken by [Hinode](https://en.wikipedia.org/wiki/Hinode)'s Solar Optical Telescope on 12 January 2007, this image of the Sun reveals the filamentary nature of the plasma connecting regions of different magnetic polarity.

Above the chromosphere, in a thin (about 200 km) [transition region](https://en.wikipedia.org/wiki/Solar_transition_region), the temperature rises rapidly from around 20,000 [K](https://en.wikipedia.org/wiki/Kelvin) in the upper chromosphere to coronal temperatures closer to 1,000,000 [K](https://en.wikipedia.org/wiki/Kelvin).[[87]](https://en.wikipedia.org/wiki/Sun#cite_note-Erdelyi2007-92) The temperature increase is facilitated by the full ionization of helium in the transition region, which significantly reduces radiative cooling of the plasma.[[86]](https://en.wikipedia.org/wiki/Sun#cite_note-Hansteen1997-91) The transition region does not occur at a well-defined altitude. Rather, it forms a kind of [nimbus](https://en.wikipedia.org/wiki/Halo_(optical_phenomenon)) around chromospheric features such as [spicules](https://en.wikipedia.org/wiki/Spicule_(solar_physics)) and [filaments](https://en.wikipedia.org/wiki/Solar_filament), and is in constant, chaotic motion.[[76]](https://en.wikipedia.org/wiki/Sun#cite_note-autogenerated1-81) The transition region is not easily visible from Earth's surface, but is readily observable from[space](https://en.wikipedia.org/wiki/Outer_space) by instruments sensitive to the [extreme ultraviolet](https://en.wikipedia.org/wiki/Extreme_ultraviolet) portion of the [spectrum](https://en.wikipedia.org/wiki/Electromagnetic_spectrum).[[88]](https://en.wikipedia.org/wiki/Sun#cite_note-Dwivedi2006-93)

The [corona](https://en.wikipedia.org/wiki/Corona) is the next layer of the Sun. The low corona, near the surface of the Sun, has a particle density around 1015 m−3 to 1016 m−3.[[86]](https://en.wikipedia.org/wiki/Sun#cite_note-Hansteen1997-91)[[f]](https://en.wikipedia.org/wiki/Sun#cite_note-particle_density-94) The average temperature of the corona and solar wind is about 1,000,000–2,000,000 K; however, in the hottest regions it is 8,000,000–20,000,000 K.[[87]](https://en.wikipedia.org/wiki/Sun#cite_note-Erdelyi2007-92) Although no complete theory yet exists to account for the temperature of the corona, at least some of its heat is known to be from [magnetic reconnection](https://en.wikipedia.org/wiki/Magnetic_reconnection).[[87]](https://en.wikipedia.org/wiki/Sun#cite_note-Erdelyi2007-92)[[89]](https://en.wikipedia.org/wiki/Sun#cite_note-Russell2001-95) The corona is the extended atmosphere of the Sun, which has a volume much larger than the volume enclosed by the Sun's photosphere. A flow of plasma outward from the Sun into interplanetary space is the [solar wind](https://en.wikipedia.org/wiki/Solar_wind).[[89]](https://en.wikipedia.org/wiki/Sun#cite_note-Russell2001-95)

The [heliosphere](https://en.wikipedia.org/wiki/Heliosphere), the tenuous outermost atmosphere of the Sun, is filled with the solar wind plasma. This outermost layer of the Sun is defined to begin at the distance where the flow of the [solar wind](https://en.wikipedia.org/wiki/Solar_wind)becomes *superalfvénic*—that is, where the flow becomes faster than the speed of [Alfvén waves](https://en.wikipedia.org/wiki/Alfv%C3%A9n_wave),[[90]](https://en.wikipedia.org/wiki/Sun#cite_note-96) at approximately 20 solar radii (0.1 AU). Turbulence and dynamic forces in the heliosphere cannot affect the shape of the solar corona within, because the information can only travel at the speed of Alfvén waves. The solar wind travels outward continuously through the heliosphere,[[91]](https://en.wikipedia.org/wiki/Sun#cite_note-97)[[92]](https://en.wikipedia.org/wiki/Sun#cite_note-98) forming the solar magnetic field into a [spiral](https://en.wikipedia.org/wiki/Parker_spiral) shape,[[89]](https://en.wikipedia.org/wiki/Sun#cite_note-Russell2001-95) until it impacts the [heliopause](https://en.wikipedia.org/wiki/Heliopause_(astronomy)) more than 50 [AU](https://en.wikipedia.org/wiki/Astronomical_unit) from the Sun. In December 2004, the [Voyager 1](https://en.wikipedia.org/wiki/Voyager_1) probe passed through a shock front that is thought to be part of the heliopause.[[93]](https://en.wikipedia.org/wiki/Sun#cite_note-99) In late 2012 Voyager 1 recorded a marked increase in [cosmic ray](https://en.wikipedia.org/wiki/Cosmic_ray) collisions and a sharp drop in lower energy particles from the solar wind, which suggested that the probe had passed through the heliopause and entered the [interstellar medium](https://en.wikipedia.org/wiki/Interstellar_medium).[[94]](https://en.wikipedia.org/wiki/Sun#cite_note-100)

### Photons and neutrinos

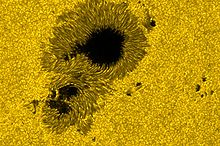
High-energy [gamma-ray](https://en.wikipedia.org/wiki/Gamma_ray) photons initially released with fusion reactions in the core are almost immediately absorbed by the solar plasma of the radiative zone, usually after traveling only a few millimeters. Re-emission happens in a random direction and usually at a slightly lower energy. With this sequence of emissions and absorptions, it takes a long time for radiation to reach the Sun's surface. Estimates of the photon travel time range between 10,000 and 170,000 years.[[95]](https://en.wikipedia.org/wiki/Sun#cite_note-NASA-101) In contrast, it takes only 2.3 seconds for the[neutrinos](https://en.wikipedia.org/wiki/Neutrino), which account for about 2% of the total energy production of the Sun, to reach the surface. Because energy transport in the Sun is a process that involves photons in thermodynamic equilibrium with matter, the time scale of energy transport in the Sun is longer, on the order of 30,000,000 years. This is the time it would take the Sun to return to a stable state, if the rate of energy generation in its core were suddenly changed.[[96]](https://en.wikipedia.org/wiki/Sun#cite_note-102)

Neutrinos are also released by the fusion reactions in the core, but, unlike photons, they rarely interact with matter, so almost all are able to escape the Sun immediately. For many years measurements of the number of neutrinos produced in the Sun were [lower than theories predicted](https://en.wikipedia.org/wiki/Solar_neutrino_problem) by a factor of 3. This discrepancy was resolved in 2001 through the discovery of the effects of [neutrino oscillation](https://en.wikipedia.org/wiki/Neutrino_oscillation): the Sun emits the number of neutrinos predicted by the [theory](https://en.wikipedia.org/wiki/Theory), but neutrino detectors were missing 2⁄3 of them because the neutrinos had changed [flavor](https://en.wikipedia.org/wiki/Flavor_(particle_physics)) by the time they were detected.[[97]](https://en.wikipedia.org/wiki/Sun#cite_note-Schlattl-103)

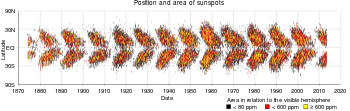
## Magnetism and activity

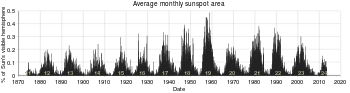
### Magnetic field

*See also:*[*Stellar magnetic field*](https://en.wikipedia.org/wiki/Stellar_magnetic_field)*,*[*Sunspots*](https://en.wikipedia.org/wiki/Sunspots)*,*[*List of solar cycles*](https://en.wikipedia.org/wiki/List_of_solar_cycles)*, and*[*Solar phenomena*](https://en.wikipedia.org/wiki/Solar_phenomena)

[](https://en.wikipedia.org/wiki/File:172197main_NASA_Flare_Gband_lg-withouttext.jpg)

Visible light photograph of sunspot, 13 December 2006

[](https://en.wikipedia.org/wiki/File:Sunspot_butterfly_diagram.svg)

[](https://en.wikipedia.org/wiki/File:Sunspot_area_variation.svg)

[Butterfly diagram](https://en.wikipedia.org/wiki/Solar_cycle#Sunspots) showing paired sunspot pattern. Graph is of sunspot area.

[](https://en.wikipedia.org/wiki/File:Sun_-_August_1,_2010.jpg)

In this false-color ultraviolet image, the Sun shows a C3-class solar flare (white area on upper left), a solar tsunami (wave-like structure, upper right) and multiple filaments of [plasma](https://en.wikipedia.org/wiki/Plasma_(physics))following a magnetic field, rising from the stellar surface.

[](https://en.wikipedia.org/wiki/File:Heliospheric-current-sheet.gif)

The [heliospheric current sheet](https://en.wikipedia.org/wiki/Heliospheric_current_sheet)extends to the outer reaches of the Solar System, and results from the influence of the Sun's rotating magnetic field on the [plasma](https://en.wikipedia.org/wiki/Plasma_(physics)) in the [interplanetary medium](https://en.wikipedia.org/wiki/Interplanetary_medium).[[98]](https://en.wikipedia.org/wiki/Sun#cite_note-104)

The Sun has a [magnetic field](https://en.wikipedia.org/wiki/Magnetic_field) that varies across the surface of the Sun. Its polar field is 1–2 [gauss](https://en.wikipedia.org/wiki/Gauss_(unit)) (0.0001–0.0002 [T](https://en.wikipedia.org/wiki/Tesla_(unit))), whereas the field is typically 3,000 gauss (0.3 T) in features on the Sun called [sunspots](https://en.wikipedia.org/wiki/Sunspot) and 10–100 gauss (0.001–0.01 T) in [solar prominences](https://en.wikipedia.org/wiki/Solar_prominence).[[1]](https://en.wikipedia.org/wiki/Sun#cite_note-nssdc-1)

The magnetic field also varies in time and location. The quasi-periodic 11-year [solar cycle](https://en.wikipedia.org/wiki/Solar_cycle) is the most prominent variation in which the number and size of sunspots waxes and wanes.[[15]](https://en.wikipedia.org/wiki/Sun#cite_note-doi10.1146.2Fannurev-astro-081913-040012-15)[[99]](https://en.wikipedia.org/wiki/Sun#cite_note-Zirker2002-119-105)[[100]](https://en.wikipedia.org/wiki/Sun#cite_note-Lang-106)

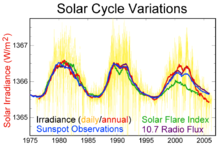
Sunspots are visible as dark patches on the Sun's [photosphere](https://en.wikipedia.org/wiki/Photosphere), and correspond to concentrations of magnetic field where the [convective transport](https://en.wikipedia.org/wiki/Convection) of heat is inhibited from the solar interior to the surface. As a result, sunspots are slightly cooler than the surrounding photosphere, and, so, they appear dark. At a typical [solar minimum](https://en.wikipedia.org/wiki/Solar_minimum), few sunspots are visible, and occasionally none can be seen at all. Those that do appear are at high solar latitudes. As the solar cycle progresses towards its [maximum](https://en.wikipedia.org/wiki/Solar_maximum), sunspots tend form closer to the solar equator, a phenomenon known as [Spörer's law](https://en.wikipedia.org/wiki/Sp%C3%B6rer%27s_law). The largest sunspots can be tens of thousands of kilometers across.[[101]](https://en.wikipedia.org/wiki/Sun#cite_note-Sunspot2001-107)

An 11-year sunspot cycle is half of a 22-year [Babcock](https://en.wikipedia.org/wiki/Babcock_Model)–Leighton [dynamo](https://en.wikipedia.org/wiki/Solar_dynamo) cycle, which corresponds to an oscillatory exchange of energy between [toroidal and poloidal](https://en.wikipedia.org/wiki/Toroidal_and_poloidal) solar magnetic fields. At [solar-cycle maximum](https://en.wikipedia.org/wiki/Solar_maximum), the external poloidal dipolar magnetic field is near its dynamo-cycle minimum strength, but an internal [toroidal](https://en.wikipedia.org/wiki/Toroidal_and_poloidal) quadrupolar field, generated through differential rotation within the tachocline, is near its maximum strength. At this point in the dynamo cycle, buoyant upwelling within the convective zone forces emergence of toroidal magnetic field through the photosphere, giving rise to pairs of sunspots, roughly aligned east–west and having footprints with opposite magnetic polarities. The magnetic polarity of sunspot pairs alternates every solar cycle, a phenomenon known as the Hale cycle.[[102]](https://en.wikipedia.org/wiki/Sun#cite_note-108)[[103]](https://en.wikipedia.org/wiki/Sun#cite_note-solarcycle-109)

During the solar cycle’s declining phase, energy shifts from the internal toroidal magnetic field to the external poloidal field, and sunspots diminish in number. At [solar-cycle minimum](https://en.wikipedia.org/wiki/Solar_minimum), the toroidal field is, correspondingly, at minimum strength, sunspots are relatively rare, and the poloidal field is at its maximum strength. With the rise of the next 11-year sunspot cycle, differential rotation shifts magnetic energy back from the poloidal to the toroidal field, but with a polarity that is opposite to the previous cycle. The process carries on continuously, and in an idealized, simplified scenario, each 11-year sunspot cycle corresponds to a change, then, in the overall polarity of the Sun's large-scale magnetic field.[[104]](https://en.wikipedia.org/wiki/Sun#cite_note-110)[[105]](https://en.wikipedia.org/wiki/Sun#cite_note-111)

The solar magnetic field extends well beyond the Sun itself. The electrically conducting solar wind plasma carries the Sun's magnetic field into space, forming what is called the [interplanetary magnetic field](https://en.wikipedia.org/wiki/Interplanetary_magnetic_field).[[89]](https://en.wikipedia.org/wiki/Sun#cite_note-Russell2001-95) In an approximation known as ideal [magnetohydrodynamics](https://en.wikipedia.org/wiki/Magnetohydrodynamics), plasma particles only move along the magnetic field lines. As a result, the outward-flowing solar wind stretches the interplanetary magnetic field outward, forcing it into a roughly radial structure. For a simple dipolar solar magnetic field, with opposite hemispherical polarities on either side of the solar magnetic equator, a thin [current sheet](https://en.wikipedia.org/wiki/Heliospheric_current_sheet) is formed in the solar wind.[[89]](https://en.wikipedia.org/wiki/Sun#cite_note-Russell2001-95) At great distances, the rotation of the Sun twists the dipolar magnetic field and corresponding current sheet into an [Archimedean spiral](https://en.wikipedia.org/wiki/Archimedean_spiral) structure called the [Parker spiral](https://en.wikipedia.org/wiki/Parker_spiral).[[89]](https://en.wikipedia.org/wiki/Sun#cite_note-Russell2001-95) The interplanetary magnetic field is much stronger than the dipole component of the solar magnetic field. The Sun's dipole magnetic field of 50–400 [μT](https://en.wikipedia.org/wiki/Tesla_(unit)) (at the photosphere) reduces with the inverse-cube of the distance to about 0.1 nT at the distance of Earth. However, according to spacecraft observations the interplanetary field at Earth's location is around 5 nT, about a hundred times greater.[[106]](https://en.wikipedia.org/wiki/Sun#cite_note-Wang2003-112) The difference is due to magnetic fields generated by electrical currents in the plasma surrounding the Sun.

### Variation in activity

[](https://en.wikipedia.org/wiki/File:Solar-cycle-data.png)

Measurements of solar cycle variation during the last 30 years

The Sun's magnetic field leads to many effects that are collectively called [solar activity](https://en.wikipedia.org/wiki/Solar_variation). [Solar flares](https://en.wikipedia.org/wiki/Solar_flares) and [coronal-mass ejections](https://en.wikipedia.org/wiki/Coronal_mass_ejections) tend to occur at sunspot groups. Slowly changing high-speed streams of [solar wind](https://en.wikipedia.org/wiki/Solar_wind) are emitted from [coronal holes](https://en.wikipedia.org/wiki/Coronal_holes) at the photospheric surface. Both coronal-mass ejections and high-speed streams of solar wind carry plasma and [interplanetary magnetic field](https://en.wikipedia.org/wiki/Interplanetary_magnetic_field) outward into the Solar System.[[107]](https://en.wikipedia.org/wiki/Sun#cite_note-Zirker2002-113) The effects of solar activity on Earth include [auroras](https://en.wikipedia.org/wiki/Aurora_(astronomy)) at moderate to high latitudes and the disruption of radio communications and [electric power](https://en.wikipedia.org/wiki/Electric_power). Solar activity is thought to have played a large role in the [formation and evolution of the Solar System](https://en.wikipedia.org/wiki/Formation_and_evolution_of_the_Solar_System).

With solar-cycle modulation of sunspot number comes a corresponding modulation of [space weather](https://en.wikipedia.org/wiki/Space_weather) conditions, including those surrounding Earth where technological systems can be affected.

### Long-term change

Long-term secular change in sunspot number is thought, by some scientists, to be correlated with long-term change in solar irradiance,[[108]](https://en.wikipedia.org/wiki/Sun#cite_note-114) which, in turn, might influence Earth's long-term climate.[[109]](https://en.wikipedia.org/wiki/Sun#cite_note-115) For example, in the 17th century, the solar cycle appeared to have stopped entirely for several decades; few sunspots were observed during a period known as the [Maunder minimum](https://en.wikipedia.org/wiki/Maunder_minimum). This coincided in time with the era of the [Little Ice Age](https://en.wikipedia.org/wiki/Little_Ice_Age), when Europe experienced unusually cold temperatures.[[110]](https://en.wikipedia.org/wiki/Sun#cite_note-Lean-116) Earlier extended minima have been discovered through analysis of [tree rings](https://en.wikipedia.org/wiki/Tree_ring) and appear to have coincided with lower-than-average global temperatures.[[111]](https://en.wikipedia.org/wiki/Sun#cite_note-117)

A recent theory claims that there are magnetic instabilities in the core of the Sun that cause fluctuations with periods of either 41,000 or 100,000 years. These could provide a better explanation of the [ice ages](https://en.wikipedia.org/wiki/Ice_age) than the[Milankovitch cycles](https://en.wikipedia.org/wiki/Milankovitch_cycles).[[112]](https://en.wikipedia.org/wiki/Sun#cite_note-118)[[113]](https://en.wikipedia.org/wiki/Sun#cite_note-119)

## Life phases

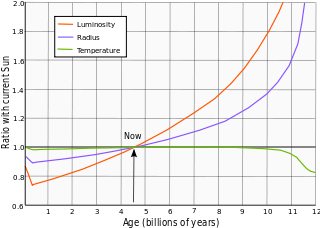
*Main articles:*[*Formation and evolution of the Solar System*](https://en.wikipedia.org/wiki/Formation_and_evolution_of_the_Solar_System)*and*[*Stellar evolution*](https://en.wikipedia.org/wiki/Stellar_evolution)

The Sun today is roughly halfway through the most stable part of its life. It has not changed dramatically for over four billion[[a]](https://en.wikipedia.org/wiki/Sun#cite_note-short-18) years, and will remain fairly stable for more than five billion more. However, after hydrogen fusion in its core has stopped, the Sun will undergo severe changes, both internally and externally.

### Formation

The Sun formed about 4.6 billion years ago from the collapse of part of a giant [molecular cloud](https://en.wikipedia.org/wiki/Molecular_cloud) that consisted mostly of hydrogen and helium and that probably gave birth to many other stars.[[114]](https://en.wikipedia.org/wiki/Sun#cite_note-Zirker2002-7-120) This age is estimated using[computer models](https://en.wikipedia.org/wiki/Computer_simulation) of [stellar evolution](https://en.wikipedia.org/wiki/Stellar_evolution) and through [nucleocosmochronology](https://en.wikipedia.org/wiki/Nucleocosmochronology).[[9]](https://en.wikipedia.org/wiki/Sun#cite_note-Bonanno-9) The result is consistent with the [radiometric date](https://en.wikipedia.org/wiki/Radiometric_dating) of the oldest Solar System material, at 4.567 billion years ago.[[115]](https://en.wikipedia.org/wiki/Sun#cite_note-121)[[116]](https://en.wikipedia.org/wiki/Sun#cite_note-nature436-122) Studies of ancient [meteorites](https://en.wikipedia.org/wiki/Meteorite)reveal traces of stable daughter nuclei of short-lived isotopes, such as [iron-60](https://en.wikipedia.org/wiki/Iron-60), that form only in exploding, short-lived stars. This indicates that one or more supernovae must have occurred near the location where the Sun formed. A [shock wave](https://en.wikipedia.org/wiki/Shock_wave) from a nearby supernova would have triggered the formation of the Sun by compressing the matter within the molecular cloud and causing certain regions to collapse under their own gravity.[[117]](https://en.wikipedia.org/wiki/Sun#cite_note-123) As one fragment of the cloud collapsed it also began to rotate because of [conservation of angular momentum](https://en.wikipedia.org/wiki/Conservation_of_angular_momentum) and heat up with the increasing pressure. Much of the mass became concentrated in the center, whereas the rest flattened out into a disk that would become the planets and other Solar System bodies. Gravity and pressure within the core of the cloud generated a lot of heat as it accreted more matter from the surrounding disk, eventually triggering[nuclear fusion](https://en.wikipedia.org/wiki/Stellar_nucleosynthesis). Thus, the Sun was born.

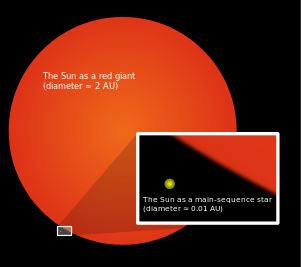
### Main sequence

[](https://en.wikipedia.org/wiki/File:Solar_evolution_(English).svg)

Evolution of the Sun's [luminosity](https://en.wikipedia.org/wiki/Solar_luminosity), [radius](https://en.wikipedia.org/wiki/Solar_radius) and [effective temperature](https://en.wikipedia.org/wiki/Effective_temperature) compared to the present Sun. After Ribas (2010)[[118]](https://en.wikipedia.org/wiki/Sun#cite_note-ribas2010-124)

The Sun is about halfway through its [main-sequence](https://en.wikipedia.org/wiki/Main_sequence) stage, during which nuclear fusion reactions in its core fuse hydrogen into helium. Each second, more than four million [tonnes](https://en.wikipedia.org/wiki/Tonne) of matter are converted into energy within the Sun's core, producing [neutrinos](https://en.wikipedia.org/wiki/Neutrino) and [solar radiation](https://en.wikipedia.org/wiki/Solar_radiation). At this rate, the Sun has so far converted around 100 times the mass of Earth into energy, about 0.03% of the total mass of the Sun. The Sun will spend a total of approximately 10 [billion](https://en.wikipedia.org/wiki/1000000000_(number)) years as a main-sequence star.[[119]](https://en.wikipedia.org/wiki/Sun#cite_note-125) The Sun is gradually becoming hotter during its time on the main sequence, because the helium atoms in the core occupy less volume than the [hydrogen atoms](https://en.wikipedia.org/wiki/Hydrogen_atom) that were fused. The core is therefore shrinking, allowing the outer layers of the Sun to move closer to the centre and experience a stronger gravitational force, according to the [inverse-square law](https://en.wikipedia.org/wiki/Inverse-square_law). This stronger force increases the pressure on the core, which is resisted by a gradual increase in the rate at which fusion occurs. This process speeds up as the core gradually becomes denser. It is estimated that the Sun has become 30% brighter in the last 4.5 billion years.[[120]](https://en.wikipedia.org/wiki/Sun#cite_note-126) At present, it is increasing in brightness by about 1% every 100 million years.[[121]](https://en.wikipedia.org/wiki/Sun#cite_note-127)

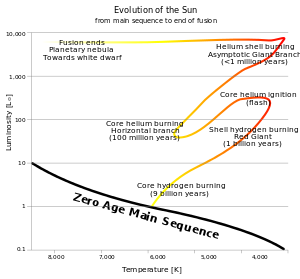
### After core hydrogen exhaustion

[](https://en.wikipedia.org/wiki/File:Sun_red_giant.svg)

The size of the current Sun (now in the [main sequence](https://en.wikipedia.org/wiki/Main_sequence)) compared to its estimated size during its red-giant phase in the future

The Sun does not have enough mass to explode as a [supernova](https://en.wikipedia.org/wiki/Supernova). Instead it will exit the [main sequence](https://en.wikipedia.org/wiki/Main_sequence) in approximately 5 billion years and start to turn into a [red giant](https://en.wikipedia.org/wiki/Red_giant).[[122]](https://en.wikipedia.org/wiki/Sun#cite_note-128)[[123]](https://en.wikipedia.org/wiki/Sun#cite_note-schroder-129) As a red giant, the Sun will grow so large that it will engulf Mercury, Venus, and probably Earth.[[123]](https://en.wikipedia.org/wiki/Sun#cite_note-schroder-129)[[124]](https://en.wikipedia.org/wiki/Sun#cite_note-sackmann-130)

Even before it becomes a red giant, the luminosity of the Sun will have nearly doubled, and Earth will be hotter than Venus is today. Once the core hydrogen is exhausted in 5.4 billion years, the Sun will expand into a [subgiant](https://en.wikipedia.org/wiki/Subgiant) phase and slowly double in size over about half a billion years. It will then expand more rapidly over about half a billion years until it is over two hundred times larger than today and a couple of thousand times more luminous. This then starts the[red-giant-branch](https://en.wikipedia.org/wiki/Red_giant_branch) phase where the Sun will spend around a billion years and lose around a third of its mass.[[123]](https://en.wikipedia.org/wiki/Sun#cite_note-schroder-129)

[](https://en.wikipedia.org/wiki/File:Evolution_of_a_Sun-like_star.svg)

Evolution of a Sun-like star. The track of a one solar mass star on the [Hertzsprung–Russell diagram](https://en.wikipedia.org/wiki/Hertzsprung%E2%80%93Russell_diagram)is shown from the main sequence to the post-asymptotic-giant-branch stage.

After the red-giant branch the Sun has approximately 120 million years of active life left, but much happens. First, the core, full of [degenerate](https://en.wikipedia.org/wiki/Degenerate_matter) helium ignites violently in the [helium flash](https://en.wikipedia.org/wiki/Helium_flash), where it is estimated that 6% of the core, itself 40% of the Sun's mass, will be converted into carbon within a matter of minutes through the [triple-alpha process](https://en.wikipedia.org/wiki/Triple-alpha_process).[[125]](https://en.wikipedia.org/wiki/Sun#cite_note-131) The Sun then shrinks to around 10 times its current size and 50 times the luminosity, with a temperature a little lower than today. It will then have reached the [red clump](https://en.wikipedia.org/wiki/Red_clump) or [horizontal branch](https://en.wikipedia.org/wiki/Horizontal_branch), but a star of the Sun's mass does not evolve blueward along the horizontal branch. Instead, it just becomes moderately larger and more luminous over about 100 million years as it continues to burn helium in the core.[[123]](https://en.wikipedia.org/wiki/Sun#cite_note-schroder-129)

When the helium is exhausted, the Sun will repeat the expansion it followed when the hydrogen in the core was exhausted, except that this time it all happens faster, and the Sun becomes larger and more luminous. This is the [asymptotic-giant-branch](https://en.wikipedia.org/wiki/Asymptotic_giant_branch) phase, and the Sun is alternately burning hydrogen in a shell or helium in a deeper shell. After about 20 million years on the early asymptotic giant branch, the Sun becomes increasingly unstable, with rapid mass loss and[thermal pulses](https://en.wikipedia.org/wiki/Thermal_pulse) that increase the size and luminosity for a few hundred years every 100,000 years or so. The thermal pulses become larger each time, with the later pulses pushing the luminosity to as much as 5,000 times the current level and the radius to over 1 AU.[[126]](https://en.wikipedia.org/wiki/Sun#cite_note-agb-132) According to a 2008 model, Earth's orbit is shrinking due to [tidal forces](https://en.wikipedia.org/wiki/Tidal_forces) (and, eventually, drag from the lower [chromosphere](https://en.wikipedia.org/wiki/Chromosphere)), so that it is engulfed by the Sun near the end of the asymptotic-giant-branch phase. Models vary depending on the rate and timing of mass loss. Models that have higher mass loss on the red-giant branch produce smaller, less luminous stars at the tip of the asymptotic giant branch, perhaps only 2,000 times the luminosity and less than 200 times the radius.[[123]](https://en.wikipedia.org/wiki/Sun#cite_note-schroder-129) For the Sun, four thermal pulses are predicted before it completely loses its outer envelope and starts to make a [planetary nebula](https://en.wikipedia.org/wiki/Planetary_nebula). By the end of that phase – lasting approximately 500,000 years – the Sun will only have about half of its current mass.

The post-asymptotic-giant-branch evolution is even faster. The luminosity stays approximately constant as the temperature increases, with the ejected half of the Sun's mass becoming ionised into a [planetary nebula](https://en.wikipedia.org/wiki/Planetary_nebula) as the exposed core reaches 30,000 K. The final naked core temperature will be over 100,000 K, after which the remnant will cool towards a [white dwarf](https://en.wikipedia.org/wiki/White_dwarf) that contains an estimated 54.05% of the Sun's present day mass.[[123]](https://en.wikipedia.org/wiki/Sun#cite_note-schroder-129) The planetary nebula will disperse in about 10,000 years, but the white dwarf will survive for trillions of years before fading to [black](https://en.wikipedia.org/wiki/Black_dwarf).[[127]](https://en.wikipedia.org/wiki/Sun#cite_note-bloecker1-133)[[128]](https://en.wikipedia.org/wiki/Sun#cite_note-bloecker2-134)

## Motion and location

### Orbit in Milky Way

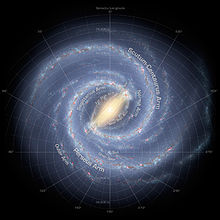
[](https://en.wikipedia.org/wiki/File:236084main_MilkyWay-full-annotated.jpg)

Illustration of the Milky Way, showing the location of the Sun

The Sun lies close to the inner rim of the [Milky Way](https://en.wikipedia.org/wiki/Milky_Way)'s [Orion Arm](https://en.wikipedia.org/wiki/Orion_Arm), in the [Local Interstellar Cloud](https://en.wikipedia.org/wiki/Local_Interstellar_Cloud) or the [Gould Belt](https://en.wikipedia.org/wiki/Gould_Belt), at a distance of 7.5–8.5 [kpc](https://en.wikipedia.org/wiki/Kiloparsec) (25,000–28,000 light-years) from the [Galactic Center](https://en.wikipedia.org/wiki/Galactic_Center).[[129]](https://en.wikipedia.org/wiki/Sun#cite_note-135)[[130]](https://en.wikipedia.org/wiki/Sun#cite_note-136)[[131]](https://en.wikipedia.org/wiki/Sun#cite_note-distance1-137)[[132]](https://en.wikipedia.org/wiki/Sun#cite_note-distance2-138)[[133]](https://en.wikipedia.org/wiki/Sun#cite_note-distance3-139)[[134]](https://en.wikipedia.org/wiki/Sun#cite_note-eisenhaueretal2005-140) The Sun is contained within the [Local Bubble](https://en.wikipedia.org/wiki/Local_Bubble), a space of rarefied hot gas, possibly produced by the supernova remnant [Geminga](https://en.wikipedia.org/wiki/Geminga).[[135]](https://en.wikipedia.org/wiki/Sun#cite_note-141) The distance between the local arm and the next arm out, the[Perseus Arm](https://en.wikipedia.org/wiki/Perseus_Arm), is about 6,500 light-years.[[136]](https://en.wikipedia.org/wiki/Sun#cite_note-fn9-142) The Sun, and thus the Solar System, is found in what scientists call the [galactic habitable zone](https://en.wikipedia.org/wiki/Galactic_habitable_zone). The *Apex of the Sun's Way*, or the [solar apex](https://en.wikipedia.org/wiki/Solar_apex), is the direction that the Sun travels relative to other nearby stars. This motion is towards a point in the constellation [Hercules](https://en.wikipedia.org/wiki/Hercules_(constellation)), near the star [Vega](https://en.wikipedia.org/wiki/Vega). Of the 50 [nearest stellar systems](https://en.wikipedia.org/wiki/Nearest_stars) within 17 light-years from Earth (the closest being the red dwarf [Proxima Centauri](https://en.wikipedia.org/wiki/Proxima_Centauri) at approximately 4.2 light-years), the Sun ranks fourth in mass.[[137]](https://en.wikipedia.org/wiki/Sun#cite_note-143)

The sun is orbiting the center of the Milky Way, going in the direction of [Cygnus](https://en.wikipedia.org/wiki/Cygnus_(constellation)). The Sun's orbit around the Milky Way is expected to be roughly elliptical with the addition of perturbations due to the galactic spiral arms and non-uniform mass distributions. In addition the Sun oscillates up and down relative to the galactic plane approximately 2.7 times per orbit.[[138]](https://en.wikipedia.org/wiki/Sun#cite_note-144) It has been argued that the Sun's passage through the higher density spiral arms often coincides with [mass extinctions](https://en.wikipedia.org/wiki/Mass_extinction) on Earth, perhaps due to increased [impact events](https://en.wikipedia.org/wiki/Impact_events).[[139]](https://en.wikipedia.org/wiki/Sun#cite_note-extinction-145) It takes the Solar System about 225–250 million years to complete one orbit through the Milky Way (a [*galactic year*](https://en.wikipedia.org/wiki/Galactic_year)),[[140]](https://en.wikipedia.org/wiki/Sun#cite_note-fn10-146) so it is thought to have completed 20–25 orbits during the lifetime of the Sun. The [orbital speed](https://en.wikipedia.org/wiki/Orbital_speed) of the Solar System about the center of the Milky Way is approximately 251 km/s (156 mi/s).[[141]](https://en.wikipedia.org/wiki/Sun#cite_note-space.newscientist.com-147) At this speed, it takes around 1,190 years for the Solar System to travel a distance of 1 light-year, or 7 days to travel 1 [AU](https://en.wikipedia.org/wiki/Astronomical_unit).[[142]](https://en.wikipedia.org/wiki/Sun#cite_note-148)

The Milky Way is moving with respect to the [cosmic microwave background radiation](https://en.wikipedia.org/wiki/Cosmic_microwave_background_radiation) (CMB) in the direction of the constellation [Hydra](https://en.wikipedia.org/wiki/Hydra_(constellation)) with a speed of 550 km/s, and the Sun's resultant velocity with respect to the CMB is about 370 km/s in the direction of [Crater](https://en.wikipedia.org/wiki/Crater_(constellation)) or [Leo](https://en.wikipedia.org/wiki/Leo_(constellation)).[[143]](https://en.wikipedia.org/wiki/Sun#cite_note-149)

## Theoretical problems

[](https://en.wikipedia.org/wiki/File:Map_of_the_full_sun.jpg)

Map of the full Sun by STEREO and[SDO](https://en.wikipedia.org/wiki/Solar_Dynamics_Observatory) spacecraft

### Coronal heating problem

*Main article:*[*Corona*](https://en.wikipedia.org/wiki/Corona)

The temperature of the photosphere is approximately 6,000 K, whereas the temperature of the corona reaches 1,000,000–2,000,000 K.[[87]](https://en.wikipedia.org/wiki/Sun#cite_note-Erdelyi2007-92) The high temperature of the corona shows that it is heated by something other than direct [heat conduction](https://en.wikipedia.org/wiki/Heat_conduction) from the photosphere.[[89]](https://en.wikipedia.org/wiki/Sun#cite_note-Russell2001-95)

It is thought that the energy necessary to heat the corona is provided by turbulent motion in the convection zone below the photosphere, and two main mechanisms have been proposed to explain coronal heating.[[87]](https://en.wikipedia.org/wiki/Sun#cite_note-Erdelyi2007-92) The first is[wave](https://en.wikipedia.org/wiki/Wave) heating, in which sound, gravitational or magnetohydrodynamic waves are produced by turbulence in the convection zone.[[87]](https://en.wikipedia.org/wiki/Sun#cite_note-Erdelyi2007-92) These waves travel upward and dissipate in the corona, depositing their energy in the ambient matter in the form of heat.[[144]](https://en.wikipedia.org/wiki/Sun#cite_note-Alfven-150) The other is [magnetic](https://en.wikipedia.org/wiki/Magnetic_field) heating, in which magnetic energy is continuously built up by photospheric motion and released through [magnetic reconnection](https://en.wikipedia.org/wiki/Magnetic_reconnection) in the form of large [solar flares](https://en.wikipedia.org/wiki/Solar_flare) and myriad similar but smaller events—[nanoflares](https://en.wikipedia.org/wiki/Nanoflares).[[145]](https://en.wikipedia.org/wiki/Sun#cite_note-Parker2-151)

Currently, it is unclear whether waves are an efficient heating mechanism. All waves except [Alfvén waves](https://en.wikipedia.org/wiki/Alfv%C3%A9n_wave) have been found to dissipate or refract before reaching the corona.[[146]](https://en.wikipedia.org/wiki/Sun#cite_note-Sturrock-152) In addition, Alfvén waves do not easily dissipate in the corona. Current research focus has therefore shifted towards flare heating mechanisms.[[87]](https://en.wikipedia.org/wiki/Sun#cite_note-Erdelyi2007-92)

### Faint young Sun problem

*Main article:*[*Faint young Sun paradox*](https://en.wikipedia.org/wiki/Faint_young_Sun_paradox)

Theoretical models of the Sun's development suggest that 3.8 to 2.5 billion years ago, during the [Archean period](https://en.wikipedia.org/wiki/Archean), the Sun was only about 75% as bright as it is today. Such a weak star would not have been able to sustain liquid water on Earth's surface, and thus life should not have been able to develop. However, the geological record demonstrates that Earth has remained at a fairly constant temperature throughout its history, and that the young Earth was somewhat warmer than it is today. The consensus among scientists is that the atmosphere of the young Earth contained much larger quantities of [greenhouse gases](https://en.wikipedia.org/wiki/Greenhouse_gas) (such as [carbon dioxide](https://en.wikipedia.org/wiki/Carbon_dioxide), [methane](https://en.wikipedia.org/wiki/Methane) and/or [ammonia](https://en.wikipedia.org/wiki/Ammonia)) than are present today, which trapped enough heat to compensate for the smaller amount of [solar energy](https://en.wikipedia.org/wiki/Solar_energy) reaching it.[[147]](https://en.wikipedia.org/wiki/Sun#cite_note-Kasting-153)

## History of observation

The enormous effect of the Sun on Earth has been recognized since [prehistoric times](https://en.wikipedia.org/wiki/Prehistoric_times), and the Sun has been [regarded by some cultures](https://en.wikipedia.org/wiki/Solar_deity) as a [deity](https://en.wikipedia.org/wiki/Deity).

### Early understanding

[](https://en.wikipedia.org/wiki/File:Solvognen_DO-6865_2000.jpg)

The [Trundholm sun chariot](https://en.wikipedia.org/wiki/Trundholm_sun_chariot) pulled by a horse is a sculpture believed to be illustrating an important part of [Nordic Bronze Age](https://en.wikipedia.org/wiki/Nordic_Bronze_Age) mythology. The sculpture is probably from around 1350 [BC](https://en.wikipedia.org/wiki/Anno_Domini). It is displayed at the [National Museum of Denmark](https://en.wikipedia.org/wiki/National_Museum_of_Denmark).

*See also:*[*The Sun in culture*](https://en.wikipedia.org/wiki/The_Sun_in_culture)

The Sun has been an object of veneration in many cultures throughout human history. Humanity's most fundamental understanding of the Sun is as the luminous disk in the [sky](https://en.wikipedia.org/wiki/Sky), whose presence above the [horizon](https://en.wikipedia.org/wiki/Horizon) creates day and whose absence causes night. In many prehistoric and ancient cultures, the Sun was thought to be a [solar deity](https://en.wikipedia.org/wiki/Solar_deity) or other [supernatural](https://en.wikipedia.org/wiki/Supernatural) entity. [Worship of the Sun](https://en.wikipedia.org/wiki/Sun_worship) was central to civilizations such as the [ancient Egyptians](https://en.wikipedia.org/wiki/Ancient_Egypt), the[Inca](https://en.wikipedia.org/wiki/Inca) of South America and the [Aztecs](https://en.wikipedia.org/wiki/Aztec) of what is now [Mexico](https://en.wikipedia.org/wiki/Mexico). In religions such as [Hinduism](https://en.wikipedia.org/wiki/Hinduism), the Sun is still considered a god. Many ancient monuments were constructed with solar phenomena in mind; for example, stone[megaliths](https://en.wikipedia.org/wiki/Megalith) accurately mark the summer or winter [solstice](https://en.wikipedia.org/wiki/Solstice) (some of the most prominent megaliths are located in [Nabta Playa](https://en.wikipedia.org/wiki/Nabta_Playa), [Egypt](https://en.wikipedia.org/wiki/Egypt); [Mnajdra](https://en.wikipedia.org/wiki/Mnajdra), Malta and at [Stonehenge](https://en.wikipedia.org/wiki/Stonehenge), England); [Newgrange](https://en.wikipedia.org/wiki/Newgrange), a prehistoric human-built mount in Ireland, was designed to detect the winter solstice; the pyramid of [El Castillo](https://en.wikipedia.org/wiki/El_Castillo,_Chichen_Itza) at [Chichén Itzá](https://en.wikipedia.org/wiki/Chich%C3%A9n_Itz%C3%A1) in Mexico is designed to cast shadows in the shape of serpents climbing the [pyramid](https://en.wikipedia.org/wiki/Pyramid) at the vernal and autumn [equinoxes](https://en.wikipedia.org/wiki/Equinox).

The Egyptians portrayed the god [Ra](https://en.wikipedia.org/wiki/Ra) as being carried across the sky in a solar barque, accompanied by lesser gods, and to the Greeks, he was [Helios](https://en.wikipedia.org/wiki/Helios), carried by a chariot drawn by fiery horses. From the reign of [Elagabalus](https://en.wikipedia.org/wiki/Elagabalus) in the [late Roman Empire](https://en.wikipedia.org/wiki/Decline_of_the_Roman_Empire) the Sun's birthday was a holiday celebrated as [Sol Invictus](https://en.wikipedia.org/wiki/Sol_Invictus) (literally "Unconquered Sun") soon after the winter solstice, which may have been an antecedent to Christmas. Regarding the [fixed stars](https://en.wikipedia.org/wiki/Fixed_star), the Sun appears from Earth to revolve once a year along the [ecliptic](https://en.wikipedia.org/wiki/Ecliptic) through the [zodiac](https://en.wikipedia.org/wiki/Zodiac), and so Greek astronomers considered it to be one of the seven [planets](https://en.wikipedia.org/wiki/Planet) (Greek *planetes*, “wanderer”), after which the seven days of the week are named in some languages.[[148]](https://en.wikipedia.org/wiki/Sun#cite_note-oed-154)[[149]](https://en.wikipedia.org/wiki/Sun#cite_note-almagest-155)[[150]](https://en.wikipedia.org/wiki/Sun#cite_note-156)

### Development of scientific understanding

In the early first millennium BC, [Babylonian astronomers](https://en.wikipedia.org/wiki/Babylonian_astronomy) observed that the Sun's motion along the ecliptic is not uniform, though they did not know why; it is today known that this is due to the movement of [Earth](https://en.wikipedia.org/wiki/Earth) in an [elliptic orbit](https://en.wikipedia.org/wiki/Elliptic_orbit) around the Sun, with Earth moving faster when it is nearer to the Sun at [perihelion](https://en.wikipedia.org/wiki/Apsis) and moving slower when it is farther away at [aphelion](https://en.wikipedia.org/wiki/Apsis).[[151]](https://en.wikipedia.org/wiki/Sun#cite_note-157)

One of the first people to offer a scientific or philosophical explanation for the Sun was the [Greek](https://en.wikipedia.org/wiki/Ancient_Greece) [philosopher](https://en.wikipedia.org/wiki/Philosopher) [Anaxagoras](https://en.wikipedia.org/wiki/Anaxagoras), who reasoned that it is a giant flaming ball of metal even larger than the [Peloponnesus](https://en.wikipedia.org/wiki/Peloponnese) rather than the [chariot](https://en.wikipedia.org/wiki/Chariot) of [Helios](https://en.wikipedia.org/wiki/Helios), and that the [Moon](https://en.wikipedia.org/wiki/Moon)reflected the light of the Sun.[[152]](https://en.wikipedia.org/wiki/Sun#cite_note-158) For teaching this [heresy](https://en.wikipedia.org/wiki/Heresy), he was imprisoned by the authorities and [sentenced to death](https://en.wikipedia.org/wiki/Capital_punishment), though he was later released through the intervention of [Pericles](https://en.wikipedia.org/wiki/Pericles). [Eratosthenes](https://en.wikipedia.org/wiki/Eratosthenes) estimated the distance between Earth and the Sun in the 3rd century BC as "of stadia [myriads](https://en.wikipedia.org/wiki/Myriad) 400 and 80000", the translation of which is ambiguous, implying either 4,080,000 [stadia](https://en.wikipedia.org/wiki/Stadion_(unit)) (755,000 km) or 804,000,000 stadia (148 to 153 million kilometers or 0.99 to 1.02 AU); the latter value is correct to within a few percent. In the 1st century AD, [Ptolemy](https://en.wikipedia.org/wiki/Ptolemy) estimated the distance as 1,210 times [the radius of Earth](https://en.wikipedia.org/wiki/Earth_radius), approximately 7.71 million kilometers (0.0515 AU).[[153]](https://en.wikipedia.org/wiki/Sun#cite_note-159)

The theory that the Sun is the center around which the planets orbit was first proposed by the ancient Greek [Aristarchus of Samos](https://en.wikipedia.org/wiki/Aristarchus_of_Samos) in the 3rd century BC, and later adopted by [Seleucus of Seleucia](https://en.wikipedia.org/wiki/Seleucus_of_Seleucia) (see [Heliocentrism](https://en.wikipedia.org/wiki/Heliocentrism)). This view was developed in a more detailed[mathematical model](https://en.wikipedia.org/wiki/Mathematical_model) of a heliocentric system in the 16th century by [Nicolaus Copernicus](https://en.wikipedia.org/wiki/Nicolaus_Copernicus).

Observations of sunspots were recorded during the [Han Dynasty](https://en.wikipedia.org/wiki/Han_Dynasty) (206 BC–AD 220) by [Chinese astronomers](https://en.wikipedia.org/wiki/Chinese_astronomy), who maintained records of these observations for centuries. [Averroes](https://en.wikipedia.org/wiki/Averroes) also provided a description of sunspots in the 12th century.[[154]](https://en.wikipedia.org/wiki/Sun#cite_note-160) The invention of the[telescope](https://en.wikipedia.org/wiki/Telescope) in the early 17th century permitted detailed observations of [sunspots](https://en.wikipedia.org/wiki/Sunspot) by [Thomas Harriot](https://en.wikipedia.org/wiki/Thomas_Harriot), [Galileo Galilei](https://en.wikipedia.org/wiki/Galileo_Galilei) and other astronomers. Galileo posited that sunspots were on the surface of the Sun rather than small objects passing between Earth and the Sun.[[155]](https://en.wikipedia.org/wiki/Sun#cite_note-161)

[Arabic astronomical contributions](https://en.wikipedia.org/wiki/Astronomy_in_medieval_Islam) include [Albatenius](https://en.wikipedia.org/wiki/Muhammad_ibn_J%C4%81bir_al-Harr%C4%81n%C4%AB_al-Batt%C4%81n%C4%AB)' discovery that the direction of the Sun's [apogee](https://en.wikipedia.org/wiki/Apogee) (the place in the Sun's orbit against the fixed stars where it seems to be moving slowest) is changing.[[156]](https://en.wikipedia.org/wiki/Sun#cite_note-162) (In modern heliocentric terms, this is caused by a gradual motion of the aphelion of the *Earth's* orbit). [Ibn Yunus](https://en.wikipedia.org/wiki/Ibn_Yunus) observed more than 10,000 entries for the Sun's position for many years using a large [astrolabe](https://en.wikipedia.org/wiki/Astrolabe).[[157]](https://en.wikipedia.org/wiki/Sun#cite_note-163)

[](https://en.wikipedia.org/wiki/File:Sun-bonatti.png)

Sol, the Sun, from a 1550 edition of[Guido Bonatti](https://en.wikipedia.org/wiki/Guido_Bonatti)'s *Liber astronomiae*.

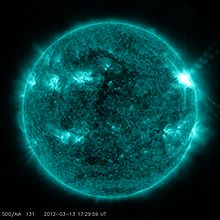
From an observation of a [transit of Venus](https://en.wikipedia.org/wiki/Transit_of_Venus) in 1032, the Persian astronomer and polymath [Avicenna](https://en.wikipedia.org/wiki/Avicenna) concluded that Venus is closer to Earth than the Sun.[[158]](https://en.wikipedia.org/wiki/Sun#cite_note-Goldstein-164) In 1672 [Giovanni Cassini](https://en.wikipedia.org/wiki/Giovanni_Cassini) and [Jean Richer](https://en.wikipedia.org/wiki/Jean_Richer) determined the distance to[Mars](https://en.wikipedia.org/wiki/Mars) and were thereby able to calculate the distance to the Sun.

In 1666, [Isaac Newton](https://en.wikipedia.org/wiki/Isaac_Newton) observed the Sun's light using a [prism](https://en.wikipedia.org/wiki/Prism_(optics)), and showed that it is made up of light of many colors.[[159]](https://en.wikipedia.org/wiki/Sun#cite_note-165) In 1800, [William Herschel](https://en.wikipedia.org/wiki/William_Herschel) discovered [infrared](https://en.wikipedia.org/wiki/Infrared) radiation beyond the red part of the solar spectrum.[[160]](https://en.wikipedia.org/wiki/Sun#cite_note-166)The 19th century saw advancement in spectroscopic studies of the Sun; [Joseph von Fraunhofer](https://en.wikipedia.org/wiki/Joseph_von_Fraunhofer) recorded more than 600 [absorption lines](https://en.wikipedia.org/wiki/Absorption_lines) in the spectrum, the strongest of which are still often referred to as [Fraunhofer lines](https://en.wikipedia.org/wiki/Fraunhofer_lines). In the early years of the modern scientific era, the source of the Sun's energy was a significant puzzle. [Lord Kelvin](https://en.wikipedia.org/wiki/Lord_Kelvin) suggested that the Sun is a gradually cooling liquid body that is radiating an internal store of heat.[[161]](https://en.wikipedia.org/wiki/Sun#cite_note-kelvin-167) Kelvin and[Hermann von Helmholtz](https://en.wikipedia.org/wiki/Hermann_von_Helmholtz) then proposed a [gravitational contraction](https://en.wikipedia.org/wiki/Kelvin%E2%80%93Helmholtz_mechanism) mechanism to explain the energy output, but the resulting age estimate was only 20 million years, well short of the time span of at least 300 million years suggested by some geological discoveries of that time.[[161]](https://en.wikipedia.org/wiki/Sun#cite_note-kelvin-167) In 1890 [Joseph Lockyer](https://en.wikipedia.org/wiki/Joseph_Norman_Lockyer), who discovered helium in the solar spectrum, proposed a meteoritic hypothesis for the formation and evolution of the Sun.[[162]](https://en.wikipedia.org/wiki/Sun#cite_note-168)

Not until 1904 was a documented solution offered. [Ernest Rutherford](https://en.wikipedia.org/wiki/Ernest_Rutherford) suggested that the Sun's output could be maintained by an internal source of heat, and suggested [radioactive decay](https://en.wikipedia.org/wiki/Radioactive_decay) as the source.[[163]](https://en.wikipedia.org/wiki/Sun#cite_note-169) However, it would be[Albert Einstein](https://en.wikipedia.org/wiki/Albert_Einstein) who would provide the essential clue to the source of the Sun's energy output with his [mass-energy equivalence](https://en.wikipedia.org/wiki/Mass-energy_equivalence) relation *E* = *mc*2.[[164]](https://en.wikipedia.org/wiki/Sun#cite_note-170) In 1920, Sir [Arthur Eddington](https://en.wikipedia.org/wiki/Arthur_Eddington) proposed that the pressures and temperatures at the core of the Sun could produce a nuclear fusion reaction that merged hydrogen (protons) into helium nuclei, resulting in a production of energy from the net change in mass.[[165]](https://en.wikipedia.org/wiki/Sun#cite_note-171) The preponderance of hydrogen in the Sun was confirmed in 1925 by [Cecilia Payne](https://en.wikipedia.org/wiki/Cecilia_Payne-Gaposchkin) using the [ionization](https://en.wikipedia.org/wiki/Ionization) theory developed by [Meghnad Saha](https://en.wikipedia.org/wiki/Meghnad_Saha), an Indian physicist. The theoretical concept of fusion was developed in the 1930s by the astrophysicists [Subrahmanyan Chandrasekhar](https://en.wikipedia.org/wiki/Subrahmanyan_Chandrasekhar) and [Hans Bethe](https://en.wikipedia.org/wiki/Hans_Bethe). Hans Bethe calculated the details of the two main energy-producing nuclear reactions that power the Sun.[[166]](https://en.wikipedia.org/wiki/Sun#cite_note-Bethe-172)[[167]](https://en.wikipedia.org/wiki/Sun#cite_note-Bethe2-173) In 1957, [Margaret Burbidge](https://en.wikipedia.org/wiki/Margaret_Burbidge), [Geoffrey Burbidge](https://en.wikipedia.org/wiki/Geoffrey_Burbidge), [William Fowler](https://en.wikipedia.org/wiki/William_Alfred_Fowler) and [Fred Hoyle](https://en.wikipedia.org/wiki/Fred_Hoyle) showed that most of the elements in the universe have been [synthesized](https://en.wikipedia.org/wiki/Nucleosynthesis) by nuclear reactions inside stars, some like the Sun.[[168]](https://en.wikipedia.org/wiki/Sun#cite_note-174)

### Solar space missions

*See also:*[*Solar observatory*](https://en.wikipedia.org/wiki/Solar_observatory)

[](https://en.wikipedia.org/wiki/File:Sunspots_and_Solar_Flares.jpg)

The Sun giving out a large geomagnetic storm on 1:29 pm, EST, 13 March 2012



A lunar transit of the Sun captured during calibration of STEREO B's ultraviolet imaging cameras[[169]](https://en.wikipedia.org/wiki/Sun#cite_note-175)

The first satellites designed to observe the Sun were [NASA](https://en.wikipedia.org/wiki/NASA)'s [Pioneers](https://en.wikipedia.org/wiki/Pioneer_program) 5, 6, 7, 8 and 9, which were launched between 1959 and 1968. These probes orbited the Sun at a distance similar to that of Earth, and made the first detailed measurements of the solar wind and the solar magnetic field. [Pioneer 9](https://en.wikipedia.org/wiki/Pioneer_9) operated for a particularly long time, transmitting data until May 1983.[[170]](https://en.wikipedia.org/wiki/Sun#cite_note-176)[[171]](https://en.wikipedia.org/wiki/Sun#cite_note-177)

In the 1970s, two [Helios](https://en.wikipedia.org/wiki/Helios_probes) spacecraft and the [Skylab](https://en.wikipedia.org/wiki/Skylab) [Apollo Telescope Mount](https://en.wikipedia.org/wiki/Apollo_Telescope_Mount) provided scientists with significant new data on solar wind and the solar corona. The Helios 1 and 2 probes were U.S.–German collaborations that studied the solar wind from an orbit carrying the spacecraft inside [Mercury](https://en.wikipedia.org/wiki/Mercury_(planet))'s orbit at [perihelion](https://en.wikipedia.org/wiki/Perihelion).[[172]](https://en.wikipedia.org/wiki/Sun#cite_note-Burlaga2001-178) The Skylab space station, launched by NASA in 1973, included a solar [observatory](https://en.wikipedia.org/wiki/Observatory) module called the Apollo Telescope Mount that was operated by astronauts resident on the station.[[88]](https://en.wikipedia.org/wiki/Sun#cite_note-Dwivedi2006-93) Skylab made the first time-resolved observations of the solar transition region and of ultraviolet emissions from the solar corona.[[88]](https://en.wikipedia.org/wiki/Sun#cite_note-Dwivedi2006-93) Discoveries included the first observations of [coronal mass ejections](https://en.wikipedia.org/wiki/Coronal_mass_ejection), then called "coronal transients", and of [coronal holes](https://en.wikipedia.org/wiki/Coronal_hole), now known to be intimately associated with the [solar wind](https://en.wikipedia.org/wiki/Solar_wind).[[172]](https://en.wikipedia.org/wiki/Sun#cite_note-Burlaga2001-178)

In 1980, the [Solar Maximum Mission](https://en.wikipedia.org/wiki/Solar_Maximum_Mission) was launched by [NASA](https://en.wikipedia.org/wiki/NASA). This spacecraft was designed to observe [gamma rays](https://en.wikipedia.org/wiki/Gamma_ray), [X-rays](https://en.wikipedia.org/wiki/X-ray) and [UV](https://en.wikipedia.org/wiki/Ultraviolet) radiation from [solar flares](https://en.wikipedia.org/wiki/Solar_flare) during a time of high solar activity and [solar luminosity](https://en.wikipedia.org/wiki/Sun#External_links). Just a few months after launch, however, an electronics failure caused the probe to go into standby mode, and it spent the next three years in this inactive state. In 1984 [Space Shuttle *Challenger*](https://en.wikipedia.org/wiki/Space_Shuttle_Challenger) mission [STS-41C](https://en.wikipedia.org/wiki/STS-41C) retrieved the satellite and repaired its electronics before re-releasing it into orbit. The Solar Maximum Mission subsequently acquired thousands of images of the solar corona before [re-entering](https://en.wikipedia.org/wiki/Atmospheric_reentry) Earth's atmosphere in June 1989.[[173]](https://en.wikipedia.org/wiki/Sun#cite_note-179)

Launched in 1991, Japan's [Yohkoh](https://en.wikipedia.org/wiki/Yohkoh) (*Sunbeam*) satellite observed solar flares at X-ray wavelengths. Mission data allowed scientists to identify several different types of flares, and demonstrated that the corona away from regions of peak activity was much more dynamic and active than had previously been supposed. Yohkoh observed an entire solar cycle but went into standby mode when an [annular eclipse](https://en.wikipedia.org/wiki/Solar_eclipse) in 2001 caused it to lose its lock on the Sun. It was destroyed by atmospheric re-entry in 2005.[[174]](https://en.wikipedia.org/wiki/Sun#cite_note-180)

One of the most important solar missions to date has been the [Solar and Heliospheric Observatory](https://en.wikipedia.org/wiki/Solar_and_Heliospheric_Observatory), jointly built by the [European Space Agency](https://en.wikipedia.org/wiki/European_Space_Agency) and [NASA](https://en.wikipedia.org/wiki/NASA) and launched on 2 December 1995.[[88]](https://en.wikipedia.org/wiki/Sun#cite_note-Dwivedi2006-93) Originally intended to serve a two-year mission, a mission extension through 2012 was approved in October 2009.[[175]](https://en.wikipedia.org/wiki/Sun#cite_note-sohoext-181) It has proven so useful that a follow-on mission, the [Solar Dynamics Observatory](https://en.wikipedia.org/wiki/Solar_Dynamics_Observatory) (SDO), was launched in February 2010.[[176]](https://en.wikipedia.org/wiki/Sun#cite_note-sdolaunch-182) Situated at the [Lagrangian point](https://en.wikipedia.org/wiki/Lagrangian_point) between Earth and the Sun (at which the gravitational pull from both is equal), SOHO has provided a constant view of the Sun at many wavelengths since its launch.[[88]](https://en.wikipedia.org/wiki/Sun#cite_note-Dwivedi2006-93) Besides its direct solar observation, SOHO has enabled the discovery of a large number of [comets](https://en.wikipedia.org/wiki/Comet), mostly tiny [sungrazing comets](https://en.wikipedia.org/wiki/Sungrazing_comet) that incinerate as they pass the Sun.[[177]](https://en.wikipedia.org/wiki/Sun#cite_note-183)

[](https://en.wikipedia.org/wiki/File:Giant_prominence_on_the_sun_erupted.jpg)

A solar prominence erupts in August 2012, as captured by SDO

All these satellites have observed the Sun from the plane of the ecliptic, and so have only observed its equatorial regions in detail. The [Ulysses probe](https://en.wikipedia.org/wiki/Ulysses_probe) was launched in 1990 to study the Sun's polar regions. It first travelled to [Jupiter](https://en.wikipedia.org/wiki/Jupiter), to "slingshot" into an orbit that would take it far above the plane of the ecliptic. Once Ulysses was in its scheduled orbit, it began observing the solar wind and magnetic field strength at high solar latitudes, finding that the solar wind from high latitudes was moving at about 750 km/s, which was slower than expected, and that there were large magnetic waves emerging from high latitudes that scattered galactic [cosmic rays](https://en.wikipedia.org/wiki/Cosmic_ray).[[178]](https://en.wikipedia.org/wiki/Sun#cite_note-184)

Elemental abundances in the photosphere are well known from [spectroscopic](https://en.wikipedia.org/wiki/Astronomical_spectroscopy) studies, but the composition of the interior of the Sun is more poorly understood. A [solar wind](https://en.wikipedia.org/wiki/Solar_wind) sample return mission, [Genesis](https://en.wikipedia.org/wiki/Genesis_(spacecraft)), was designed to allow astronomers to directly measure the composition of solar material.[[179]](https://en.wikipedia.org/wiki/Sun#cite_note-185)

The [Solar Terrestrial Relations Observatory](https://en.wikipedia.org/wiki/STEREO) (STEREO) mission was launched in October 2006. Two identical spacecraft were launched into orbits that cause them to (respectively) pull further ahead of and fall gradually behind Earth. This enables [stereoscopic](https://en.wikipedia.org/wiki/Stereoscopic) imaging of the Sun and solar phenomena, such as [coronal mass ejections](https://en.wikipedia.org/wiki/Coronal_mass_ejections).[[180]](https://en.wikipedia.org/wiki/Sun#cite_note-inst-186)[[181]](https://en.wikipedia.org/wiki/Sun#cite_note-187)

The [Indian Space Research Organisation](https://en.wikipedia.org/wiki/Indian_Space_Research_Organisation) has scheduled the launch of a 100 kg satellite named [Aditya](https://en.wikipedia.org/wiki/Aditya_(spacecraft)) for 2017–18. Its main instrument will be a [coronagraph](https://en.wikipedia.org/wiki/Coronagraph) for studying the dynamics of the Solar corona.[[182]](https://en.wikipedia.org/wiki/Sun#cite_note-188)

## Observation and effects

[](https://en.wikipedia.org/wiki/File:Anatomy_of_a_Sunset-2.jpg)

During certain atmospheric conditions, the Sun becomes clearly visible to the naked eye, and can be observed without stress to the eyes. Click on this photo to see the full cycle of a [sunset](https://en.wikipedia.org/wiki/Sunset), as observed from the high plains of the [Mojave Desert](https://en.wikipedia.org/wiki/Mojave_Desert).

[](https://en.wikipedia.org/wiki/File:STS-134_EVA4_view_to_the_Russian_Orbital_Segment.jpg)

The Sun, as seen from low Earth orbit overlooking the [International Space Station](https://en.wikipedia.org/wiki/International_Space_Station). This sunlight is not filtered by the lower atmosphere, which blocks much of the solar spectrum

The brightness of the Sun can cause pain from looking at it with the [naked eye](https://en.wikipedia.org/wiki/Naked_eye); however, doing so for brief periods is not hazardous for normal non-dilated eyes.[[183]](https://en.wikipedia.org/wiki/Sun#cite_note-189)[[184]](https://en.wikipedia.org/wiki/Sun#cite_note-190) Looking directly at the Sun causes[phosphene](https://en.wikipedia.org/wiki/Phosphene) visual artifacts and temporary partial blindness. It also delivers about 4 milliwatts of sunlight to the retina, slightly heating it and potentially causing damage in eyes that cannot respond properly to the brightness.[[185]](https://en.wikipedia.org/wiki/Sun#cite_note-191)[[186]](https://en.wikipedia.org/wiki/Sun#cite_note-192) [UV](https://en.wikipedia.org/wiki/Ultraviolet) exposure gradually yellows the lens of the eye over a period of years, and is thought to contribute to the formation of [cataracts](https://en.wikipedia.org/wiki/Cataracts), but this depends on general exposure to solar UV, and not whether one looks directly at the Sun.[[187]](https://en.wikipedia.org/wiki/Sun#cite_note-193) Long-duration viewing of the direct Sun with the naked eye can begin to cause UV-induced, sunburn-like lesions on the retina after about 100 seconds, particularly under conditions where the UV light from the Sun is intense and well focused;[[188]](https://en.wikipedia.org/wiki/Sun#cite_note-194)[[189]](https://en.wikipedia.org/wiki/Sun#cite_note-195) conditions are worsened by young eyes or new lens implants (which admit more UV than aging natural eyes), Sun angles near the zenith, and observing locations at high altitude.

Viewing the Sun through light-concentrating [optics](https://en.wikipedia.org/wiki/Optics) such as [binoculars](https://en.wikipedia.org/wiki/Binoculars) may result in permanent damage to the retina without an appropriate filter that blocks UV and substantially dims the sunlight. When using an attenuating filter to view the Sun, the viewer is cautioned to use a filter specifically designed for that use. Some improvised filters that pass UV or [IR](https://en.wikipedia.org/wiki/Infrared) rays, can actually harm the eye at high brightness levels.[[190]](https://en.wikipedia.org/wiki/Sun#cite_note-196)[Herschel wedges](https://en.wikipedia.org/wiki/Herschel_wedge), also called Solar Diagonals, are effective and inexpensive for small telescopes. The sunlight that is destined for the eyepiece is reflected from an unsilvered surface of a piece of glass. Only a very small fraction of the incident light is reflected. The rest passes through the glass and leaves the instrument. If the glass breaks because of the heat, no light at all is reflected, making the device fail-safe. Simple filters made of darkened glass allow the full intensity of sunlight to pass through if they break, endangering the observer's eyesight. Unfiltered binoculars can deliver hundreds of times as much energy as using the naked eye, possibly causing immediate damage. It is claimed that even brief glances at the midday Sun through an unfiltered telescope can cause permanent damage.[[191]](https://en.wikipedia.org/wiki/Sun#cite_note-Macdonald-197)

[](https://en.wikipedia.org/wiki/File:Doppelsonne_Halo_Echzell_Hessen_12-08-2012.jpg)

[Halo](https://en.wikipedia.org/wiki/Halo_(optical_phenomenon)) with [sun dogs](https://en.wikipedia.org/wiki/Sun_dog)

Partial [solar eclipses](https://en.wikipedia.org/wiki/Solar_eclipse) are hazardous to view because the eye's [pupil](https://en.wikipedia.org/wiki/Pupil) is not adapted to the unusually high visual contrast: the pupil dilates according to the total amount of light in the field of view, *not* by the brightest object in the field. During partial eclipses most sunlight is blocked by the [Moon](https://en.wikipedia.org/wiki/Moon) passing in front of the Sun, but the uncovered parts of the photosphere have the same [surface brightness](https://en.wikipedia.org/wiki/Surface_brightness) as during a normal day. In the overall gloom, the pupil expands from ~2 mm to ~6 mm, and each retinal cell exposed to the solar image receives up to ten times more light than it would looking at the non-eclipsed Sun. This can damage or kill those cells, resulting in small permanent blind spots for the viewer.[[192]](https://en.wikipedia.org/wiki/Sun#cite_note-Espenak-198) The hazard is insidious for inexperienced observers and for children, because there is no perception of pain: it is not immediately obvious that one's vision is being destroyed.

[](https://en.wikipedia.org/wiki/File:Actual_Sunrise.jpeg)

A sunrise

During [sunrise](https://en.wikipedia.org/wiki/Sunrise) and [sunset](https://en.wikipedia.org/wiki/Sunset), sunlight is attenuated because of [Rayleigh scattering](https://en.wikipedia.org/wiki/Rayleigh_scattering) and [Mie scattering](https://en.wikipedia.org/wiki/Mie_theory) from a particularly long passage through Earth's atmosphere,[[193]](https://en.wikipedia.org/wiki/Sun#cite_note-Haber2005-199) and the Sun is sometimes faint enough to be viewed comfortably with the naked eye or safely with optics (provided there is no risk of bright sunlight suddenly appearing through a break between clouds). Hazy conditions, atmospheric dust, and high humidity contribute to this atmospheric attenuation.[[194]](https://en.wikipedia.org/wiki/Sun#cite_note-200)

An [optical phenomenon](https://en.wikipedia.org/wiki/Optical_phenomenon), known as a [green flash](https://en.wikipedia.org/wiki/Green_flash), can sometimes be seen shortly after sunset or before sunrise. The flash is caused by light from the Sun just below the horizon being[bent](https://en.wikipedia.org/wiki/Refraction) (usually through a [temperature inversion](https://en.wikipedia.org/wiki/Temperature_inversion)) towards the observer. Light of shorter wavelengths (violet, blue, green) is bent more than that of longer wavelengths (yellow, orange, red) but the violet and blue light is [scattered](https://en.wikipedia.org/wiki/Rayleigh_scattering) more, leaving light that is perceived as green.[[195]](https://en.wikipedia.org/wiki/Sun#cite_note-201)

[Ultraviolet](https://en.wikipedia.org/wiki/Ultraviolet) light from the Sun has [antiseptic](https://en.wikipedia.org/wiki/Antiseptic) properties and can be used to sanitize tools and water. It also causes [sunburn](https://en.wikipedia.org/wiki/Sunburn), and has other biological effects such as the production of [vitamin D](https://en.wikipedia.org/wiki/Vitamin_D) and [sun tanning](https://en.wikipedia.org/wiki/Sun_tanning). Ultraviolet light is strongly attenuated by Earth's [ozone layer](https://en.wikipedia.org/wiki/Ozone_layer), so that the amount of UV varies greatly with [latitude](https://en.wikipedia.org/wiki/Latitude) and has been partially responsible for many biological adaptations, including variations in [human skin color](https://en.wikipedia.org/wiki/Human_skin_color) in different regions of the globe.[[196]](https://en.wikipedia.org/wiki/Sun#cite_note-202)

## See also

|  |  |
| --- | --- |
| Book icon | * [**Book: The Sun**](https://en.wikipedia.org/wiki/Book:The_Sun) |

* [Advanced Composition Explorer](https://en.wikipedia.org/wiki/Advanced_Composition_Explorer)
* [Antisolar point](https://en.wikipedia.org/wiki/Antisolar_point)
* [List of brightest stars](https://en.wikipedia.org/wiki/List_of_brightest_stars)
* [Solar energy](https://en.wikipedia.org/wiki/Solar_energy)
* [Solar System](https://en.wikipedia.org/wiki/Solar_System)
* [Sun dogs](https://en.wikipedia.org/wiki/Sun_dogs)
* [Sun path](https://en.wikipedia.org/wiki/Sun_path)
* [Sun-Earth Day](https://en.wikipedia.org/wiki/Sun-Earth_Day)
* [Sunday](https://en.wikipedia.org/wiki/Sunday)
* [Sungazing](https://en.wikipedia.org/wiki/Sungazing)
* [Timeline of the far future](https://en.wikipedia.org/wiki/Timeline_of_the_far_future)

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| --- | --- |
| |  | | --- | | * [icon](https://en.wikipedia.org/wiki/File:He1523a.jpg)[**Star portal**](https://en.wikipedia.org/wiki/Portal:Star)      * https://upload.wikimedia.org/wikipedia/commons/thumb/8/83/Solar_system.jpg/17px-Solar_system.jpg[**Solar System portal**](https://en.wikipedia.org/wiki/Portal:Solar_System) | |

## Notes

* 1. ^ [Jump up to:***a***](https://en.wikipedia.org/wiki/Sun#cite_ref-short_18-0) [***b***](https://en.wikipedia.org/wiki/Sun#cite_ref-short_18-1) [***c***](https://en.wikipedia.org/wiki/Sun#cite_ref-short_18-2) All numbers in this article are short scale. One billion is 109, or 1,000,000,000.
  2. [**Jump up^**](https://en.wikipedia.org/wiki/Sun#cite_ref-heavy_elements_32-0) In [astronomical sciences](https://en.wikipedia.org/wiki/Astronomy), the term *heavy elements* (or *metals*) refers to all [elements](https://en.wikipedia.org/wiki/Chemical_element) except hydrogen and helium.
  3. [**Jump up^**](https://en.wikipedia.org/wiki/Sun#cite_ref-38) [Hydrothermal vent communities](https://en.wikipedia.org/wiki/Hydrothermal_vent_communities) live so deep under the sea that they have no access to sunlight. Bacteria instead use sulfur compounds as an energy source, via [chemosynthesis](https://en.wikipedia.org/wiki/Chemosynthesis).
  4. [**Jump up^**](https://en.wikipedia.org/wiki/Sun#cite_ref-56) 1.88 Gcd/m2 is calculated from the solar illuminance of 128000 lux (see [sunlight](https://en.wikipedia.org/wiki/Sunlight)) times the square of the distance to the center of the Sun, divided by the cross sectional area of the Sun. 1.44 Gcd/m2 is calculated using 98000 lux.
  5. [**Jump up^**](https://en.wikipedia.org/wiki/Sun#cite_ref-power_production_density_78-0) A 50 kg adult human has a volume of about 0.05 m3, which corresponds to 13.8 watts, at the volumetric power of the solar center. This is 285 kcal/day, about 10% of the actual average caloric intake and output for humans in non-stressful conditions.
  6. [**Jump up^**](https://en.wikipedia.org/wiki/Sun#cite_ref-particle_density_94-0) Earth's atmosphere near sea level has a particle density of about 2×1025 m−3.

## References

* 1. ^ [Jump up to:***a***](https://en.wikipedia.org/wiki/Sun#cite_ref-nssdc_1-0) [***b***](https://en.wikipedia.org/wiki/Sun#cite_ref-nssdc_1-1) [***c***](https://en.wikipedia.org/wiki/Sun#cite_ref-nssdc_1-2) [***d***](https://en.wikipedia.org/wiki/Sun#cite_ref-nssdc_1-3) [***e***](https://en.wikipedia.org/wiki/Sun#cite_ref-nssdc_1-4) [***f***](https://en.wikipedia.org/wiki/Sun#cite_ref-nssdc_1-5) [***g***](https://en.wikipedia.org/wiki/Sun#cite_ref-nssdc_1-6) [***h***](https://en.wikipedia.org/wiki/Sun#cite_ref-nssdc_1-7) [***i***](https://en.wikipedia.org/wiki/Sun#cite_ref-nssdc_1-8) [***j***](https://en.wikipedia.org/wiki/Sun#cite_ref-nssdc_1-9) [***k***](https://en.wikipedia.org/wiki/Sun#cite_ref-nssdc_1-10) [***l***](https://en.wikipedia.org/wiki/Sun#cite_ref-nssdc_1-11) [***m***](https://en.wikipedia.org/wiki/Sun#cite_ref-nssdc_1-12) [***n***](https://en.wikipedia.org/wiki/Sun#cite_ref-nssdc_1-13) [***o***](https://en.wikipedia.org/wiki/Sun#cite_ref-nssdc_1-14) [***p***](https://en.wikipedia.org/wiki/Sun#cite_ref-nssdc_1-15) [***q***](https://en.wikipedia.org/wiki/Sun#cite_ref-nssdc_1-16) Williams, D. R. (1 July 2013).[*"Sun Fact Sheet"*](http://nssdc.gsfc.nasa.gov/planetary/factsheet/sunfact.html).[*NASA Goddard Space Flight Center*](https://en.wikipedia.org/wiki/NASA_Goddard_Space_Flight_Center)*. Retrieved12 August 2013*.
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## Further reading

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* [Satellite observations of solar luminosity](http://www.acrim.com/)
* [Sun|Trek, an educational website about the Sun](http://www.suntrek.org/)
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* [An animated explanation of the structure of the Sun](http://alienworlds.glam.ac.uk/sunStructure.html) (University of Glamorgan)
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* [Solar Conveyor Belt Speeds Up](http://science.nasa.gov/headlines/y2010/12mar_conveyorbelt.htm) – NASA – images, link to report on Science
* [NASA 5-year timelapse video of the Sun](https://www.youtube.com/watch?v=w-41gAPmUG0&feature=youtube_gdata&ab_channel=NASAGoddard)
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# Moon

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| [Full moon in the darkness of the night sky. It is patterned with a mix of light-tone regions and darker, irregular blotches, and scattered with varying sizes of impact craters, circles surrounded by out-thrown rays of bright ejecta.](https://en.wikipedia.org/wiki/File:FullMoon2010.jpg)  [Full moon](https://en.wikipedia.org/wiki/Full_moon) as seen from Earth's [northern hemisphere](https://en.wikipedia.org/wiki/Northern_hemisphere) | |
| **Designations** | |
| [**Adjectives**](https://en.wikipedia.org/wiki/List_of_adjectivals_and_demonyms_of_astronomical_bodies) | * [lunar](https://en.wiktionary.org/wiki/lunar) * [selenic](https://en.wiktionary.org/wiki/selenic) |
| [**Orbital characteristics**](https://en.wikipedia.org/wiki/Osculating_orbit) | |
| [**Perigee**](https://en.wikipedia.org/wiki/Apsis) | 362600 km (356400–370400 km) |
| [**Apogee**](https://en.wikipedia.org/wiki/Apsis) | 405400 km (404000–406700 km) |
| [**Semi-major axis**](https://en.wikipedia.org/wiki/Semi-major_axis) | 384399 km  (0.00257 AU)[[1]](https://en.wikipedia.org/wiki/Moon#cite_note-W06-1) |
| [**Eccentricity**](https://en.wikipedia.org/wiki/Orbital_eccentricity) | 0.0549[[1]](https://en.wikipedia.org/wiki/Moon#cite_note-W06-1) |
| [**Orbital period**](https://en.wikipedia.org/wiki/Orbital_period) | 27.321661 [d](https://en.wikipedia.org/wiki/Day) (27 d 7 h 43.19 min 11.5 s[[1]](https://en.wikipedia.org/wiki/Moon#cite_note-W06-1)) |
| [**Synodic period**](https://en.wikipedia.org/wiki/Orbital_period) | 29.530589 d (29 d 12 h 44 min 2.9 s) |
| **Average**[**orbital speed**](https://en.wikipedia.org/wiki/Orbital_speed) | 1.022 [km/s](https://en.wikipedia.org/wiki/Metre_per_second) |
| [**Inclination**](https://en.wikipedia.org/wiki/Orbital_inclination) | 5.145° to the [ecliptic](https://en.wikipedia.org/wiki/Ecliptic)[[2]](https://en.wikipedia.org/wiki/Moon#cite_note-Lang2011-2)[[a]](https://en.wikipedia.org/wiki/Moon#cite_note-inclination-3) |
| [**Longitude of ascending node**](https://en.wikipedia.org/wiki/Longitude_of_the_ascending_node) | regressing by one [revolution](https://en.wikipedia.org/wiki/Orbital_revolution) in 18.6 years |
| [**Argument of perigee**](https://en.wikipedia.org/wiki/Argument_of_periapsis) | progressing by one revolution in 8.85 years |
| [**Satellite of**](https://en.wikipedia.org/wiki/Natural_satellite) | [Earth](https://en.wikipedia.org/wiki/Earth)[[b]](https://en.wikipedia.org/wiki/Moon#cite_note-near-Earth_asteroids-4)[[3]](https://en.wikipedia.org/wiki/Moon#cite_note-Morais2002-5) |
| **Physical characteristics** | |
| **Mean radius** | 1737.1 km  (0.273 Earths)[[1]](https://en.wikipedia.org/wiki/Moon#cite_note-W06-1)[[4]](https://en.wikipedia.org/wiki/Moon#cite_note-NSSDC-6)[[5]](https://en.wikipedia.org/wiki/Moon#cite_note-7) |
| [**Equatorial**](https://en.wikipedia.org/wiki/Equator)**radius** | 1738.1 km  (0.273 Earths)[[4]](https://en.wikipedia.org/wiki/Moon#cite_note-NSSDC-6) |
| [**Polar**](https://en.wikipedia.org/wiki/Geographical_pole)**radius** | 1736.0 km  (0.273 Earths)[[4]](https://en.wikipedia.org/wiki/Moon#cite_note-NSSDC-6) |
| [**Flattening**](https://en.wikipedia.org/wiki/Flattening) | 0.0012[[4]](https://en.wikipedia.org/wiki/Moon#cite_note-NSSDC-6) |
| **Circumference** | 10921 km  ([equatorial](https://en.wikipedia.org/wiki/Equator)) |
| [**Surface area**](https://en.wikipedia.org/wiki/Spheroid#Surface_area) | 3.793×107 km2  (0.074 Earths) |
| [**Volume**](https://en.wikipedia.org/wiki/Volume) | 2.1958×1010 km3  (0.020 Earths)[[4]](https://en.wikipedia.org/wiki/Moon#cite_note-NSSDC-6) |
| [**Mass**](https://en.wikipedia.org/wiki/Mass) | 7.342×1022 kg  (0.012300 Earths)[[1]](https://en.wikipedia.org/wiki/Moon#cite_note-W06-1)[[4]](https://en.wikipedia.org/wiki/Moon#cite_note-NSSDC-6) |
| **Mean**[**density**](https://en.wikipedia.org/wiki/Density) | 3.344 [g/cm3](https://en.wikipedia.org/wiki/Gram_per_cubic_centimetre)[[1]](https://en.wikipedia.org/wiki/Moon#cite_note-W06-1)[[4]](https://en.wikipedia.org/wiki/Moon#cite_note-NSSDC-6) 0.606 × Earth |
| [**Surface gravity**](https://en.wikipedia.org/wiki/Surface_gravity) | 1.62 [m/s2](https://en.wikipedia.org/wiki/Metre_per_second_squared)  (0.1654 [g](https://en.wikipedia.org/wiki/G-force))[[4]](https://en.wikipedia.org/wiki/Moon#cite_note-NSSDC-6) |
| [**Moment of inertia factor**](https://en.wikipedia.org/wiki/Moment_of_inertia_factor) | 0.3929±0.0009[[6]](https://en.wikipedia.org/wiki/Moon#cite_note-Williams1996-8) |
| [**Escape velocity**](https://en.wikipedia.org/wiki/Escape_velocity) | 2.38 [km/s](https://en.wikipedia.org/wiki/Metre_per_second) |
| **Sidereal**[**rotation period**](https://en.wikipedia.org/wiki/Rotation_period) | 27.321661 d  ([synchronous](https://en.wikipedia.org/wiki/Synchronous_rotation)) |
| **Equatorial rotation velocity** | 4.627 m/s |
| [**Axial tilt**](https://en.wikipedia.org/wiki/Axial_tilt) | * 1.5424° to [ecliptic](https://en.wikipedia.org/wiki/Ecliptic) * 6.687° to [orbit plane](https://en.wikipedia.org/wiki/Orbital_plane_(astronomy))[[2]](https://en.wikipedia.org/wiki/Moon#cite_note-Lang2011-2) |
| [**Albedo**](https://en.wikipedia.org/wiki/Albedo) | 0.136[[7]](https://en.wikipedia.org/wiki/Moon#cite_note-Saari-9) |
| |  |  |  |  | | --- | --- | --- | --- | | **Surface**[**temp.**](https://en.wikipedia.org/wiki/Temperature) | **min** | **mean** | **max** | | **Equator** | 100 [K](https://en.wikipedia.org/wiki/Kelvin) | 220 K | 390 K | | **85°N** |  | 150 K | 230 K[[8]](https://en.wikipedia.org/wiki/Moon#cite_note-Vasavada1999-12) | | |
| [**Apparent magnitude**](https://en.wikipedia.org/wiki/Apparent_magnitude) | * −2.5 to −12.9[[c]](https://en.wikipedia.org/wiki/Moon#cite_note-maxval-10) * −12.74  (mean [full moon](https://en.wikipedia.org/wiki/Full_moon))[[4]](https://en.wikipedia.org/wiki/Moon#cite_note-NSSDC-6) |
| [**Angular diameter**](https://en.wikipedia.org/wiki/Angular_diameter) | 29.3 to 34.1 [arcminutes](https://en.wikipedia.org/wiki/Minute_of_arc)[[4]](https://en.wikipedia.org/wiki/Moon#cite_note-NSSDC-6)[[d]](https://en.wikipedia.org/wiki/Moon#cite_note-angular_size-11) |
| **Atmosphere**[[9]](https://en.wikipedia.org/wiki/Moon#cite_note-L06-13) | |
| **Surface**[**pressure**](https://en.wikipedia.org/wiki/Atmospheric_pressure) | * 10−7 [Pa](https://en.wikipedia.org/wiki/Pascal_(unit)) (1 [picobar](https://en.wikipedia.org/wiki/Bar_(unit)))  (day) * 10−10 Pa (1 femtobar)   (night)[[e]](https://en.wikipedia.org/wiki/Moon#cite_note-pressure_explanation-14) |
| [**Composition by volume**](https://en.wikipedia.org/wiki/Atmospheric_chemistry#Atmospheric_composition) | * [He](https://en.wikipedia.org/wiki/Helium) * [Ar](https://en.wikipedia.org/wiki/Argon) * [Ne](https://en.wikipedia.org/wiki/Neon) * [Na](https://en.wikipedia.org/wiki/Sodium) * [K](https://en.wikipedia.org/wiki/Potassium) * [H](https://en.wikipedia.org/wiki/Hydrogen) * [Rn](https://en.wikipedia.org/wiki/Radon) |
|  | |

The **Moon** is [Earth](https://en.wikipedia.org/wiki/Earth)'s only [permanent](https://en.wikipedia.org/wiki/Claimed_moons_of_Earth#Temporary_satellites) [natural satellite](https://en.wikipedia.org/wiki/Natural_satellite). It is one of [the largest natural satellites in](https://en.wikipedia.org/wiki/List_of_Solar_System_objects_by_size#List_of_objects_by_radius) the [Solar System](https://en.wikipedia.org/wiki/Solar_System), and the largest among planetary satellites relative to the size of the planet that it orbits (its [primary](https://en.wikipedia.org/wiki/Primary_(astronomy))). It is the second-[densest](https://en.wikipedia.org/wiki/Density) satellite among those whose densities are known (after [Jupiter](https://en.wikipedia.org/wiki/Jupiter)'s satellite [Io](https://en.wikipedia.org/wiki/Io_(moon))).

The Moon is thought to have formed approximately 4.5 billion years ago, [not long after Earth](https://en.wikipedia.org/wiki/Age_of_the_Earth). There are several hypotheses for its origin; the most widely accepted explanation is that the Moon formed from the debris left over after a [giant impact](https://en.wikipedia.org/wiki/Giant_impact_hypothesis) between Earth and a [Mars](https://en.wikipedia.org/wiki/Mars)-sized body called [Theia](https://en.wikipedia.org/wiki/Theia_(planet)).

The Moon is in [synchronous rotation](https://en.wikipedia.org/wiki/Synchronous_rotation) with Earth, always showing the same face, with its [near side](https://en.wikipedia.org/wiki/Near_side_of_the_Moon) marked by dark volcanic [maria](https://en.wikipedia.org/wiki/Lunar_mare) that fill the spaces between the bright ancient crustal highlands and the prominent[impact craters](https://en.wikipedia.org/wiki/Impact_crater). It is the second-brightest regularly visible [celestial object](https://en.wikipedia.org/wiki/Celestial_object) in Earth's sky after the [Sun](https://en.wikipedia.org/wiki/Sun), as measured by [illuminance](https://en.wikipedia.org/wiki/Illuminance) on Earth's surface. Its surface is actually dark (although it can appear a [very bright white](https://en.wikipedia.org/wiki/Moonlight)) with a [reflectance](https://en.wikipedia.org/wiki/Reflectance) just slightly higher than that of worn [asphalt](https://en.wikipedia.org/wiki/Asphalt_concrete). Its prominence in the sky and its regular cycle of [phases](https://en.wikipedia.org/wiki/Lunar_phases) have made the Moon an important [cultural](https://en.wikipedia.org/wiki/Culture) influence since [ancient](https://en.wikipedia.org/wiki/Ancient_history) times on [language](https://en.wikipedia.org/wiki/Moon#Name_and_etymology),[calendars](https://en.wikipedia.org/wiki/Lunar_calendar), [art](https://en.wikipedia.org/wiki/Moon_in_fiction), and [mythology](https://en.wikipedia.org/wiki/Lunar_deity).

The Moon's gravitational influence produces the [ocean tides](https://en.wikipedia.org/wiki/Ocean_tides), [body tides](https://en.wikipedia.org/wiki/Earth_tide), and the [slight lengthening](https://en.wikipedia.org/wiki/Tidal_acceleration) of the day. The Moon's current orbital distance is about thirty times the diameter of Earth, with its [apparent size](https://en.wikipedia.org/wiki/Angular_diameter) in the sky almost the same as that of the Sun, resulting in the Moon covering the Sun nearly precisely in total [solar eclipse](https://en.wikipedia.org/wiki/Solar_eclipse). This matching of apparent visual size will not continue in the far future. The Moon's linear distance from Earth is currently increasing at a rate of 3.82 ± 0.07 centimetres (1.504 ± 0.028 in) per year, but this rate is not constant.

The [Soviet Union](https://en.wikipedia.org/wiki/Soviet_Union)'s [Luna programme](https://en.wikipedia.org/wiki/Luna_programme) was the first to reach the Moon with [unmanned spacecraft](https://en.wikipedia.org/wiki/Unmanned_spacecraft) in 1959; the [United States](https://en.wikipedia.org/wiki/United_States)' [NASA](https://en.wikipedia.org/wiki/NASA) [Apollo program](https://en.wikipedia.org/wiki/Apollo_program) achieved the only manned missions to date, beginning with the first manned lunar orbiting mission by [Apollo 8](https://en.wikipedia.org/wiki/Apollo_8) in 1968, and six manned lunar landings between 1969 and 1972, with the first being [Apollo 11](https://en.wikipedia.org/wiki/Apollo_11). These missions returned over 380 kg (840 lb) of [lunar rocks](https://en.wikipedia.org/wiki/Moon_rock), which have been used to develop a [geological](https://en.wikipedia.org/wiki/Geology) understanding of the Moon's origin, the formation of [its internal structure](https://en.wikipedia.org/wiki/Internal_structure_of_the_Moon), and [its subsequent history](https://en.wikipedia.org/wiki/Geology_of_the_Moon). After the [Apollo 17](https://en.wikipedia.org/wiki/Apollo_17) mission in 1972, the Moon has been visited only by unmanned spacecraft.

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## Name and etymology

[](https://en.wikipedia.org/wiki/File:Lunar_eclipse_October_8_2014_California_Alfredo_Garcia_Jr_mideclipse.JPG)

The Moon, tinted reddish, during a[lunar eclipse](https://en.wikipedia.org/wiki/Lunar_eclipse)

*See also:*[*list of lunar deities*](https://en.wikipedia.org/wiki/List_of_lunar_deities)

The usual English [proper name](https://en.wikipedia.org/wiki/Proper_name) for Earth's natural satellite is "the Moon".[[10]](https://en.wikipedia.org/wiki/Moon#cite_note-15)[[11]](https://en.wikipedia.org/wiki/Moon#cite_note-PN-FAQ-16) The noun *moon* is derived from *moone* (around 1380), which developed from *mone* (1135), which is derived from [Old English](https://en.wikipedia.org/wiki/Old_English) *mōna*(dating from before 725), which ultimately stems from [Proto-Germanic](https://en.wikipedia.org/wiki/Proto-Germanic) *\*mǣnōn*, like all [Germanic language](https://en.wikipedia.org/wiki/Germanic_languages) cognates.[[12]](https://en.wikipedia.org/wiki/Moon#cite_note-barnhart1995-17) Occasionally, the name "Luna" is used, in poetry for a personified Moon, or in science fiction to distinguish it from other moons.[[13]](https://en.wikipedia.org/wiki/Moon#cite_note-18)

The principal modern English adjective pertaining to the Moon is *lunar*, derived from the Latin *Luna*. A less common adjective is *selenic*, derived from the Ancient Greek [*Selene*](https://en.wikipedia.org/wiki/Selene) (*Σελήνη*), from which is derived the prefix "seleno-" (as in [*selenography*](https://en.wikipedia.org/wiki/Selenography)).[[14]](https://en.wikipedia.org/wiki/Moon#cite_note-oed-19)[[15]](https://en.wikipedia.org/wiki/Moon#cite_note-20) Both the Greek Selene and the Roman goddess [Diana](https://en.wikipedia.org/wiki/Diana_(mythology)) were alternatively called [Cynthia](https://en.wikipedia.org/wiki/Cynthia).[[16]](https://en.wikipedia.org/wiki/Moon#cite_note-Pannen2010-21) The names Luna, Cynthia, and Selene are reflected in terminology for [lunar orbits](https://en.wikipedia.org/wiki/Lunar_orbit) in words such as *apolune*, *pericynthion*, and *selenocentric*. The name Diana is connected to *dies* meaning 'day'.

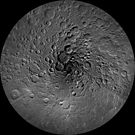
**The Moon**

[](https://en.wikipedia.org/wiki/File:LRO_WAC_Nearside_Mosaic.jpg)

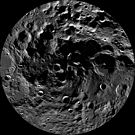
[Near side of the Moon](https://en.wikipedia.org/wiki/Near_side_of_the_Moon)

[](https://en.wikipedia.org/wiki/File:Moon_Farside_LRO.jpg)

[Far side of the Moon](https://en.wikipedia.org/wiki/Far_side_of_the_Moon)

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[](https://en.wikipedia.org/wiki/File:LRO_WAC_South_Pole_Mosaic.jpg)

[Lunar south pole](https://en.wikipedia.org/wiki/Lunar_south_pole)

## Formation

*Main articles:*[*Origin of the Moon*](https://en.wikipedia.org/wiki/Origin_of_the_Moon)*and*[*Giant impact hypothesis*](https://en.wikipedia.org/wiki/Giant_impact_hypothesis)

Several mechanisms have been proposed for the Moon's formation 4.527 ± 0.010 billion years ago,[[f]](https://en.wikipedia.org/wiki/Moon#cite_note-age-22) some 30–50 million years after the origin of the Solar System.[[17]](https://en.wikipedia.org/wiki/Moon#cite_note-23) Recent research presented by Rick Carlson indicates a slightly lower age of between 4.40 and 4.45 billion years.[[18]](https://en.wikipedia.org/wiki/Moon#cite_note-24) [[19]](https://en.wikipedia.org/wiki/Moon#cite_note-25) These mechanisms included the fission of the Moon from Earth's crust through [centrifugal force](https://en.wikipedia.org/wiki/Centrifugal_force)[[20]](https://en.wikipedia.org/wiki/Moon#cite_note-Binder-26) (which would require too great an initial spin of Earth),[[21]](https://en.wikipedia.org/wiki/Moon#cite_note-BotM-27) the gravitational capture of a pre-formed Moon[[22]](https://en.wikipedia.org/wiki/Moon#cite_note-Mitler-28) (which would require an unfeasibly extended [atmosphere of Earth](https://en.wikipedia.org/wiki/Earth%27s_atmosphere) to [dissipate](https://en.wikipedia.org/wiki/Dissipation) the energy of the passing Moon),[[21]](https://en.wikipedia.org/wiki/Moon#cite_note-BotM-27) and the co-formation of Earth and the Moon together in the primordial [accretion disk](https://en.wikipedia.org/wiki/Accretion_disk) (which does not explain the depletion of metals in the Moon).[[21]](https://en.wikipedia.org/wiki/Moon#cite_note-BotM-27) These hypotheses also cannot account for the high [angular momentum](https://en.wikipedia.org/wiki/Angular_momentum) of the Earth–Moon system.[[23]](https://en.wikipedia.org/wiki/Moon#cite_note-29)



The evolution of the Moon and a tour of the Moon

The prevailing hypothesis today is that the Earth–Moon system formed as a result of a [giant impact](https://en.wikipedia.org/wiki/Giant_impact_hypothesis), where a [Mars](https://en.wikipedia.org/wiki/Mars)-sized body (named [*Theia*](https://en.wikipedia.org/wiki/Theia_(planet))) collided with the newly formed [proto-Earth](https://en.wikipedia.org/wiki/History_of_the_Earth), blasting material into orbit around it that accreted to form the Moon.[[24]](https://en.wikipedia.org/wiki/Moon#cite_note-taylor1998-30)[[25]](https://en.wikipedia.org/wiki/Moon#cite_note-31)

This [hypothesis](https://en.wikipedia.org/wiki/Hypothesis) perhaps best explains the evidence, although not perfectly. Eighteen months prior to an October 1984 conference on lunar origins, Bill Hartmann, Roger Phillips, and Jeff Taylor challenged fellow lunar scientists: "You have eighteen months. Go back to your Apollo data, go back to your computer, do whatever you have to, but make up your mind. Don't come to our conference unless you have something to say about the Moon's birth." At the 1984 conference at Kona, Hawaii, the giant impact hypothesis emerged as the most popular.

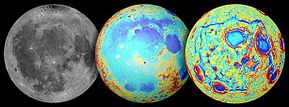
Before the conference, there were partisans of the three "traditional" theories, plus a few people who were starting to take the giant impact seriously, and there was a huge apathetic middle who didn’t think the debate would ever be resolved. Afterward there were essentially only two groups: the giant impact camp and the agnostics.[[26]](https://en.wikipedia.org/wiki/Moon#cite_note-Dana-Mackenzie.27s-book-32)

[Giant impacts](https://en.wikipedia.org/wiki/Late_Heavy_Bombardment) 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. These simulations also show that most of the Moon came from the impactor, not from the proto-Earth.[[27]](https://en.wikipedia.org/wiki/Moon#cite_note-33) However, more-recent tests suggest more of the Moon coalesced from Earth and not the impactor.[[28]](https://en.wikipedia.org/wiki/Moon#cite_note-34)[[29]](https://en.wikipedia.org/wiki/Moon#cite_note-35)[[30]](https://en.wikipedia.org/wiki/Moon#cite_note-36)[[31]](https://en.wikipedia.org/wiki/Moon#cite_note-37) [Meteorites](https://en.wikipedia.org/wiki/Meteorite) show that other inner Solar System bodies such as [Mars](https://en.wikipedia.org/wiki/Mars) and [Vesta](https://en.wikipedia.org/wiki/Vesta_(asteroid)) have very different oxygen and tungsten [isotopic](https://en.wikipedia.org/wiki/Isotope) compositions to Earth, whereas Earth and the Moon have nearly identical isotopic compositions. Post-impact mixing of the vaporized material between the forming Earth and Moon could have equalized their isotopic compositions,[[32]](https://en.wikipedia.org/wiki/Moon#cite_note-Pahlevan2007-38) although this is debated.[[33]](https://en.wikipedia.org/wiki/Moon#cite_note-39)

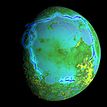
The large amount of energy released in the giant impact event and the subsequent re-accretion of material in Earth orbit would have melted the outer shell of Earth, forming a magma ocean.[[34]](https://en.wikipedia.org/wiki/Moon#cite_note-Warren1985-40)[[35]](https://en.wikipedia.org/wiki/Moon#cite_note-41) The newly formed Moon would also have had its own [lunar magma ocean](https://en.wikipedia.org/wiki/Lunar_magma_ocean); estimates for its depth range from about 500 km (300 miles) to the entire radius of the Moon (1,737 km (1,079 miles)).[[34]](https://en.wikipedia.org/wiki/Moon#cite_note-Warren1985-40)

Despite its accuracy in explaining many lines of evidence, there are still some difficulties that are not fully explained by the giant impact hypothesis, most of them involving the Moon's composition.[[36]](https://en.wikipedia.org/wiki/Moon#cite_note-42)

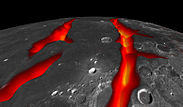
[**Oceanus Procellarum**](https://en.wikipedia.org/wiki/Oceanus_Procellarum)**("Ocean of Storms")**

[](https://en.wikipedia.org/wiki/File:14-236-LunarGrailMission-OceanusProcellarum-Rifts-Overall-20141001.jpg)

Ancient [rift valleys](https://en.wikipedia.org/wiki/Rift_valley) – rectangular structure (visible – topography – [GRAIL gravity gradients](https://en.wikipedia.org/wiki/Gravity_Recovery_and_Interior_Laboratory))

[](https://en.wikipedia.org/wiki/File:PIA18822-LunarGrailMission-OceanusProcellarum-Rifts-Overall-20141001.jpg)

Ancient [rift valleys](https://en.wikipedia.org/wiki/Rift_valley)– context.

[](https://en.wikipedia.org/wiki/File:PIA18821-LunarGrailMission-OceanusProcellarum-Rifts-Closeup-20141001.jpg)

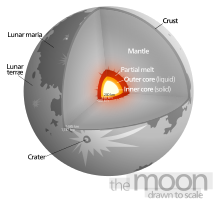
Ancient [rift valleys](https://en.wikipedia.org/wiki/Rift_valley) – closeup (artist's concept).

In 2001, a team at the Carnegie Institute of Washington reported the most precise measurement of the isotopic signatures of lunar rocks.[[37]](https://en.wikipedia.org/wiki/Moon#cite_note-wiechert-43) To their surprise, the team found that the rocks from the [Apollo program](https://en.wikipedia.org/wiki/Apollo_program) carried an isotopic signature that was identical with rocks from Earth, and were different from almost all other bodies in the Solar System. Because most of the material that went into orbit to form the Moon was thought to come from [Theia](https://en.wikipedia.org/wiki/Theia_(planet)), this observation was unexpected. In 2007, researchers from the California Institute of Technology announced that there was less than a 1% chance that Theia and Earth had identical isotopic signatures.[[38]](https://en.wikipedia.org/wiki/Moon#cite_note-ps2007-44) Published in 2012, an analysis of titanium isotopes in Apollo lunar samples showed that the Moon has the same composition as Earth,[[39]](https://en.wikipedia.org/wiki/Moon#cite_note-test-45) which [conflicts](https://en.wikipedia.org/wiki/Giant_impact_hypothesis#Difficulties) with what is expected if the Moon formed far from Earth's orbit or from Theia. Variations on the giant impact hypothesis may explain this data.

## Physical characteristics

### Internal structure

*Main article:*[*Internal structure of the Moon*](https://en.wikipedia.org/wiki/Internal_structure_of_the_Moon)

[](https://en.wikipedia.org/wiki/File:Moon_diagram.svg)

Structure of the Moon

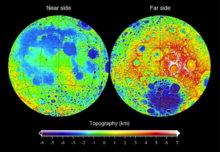
|  |  |  |  |
| --- | --- | --- | --- |
| **Chemical composition of the lunar surface regolith (derived from crustal rocks)**[[40]](https://en.wikipedia.org/wiki/Moon#cite_note-46) | | | |
| **Compound** | **Formula** | **Composition (wt %)** | |
| **Maria** | **Highlands** |
| [silica](https://en.wikipedia.org/wiki/Silicon_dioxide) | SiO2 | 45.4% | 45.5% |
| [alumina](https://en.wikipedia.org/wiki/Aluminium_oxide) | Al2O3 | 14.9% | 24.0% |
| [lime](https://en.wikipedia.org/wiki/Calcium_oxide) | CaO | 11.8% | 15.9% |
| [iron(II) oxide](https://en.wikipedia.org/wiki/Iron(II)_oxide) | FeO | 14.1% | 5.9% |
| [magnesia](https://en.wikipedia.org/wiki/Magnesium_oxide) | MgO | 9.2% | 7.5% |
| [titanium dioxide](https://en.wikipedia.org/wiki/Titanium_dioxide) | TiO2 | 3.9% | 0.6% |
| [sodium oxide](https://en.wikipedia.org/wiki/Sodium_oxide) | Na2O | 0.6% | 0.6% |
| **Total** | | **99.9%** | **100.0%** |

The Moon is a [differentiated](https://en.wikipedia.org/wiki/Planetary_differentiation) body: it has a [geochemically](https://en.wikipedia.org/wiki/Geochemistry) distinct [crust](https://en.wikipedia.org/wiki/Crust_(geology)), [mantle](https://en.wikipedia.org/wiki/Mantle_(geology)), and [core](https://en.wikipedia.org/wiki/Planetary_core). The Moon has a solid iron-rich inner core with a radius of 240 km (150 mi) and a fluid outer core primarily made of liquid iron with a radius of roughly 300 km (190 mi). Around the core is a partially molten boundary layer with a radius of about 500 km (310 mi).[[41]](https://en.wikipedia.org/wiki/Moon#cite_note-47) This structure is thought to have developed through the [fractional crystallization](https://en.wikipedia.org/wiki/Fractional_crystallization_(geology)) of a global [magma ocean](https://en.wikipedia.org/wiki/Lunar_magma_ocean) shortly after the Moon's formation 4.5 billion years ago.[[42]](https://en.wikipedia.org/wiki/Moon#cite_note-48) Crystallization of this magma ocean would have created a [mafic](https://en.wikipedia.org/wiki/Mafic) mantle from the [precipitation](https://en.wikipedia.org/wiki/Precipitation_(chemistry)) and sinking of the minerals [olivine](https://en.wikipedia.org/wiki/Olivine), [clinopyroxene](https://en.wikipedia.org/wiki/Clinopyroxene), and [orthopyroxene](https://en.wikipedia.org/wiki/Orthopyroxene); after about three-quarters of the magma ocean had crystallised, lower-density [plagioclase](https://en.wikipedia.org/wiki/Plagioclase) minerals could form and float into a crust on top.[[43]](https://en.wikipedia.org/wiki/Moon#cite_note-S06-49) The final liquids to crystallise would have been initially sandwiched between the crust and mantle, with a high abundance of [incompatible](https://en.wikipedia.org/wiki/Compatibility_(geochemistry)) and heat-producing elements.[[1]](https://en.wikipedia.org/wiki/Moon#cite_note-W06-1) Consistent with this, geochemical mapping from orbit shows the crust is mostly [anorthosite](https://en.wikipedia.org/wiki/Anorthosite),[[9]](https://en.wikipedia.org/wiki/Moon#cite_note-L06-13) and [moon rock](https://en.wikipedia.org/wiki/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]](https://en.wikipedia.org/wiki/Moon#cite_note-W06-1) Geophysical techniques suggest that the crust is on average circa 50 km (31 mi) thick.[[1]](https://en.wikipedia.org/wiki/Moon#cite_note-W06-1)

The Moon is the second densest satellite in the Solar System after [Io](https://en.wikipedia.org/wiki/Io_(moon)).[[44]](https://en.wikipedia.org/wiki/Moon#cite_note-Schubert2004-50) However, the inner core of the Moon is small, with a radius of about 350 km (220 mi) or less,[[1]](https://en.wikipedia.org/wiki/Moon#cite_note-W06-1)around 20% of the radius of the Moon. Its composition is not well constrained, but it is probably metallic iron alloyed with a small amount of [sulfur](https://en.wikipedia.org/wiki/Sulfur) and nickel; analyses of the Moon's time-variable rotation indicate that it is at least partly molten.[[45]](https://en.wikipedia.org/wiki/Moon#cite_note-51)

### Surface geology

*Main articles:*[*Geology of the Moon*](https://en.wikipedia.org/wiki/Geology_of_the_Moon)*and*[*Moon rocks*](https://en.wikipedia.org/wiki/Moon_rocks)

[](https://en.wikipedia.org/wiki/File:MoonTopoLOLA.png)

Topography of the Moon

The [topography of the Moon](https://en.wikipedia.org/wiki/Topography_of_the_Moon) has been measured with [laser altimetry](https://en.wikipedia.org/wiki/Laser_altimetry) and [stereo image analysis](https://en.wikipedia.org/wiki/Stereoscopy).[[46]](https://en.wikipedia.org/wiki/Moon#cite_note-52) The most visible [topographic feature](https://en.wikipedia.org/wiki/List_of_features_on_the_Moon) is the giant far-side [South Pole–Aitken basin](https://en.wikipedia.org/wiki/South_Pole%E2%80%93Aitken_basin), some 2,240 km (1,390 mi) in diameter, the largest crater on the Moon and the second-largest confirmed impact [crater in the Solar System](https://en.wikipedia.org/wiki/List_of_largest_craters_in_the_Solar_System).[[47]](https://en.wikipedia.org/wiki/Moon#cite_note-Spudis1994-53)[[48]](https://en.wikipedia.org/wiki/Moon#cite_note-54) At 13 km (8.1 mi) deep, its floor is the lowest point on the surface of the Moon.[[47]](https://en.wikipedia.org/wiki/Moon#cite_note-Spudis1994-53)[[49]](https://en.wikipedia.org/wiki/Moon#cite_note-55) The highest elevations on the surface of the Moon are located directly to the northeast, and it has been suggested that this area might have been thickened by the oblique formation impact of the South Pole–Aitken basin.[[50]](https://en.wikipedia.org/wiki/Moon#cite_note-56) Other large impact basins, such as[Imbrium](https://en.wikipedia.org/wiki/Mare_Imbrium), [Serenitatis](https://en.wikipedia.org/wiki/Mare_Serenitatis), [Crisium](https://en.wikipedia.org/wiki/Mare_Crisium), [Smythii](https://en.wikipedia.org/wiki/Mare_Smythii), and [Orientale](https://en.wikipedia.org/wiki/Mare_Orientale), also possess regionally low elevations and elevated rims.[[47]](https://en.wikipedia.org/wiki/Moon#cite_note-Spudis1994-53) The lunar far side is on average about 1.9 km (1.2 mi) higher than the near side.[[1]](https://en.wikipedia.org/wiki/Moon#cite_note-W06-1)

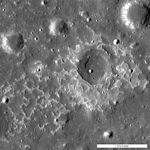
#### Volcanic features

*Main article:*[*Lunar mare*](https://en.wikipedia.org/wiki/Lunar_mare)

[](https://en.wikipedia.org/wiki/File:Moon_names.svg)

[Lunar nearside](https://en.wikipedia.org/wiki/Near_side_of_the_Moon) with [major maria](https://en.wikipedia.org/wiki/Lunar_mare)and [craters](https://en.wikipedia.org/wiki/Lunar_craters) labeled

The dark and relatively featureless lunar plains that can clearly be seen with the naked eye are called [*maria*](https://en.wikipedia.org/wiki/Lunar_mare) ([Latin](https://en.wikipedia.org/wiki/Latin_language) for "seas"; singular *mare*), because they were believed by ancient astronomers to be filled with water.[[51]](https://en.wikipedia.org/wiki/Moon#cite_note-57) They are now known to be vast solidified pools of ancient [basaltic](https://en.wikipedia.org/wiki/Basalt) lava. Although similar to terrestrial basalts, lunar basalts have more iron and no minerals altered by water.[[52]](https://en.wikipedia.org/wiki/Moon#cite_note-58)[[53]](https://en.wikipedia.org/wiki/Moon#cite_note-59) The majority of these lavas erupted or flowed into the depressions associated with [impact basins](https://en.wikipedia.org/wiki/Impact_crater). Several [geologic provinces](https://en.wikipedia.org/wiki/Geologic_province) containing [shield volcanoes](https://en.wikipedia.org/wiki/Shield_volcano) and volcanic [domes](https://en.wikipedia.org/wiki/Lunar_dome) are found within the near side maria.[[54]](https://en.wikipedia.org/wiki/Moon#cite_note-60)

[](https://en.wikipedia.org/wiki/File:14284-Moon-Maskelyne-LRO-20141012.jpg)

Evidence of [young lunar volcanism](https://en.wikipedia.org/wiki/Irregular_mare_patch)

Almost all maria are on the near side of the Moon, covering 31% of the surface on the near side,[[55]](https://en.wikipedia.org/wiki/Moon#cite_note-worldbook-61) compared with a few scattered patches on the far side covering only 2%.[[56]](https://en.wikipedia.org/wiki/Moon#cite_note-62) This is thought to be due to a [concentration of heat-producing elements](https://en.wikipedia.org/wiki/KREEP) under the crust on the near side, seen on geochemical maps obtained by [*Lunar Prospector*](https://en.wikipedia.org/wiki/Lunar_Prospector)*'*s gamma-ray spectrometer, which would have caused the underlying mantle to heat up, partially melt, rise to the surface and erupt.[[43]](https://en.wikipedia.org/wiki/Moon#cite_note-S06-49)[[57]](https://en.wikipedia.org/wiki/Moon#cite_note-63)[[58]](https://en.wikipedia.org/wiki/Moon#cite_note-64) Most of the Moon's [mare basalts](https://en.wikipedia.org/wiki/Lunar_mare) 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.[[59]](https://en.wikipedia.org/wiki/Moon#cite_note-Papike-65) Until recently, the youngest eruptions, dated by [crater counting](https://en.wikipedia.org/wiki/Crater_counting), appeared to have been only 1.2 billion years ago.[[60]](https://en.wikipedia.org/wiki/Moon#cite_note-Hiesinger-66) In 2006, a study of [Ina](https://en.wikipedia.org/wiki/Ina_(crater)), a tiny depression in [Lacus Felicitatis](https://en.wikipedia.org/wiki/Lacus_Felicitatis), found jagged, relatively dust-free features that, due to the lack of erosion by infalling debris, appeared to be only 2 million years old.[[61]](https://en.wikipedia.org/wiki/Moon#cite_note-Berardelli-67) [Moonquakes](https://en.wikipedia.org/wiki/Moonquake) and releases of gas also indicate some continued lunar activity.[[61]](https://en.wikipedia.org/wiki/Moon#cite_note-Berardelli-67) In 2014 NASA announced "widespread evidence of young lunar volcanism" at 70 [irregular mare patches](https://en.wikipedia.org/wiki/Irregular_mare_patch) identified by the [Lunar Reconnaissance Orbiter](https://en.wikipedia.org/wiki/Lunar_Reconnaissance_Orbiter), some less than 50 million years old. This raises the possibility of a much warmer lunar mantle than previously believed, at least on the near side where the deep crust is substantially warmer due to the greater concentration of radioactive elements.[[62]](https://en.wikipedia.org/wiki/Moon#cite_note-68)[[63]](https://en.wikipedia.org/wiki/Moon#cite_note-69)[[64]](https://en.wikipedia.org/wiki/Moon#cite_note-70)[[65]](https://en.wikipedia.org/wiki/Moon#cite_note-71) Just prior to this, evidence has been presented for 2–10 million years younger basaltic volcanism inside Lowell crater,[[66]](https://en.wikipedia.org/wiki/Moon#cite_note-72)[[67]](https://en.wikipedia.org/wiki/Moon#cite_note-73) Orientale basin, located in the transition zone between the near and far sides of the Moon. An initially hotter mantle and/or local enrichment of heat-producing elements in the mantle could be responsible for prolonged activities also on the far side in the Orientale basin.[[68]](https://en.wikipedia.org/wiki/Moon#cite_note-74)[[69]](https://en.wikipedia.org/wiki/Moon#cite_note-75)

The lighter-coloured regions of the Moon are called *terrae*, or more commonly *highlands*, because they are higher than most maria. They have been radiometrically dated to having formed 4.4 billion years ago, and may represent [plagioclase](https://en.wikipedia.org/wiki/Plagioclase) [cumulates](https://en.wikipedia.org/wiki/Cumulate_rock) of the [lunar magma ocean](https://en.wikipedia.org/wiki/Lunar_magma_ocean).[[59]](https://en.wikipedia.org/wiki/Moon#cite_note-Papike-65)[[60]](https://en.wikipedia.org/wiki/Moon#cite_note-Hiesinger-66) In contrast to Earth, no major lunar mountains are believed to have formed as a result of tectonic events.[[70]](https://en.wikipedia.org/wiki/Moon#cite_note-76)

The concentration of maria on the Near Side likely reflects the substantially thicker crust of the highlands of the Far Side, which may have formed in a slow-velocity impact of a second moon of Earth a few tens of millions of years after their formation.[[71]](https://en.wikipedia.org/wiki/Moon#cite_note-77)[[72]](https://en.wikipedia.org/wiki/Moon#cite_note-78)

#### Impact craters

*Further information:*[*List of craters on the Moon*](https://en.wikipedia.org/wiki/List_of_craters_on_the_Moon)

[](https://en.wikipedia.org/wiki/File:Moon-craters.jpg)

Lunar crater [Daedalus](https://en.wikipedia.org/wiki/Daedalus_(crater)) on the [Moon's far side](https://en.wikipedia.org/wiki/Far_side_of_the_Moon)

The other major geologic process that has affected the Moon's surface is [impact cratering](https://en.wikipedia.org/wiki/Impact_crater),[[73]](https://en.wikipedia.org/wiki/Moon#cite_note-79) 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 (0.6 mi) on the Moon's near side alone.[[74]](https://en.wikipedia.org/wiki/Moon#cite_note-80) Some of these are [named](https://en.wikipedia.org/wiki/Selenography#Mapping_and_naming_the_Moon) for scholars, scientists, artists and explorers.[[75]](https://en.wikipedia.org/wiki/Moon#cite_note-gazetteer-81) The [lunar geologic timescale](https://en.wikipedia.org/wiki/Lunar_geologic_timescale) is based on the most prominent impact events, including [Nectaris](https://en.wikipedia.org/wiki/Nectarian), [Imbrium](https://en.wikipedia.org/wiki/Lower_Imbrian), and[Orientale](https://en.wikipedia.org/wiki/Mare_Orientale), structures characterized 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](https://en.wikipedia.org/wiki/Stratigraphy).[[76]](https://en.wikipedia.org/wiki/Moon#cite_note-geologic-82) The lack of an atmosphere, weather and recent geological processes mean that many of these craters are well-preserved. Although only a few multi-ring basins have been definitively dated, they are useful for assigning relative ages. Because 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.[[76]](https://en.wikipedia.org/wiki/Moon#cite_note-geologic-82) The radiometric ages of impact-melted rocks collected during the [Apollo missions](https://en.wikipedia.org/wiki/Apollo_missions) cluster between 3.8 and 4.1 billion years old: this has been used to propose a [Late Heavy Bombardment](https://en.wikipedia.org/wiki/Late_Heavy_Bombardment) of impacts.[[77]](https://en.wikipedia.org/wiki/Moon#cite_note-83)

Blanketed on top of the Moon's crust is a highly [comminuted](https://en.wikipedia.org/wiki/Comminution) (broken into ever smaller particles) and [impact gardened](https://en.wikipedia.org/wiki/Impact_gardening) surface layer called [regolith](https://en.wikipedia.org/wiki/Regolith), formed by impact processes. The finer regolith, the [lunar soil](https://en.wikipedia.org/wiki/Lunar_soil) of [silicon dioxide](https://en.wikipedia.org/wiki/Silicon_dioxide) glass, has a texture resembling snow and a scent resembling spent [gunpowder](https://en.wikipedia.org/wiki/Gunpowder).[[78]](https://en.wikipedia.org/wiki/Moon#cite_note-84) The regolith of older surfaces is generally thicker than for younger surfaces: it varies in thickness from 10–20 km (6.2–12.4 mi) in the highlands and 3–5 km (1.9–3.1 mi) in the maria.[[79]](https://en.wikipedia.org/wiki/Moon#cite_note-85) Beneath the finely comminuted regolith layer is the *megaregolith*, a layer of highly fractured bedrock many kilometres thick.[[80]](https://en.wikipedia.org/wiki/Moon#cite_note-86)

[](https://en.wikipedia.org/wiki/File:Reiner-gamma-clem1.jpg)

[Lunar swirls](https://en.wikipedia.org/wiki/Lunar_swirls) at [Reiner Gamma](https://en.wikipedia.org/wiki/Reiner_Gamma)

#### Lunar swirls

*Main article:*[*Lunar swirls*](https://en.wikipedia.org/wiki/Lunar_swirls)

Lunar swirls are enigmatic features found across the Moon’s surface, which are characterized by having a high albedo, appearing optically immature (i.e. having the optical characteristics of a relatively young regolith), and (often) having a sinuous shape. Their curvilinear shape is often accentuated by low albedo regions that wind between the bright swirls.

#### Presence of water

*Main article:*[*Lunar water*](https://en.wikipedia.org/wiki/Lunar_water)

Liquid water cannot persist on the lunar surface. When exposed to solar radiation, water quickly decomposes through a process known as [photodissociation](https://en.wikipedia.org/wiki/Photodissociation) and is lost to space. However, since the 1960s, scientists have hypothesized that water ice may be deposited by impacting [comets](https://en.wikipedia.org/wiki/Comets) or possibly produced by the reaction of oxygen-rich lunar rocks, and hydrogen from [solar wind](https://en.wikipedia.org/wiki/Solar_wind), leaving traces of water which could possibly survive in cold, permanently shadowed craters at either pole on the Moon.[[81]](https://en.wikipedia.org/wiki/Moon#cite_note-Margot1999-87)[[82]](https://en.wikipedia.org/wiki/Moon#cite_note-88) Computer simulations suggest that up to 14,000 km2 (5,400 sq mi) of the surface may be in permanent shadow.[[83]](https://en.wikipedia.org/wiki/Moon#cite_note-M03-89) The presence of usable quantities of water on the Moon is an important factor in rendering [lunar habitation](https://en.wikipedia.org/wiki/Colonization_of_the_Moon) as a cost-effective plan; the alternative of transporting water from Earth would be prohibitively expensive.[[84]](https://en.wikipedia.org/wiki/Moon#cite_note-seedhouse2009-90)

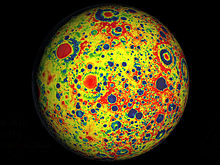
In years since, signatures of water have been found to exist on the lunar surface.[[85]](https://en.wikipedia.org/wiki/Moon#cite_note-moonwater_18032010-91) In 1994, the [bistatic radar experiment](https://en.wikipedia.org/wiki/Clementine_mission#Bistatic_Radar_Experiment) located on the [*Clementine*](https://en.wikipedia.org/wiki/Clementine_(spacecraft)) spacecraft, indicated the existence of small, frozen pockets of water close to the surface. However, later radar observations by [Arecibo](https://en.wikipedia.org/wiki/Arecibo_Observatory), suggest these findings may rather be rocks ejected from young impact craters.[[86]](https://en.wikipedia.org/wiki/Moon#cite_note-92) In 1998, the [neutron spectrometer](https://en.wikipedia.org/wiki/Lunar_Prospector#Neutron_Spectrometer_.28NS.29) located on the *Lunar Prospector* spacecraft, indicated that high concentrations of hydrogen are present in the first meter of depth in the regolith near the polar regions.[[87]](https://en.wikipedia.org/wiki/Moon#cite_note-Feldman1998-93) In 2008, an analysis of volcanic lava beads, brought back to Earth aboard Apollo 15, showed small amounts of water to exist in the interior of the beads.[[88]](https://en.wikipedia.org/wiki/Moon#cite_note-Saal2008-94)

The 2008 [*Chandrayaan-1*](https://en.wikipedia.org/wiki/Chandrayaan-1) spacecraft has since confirmed the existence of surface water ice, using the on-board [Moon Mineralogy Mapper](https://en.wikipedia.org/wiki/Moon_Mineralogy_Mapper). The spectrometer observed absorption lines common to [hydroxyl](https://en.wikipedia.org/wiki/Hydroxyl), in reflected sunlight, providing evidence of large quantities of water ice, on the lunar surface. The spacecraft showed that concentrations may possibly be as high as 1,000 [ppm](https://en.wikipedia.org/wiki/Parts_per_million).[[89]](https://en.wikipedia.org/wiki/Moon#cite_note-Pieters2009-95) In 2009, [*LCROSS*](https://en.wikipedia.org/wiki/LCROSS) sent a 2,300 kg (5,100 lb) impactor into a permanently shadowed polar crater, and detected at least 100 kg (220 lb) of water in a plume of ejected material.[[90]](https://en.wikipedia.org/wiki/Moon#cite_note-Planetary-96)[[91]](https://en.wikipedia.org/wiki/Moon#cite_note-Colaprete-97) Another examination of the LCROSS data showed the amount of detected water to be closer to 155 ± 12 kg (342 ± 26 lb).[[92]](https://en.wikipedia.org/wiki/Moon#cite_note-Colaprete2010-98)

In May 2011, Erik Hauri et al. reported[[93]](https://en.wikipedia.org/wiki/Moon#cite_note-hauri-99) 615–1410 ppm water in [melt inclusions](https://en.wikipedia.org/wiki/Melt_inclusions) in lunar sample 74220, the famous high-titanium "orange glass soil" of volcanic origin collected during the [Apollo 17](https://en.wikipedia.org/wiki/Apollo_17) mission in 1972. The inclusions were formed during explosive eruptions on the Moon approximately 3.7 billion years ago. This concentration is comparable with that of magma in Earth's [upper mantle](https://en.wikipedia.org/wiki/Upper_mantle). Although of considerable selenological interest, Hauri's announcement affords little comfort to would-be lunar colonists—the sample originated many kilometers below the surface, and the inclusions are so difficult to access that it took 39 years to find them with a state-of-the-art ion microprobe instrument.

### Gravitational field

*Main article:*[*Gravity of the Moon*](https://en.wikipedia.org/wiki/Gravity_of_the_Moon)

[](https://en.wikipedia.org/wiki/File:GRAIL's_gravity_map_of_the_moon.jpg)

[GRAIL](https://en.wikipedia.org/wiki/Gravity_Recovery_and_Interior_Laboratory)'s gravity map of the Moon

The gravitational field of the Moon has been measured through tracking the [Doppler shift](https://en.wikipedia.org/wiki/Doppler_effect) of radio signals emitted by orbiting spacecraft. The main lunar gravity features are [mascons](https://en.wikipedia.org/wiki/Mass_concentration_(astronomy)), large positive gravitational anomalies associated with some of the giant [impact basins](https://en.wikipedia.org/wiki/Impact_crater), partly caused by the dense mare basaltic lava flows that fill these basins.[[94]](https://en.wikipedia.org/wiki/Moon#cite_note-100)[[95]](https://en.wikipedia.org/wiki/Moon#cite_note-101) 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.[[96]](https://en.wikipedia.org/wiki/Moon#cite_note-102)

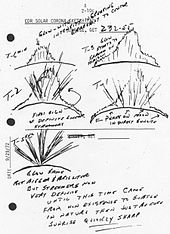
### Magnetic field

*Main article:*[*Magnetic field of the Moon*](https://en.wikipedia.org/wiki/Magnetic_field_of_the_Moon)

The Moon has an external [magnetic field](https://en.wikipedia.org/wiki/Magnetic_field) of about 1–100 [nanoteslas](https://en.wikipedia.org/wiki/Tesla_(unit)), less than one-hundredth [that of Earth](https://en.wikipedia.org/wiki/Earth%27s_magnetic_field). It does not currently have a global [dipolar](https://en.wikipedia.org/wiki/Dipole) magnetic field and only has crustal magnetization, probably acquired early in lunar history when a dynamo was still operating.[[97]](https://en.wikipedia.org/wiki/Moon#cite_note-GB2009-103)[[98]](https://en.wikipedia.org/wiki/Moon#cite_note-104) 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](https://en.wikipedia.org/wiki/Antipodes) of the giant impact basins.[[99]](https://en.wikipedia.org/wiki/Moon#cite_note-105)

### Atmosphere

*Main article:*[*Atmosphere of the Moon*](https://en.wikipedia.org/wiki/Atmosphere_of_the_Moon)

[](https://en.wikipedia.org/wiki/File:Apollo_17_twilight_ray_sketch.jpg)

Sketch by the Apollo 17 astronauts. The lunar atmosphere was later studied by [LADEE](https://en.wikipedia.org/wiki/LADEE).[[100]](https://en.wikipedia.org/wiki/Moon#cite_note-106)[[101]](https://en.wikipedia.org/wiki/Moon#cite_note-107)

The Moon has an atmosphere so tenuous as to be nearly [vacuum](https://en.wikipedia.org/wiki/Vacuum), with a total mass of less than 10 metric tons (9.8 long tons; 11 short tons).[[102]](https://en.wikipedia.org/wiki/Moon#cite_note-108) The surface pressure of this small mass is around 3 × 10−15 [atm](https://en.wikipedia.org/wiki/Atmosphere_(unit)) (0.3 [nPa](https://en.wikipedia.org/wiki/Nanopascal)); it varies with the lunar day. Its sources include [outgassing](https://en.wikipedia.org/wiki/Outgassing) and [sputtering](https://en.wikipedia.org/wiki/Sputtering), the release of atoms from the bombardment of lunar soil by [solar wind](https://en.wikipedia.org/wiki/Solar_wind) ions.[[9]](https://en.wikipedia.org/wiki/Moon#cite_note-L06-13)[[103]](https://en.wikipedia.org/wiki/Moon#cite_note-109) Elements that have been detected include [sodium](https://en.wikipedia.org/wiki/Sodium) and [potassium](https://en.wikipedia.org/wiki/Potassium), produced by sputtering, which are also found in the atmospheres of [Mercury](https://en.wikipedia.org/wiki/Mercury_(planet)) and [Io](https://en.wikipedia.org/wiki/Io_(moon)); [helium-4](https://en.wikipedia.org/wiki/Helium-4) and [neon](https://en.wikipedia.org/wiki/Neon)[[104]](https://en.wikipedia.org/wiki/Moon#cite_note-NASA-20150817-110) from the solar wind; and [argon-40](https://en.wikipedia.org/wiki/Argon), [radon-222](https://en.wikipedia.org/wiki/Radon), and [polonium-210](https://en.wikipedia.org/wiki/Polonium-210), outgassed after their creation by [radioactive decay](https://en.wikipedia.org/wiki/Radioactive_decay) within the crust and mantle.[[105]](https://en.wikipedia.org/wiki/Moon#cite_note-Stern1999-111)[[106]](https://en.wikipedia.org/wiki/Moon#cite_note-112) The absence of such neutral species (atoms or molecules) as [oxygen](https://en.wikipedia.org/wiki/Oxygen), [nitrogen](https://en.wikipedia.org/wiki/Nitrogen), [carbon](https://en.wikipedia.org/wiki/Carbon), [hydrogen](https://en.wikipedia.org/wiki/Hydrogen) and [magnesium](https://en.wikipedia.org/wiki/Magnesium), which are present in the [regolith](https://en.wikipedia.org/wiki/Regolith), is not understood.[[105]](https://en.wikipedia.org/wiki/Moon#cite_note-Stern1999-111) Water vapour has been detected by[*Chandrayaan-1*](https://en.wikipedia.org/wiki/Chandrayaan-1) and found to vary with latitude, with a maximum at ~60–70 degrees; it is possibly generated from the [sublimation](https://en.wikipedia.org/wiki/Sublimation_(chemistry)) of water ice in the regolith.[[107]](https://en.wikipedia.org/wiki/Moon#cite_note-Sridharan2010-113) 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 ionized, by being swept away by the solar wind's magnetic field.[[105]](https://en.wikipedia.org/wiki/Moon#cite_note-Stern1999-111)

#### Dust

A permanent asymmetric [moon dust](https://en.wikipedia.org/wiki/Moon_dust) cloud exists around the Moon, created by small particles from [comets](https://en.wikipedia.org/wiki/Comets). Estimates are 5 tons of comet particles strike the Moon's surface each 24 hours. The particles strike the Moon's surface ejecting moon dust above the Moon. The dust stays above the Moon approximately 10 minutes, taking 5 minutes to rise, and 5 minutes to fall. On average, 120 kilograms of dust are present above the Moon, rising to 100 kilometers above the surface. The dust measurements were made by [LADEE](https://en.wikipedia.org/wiki/Lunar_Atmosphere_and_Dust_Environment_Explorer)'s Lunar Dust EXperiment (LDEX), between 20 and 100 kilometers above the surface, during a six-month period. LDEX detected an average of one 0.3 micrometer moon dust particle each minute. Dust particle counts peaked during the [Geminid](https://en.wikipedia.org/wiki/Geminids), [Quadrantid](https://en.wikipedia.org/wiki/Quadrantids), [Northern Taurid](https://en.wikipedia.org/wiki/Taurids), and [Omicron Centaurid](https://en.wikipedia.org/wiki/Omicron_Centaurids) [meteor showers](https://en.wikipedia.org/wiki/Meteor_shower), when the Earth, and Moon, pass through comet debris. The cloud is asymmetric, more dense near the boundary between the Moon's dayside and nightside.[[108]](https://en.wikipedia.org/wiki/Moon#cite_note-114)[[109]](https://en.wikipedia.org/wiki/Moon#cite_note-115)

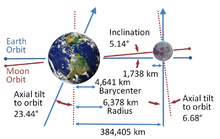
### Seasons

The Moon's [axial tilt](https://en.wikipedia.org/wiki/Axial_tilt) with respect to the [ecliptic](https://en.wikipedia.org/wiki/Ecliptic) is only 1.5424°,[[110]](https://en.wikipedia.org/wiki/Moon#cite_note-SolarViews-116) much less than the 23.44° of Earth. Because of this, the Moon's solar illumination varies much less with season, and topographical details play a crucial role in seasonal effects.[[111]](https://en.wikipedia.org/wiki/Moon#cite_note-bbc-117) From images taken by [*Clementine*](https://en.wikipedia.org/wiki/Clementine_(spacecraft)) in 1994, it appears that four mountainous regions on the rim of [Peary Crater](https://en.wikipedia.org/wiki/Peary_(crater)) at the Moon's north pole may remain illuminated for the entire [lunar day](https://en.wikipedia.org/wiki/Lunar_day), creating [peaks of eternal light](https://en.wikipedia.org/wiki/Peak_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,[[83]](https://en.wikipedia.org/wiki/Moon#cite_note-M03-89) and these dark craters are extremely cold: [*Lunar Reconnaissance Orbiter*](https://en.wikipedia.org/wiki/Lunar_Reconnaissance_Orbiter) measured the lowest summer temperatures in craters at the southern pole at 35 K (−238 °C; −397 °F)[[112]](https://en.wikipedia.org/wiki/Moon#cite_note-118) and just 26 K (−247 °C; −413 °F) close to the winter solstice in north polar [Hermite Crater](https://en.wikipedia.org/wiki/Hermite_(crater)). This is the coldest temperature in the Solar System ever measured by a spacecraft, colder even than the surface of [Pluto](https://en.wikipedia.org/wiki/Pluto).[[111]](https://en.wikipedia.org/wiki/Moon#cite_note-bbc-117) Average temperatures of the Moon's surface are reported, but temperatures of different areas will vary greatly depending upon whether a spot is in sunlight or in shadow.[[113]](https://en.wikipedia.org/wiki/Moon#cite_note-119)

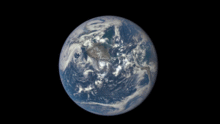
## Relationship to Earth

### Orbit

*Main articles:*[*Orbit of the Moon*](https://en.wikipedia.org/wiki/Orbit_of_the_Moon)*and*[*Lunar theory*](https://en.wikipedia.org/wiki/Lunar_theory)

[](https://en.wikipedia.org/wiki/File:Earth-Moon.PNG)

Earth–Moon system (schematic)

[](https://en.wikipedia.org/wiki/File:Dscovrepicmoontransitfull.gif)

[DSCOVR satellite](https://en.wikipedia.org/wiki/DSCOVR) sees the Moon passing in front of Earth

The Moon makes a complete orbit around Earth with respect to the fixed stars about once every 27.3 days[[g]](https://en.wikipedia.org/wiki/Moon#cite_note-orbpd-120) (its [sidereal period](https://en.wikipedia.org/wiki/Sidereal_period)). However, because Earth is moving in its orbit around the Sun at the same time, it takes slightly longer for the Moon to show the same [phase](https://en.wikipedia.org/wiki/Lunar_phase) to Earth, which is about 29.5 days[[h]](https://en.wikipedia.org/wiki/Moon#cite_note-synpd-121) (its [synodic period](https://en.wikipedia.org/wiki/Synodic_period)).[[55]](https://en.wikipedia.org/wiki/Moon#cite_note-worldbook-61) Unlike most satellites of other planets, the Moon orbits closer to the [ecliptic plane](https://en.wikipedia.org/wiki/Ecliptic_plane) than to the planet's [equatorial plane](https://en.wikipedia.org/wiki/Equatorial_plane). The Moon's orbit is subtly [perturbed](https://en.wikipedia.org/wiki/Perturbation_(astronomy)) by the Sun and Earth in many small, complex and interacting ways. For example, the plane of the Moon's orbital motion [gradually rotates](https://en.wikipedia.org/wiki/Precession), which affects other aspects of lunar motion. These follow-on effects are mathematically described by [Cassini's laws](https://en.wikipedia.org/wiki/Cassini%27s_Laws).[[114]](https://en.wikipedia.org/wiki/Moon#cite_note-Beletskii2-122)

### Relative size

The Moon is exceptionally large relative to Earth: a quarter its diameter and 1/81 its mass.[[55]](https://en.wikipedia.org/wiki/Moon#cite_note-worldbook-61) It is the largest moon in the Solar System relative to the size of its planet,[[i]](https://en.wikipedia.org/wiki/Moon#cite_note-123) though [Charon](https://en.wikipedia.org/wiki/Charon_(moon)) is larger relative to the dwarf planet [Pluto](https://en.wikipedia.org/wiki/Pluto), at 1/9 Pluto's mass.[[j]](https://en.wikipedia.org/wiki/Moon#cite_note-Moon_vs._Charon-124)[[115]](https://en.wikipedia.org/wiki/Moon#cite_note-125) Earth and the Moon are nevertheless still considered a planet–satellite system, rather than a [double planet](https://en.wikipedia.org/wiki/Double_planet), because their [barycentre](https://en.wikipedia.org/wiki/Barycentre), the common centre of mass, is located 1,700 km (1,100 mi) (about a quarter of Earth's radius) beneath Earth's surface.[[116]](https://en.wikipedia.org/wiki/Moon#cite_note-126)

### Appearance from Earth

*See also:*[*Lunar phase*](https://en.wikipedia.org/wiki/Lunar_phase)*,*[*Earthshine*](https://en.wikipedia.org/wiki/Earthshine)*, and*[*Observing the Moon*](https://en.wikipedia.org/wiki/Observing_the_Moon)

[](https://en.wikipedia.org/wiki/File:Mountain_Moonset.jpg)

Moon setting in western sky over the[High Desert](https://en.wikipedia.org/wiki/High_Desert_(California)) in California

The Moon is in [synchronous rotation](https://en.wikipedia.org/wiki/Synchronous_rotation): it rotates about its axis in about the same time it takes to [orbit](https://en.wikipedia.org/wiki/Orbit) Earth. This results in it nearly always keeping the same face turned towards Earth. The Moon used to rotate at a faster rate, but early in its history, its rotation slowed and became [tidally locked](https://en.wikipedia.org/wiki/Tidal_locking) in this orientation as a result of [frictional](https://en.wikipedia.org/wiki/Friction) effects associated with [tidal](https://en.wikipedia.org/wiki/Tidal_force)deformations caused by Earth.[[117]](https://en.wikipedia.org/wiki/Moon#cite_note-127) The side of the Moon that faces Earth is called the [near side](https://en.wikipedia.org/wiki/Near_side_of_the_Moon), and the opposite side the [far side](https://en.wikipedia.org/wiki/Far_side_of_the_Moon). The far side is often inaccurately called the "dark side", but in fact, it is illuminated 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.[[118]](https://en.wikipedia.org/wiki/Moon#cite_note-128) In 2016, planetary scientists, using data collected on the much earlier Nasa [Lunar Prospector](https://en.wikipedia.org/wiki/Lunar_Prospector) mission, found two hydrogen-rich areas on opposite sides of the Moon, probably in the form of water ice. It is speculated that these patches were the poles of the Moon billions of years ago, before it was tidally locked to Earth.[[119]](https://en.wikipedia.org/wiki/Moon#cite_note-129)

The Moon has an exceptionally low [albedo](https://en.wikipedia.org/wiki/Albedo), giving it a reflectance that is slightly brighter than that of worn asphalt. Despite this, it is the brightest object in the sky after the [Sun](https://en.wikipedia.org/wiki/Sun).[[55]](https://en.wikipedia.org/wiki/Moon#cite_note-worldbook-61)[[k]](https://en.wikipedia.org/wiki/Moon#cite_note-brightness-130) This is partly due to the brightness enhancement of the [opposition effect](https://en.wikipedia.org/wiki/Opposition_effect); at quarter phase, the Moon is only one-tenth as bright, rather than half as bright, as at full moon.[[120]](https://en.wikipedia.org/wiki/Moon#cite_note-Moon-131)

Additionally, [colour constancy](https://en.wikipedia.org/wiki/Colour_constancy) in the [visual system](https://en.wikipedia.org/wiki/Visual_system) recalibrates the relations between the colours of an object and its surroundings, and because 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](https://en.wikipedia.org/wiki/Limb_darkening), due to the [reflective properties](https://en.wikipedia.org/wiki/Lambert%27s_cosine_law#Lambertian_scatterers) of [lunar soil](https://en.wikipedia.org/wiki/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](https://en.wikipedia.org/wiki/Moon_illusion), first described in the 7th century BC.[[121]](https://en.wikipedia.org/wiki/Moon#cite_note-132) The full moon subtends an arc of about 0.52° (on average) in the sky, roughly the same apparent size as the Sun (see [§ Eclipses](https://en.wikipedia.org/wiki/Moon#Eclipses)).

The highest [altitude](https://en.wikipedia.org/wiki/Altitude_(astronomy)) of the Moon in the sky varies with the lunar phase and the season of the year. The full moon is highest during winter. The 18.6-year [nodes cycle](https://en.wikipedia.org/wiki/Lunar_node) also has an influence: when the [ascending node](https://en.wikipedia.org/wiki/Orbital_node) of the lunar orbit is in the [vernal equinox](https://en.wikipedia.org/wiki/Vernal_equinox), the lunar[declination](https://en.wikipedia.org/wiki/Declination) can go as far as 28° each month. This means the Moon can go overhead at latitudes up to 28° from 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 smile-shaped crescent moon.[[122]](https://en.wikipedia.org/wiki/Moon#cite_note-133)

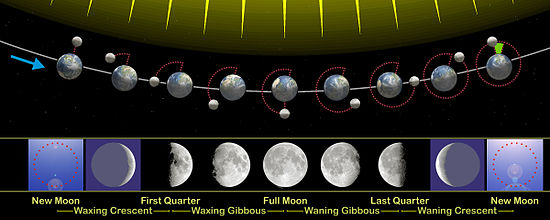
The moon is visible for two weeks every 27.3 days at the [North](https://en.wikipedia.org/wiki/North_Pole) and [South Pole](https://en.wikipedia.org/wiki/South_Pole). The moon's light is used by [zooplankton](https://en.wikipedia.org/wiki/Zooplankton) in the Arctic when the sun is below the horizon for months on end.[[123]](https://en.wikipedia.org/wiki/Moon#cite_note-134)

The distance between the Moon and Earth varies from around 356,400 km (221,500 mi) to 406,700 km (252,700 mi) at [perigees](https://en.wikipedia.org/wiki/Apsis) (closest) and apogees (farthest), respectively. On 19 March 2011, it was closer to Earth when at full phase than it has been since 1993, 14% closer than its farthest position in apogee.[[124]](https://en.wikipedia.org/wiki/Moon#cite_note-135) Reported as a "[super moon](https://en.wikipedia.org/wiki/Supermoon)", this closest point coincides within an hour of a [full moon](https://en.wikipedia.org/wiki/Full_moon), and it was 30% more luminous than when at its greatest distance due to its angular diameter being 14% greater, because {\displaystyle \scriptstyle 1.14^{2}\approx 1.30}.[[125]](https://en.wikipedia.org/wiki/Moon#cite_note-136)[[126]](https://en.wikipedia.org/wiki/Moon#cite_note-137)[[127]](https://en.wikipedia.org/wiki/Moon#cite_note-138) At lower levels, the human perception of reduced brightness as a percentage is provided by the following formula:[[128]](https://en.wikipedia.org/wiki/Moon#cite_note-139)[[129]](https://en.wikipedia.org/wiki/Moon#cite_note-140)

{\displaystyle {\text{perceived reduction}}\%=100\times {\sqrt {{\text{actual reduction}}\% \over 100}}}

When the actual reduction is 1.00 / 1.30, or about 0.770, the perceived reduction is about 0.877, or 1.00 / 1.14. This gives a maximum perceived increase of 14% between apogee and perigee moons of the same phase.[[130]](https://en.wikipedia.org/wiki/Moon#cite_note-141)

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](https://en.wikipedia.org/wiki/Astronomical_seeing), or inadequate drawings. However, [outgassing](https://en.wikipedia.org/wiki/Outgassing) does occasionally occur, and could be responsible for a minor percentage of the reported [lunar transient phenomena](https://en.wikipedia.org/wiki/Transient_lunar_phenomenon). Recently, it has been suggested that a roughly 3 km (1.9 mi) diameter region of the lunar surface was modified by a gas release event about a million years ago.[[131]](https://en.wikipedia.org/wiki/Moon#cite_note-142)[[132]](https://en.wikipedia.org/wiki/Moon#cite_note-143) The Moon's appearance, like that of the Sun, can be affected by Earth's atmosphere: common effects are a 22° [halo ring](https://en.wikipedia.org/wiki/Halo_(optical_phenomenon)) formed when the Moon's light is refracted through the ice crystals of high [cirrostratus](https://en.wikipedia.org/wiki/Cirrostratus)cloud, and smaller [coronal rings](https://en.wikipedia.org/wiki/Corona_(meteorology)) when the Moon is seen through thin clouds.[[133]](https://en.wikipedia.org/wiki/Moon#cite_note-144)

[](https://en.wikipedia.org/wiki/File:Moon_phases_en.jpg)

The monthly changes of angle between the direction of illumination by the Sun and viewing from Earth, and the [phases of the Moon](https://en.wikipedia.org/wiki/Lunar_phase) that result

The illuminated area of the visible sphere (degree of illumination) is given by {\displaystyle {\frac {1}{2}}(1-\cos e)}, where {\displaystyle e} is the [elongation](https://en.wikipedia.org/wiki/Elongation_(astronomy)) (i.e. the angle between Moon, the observer (on Earth) and the Sun).

### Tidal effects

*Main articles:*[*Tidal force*](https://en.wikipedia.org/wiki/Tidal_force)*,*[*Tidal acceleration*](https://en.wikipedia.org/wiki/Tidal_acceleration)*,*[*Tide*](https://en.wikipedia.org/wiki/Tide)*, and*[*Theory of tides*](https://en.wikipedia.org/wiki/Theory_of_tides)

[](https://en.wikipedia.org/wiki/File:Lunar_libration_with_phase_Oct_2007_450px.gif)

The [libration](https://en.wikipedia.org/wiki/Libration) of the Moon over a single lunar month. Also visible is the slight variation in the Moon's visual size from Earth.

The tides on Earth are mostly generated by the gradient in intensity of the Moon's gravitational pull from one side of Earth to the other, the [tidal forces](https://en.wikipedia.org/wiki/Tidal_forces). This forms two tidal bulges on Earth, which are most clearly seen in elevated sea level as [ocean tides](https://en.wikipedia.org/wiki/Tide).[[134]](https://en.wikipedia.org/wiki/Moon#cite_note-Lambeck1977-145) Because Earth spins about 27 times faster than the Moon moves around it, the bulges are dragged along with Earth's surface faster than the Moon moves, rotating around Earth once a day as it spins on its axis.[[134]](https://en.wikipedia.org/wiki/Moon#cite_note-Lambeck1977-145) The ocean tides are magnified by other effects: frictional coupling of water to Earth's rotation through the ocean floors, the [inertia](https://en.wikipedia.org/wiki/Inertia) of water's movement, ocean basins that get shallower near land, and oscillations between different ocean basins.[[135]](https://en.wikipedia.org/wiki/Moon#cite_note-146) The tidal effect of the Sun on Earth's oceans is almost half that of the Moon, and their gravitational interplay is responsible for [spring and neap tides](https://en.wikipedia.org/wiki/Spring_tide).[[134]](https://en.wikipedia.org/wiki/Moon#cite_note-Lambeck1977-145)

Gravitational coupling between the Moon and the bulge nearest the Moon acts as a [torque](https://en.wikipedia.org/wiki/Torque) on Earth's rotation, draining [angular momentum](https://en.wikipedia.org/wiki/Angular_momentum) and rotational [kinetic energy](https://en.wikipedia.org/wiki/Kinetic_energy) from Earth's spin.[[134]](https://en.wikipedia.org/wiki/Moon#cite_note-Lambeck1977-145)[[136]](https://en.wikipedia.org/wiki/Moon#cite_note-touma1994-147) In turn, angular momentum is added to the Moon's orbit in a process confusingly known as [tidal acceleration](https://en.wikipedia.org/wiki/Tidal_acceleration), which lifts the Moon into a higher orbit with a lower orbital speed and a longer period. Thus the distance between Earth and Moon is [increasing](https://en.wikipedia.org/wiki/Tidal_acceleration), and Earth's spin is slowing down.[[136]](https://en.wikipedia.org/wiki/Moon#cite_note-touma1994-147) Measurements from [lunar ranging experiments](https://en.wikipedia.org/wiki/Lunar_laser_ranging_experiment) with laser reflectors left during the Apollo missions have found that the Moon's distance to Earth increases by 38 mm (1.5 in) per year[[137]](https://en.wikipedia.org/wiki/Moon#cite_note-148)(roughly the rate at which human fingernails grow).[[138]](https://en.wikipedia.org/wiki/Moon#cite_note-149) [Atomic clocks](https://en.wikipedia.org/wiki/Atomic_clock) also show that Earth's day lengthens by about 15 [microseconds](https://en.wikipedia.org/wiki/Microsecond) every year,[[139]](https://en.wikipedia.org/wiki/Moon#cite_note-150) slowly increasing the rate at which [UTC](https://en.wikipedia.org/wiki/Coordinated_Universal_Time) is adjusted by [leap seconds](https://en.wikipedia.org/wiki/Leap_second). Left to run its course, this tidal drag would continue until the spin of Earth and the orbital period of the Moon matched, creating mutual tidal locking between the two, as is already currently the case with [Pluto](https://en.wikipedia.org/wiki/Pluto) and its moon [Charon](https://en.wikipedia.org/wiki/Charon_(moon)). However, the Sun will become a [red giant](https://en.wikipedia.org/wiki/Red_giant#The_Sun_as_a_red_giant) long before that, engulfing Earth.[[140]](https://en.wikipedia.org/wiki/Moon#cite_note-151)[[141]](https://en.wikipedia.org/wiki/Moon#cite_note-152)

The lunar surface also experiences tides of around 10 cm (4 in) amplitude over 27 days, with two components: a fixed one due to Earth, because they are in [synchronous rotation](https://en.wikipedia.org/wiki/Synchronous_rotation), and a varying component from the Sun.[[136]](https://en.wikipedia.org/wiki/Moon#cite_note-touma1994-147)The Earth-induced component arises from [libration](https://en.wikipedia.org/wiki/Libration), a result of the Moon's orbital eccentricity; if the Moon's orbit were perfectly circular, there would only be solar tides.[[136]](https://en.wikipedia.org/wiki/Moon#cite_note-touma1994-147) Libration also changes the angle from which the Moon is seen, allowing about 59% of its surface to be seen from Earth (but only half at any instant).[[55]](https://en.wikipedia.org/wiki/Moon#cite_note-worldbook-61) The cumulative effects of stress built up by these tidal forces produces [moonquakes](https://en.wikipedia.org/wiki/Moonquakes). Moonquakes are much less common and weaker than earthquakes, although they can last for up to an hour—a significantly longer time than terrestrial earthquakes—because of the absence of water to damp out the seismic vibrations. The existence of moonquakes was an unexpected discovery from [seismometers](https://en.wikipedia.org/wiki/Seismometer) placed on the Moon by [Apollo](https://en.wikipedia.org/wiki/Apollo_program) [astronauts](https://en.wikipedia.org/wiki/Astronaut) from 1969 through 1972.[[142]](https://en.wikipedia.org/wiki/Moon#cite_note-153)

### Eclipses

*Main articles:*[*Solar eclipse*](https://en.wikipedia.org/wiki/Solar_eclipse)*,*[*Lunar eclipse*](https://en.wikipedia.org/wiki/Lunar_eclipse)*, and*[*Eclipse cycle*](https://en.wikipedia.org/wiki/Eclipse_cycle)

[](https://en.wikipedia.org/wiki/File:Solar_eclipse_1999_4_NR.jpg)

[](https://en.wikipedia.org/wiki/File:STEREO-B_solar_eclipse.jpg)

From Earth, the Moon and the Sun appear the same size, as seen in the [1999 solar eclipse](https://en.wikipedia.org/wiki/Solar_eclipse_of_August_11,_1999) (left), whereas from the [*STEREO-B*](https://en.wikipedia.org/wiki/Solar_Terrestrial_Relations_Observatory) spacecraft in an Earth-trailing orbit, the Moon appears much smaller than the Sun (right).[[143]](https://en.wikipedia.org/wiki/Moon#cite_note-154)

Eclipses can only occur when the Sun, Earth, and Moon are all in a straight line (termed "[syzygy](https://en.wikipedia.org/wiki/Syzygy_(astronomy))"). [Solar eclipses](https://en.wikipedia.org/wiki/Solar_eclipse) occur at [new moon](https://en.wikipedia.org/wiki/New_moon), when the Moon is between the Sun and Earth. In contrast, [lunar eclipses](https://en.wikipedia.org/wiki/Lunar_eclipse)occur at [full moon](https://en.wikipedia.org/wiki/Full_moon), when Earth is between the Sun and Moon. The apparent size of the Moon is roughly the same as that of the Sun, with both being viewed at close to one-half a degree wide. The Sun is much larger than the Moon but it is the precise vastly greater distance that gives it the same apparent size as the much closer and much smaller Moon from the perspective of Earth. The variations in apparent size, due to the non-circular orbits, are nearly the same as well, though occurring in different cycles. This makes possible both [total](https://en.wikipedia.org/wiki/Total_eclipse) (with the Moon appearing larger than the Sun) and [annular](https://en.wikipedia.org/wiki/Annular_eclipse) (with the Moon appearing smaller than the Sun) solar eclipses.[[144]](https://en.wikipedia.org/wiki/Moon#cite_note-155) In a total eclipse, the Moon completely covers the disc of the Sun and the solar [corona](https://en.wikipedia.org/wiki/Corona) becomes visible to the [naked eye](https://en.wikipedia.org/wiki/Naked_eye). Because the distance between the Moon and Earth is very slowly increasing over time,[[134]](https://en.wikipedia.org/wiki/Moon#cite_note-Lambeck1977-145) the angular diameter of the Moon is decreasing. Also, as it evolves toward becoming a [red giant](https://en.wikipedia.org/wiki/Red_giant), the size of the Sun, and its apparent diameter in the sky, are slowly increasing.[[l]](https://en.wikipedia.org/wiki/Moon#cite_note-size_changes-156) The combination of these two changes 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, hundreds of millions of years in the future, the Moon will no longer cover the Sun completely, and total solar eclipses will not occur.[[145]](https://en.wikipedia.org/wiki/Moon#cite_note-fourmilab-157)

Because the Moon's orbit around Earth is inclined by about 5° to the [orbit of Earth around the Sun](https://en.wikipedia.org/wiki/Ecliptic), 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.[[146]](https://en.wikipedia.org/wiki/Moon#cite_note-eclipse-158) The periodicity and recurrence of eclipses of the Sun by the Moon, and of the Moon by Earth, is described by the [saros](https://en.wikipedia.org/wiki/Saros_(astronomy)), which has a period of approximately 18 years.[[147]](https://en.wikipedia.org/wiki/Moon#cite_note-159)

Because the Moon is continuously blocking our view of a half-degree-wide circular area of the sky,[[m]](https://en.wikipedia.org/wiki/Moon#cite_note-area-160)[[148]](https://en.wikipedia.org/wiki/Moon#cite_note-161) the related phenomenon of [occultation](https://en.wikipedia.org/wiki/Occultation) 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 Earth, occultations of individual stars are not visible everywhere on the planet, nor at the same time. Because of the [precession](https://en.wikipedia.org/wiki/Precession) of the lunar orbit, each year different stars are occulted.[[149]](https://en.wikipedia.org/wiki/Moon#cite_note-162)

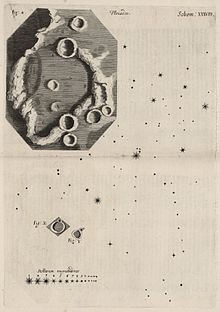
## Observation and exploration

### Ancient and medieval studies

*Main articles:*[*Exploration of the Moon: Early history*](https://en.wikipedia.org/wiki/Exploration_of_the_Moon#Early_history)*,*[*Selenography*](https://en.wikipedia.org/wiki/Selenography)*, and*[*Lunar theory*](https://en.wikipedia.org/wiki/Lunar_theory)

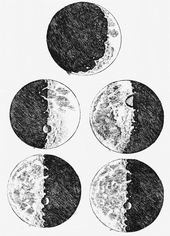
[](https://en.wikipedia.org/wiki/File:Moon_by_Johannes_hevelius_1645.PNG)

Map of the Moon by [Johannes Hevelius](https://en.wikipedia.org/wiki/Johannes_Hevelius) from his [*Selenographia*](https://en.wikipedia.org/wiki/Selenographia)(1647), the first map to include the[libration](https://en.wikipedia.org/wiki/Libration) zones

[](https://en.wikipedia.org/wiki/File:Micrographia_Schem_38.jpg)

A study of the Moon by [Robert Hooke's](https://en.wikipedia.org/wiki/Robert_Hooke) [Micrographia](https://en.wikipedia.org/wiki/Micrographia), 1665

Understanding of the Moon's cycles was an early development of astronomy: by the 5th century BC, [Babylonian astronomers](https://en.wikipedia.org/wiki/Babylonian_astronomy) had recorded the 18-year [Saros cycle](https://en.wikipedia.org/wiki/Saros_cycle) of [lunar eclipses](https://en.wikipedia.org/wiki/Lunar_eclipse),[[150]](https://en.wikipedia.org/wiki/Moon#cite_note-163) and [Indian astronomers](https://en.wikipedia.org/wiki/Indian_astronomy) had described the Moon's monthly elongation.[[151]](https://en.wikipedia.org/wiki/Moon#cite_note-Sarma-Ast-Ind-164) The [Chinese astronomer](https://en.wikipedia.org/wiki/Chinese_astronomy) [Shi Shen](https://en.wikipedia.org/wiki/Shi_Shen) (fl. 4th century BC) gave instructions for predicting solar and lunar eclipses.[[152]](https://en.wikipedia.org/wiki/Moon#cite_note-FOOTNOTENeedham1986411-165) Later, the physical form of the Moon and the cause of [moonlight](https://en.wikipedia.org/wiki/Moonlight) became understood. The [ancient Greek](https://en.wikipedia.org/wiki/Ancient_Greece) philosopher [Anaxagoras](https://en.wikipedia.org/wiki/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.[[153]](https://en.wikipedia.org/wiki/Moon#cite_note-166)[[154]](https://en.wikipedia.org/wiki/Moon#cite_note-FOOTNOTENeedham1986227-167) Although the Chinese of the [Han Dynasty](https://en.wikipedia.org/wiki/Han_Dynasty) believed the Moon to be energy equated to [*qi*](https://en.wikipedia.org/wiki/Qi), their 'radiating influence' theory also recognized that the light of the Moon was merely a reflection of the Sun, and [Jing Fang](https://en.wikipedia.org/wiki/Jing_Fang) (78–37 BC) noted the sphericity of the Moon.[[155]](https://en.wikipedia.org/wiki/Moon#cite_note-FOOTNOTENeedham1986413.E2.80.93414-168) In the 2nd century AD [Lucian](https://en.wikipedia.org/wiki/Lucian) wrote a novel where the heroes travel to the Moon, which is inhabited. In 499 AD, the Indian astronomer [Aryabhata](https://en.wikipedia.org/wiki/Aryabhata) mentioned in his [*Aryabhatiya*](https://en.wikipedia.org/wiki/Aryabhatiya) that reflected sunlight is the cause of the shining of the Moon.[[156]](https://en.wikipedia.org/wiki/Moon#cite_note-169) The astronomer and physicist [Alhazen](https://en.wikipedia.org/wiki/Alhazen) (965–1039) found that [sunlight](https://en.wikipedia.org/wiki/Sunlight) was not reflected from the Moon like a mirror, but that light was emitted from every part of the Moon's sunlit surface in all directions.[[157]](https://en.wikipedia.org/wiki/Moon#cite_note-170) [Shen Kuo](https://en.wikipedia.org/wiki/Shen_Kuo) (1031–1095) of the [Song dynasty](https://en.wikipedia.org/wiki/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.[[158]](https://en.wikipedia.org/wiki/Moon#cite_note-FOOTNOTENeedham1986415.E2.80.93416-171)

[](https://en.wikipedia.org/wiki/File:Galileo's_sketches_of_the_moon.png)

[Galileo](https://en.wikipedia.org/wiki/Galileo_Galilei)'s sketches of the Moon from [*Sidereus Nuncius*](https://en.wikipedia.org/wiki/Sidereus_Nuncius)

In [Aristotle](https://en.wikipedia.org/wiki/Aristotle)'s (384–322 BC) [description of the universe](https://en.wikipedia.org/wiki/On_the_Heavens), the Moon marked the boundary between the spheres of the mutable elements (earth, water, air and fire), and the imperishable stars of [aether](https://en.wikipedia.org/wiki/Aether_(classical_element)), an [influential philosophy](https://en.wikipedia.org/wiki/Aristotelian_physics)that would dominate for centuries.[[159]](https://en.wikipedia.org/wiki/Moon#cite_note-172) However, in the 2nd century BC, [Seleucus of Seleucia](https://en.wikipedia.org/wiki/Seleucus_of_Seleucia) correctly theorized that [tides](https://en.wikipedia.org/wiki/Tide) were due to the attraction of the Moon, and that their height depends on the Moon's position relative to the [Sun](https://en.wikipedia.org/wiki/Sun).[[160]](https://en.wikipedia.org/wiki/Moon#cite_note-173) In the same century, [Aristarchus](https://en.wikipedia.org/wiki/Aristarchus_of_Samos) [computed the size and distance](https://en.wikipedia.org/wiki/Aristarchus_On_the_Sizes_and_Distances) of the Moon from Earth, obtaining a value of about twenty times the [radius of Earth](https://en.wikipedia.org/wiki/Earth_radius) for the distance. These figures were greatly improved by[Ptolemy](https://en.wikipedia.org/wiki/Ptolemy) (90–168 AD): his values of a mean distance of 59 times Earth's radius and a diameter of 0.292 Earth diameters were close to the correct values of about 60 and 0.273 respectively.[[161]](https://en.wikipedia.org/wiki/Moon#cite_note-174) [Archimedes](https://en.wikipedia.org/wiki/Archimedes) (287–212 BC) designed a planetarium that could calculate the motions of the Moon and other objects in the Solar System.[[162]](https://en.wikipedia.org/wiki/Moon#cite_note-175)

During the [Middle Ages](https://en.wikipedia.org/wiki/Middle_Ages), before the invention of the telescope, the Moon was increasingly recognised as a sphere, though many believed that it was "perfectly smooth".[[163]](https://en.wikipedia.org/wiki/Moon#cite_note-176)

In 1609, [Galileo Galilei](https://en.wikipedia.org/wiki/Galileo_Galilei) drew one of the first telescopic drawings of the Moon in his book [*Sidereus Nuncius*](https://en.wikipedia.org/wiki/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](https://en.wikipedia.org/wiki/Giovanni_Battista_Riccioli) and [Francesco Maria Grimaldi](https://en.wikipedia.org/wiki/Francesco_Maria_Grimaldi) led to the system of naming of lunar features in use today. The more exact 1834–36 *Mappa Selenographica* of [Wilhelm Beer](https://en.wikipedia.org/wiki/Wilhelm_Beer) and [Johann Heinrich Mädler](https://en.wikipedia.org/wiki/Johann_Heinrich_M%C3%A4dler), and their associated 1837 book *Der Mond*, the first [trigonometrically](https://en.wikipedia.org/wiki/Trigonometry) 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.[[164]](https://en.wikipedia.org/wiki/Moon#cite_note-177) Lunar craters, first noted by Galileo, were thought to be[volcanic](https://en.wikipedia.org/wiki/Volcanic) until the 1870s proposal of [Richard Proctor](https://en.wikipedia.org/wiki/Richard_Proctor) that they were formed by collisions.[[55]](https://en.wikipedia.org/wiki/Moon#cite_note-worldbook-61) This view gained support in 1892 from the experimentation of geologist [Grove Karl Gilbert](https://en.wikipedia.org/wiki/Grove_Karl_Gilbert), and from comparative studies from 1920 to the 1940s,[[165]](https://en.wikipedia.org/wiki/Moon#cite_note-Hall1977-178) leading to the development of [lunar stratigraphy](https://en.wikipedia.org/wiki/Lunar_geologic_timescale), which by the 1950s was becoming a new and growing branch of [astrogeology](https://en.wikipedia.org/wiki/Astrogeology).[[55]](https://en.wikipedia.org/wiki/Moon#cite_note-worldbook-61)

### By spacecraft

*See also:*[*Robotic exploration of the Moon*](https://en.wikipedia.org/wiki/Robotic_exploration_of_the_Moon)*,*[*List of proposed missions to the Moon*](https://en.wikipedia.org/wiki/List_of_proposed_missions_to_the_Moon)*,*[*Colonization of the Moon*](https://en.wikipedia.org/wiki/Colonization_of_the_Moon)*, and*[*List of artificial objects on the Moon*](https://en.wikipedia.org/wiki/List_of_artificial_objects_on_the_Moon)

#### 20th century

##### Soviet missions

*Main articles:*[*Luna program*](https://en.wikipedia.org/wiki/Luna_program)*and*[*Lunokhod programme*](https://en.wikipedia.org/wiki/Lunokhod_programme)

[](https://en.wikipedia.org/wiki/File:Luna_2_Soviet_moon_probe.jpg)

[](https://en.wikipedia.org/wiki/File:Soviet_moonrover.JPG)

[Luna 2](https://en.wikipedia.org/wiki/Luna_2), the first human-made object to reach the surface of the Moon (left) and Soviet moon rover [Lunokhod 1](https://en.wikipedia.org/wiki/Lunokhod_1)

The [Cold War](https://en.wikipedia.org/wiki/Cold_War)-inspired [Space Race](https://en.wikipedia.org/wiki/Space_Race) between the Soviet Union and the U.S. led to an acceleration of interest in [exploration of the Moon](https://en.wikipedia.org/wiki/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](https://en.wikipedia.org/wiki/Luna_programme) were the first to accomplish a number of goals: following three unnamed, failed missions in 1958,[[166]](https://en.wikipedia.org/wiki/Moon#cite_note-179) the first human-made object to escape Earth's gravity and pass near the Moon was [*Luna 1*](https://en.wikipedia.org/wiki/Luna_1); the first human-made object to impact the lunar surface was [*Luna 2*](https://en.wikipedia.org/wiki/Luna_2), and the first photographs of the normally occluded far side of the Moon were made by [*Luna 3*](https://en.wikipedia.org/wiki/Luna_3), all in 1959.

The first spacecraft to perform a successful lunar [soft landing](https://en.wikipedia.org/wiki/Lander_(spacecraft)) was [*Luna 9*](https://en.wikipedia.org/wiki/Luna_9) and the first unmanned vehicle to orbit the Moon was [*Luna 10*](https://en.wikipedia.org/wiki/Luna_10), both in 1966.[[55]](https://en.wikipedia.org/wiki/Moon#cite_note-worldbook-61) [Rock and soil samples](https://en.wikipedia.org/wiki/Moon_rock) were brought back to Earth by three *Luna* [sample return missions](https://en.wikipedia.org/wiki/Sample_return_mission) ([*Luna 16*](https://en.wikipedia.org/wiki/Luna_16) in 1970, [*Luna 20*](https://en.wikipedia.org/wiki/Luna_20) in 1972, and [*Luna 24*](https://en.wikipedia.org/wiki/Luna_24) in 1976), which returned 0.3 kg total.[[167]](https://en.wikipedia.org/wiki/Moon#cite_note-180) Two pioneering robotic [rovers](https://en.wikipedia.org/wiki/Rover_(space_exploration)) landed on the Moon in 1970 and 1973 as a part of Soviet [Lunokhod programme](https://en.wikipedia.org/wiki/Lunokhod_programme).

##### United States missions

*Main articles:*[*Apollo program*](https://en.wikipedia.org/wiki/Apollo_program)*and*[*Moon landing*](https://en.wikipedia.org/wiki/Moon_landing)

[](https://en.wikipedia.org/wiki/File:NASA-Apollo8-Dec24-Earthrise.jpg)

[Earthrise](https://en.wikipedia.org/wiki/Earthrise) ([Apollo 8](https://en.wikipedia.org/wiki/Apollo_8), 1968)

[](https://en.wikipedia.org/wiki/File:Lunar_basalt_70017.jpg)

[Moon rock](https://en.wikipedia.org/wiki/Lunar_basalt_70017) ([Apollo 17](https://en.wikipedia.org/wiki/Apollo_17), 1972)

The United States launched unmanned probes to develop an understanding of the lunar surface for an eventual manned landing: the [Jet Propulsion Laboratory](https://en.wikipedia.org/wiki/Jet_Propulsion_Laboratory)'s [Ranger program](https://en.wikipedia.org/wiki/Ranger_program)produced the first close-up pictures; the [Lunar Orbiter program](https://en.wikipedia.org/wiki/Lunar_Orbiter_program) produced maps of the entire Moon; the [Surveyor program](https://en.wikipedia.org/wiki/Surveyor_program) landed [its first spacecraft](https://en.wikipedia.org/wiki/Surveyor_1) four months after *Luna 9*.[NASA](https://en.wikipedia.org/wiki/NASA)'s manned [Apollo program](https://en.wikipedia.org/wiki/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](https://en.wikipedia.org/wiki/Soviet_manned_lunar_programs), in 1968 [Apollo 8](https://en.wikipedia.org/wiki/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.[[168]](https://en.wikipedia.org/wiki/Moon#cite_note-CNN-181)

[](https://en.wikipedia.org/wiki/File:As11-40-5886,_uncropped.jpg)

[Neil Armstrong](https://en.wikipedia.org/wiki/Neil_Armstrong) working at the [lunar module](https://en.wikipedia.org/wiki/Lunar_module)

|  |  |
| --- | --- |
| https://upload.wikimedia.org/wikipedia/commons/thumb/8/87/Gnome-mime-sound-openclipart.svg/50px-Gnome-mime-sound-openclipart.svg.png | ["That's one small step ..."](https://en.wikipedia.org/wiki/File:Frase_de_Neil_Armstrong.ogg)  0:00 |
| *Problems playing this file? See*[*media help*](https://en.wikipedia.org/wiki/Wikipedia:Media_help)*.* | |

[Neil Armstrong](https://en.wikipedia.org/wiki/Neil_Armstrong) became the first person to walk on the Moon as the commander of the American mission [Apollo 11](https://en.wikipedia.org/wiki/Apollo_11) by first setting foot on the Moon at 02:56 UTC on 21 July 1969.[[169]](https://en.wikipedia.org/wiki/Moon#cite_note-182) An estimated 500 million people worldwide watched the transmission by the [Apollo TV camera](https://en.wikipedia.org/wiki/Apollo_TV_camera), the largest television audience for a live broadcast at that time.[[170]](https://en.wikipedia.org/wiki/Moon#cite_note-183)[[171]](https://en.wikipedia.org/wiki/Moon#cite_note-184) The Apollo missions 11 to 17 (except [Apollo 13](https://en.wikipedia.org/wiki/Apollo_13), which aborted its planned lunar landing) returned 380.05 kilograms (837.87 lb) of lunar rock and soil in 2,196 separate samples.[[172]](https://en.wikipedia.org/wiki/Moon#cite_note-185) The American [Moon landing](https://en.wikipedia.org/wiki/Moon_landing) and return was enabled by considerable technological advances in the early 1960s, in domains such as [ablation](https://en.wikipedia.org/wiki/Ablation) chemistry, [software engineering](https://en.wikipedia.org/wiki/Software_engineering) and [atmospheric re-entry](https://en.wikipedia.org/wiki/Atmospheric_re-entry) technology, and by highly competent management of the enormous technical undertaking.[[173]](https://en.wikipedia.org/wiki/Moon#cite_note-186)[[174]](https://en.wikipedia.org/wiki/Moon#cite_note-187)

Scientific instrument packages were installed on the lunar surface during all the Apollo landings. Long-lived [instrument stations](https://en.wikipedia.org/wiki/Apollo_Lunar_Surface_Experiments_Package), including heat flow probes, [seismometers](https://en.wikipedia.org/wiki/Seismometer), and [magnetometers](https://en.wikipedia.org/wiki/Magnetometer), were installed at the [Apollo 12](https://en.wikipedia.org/wiki/Apollo_12), [14](https://en.wikipedia.org/wiki/Apollo_14), [15](https://en.wikipedia.org/wiki/Apollo_15), [16](https://en.wikipedia.org/wiki/Apollo_16), and [17](https://en.wikipedia.org/wiki/Apollo_17) landing sites. Direct transmission of data to Earth concluded in late 1977 due to budgetary considerations,[[175]](https://en.wikipedia.org/wiki/Moon#cite_note-188)[[176]](https://en.wikipedia.org/wiki/Moon#cite_note-189) but as the stations' [lunar laser ranging](https://en.wikipedia.org/wiki/Lunar_laser_ranging_experiment)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.[[177]](https://en.wikipedia.org/wiki/Moon#cite_note-190)

##### 1980s–2000

[](https://en.wikipedia.org/wiki/File:Moon_Crescent_-_False_Color_Mosaic.jpg)

An [artificially](https://en.wikipedia.org/wiki/False-color) coloured mosaic constructed from a series of 53 images taken through three [spectral filters](https://en.wikipedia.org/wiki/Filter_(optics)) by *Galileo'*s imaging system as the spacecraft flew over the northern regions of the Moon on December 7, 1992.

After the first moon race there were years of near quietude but starting in the 1990s, many more countries have become involved in direct exploration of the Moon. In 1990, Japan became the third country to place a spacecraft into lunar orbit with its [*Hiten*](https://en.wikipedia.org/wiki/Hiten) spacecraft. The spacecraft released a smaller probe, *Hagoromo*, in lunar orbit, but the transmitter failed, preventing further scientific use of the mission.[[178]](https://en.wikipedia.org/wiki/Moon#cite_note-191) In 1994, the U.S. sent the joint Defense Department/NASA spacecraft [*Clementine*](https://en.wikipedia.org/wiki/Clementine_(spacecraft)) to lunar orbit. This mission obtained the first near-global topographic map of the Moon, and the first global[multispectral](https://en.wikipedia.org/wiki/Multi-spectral_image) images of the lunar surface.[[179]](https://en.wikipedia.org/wiki/Moon#cite_note-192) This was followed in 1998 by the [*Lunar Prospector*](https://en.wikipedia.org/wiki/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.[[180]](https://en.wikipedia.org/wiki/Moon#cite_note-193)

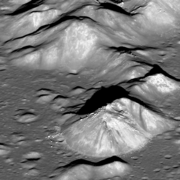
India, Japan, China, the United States, and the [European Space Agency](https://en.wikipedia.org/wiki/European_Space_Agency) each sent lunar orbiters, especially [ISRO](https://en.wikipedia.org/wiki/ISRO)'s [*Chandrayaan-1*](https://en.wikipedia.org/wiki/Chandrayaan-1) has contributed to confirming the discovery of [lunar water ice](https://en.wikipedia.org/wiki/Lunar_water) in permanently shadowed craters at the poles and bound into the lunar [regolith](https://en.wikipedia.org/wiki/Regolith). The post-Apollo era has also seen two [rover](https://en.wikipedia.org/wiki/Rover_(space_exploration)) missions: the final Soviet [Lunokhod](https://en.wikipedia.org/wiki/Lunokhod) mission in 1973, and China's ongoing [Chang'e 3](https://en.wikipedia.org/wiki/Chang%27e_3) mission, which deployed its [Yutu rover](https://en.wikipedia.org/wiki/Yutu_(rover)) on 14 December 2013. The Moon remains, under the [Outer Space Treaty](https://en.wikipedia.org/wiki/Outer_Space_Treaty), free to all nations to explore for peaceful purposes.

#### 21st century

The European spacecraft [*SMART-1*](https://en.wikipedia.org/wiki/SMART-1), the second [ion-propelled](https://en.wikipedia.org/wiki/Ion_propulsion) spacecraft, was in lunar orbit from 15 November 2004 until its lunar impact on 3 September 2006, and made the first detailed survey of chemical elements on the lunar surface.[[181]](https://en.wikipedia.org/wiki/Moon#cite_note-194)

China has pursued an ambitious [program of lunar exploration](https://en.wikipedia.org/wiki/Chinese_Lunar_Exploration_Program), beginning with [*Chang'e 1*](https://en.wikipedia.org/wiki/Chang%27e_1), which successfully orbited the Moon from 5 November 2007 until its controlled lunar impact on 1 March 2009.[[182]](https://en.wikipedia.org/wiki/Moon#cite_note-xinhua_20090301-195) In its sixteen-month mission, it obtained a full image map of the Moon. China followed up this success with [*Chang'e 2*](https://en.wikipedia.org/wiki/Chang%27e_2) beginning in October 2010, which reached the Moon over twice as fast as *Chang'e 1*, mapped the Moon at a higher resolution over an eight-month period, then left lunar orbit in favor of an extended stay at the Earth–Sun L2 [Lagrangian point](https://en.wikipedia.org/wiki/Lagrangian_point), before finally performing a flyby of asteroid [4179 Toutatis](https://en.wikipedia.org/wiki/4179_Toutatis) on 13 December 2012, and then heading off into deep space. On 14 December 2013, [*Chang'e 3*](https://en.wikipedia.org/wiki/Chang%27e_3) improved upon its orbital mission predecessors by landing a lunar [lander](https://en.wikipedia.org/wiki/Lander_(spacecraft)) onto the Moon's surface, which in turn deployed a [lunar rover](https://en.wikipedia.org/wiki/Lunar_rover), named *Yutu* (Chinese: 玉兔; literally "Jade Rabbit"). In so doing, *Chang'e 3* made the first lunar [soft landing](https://en.wikipedia.org/wiki/Soft_landing_(rocketry)) since [*Luna 24*](https://en.wikipedia.org/wiki/Luna_24) in 1976, and the first lunar rover mission since [*Lunokhod 2*](https://en.wikipedia.org/wiki/Lunokhod_2) in 1973. China intends to launch another rover mission ([*Chang'e 4*](https://en.wikipedia.org/wiki/Chang%27e_4)) before 2020, followed by a [sample return mission](https://en.wikipedia.org/wiki/Sample_return_mission) ([*Chang'e 5*](https://en.wikipedia.org/wiki/Chang%27e_5)) soon after.[[183]](https://en.wikipedia.org/wiki/Moon#cite_note-196)

Between 4 October 2007 and 10 June 2009, the [Japan Aerospace Exploration Agency](https://en.wikipedia.org/wiki/Japan_Aerospace_Exploration_Agency)'s [*Kaguya*](https://en.wikipedia.org/wiki/SELENE)*(Selene)* mission, a lunar orbiter fitted with a [high-definition video](https://en.wikipedia.org/wiki/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.[[184]](https://en.wikipedia.org/wiki/Moon#cite_note-197)[[185]](https://en.wikipedia.org/wiki/Moon#cite_note-198) India's first lunar mission, [*Chandrayaan I*](https://en.wikipedia.org/wiki/Chandrayaan-1), orbited from 8 November 2008 until loss of contact on 27 August 2009, creating a high resolution chemical, mineralogical and photo-geological map of the lunar surface, and confirming the presence of water molecules in lunar soil.[[186]](https://en.wikipedia.org/wiki/Moon#cite_note-199) The [Indian Space Research Organisation](https://en.wikipedia.org/wiki/Indian_Space_Research_Organisation) planned to launch [*Chandrayaan II*](https://en.wikipedia.org/wiki/Chandrayaan_II) in 2013, which would have included a Russian robotic lunar rover.[[187]](https://en.wikipedia.org/wiki/Moon#cite_note-200)[[188]](https://en.wikipedia.org/wiki/Moon#cite_note-201) However, the failure of Russia's [*Fobos-Grunt*](https://en.wikipedia.org/wiki/Fobos-Grunt) mission has delayed this project.

[](https://en.wikipedia.org/wiki/File:Copernicus_central_peaks.png)

[Copernicus](https://en.wikipedia.org/wiki/Copernicus_(lunar_crater))'s central peaks as observed by the [LRO](https://en.wikipedia.org/wiki/Lunar_Reconnaissance_Orbiter), 2012

[](https://en.wikipedia.org/wiki/File:Ina_(LRO).jpg)

The [Ina](https://en.wikipedia.org/wiki/Ina_(crater)) formation, 2009

The U.S. co-launched the [*Lunar Reconnaissance Orbiter*](https://en.wikipedia.org/wiki/Lunar_Reconnaissance_Orbiter) (LRO) and the [*LCROSS*](https://en.wikipedia.org/wiki/LCROSS) impactor and follow-up observation orbiter on 18 June 2009; *LCROSS* completed its mission by making a planned and widely observed impact in the crater [Cabeus](https://en.wikipedia.org/wiki/Cabeus_(crater)) on 9 October 2009,[[189]](https://en.wikipedia.org/wiki/Moon#cite_note-202) whereas *LRO* is currently in operation, obtaining precise lunar [altimetry](https://en.wikipedia.org/wiki/Altimetry) and high-resolution imagery. In November 2011, the LRO passed over the [Aristarchus crater](https://en.wikipedia.org/wiki/Aristarchus_(crater)), which spans 40 km (25 mi) and sinks more than 3.5 km (2.2 mi) deep. The crater is one of the most visible ones from Earth. "The Aristarchus plateau is one of the most geologically diverse places on the Moon: a mysterious raised flat plateau, a giant rille carved by enormous outpourings of lava, fields of explosive volcanic ash, and all surrounded by massive flood basalts", said Mark Robinson, principal investigator of the Lunar Reconnaissance Orbiter Camera at [Arizona State University](https://en.wikipedia.org/wiki/Arizona_State_University). NASA released photos of the crater on 25 December 2011.[[190]](https://en.wikipedia.org/wiki/Moon#cite_note-203)

Two [NASA](https://en.wikipedia.org/wiki/NASA) [GRAIL](https://en.wikipedia.org/wiki/Gravity_Recovery_and_Interior_Laboratory) spacecraft began orbiting the Moon around 1 January 2012,[[191]](https://en.wikipedia.org/wiki/Moon#cite_note-204) on a mission to learn more about the Moon's internal structure. NASA's [*LADEE*](https://en.wikipedia.org/wiki/Lunar_Atmosphere_and_Dust_Environment_Explorer) probe, designed to study the lunar [exosphere](https://en.wikipedia.org/wiki/Exosphere), achieved orbit on 6 October 2013.

Upcoming lunar missions include Russia's [*Luna-Glob*](https://en.wikipedia.org/wiki/Luna-Glob): an unmanned lander with a set of seismometers, and an orbiter based on its failed Martian [*Fobos-Grunt*](https://en.wikipedia.org/wiki/Fobos-Grunt) mission.[[192]](https://en.wikipedia.org/wiki/Moon#cite_note-205)[[193]](https://en.wikipedia.org/wiki/Moon#cite_note-206) Privately funded lunar exploration has been promoted by the [Google Lunar X Prize](https://en.wikipedia.org/wiki/Google_Lunar_X_Prize), announced 13 September 2007, which offers US$20 million to anyone who can land a robotic rover on the Moon and meet other specified criteria.[[194]](https://en.wikipedia.org/wiki/Moon#cite_note-207) [Shackleton Energy Company](https://en.wikipedia.org/wiki/Shackleton_Energy_Company) is building a program to establish operations on the south pole of the Moon to harvest water and supply their [Propellant Depots](https://en.wikipedia.org/wiki/Propellant_Depot).[[195]](https://en.wikipedia.org/wiki/Moon#cite_note-208)

NASA began to [plan to resume manned missions](https://en.wikipedia.org/wiki/Vision_for_Space_Exploration) following the call by U.S. President [George W. Bush](https://en.wikipedia.org/wiki/George_W._Bush) on 14 January 2004 for a manned mission to the Moon by 2019 and the construction of a lunar base by 2024.[[196]](https://en.wikipedia.org/wiki/Moon#cite_note-209) The[Constellation program](https://en.wikipedia.org/wiki/Constellation_program) was funded and construction and testing begun on a [manned spacecraft](https://en.wikipedia.org/wiki/Orion_(Constellation_program)) and [launch vehicle](https://en.wikipedia.org/wiki/Ares_(rocket)),[[197]](https://en.wikipedia.org/wiki/Moon#cite_note-210) and design studies for a lunar base.[[198]](https://en.wikipedia.org/wiki/Moon#cite_note-211) However, that program has been cancelled in favor of a manned asteroid landing by 2025 and a manned [Mars](https://en.wikipedia.org/wiki/Mars) orbit by 2035.[[199]](https://en.wikipedia.org/wiki/Moon#cite_note-212) [India](https://en.wikipedia.org/wiki/India) has also expressed its hope to send a manned mission to the Moon by 2020.[[200]](https://en.wikipedia.org/wiki/Moon#cite_note-213)

## Astronomy from the Moon

For many years, the Moon has been recognized as an excellent site for telescopes.[[201]](https://en.wikipedia.org/wiki/Moon#cite_note-214) It is relatively nearby; [astronomical seeing](https://en.wikipedia.org/wiki/Astronomical_seeing) is not a concern; certain craters near the poles are permanently dark and cold, and thus especially useful for [infrared telescopes](https://en.wikipedia.org/wiki/Infrared_telescope); and [radio telescopes](https://en.wikipedia.org/wiki/Radio_telescope) on the far side would be shielded from the radio chatter of Earth.[[202]](https://en.wikipedia.org/wiki/Moon#cite_note-215) The [lunar soil](https://en.wikipedia.org/wiki/Lunar_soil), although it poses a problem for any moving parts of [telescopes](https://en.wikipedia.org/wiki/Telescope), can be mixed with [carbon nanotubes](https://en.wikipedia.org/wiki/Carbon_nanotube) and [epoxies](https://en.wikipedia.org/wiki/Epoxy) in the construction of mirrors up to 50 meters in diameter.[[203]](https://en.wikipedia.org/wiki/Moon#cite_note-216) A lunar [zenith telescope](https://en.wikipedia.org/wiki/Zenith_telescope) can be made cheaply with [ionic liquid](https://en.wikipedia.org/wiki/Ionic_liquid).[[204]](https://en.wikipedia.org/wiki/Moon#cite_note-217)

In April 1972, the [Apollo 16](https://en.wikipedia.org/wiki/Apollo_16) mission recorded various astronomical photos and spectra in ultraviolet with the [Far Ultraviolet Camera/Spectrograph](https://en.wikipedia.org/wiki/Far_Ultraviolet_Camera/Spectrograph).[[205]](https://en.wikipedia.org/wiki/Moon#cite_note-218)

## Legal status

*Main article:*[*Space law*](https://en.wikipedia.org/wiki/Space_law)

[](https://en.wikipedia.org/wiki/File:Marius_Crater.jpg)

[Marius crater](https://en.wikipedia.org/wiki/Marius_crater)

During the [Cold War](https://en.wikipedia.org/wiki/Cold_War), the United States Army conducted a classified [feasibility study](https://en.wikipedia.org/wiki/Feasibility_study) in the late 1950s called [Project Horizon](https://en.wikipedia.org/wiki/Project_Horizon), to construct a manned military outpost on the Moon, which would have been home to a bombing system targeted at rivals on Earth. The study included the possibility of conducting a lunar-based nuclear test.[[206]](https://en.wikipedia.org/wiki/Moon#cite_note-219) The Air Force, which at the time was in competition with the Army for a leading role in the space program, developed its own, similar plan called [Lunex](https://en.wikipedia.org/wiki/Lunex_Project).[[207]](https://en.wikipedia.org/wiki/Moon#cite_note-220)[[208]](https://en.wikipedia.org/wiki/Moon#cite_note-JFK-221) However, both these proposals were ultimately passed over as the space program was largely transferred from the military to the civilian agency NASA.[[208]](https://en.wikipedia.org/wiki/Moon#cite_note-JFK-221)

Although [*Luna*](https://en.wikipedia.org/wiki/Luna_program) landers scattered pennants of the [Soviet Union](https://en.wikipedia.org/wiki/Soviet_Union) on the Moon, and [U.S. flags](https://en.wikipedia.org/wiki/Lunar_Flag_Assembly) were symbolically planted at their landing sites by the [Apollo astronauts](https://en.wikipedia.org/wiki/List_of_Apollo_astronauts), no nation claims ownership of any part of the Moon's surface.[[209]](https://en.wikipedia.org/wiki/Moon#cite_note-unoosa_q6-222)Russia and the U.S. are party to the 1967 [Outer Space Treaty](https://en.wikipedia.org/wiki/Outer_Space_Treaty),[[210]](https://en.wikipedia.org/wiki/Moon#cite_note-unoosa_q4-223) which defines the Moon and all outer space as the "[province of all mankind](https://en.wikipedia.org/wiki/Common_heritage_of_mankind)".[[209]](https://en.wikipedia.org/wiki/Moon#cite_note-unoosa_q6-222) This treaty also restricts the use of the Moon to peaceful purposes, explicitly banning military installations and [weapons of mass destruction](https://en.wikipedia.org/wiki/Weapons_of_mass_destruction).[[211]](https://en.wikipedia.org/wiki/Moon#cite_note-unoosa_q5-224) The 1979 [Moon Agreement](https://en.wikipedia.org/wiki/Moon_Treaty) was created to restrict the exploitation of the Moon's resources by any single nation, but as of 2014, it has been signed and ratified by only 16 nations, none of which engages in self-launched [human space exploration](https://en.wikipedia.org/wiki/Human_spaceflight) or has plans to do so.[[212]](https://en.wikipedia.org/wiki/Moon#cite_note-unoosa_moon-225) Although several individuals have made [claims to the Moon](https://en.wikipedia.org/wiki/Extraterrestrial_real_estate) in whole or in part, none of these are considered credible.[[213]](https://en.wikipedia.org/wiki/Moon#cite_note-unoosa_q7-226)[[214]](https://en.wikipedia.org/wiki/Moon#cite_note-iisl_2004-227)[[215]](https://en.wikipedia.org/wiki/Moon#cite_note-iisl_2009-228)

## In culture

*Further information:*[*Moon in fiction*](https://en.wikipedia.org/wiki/Moon_in_fiction)*,*[*Lunar calendar*](https://en.wikipedia.org/wiki/Lunar_calendar)*,*[*Metonic cycle*](https://en.wikipedia.org/wiki/Metonic_cycle)*,*[*Lunar deity*](https://en.wikipedia.org/wiki/Lunar_deity)*,*[*Lunar effect*](https://en.wikipedia.org/wiki/Lunar_effect)*, and*[*Blue moon*](https://en.wikipedia.org/wiki/Blue_moon)

[](https://en.wikipedia.org/wiki/File:Moon-bonatti.png)

Luna, the Moon, from a 1550 edition of [Guido Bonatti](https://en.wikipedia.org/wiki/Guido_Bonatti)'s *Liber astronomiae*

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. [Tally sticks](https://en.wikipedia.org/wiki/Tally_stick), notched bones dating as far back as 20–30,000 years ago, are believed by some to mark the phases of the Moon.[[216]](https://en.wikipedia.org/wiki/Moon#cite_note-Marshack-229)[[217]](https://en.wikipedia.org/wiki/Moon#cite_note-230)[[218]](https://en.wikipedia.org/wiki/Moon#cite_note-231) The ~30-day month is an approximation of the [lunar cycle](https://en.wikipedia.org/wiki/Lunar_cycle). The English noun *month* and its cognates in other Germanic languages stem from Proto-Germanic*\*mǣnṓth-*, which is connected to the above-mentioned Proto-Germanic *\*mǣnōn*, indicating the usage of a [lunar calendar](https://en.wikipedia.org/wiki/Lunar_calendar) among the [Germanic peoples](https://en.wikipedia.org/wiki/Germanic_peoples) ([Germanic calendar](https://en.wikipedia.org/wiki/Germanic_calendar)) prior to the adoption of a [solar calendar](https://en.wikipedia.org/wiki/Solar_calendar).[[219]](https://en.wikipedia.org/wiki/Moon#cite_note-barnhart-and-germania-232) The[PIE root](https://en.wikipedia.org/wiki/Proto-Indo-European_language) of *moon*, \**méh1nōt*, derives from the PIE verbal root \**meh1*-, "to measure", "indicat[ing] a functional conception of the moon, i.e. marker of the month" ([cf.](https://en.wikipedia.org/wiki/Cf.) the English words *measure* and *menstrual*),[[220]](https://en.wikipedia.org/wiki/Moon#cite_note-233)[[221]](https://en.wikipedia.org/wiki/Moon#cite_note-234)[[222]](https://en.wikipedia.org/wiki/Moon#cite_note-235) and echoing the Moon's importance to many ancient cultures in measuring time (see [Latin](https://en.wikipedia.org/wiki/Latin) *mensis* and [Ancient Greek](https://en.wikipedia.org/wiki/Ancient_Greek) *μείς* (*meis*) or μήν (mēn), meaning "month").[[223]](https://en.wikipedia.org/wiki/Moon#cite_note-236)[[224]](https://en.wikipedia.org/wiki/Moon#cite_note-237)[[225]](https://en.wikipedia.org/wiki/Moon#cite_note-238)[[226]](https://en.wikipedia.org/wiki/Moon#cite_note-239)

[](https://en.wikipedia.org/wiki/File:Moonstar.jpg)

A [star and crescent](https://en.wikipedia.org/wiki/Star_and_crescent) moon are common [symbols of Islam](https://en.wikipedia.org/wiki/Symbols_of_Islam).  
[Algeria](https://en.wikipedia.org/wiki/Algeria) **·** [Malaysia](https://en.wikipedia.org/wiki/Malaysia) **·** [Pakistan](https://en.wikipedia.org/wiki/Pakistan) **·** [Turkey](https://en.wikipedia.org/wiki/Turkey)

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](https://en.wikipedia.org/wiki/Knowth), Ireland, may represent the Moon, which would be the earliest depiction discovered.[[227]](https://en.wikipedia.org/wiki/Moon#cite_note-spacetoday-240) The contrast between the brighter highlands and the darker maria creates the patterns seen by different cultures as the [Man in the Moon](https://en.wikipedia.org/wiki/Man_in_the_Moon), the [rabbit](https://en.wikipedia.org/wiki/Moon_rabbit) and the buffalo, among others. In many prehistoric and ancient cultures, the Moon was personified as [a deity](https://en.wikipedia.org/wiki/Lunar_deity)or other [supernatural](https://en.wikipedia.org/wiki/Supernatural) phenomenon, and [astrological views of the Moon](https://en.wikipedia.org/wiki/Moon_(astrology)) continue to be propagated today.

The Moon plays an important role in [Islam](https://en.wikipedia.org/wiki/Islam); the [Islamic calendar](https://en.wikipedia.org/wiki/Islamic_calendar) is strictly lunar, and in many Muslim countries the months are determined by the visual sighting of the [hilal](https://en.wikipedia.org/wiki/Hilal_(crescent_moon)), or earliest crescent moon, over the horizon.[[228]](https://en.wikipedia.org/wiki/Moon#cite_note-241) The [splitting of the moon](https://en.wikipedia.org/wiki/Splitting_of_the_moon) ([Arabic](https://en.wikipedia.org/wiki/Arabic_language): انشقاق القمر‎‎) was a miracle attributed to [Muhammad](https://en.wikipedia.org/wiki/Muhammad).[[229]](https://en.wikipedia.org/wiki/Moon#cite_note-242)

The Moon has long been associated with insanity and irrationality; the words *lunacy* and [*lunatic*](https://en.wikipedia.org/wiki/Lunatic) (popular shortening *loony*) are derived from the Latin name for the Moon, *Luna*. Philosophers [Aristotle](https://en.wikipedia.org/wiki/Aristotle) and [Pliny the Elder](https://en.wikipedia.org/wiki/Pliny_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.[[230]](https://en.wikipedia.org/wiki/Moon#cite_note-sciam-243)Even today, people who believe in a [lunar effect](https://en.wikipedia.org/wiki/Lunar_effect) claim that admissions to psychiatric hospitals, traffic accidents, homicides or suicides increase during a full moon, but dozens of studies invalidate these claims.[[230]](https://en.wikipedia.org/wiki/Moon#cite_note-sciam-243)[[231]](https://en.wikipedia.org/wiki/Moon#cite_note-RottonKelly1985-244)[[232]](https://en.wikipedia.org/wiki/Moon#cite_note-MartensKelly1988-245)[[233]](https://en.wikipedia.org/wiki/Moon#cite_note-kelly-246)[[234]](https://en.wikipedia.org/wiki/Moon#cite_note-FosterRoenneberg2008-247)

## See also

* ***https://upload.wikimedia.org/wikipedia/commons/thumb/8/83/Solar_system.jpg/22px-Solar_system.jpg***[***Solar System portal***](https://en.wikipedia.org/wiki/Portal:Solar_System)
* ***[icon](https://en.wikipedia.org/wiki/File:Moon-Mdf-2005.jpg)***[***Moon portal***](https://en.wikipedia.org/wiki/Portal:Moon)
* ***https://upload.wikimedia.org/wikipedia/commons/thumb/0/00/Crab_Nebula.jpg/28px-Crab_Nebula.jpg***[***Astronomy portal***](https://en.wikipedia.org/wiki/Portal:Astronomy)
* [Former classification of planets](https://en.wikipedia.org/wiki/Planet#Objects_formerly_considered_planets)
* [Other moons of Earth](https://en.wikipedia.org/wiki/Other_moons_of_Earth)
* [2006 RH120](https://en.wikipedia.org/wiki/2006_RH120)
* [List of natural satellites](https://en.wikipedia.org/wiki/List_of_natural_satellites)
* [Tourism on the Moon](https://en.wikipedia.org/wiki/Tourism_on_the_Moon)
* [Timeline of the far future](https://en.wikipedia.org/wiki/Timeline_of_the_far_future)

## References

### Notes

* 1. [**Jump up^**](https://en.wikipedia.org/wiki/Moon#cite_ref-inclination_3-0) Between 18.29° and 28.58° to Earth's [equator](https://en.wikipedia.org/wiki/Equator).[[1]](https://en.wikipedia.org/wiki/Moon#cite_note-W06-1)
  2. [**Jump up^**](https://en.wikipedia.org/wiki/Moon#cite_ref-near-Earth_asteroids_4-0) There are a number of [near-Earth asteroids](https://en.wikipedia.org/wiki/Near-Earth_asteroid), including [3753 Cruithne](https://en.wikipedia.org/wiki/3753_Cruithne), that are [co-orbital](https://en.wikipedia.org/wiki/Co-orbital)with Earth: their orbits bring them close to Earth for periods of time but then alter in the long term (Morais et al, 2002). These are [quasi-satellites](https://en.wikipedia.org/wiki/Quasi-satellite) – they are not moons as they do not orbit Earth. For more information, see [Other moons of Earth](https://en.wikipedia.org/wiki/Other_moons_of_Earth).
  3. [**Jump up^**](https://en.wikipedia.org/wiki/Moon#cite_ref-maxval_10-0) 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 Earth's equatorial radius of 6 378 km, giving 350 600 km. The *minimum value* (for a distant [new moon](https://en.wikipedia.org/wiki/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](https://en.wikipedia.org/wiki/Earthshine) onto such a new moon. The brightness of the earthshine is[ Earth [albedo](https://en.wikipedia.org/wiki/Albedo) × ([Earth radius](https://en.wikipedia.org/wiki/Earth_radius) / Radius of [Moon's orbit](https://en.wikipedia.org/wiki/Orbit_of_the_Moon))2 ] relative to the direct solar illumination that occurs for a full moon. (Earth albedo = 0.367; Earth radius = (polarradius × equatorial radius)½ = 6 367 km.)
  4. [**Jump up^**](https://en.wikipedia.org/wiki/Moon#cite_ref-angular_size_11-0) 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](https://en.wikipedia.org/wiki/Angular_diameter) is 1896 [arcseconds](https://en.wikipedia.org/wiki/Arcsecond). 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 Earth's equatorial radius of 6 378 km, giving 350 600 km.
  5. [**Jump up^**](https://en.wikipedia.org/wiki/Moon#cite_ref-pressure_explanation_14-0) Lucey et al. (2006) give 107 particles cm−3 by day and 105 particles cm−3 by night. Along with equatorial surface temperatures of 390 [K](https://en.wikipedia.org/wiki/Kelvin) by day and 100 K by night, the [ideal gas law](https://en.wikipedia.org/wiki/Ideal_gas_law) yields the pressures given in the infobox (rounded to the nearest [order of magnitude](https://en.wikipedia.org/wiki/Order_of_magnitude)): 10−7 [Pa](https://en.wikipedia.org/wiki/Pascal_(unit)) by day and 10−10 Pa by night.
  6. [**Jump up^**](https://en.wikipedia.org/wiki/Moon#cite_ref-age_22-0) This age is calculated from isotope dating of lunar rocks.
  7. [**Jump up^**](https://en.wikipedia.org/wiki/Moon#cite_ref-orbpd_120-0) More accurately, the Moon's mean sidereal period (fixed star to fixed star) is 27.321661 days (27 d 07 h 43 min 11.5 s), and its mean tropical orbital period (from equinox to equinox) is 27.321582 days (27 d 07 h 43 min 04.7 s) (*Explanatory Supplement to the Astronomical Ephemeris*, 1961, at p.107).
  8. [**Jump up^**](https://en.wikipedia.org/wiki/Moon#cite_ref-synpd_121-0) More accurately, the Moon's mean synodic period (between mean solar conjunctions) is 29.530589 days (29 d 12 h 44 min 02.9 s) (*Explanatory Supplement to the Astronomical Ephemeris*, 1961, at p.107).
  9. [**Jump up^**](https://en.wikipedia.org/wiki/Moon#cite_ref-123) There is no strong correlation between the sizes of planets and the sizes of their satellites. Larger planets tend to have more satellites, both large and small, than smaller planets.
  10. [**Jump up^**](https://en.wikipedia.org/wiki/Moon#cite_ref-Moon_vs._Charon_124-0) With 27% the diameter and 60% the density of Earth, the Moon has 1.23% of the mass of Earth. The moon [Charon](https://en.wikipedia.org/wiki/Charon_(moon)) is larger relative to its primary [Pluto](https://en.wikipedia.org/wiki/Pluto), but Pluto is now considered to be a [dwarf planet](https://en.wikipedia.org/wiki/Dwarf_planet).
  11. [**Jump up^**](https://en.wikipedia.org/wiki/Moon#cite_ref-brightness_130-0) The Sun's [apparent magnitude](https://en.wikipedia.org/wiki/Apparent_magnitude) is −26.7, while the full moon's apparent magnitude is −12.7.
  12. [**Jump up^**](https://en.wikipedia.org/wiki/Moon#cite_ref-size_changes_156-0) See graph in [Sun#Life phases](https://en.wikipedia.org/wiki/Sun#Life_phases). At present, the diameter of the Sun is increasing at a rate of about five percent per billion years. This is very similar to the rate at which the apparent angular diameter of the Moon is decreasing as it recedes from Earth.
  13. [**Jump up^**](https://en.wikipedia.org/wiki/Moon#cite_ref-area_160-0) On average, the Moon covers an area of 0.21078 square degrees on the night sky.

### Citations

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* [APOD - Video of lunar drive](http://apod.nasa.gov/apod/ap130129.html)
* [The Moon on Google Maps](https://www.google.com/maps/space/moon/@6.1467095,139.2754359,23010541m/data=!3m1!1e3), a 3-D rendition of the moon akin to Google Earth

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* [Large image of the Moon's north pole area](http://home.bt.com/techgadgets/technews/explore-the-lunar-north-pole-11363885909226?s_intcid=con_RL_LunarNorthPole)

### Observation tools

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### General

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* [Create account](https://en.wikipedia.org/w/index.php?title=Special:CreateAccount&returnto=Moon)
* [Log in](https://en.wikipedia.org/w/index.php?title=Special:UserLogin&returnto=Moon)
* [Article](https://en.wikipedia.org/wiki/Moon)
* [Talk](https://en.wikipedia.org/wiki/Talk:Moon)
* [Read](https://en.wikipedia.org/wiki/Moon)
* [View source](https://en.wikipedia.org/w/index.php?title=Moon&action=edit)
* [View history](https://en.wikipedia.org/w/index.php?title=Moon&action=history)

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* [Main page](https://en.wikipedia.org/wiki/Main_Page)
* [Contents](https://en.wikipedia.org/wiki/Portal:Contents)
* [Featured content](https://en.wikipedia.org/wiki/Portal:Featured_content)
* [Current events](https://en.wikipedia.org/wiki/Portal:Current_events)
* [Random article](https://en.wikipedia.org/wiki/Special:Random)
* [Donate to Wikipedia](https://donate.wikimedia.org/wiki/Special:FundraiserRedirector?utm_source=donate&utm_medium=sidebar&utm_campaign=C13_en.wikipedia.org&uselang=en)
* [Wikipedia store](https://shop.wikimedia.org/)

### Interaction

* [Help](https://en.wikipedia.org/wiki/Help:Contents)
* [About Wikipedia](https://en.wikipedia.org/wiki/Wikipedia:About)
* [Community portal](https://en.wikipedia.org/wiki/Wikipedia:Community_portal)
* [Recent changes](https://en.wikipedia.org/wiki/Special:RecentChanges)
* [Contact page](https://en.wikipedia.org/wiki/Wikipedia:Contact_us)

### Tools

* [What links here](https://en.wikipedia.org/wiki/Special:WhatLinksHere/Moon)
* [Related changes](https://en.wikipedia.org/wiki/Special:RecentChangesLinked/Moon)
* [Upload file](https://en.wikipedia.org/wiki/Wikipedia:File_Upload_Wizard)
* [Special pages](https://en.wikipedia.org/wiki/Special:SpecialPages)
* [Permanent link](https://en.wikipedia.org/w/index.php?title=Moon&oldid=728824072)
* [Page information](https://en.wikipedia.org/w/index.php?title=Moon&action=info)
* [Wikidata item](https://www.wikidata.org/wiki/Q405)
* [Cite this page](https://en.wikipedia.org/w/index.php?title=Special:CiteThisPage&page=Moon&id=728824072)

### Print/export

* [Create a book](https://en.wikipedia.org/w/index.php?title=Special:Book&bookcmd=book_creator&referer=Moon)
* [Download as PDF](https://en.wikipedia.org/w/index.php?title=Special:Book&bookcmd=render_article&arttitle=Moon&returnto=Moon&oldid=728824072&writer=rdf2latex)
* [Printable version](https://en.wikipedia.org/w/index.php?title=Moon&printable=yes)

### In other projects

* [Wikimedia Commons](https://commons.wikimedia.org/wiki/Category:Moon)
* [Wikinews](https://en.wikinews.org/wiki/Category:The_Moon)
* [Wikiquote](https://en.wikiquote.org/wiki/Moon)
* [Wikivoyage](https://en.wikivoyage.org/wiki/Moon)

### Languages

* [Адыгэбзэ](https://kbd.wikipedia.org/wiki/%D0%9C%D0%B0%D0%B7%D1%8D)
* [Afrikaans](https://af.wikipedia.org/wiki/Maan)
* [Alemannisch](https://als.wikipedia.org/wiki/Mond)
* [አማርኛ](https://am.wikipedia.org/wiki/%E1%8C%A8%E1%88%A8%E1%89%83)
* [Ænglisc](https://ang.wikipedia.org/wiki/M%C5%8Dna)
* [Аҧсшәа](https://ab.wikipedia.org/wiki/%D0%90%D0%BC%D0%B7%D0%B0)
* [العربية](https://ar.wikipedia.org/wiki/%D8%A7%D9%84%D9%82%D9%85%D8%B1)
* [Aragonés](https://an.wikipedia.org/wiki/Luna)
* [ܐܪܡܝܐ](https://arc.wikipedia.org/wiki/%DC%A3%DC%97%DC%AA%DC%90)
* [Armãneashti](https://roa-rup.wikipedia.org/wiki/Lun%C3%A2)
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* [Авар](https://av.wikipedia.org/wiki/%D0%9C%D0%BE%D1%86%D0%86_(%D0%B7%D0%BE%D0%B1))
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* [Беларуская](https://be.wikipedia.org/wiki/%D0%9C%D0%B5%D1%81%D1%8F%D1%86,_%D1%81%D0%BF%D0%B0%D0%B4%D0%B0%D1%80%D0%BE%D0%B6%D0%BD%D1%96%D0%BA_%D0%97%D1%8F%D0%BC%D0%BB%D1%96)
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* [தமிழ்](https://ta.wikipedia.org/wiki/%E0%AE%A8%E0%AE%BF%E0%AE%B2%E0%AE%BE)
* [Taqbaylit](https://kab.wikipedia.org/wiki/Ayyur_(itri))
* [Татарча/tatarça](https://tt.wikipedia.org/wiki/%D0%90%D0%B9_(%D0%B8%D1%8F%D1%80%D1%87%D0%B5%D0%BD))
* [తెలుగు](https://te.wikipedia.org/wiki/%E0%B0%9A%E0%B0%82%E0%B0%A6%E0%B1%8D%E0%B0%B0%E0%B1%81%E0%B0%A1%E0%B1%81)
* [ไทย](https://th.wikipedia.org/wiki/%E0%B8%94%E0%B8%A7%E0%B8%87%E0%B8%88%E0%B8%B1%E0%B8%99%E0%B8%97%E0%B8%A3%E0%B9%8C)
* [Тоҷикӣ](https://tg.wikipedia.org/wiki/%D0%9C%D0%BE%D2%B3%D1%82%D0%BE%D0%B1)
* [Tsetsêhestâhese](https://chy.wikipedia.org/wiki/Taa%27%C3%A9-e%C5%A1e%27he)
* [Türkçe](https://tr.wikipedia.org/wiki/Ay)
* [Türkmençe](https://tk.wikipedia.org/wiki/A%C3%BD_(hemra))
* [Twi](https://tw.wikipedia.org/wiki/%C6%86bosome)
* [Тыва дыл](https://tyv.wikipedia.org/wiki/%D0%90%D0%B9)
* [Удмурт](https://udm.wikipedia.org/wiki/%D0%A2%D0%BE%D0%BB%D1%8D%D0%B7%D1%8C_(%D0%90%D1%81%D1%82%D1%80%D0%BE%D0%BD%D0%BE%D0%BC%D0%B8%D1%8F))
* [Українська](https://uk.wikipedia.org/wiki/%D0%9C%D1%96%D1%81%D1%8F%D1%86%D1%8C_(%D1%81%D1%83%D0%BF%D1%83%D1%82%D0%BD%D0%B8%D0%BA))
* [اردو](https://ur.wikipedia.org/wiki/%DA%86%D8%A7%D9%86%D8%AF)
* [Vahcuengh](https://za.wikipedia.org/wiki/Ronghndwen)
* [Vèneto](https://vec.wikipedia.org/wiki/%C5%81una)
* [Vepsän kel’](https://vep.wikipedia.org/wiki/Kudmaine)
* [Tiếng Việt](https://vi.wikipedia.org/wiki/M%E1%BA%B7t_Tr%C4%83ng)
* [Volapük](https://vo.wikipedia.org/wiki/Mun)
* [Võro](https://fiu-vro.wikipedia.org/wiki/Kuu)
* [Walon](https://wa.wikipedia.org/wiki/Lune)
* [文言](https://zh-classical.wikipedia.org/wiki/%E6%9C%88)
* [West-Vlams](https://vls.wikipedia.org/wiki/Moane)
* [Winaray](https://war.wikipedia.org/wiki/Bulan_(astronomiya))
* [吴语](https://wuu.wikipedia.org/wiki/%E6%9C%88%E7%90%83)
* [ייִדיש](https://yi.wikipedia.org/wiki/%D7%9C%D7%91%D7%A0%D7%94)
* [Yorùbá](https://yo.wikipedia.org/wiki/%C3%92%E1%B9%A3%C3%B9p%C3%A1)
* [粵語](https://zh-yue.wikipedia.org/wiki/%E6%9C%88%E5%85%89)
* [Zeêuws](https://zea.wikipedia.org/wiki/Maen_(Aerde))
* [Žemaitėška](https://bat-smg.wikipedia.org/wiki/Mienolis)
* [中文](https://zh.wikipedia.org/wiki/%E6%9C%88%E7%90%83)

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# Jupiter

From Wikipedia, the free encyclopedia

*This article is about the planet. For the Roman god, see*[*Jupiter (mythology)*](https://en.wikipedia.org/wiki/Jupiter_(mythology))*. For other uses, see*[*Jupiter (disambiguation)*](https://en.wikipedia.org/wiki/Jupiter_(disambiguation))*.*

|  |  |
| --- | --- |
| **Jupiter [Astronomical symbol of Jupiter](https://en.wikipedia.org/wiki/File:Jupiter_symbol.svg)** | |
| [An image of Jupiter taken by the Hubble Space Telescope](https://en.wikipedia.org/wiki/File:Jupiter_and_its_shrunken_Great_Red_Spot.jpg)  Full-disc view of Jupiter in natural color in April 2014[[a]](https://en.wikipedia.org/wiki/Jupiter#cite_note-caption-1) | |
| **Designations** | |
| **Pronunciation** | [Listen](https://upload.wikimedia.org/wikipedia/commons/c/c5/En-us-Jupiter.ogg)[**i**](https://en.wikipedia.org/wiki/File:En-us-Jupiter.ogg)[/ˈdʒuːpᵻtər/](https://en.wikipedia.org/wiki/Help:IPA_for_English)[[1]](https://en.wikipedia.org/wiki/Jupiter#cite_note-2) |
| [**Adjectives**](https://en.wikipedia.org/wiki/List_of_adjectivals_and_demonyms_of_astronomical_bodies) | [Jovian](https://en.wikipedia.org/wiki/Jovian_(disambiguation)) |
| [**Orbital characteristics**](https://en.wikipedia.org/wiki/Osculating_orbit)[[5]](https://en.wikipedia.org/wiki/Jupiter#cite_note-VSOP87-6) | |
| [Epoch](https://en.wikipedia.org/wiki/Epoch_(astronomy)) [J2000](https://en.wikipedia.org/wiki/J2000) | |
| [**Aphelion**](https://en.wikipedia.org/wiki/Aphelion) | 5.45492 [AU](https://en.wikipedia.org/wiki/Astronomical_unit) (816.04 [Gm](https://en.wikipedia.org/wiki/Gigametre)) |
| [**Perihelion**](https://en.wikipedia.org/wiki/Perihelion) | 4.95029 AU (740.55 Gm) |
| [**Semi-major axis**](https://en.wikipedia.org/wiki/Semi-major_axis) | 5.20260 AU (778.299 Gm) |
| [**Eccentricity**](https://en.wikipedia.org/wiki/Orbital_eccentricity) | 0.048498 |
| [**Orbital period**](https://en.wikipedia.org/wiki/Orbital_period) | * 11.8618 [yr](https://en.wikipedia.org/wiki/Julian_year_(astronomy)) * 4,332.59 d * 10,475.8 Jovian [solar days](https://en.wikipedia.org/wiki/Solar_day)[[2]](https://en.wikipedia.org/wiki/Jupiter#cite_note-planet_years-3) |
| [**Synodic period**](https://en.wikipedia.org/wiki/Orbital_period) | 398.88 d[[3]](https://en.wikipedia.org/wiki/Jupiter#cite_note-fact-4) |
| **Average**[**orbital speed**](https://en.wikipedia.org/wiki/Orbital_speed) | 13.07 km/s[[3]](https://en.wikipedia.org/wiki/Jupiter#cite_note-fact-4) |
| [**Mean anomaly**](https://en.wikipedia.org/wiki/Mean_anomaly) | 20.020° |
| [**Inclination**](https://en.wikipedia.org/wiki/Orbital_inclination) | * 1.303° to [ecliptic](https://en.wikipedia.org/wiki/Ecliptic) * 6.09° to [Sun](https://en.wikipedia.org/wiki/Sun)'s [equator](https://en.wikipedia.org/wiki/Equator) * 0.32° to [invariable plane](https://en.wikipedia.org/wiki/Invariable_plane)[[4]](https://en.wikipedia.org/wiki/Jupiter#cite_note-meanplane-5) |
| [**Longitude of ascending node**](https://en.wikipedia.org/wiki/Longitude_of_the_ascending_node) | 100.464° |
| [**Argument of perihelion**](https://en.wikipedia.org/wiki/Argument_of_periapsis) | 273.867° |
| **Known**[**satellites**](https://en.wikipedia.org/wiki/Natural_satellite) | [67](https://en.wikipedia.org/wiki/Moons_of_Jupiter) (as of 2014) |
| **Physical characteristics** | |
| **Mean radius** | 69,911±6 km[[6]](https://en.wikipedia.org/wiki/Jupiter#cite_note-Seidelmann_Archinal_A.27hearn_et_al._2007-7)[[b]](https://en.wikipedia.org/wiki/Jupiter#cite_note-1bar-8) |
| [**Equatorial**](https://en.wikipedia.org/wiki/Equator)**radius** | * 71,492±4 km[[6]](https://en.wikipedia.org/wiki/Jupiter#cite_note-Seidelmann_Archinal_A.27hearn_et_al._2007-7)[[b]](https://en.wikipedia.org/wiki/Jupiter#cite_note-1bar-8) * 11.209 [Earths](https://en.wikipedia.org/wiki/Earth) |
| [**Polar**](https://en.wikipedia.org/wiki/Geographical_pole)**radius** | * 66,854±10 km[[6]](https://en.wikipedia.org/wiki/Jupiter#cite_note-Seidelmann_Archinal_A.27hearn_et_al._2007-7)[[b]](https://en.wikipedia.org/wiki/Jupiter#cite_note-1bar-8) * 10.517 Earths |
| [**Flattening**](https://en.wikipedia.org/wiki/Flattening) | 0.06487±0.00015 |
| [**Surface area**](https://en.wikipedia.org/wiki/Spheroid#Surface_area) | * 6.1419×1010 km2[[b]](https://en.wikipedia.org/wiki/Jupiter#cite_note-1bar-8)[[7]](https://en.wikipedia.org/wiki/Jupiter#cite_note-nasafact-9) * 121.9 Earths |
| [**Volume**](https://en.wikipedia.org/wiki/Volume) | * 1.4313×1015 km3[[3]](https://en.wikipedia.org/wiki/Jupiter#cite_note-fact-4)[[b]](https://en.wikipedia.org/wiki/Jupiter#cite_note-1bar-8) * 1,321 Earths |
| [**Mass**](https://en.wikipedia.org/wiki/Mass) | * 1.8986×1027 kg[[3]](https://en.wikipedia.org/wiki/Jupiter#cite_note-fact-4) * 317.8 Earths * 1/1047 Sun[[8]](https://en.wikipedia.org/wiki/Jupiter#cite_note-ssd-constants-10) |
| **Mean**[**density**](https://en.wikipedia.org/wiki/Density) | 1.326 g/cm3[[3]](https://en.wikipedia.org/wiki/Jupiter#cite_note-fact-4)[[b]](https://en.wikipedia.org/wiki/Jupiter#cite_note-1bar-8) |
| [**Surface gravity**](https://en.wikipedia.org/wiki/Surface_gravity) | 24.79 [m/s2](https://en.wikipedia.org/wiki/Metre_per_second_squared)[[3]](https://en.wikipedia.org/wiki/Jupiter#cite_note-fact-4)[[b]](https://en.wikipedia.org/wiki/Jupiter#cite_note-1bar-8) 2.528 [g](https://en.wikipedia.org/wiki/G-force) |
| [**Escape velocity**](https://en.wikipedia.org/wiki/Escape_velocity) | 59.5 km/s[[3]](https://en.wikipedia.org/wiki/Jupiter#cite_note-fact-4)[[b]](https://en.wikipedia.org/wiki/Jupiter#cite_note-1bar-8) |
| **Sidereal**[**rotation period**](https://en.wikipedia.org/wiki/Rotation_period) | 9.925 h[[9]](https://en.wikipedia.org/wiki/Jupiter#cite_note-11) (9 h 55 m 30 s) |
| **Equatorial rotation velocity** | 12.6 km/s 45300 km/h |
| [**Axial tilt**](https://en.wikipedia.org/wiki/Axial_tilt) | 3.13° (to orbit)[[3]](https://en.wikipedia.org/wiki/Jupiter#cite_note-fact-4) |
| **North pole**[**right ascension**](https://en.wikipedia.org/wiki/Right_ascension) | 268.057° 17h 52m 14s[[6]](https://en.wikipedia.org/wiki/Jupiter#cite_note-Seidelmann_Archinal_A.27hearn_et_al._2007-7) |
| **North pole**[**declination**](https://en.wikipedia.org/wiki/Declination) | 64.496°[[6]](https://en.wikipedia.org/wiki/Jupiter#cite_note-Seidelmann_Archinal_A.27hearn_et_al._2007-7) |
| [**Albedo**](https://en.wikipedia.org/wiki/Albedo) | 0.343 ([Bond](https://en.wikipedia.org/wiki/Bond_albedo)) 0.52 ([geom.](https://en.wikipedia.org/wiki/Geometric_albedo))[[3]](https://en.wikipedia.org/wiki/Jupiter#cite_note-fact-4) |
| |  |  |  |  | | --- | --- | --- | --- | | **Surface**[**temp.**](https://en.wikipedia.org/wiki/Temperature) | **min** | **mean** | **max** | | **1 bar level** |  | 165 [K](https://en.wikipedia.org/wiki/Kelvin) (−108 °C)[[3]](https://en.wikipedia.org/wiki/Jupiter#cite_note-fact-4) |  | | **0.1 bar** |  | 112 K[[3]](https://en.wikipedia.org/wiki/Jupiter#cite_note-fact-4) |  | | |
| [**Apparent magnitude**](https://en.wikipedia.org/wiki/Apparent_magnitude) | −1.6 to −2.94[[3]](https://en.wikipedia.org/wiki/Jupiter#cite_note-fact-4) |
| [**Angular diameter**](https://en.wikipedia.org/wiki/Angular_diameter) | 29.8″ to 50.1″[[3]](https://en.wikipedia.org/wiki/Jupiter#cite_note-fact-4) |
| **Atmosphere**[[3]](https://en.wikipedia.org/wiki/Jupiter#cite_note-fact-4) | |
| **Surface**[**pressure**](https://en.wikipedia.org/wiki/Atmospheric_pressure) | 20–200 [kPa](https://en.wikipedia.org/wiki/Pascal_(unit))[[10]](https://en.wikipedia.org/wiki/Jupiter#cite_note-12) (cloud layer) |
| [**Scale height**](https://en.wikipedia.org/wiki/Scale_height) | 27 km |
| [**Composition by volume**](https://en.wikipedia.org/wiki/Atmospheric_chemistry#Atmospheric_composition) | by volume:   |  |  | | --- | --- | | 89.8±2.0% | [hydrogen](https://en.wikipedia.org/wiki/Hydrogen) (H2) | | 10.2±2.0% | [helium](https://en.wikipedia.org/wiki/Helium) (He) | | ≈ 0.3% | [methane](https://en.wikipedia.org/wiki/Methane) (CH4) | | ≈ 0.026% | [ammonia](https://en.wikipedia.org/wiki/Ammonia) (NH3) | | ≈ 0.003% | [hydrogen deuteride](https://en.wikipedia.org/wiki/Hydrogen_deuteride) (HD) | | 0.0006% | [ethane](https://en.wikipedia.org/wiki/Ethane) (C2H6) | | 0.0004% | water (H2O) |   **Ices**:   * [ammonia](https://en.wikipedia.org/wiki/Ammonia) (NH3) * [water](https://en.wikipedia.org/wiki/Water_(molecule)) (H2O) * [ammonium hydrosulfide](https://en.wikipedia.org/wiki/Ammonium_hydrosulfide)(NH4SH) |
|  | |

**Jupiter** is the fifth [planet](https://en.wikipedia.org/wiki/Planet) from the [Sun](https://en.wikipedia.org/wiki/Sun) and the [largest](https://en.wikipedia.org/wiki/List_of_Solar_System_objects_by_size) in the [Solar System](https://en.wikipedia.org/wiki/Solar_System). It is a [giant planet](https://en.wikipedia.org/wiki/Giant_planet) with a [mass](https://en.wikipedia.org/wiki/Mass) one-thousandth that of the Sun, but two and a half times that of all the other planets in the Solar System combined. Jupiter is a [gas giant](https://en.wikipedia.org/wiki/Gas_giant), along with [Saturn](https://en.wikipedia.org/wiki/Saturn), with the other two [giant planets](https://en.wikipedia.org/wiki/Giant_planet), [Uranus](https://en.wikipedia.org/wiki/Uranus) and [Neptune](https://en.wikipedia.org/wiki/Neptune), being [ice giants](https://en.wikipedia.org/wiki/Ice_giant). Jupiter was known to [astronomers](https://en.wikipedia.org/wiki/Astronomer) of ancient times.[[11]](https://en.wikipedia.org/wiki/Jupiter#cite_note-13) The [Romans](https://en.wikipedia.org/wiki/Ancient_Rome) named it after [their god](https://en.wikipedia.org/wiki/Roman_mythology)[Jupiter](https://en.wikipedia.org/wiki/Jupiter_(mythology)).[[12]](https://en.wikipedia.org/wiki/Jupiter#cite_note-14) When viewed from [Earth](https://en.wikipedia.org/wiki/Earth), Jupiter can reach an [apparent magnitude](https://en.wikipedia.org/wiki/Apparent_magnitude) of −2.94, bright enough for its reflected light to cast shadows,[[13]](https://en.wikipedia.org/wiki/Jupiter#cite_note-15) and making it on average the third-brightest object in the [night sky](https://en.wikipedia.org/wiki/Night_sky) after the[Moon](https://en.wikipedia.org/wiki/Moon) and [Venus](https://en.wikipedia.org/wiki/Venus).

Jupiter is primarily composed of [hydrogen](https://en.wikipedia.org/wiki/Hydrogen) with a quarter of its mass being [helium](https://en.wikipedia.org/wiki/Helium), though helium comprises only about a tenth of the number of molecules. It may also have a rocky core of heavier elements,[[14]](https://en.wikipedia.org/wiki/Jupiter#cite_note-coreuncertainty-16) but like the other giant planets, Jupiter lacks a well-defined solid surface. Because of its rapid rotation, the planet's shape is that of an [oblate spheroid](https://en.wikipedia.org/wiki/Oblate_spheroid) (it has a slight but noticeable bulge around the equator). The outer atmosphere is visibly segregated into several bands at different latitudes, resulting in turbulence and storms along their interacting boundaries. A prominent result is the [Great Red Spot](https://en.wikipedia.org/wiki/Great_Red_Spot), a giant storm that is known to have existed since at least the 17th century when it was first seen by [telescope](https://en.wikipedia.org/wiki/Telescope). Surrounding Jupiter is a faint [planetary ring](https://en.wikipedia.org/wiki/Planetary_ring) system and a powerful [magnetosphere](https://en.wikipedia.org/wiki/Magnetosphere). Jupiter has at least [67 moons](https://en.wikipedia.org/wiki/Moons_of_Jupiter), including the four large[Galilean moons](https://en.wikipedia.org/wiki/Galilean_moons) discovered by [Galileo Galilei](https://en.wikipedia.org/wiki/Galileo_Galilei) in 1610. [Ganymede](https://en.wikipedia.org/wiki/Ganymede_(moon)), the largest of these, has a diameter greater than that of the planet [Mercury](https://en.wikipedia.org/wiki/Mercury_(planet)).

Jupiter has been explored on several occasions by [robotic spacecraft](https://en.wikipedia.org/wiki/Robotic_spacecraft), most notably during the early [*Pioneer*](https://en.wikipedia.org/wiki/Pioneer_program) and [*Voyager*](https://en.wikipedia.org/wiki/Voyager_program) [flyby](https://en.wikipedia.org/wiki/Planetary_flyby) missions and later by the [*Galileo* orbiter](https://en.wikipedia.org/wiki/Galileo_(spacecraft)). In late February 2007, Jupiter was visited by the[*New Horizons*](https://en.wikipedia.org/wiki/New_Horizons) probe, which [used Jupiter's gravity](https://en.wikipedia.org/wiki/Gravitational_slingshot) to increase its speed and bend its trajectory en route to [Pluto](https://en.wikipedia.org/wiki/Pluto). The latest probe to visit the planet is [*Juno*](https://en.wikipedia.org/wiki/Juno_(spacecraft)), which entered into orbit around Jupiter on July 4, 2016.[[15]](https://en.wikipedia.org/wiki/Jupiter#cite_note-NYT-20160705-17)[[16]](https://en.wikipedia.org/wiki/Jupiter#cite_note-NYT-20160630-18)Future targets for exploration in the Jupiter system include the probable ice-covered liquid ocean of its moon [Europa](https://en.wikipedia.org/wiki/Europa_(moon)).

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* [2Physical characteristics](https://en.wikipedia.org/wiki/Jupiter#Physical_characteristics)
  + [2.1Composition](https://en.wikipedia.org/wiki/Jupiter#Composition)
  + [2.2Mass and size](https://en.wikipedia.org/wiki/Jupiter#Mass_and_size)
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    - [5.4.2*Galileo* mission](https://en.wikipedia.org/wiki/Jupiter#Galileo_mission)
    - [5.4.3*Juno* mission](https://en.wikipedia.org/wiki/Jupiter#Juno_mission)
    - [5.4.4Future probes](https://en.wikipedia.org/wiki/Jupiter#Future_probes)
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* [7Interaction with the Solar System](https://en.wikipedia.org/wiki/Jupiter#Interaction_with_the_Solar_System)
  + [7.1Impacts](https://en.wikipedia.org/wiki/Jupiter#Impacts)
* [8Possibility of life](https://en.wikipedia.org/wiki/Jupiter#Possibility_of_life)
* [9Mythology](https://en.wikipedia.org/wiki/Jupiter#Mythology)
* [10See also](https://en.wikipedia.org/wiki/Jupiter#See_also)
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## Formation and migration

*Main article:*[*Grand Tack Hypothesis*](https://en.wikipedia.org/wiki/Grand_Tack_Hypothesis)

*See also:*[*Formation and evolution of the Solar System*](https://en.wikipedia.org/wiki/Formation_and_evolution_of_the_Solar_System)

Earth and its neighbor planets may have formed from fragments of planets after collisions with Jupiter destroyed those super-Earths near the Sun. As Jupiter came toward the inner Solar System, in what theorists call the[Grand Tack Hypothesis](https://en.wikipedia.org/wiki/Grand_Tack_Hypothesis), gravitational tugs and pulls occurred causing a series of collisions between the super-Earths as their orbits began to overlap.[[17]](https://en.wikipedia.org/wiki/Jupiter#cite_note-19)

Astronomers have discovered nearly 500 planetary systems with multiple planets. Regularly these systems include a few planets with masses several times greater than Earth's (super-Earths), orbiting closer to their star than Mercury is to the Sun, and sometimes also Jupiter-mass gas giants close to their star.

Jupiter moving out of the inner Solar System would have allowed the formation of inner planets, including [Earth](https://en.wikipedia.org/wiki/Earth).[[18]](https://en.wikipedia.org/wiki/Jupiter#cite_note-20)

## Physical characteristics

Jupiter is composed primarily of gaseous and liquid matter. It is the largest of the four giant planets in the Solar System and hence its largest planet. It has a diameter of 142,984 km (88,846 mi) at its [equator](https://en.wikipedia.org/wiki/Equator). The average density of Jupiter, 1.326 g/cm3, is the second highest of the giant planets, but lower than those of the four [terrestrial planets](https://en.wikipedia.org/wiki/Terrestrial_planet).

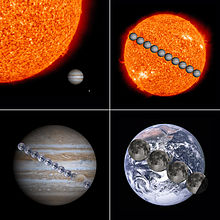
### Composition

Jupiter's upper atmosphere is composed of about 88–92% hydrogen and 8–12% helium by percent volume of gas [molecules](https://en.wikipedia.org/wiki/Molecule). A helium atom has about four times as much mass as a hydrogen atom, so the composition changes when described as the proportion of mass contributed by different atoms. Thus, [Jupiter's atmosphere](https://en.wikipedia.org/wiki/Atmosphere_of_Jupiter) is approximately 75% hydrogen and 24% helium by mass, with the remaining one percent of the mass consisting of other elements. The interior contains denser materials, such that the distribution is roughly 71% hydrogen, 24% helium, and 5% other elements by mass. The atmosphere contains trace amounts of [methane](https://en.wikipedia.org/wiki/Methane),[water vapor](https://en.wikipedia.org/wiki/Water_vapor), [ammonia](https://en.wikipedia.org/wiki/Ammonia), and [silicon](https://en.wikipedia.org/wiki/Silicon)-based compounds. There are also traces of [carbon](https://en.wikipedia.org/wiki/Carbon), [ethane](https://en.wikipedia.org/wiki/Ethane), [hydrogen sulfide](https://en.wikipedia.org/wiki/Hydrogen_sulfide), [neon](https://en.wikipedia.org/wiki/Neon), [oxygen](https://en.wikipedia.org/wiki/Oxygen), [phosphine](https://en.wikipedia.org/wiki/Phosphine), and [sulfur](https://en.wikipedia.org/wiki/Sulfur). The outermost layer of the atmosphere contains [crystals](https://en.wikipedia.org/wiki/Crystal) of frozen ammonia.[[19]](https://en.wikipedia.org/wiki/Jupiter#cite_note-voyager-21)[[20]](https://en.wikipedia.org/wiki/Jupiter#cite_note-cassini-22) Through [infrared](https://en.wikipedia.org/wiki/Infrared) and [ultraviolet](https://en.wikipedia.org/wiki/Ultraviolet) measurements, trace amounts of [benzene](https://en.wikipedia.org/wiki/Benzene) and other [hydrocarbons](https://en.wikipedia.org/wiki/Hydrocarbon) have also been found.[[21]](https://en.wikipedia.org/wiki/Jupiter#cite_note-23)

The atmospheric proportions of hydrogen and helium are close to the theoretical composition of the primordial [solar nebula](https://en.wikipedia.org/wiki/Solar_nebula). Neon in the upper atmosphere only consists of 20 parts per million by mass, which is about a tenth as abundant as in the Sun.[[22]](https://en.wikipedia.org/wiki/Jupiter#cite_note-24) Helium is also depleted to about 80% of the Sun's helium composition. This depletion is a result of [precipitation](https://en.wikipedia.org/wiki/Precipitation_(meteorology)) of these elements into the interior of the planet.[[23]](https://en.wikipedia.org/wiki/Jupiter#cite_note-galileo_ms-25)

Based on [spectroscopy](https://en.wikipedia.org/wiki/Spectroscopy), Saturn is thought to be similar in composition to Jupiter, but the other giant planets [Uranus](https://en.wikipedia.org/wiki/Uranus) and [Neptune](https://en.wikipedia.org/wiki/Neptune) have relatively less hydrogen and helium.[[24]](https://en.wikipedia.org/wiki/Jupiter#cite_note-26)

### Mass and size

[](https://en.wikipedia.org/wiki/File:SolarSystem_OrdersOfMagnitude_Sun-Jupiter-Earth-Moon.jpg)

Jupiter's diameter is one [order of magnitude](https://en.wikipedia.org/wiki/Order_of_magnitude) smaller (×0.10045) than the Sun, and one order of magnitude larger (×10.9733) than Earth. The Great Red Spot is roughly the same size as Earth.

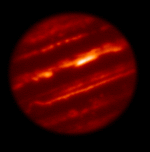
Jupiter's mass is 2.5 times that of all the other planets in the Solar System combined—this is so massive that its [barycenter](https://en.wikipedia.org/wiki/Barycenter) with the [Sun](https://en.wikipedia.org/wiki/Sun) lies above the [Sun's surface](https://en.wikipedia.org/wiki/Photosphere) at 1.068 [solar radii](https://en.wikipedia.org/wiki/Solar_radius) from the Sun's center. Jupiter is much larger than Earth and considerably less dense: its volume is that of about 1,321 Earths, but it is only 318 times as massive.[[3]](https://en.wikipedia.org/wiki/Jupiter#cite_note-fact-4)[[25]](https://en.wikipedia.org/wiki/Jupiter#cite_note-burgess-27) Jupiter's radius is about 1/10 the [radius of the Sun](https://en.wikipedia.org/wiki/Solar_radius),[[26]](https://en.wikipedia.org/wiki/Jupiter#cite_note-shu82-28) and its mass is 0.001 times the [mass of the Sun](https://en.wikipedia.org/wiki/Solar_mass), so the densities of the two bodies are similar.[[27]](https://en.wikipedia.org/wiki/Jupiter#cite_note-davis_turekian05-29) A "[Jupiter mass](https://en.wikipedia.org/wiki/Jupiter_mass)" (*M*J or *M*Jup) is often used as a unit to describe masses of other objects, particularly [extrasolar planets](https://en.wikipedia.org/wiki/Extrasolar_planet) and [brown dwarfs](https://en.wikipedia.org/wiki/Brown_dwarfs). So, for example, the extrasolar planet [HD 209458 b](https://en.wikipedia.org/wiki/HD_209458_b) has a mass of 0.69 *M*J, while [Kappa Andromedae b](https://en.wikipedia.org/wiki/Kappa_Andromedae_b) has a mass of 12.8 *M*J.[[28]](https://en.wikipedia.org/wiki/Jupiter#cite_note-30)

Theoretical models indicate that if Jupiter had much more mass than it does at present, it would shrink.[[29]](https://en.wikipedia.org/wiki/Jupiter#cite_note-Seager2007-31) For small changes in mass, the [radius](https://en.wikipedia.org/wiki/Radius) would not change appreciably, and above about 500 [*M*⊕](https://en.wikipedia.org/wiki/Earth_mass) (1.6 Jupiter masses)[[29]](https://en.wikipedia.org/wiki/Jupiter#cite_note-Seager2007-31) the interior would become so much more compressed under the increased pressure that its volume would *decrease* despite the increasing amount of matter. As a result, Jupiter is thought to have about as large a diameter as a planet of its composition and evolutionary history can achieve.[[30]](https://en.wikipedia.org/wiki/Jupiter#cite_note-HTUW-32) The process of further shrinkage with increasing mass would continue until appreciable [stellar ignition](https://en.wikipedia.org/wiki/Stellar_ignition) is achieved as in high-mass [brown dwarfs](https://en.wikipedia.org/wiki/Brown_dwarf) having around 50 Jupiter masses.[[31]](https://en.wikipedia.org/wiki/Jupiter#cite_note-tristan286-33)

Although Jupiter would need to be about 75 times as massive to [fuse hydrogen](https://en.wikipedia.org/wiki/Hydrogen_fusion) and become a [star](https://en.wikipedia.org/wiki/Star), the smallest [red dwarf](https://en.wikipedia.org/wiki/Red_dwarf) is only about 30 percent larger in radius than Jupiter.[[32]](https://en.wikipedia.org/wiki/Jupiter#cite_note-34)[[33]](https://en.wikipedia.org/wiki/Jupiter#cite_note-35) Despite this, Jupiter still radiates more heat than it receives from the Sun; the amount of heat produced inside it is similar to the total [solar radiation](https://en.wikipedia.org/wiki/Solar_radiation) it receives.[[34]](https://en.wikipedia.org/wiki/Jupiter#cite_note-elkins-tanton-36) This additional heat is generated by the [Kelvin–Helmholtz mechanism](https://en.wikipedia.org/wiki/Kelvin%E2%80%93Helmholtz_mechanism) through contraction. This process causes Jupiter to shrink by about 2 cm each year.[[35]](https://en.wikipedia.org/wiki/Jupiter#cite_note-guillot04-37) When it was first formed, Jupiter was much hotter and was about twice its current diameter.[[36]](https://en.wikipedia.org/wiki/Jupiter#cite_note-38)

### Internal structure

Jupiter is thought to consist of a dense [core](https://en.wikipedia.org/wiki/Planetary_core) with a mixture of elements, a surrounding layer of liquid [metallic hydrogen](https://en.wikipedia.org/wiki/Metallic_hydrogen) with some helium, and an outer layer predominantly of [molecular hydrogen](https://en.wikipedia.org/wiki/Molecular_hydrogen).[[35]](https://en.wikipedia.org/wiki/Jupiter#cite_note-guillot04-37) Beyond this basic outline, there is still considerable uncertainty. The core is often described as [rocky](https://en.wikipedia.org/wiki/Rock_(geology)), but its detailed composition is unknown, as are the properties of materials at the temperatures and pressures of those depths (see below). In 1997, the existence of the core was suggested by gravitational measurements,[[35]](https://en.wikipedia.org/wiki/Jupiter#cite_note-guillot04-37)indicating a mass of from 12 to 45 times that of Earth, or roughly 4%–14% of the total mass of Jupiter.[[34]](https://en.wikipedia.org/wiki/Jupiter#cite_note-elkins-tanton-36)[[37]](https://en.wikipedia.org/wiki/Jupiter#cite_note-39) The presence of a core during at least part of Jupiter's history is suggested by models of planetary formation that require the formation of a rocky or icy core massive enough to collect its bulk of hydrogen and helium from the [protosolar nebula](https://en.wikipedia.org/wiki/Nebular_hypothesis). Assuming it did exist, it may have shrunk as convection currents of hot liquid metallic hydrogen mixed with the molten core and carried its contents to higher levels in the planetary interior. A core may now be entirely absent, as gravitational measurements are not yet precise enough to rule that possibility out entirely.[[35]](https://en.wikipedia.org/wiki/Jupiter#cite_note-guillot04-37)[[38]](https://en.wikipedia.org/wiki/Jupiter#cite_note-40)

[](https://en.wikipedia.org/wiki/File:PIA19640-Jupiter-Infrared-Animation-20150516.gif)

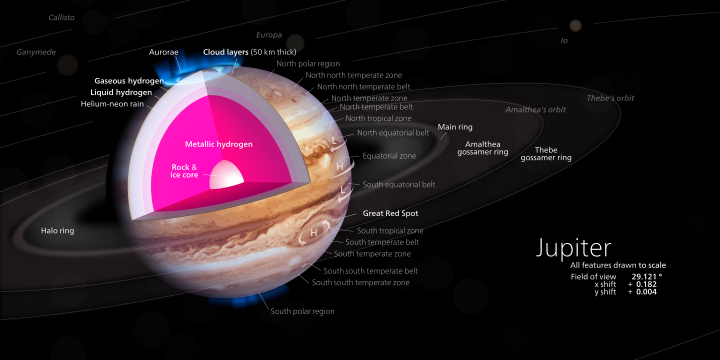
Animation of Jupiter seen in infrared

The uncertainty of the models is tied to the error margin in hitherto measured parameters: one of the rotational coefficients (J6) used to describe the planet's gravitational moment, Jupiter's equatorial radius, and its temperature at 1 bar pressure. The [Juno mission](https://en.wikipedia.org/wiki/Juno_(spacecraft)), which arrived in July 2016,[[15]](https://en.wikipedia.org/wiki/Jupiter#cite_note-NYT-20160705-17) is expected to further constrain the values of these parameters for better models of the core.[[39]](https://en.wikipedia.org/wiki/Jupiter#cite_note-41)

The core region is surrounded by dense [metallic hydrogen](https://en.wikipedia.org/wiki/Metallic_hydrogen), which extends outward to about 78% of the radius of the planet.[[34]](https://en.wikipedia.org/wiki/Jupiter#cite_note-elkins-tanton-36) Rain-like droplets of helium and neon precipitate downward through this layer, depleting the abundance of these elements in the upper atmosphere.[[23]](https://en.wikipedia.org/wiki/Jupiter#cite_note-galileo_ms-25)[[40]](https://en.wikipedia.org/wiki/Jupiter#cite_note-42)

Above the layer of metallic hydrogen lies a transparent interior atmosphere of hydrogen. At this depth, the pressure and temperature are above hydrogen's [critical pressure](https://en.wikipedia.org/wiki/Critical_pressure) of 1.2858 MPa and [critical temperature](https://en.wikipedia.org/wiki/Critical_temperature) of only 32.938 [K](https://en.wikipedia.org/wiki/Kelvin).[[41]](https://en.wikipedia.org/wiki/Jupiter#cite_note-43) In this state, there are no distinct liquid and gas phases—hydrogen is said to be in a supercritical fluid state. It is convenient to treat hydrogen as gas in the upper layer extending downward from the cloud layer to a depth of about 1,000 [km](https://en.wikipedia.org/wiki/Km),[[34]](https://en.wikipedia.org/wiki/Jupiter#cite_note-elkins-tanton-36) and as liquid in deeper layers. Physically, there is no clear boundary—the gas smoothly becomes hotter and denser as one descends.[[42]](https://en.wikipedia.org/wiki/Jupiter#cite_note-44)[[43]](https://en.wikipedia.org/wiki/Jupiter#cite_note-lang03-45)

The temperature and pressure inside Jupiter increase steadily toward the core, due to the [Kelvin–Helmholtz mechanism](https://en.wikipedia.org/wiki/Kelvin%E2%80%93Helmholtz_mechanism). At the "surface" pressure level of 10 [bars](https://en.wikipedia.org/wiki/Bar_(unit)), the temperature is around 340 K (67 °C; 152 °F). At the [phase transition](https://en.wikipedia.org/wiki/Phase_transition)region where hydrogen—heated beyond its critical point—becomes metallic, it is calculated the temperature is 10,000 K (9,700 °C; 17,500 °F) and the pressure is [200](https://en.wikipedia.org/wiki/Orders_of_magnitude_(pressure)#1GPa) [GPa](https://en.wikipedia.org/wiki/Pascal_(unit)). The temperature at the core boundary is estimated to be 36,000 K (35,700 °C; 64,300 °F) and the interior pressure is roughly [3,000](https://en.wikipedia.org/wiki/Orders_of_magnitude_(pressure)#1TPa)–4,500 GPa.[[34]](https://en.wikipedia.org/wiki/Jupiter#cite_note-elkins-tanton-36)

[](https://en.wikipedia.org/wiki/File:Jupiter_diagram.svg)

This cut-away illustrates a model of the interior of Jupiter, with a rocky core overlaid by a deep layer of liquid [metallic hydrogen](https://en.wikipedia.org/wiki/Metallic_hydrogen).

### Atmosphere

*Main article:*[*Atmosphere of Jupiter*](https://en.wikipedia.org/wiki/Atmosphere_of_Jupiter)

Jupiter has the largest planetary atmosphere in the Solar System, spanning over 5,000 km (3,000 mi) in altitude.[[44]](https://en.wikipedia.org/wiki/Jupiter#cite_note-Sieff-46)[[45]](https://en.wikipedia.org/wiki/Jupiter#cite_note-Miller_Aylward_et_al._2005-47) Because Jupiter has no surface, the base of its atmosphere is usually considered to be the point at which atmospheric pressure is equal to 100 kPa (1.0 bar).

#### Cloud layers

[](https://en.wikipedia.org/wiki/File:Great_Red_Spot_From_Voyager_1.jpg)

This view of Jupiter's Great Red Spot and its surroundings was obtained by [Voyager 1](https://en.wikipedia.org/wiki/Voyager_1) on February 25, 1979, when the spacecraft was 9.2 million km (5.7 million mi) from Jupiter. The white oval storm directly below the Great Red Spot is approximately the same diameter as Earth.

Jupiter is perpetually covered with clouds composed of ammonia crystals and possibly [ammonium hydrosulfide](https://en.wikipedia.org/wiki/Ammonium_hydrosulfide). The clouds are located in the [tropopause](https://en.wikipedia.org/wiki/Tropopause) and are arranged into bands of different latitudes, known as tropical regions. These are sub-divided into lighter-hued *zones* and darker *belts*. The interactions of these conflicting [circulation](https://en.wikipedia.org/wiki/Atmospheric_circulation) patterns cause storms and [turbulence](https://en.wikipedia.org/wiki/Turbulence). [Wind speeds](https://en.wikipedia.org/wiki/Wind_speed) of 100 m/s (360 km/h) are common in zonal jets.[[46]](https://en.wikipedia.org/wiki/Jupiter#cite_note-48)The zones have been observed to vary in width, color and intensity from year to year, but they have remained sufficiently stable for scientists to give them identifying designations.[[25]](https://en.wikipedia.org/wiki/Jupiter#cite_note-burgess-27)



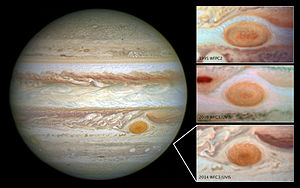
This looping animation shows the movement of Jupiter's counter-rotating cloud bands. In this image, the planet's exterior is mapped onto a [cylindrical projection](https://en.wikipedia.org/wiki/Cylindrical_projection). Animation at larger widths:[720 pixels](https://en.wikipedia.org/wiki/File:PIA02863_-_Jupiter_surface_motion_animation_thumbnail_720px_10fps.ogv), [1799 pixels](https://en.wikipedia.org/wiki/File:PIA02863_-_Jupiter_surface_motion_animation_1fps.ogv).

The cloud layer is only about 50 km (31 mi) deep, and consists of at least two decks of clouds: a thick lower deck and a thin clearer region. There may also be a thin layer of [water](https://en.wikipedia.org/wiki/Water_(properties)) clouds underlying the ammonia layer, as evidenced by flashes of [lightning](https://en.wikipedia.org/wiki/Lightning) detected in the atmosphere of Jupiter. This is caused by water's [polarity](https://en.wikipedia.org/wiki/Polar_molecule), which makes it capable of creating the charge separation needed to produce lightning.[[34]](https://en.wikipedia.org/wiki/Jupiter#cite_note-elkins-tanton-36) These electrical discharges can be up to a thousand times as powerful as lightning on Earth.[[47]](https://en.wikipedia.org/wiki/Jupiter#cite_note-49) The water clouds can form thunderstorms driven by the heat rising from the interior.[[48]](https://en.wikipedia.org/wiki/Jupiter#cite_note-50)

The orange and brown coloration in the clouds of Jupiter are caused by upwelling compounds that change color when they are exposed to [ultraviolet](https://en.wikipedia.org/wiki/Ultraviolet) light from the Sun. The exact makeup remains uncertain, but the substances are thought to be phosphorus, sulfur or possibly [hydrocarbons](https://en.wikipedia.org/wiki/Hydrocarbon).[[34]](https://en.wikipedia.org/wiki/Jupiter#cite_note-elkins-tanton-36)[[49]](https://en.wikipedia.org/wiki/Jupiter#cite_note-51) These colorful compounds, known as [chromophores](https://en.wikipedia.org/wiki/Chromophore), mix with the warmer, lower deck of clouds. The zones are formed when rising [convection cells](https://en.wikipedia.org/wiki/Convection_cell) form crystallizing ammonia that masks out these lower clouds from view.[[50]](https://en.wikipedia.org/wiki/Jupiter#cite_note-worldbook-52)

Jupiter's low [axial tilt](https://en.wikipedia.org/wiki/Axial_tilt) means that the poles constantly receive less [solar radiation](https://en.wikipedia.org/wiki/Solar_radiation) than at the planet's equatorial region. [Convection](https://en.wikipedia.org/wiki/Convection) within the interior of the planet transports more energy to the poles, balancing out the temperatures at the cloud layer.[[25]](https://en.wikipedia.org/wiki/Jupiter#cite_note-burgess-27)

#### Great Red Spot and other vortices

[](https://en.wikipedia.org/wiki/File:NASA14135-Jupiter-GreatRedSpot-Shrinks-20140515.jpg)

Jupiter – [Great Red Spot](https://en.wikipedia.org/wiki/Great_Red_Spot) is decreasing in size (May 15, 2014).[[51]](https://en.wikipedia.org/wiki/Jupiter#cite_note-NASA-20140515-53)

The best known feature of Jupiter is the [Great Red Spot](https://en.wikipedia.org/wiki/Great_Red_Spot), a persistent [anticyclonic](https://en.wikipedia.org/wiki/Anticyclone) storm that is larger than Earth, located 22° south of the equator. It is known to have been in existence since at least 1831,[[52]](https://en.wikipedia.org/wiki/Jupiter#cite_note-54) and possibly since 1665.[[53]](https://en.wikipedia.org/wiki/Jupiter#cite_note-kyrala26-55)[[54]](https://en.wikipedia.org/wiki/Jupiter#cite_note-56) Images by the [Hubble Space Telescope](https://en.wikipedia.org/wiki/Hubble_Space_Telescope) have shown as many as two "red spots" adjacent to the Great Red Spot.[[55]](https://en.wikipedia.org/wiki/Jupiter#cite_note-57)[[56]](https://en.wikipedia.org/wiki/Jupiter#cite_note-58) The storm is large enough to be visible through Earth-based [telescopes](https://en.wikipedia.org/wiki/Telescope) with an [aperture](https://en.wikipedia.org/wiki/Aperture) of12 cm or larger.[[57]](https://en.wikipedia.org/wiki/Jupiter#cite_note-59) [Mathematical models](https://en.wikipedia.org/wiki/Mathematical_model) suggest that the storm is stable and may be a permanent feature of the planet.[[58]](https://en.wikipedia.org/wiki/Jupiter#cite_note-60)



Time-lapse sequence (over 1 month) from the approach of [Voyager 1](https://en.wikipedia.org/wiki/Voyager_1)to Jupiter, showing the motion of atmospheric bands, and circulation of the Great Red Spot. [Full size video here](https://en.wikipedia.org/wiki/File:Jupiter_from_Voyager_1_PIA02855_max_quality.ogv)

The [oval](https://en.wikipedia.org/wiki/Oval_(geometry)) object [rotates](https://en.wikipedia.org/wiki/Rotation) [counterclockwise](https://en.wikipedia.org/wiki/Counterclockwise), with a [period](https://en.wikipedia.org/wiki/Period_(physics)) of about six days.[[59]](https://en.wikipedia.org/wiki/Jupiter#cite_note-61) The Great Red Spot's [dimensions](https://en.wikipedia.org/wiki/Dimension) are 24–40,000 km × 12–14,000 km. It is large enough to contain two or three planets of Earth's diameter.[[60]](https://en.wikipedia.org/wiki/Jupiter#cite_note-62) The maximum altitude of this storm is about 8 km (5 mi) above the surrounding cloudtops.[[61]](https://en.wikipedia.org/wiki/Jupiter#cite_note-63)

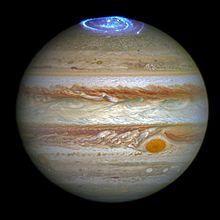
Storms such as this are common within the [turbulent](https://en.wikipedia.org/wiki/Turbulent) [atmospheres](https://en.wikipedia.org/wiki/Celestial_body_atmosphere) of [giant planets](https://en.wikipedia.org/wiki/Giant_planet). Jupiter also has white ovals and brown ovals, which are lesser unnamed storms. White ovals tend to consist of relatively cool clouds within the upper atmosphere. Brown ovals are warmer and located within the "normal cloud layer". Such storms can last as little as a few hours or stretch on for centuries.

Even before Voyager proved that the feature was a storm, there was strong evidence that the spot could not be associated with any deeper feature on the planet's surface, as the Spot rotates differentially with respect to the rest of the atmosphere, sometimes faster and sometimes more slowly.

In 2000, an atmospheric feature formed in the southern hemisphere that is similar in appearance to the Great Red Spot, but smaller. This was created when several smaller, white oval-shaped storms merged to form a single feature—these three smaller white ovals were first observed in 1938. The merged feature was named [Oval BA](https://en.wikipedia.org/wiki/Oval_BA), and has been nicknamed Red Spot Junior. It has since increased in intensity and changed color from white to red.[[62]](https://en.wikipedia.org/wiki/Jupiter#cite_note-64)[[63]](https://en.wikipedia.org/wiki/Jupiter#cite_note-65)[[64]](https://en.wikipedia.org/wiki/Jupiter#cite_note-66)

### Magnetosphere

*Main article:*[*Magnetosphere of Jupiter*](https://en.wikipedia.org/wiki/Magnetosphere_of_Jupiter)

[](https://en.wikipedia.org/wiki/File:Hubble_Captures_Vivid_Auroras_in_Jupiter%27s_Atmosphere.jpg)

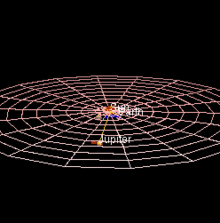
[Aurorae](https://en.wikipedia.org/wiki/Aurora_(astronomy)) on the north pole of Jupiter  
as viewed by [Hubble](https://en.wikipedia.org/wiki/Hubble_Space_Telescope)

Jupiter's [magnetic field](https://en.wikipedia.org/wiki/Magnetic_field) is fourteen times as strong as that of Earth, ranging from 4.2 [gauss](https://en.wikipedia.org/wiki/Gauss_(unit)) (0.42 [mT](https://en.wikipedia.org/wiki/Millitesla)) at the equator to 10–14 gauss (1.0–1.4 mT) at the poles, making it the strongest in the Solar System (except for [sunspots](https://en.wikipedia.org/wiki/Sunspot)).[[50]](https://en.wikipedia.org/wiki/Jupiter#cite_note-worldbook-52) This field is thought to be generated by [eddy currents](https://en.wikipedia.org/wiki/Eddy_current)—swirling movements of conducting materials—within the liquid metallic hydrogen core. The volcanoes on the moon [Io](https://en.wikipedia.org/wiki/Io_(moon)) emit large amounts of [sulfur dioxide](https://en.wikipedia.org/wiki/Sulfur_dioxide) forming a gas torus along the moon's orbit. The gas is ionized in the magnetosphere producing [sulfur](https://en.wikipedia.org/wiki/Sulfur) and [oxygen](https://en.wikipedia.org/wiki/Oxygen)[ions](https://en.wikipedia.org/wiki/Ion). They, together with hydrogen ions originating from the atmosphere of Jupiter, form a [plasma sheet](https://en.wikipedia.org/wiki/Plasma_sheet) in Jupiter's equatorial plane. The plasma in the sheet co-rotates with the planet causing deformation of the dipole magnetic field into that of magnetodisk. Electrons within the plasma sheet generate a strong radio signature that produces bursts in the range of 0.6–30 [MHz](https://en.wikipedia.org/wiki/Hertz).[[65]](https://en.wikipedia.org/wiki/Jupiter#cite_note-67)

At about 75 Jupiter radii from the planet, the interaction of the magnetosphere with the [solar wind](https://en.wikipedia.org/wiki/Solar_wind) generates a [bow shock](https://en.wikipedia.org/wiki/Bow_shock). Surrounding Jupiter's magnetosphere is a [magnetopause](https://en.wikipedia.org/wiki/Magnetopause), located at the inner edge of a[magnetosheath](https://en.wikipedia.org/wiki/Magnetosheath)—a region between it and the bow shock. The solar wind interacts with these regions, elongating the magnetosphere on Jupiter's [lee side](https://en.wikipedia.org/wiki/Lee_side) and extending it outward until it nearly reaches the orbit of Saturn. The four largest moons of Jupiter all orbit within the magnetosphere, which protects them from the solar wind.[[34]](https://en.wikipedia.org/wiki/Jupiter#cite_note-elkins-tanton-36)

The magnetosphere of Jupiter is responsible for intense episodes of [radio emission](https://en.wikipedia.org/wiki/Radio_wave) from the planet's polar regions. Volcanic activity on Jupiter's moon Io (see below) injects gas into Jupiter's magnetosphere, producing a torus of particles about the planet. As Io moves through this torus, the interaction generates [Alfvén waves](https://en.wikipedia.org/wiki/Alfv%C3%A9n_wave) that carry ionized matter into the polar regions of Jupiter. As a result, radio waves are generated through a [cyclotron](https://en.wikipedia.org/wiki/Cyclotron) [maser mechanism](https://en.wikipedia.org/wiki/Astrophysical_maser), and the energy is transmitted out along a cone-shaped surface. When Earth intersects this cone, the radio emissions from Jupiter can exceed the solar radio output.[[66]](https://en.wikipedia.org/wiki/Jupiter#cite_note-68)

## Orbit and rotation

[](https://en.wikipedia.org/wiki/File:Solarsystem3DJupiter.gif)

Jupiter (red) completes one orbit of the Sun (center) for every 11.86 orbits of Earth (blue)

Jupiter is the only planet whose [barycenter](https://en.wikipedia.org/wiki/Barycenter) with the Sun lies outside the volume of the Sun, though by only 7% of the Sun's radius.[[67]](https://en.wikipedia.org/wiki/Jupiter#cite_note-69) The average distance between Jupiter and the Sun is 778 million km (about 5.2 times the average distance between Earth and the Sun, or 5.2 [AU](https://en.wikipedia.org/wiki/Astronomical_unit)) and it completes an orbit every 11.86 years. This is two-fifths the orbital period of Saturn, forming a 5:2 [orbital resonance](https://en.wikipedia.org/wiki/Orbital_resonance) between the two largest planets in the Solar System.[[68]](https://en.wikipedia.org/wiki/Jupiter#cite_note-70) The elliptical orbit of Jupiter is inclined 1.31° compared to Earth. Because of an [eccentricity](https://en.wikipedia.org/wiki/Orbital_eccentricity) its orbit of 0.048, Jupiter's distance from the Sun varies by 75 million km between its nearest approach ([perihelion](https://en.wikipedia.org/wiki/Perihelion)) and furthest distance ([aphelion](https://en.wikipedia.org/wiki/Aphelion)).

The [axial tilt](https://en.wikipedia.org/wiki/Axial_tilt) of Jupiter is relatively small: only 3.13°. As a result, it does not experience significant seasonal changes, in contrast to, for example, Earth and Mars.[[69]](https://en.wikipedia.org/wiki/Jupiter#cite_note-71)

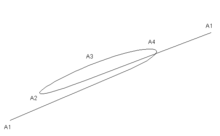
Jupiter's [rotation](https://en.wikipedia.org/wiki/Period_of_revolution) is the fastest of all the Solar System's planets, completing a rotation on its [axis](https://en.wikipedia.org/wiki/Coordinate_axis) in slightly less than ten hours; this creates an [equatorial bulge](https://en.wikipedia.org/wiki/Equatorial_bulge) easily seen through an Earth-based amateur [telescope](https://en.wikipedia.org/wiki/Telescope). The planet is shaped as an [oblate spheroid](https://en.wikipedia.org/wiki/Oblate_spheroid), meaning that the diameter across its [equator](https://en.wikipedia.org/wiki/Equator) is longer than the diameter measured between its [poles](https://en.wikipedia.org/wiki/Geographic_pole). On Jupiter, the equatorial diameter is 9,275 km (5,763 mi) longer than the diameter measured through the poles.[[43]](https://en.wikipedia.org/wiki/Jupiter#cite_note-lang03-45)

Because Jupiter is not a solid body, its upper atmosphere undergoes [differential rotation](https://en.wikipedia.org/wiki/Differential_rotation). The rotation of Jupiter's polar atmosphere is about 5 minutes longer than that of the equatorial atmosphere; three systems are used as frames of reference, particularly when graphing the motion of atmospheric features. System I applies from the latitudes 10° N to 10° S; its period is the planet's shortest, at 9h 50m 30.0s. System II applies at all latitudes north and south of these; its period is 9h 55m 40.6s. System III was first defined by [radio astronomers](https://en.wikipedia.org/wiki/Radio_astronomer), and corresponds to the rotation of the planet's magnetosphere; its period is Jupiter's official rotation.[[70]](https://en.wikipedia.org/wiki/Jupiter#cite_note-72)

## Observation

[](https://en.wikipedia.org/wiki/File:Conjunction_of_Jupiter_and_Moon.jpg)

Conjunction of Jupiter and the Moon

[](https://en.wikipedia.org/wiki/File:Retrogadation1.png)

The retrograde motion of an outer planet is caused by its relative location with respect to Earth

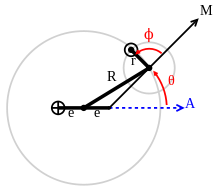
Jupiter is usually the fourth brightest object in the sky (after the Sun, the [Moon](https://en.wikipedia.org/wiki/Moon) and [Venus](https://en.wikipedia.org/wiki/Venus));[[50]](https://en.wikipedia.org/wiki/Jupiter#cite_note-worldbook-52) at times [Mars](https://en.wikipedia.org/wiki/Mars#Viewing) appears brighter than Jupiter. Depending on Jupiter's position with respect to the [Earth](https://en.wikipedia.org/wiki/Earth), it can vary in visual magnitude from as bright as −2.9 at [opposition](https://en.wikipedia.org/wiki/Opposition_(astronomy)) down to −1.6 during [conjunction](https://en.wikipedia.org/wiki/Conjunction_(astronomy_and_astrology)) with the Sun. The [angular diameter](https://en.wikipedia.org/wiki/Angular_diameter) of Jupiter likewise varies from 50.1 to 29.8 [arc seconds](https://en.wikipedia.org/wiki/Arc_second).[[3]](https://en.wikipedia.org/wiki/Jupiter#cite_note-fact-4) Favorable oppositions occur when Jupiter is passing through [perihelion](https://en.wikipedia.org/wiki/Apsis), an event that occurs once per orbit.

Earth overtakes Jupiter every 398.9 days as it orbits the Sun, a duration called the [synodic period](https://en.wikipedia.org/wiki/Synodic_period). As it does so, Jupiter appears to undergo [retrograde motion](https://en.wikipedia.org/wiki/Apparent_retrograde_motion) with respect to the background stars. That is, for a period Jupiter seems to move backward in the night sky, performing a looping motion.

Because the orbit of Jupiter is outside that of Earth, the [phase angle](https://en.wikipedia.org/wiki/Phase_angle_(astronomy)) of Jupiter as viewed from Earth never exceeds 11.5°. That is, the planet always appears nearly fully illuminated when viewed through Earth-based telescopes. It was only during spacecraft missions to Jupiter that crescent views of the planet were obtained.[[71]](https://en.wikipedia.org/wiki/Jupiter#cite_note-73) A small telescope will usually show Jupiter's four [Galilean moons](https://en.wikipedia.org/wiki/Galilean_moons) and the prominent cloud belts across [Jupiter's atmosphere](https://en.wikipedia.org/wiki/Atmosphere_of_Jupiter).[[72]](https://en.wikipedia.org/wiki/Jupiter#cite_note-74) A large telescope will show Jupiter's [Great Red Spot](https://en.wikipedia.org/wiki/Great_Red_Spot) when it faces Earth.

## Research and exploration

### Pre-telescopic research

[](https://en.wikipedia.org/wiki/File:Almagest-planets.svg)

Model in the [*Almagest*](https://en.wikipedia.org/wiki/Almagest) of the longitudinal motion of Jupiter (☉) relative to Earth (⊕)

The observation of Jupiter dates back to the [Babylonian astronomers](https://en.wikipedia.org/wiki/Babylonian_astronomy) of the 7th or 8th century BC.[[73]](https://en.wikipedia.org/wiki/Jupiter#cite_note-75) The ancient Chinese referred to Jupiter as "the Year Star" (*Sui-xing* 歲星), and by the 4th century BC had divided the sky into twelve zodiacal regions, with Jupiter passing through one each year.[[74]](https://en.wikipedia.org/wiki/Jupiter#cite_note-76) The Chinese historian [Xi Zezong](https://en.wikipedia.org/wiki/Xi_Zezong) has claimed that [Gan De](https://en.wikipedia.org/wiki/Gan_De), an ancient [Chinese astronomer](https://en.wikipedia.org/wiki/Chinese_astronomy), discovered one of [Jupiter's moons](https://en.wikipedia.org/wiki/Moons_of_Jupiter) in 362 BC with the unaided eye. If accurate, this would predate Galileo's discovery by nearly two millennia.[[75]](https://en.wikipedia.org/wiki/Jupiter#cite_note-77)[[76]](https://en.wikipedia.org/wiki/Jupiter#cite_note-78) In his 2nd century work the [*Almagest*](https://en.wikipedia.org/wiki/Almagest), the Hellenistic astronomer [Claudius Ptolemaeus](https://en.wikipedia.org/wiki/Claudius_Ptolemaeus) constructed a [geocentric](https://en.wikipedia.org/wiki/Geocentric) planetary model based on [deferents](https://en.wikipedia.org/wiki/Deferent) and [epicycles](https://en.wikipedia.org/wiki/Epicycle) to explain Jupiter's motion relative to Earth, giving its orbital period around Earth as 4332.38 days, or 11.86 years.[[77]](https://en.wikipedia.org/wiki/Jupiter#cite_note-79) In 499, [Aryabhata](https://en.wikipedia.org/wiki/Aryabhata), a mathematician–astronomer from the classical age of[Indian mathematics](https://en.wikipedia.org/wiki/Indian_mathematics) and [astronomy](https://en.wikipedia.org/wiki/Indian_astronomy), also used a geocentric model to estimate Jupiter's period as 4332.2722 days, or 11.86 years.[[78]](https://en.wikipedia.org/wiki/Jupiter#cite_note-80)

### Ground-based telescope research

In 1610, [Galileo Galilei](https://en.wikipedia.org/wiki/Galileo_Galilei) discovered the four largest [moons](https://en.wikipedia.org/wiki/Natural_satellite) of Jupiter (now known as the [Galilean moons](https://en.wikipedia.org/wiki/Galilean_moon)) using a telescope; thought to be the first telescopic observation of moons other than Earth's. One day after Galileo,[Simon Marius](https://en.wikipedia.org/wiki/Simon_Marius) independently discovered moons around Jupiter, though he did not publish his discovery in a book until 1614.[[79]](https://en.wikipedia.org/wiki/Jupiter#cite_note-81) It was Marius's names for the four major moons, however, that stuck—Io, Europa, Ganymede and[Callisto](https://en.wikipedia.org/wiki/Callisto_(moon)). These findings were also the first discovery of [celestial motion](https://en.wikipedia.org/wiki/Celestial_mechanics) not apparently centered on Earth. The discovery was a major point in favor of [Copernicus'](https://en.wikipedia.org/wiki/Nicolaus_Copernicus) [heliocentric](https://en.wikipedia.org/wiki/Heliocentrism) theory of the motions of the planets; Galileo's outspoken support of the Copernican theory placed him under the threat of the [Inquisition](https://en.wikipedia.org/wiki/Inquisition).[[80]](https://en.wikipedia.org/wiki/Jupiter#cite_note-82)

During the 1660s, [Giovanni Cassini](https://en.wikipedia.org/wiki/Giovanni_Domenico_Cassini) used a new telescope to discover spots and colorful bands on Jupiter and observed that the planet appeared oblate; that is, flattened at the poles. He was also able to estimate the rotation period of the planet.[[81]](https://en.wikipedia.org/wiki/Jupiter#cite_note-cassini1-83) In 1690 Cassini noticed that the atmosphere undergoes [differential rotation](https://en.wikipedia.org/wiki/Differential_rotation).[[34]](https://en.wikipedia.org/wiki/Jupiter#cite_note-elkins-tanton-36)

The Great Red Spot, a prominent oval-shaped feature in the southern hemisphere of Jupiter, may have been observed as early as 1664 by [Robert Hooke](https://en.wikipedia.org/wiki/Robert_Hooke) and in 1665 by Cassini, although this is disputed. The pharmacist[Heinrich Schwabe](https://en.wikipedia.org/wiki/Samuel_Heinrich_Schwabe) produced the earliest known drawing to show details of the Great Red Spot in 1831.[[82]](https://en.wikipedia.org/wiki/Jupiter#cite_note-84)

The Red Spot was reportedly lost from sight on several occasions between 1665 and 1708 before becoming quite conspicuous in 1878. It was recorded as fading again in 1883 and at the start of the 20th century.[[83]](https://en.wikipedia.org/wiki/Jupiter#cite_note-85)

Both [Giovanni Borelli](https://en.wikipedia.org/wiki/Giovanni_Alfonso_Borelli) and Cassini made careful tables of the motions of Jupiter's moons, allowing predictions of the times when the moons would pass before or behind the planet. By the 1670s, it was observed that when Jupiter was on the opposite side of the Sun from Earth, these events would occur about 17 minutes later than expected. [Ole Rømer](https://en.wikipedia.org/wiki/Ole_R%C3%B8mer) deduced that sight is not instantaneous (a conclusion that Cassini had earlier rejected),[[20]](https://en.wikipedia.org/wiki/Jupiter#cite_note-cassini-22)and this timing discrepancy was used to estimate the [speed of light](https://en.wikipedia.org/wiki/Speed_of_light).[[84]](https://en.wikipedia.org/wiki/Jupiter#cite_note-86)

In 1892, [E. E. Barnard](https://en.wikipedia.org/wiki/E._E._Barnard) observed a fifth satellite of Jupiter with the 36-inch (910 mm) refractor at [Lick Observatory](https://en.wikipedia.org/wiki/Lick_Observatory) in California. The discovery of this relatively small object, a testament to his keen eyesight, quickly made him famous. This moon was later named[Amalthea](https://en.wikipedia.org/wiki/Amalthea_(moon)).[[85]](https://en.wikipedia.org/wiki/Jupiter#cite_note-87) It was the last planetary moon to be discovered directly by visual observation.[[86]](https://en.wikipedia.org/wiki/Jupiter#cite_note-88)

[](https://en.wikipedia.org/wiki/File:Jupiter_MAD.jpg)

Infrared image of Jupiter taken by [ESO](https://en.wikipedia.org/wiki/ESO)'s[Very Large Telescope](https://en.wikipedia.org/wiki/Very_Large_Telescope).

In 1932, [Rupert Wildt](https://en.wikipedia.org/wiki/Rupert_Wildt) identified absorption bands of ammonia and methane in the spectra of Jupiter.[[87]](https://en.wikipedia.org/wiki/Jupiter#cite_note-89)

Three long-lived anticyclonic features termed white ovals were observed in 1938. For several decades they remained as separate features in the atmosphere, sometimes approaching each other but never merging. Finally, two of the ovals merged in 1998, then absorbed the third in 2000, becoming [Oval BA](https://en.wikipedia.org/wiki/Oval_BA).[[88]](https://en.wikipedia.org/wiki/Jupiter#cite_note-90)

### Radiotelescope research

In 1955, Bernard Burke and [Kenneth Franklin](https://en.wikipedia.org/wiki/Kenneth_Franklin) detected bursts of radio signals coming from Jupiter at 22.2 MHz.[[34]](https://en.wikipedia.org/wiki/Jupiter#cite_note-elkins-tanton-36) The period of these bursts matched the rotation of the planet, and they were also able to use this information to refine the rotation rate. Radio bursts from Jupiter were found to come in two forms: long bursts (or L-bursts) lasting up to several seconds, and short bursts (or S-bursts) that had a duration of less than a hundredth of a second.[[89]](https://en.wikipedia.org/wiki/Jupiter#cite_note-91)

Scientists discovered that there were three forms of radio signals transmitted from Jupiter.

* Decametric radio bursts (with a wavelength of tens of meters) vary with the rotation of Jupiter, and are influenced by interaction of Io with Jupiter's magnetic field.[[90]](https://en.wikipedia.org/wiki/Jupiter#cite_note-92)
* Decimetric radio emission (with wavelengths measured in centimeters) was first observed by [Frank Drake](https://en.wikipedia.org/wiki/Frank_Drake) and Hein Hvatum in 1959.[[34]](https://en.wikipedia.org/wiki/Jupiter#cite_note-elkins-tanton-36) The origin of this signal was from a torus-shaped belt around Jupiter's equator. This signal is caused by [cyclotron radiation](https://en.wikipedia.org/wiki/Cyclotron_radiation) from electrons that are accelerated in Jupiter's magnetic field.[[91]](https://en.wikipedia.org/wiki/Jupiter#cite_note-93)
* Thermal radiation is produced by heat in the atmosphere of Jupiter.[[34]](https://en.wikipedia.org/wiki/Jupiter#cite_note-elkins-tanton-36)

### Exploration

*Main article:*[*Exploration of Jupiter*](https://en.wikipedia.org/wiki/Exploration_of_Jupiter)

Since 1973 a number of automated spacecraft have visited Jupiter, most notably the [Pioneer 10](https://en.wikipedia.org/wiki/Pioneer_10) space probe, the first spacecraft to get close enough to Jupiter to send back revelations about the properties and phenomena of the Solar System's largest planet.[[92]](https://en.wikipedia.org/wiki/Jupiter#cite_note-94)[[93]](https://en.wikipedia.org/wiki/Jupiter#cite_note-95)Flights to other planets within the Solar System are accomplished at a cost in energy, which is described by the net change in velocity of the spacecraft, or [delta-v](https://en.wikipedia.org/wiki/Delta-v). Entering a [Hohmann transfer orbit](https://en.wikipedia.org/wiki/Hohmann_transfer_orbit) from Earth to Jupiter from [low Earth orbit](https://en.wikipedia.org/wiki/Low_Earth_orbit) requires a delta-v of 6.3 km/s[[94]](https://en.wikipedia.org/wiki/Jupiter#cite_note-96) which is comparable to the 9.7 km/s delta-v needed to reach low Earth orbit.[[95]](https://en.wikipedia.org/wiki/Jupiter#cite_note-97) Fortunately, [gravity assists](https://en.wikipedia.org/wiki/Gravitational_slingshot) through planetary [flybys](https://en.wikipedia.org/wiki/Gravitational_slingshot) can be used to reduce the energy required to reach Jupiter, albeit at the cost of a significantly longer flight duration.[[96]](https://en.wikipedia.org/wiki/Jupiter#cite_note-delta-v-98)

#### Flyby missions

|  |  |  |
| --- | --- | --- |
| **Flyby missions** | | |
| **Spacecraft** | **Closest approach** | **Distance** |
| [Pioneer 10](https://en.wikipedia.org/wiki/Pioneer_10) | December 3, 1973 | 130,000 km |
| [Pioneer 11](https://en.wikipedia.org/wiki/Pioneer_11) | December 4, 1974 | 34,000 km |
| [Voyager 1](https://en.wikipedia.org/wiki/Voyager_1) | March 5, 1979 | 349,000 km |
| [Voyager 2](https://en.wikipedia.org/wiki/Voyager_2) | July 9, 1979 | 570,000 km |
| [Ulysses](https://en.wikipedia.org/wiki/Ulysses_probe) | February 8, 1992[[97]](https://en.wikipedia.org/wiki/Jupiter#cite_note-ulysses-99) | 408,894 km |
| February 4, 2004[[97]](https://en.wikipedia.org/wiki/Jupiter#cite_note-ulysses-99) | 120,000,000 km |
| [Cassini](https://en.wikipedia.org/wiki/Cassini%E2%80%93Huygens) | December 30, 2000 | 10,000,000 km |
| [New Horizons](https://en.wikipedia.org/wiki/New_Horizons) | February 28, 2007 | 2,304,535 km |

Beginning in 1973, several spacecraft have performed planetary flyby maneuvers that brought them within observation range of Jupiter. The [Pioneer](https://en.wikipedia.org/wiki/Pioneer_program) missions obtained the first close-up images of Jupiter's atmosphere and several of its moons. They discovered that the radiation fields near the planet were much stronger than expected, but both spacecraft managed to survive in that environment. The trajectories of these spacecraft were used to refine the mass estimates of the Jovian system. [Radio occultations](https://en.wikipedia.org/wiki/Radio_occultations) by the planet resulted in better measurements of Jupiter's diameter and the amount of polar flattening.[[25]](https://en.wikipedia.org/wiki/Jupiter#cite_note-burgess-27)[[98]](https://en.wikipedia.org/wiki/Jupiter#cite_note-cosmology_101-100)

Six years later, the [Voyager](https://en.wikipedia.org/wiki/Voyager_program) missions vastly improved the understanding of the [Galilean moons](https://en.wikipedia.org/wiki/Galilean_moon) and discovered Jupiter's rings. They also confirmed that the Great Red Spot was anticyclonic. Comparison of images showed that the Red Spot had changed hue since the Pioneer missions, turning from orange to dark brown. A torus of ionized atoms was discovered along Io's orbital path, and volcanoes were found on the moon's surface, some in the process of erupting. As the spacecraft passed behind the planet, it observed flashes of lightning in the night side atmosphere.[[25]](https://en.wikipedia.org/wiki/Jupiter#cite_note-burgess-27)[[99]](https://en.wikipedia.org/wiki/Jupiter#cite_note-voyager1-101)

The next mission to encounter Jupiter was the Ulysses solar probe. It performed a flyby maneuver to attain a [polar orbit](https://en.wikipedia.org/wiki/Polar_orbit) around the Sun. During this pass, the spacecraft conducted studies on Jupiter's magnetosphere. Ulysses has no cameras so no images were taken. A second flyby six years later was at a much greater distance.[[97]](https://en.wikipedia.org/wiki/Jupiter#cite_note-ulysses-99)

[](https://en.wikipedia.org/wiki/File:PIA02879_-_A_New_Year_for_Jupiter_and_Io.jpg)

Cassini views Jupiter and Io on January 1, 2001

In 2000, the Cassini probe flew by Jupiter *en route* to [Saturn](https://en.wikipedia.org/wiki/Saturn), and provided some of the highest-resolution images ever made of the planet.[[100]](https://en.wikipedia.org/wiki/Jupiter#cite_note-102)

The [New Horizons](https://en.wikipedia.org/wiki/New_Horizons) probe flew by Jupiter for gravity assist *en route* to [Pluto](https://en.wikipedia.org/wiki/Pluto). Its closest approach was on February 28, 2007.[[101]](https://en.wikipedia.org/wiki/Jupiter#cite_note-103) The probe's cameras measured plasma output from volcanoes on Io and studied all four Galilean moons in detail, as well as making long-distance observations of the outer moons [Himalia](https://en.wikipedia.org/wiki/Himalia_(moon)) and [Elara](https://en.wikipedia.org/wiki/Elara_(moon)).[[102]](https://en.wikipedia.org/wiki/Jupiter#cite_note-104) Imaging of the Jovian system began September 4, 2006.[[103]](https://en.wikipedia.org/wiki/Jupiter#cite_note-105)[[104]](https://en.wikipedia.org/wiki/Jupiter#cite_note-106)

#### *Galileo* mission

*Main article:*[*Galileo (spacecraft)*](https://en.wikipedia.org/wiki/Galileo_(spacecraft))

[](https://en.wikipedia.org/wiki/File:Portrait_of_Jupiter_from_Cassini.jpg)

Jupiter as seen by the space probe[*Cassini*](https://en.wikipedia.org/wiki/Cassini%E2%80%93Huygens)

The first spacecraft to orbit Jupiter was the [*Galileo*](https://en.wikipedia.org/wiki/Galileo_spacecraft) probe, which entered orbit on December 7, 1995.[[30]](https://en.wikipedia.org/wiki/Jupiter#cite_note-HTUW-32) It orbited the planet for over seven years, conducting multiple flybys of all the Galilean moons and [Amalthea](https://en.wikipedia.org/wiki/Amalthea_(moon)). The spacecraft also witnessed the impact of [Comet Shoemaker–Levy 9](https://en.wikipedia.org/wiki/Comet_Shoemaker%E2%80%93Levy_9) as it approached Jupiter in 1994, giving a unique vantage point for the event. Its originally designed capacity was limited by the failed deployment of its high-gain radio antenna, although extensive information was still gained about the Jovian system from *Galileo*.[[105]](https://en.wikipedia.org/wiki/Jupiter#cite_note-galileo-107)

A 340-kilogram titanium [atmospheric probe](https://en.wikipedia.org/wiki/Galileo_(spacecraft)#Galileo_Probe) was released from the spacecraft in July 1995, entering Jupiter's atmosphere on December 7.[[30]](https://en.wikipedia.org/wiki/Jupiter#cite_note-HTUW-32) It parachuted through 150 km (93 mi) of the atmosphere at a speed of about 2,575 km/h (1600 mph)[[30]](https://en.wikipedia.org/wiki/Jupiter#cite_note-HTUW-32) and collected data for 57.6 minutes before it was crushed by the pressure of about 23 [atmospheres](https://en.wikipedia.org/wiki/Atmosphere_(pressure)) at a temperature of 153 °C.[[106]](https://en.wikipedia.org/wiki/Jupiter#cite_note-108) It melted thereafter, and possibly vaporized. The *Galileo* orbiter itself experienced a more rapid version of the same fate when it was deliberately steered into the planet on September 21, 2003 at a speed of over 50 km/s to avoid any possibility of it crashing into and possibly contaminating Europa, a moon which has been hypothesized to have the possibility of [harboring life](https://en.wikipedia.org/wiki/Life_on_Europa).[[105]](https://en.wikipedia.org/wiki/Jupiter#cite_note-galileo-107)

Data from this mission revealed that hydrogen composes up to 90% of Jupiter's atmosphere.[[30]](https://en.wikipedia.org/wiki/Jupiter#cite_note-HTUW-32) The recorded temperature was more than 300 °C (>570 °F) and the windspeed measured more than 644 km/h (>400 mph) before the probes vapourised.[[30]](https://en.wikipedia.org/wiki/Jupiter#cite_note-HTUW-32)

#### *Juno* mission

NASA's [Juno](https://en.wikipedia.org/wiki/Juno_(spacecraft)) mission arrived at Jupiter on July 4, 2016[[15]](https://en.wikipedia.org/wiki/Jupiter#cite_note-NYT-20160705-17) and will study the planet in detail from a [polar orbit](https://en.wikipedia.org/wiki/Polar_orbit).[[107]](https://en.wikipedia.org/wiki/Jupiter#cite_note-109)

#### Future probes

The next planned mission to the Jovian system will be the [European Space Agency](https://en.wikipedia.org/wiki/European_Space_Agency)'s [Jupiter Icy Moon Explorer](https://en.wikipedia.org/wiki/Jupiter_Icy_Moon_Explorer) (JUICE), due to launch in 2022,[[108]](https://en.wikipedia.org/wiki/Jupiter#cite_note-selection-110) followed by NASA's [Europa Clipper](https://en.wikipedia.org/wiki/Europa_Clipper) mission in 2025.[[109]](https://en.wikipedia.org/wiki/Jupiter#cite_note-111)

#### Canceled missions

There has been great interest in studying the icy moons in detail because of the possibility of subsurface liquid oceans on Jupiter's moons Europa, Ganymede, and Callisto. Funding difficulties have delayed progress. NASA's [*JIMO*](https://en.wikipedia.org/wiki/Jupiter_Icy_Moons_Orbiter) (*Jupiter Icy Moons Orbiter*) was cancelled in 2005.[[110]](https://en.wikipedia.org/wiki/Jupiter#cite_note-112) A subsequent proposal was developed for a joint [NASA](https://en.wikipedia.org/wiki/NASA)/[ESA](https://en.wikipedia.org/wiki/ESA) mission called [EJSM/Laplace](https://en.wikipedia.org/wiki/EJSM/Laplace), with a provisional launch date around 2020. EJSM/Laplace would have consisted of the NASA-led [Jupiter Europa Orbiter](https://en.wikipedia.org/wiki/Jupiter_Europa_Orbiter) and the ESA-led [Jupiter Ganymede Orbiter](https://en.wikipedia.org/wiki/Jupiter_Ganymede_Orbiter).[[111]](https://en.wikipedia.org/wiki/Jupiter#cite_note-113) However, ESA had formally ended the partnership by April 2011, citing budget issues at NASA and the consequences on the mission timetable. Instead, ESA planned to go ahead with a European-only mission to compete in its L1 [Cosmic Vision](https://en.wikipedia.org/wiki/Cosmic_Vision) selection.[[112]](https://en.wikipedia.org/wiki/Jupiter#cite_note-esaled-114)

## Moons

|  |  |
| --- | --- |
| [https://upload.wikimedia.org/wikipedia/en/thumb/4/4a/Commons-logo.svg/30px-Commons-logo.svg.png](https://en.wikipedia.org/wiki/File:Commons-logo.svg) | Wikimedia Commons has media related to [***Moons of Jupiter***](https://commons.wikimedia.org/wiki/Category:Moons_of_Jupiter). |

*Main article:*[*Moons of Jupiter*](https://en.wikipedia.org/wiki/Moons_of_Jupiter)

*See also:*[*Timeline of discovery of Solar System planets and their moons*](https://en.wikipedia.org/wiki/Timeline_of_discovery_of_Solar_System_planets_and_their_moons)

Jupiter has 67 [natural satellites](https://en.wikipedia.org/wiki/Natural_satellite).[[113]](https://en.wikipedia.org/wiki/Jupiter#cite_note-shep-main-115) Of these, 51 are less than 10 kilometres in diameter and have only been discovered since 1975. The four largest moons, visible from Earth with binoculars on a clear night, known as the "[Galilean moons](https://en.wikipedia.org/wiki/Galilean_moons)", are Io, Europa, Ganymede, and Callisto.

### Galilean moons

*Main article:*[*Galilean moons*](https://en.wikipedia.org/wiki/Galilean_moons)

The moons discovered by Galileo—Io, Europa, Ganymede, and Callisto—are among the largest satellites in the Solar System. The orbits of three of them (Io, Europa, and Ganymede) form a pattern known as a [Laplace resonance](https://en.wikipedia.org/wiki/Laplace_resonance); for every four orbits that Io makes around Jupiter, Europa makes exactly two orbits and Ganymede makes exactly one. This resonance causes the [gravitational](https://en.wikipedia.org/wiki/Gravity) effects of the three large moons to distort their orbits into elliptical shapes, because each moon receives an extra tug from its neighbors at the same point in every orbit it makes. The [tidal force](https://en.wikipedia.org/wiki/Tidal_force) from Jupiter, on the other hand, works to [circularize](https://en.wikipedia.org/wiki/Tidal_circularization) their orbits.[[114]](https://en.wikipedia.org/wiki/Jupiter#cite_note-116)

The [eccentricity](https://en.wikipedia.org/wiki/Orbital_eccentricity) of their orbits causes regular flexing of the three moons' shapes, with Jupiter's gravity stretching them out as they approach it and allowing them to spring back to more spherical shapes as they swing away. This tidal flexing [heats](https://en.wikipedia.org/wiki/Tidal_acceleration#Tidal_heating) the moons' interiors by [friction](https://en.wikipedia.org/wiki/Friction). This is seen most dramatically in the extraordinary [volcanic activity](https://en.wikipedia.org/wiki/Io_(moon)#Volcanism) of innermost Io (which is subject to the strongest tidal forces), and to a lesser degree in the geological youth of [Europa's surface](https://en.wikipedia.org/wiki/Europa_(moon)#Surface_features) (indicating recent resurfacing of the moon's exterior).

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| |  |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | | **The Galilean moons, compared to Earth's**[**Moon**](https://en.wikipedia.org/wiki/Moon) | | | | | | | | | | | **Name** | [**IPA**](https://en.wikipedia.org/wiki/Help:IPA_for_English) | **Diameter** | | **Mass** | | **Orbital radius** | | **Orbital period** | | | **km** | **%** | **kg** | **%** | **km** | **%** | **days** | **%** | | [**Io**](https://en.wikipedia.org/wiki/Io_(moon)) | /ˈaɪ.oʊ/ | 3,643 | 105 | 8.9×1022 | 120 | 421,700 | 110 | 1.77 | 7 | | [**Europa**](https://en.wikipedia.org/wiki/Europa_(moon)) | /jʊˈroʊpə/ | 3,122 | 90 | 4.8×1022 | 65 | 671,034 | 175 | 3.55 | 13 | | [**Ganymede**](https://en.wikipedia.org/wiki/Ganymede_(moon)) | /ˈɡænimiːd/ | 5,262 | 150 | 14.8×1022 | 200 | 1,070,412 | 280 | 7.15 | 26 | | [**Callisto**](https://en.wikipedia.org/wiki/Callisto_(moon)) | /kəˈlɪstoʊ/ | 4,821 | 140 | 10.8×1022 | 150 | 1,882,709 | 490 | 16.69 | 61 | |
| [The Galilean moons. From left to right, in order of increasing distance from Jupiter: Io, Europa, Ganymede, Callisto.](https://en.wikipedia.org/wiki/File:The_Galilean_satellites_(the_four_largest_moons_of_Jupiter).tif) |
| The Galilean moons [Io](https://en.wikipedia.org/wiki/Io_(moon)), [Europa](https://en.wikipedia.org/wiki/Europa_(moon)), [Ganymede](https://en.wikipedia.org/wiki/Ganymede_(moon)), [Callisto](https://en.wikipedia.org/wiki/Callisto_(moon)) (in order of increasing distance from Jupiter) |

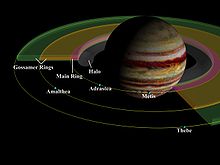
### Classification

Before the discoveries of the Voyager missions, Jupiter's moons were arranged neatly into four groups of four, based on commonality of their [orbital elements](https://en.wikipedia.org/wiki/Orbital_elements). Since then, the large number of new small outer moons has complicated this picture. There are now thought to be six main groups, although some are more distinct than others.

A basic sub-division is a grouping of the eight inner regular moons, which have nearly circular orbits near the plane of Jupiter's equator and are thought to have formed with Jupiter. The remainder of the moons consist of an unknown number of small irregular moons with elliptical and inclined orbits, which are thought to be captured asteroids or fragments of captured asteroids. Irregular moons that belong to a group share similar orbital elements and thus may have a common origin, perhaps as a larger moon or captured body that broke up.[[115]](https://en.wikipedia.org/wiki/Jupiter#cite_note-117)[[116]](https://en.wikipedia.org/wiki/Jupiter#cite_note-118)

|  |  |
| --- | --- |
| **Regular moons** | |
| [Inner group](https://en.wikipedia.org/wiki/Inner_satellites_of_Jupiter) | The inner group of four small moons all have diameters of less than 200 km, orbit at radii less than 200,000 km, and have orbital inclinations of less than half a degree. |
| [Galilean moons](https://en.wikipedia.org/wiki/Galilean_moons)[[117]](https://en.wikipedia.org/wiki/Jupiter#cite_note-119) | These four moons, discovered by [Galileo Galilei](https://en.wikipedia.org/wiki/Galileo_Galilei) and by [Simon Marius](https://en.wikipedia.org/wiki/Simon_Marius) in parallel, orbit between 400,000 and 2,000,000 km, and are some of the largest moons in the Solar System. |
| **Irregular moons** | |
| [Themisto](https://en.wikipedia.org/wiki/Themisto_(moon)) | This is a single moon belonging to a group of its own, orbiting halfway between the Galilean moons and the Himalia group. |
| [Himalia group](https://en.wikipedia.org/wiki/Himalia_group) | A tightly clustered group of moons with orbits around 11,000,000–12,000,000 km from Jupiter. |
| [Carpo](https://en.wikipedia.org/wiki/Carpo_(moon)) | Another isolated case; at the inner edge of the Ananke group, it orbits Jupiter in prograde direction. |
| [Ananke group](https://en.wikipedia.org/wiki/Ananke_group) | This [retrograde orbit](https://en.wikipedia.org/wiki/Retrograde_motion) group has rather indistinct borders, averaging 21,276,000 km from Jupiter with an average inclination of 149 degrees. |
| [Carme group](https://en.wikipedia.org/wiki/Carme_group) | A fairly distinct retrograde group that averages 23,404,000 km from Jupiter with an average inclination of 165 degrees. |
| [Pasiphaë group](https://en.wikipedia.org/wiki/Pasipha%C3%AB_group) | A dispersed and only vaguely distinct retrograde group that covers all the outermost moons. |

### Planetary rings

[](https://en.wikipedia.org/wiki/File:PIA01627_Ringe.jpg)

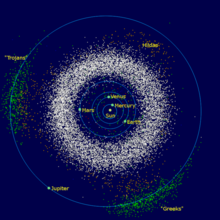
The [rings of Jupiter](https://en.wikipedia.org/wiki/Rings_of_Jupiter)

*Main article:*[*Rings of Jupiter*](https://en.wikipedia.org/wiki/Rings_of_Jupiter)

Jupiter has a faint [planetary ring](https://en.wikipedia.org/wiki/Planetary_ring) system composed of three main segments: an inner [torus](https://en.wikipedia.org/wiki/Torus) of particles known as the halo, a relatively bright main ring, and an outer gossamer ring.[[118]](https://en.wikipedia.org/wiki/Jupiter#cite_note-120) These rings appear to be made of dust, rather than ice as with Saturn's rings.[[34]](https://en.wikipedia.org/wiki/Jupiter#cite_note-elkins-tanton-36) The main ring is probably made of material ejected from the satellites [Adrastea](https://en.wikipedia.org/wiki/Adrastea_(moon)) and [Metis](https://en.wikipedia.org/wiki/Metis_(moon)). Material that would normally fall back to the moon is pulled into Jupiter because of its strong gravitational influence. The orbit of the material veers towards Jupiter and new material is added by additional impacts.[[119]](https://en.wikipedia.org/wiki/Jupiter#cite_note-Burns1999-121) In a similar way, the moons [Thebe](https://en.wikipedia.org/wiki/Thebe_(moon)) and [Amalthea](https://en.wikipedia.org/wiki/Amalthea_(moon)) probably produce the two distinct components of the dusty gossamer ring.[[119]](https://en.wikipedia.org/wiki/Jupiter#cite_note-Burns1999-121) There is also evidence of a rocky ring strung along Amalthea's orbit which may consist of collisional debris from that moon.[[120]](https://en.wikipedia.org/wiki/Jupiter#cite_note-122)

## Interaction with the Solar System

Along with the Sun, the [gravitational](https://en.wikipedia.org/wiki/Gravity) influence of Jupiter has helped shape the Solar System. The orbits of most of the system's planets lie closer to Jupiter's [orbital plane](https://en.wikipedia.org/wiki/Orbital_plane_(astronomy)) than the Sun's [equatorial plane](https://en.wikipedia.org/wiki/Celestial_equator) ([Mercury](https://en.wikipedia.org/wiki/Mercury_(planet)) is the only planet that is closer to the Sun's equator in orbital tilt), the [Kirkwood gaps](https://en.wikipedia.org/wiki/Kirkwood_gap) in the [asteroid belt](https://en.wikipedia.org/wiki/Asteroid_belt) are mostly caused by Jupiter, and the planet may have been responsible for the [Late Heavy Bombardment](https://en.wikipedia.org/wiki/Late_Heavy_Bombardment) of the inner Solar System's history.[[121]](https://en.wikipedia.org/wiki/Jupiter#cite_note-123)

[](https://en.wikipedia.org/wiki/File:InnerSolarSystem-en.png)

This diagram shows the [Trojan asteroids](https://en.wikipedia.org/wiki/Trojan_(astronomy)) in Jupiter's orbit, as well as the main [asteroid belt](https://en.wikipedia.org/wiki/Asteroid_belt).

Along with its moons, Jupiter's gravitational field controls numerous [asteroids](https://en.wikipedia.org/wiki/Asteroid) that have settled into the regions of the [Lagrangian points](https://en.wikipedia.org/wiki/Lagrangian_point) preceding and following Jupiter in its orbit around the Sun. These are known as the[Trojan asteroids](https://en.wikipedia.org/wiki/Trojan_asteroid), and are divided into [Greek](https://en.wikipedia.org/wiki/List_of_Trojan_asteroids_(Greek_camp)) and [Trojan](https://en.wikipedia.org/wiki/List_of_Trojan_asteroids_(Trojan_camp)) "camps" to commemorate the [*Iliad*](https://en.wikipedia.org/wiki/Iliad). The first of these, [588 Achilles](https://en.wikipedia.org/wiki/588_Achilles), was discovered by [Max Wolf](https://en.wikipedia.org/wiki/Max_Wolf) in 1906; since then more than two thousand have been discovered.[[122]](https://en.wikipedia.org/wiki/Jupiter#cite_note-124)The largest is [624 Hektor](https://en.wikipedia.org/wiki/624_Hektor).

Most [short-period comets](https://en.wikipedia.org/wiki/List_of_periodic_comets) belong to the Jupiter family—defined as comets with [semi-major axes](https://en.wikipedia.org/wiki/Semi-major_axis) smaller than Jupiter's. Jupiter family comets are thought to form in the [Kuiper belt](https://en.wikipedia.org/wiki/Kuiper_belt) outside the orbit of Neptune. During close encounters with Jupiter their orbits are [perturbed](https://en.wikipedia.org/wiki/Perturbation_(astronomy)) into a smaller period and then circularized by regular gravitational interaction with the Sun and Jupiter.[[123]](https://en.wikipedia.org/wiki/Jupiter#cite_note-125)

### Impacts

*See also:*[*Comet Shoemaker–Levy 9*](https://en.wikipedia.org/wiki/Comet_Shoemaker%E2%80%93Levy_9)*,*[*2009 Jupiter impact event*](https://en.wikipedia.org/wiki/2009_Jupiter_impact_event)*, and*[*2010 Jupiter impact event*](https://en.wikipedia.org/wiki/2010_Jupiter_impact_event)

[](https://en.wikipedia.org/wiki/File:Hs-2009-23-crop.jpg)

[Hubble](https://en.wikipedia.org/wiki/Hubble_Space_Telescope) image taken on July 23, 2009, showing a blemish of about 5,000 miles long left by the [2009 Jupiter impact](https://en.wikipedia.org/wiki/2009_Jupiter_impact_event).[[124]](https://en.wikipedia.org/wiki/Jupiter#cite_note-126)

Jupiter has been called the Solar System's vacuum cleaner,[[125]](https://en.wikipedia.org/wiki/Jupiter#cite_note-127) because of its immense [gravity well](https://en.wikipedia.org/wiki/Gravity_well) and location near the inner Solar System. It receives the most frequent comet impacts of the Solar System's planets.[[126]](https://en.wikipedia.org/wiki/Jupiter#cite_note-128) It was thought that the planet served to partially shield the inner system from cometary bombardment.[[30]](https://en.wikipedia.org/wiki/Jupiter#cite_note-HTUW-32) However, recent computer simulations suggest that Jupiter does not cause a net decrease in the number of comets that pass through the inner Solar System, as its gravity perturbs their orbits inward roughly as often as it accretes or ejects them.[[127]](https://en.wikipedia.org/wiki/Jupiter#cite_note-129) This topic remains controversial among scientists, as some think it draws comets towards Earth from the [Kuiper belt](https://en.wikipedia.org/wiki/Kuiper_belt) while others think that Jupiter protects Earth from the alleged [Oort cloud](https://en.wikipedia.org/wiki/Oort_cloud).[[128]](https://en.wikipedia.org/wiki/Jupiter#cite_note-130) Jupiter experiences about 200 times more [asteroid](https://en.wikipedia.org/wiki/Asteroid) and [comet](https://en.wikipedia.org/wiki/Comet) impacts than Earth.[[30]](https://en.wikipedia.org/wiki/Jupiter#cite_note-HTUW-32)

A 1997 survey of historical astronomical drawings suggested that [Cassini](https://en.wikipedia.org/wiki/Giovanni_Domenico_Cassini) may have recorded an impact scar in 1690. The survey produced eight other candidate observations between 1664 and 1839, but they had low or no possibility of being the result of an impact.[[129]](https://en.wikipedia.org/wiki/Jupiter#cite_note-131)

More recent discoveries include the following:

1. A [fireball](https://en.wikipedia.org/wiki/Fireball_(meteor)) was photographed by Voyager 1 during its Jupiter encounter in March 1979.[[130]](https://en.wikipedia.org/wiki/Jupiter#cite_note-impact2012-132)
2. During the period July 16, 1994, to July 22, 1994, over 20 fragments from the [comet](https://en.wikipedia.org/wiki/Comet) [Shoemaker–Levy 9](https://en.wikipedia.org/wiki/Comet_Shoemaker%E2%80%93Levy_9) (SL9, formally designated D/1993 F2) collided with Jupiter's [southern hemisphere](https://en.wikipedia.org/wiki/Southern_hemisphere), providing the first direct observation of a collision between two Solar System objects. This impact provided useful data on the composition of Jupiter's atmosphere.[[131]](https://en.wikipedia.org/wiki/Jupiter#cite_note-133)[[132]](https://en.wikipedia.org/wiki/Jupiter#cite_note-134)
3. On July 19, 2009, an [impact site](https://en.wikipedia.org/wiki/2009_Jupiter_impact_event) was discovered at approximately 216 degrees longitude in System 2.[[133]](https://en.wikipedia.org/wiki/Jupiter#cite_note-135)[[134]](https://en.wikipedia.org/wiki/Jupiter#cite_note-136) This impact left behind a black spot in Jupiter's atmosphere, similar in size to [Oval BA](https://en.wikipedia.org/wiki/Oval_BA). Infrared observation showed a bright spot where the impact took place, meaning the impact warmed up the lower atmosphere in the area near Jupiter's south pole.[[135]](https://en.wikipedia.org/wiki/Jupiter#cite_note-137)
4. [A fireball](https://en.wikipedia.org/wiki/2010_Jupiter_impact_event), smaller than the previous observed impacts, was detected on June 3, 2010, by [Anthony Wesley](https://en.wikipedia.org/wiki/Anthony_Wesley), an [amateur astronomer](https://en.wikipedia.org/wiki/Amateur_astronomy) in Australia, and was later discovered to have been captured on video by another amateur astronomer in the [Philippines](https://en.wikipedia.org/wiki/Philippines).[[136]](https://en.wikipedia.org/wiki/Jupiter#cite_note-138)
5. Yet another fireball was seen on August 20, 2010.[[137]](https://en.wikipedia.org/wiki/Jupiter#cite_note-139)
6. On September 10, 2012, another fireball was detected.[[130]](https://en.wikipedia.org/wiki/Jupiter#cite_note-impact2012-132)[[138]](https://en.wikipedia.org/wiki/Jupiter#cite_note-140)
7. March 17, 2016 an asteroid or comet struck and was filmed on video.[[139]](https://en.wikipedia.org/wiki/Jupiter#cite_note-141)

## Possibility of life

*Further information:*[*Extraterrestrial life*](https://en.wikipedia.org/wiki/Extraterrestrial_life)

In 1953, the [Miller–Urey experiment](https://en.wikipedia.org/wiki/Miller%E2%80%93Urey_experiment) demonstrated that a combination of lightning and the chemical compounds that existed in the atmosphere of a primordial Earth could form organic compounds (including [amino acids](https://en.wikipedia.org/wiki/Amino_acid)) that could serve as the building blocks of life. The simulated atmosphere included water, methane, ammonia, and molecular hydrogen, all molecules still found in Jupiter's atmosphere. Jupiter's atmosphere has a strong vertical air circulation, which would carry these compounds down into the lower regions. The higher temperatures within the interior of the atmosphere would break down these chemicals, hindering the formation of Earth-like life.[[140]](https://en.wikipedia.org/wiki/Jupiter#cite_note-142)

It is considered highly unlikely that there is any Earth-like life on Jupiter, because there is only a small amount of water in Jupiter's atmosphere and any possible solid surface deep within Jupiter would be under extreme pressures. Still, it has been hypothesized that[ammonia-](https://en.wikipedia.org/wiki/Hypothetical_types_of_biochemistry#Ammonia) or water-based life could evolve in Jupiter's upper atmosphere.[[141]](https://en.wikipedia.org/wiki/Jupiter#cite_note-143)[[142]](https://en.wikipedia.org/wiki/Jupiter#cite_note-144)[[143]](https://en.wikipedia.org/wiki/Jupiter#cite_note-universe_today-145)[[144]](https://en.wikipedia.org/wiki/Jupiter#cite_note-time_life_on_jupiter-146) The possible presence of underground oceans on some of Jupiter's moons has led to speculation that the presence of life is more likely there.

## Mythology

[](https://en.wikipedia.org/wiki/File:Jupiter-bonatti.png)

Jupiter, woodcut from a 1550 edition of [Guido Bonatti](https://en.wikipedia.org/wiki/Guido_Bonatti)'s *Liber Astronomiae*

Antiope lying on the ground and Jupiter bending over her, 17th century.

The planet Jupiter has been known since ancient times. It is visible to the naked eye in the night sky and can occasionally be seen in the daytime when the Sun is low.[[145]](https://en.wikipedia.org/wiki/Jupiter#cite_note-147) To the [Babylonians](https://en.wikipedia.org/wiki/Babylon), this object represented their god[Marduk](https://en.wikipedia.org/wiki/Marduk). They used Jupiter's roughly 12-year orbit along the [ecliptic](https://en.wikipedia.org/wiki/Ecliptic) to define the [constellations](https://en.wikipedia.org/wiki/Constellation) of their [zodiac](https://en.wikipedia.org/wiki/Zodiac).[[25]](https://en.wikipedia.org/wiki/Jupiter#cite_note-burgess-27)[[146]](https://en.wikipedia.org/wiki/Jupiter#cite_note-148)

The Romans named it after [Jupiter](https://en.wikipedia.org/wiki/Jupiter_(mythology)) ([Latin](https://en.wikipedia.org/wiki/Latin_language): *Iuppiter, Iūpiter*) (also called Jove), the principal [god](https://en.wikipedia.org/wiki/God_(male_deity)) of [Roman mythology](https://en.wikipedia.org/wiki/Roman_mythology), whose name comes from the [Proto-Indo-European](https://en.wikipedia.org/wiki/Proto-Indo-European_language) [vocative](https://en.wikipedia.org/wiki/Vocative) compound \**Dyēu-pəter* (nominative: \*[*Dyēus*](https://en.wikipedia.org/wiki/Dyeus)*-pətēr*, meaning "Father Sky-God", or "Father Day-God").[[147]](https://en.wikipedia.org/wiki/Jupiter#cite_note-etymologyonline-149) In turn, Jupiter was the counterpart to the [mythical Greek](https://en.wikipedia.org/wiki/Greek_mythology) [*Zeus*](https://en.wikipedia.org/wiki/Zeus) (Ζεύς), also referred to as *Dias* (Δίας), the planetary name of which is retained in modern [Greek](https://en.wikipedia.org/wiki/Greek_language).[[148]](https://en.wikipedia.org/wiki/Jupiter#cite_note-150)

The [astronomical symbol](https://en.wikipedia.org/wiki/Astronomical_symbol) for the planet, [♃](https://en.wikipedia.org/wiki/File:Jupiter_symbol.svg), is a stylized representation of the god's lightning bolt. The original Greek deity *Zeus* supplies the root *zeno-*, used to form some Jupiter-related words, such as [*zenographic*](https://en.wiktionary.org/wiki/zenographic).[[149]](https://en.wikipedia.org/wiki/Jupiter#cite_note-151)

*Jovian* is the [adjectival](https://en.wikipedia.org/wiki/Adjective) form of Jupiter. The older adjectival form *jovial*, employed by astrologers in the [Middle Ages](https://en.wikipedia.org/wiki/Middle_Ages), has come to mean "happy" or "merry", moods ascribed to [Jupiter's astrological influence](https://en.wikipedia.org/wiki/Jupiter_(astrology)).[[150]](https://en.wikipedia.org/wiki/Jupiter#cite_note-152)

The Chinese, Koreans and Japanese called it the "wood star" ([Chinese](https://en.wikipedia.org/wiki/Chinese_language): 木星; [pinyin](https://en.wikipedia.org/wiki/Pinyin): *mùxīng*), based on the Chinese [Five Elements](https://en.wikipedia.org/wiki/Five_elements_(Chinese_philosophy)).[[151]](https://en.wikipedia.org/wiki/Jupiter#cite_note-153)[[152]](https://en.wikipedia.org/wiki/Jupiter#cite_note-154)[[153]](https://en.wikipedia.org/wiki/Jupiter#cite_note-155) Chinese Taoism personified it as the [Fu star](https://en.wikipedia.org/wiki/Fu_star). The Greeks called it Φαέθων,*Phaethon*, "blazing". In [Vedic astrology](https://en.wikipedia.org/wiki/Jyotisha), Hindu astrologers named the planet after [Brihaspati](https://en.wikipedia.org/wiki/Brihaspati), the religious teacher of the gods, and often called it "[Guru](https://en.wikipedia.org/wiki/Guru)", which literally means the "Heavy One".[[154]](https://en.wikipedia.org/wiki/Jupiter#cite_note-156)

In [Germanic mythology](https://en.wikipedia.org/wiki/Germanic_paganism), Jupiter is equated to [Thor](https://en.wikipedia.org/wiki/Thor), whence the English name *Thursday* for the Roman *dies Jovis*.[[155]](https://en.wikipedia.org/wiki/Jupiter#cite_note-157)

In the [Central Asian-Turkic myths](https://en.wikipedia.org/wiki/Mythology_of_the_Turkic_and_Mongolian_peoples), Jupiter is called *Erendiz* or *Erentüz*, from *eren* (of uncertain meaning) and *yultuz* ("star"). There are many theories about the meaning of *eren*. These peoples calculated the period of the orbit of Jupiter as 11 years and 300 days. They believed that some social and natural events connected to Erentüz's movements on the sky.[[156]](https://en.wikipedia.org/wiki/Jupiter#cite_note-158)

## See also

* ***https://upload.wikimedia.org/wikipedia/commons/thumb/5/5a/Jupiter_by_Cassini-Huygens.jpg/30px-Jupiter_by_Cassini-Huygens.jpg***[***Jupiter portal***](https://en.wikipedia.org/wiki/Portal:Jupiter)
* ***https://upload.wikimedia.org/wikipedia/commons/thumb/8/83/Solar_system.jpg/22px-Solar_system.jpg***[***Solar System portal***](https://en.wikipedia.org/wiki/Portal:Solar_System)

|  |  |
| --- | --- |
| Book icon | * [**Book: Jupiter**](https://en.wikipedia.org/wiki/Book:Jupiter) * [**Book: Solar System**](https://en.wikipedia.org/wiki/Book:Solar_System) |

* [HIP 11915](https://en.wikipedia.org/wiki/HIP_11915) – A [solar analog](https://en.wikipedia.org/wiki/Solar_analog) approximately 186 [light-years](https://en.wikipedia.org/wiki/Light-year) from Earth, whose planetary system contains a Jupiter analog, [HIP 11915 b](https://en.wikipedia.org/wiki/HIP_11915_b)
* [Hot Jupiter](https://en.wikipedia.org/wiki/Hot_Jupiter)
* [Jovian–Plutonian gravitational effect](https://en.wikipedia.org/wiki/Jovian%E2%80%93Plutonian_gravitational_effect)
* [Jovian (fiction)](https://en.wikipedia.org/wiki/Jovian_(fiction))
* [Juno (spacecraft)](https://en.wikipedia.org/wiki/Juno_(spacecraft))
* [Jupiter in fiction](https://en.wikipedia.org/wiki/Jupiter_in_fiction)
* [Space exploration](https://en.wikipedia.org/wiki/Space_exploration)

## Notes

* 1. [**Jump up^**](https://en.wikipedia.org/wiki/Jupiter#cite_ref-caption_1-0) This image was taken by the [Hubble Space Telescope](https://en.wikipedia.org/wiki/Hubble_Space_Telescope), using the [Wide Field Camera 3](https://en.wikipedia.org/wiki/Wide_Field_Camera_3), on 21 April 2014. Jupiter's atomosphere and its appearance [constantly changes](https://en.wikipedia.org/wiki/Atmosphere_of_Jupiter#Dynamics), and hence its current appearance today may not resemble what it was when this image was taken. Depicted in this image, however, are a few features that remain consistent, such as the famous [Great Red Spot](https://en.wikipedia.org/wiki/Great_Red_Spot), featured prominently in the lower right of the image, and the planet's recognizable banded appearance.
  2. ^ [Jump up to:***a***](https://en.wikipedia.org/wiki/Jupiter#cite_ref-1bar_8-0) [***b***](https://en.wikipedia.org/wiki/Jupiter#cite_ref-1bar_8-1) [***c***](https://en.wikipedia.org/wiki/Jupiter#cite_ref-1bar_8-2) [***d***](https://en.wikipedia.org/wiki/Jupiter#cite_ref-1bar_8-3) [***e***](https://en.wikipedia.org/wiki/Jupiter#cite_ref-1bar_8-4) [***f***](https://en.wikipedia.org/wiki/Jupiter#cite_ref-1bar_8-5) [***g***](https://en.wikipedia.org/wiki/Jupiter#cite_ref-1bar_8-6) [***h***](https://en.wikipedia.org/wiki/Jupiter#cite_ref-1bar_8-7) Refers to the level of 1 bar atmospheric pressure

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* [Lumbaart](https://lmo.wikipedia.org/wiki/Giove_(pianeta))
* [Magyar](https://hu.wikipedia.org/wiki/Jupiter)
* [Македонски](https://mk.wikipedia.org/wiki/%D0%88%D1%83%D0%BF%D0%B8%D1%82%D0%B5%D1%80)
* [മലയാളം](https://ml.wikipedia.org/wiki/%E0%B4%B5%E0%B5%8D%E0%B4%AF%E0%B4%BE%E0%B4%B4%E0%B4%82)
* [Malti](https://mt.wikipedia.org/wiki/%C4%A0ove_(pjaneta))
* [मराठी](https://mr.wikipedia.org/wiki/%E0%A4%97%E0%A5%81%E0%A4%B0%E0%A5%82_%E0%A4%97%E0%A5%8D%E0%A4%B0%E0%A4%B9)
* [მარგალური](https://xmf.wikipedia.org/wiki/%E1%83%93%E1%83%98%E1%83%90_(%E1%83%9E%E1%83%9A%E1%83%90%E1%83%9C%E1%83%94%E1%83%A2%E1%83%90))
* [مصرى](https://arz.wikipedia.org/wiki/%D8%A7%D9%84%D9%85%D8%B4%D8%AA%D8%B1%D9%89)
* [مازِرونی](https://mzn.wikipedia.org/wiki/%D9%85%D8%B4%D8%AA%D8%B1%DB%8C)
* [Bahasa Melayu](https://ms.wikipedia.org/wiki/Musytari)
* [Mìng-dĕ̤ng-ngṳ̄](https://cdo.wikipedia.org/wiki/M%C5%ADk-s%C4%ADng)
* [Mirandés](https://mwl.wikipedia.org/wiki/J%C3%BApiter_(planeta))
* [Мокшень](https://mdf.wikipedia.org/wiki/%D0%AE%D0%BF%D0%B8%D1%82%D0%B5%D1%80%D1%8C_(%D1%88%D0%B0%D1%80%D1%8B_%D1%82%D1%8F%D1%88%D1%82%D0%B5))
* [Монгол](https://mn.wikipedia.org/wiki/%D0%91%D0%B0%D1%80%D1%85%D0%B0%D1%81%D0%B1%D0%B0%D0%B4%D1%8C)
* [မြန်မာဘာသာ](https://my.wikipedia.org/wiki/%E1%80%80%E1%80%BC%E1%80%AC%E1%80%9E%E1%80%95%E1%80%90%E1%80%B1%E1%80%B8%E1%80%82%E1%80%BC%E1%80%AD%E1%80%AF%E1%80%9F%E1%80%BA)
* [Nāhuatl](https://nah.wikipedia.org/wiki/Hu%C4%93yitzitzimic%C4%ABtlalli)
* [Nederlands](https://nl.wikipedia.org/wiki/Jupiter_(planeet))
* [Nedersaksies](https://nds-nl.wikipedia.org/wiki/Jupiter_(planeet))
* [नेपाली](https://ne.wikipedia.org/wiki/%E0%A4%AC%E0%A5%83%E0%A4%B9%E0%A4%B8%E0%A5%8D%E0%A4%AA%E0%A4%A4%E0%A4%BF%E0%A4%97%E0%A5%8D%E0%A4%B0%E0%A4%B9)
* [नेपाल भाषा](https://new.wikipedia.org/wiki/%E0%A4%B5%E0%A5%83%E0%A4%B9%E0%A4%B8%E0%A5%8D%E0%A4%AA%E0%A4%A4%E0%A4%BF_%E0%A4%97%E0%A5%8D%E0%A4%B0%E0%A4%B9)
* [日本語](https://ja.wikipedia.org/wiki/%E6%9C%A8%E6%98%9F)
* [Napulitano](https://nap.wikipedia.org/wiki/Giove)
* [Нохчийн](https://ce.wikipedia.org/wiki/%D0%AE%D0%BF%D0%B8%D1%82%D0%B5%D1%80)
* [Nordfriisk](https://frr.wikipedia.org/wiki/Jupiter)
* [Norsk bokmål](https://no.wikipedia.org/wiki/Jupiter)
* [Norsk nynorsk](https://nn.wikipedia.org/wiki/Planeten_Jupiter)
* [Novial](https://nov.wikipedia.org/wiki/Jupitere_(planete))
* [Occitan](https://oc.wikipedia.org/wiki/Jupit%C3%A8r_(planeta))
* [ଓଡ଼ିଆ](https://or.wikipedia.org/wiki/%E0%AC%AC%E0%AD%83%E0%AC%B9%E0%AC%B8%E0%AD%8D%E0%AC%AA%E0%AC%A4%E0%AC%BF)
* [Oʻzbekcha/ўзбекча](https://uz.wikipedia.org/wiki/Yupiter)
* [ਪੰਜਾਬੀ](https://pa.wikipedia.org/wiki/%E0%A8%AC%E0%A9%8D%E0%A8%B0%E0%A8%B9%E0%A8%BF%E0%A8%B8%E0%A8%AA%E0%A8%A4_(%E0%A8%97%E0%A9%8D%E0%A8%B0%E0%A8%B9%E0%A8%BF))
* [Pälzisch](https://pfl.wikipedia.org/wiki/Jupiter_(Planet))
* [پنجابی](https://pnb.wikipedia.org/wiki/%D9%85%D8%B4%D8%AA%D8%B1%DB%8C)
* [پښتو](https://ps.wikipedia.org/wiki/%D9%85%D8%B4%D8%AA%D8%B1%D9%8A)
* [ភាសាខ្មែរ](https://km.wikipedia.org/wiki/%E1%9E%97%E1%9E%96%E1%9E%96%E1%9F%92%E1%9E%9A%E1%9E%A0%E1%9E%9F%E1%9F%92%E1%9E%94%E1%9E%8F%E1%9E%B7%E1%9F%8D)
* [Piemontèis](https://pms.wikipedia.org/wiki/Gieuv_(pianeta))
* [Plattdüütsch](https://nds.wikipedia.org/wiki/Jupiter_(Planet))
* [Polski](https://pl.wikipedia.org/wiki/Jowisz)
* [Português](https://pt.wikipedia.org/wiki/J%C3%BApiter_(planeta))
* [Ripoarisch](https://ksh.wikipedia.org/wiki/Juppitter_(Planneet))
* [Română](https://ro.wikipedia.org/wiki/Jupiter)
* [Rumantsch](https://rm.wikipedia.org/wiki/Jupiter_(planet))
* [Runa Simi](https://qu.wikipedia.org/wiki/Pirwa)
* [Русиньскый](https://rue.wikipedia.org/wiki/%D0%AE%D0%BF%D1%96%D1%82%D0%B5%D1%80_(%D0%BF%D0%BB%D0%B0%D0%BD%D0%B5%D1%82%D0%B0))
* [Русский](https://ru.wikipedia.org/wiki/%D0%AE%D0%BF%D0%B8%D1%82%D0%B5%D1%80)
* [Саха тыла](https://sah.wikipedia.org/wiki/%D0%AE%D0%BF%D0%B8%D1%82%D0%B5%D1%80)
* [Sámegiella](https://se.wikipedia.org/wiki/Jupiter)
* [संस्कृतम्](https://sa.wikipedia.org/wiki/%E0%A4%97%E0%A5%81%E0%A4%B0%E0%A5%81%E0%A4%97%E0%A5%8D%E0%A4%B0%E0%A4%B9%E0%A4%83)
* [Sardu](https://sc.wikipedia.org/wiki/Jove)
* [Scots](https://sco.wikipedia.org/wiki/Jupiter)
* [Seeltersk](https://stq.wikipedia.org/wiki/Jupiter)
* [Shqip](https://sq.wikipedia.org/wiki/Jupiteri)
* [Sicilianu](https://scn.wikipedia.org/wiki/Giovi_(pianeta))
* [සිංහල](https://si.wikipedia.org/wiki/%E0%B6%B6%E0%B7%8A%E2%80%8D%E0%B6%BB%E0%B7%84%E0%B7%83%E0%B7%8A%E0%B6%B4%E0%B6%AD%E0%B7%92_%E0%B6%9C%E0%B7%8A%E2%80%8D%E0%B6%BB%E0%B7%84%E0%B6%BA%E0%B7%8F)
* [Simple English](https://simple.wikipedia.org/wiki/Jupiter)
* [Slovenčina](https://sk.wikipedia.org/wiki/Jupiter)
* [Slovenščina](https://sl.wikipedia.org/wiki/Jupiter)
* [Ślůnski](https://szl.wikipedia.org/wiki/Jowisz)
* [Soomaaliga](https://so.wikipedia.org/wiki/Cirjeex)
* [کوردیی ناوەندی](https://ckb.wikipedia.org/wiki/%DA%BE%D9%88%D8%B1%D9%85%D8%B2)
* [Српски / srpski](https://sr.wikipedia.org/wiki/%D0%88%D1%83%D0%BF%D0%B8%D1%82%D0%B5%D1%80)
* [Srpskohrvatski / српскохрватски](https://sh.wikipedia.org/wiki/Jupiter)
* [Basa Sunda](https://su.wikipedia.org/wiki/Jupiter)
* [Suomi](https://fi.wikipedia.org/wiki/Jupiter)
* [Svenska](https://sv.wikipedia.org/wiki/Jupiter)
* [Tagalog](https://tl.wikipedia.org/wiki/Hupiter_(planeta))
* [தமிழ்](https://ta.wikipedia.org/wiki/%E0%AE%B5%E0%AE%BF%E0%AE%AF%E0%AE%BE%E0%AE%B4%E0%AE%A9%E0%AF%8D_(%E0%AE%95%E0%AF%8B%E0%AE%B3%E0%AF%8D))
* [Татарча/tatarça](https://tt.wikipedia.org/wiki/%D0%AE%D0%BF%D0%B8%D1%82%D0%B5%D1%80_(%D0%BF%D0%BB%D0%B0%D0%BD%D0%B5%D1%82%D0%B0))
* [తెలుగు](https://te.wikipedia.org/wiki/%E0%B0%97%E0%B1%81%E0%B0%B0%E0%B1%81%E0%B0%A1%E0%B1%81)
* [ไทย](https://th.wikipedia.org/wiki/%E0%B8%94%E0%B8%B2%E0%B8%A7%E0%B8%9E%E0%B8%A4%E0%B8%AB%E0%B8%B1%E0%B8%AA%E0%B8%9A%E0%B8%94%E0%B8%B5)
* [Тоҷикӣ](https://tg.wikipedia.org/wiki/%D0%9C%D1%83%D1%88%D1%82%D0%B0%D1%80%D3%A3)
* [ᏣᎳᎩ](https://chr.wikipedia.org/wiki/%E1%8F%A7%E1%8F%88%E1%8F%93)
* [Türkçe](https://tr.wikipedia.org/wiki/J%C3%BCpiter)
* [Türkmençe](https://tk.wikipedia.org/wiki/%C3%9Dupiter)
* [Тыва дыл](https://tyv.wikipedia.org/wiki/%D0%AE%D0%BF%D0%B8%D1%82%D0%B5%D1%80)
* [Українська](https://uk.wikipedia.org/wiki/%D0%AE%D0%BF%D1%96%D1%82%D0%B5%D1%80_(%D0%BF%D0%BB%D0%B0%D0%BD%D0%B5%D1%82%D0%B0))
* [اردو](https://ur.wikipedia.org/wiki/%D9%85%D8%B4%D8%AA%D8%B1%DB%8C)
* [ئۇيغۇرچە / Uyghurche](https://ug.wikipedia.org/wiki/%D9%8A%DB%87%D9%BE%D9%89%D8%AA%DB%90%D8%B1)
* [Vahcuengh](https://za.wikipedia.org/wiki/Ndaundeiqfaex)
* [Vèneto](https://vec.wikipedia.org/wiki/Xove_(astronomia))
* [Vepsän kel’](https://vep.wikipedia.org/wiki/Jupiter_(planet))
* [Tiếng Việt](https://vi.wikipedia.org/wiki/Sao_M%E1%BB%99c)
* [Volapük](https://vo.wikipedia.org/wiki/Yupiter)
* [Võro](https://fiu-vro.wikipedia.org/wiki/Jupit%C3%B5r_(hod%27ot%C3%A4ht))
* [文言](https://zh-classical.wikipedia.org/wiki/%E6%AD%B2%E6%98%9F)
* [West-Vlams](https://vls.wikipedia.org/wiki/Jupiter_(planete))
* [Winaray](https://war.wikipedia.org/wiki/Hupiter)
* [Wolof](https://wo.wikipedia.org/wiki/Yupiter)
* [吴语](https://wuu.wikipedia.org/wiki/%E6%9C%A8%E6%98%9F)
* [ייִדיש](https://yi.wikipedia.org/wiki/%D7%99%D7%95%D7%A4%D7%99%D7%98%D7%A2%D7%A8)
* [Yorùbá](https://yo.wikipedia.org/wiki/J%C3%BAp%C3%ADt%C3%A9r%C3%AC)
* [粵語](https://zh-yue.wikipedia.org/wiki/%E6%9C%A8%E6%98%9F)
* [Zazaki](https://diq.wikipedia.org/wiki/Jupiter)
* [Zeêuws](https://zea.wikipedia.org/wiki/Jupiter_(planete))
* [Žemaitėška](https://bat-smg.wikipedia.org/wiki/Jop%C4%97teris_(planeta))
* [中文](https://zh.wikipedia.org/wiki/%E6%9C%A8%E6%98%9F)

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* [Contact Wikipedia](https://en.wikipedia.org/wiki/Wikipedia:Contact_us)
* [Developers](https://www.mediawiki.org/wiki/Special:MyLanguage/How_to_contribute)
* [Cookie statement](https://wikimediafoundation.org/wiki/Cookie_statement)
* [Mobile view](https://en.m.wikipedia.org/w/index.php?title=Jupiter&mobileaction=toggle_view_mobile)
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# Mars

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*This article is about the planet. For the deity, see*[*Mars (mythology)*](https://en.wikipedia.org/wiki/Mars_(mythology))*. For other uses, see*[*Mars (disambiguation)*](https://en.wikipedia.org/wiki/Mars_(disambiguation))*.*

|  |  |
| --- | --- |
| **Mars [Astronomical symbol of Mars](https://en.wikipedia.org/wiki/File:Mars_symbol.svg)** | |
| [The planet Mars](https://en.wikipedia.org/wiki/File:Mars_23_aug_2003_hubble.jpg)  Mars imaged by the [*Hubble Space Telescope*](https://en.wikipedia.org/wiki/Hubble_Space_Telescope) in 2003 | |
| **Designations** | |
| **Pronunciation** | [UK English](https://en.wikipedia.org/wiki/UK_English): /mɑːz/ [US English](https://en.wikipedia.org/wiki/US_English): [Listen](https://upload.wikimedia.org/wikipedia/commons/8/83/En-us-Mars.ogg)[**i**](https://en.wikipedia.org/wiki/File:En-us-Mars.ogg)[/ˈmɑːrz/](https://en.wikipedia.org/wiki/Help:IPA_for_English) |
| [**Adjectives**](https://en.wikipedia.org/wiki/List_of_adjectivals_and_demonyms_of_astronomical_bodies) | [Martian](https://en.wikipedia.org/wiki/Martian) |
| [**Orbital characteristics**](https://en.wikipedia.org/wiki/Osculating_orbit)[[2]](https://en.wikipedia.org/wiki/Mars#cite_note-VSOP87-2) | |
| [Epoch](https://en.wikipedia.org/wiki/Epoch_(astronomy)) [J2000](https://en.wikipedia.org/wiki/J2000) | |
| [**Aphelion**](https://en.wikipedia.org/wiki/Aphelion) | 1.6660 [AU](https://en.wikipedia.org/wiki/Astronomical_unit) 249.2 Gm |
| [**Perihelion**](https://en.wikipedia.org/wiki/Perihelion) | 1.3814 AU 206.7 Gm |
| [**Semi-major axis**](https://en.wikipedia.org/wiki/Semi-major_axis) | 1.523679 AU 227.9392 Gm |
| [**Eccentricity**](https://en.wikipedia.org/wiki/Orbital_eccentricity) | 0.0934 |
| [**Orbital period**](https://en.wikipedia.org/wiki/Orbital_period) | 1.8808 [Julian years](https://en.wikipedia.org/wiki/Julian_year_(astronomy)) 686.971 d 668.5991 [sols](https://en.wikipedia.org/wiki/Timekeeping_on_Mars) |
| [**Synodic period**](https://en.wikipedia.org/wiki/Orbital_period) | 779.96 days 2.135 Julian years |
| **Average**[**orbital speed**](https://en.wikipedia.org/wiki/Orbital_speed) | 24.077 km/s |
| [**Mean anomaly**](https://en.wikipedia.org/wiki/Mean_anomaly) | 19.373° |
| [**Inclination**](https://en.wikipedia.org/wiki/Orbital_inclination) | 1.850° to [ecliptic](https://en.wikipedia.org/wiki/Ecliptic) 5.65° to [Sun](https://en.wikipedia.org/wiki/Sun)'s [equator](https://en.wikipedia.org/wiki/Equator) 1.67° to [invariable plane](https://en.wikipedia.org/wiki/Invariable_plane)[[1]](https://en.wikipedia.org/wiki/Mars#cite_note-meanplane-1) |
| [**Longitude of ascending node**](https://en.wikipedia.org/wiki/Longitude_of_the_ascending_node) | 49.558° |
| [**Argument of perihelion**](https://en.wikipedia.org/wiki/Argument_of_periapsis) | 286.502° |
| [**Satellites**](https://en.wikipedia.org/wiki/Natural_satellite) | [2](https://en.wikipedia.org/wiki/Moons_of_Mars) |
| **Physical characteristics** | |
| **Mean radius** | 3,389.5±0.2 km[[a]](https://en.wikipedia.org/wiki/Mars#cite_note-best-fit_ellipsoid-3) [[3]](https://en.wikipedia.org/wiki/Mars#cite_note-Seidelmann2007-4) |
| [**Equatorial**](https://en.wikipedia.org/wiki/Equator)**radius** | 3,396.2±0.1 km[[a]](https://en.wikipedia.org/wiki/Mars#cite_note-best-fit_ellipsoid-3) [[3]](https://en.wikipedia.org/wiki/Mars#cite_note-Seidelmann2007-4)  0.533 Earths |
| [**Polar**](https://en.wikipedia.org/wiki/Geographical_pole)**radius** | 3,376.2±0.1 km[[a]](https://en.wikipedia.org/wiki/Mars#cite_note-best-fit_ellipsoid-3) [[3]](https://en.wikipedia.org/wiki/Mars#cite_note-Seidelmann2007-4)  0.531 Earths |
| [**Flattening**](https://en.wikipedia.org/wiki/Flattening) | 0.00589±0.00015 |
| [**Surface area**](https://en.wikipedia.org/wiki/Spheroid#Surface_area) | 144,798,500 km2  0.284 Earths |
| [**Volume**](https://en.wikipedia.org/wiki/Volume) | 1.6318×1011 km3[[4]](https://en.wikipedia.org/wiki/Mars#cite_note-lodders1998-5)  0.151 Earths |
| [**Mass**](https://en.wikipedia.org/wiki/Mass) | 6.4171×1023 kg[[5]](https://en.wikipedia.org/wiki/Mars#cite_note-konopliv2011-6)  0.107 Earths |
| **Mean**[**density**](https://en.wikipedia.org/wiki/Density) | 3.9335±0.0004 g/cm³[[4]](https://en.wikipedia.org/wiki/Mars#cite_note-lodders1998-5) |
| [**Surface gravity**](https://en.wikipedia.org/wiki/Surface_gravity) | 3.711 [m/s²](https://en.wikipedia.org/wiki/M/s%C2%B2)[[4]](https://en.wikipedia.org/wiki/Mars#cite_note-lodders1998-5)  0.376 [*g*](https://en.wikipedia.org/wiki/G-force) |
| [**Moment of inertia factor**](https://en.wikipedia.org/wiki/Moment_of_inertia_factor) | 0.3662±0.0017[[6]](https://en.wikipedia.org/wiki/Mars#cite_note-Folkner1997-7) |
| [**Escape velocity**](https://en.wikipedia.org/wiki/Escape_velocity) | 5.027 km/s |
| **Sidereal**[**rotation period**](https://en.wikipedia.org/wiki/Rotation_period) | 1.025957 d  24h 37m 22s[[4]](https://en.wikipedia.org/wiki/Mars#cite_note-lodders1998-5) |
| **Equatorial rotation velocity** | 868.22 km/h (241.17 m/s) |
| [**Axial tilt**](https://en.wikipedia.org/wiki/Axial_tilt) | 25.19° to its orbital plane[[7]](https://en.wikipedia.org/wiki/Mars#cite_note-nssdc-8) |
| **North pole**[**right ascension**](https://en.wikipedia.org/wiki/Right_ascension) | 21h 10m 44s  317.68143° |
| **North pole**[**declination**](https://en.wikipedia.org/wiki/Declination) | 52.88650° |
| [**Albedo**](https://en.wikipedia.org/wiki/Albedo) | 0.170 ([geometric](https://en.wikipedia.org/wiki/Geometric_albedo))[[8]](https://en.wikipedia.org/wiki/Mars#cite_note-MallamaMars-9) 0.25 ([Bond](https://en.wikipedia.org/wiki/Bond_albedo))[[7]](https://en.wikipedia.org/wiki/Mars#cite_note-nssdc-8) |
| |  |  |  |  | | --- | --- | --- | --- | | **Surface**[**temp.**](https://en.wikipedia.org/wiki/Temperature) | **min** | **mean** | **max** | | [**Kelvin**](https://en.wikipedia.org/wiki/Kelvin) | 130 K | 210 K[[7]](https://en.wikipedia.org/wiki/Mars#cite_note-nssdc-8) | 308 K | | [**Celsius**](https://en.wikipedia.org/wiki/Celsius) | −143 °C[[10]](https://en.wikipedia.org/wiki/Mars#cite_note-cold-11) | −63 °C | 35 °C[[11]](https://en.wikipedia.org/wiki/Mars#cite_note-hot-12) | | [**Farenheit**](https://en.wikipedia.org/wiki/Farenheit) | −226 °F[[10]](https://en.wikipedia.org/wiki/Mars#cite_note-cold-11) | −82 °F | 95 °F[[11]](https://en.wikipedia.org/wiki/Mars#cite_note-hot-12) | | |
| [**Apparent magnitude**](https://en.wikipedia.org/wiki/Apparent_magnitude) | +1.6 to −3.0[[9]](https://en.wikipedia.org/wiki/Mars#cite_note-MallamaSky-10) |
| [**Angular diameter**](https://en.wikipedia.org/wiki/Angular_diameter) | 3.5–25.1″[[7]](https://en.wikipedia.org/wiki/Mars#cite_note-nssdc-8) |
| **Atmosphere**[[7]](https://en.wikipedia.org/wiki/Mars#cite_note-nssdc-8)[[12]](https://en.wikipedia.org/wiki/Mars#cite_note-barlow08-13) | |
| **Surface**[**pressure**](https://en.wikipedia.org/wiki/Atmospheric_pressure) | 0.636 (0.4–0.87) [kPa](https://en.wikipedia.org/wiki/Pascal_(unit)) 0.00628 atm |
| [**Composition by volume**](https://en.wikipedia.org/wiki/Atmospheric_chemistry#Atmospheric_composition) | * 95.97% [carbon dioxide](https://en.wikipedia.org/wiki/Carbon_dioxide) * 1.93% [argon](https://en.wikipedia.org/wiki/Argon) * 1.89% [nitrogen](https://en.wikipedia.org/wiki/Nitrogen) * 0.146% [oxygen](https://en.wikipedia.org/wiki/Oxygen) * 0.0557% [carbon monoxide](https://en.wikipedia.org/wiki/Carbon_monoxide) |
|  | |

**Mars** is the fourth [planet](https://en.wikipedia.org/wiki/Planet) from the [Sun](https://en.wikipedia.org/wiki/Sun) and the second-smallest planet in the [Solar System](https://en.wikipedia.org/wiki/Solar_System), after [Mercury](https://en.wikipedia.org/wiki/Mercury_(planet)). Named after the [Roman god of war](https://en.wikipedia.org/wiki/Mars_(mythology)), it is often referred to as the "Red Planet"[[13]](https://en.wikipedia.org/wiki/Mars#cite_note-Zubrin1997-14)[[14]](https://en.wikipedia.org/wiki/Mars#cite_note-Rees2012-15) because the [iron oxide](https://en.wikipedia.org/wiki/Iron(III)_oxide)prevalent on its surface gives it a [reddish appearance](https://en.wikipedia.org/wiki/Mars_surface_color).[[15]](https://en.wikipedia.org/wiki/Mars#cite_note-nasa_hematite-16) Mars is a [terrestrial planet](https://en.wikipedia.org/wiki/Terrestrial_planet) with a thin [atmosphere](https://en.wikipedia.org/wiki/Atmosphere), having surface features reminiscent both of the [impact craters](https://en.wikipedia.org/wiki/Impact_crater) of the [Moon](https://en.wikipedia.org/wiki/Moon) and the valleys, deserts, and[polar ice caps](https://en.wikipedia.org/wiki/Polar_ice_caps) of [Earth](https://en.wikipedia.org/wiki/Earth).

The [rotational period](https://en.wikipedia.org/wiki/Rotational_period) and seasonal cycles of Mars are likewise similar to those of Earth, as is the tilt that produces the seasons. Mars is the site of [Olympus Mons](https://en.wikipedia.org/wiki/Olympus_Mons), the largest [volcano](https://en.wikipedia.org/wiki/Volcano) and second-highest known mountain in the Solar System, and of [Valles Marineris](https://en.wikipedia.org/wiki/Valles_Marineris), one of the largest canyons in the Solar System. The smooth [Borealis basin](https://en.wikipedia.org/wiki/Borealis_basin) in the northern hemisphere covers 40% of the planet and may be a giant impact feature.[[16]](https://en.wikipedia.org/wiki/Mars#cite_note-northcratersn-17)[[17]](https://en.wikipedia.org/wiki/Mars#cite_note-northcraterguard-18) Mars has two [moons](https://en.wikipedia.org/wiki/Moons_of_Mars), [Phobos](https://en.wikipedia.org/wiki/Phobos_(moon)) and [Deimos](https://en.wikipedia.org/wiki/Deimos_(moon)), which are small and irregularly shaped. These may be captured [asteroids](https://en.wikipedia.org/wiki/Asteroid),[[18]](https://en.wikipedia.org/wiki/Mars#cite_note-19)[[19]](https://en.wikipedia.org/wiki/Mars#cite_note-adler-20) similar to [5261 Eureka](https://en.wikipedia.org/wiki/5261_Eureka), a [Mars trojan](https://en.wikipedia.org/wiki/Mars_trojan).

Until the first successful Mars flyby in 1965 by [*Mariner 4*](https://en.wikipedia.org/wiki/Mariner_4), many speculated about the presence of liquid water on the planet's surface. This was based on observed periodic variations in light and dark patches, particularly in the polar [latitudes](https://en.wikipedia.org/wiki/Latitude), which appeared to be seas and continents; long, dark [striations](https://en.wikipedia.org/wiki/Striation_(geology)) were interpreted by some as irrigation channels for liquid water. These straight line features were later explained as[optical illusions](https://en.wikipedia.org/wiki/Optical_illusion), though geological evidence gathered by uncrewed missions suggests that Mars once had large-scale water coverage on its surface at an earlier stage of its existence.[[20]](https://en.wikipedia.org/wiki/Mars#cite_note-marswater-21) In 2005, radar data revealed the presence of large quantities of water ice at the poles[[21]](https://en.wikipedia.org/wiki/Mars#cite_note-specials1-22) and at mid-latitudes.[[22]](https://en.wikipedia.org/wiki/Mars#cite_note-jsg.utexas.edu-23)[[23]](https://en.wikipedia.org/wiki/Mars#cite_note-esa050221-24) The Mars rover [*Spirit*](https://en.wikipedia.org/wiki/Spirit_rover) sampled chemical compounds containing water molecules in March 2007. The [*Phoenix*](https://en.wikipedia.org/wiki/Phoenix_(spacecraft)) lander directly sampled water ice in shallow Martian soil on July 31, 2008.[[24]](https://en.wikipedia.org/wiki/Mars#cite_note-spacecraft1-25) On September 28, 2015, NASA [announced the presence of](https://en.wikipedia.org/wiki/Chronology_of_discoveries_of_water_on_Mars) briny flowing [salt water](https://en.wikipedia.org/wiki/Saline_water) on the Martian surface.[[25]](https://en.wikipedia.org/wiki/Mars#cite_note-26)

Mars is host to seven functioning [spacecraft](https://en.wikipedia.org/wiki/Spacecraft): five in orbit—[*2001 Mars Odyssey*](https://en.wikipedia.org/wiki/2001_Mars_Odyssey), [*Mars Express*](https://en.wikipedia.org/wiki/Mars_Express), [*Mars Reconnaissance Orbiter*](https://en.wikipedia.org/wiki/Mars_Reconnaissance_Orbiter), [MAVEN](https://en.wikipedia.org/wiki/MAVEN) and [Mars Orbiter Mission](https://en.wikipedia.org/wiki/Mars_Orbiter_Mission)—and two on the surface—[Mars Exploration Rover](https://en.wikipedia.org/wiki/Mars_Exploration_Rover)[*Opportunity*](https://en.wikipedia.org/wiki/Opportunity_(rover)) and the [Mars Science Laboratory](https://en.wikipedia.org/wiki/Mars_Science_Laboratory) [*Curiosity*](https://en.wikipedia.org/wiki/Curiosity_(rover)). Observations by the [*Mars Reconnaissance Orbiter*](https://en.wikipedia.org/wiki/Mars_Reconnaissance_Orbiter) have revealed possible flowing water during the warmest months on Mars.[[26]](https://en.wikipedia.org/wiki/Mars#cite_note-NASA.C2.A0.E2.80.93_NASA_Spacecraft_Data_Suggest_Water_Flowing_on_Mars-27) In 2013, NASA's *Curiosity* rover discovered that Mars's soil contains between 1.5% and 3% water by mass (albeit attached to other compounds and thus not freely accessible).[[27]](https://en.wikipedia.org/wiki/Mars#cite_note-Guardian-28)

There are ongoing investigations assessing the past [habitability](https://en.wikipedia.org/wiki/Planetary_habitability) potential of Mars, as well as [the possibility of extant life](https://en.wikipedia.org/wiki/Life_on_Mars). *In situ* investigations have been performed by the [*Viking* landers](https://en.wikipedia.org/wiki/Viking_program#Viking_landers), [*Spirit*](https://en.wikipedia.org/wiki/Spirit_(rover)) and *Opportunity* rovers,[*Phoenix*](https://en.wikipedia.org/wiki/Phoenix_(spacecraft)) lander, and *Curiosity* rover. Future astrobiology missions are planned, including the [Mars 2020](https://en.wikipedia.org/wiki/Mars_2020) and [ExoMars](https://en.wikipedia.org/wiki/ExoMars_rover) rovers.[[28]](https://en.wikipedia.org/wiki/Mars#cite_note-curiosity_search_for_life-29)[[29]](https://en.wikipedia.org/wiki/Mars#cite_note-MER_Search_for_Life-30)[[30]](https://en.wikipedia.org/wiki/Mars#cite_note-ExoMars.27s_search_for_life-31)[[31]](https://en.wikipedia.org/wiki/Mars#cite_note-Mars_2020_search_for_life-32)

Mars can easily be seen from Earth with the naked eye, as can its reddish coloring. Its [apparent magnitude](https://en.wikipedia.org/wiki/Apparent_magnitude) reaches −2.91,[[7]](https://en.wikipedia.org/wiki/Mars#cite_note-nssdc-8) which is surpassed only by [Jupiter](https://en.wikipedia.org/wiki/Jupiter), [Venus](https://en.wikipedia.org/wiki/Venus), the Moon, and the Sun. Optical ground-based telescopes are typically limited to resolving features about 300 kilometers (190 mi) across when Earth and Mars are closest because of Earth's atmosphere.[[32]](https://en.wikipedia.org/wiki/Mars#cite_note-usra-33)

## Contents

  [[hide](https://en.wikipedia.org/wiki/Mars)]

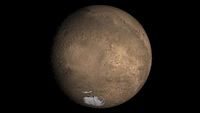
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## Physical characteristics

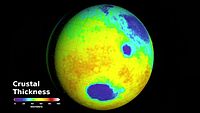
Mars is approximately half the diameter of Earth, and its surface area is only slightly less than the total area of Earth's dry land.[[7]](https://en.wikipedia.org/wiki/Mars#cite_note-nssdc-8) Mars is less dense than Earth, having about 15% of Earth's volume and 11% of Earth's[mass](https://en.wikipedia.org/wiki/Mass), resulting in about 38% of Earth's surface gravity. The red-orange appearance of the Martian surface is caused by [iron(III) oxide](https://en.wikipedia.org/wiki/Iron(III)_oxide), or rust.[[33]](https://en.wikipedia.org/wiki/Mars#cite_note-rust-34) It can look like butterscotch,[[34]](https://en.wikipedia.org/wiki/Mars#cite_note-ismars-35) and other common surface colors include golden, brown, tan, and greenish, depending on the [minerals](https://en.wikipedia.org/wiki/Mineral) present.[[34]](https://en.wikipedia.org/wiki/Mars#cite_note-ismars-35)

[](https://en.wikipedia.org/wiki/File:Mars,_Earth_size_comparison.jpg)

Comparison: [Earth](https://en.wikipedia.org/wiki/Earth) and Mars.



[Animation (00:40)](https://en.wikipedia.org/wiki/File:Mars.ogv) showing major features of Mars.



[Video (01:28)](https://en.wikipedia.org/wiki/File:GMM-3_Mars_Gravity.webm) showing how three NASA orbiters mapped the gravity field of Mars.

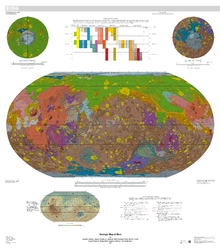
### Internal structure

Like Earth, Mars has [differentiated](https://en.wikipedia.org/wiki/Planetary_differentiation) into a dense metallic core overlaid by less dense materials.[[35]](https://en.wikipedia.org/wiki/Mars#cite_note-Nimmo_2005-36) Current models of its interior imply a core region about 1,794 ± 65 kilometers (1,115 ± 40 mi) in radius, consisting primarily of [iron and nickel](https://en.wikipedia.org/wiki/Iron%E2%80%93nickel_alloy) with about 16–17% [sulfur](https://en.wikipedia.org/wiki/Sulfur).[[36]](https://en.wikipedia.org/wiki/Mars#cite_note-icarus213_2_451-37) This [iron(II) sulfide](https://en.wikipedia.org/wiki/Iron(II)_sulfide) core is thought to be twice as rich in lighter elements than Earth's core.[[37]](https://en.wikipedia.org/wiki/Mars#cite_note-jacque03-38) The core is surrounded by a silicate [mantle](https://en.wikipedia.org/wiki/Mantle_(geology)) that formed many of the tectonic and volcanic features on the planet, but it appears to be dormant. Besides silicon and oxygen, the most abundant elements in the Martian crust are iron, [magnesium](https://en.wikipedia.org/wiki/Magnesium), [aluminum](https://en.wikipedia.org/wiki/Aluminum), [calcium](https://en.wikipedia.org/wiki/Calcium), and [potassium](https://en.wikipedia.org/wiki/Potassium). The average thickness of the planet's crust is about 50 km (31 mi), with a maximum thickness of 125 km (78 mi).[[37]](https://en.wikipedia.org/wiki/Mars#cite_note-jacque03-38) Earth's crust, averaging 40 km (25 mi), is only one third as thick as Mars', in ratio to the sizes of the two planets.

### Surface geology

*Main article:*[*Geology of Mars*](https://en.wikipedia.org/wiki/Geology_of_Mars)

Mars is a [terrestrial planet](https://en.wikipedia.org/wiki/Terrestrial_planet) that consists of minerals containing [silicon](https://en.wikipedia.org/wiki/Silicon) and [oxygen](https://en.wikipedia.org/wiki/Oxygen), [metals](https://en.wikipedia.org/wiki/Metal), and other elements that typically make up [rock](https://en.wikipedia.org/wiki/Rock_(geology)). The surface of Mars is primarily composed of [tholeiitic](https://en.wikipedia.org/wiki/Tholeiitic_magma_series) [basalt](https://en.wikipedia.org/wiki/Basalt),[[38]](https://en.wikipedia.org/wiki/Mars#cite_note-science324_5928_736-39) although parts are more [silica](https://en.wikipedia.org/wiki/Silica)-rich than typical basalt and may be similar to [andesitic](https://en.wikipedia.org/wiki/Andesitic) rocks on Earth or silica glass. Regions of low [albedo](https://en.wikipedia.org/wiki/Albedo) show concentrations of [plagioclase feldspar](https://en.wikipedia.org/wiki/Plagioclase_feldspar), with northern low albedo regions displaying higher than normal concentrations of sheet silicates and high-silicon glass. Parts of the southern highlands include detectable amounts of high-calcium [pyroxenes](https://en.wikipedia.org/wiki/Pyroxenes). Localized concentrations of [hematite](https://en.wikipedia.org/wiki/Hematite) and [olivine](https://en.wikipedia.org/wiki/Olivine) have been found.[[39]](https://en.wikipedia.org/wiki/Mars#cite_note-jgr107_E6-40) Much of the surface is deeply covered by finely grained [iron(III) oxide](https://en.wikipedia.org/wiki/Iron(III)_oxide) dust.[[40]](https://en.wikipedia.org/wiki/Mars#cite_note-sci300a-41)[[41]](https://en.wikipedia.org/wiki/Mars#cite_note-sci300b-42)

[](https://en.wikipedia.org/wiki/File:USGS-MarsMap-sim3292-20140714-crop.png)

[Geologic map](https://en.wikipedia.org/wiki/Geology_of_Mars) of Mars ([USGS](https://en.wikipedia.org/wiki/USGS), 2014)[[42]](https://en.wikipedia.org/wiki/Mars#cite_note-USGS-20140714-43)

Although Mars has no evidence of a structured global [magnetic field](https://en.wikipedia.org/wiki/Magnetic_field),[[43]](https://en.wikipedia.org/wiki/Mars#cite_note-magnetosphere-44) observations show that parts of the planet's crust have been magnetized, and that alternating polarity reversals of its dipole field have occurred in the past. This [paleomagnetism](https://en.wikipedia.org/wiki/Paleomagnetism) of magnetically susceptible minerals has properties that are similar to the [alternating bands found on the ocean floors of Earth](https://en.wikipedia.org/wiki/Magnetic_striping). One theory, published in 1999 and re-examined in October 2005 (with the help of the [*Mars Global Surveyor*](https://en.wikipedia.org/wiki/Mars_Global_Surveyor)), is that these bands demonstrate [plate tectonics](https://en.wikipedia.org/wiki/Plate_tectonics) on Mars four [billion](https://en.wikipedia.org/wiki/1000000000_(number)) years ago, before the planetary [dynamo](https://en.wikipedia.org/wiki/Dynamo_theory) ceased to function and the planet's magnetic field faded away.[[44]](https://en.wikipedia.org/wiki/Mars#cite_note-plates-45)

During the [Solar System's formation](https://en.wikipedia.org/wiki/Formation_and_evolution_of_the_Solar_System), Mars was created as the result of a [stochastic process](https://en.wikipedia.org/wiki/Stochastic_process) of run-away accretion out of the [protoplanetary disk](https://en.wikipedia.org/wiki/Protoplanetary_disk) that orbited the Sun. Mars has many distinctive chemical features caused by its position in the Solar System. Elements with comparatively low boiling points, such as [chlorine](https://en.wikipedia.org/wiki/Chlorine), [phosphorus](https://en.wikipedia.org/wiki/Phosphorus), and [sulphur](https://en.wikipedia.org/wiki/Sulphur), are much more common on Mars than Earth; these elements were probably removed from areas closer to the Sun by the young star's energetic [solar wind](https://en.wikipedia.org/wiki/Solar_wind).[[45]](https://en.wikipedia.org/wiki/Mars#cite_note-ssr96_1_4_197-46)

After the formation of the planets, all were subjected to the so-called "[Late Heavy Bombardment](https://en.wikipedia.org/wiki/Late_Heavy_Bombardment)". About 60% of the surface of Mars shows a record of impacts from that era,[[46]](https://en.wikipedia.org/wiki/Mars#cite_note-zharkov93-47)[[47]](https://en.wikipedia.org/wiki/Mars#cite_note-icarus165_1-48)[[48]](https://en.wikipedia.org/wiki/Mars#cite_note-barlow88-49) whereas much of the remaining surface is probably underlain by immense impact basins caused by those events. There is evidence of an enormous impact basin in the northern hemisphere of Mars, spanning 10,600 by 8,500 km (6,600 by 5,300 mi), or roughly four times larger than the Moon's [South Pole – Aitken basin](https://en.wikipedia.org/wiki/South_Pole_%E2%80%93_Aitken_basin), the largest impact basin yet discovered.[[16]](https://en.wikipedia.org/wiki/Mars#cite_note-northcratersn-17)[[17]](https://en.wikipedia.org/wiki/Mars#cite_note-northcraterguard-18) This theory suggests that Mars was struck by a [Pluto](https://en.wikipedia.org/wiki/Pluto)-sized body about four billion years ago. The event, thought to be the cause of the [Martian hemispheric dichotomy](https://en.wikipedia.org/wiki/Martian_hemispheric_dichotomy), created the smooth [Borealis basin](https://en.wikipedia.org/wiki/Borealis_basin) that covers 40% of the planet.[[49]](https://en.wikipedia.org/wiki/Mars#cite_note-sciam080627-50)[[50]](https://en.wikipedia.org/wiki/Mars#cite_note-nyt080626-51)

[](https://en.wikipedia.org/wiki/File:Eso1509a_-_Mars_planet.jpg)

Artist's impression of how Mars may have looked four billion years ago[[51]](https://en.wikipedia.org/wiki/Mars#cite_note-52)

The geological history of Mars can be split into many periods, but the following are the three primary periods:[[52]](https://en.wikipedia.org/wiki/Mars#cite_note-jog91-53)[[53]](https://en.wikipedia.org/wiki/Mars#cite_note-ssr_96_1_4-54)

* [**Noachian**](https://en.wikipedia.org/wiki/Noachian)**period** (named after [Noachis Terra](https://en.wikipedia.org/wiki/Noachis_Terra)): Formation of the oldest extant surfaces of Mars, 4.5 billion years ago to 3.5 billion years ago. Noachian age surfaces are scarred by many large impact craters. The [Tharsis](https://en.wikipedia.org/wiki/Tharsis) bulge, a volcanic upland, is thought to have formed during this period, with extensive flooding by liquid water late in the period.
* [**Hesperian**](https://en.wikipedia.org/wiki/Hesperian)**period** (named after [Hesperia Planum](https://en.wikipedia.org/wiki/Hesperia_Planum)): 3.5 billion years ago to 2.9–3.3 billion years ago. The Hesperian period is marked by the formation of extensive lava plains.
* [**Amazonian period**](https://en.wikipedia.org/wiki/Amazonian_(Mars)) (named after [Amazonis Planitia](https://en.wikipedia.org/wiki/Amazonis_Planitia)): 2.9–3.3 billion years ago to present. Amazonian regions have few [meteorite impact](https://en.wikipedia.org/wiki/Impact_event) craters, but are otherwise quite varied. [Olympus Mons](https://en.wikipedia.org/wiki/Olympus_Mons) formed during this period, along with lava flows elsewhere on Mars.

Geological activity is still taking place on Mars. The [Athabasca Valles](https://en.wikipedia.org/wiki/Athabasca_Valles) is home to sheet-like lava flows up to about 200 [Mya](https://en.wikipedia.org/wiki/Mya_(unit)). Water flows in the [grabens](https://en.wikipedia.org/wiki/Graben) called the [Cerberus Fossae](https://en.wikipedia.org/wiki/Cerberus_Fossae) occurred less than 20 Mya, indicating equally recent volcanic intrusions.[[54]](https://en.wikipedia.org/wiki/Mars#cite_note-ag44_4-55) On February 19, 2008, images from the [*Mars Reconnaissance Orbiter*](https://en.wikipedia.org/wiki/Mars_Reconnaissance_Orbiter) showed evidence of an avalanche from a 700 m high cliff.[[55]](https://en.wikipedia.org/wiki/Mars#cite_note-dc080304-56)

### Soil

*Main article:*[*Martian soil*](https://en.wikipedia.org/wiki/Martian_soil)

[](https://en.wikipedia.org/wiki/File:Spirit_Mars_Silica_April_20_2007.jpg)

Exposure of silica-rich dust uncovered by the [*Spirit*](https://en.wikipedia.org/wiki/Spirit_(rover)) rover

The [*Phoenix*](https://en.wikipedia.org/wiki/Phoenix_(spacecraft)) lander returned data showing Martian soil to be slightly alkaline and containing elements such as [magnesium](https://en.wikipedia.org/wiki/Magnesium), [sodium](https://en.wikipedia.org/wiki/Sodium), [potassium](https://en.wikipedia.org/wiki/Potassium) and [chlorine](https://en.wikipedia.org/wiki/Chlorine). These nutrients are found in gardens on Earth, and they are necessary for growth of plants.[[56]](https://en.wikipedia.org/wiki/Mars#cite_note-bbc080627-57) Experiments performed by the lander showed that the Martian soil has a [basic](https://en.wikipedia.org/wiki/Base_(chemistry)) [pH](https://en.wikipedia.org/wiki/PH) of 7.7, and contains 0.6% of the [salt](https://en.wikipedia.org/wiki/Salt_(chemistry)) [perchlorate](https://en.wikipedia.org/wiki/Perchlorate).[[57]](https://en.wikipedia.org/wiki/Mars#cite_note-marssalt-58)[[58]](https://en.wikipedia.org/wiki/Mars#cite_note-jpl_soil-59)[[59]](https://en.wikipedia.org/wiki/Mars#cite_note-60)[[60]](https://en.wikipedia.org/wiki/Mars#cite_note-61)

[Streaks](https://en.wikipedia.org/wiki/Dark_slope_streak) are common across Mars and new ones appear frequently on steep slopes of craters, troughs, and valleys. The streaks are dark at first and get lighter with age. The streaks can start in a tiny area which then spread out for hundreds of metres. They have been seen to follow the edges of boulders and other obstacles in their path. The commonly accepted theories include that they are dark underlying layers of soil revealed after avalanches of bright dust or [dust devils](https://en.wikipedia.org/wiki/Dust_devil).[[61]](https://en.wikipedia.org/wiki/Mars#cite_note-jpl_dust_devil-62) Several explanations have been put forward, including those that involve water or even the growth of organisms.[[62]](https://en.wikipedia.org/wiki/Mars#cite_note-gpl29_23_41-63)[[63]](https://en.wikipedia.org/wiki/Mars#cite_note-oleb33_4_515-64)

### Hydrology

*Main article:*[*Water on Mars*](https://en.wikipedia.org/wiki/Water_on_Mars)

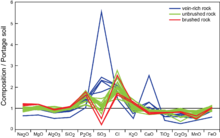
Liquid water cannot exist on the surface of Mars due to low atmospheric pressure, which is about 100 times thinner than Earth's,[[64]](https://en.wikipedia.org/wiki/Mars#cite_note-65) except at the lowest elevations for short periods.[[65]](https://en.wikipedia.org/wiki/Mars#cite_note-h-66)[[66]](https://en.wikipedia.org/wiki/Mars#cite_note-jgr110-67) The two polar ice caps appear to be made largely of water.[[67]](https://en.wikipedia.org/wiki/Mars#cite_note-kostama-68)[[68]](https://en.wikipedia.org/wiki/Mars#cite_note-sci299-69) The volume of water ice in the south polar ice cap, if melted, would be sufficient to cover the entire planetary surface to a depth of 11 meters (36 ft).[[69]](https://en.wikipedia.org/wiki/Mars#cite_note-nasa070315-70) A [permafrost](https://en.wikipedia.org/wiki/Permafrost) mantle stretches from the pole to latitudes of about 60°.[[67]](https://en.wikipedia.org/wiki/Mars#cite_note-kostama-68) [Large quantities of water ice](https://en.wikipedia.org/wiki/Water_on_terrestrial_planets_of_the_Solar_System) are thought to be trapped within the thick [cryosphere](https://en.wikipedia.org/wiki/Cryosphere) of Mars. Radar data from [*Mars Express*](https://en.wikipedia.org/wiki/Mars_Express) and the [*Mars Reconnaissance Orbiter*](https://en.wikipedia.org/wiki/Mars_Reconnaissance_Orbiter) show large quantities of water ice both at the poles (July 2005)[[21]](https://en.wikipedia.org/wiki/Mars#cite_note-specials1-22)[[70]](https://en.wikipedia.org/wiki/Mars#cite_note-bbc040124-71) and at middle latitudes (November 2008).[[22]](https://en.wikipedia.org/wiki/Mars#cite_note-jsg.utexas.edu-23) The Phoenix lander directly sampled water ice in shallow Martian soil on July 31, 2008.[[24]](https://en.wikipedia.org/wiki/Mars#cite_note-spacecraft1-25)

[](https://en.wikipedia.org/wiki/File:Nasa_mars_opportunity_rock_water_150_eng_02mar04.jpg)

Photomicrograph by [*Opportunity*](https://en.wikipedia.org/wiki/Opportunity_(rover))showing a gray [hematite](https://en.wikipedia.org/wiki/Hematite) [concretion](https://en.wikipedia.org/wiki/Concretion), nicknamed "blueberries", indicative of the past presence of liquid water

[Landforms](https://en.wikipedia.org/wiki/Geomorphology) visible on Mars strongly suggest that liquid water has existed on the planet's surface. Huge linear swathes of scoured ground, known as [outflow channels](https://en.wikipedia.org/wiki/Outflow_channels), cut across the surface in around 25 places. These are thought to record erosion which occurred during the catastrophic release of water from subsurface aquifers, though some of these structures have been hypothesized to result from the action of glaciers or lava.[[71]](https://en.wikipedia.org/wiki/Mars#cite_note-Kerr2005-72)[[72]](https://en.wikipedia.org/wiki/Mars#cite_note-Jaeger2007-73) One of the larger examples, [Ma'adim Vallis](https://en.wikipedia.org/wiki/Ma%27adim_Vallis) is 700 km (430 mi) long and much bigger than the Grand Canyon with a width of 20 km (12 mi) and a depth of 2 km (1.2 mi) in places. It is thought to have been carved by flowing water early in Mars's history.[[73]](https://en.wikipedia.org/wiki/Mars#cite_note-lucchita_rosanova-74) The youngest of these channels are thought to have formed as recently as only a few million years ago.[[74]](https://en.wikipedia.org/wiki/Mars#cite_note-nature434-75) Elsewhere, particularly on the oldest areas of the Martian surface, finer-scale, dendritic [networks of valleys](https://en.wikipedia.org/wiki/Valley_networks_(Mars)) are spread across significant proportions of the landscape. Features of these valleys and their distribution strongly imply that they were carved by [runoff](https://en.wikipedia.org/wiki/Surface_runoff) resulting from rain or snow fall in early Mars history. Subsurface water flow and [groundwater sapping](https://en.wikipedia.org/wiki/Groundwater_sapping) may play important subsidiary roles in some networks, but precipitation was probably the root cause of the incision in almost all cases.[[75]](https://en.wikipedia.org/wiki/Mars#cite_note-CraddockHoward2002-76)

Along crater and canyon walls, there are thousands of features that appear similar to terrestrial [gullies](https://en.wikipedia.org/wiki/Gullies). The gullies tend to be in the highlands of the southern hemisphere and to face the Equator; all are poleward of 30° latitude. A number of authors have suggested that their formation process involves liquid water, probably from melting ice,[[76]](https://en.wikipedia.org/wiki/Mars#cite_note-sci288-77)[[77]](https://en.wikipedia.org/wiki/Mars#cite_note-nasa061206-78) although others have argued for formation mechanisms involving carbon dioxide frost or the movement of dry dust.[[78]](https://en.wikipedia.org/wiki/Mars#cite_note-bbc061206-79)[[79]](https://en.wikipedia.org/wiki/Mars#cite_note-nasa061206b-80) No partially degraded gullies have formed by weathering and no superimposed impact craters have been observed, indicating that these are young features, possibly still active.[[77]](https://en.wikipedia.org/wiki/Mars#cite_note-nasa061206-78) Other geological features, such as [deltas](https://en.wikipedia.org/wiki/River_delta) and [alluvial fans](https://en.wikipedia.org/wiki/Alluvial_fans) preserved in craters, are further evidence for warmer, wetter conditions at an interval or intervals in earlier Mars history.[[80]](https://en.wikipedia.org/wiki/Mars#cite_note-Lewis2006-81) Such conditions necessarily require the widespread presence of [crater lakes](https://en.wikipedia.org/wiki/Crater_lake) across a large proportion of the surface, for which there is independent mineralogical, sedimentological and geomorphological evidence.[[81]](https://en.wikipedia.org/wiki/Mars#cite_note-Matsubara2011-82)

[](https://en.wikipedia.org/wiki/File:PIA16791-MarsCuriosityRover-Composition-YellowknifeBayRocks.png)

Composition of ["Yellowknife Bay" rocks](https://en.wikipedia.org/wiki/List_of_rocks_on_Mars#2012_.E2.80.93_Curiosity_rover_.28Mars_Science_Laboratory.29). [Rock veins](https://en.wikipedia.org/wiki/Vein_(geology)) are higher in [calcium](https://en.wikipedia.org/wiki/Calcium)and [sulfur](https://en.wikipedia.org/wiki/Sulfur) than "portage" soil ([*Curiosity*](https://en.wikipedia.org/wiki/Curiosity_(rover)),[APXS](https://en.wikipedia.org/wiki/Curiosity_(rover)#Alpha_Particle_X-ray_Spectrometer_.28APXS.29), 2013).

Further evidence that liquid water once existed on the surface of Mars comes from the detection of specific minerals such as [hematite](https://en.wikipedia.org/wiki/Hematite) and [goethite](https://en.wikipedia.org/wiki/Goethite), both of which sometimes form in the presence of water.[[82]](https://en.wikipedia.org/wiki/Mars#cite_note-nasa040303-83) In 2004, *Opportunity* detected the mineral [jarosite](https://en.wikipedia.org/wiki/Jarosite). This forms only in the presence of acidic water, which demonstrates that water once existed on Mars.[[83]](https://en.wikipedia.org/wiki/Mars#cite_note-nasa101001-84) More recent evidence for liquid water comes from the finding of the mineral [gypsum](https://en.wikipedia.org/wiki/Gypsum) on the surface by NASA's Mars rover Opportunity in December 2011.[[84]](https://en.wikipedia.org/wiki/Mars#cite_note-nasa-85)[[85]](https://en.wikipedia.org/wiki/Mars#cite_note-nationalgeographic-86) The study leader Francis McCubbin, a planetary scientist at the University of New Mexico in Albuquerque looking at hydroxals in crystalline minerals from Mars, states that the amount of water in the upper mantle of Mars is equal to or greater than that of Earth at 50–300 parts per million of water, which is enough to cover the entire planet to a depth of 200–1,000 m (660–3,280 ft).[[86]](https://en.wikipedia.org/wiki/Mars#cite_note-nationalgeographic1-87)

On March 18, 2013, [NASA](https://en.wikipedia.org/wiki/NASA) reported evidence from instruments on the [*Curiosity* rover](https://en.wikipedia.org/wiki/Curiosity_(rover)) of [mineral hydration](https://en.wikipedia.org/wiki/Mineral_hydration), likely hydrated [calcium sulfate](https://en.wikipedia.org/wiki/Calcium_sulfate), in several [rock samples](https://en.wikipedia.org/wiki/Rock_(geology)) including the broken fragments of ["Tintina" rock](https://en.wikipedia.org/wiki/Tintina_(rock)) and ["Sutton Inlier" rock](https://en.wikipedia.org/wiki/List_of_rocks_on_Mars#Curiosity) as well as in [veins](https://en.wikipedia.org/wiki/Vein_(geology)) and [nodules](https://en.wikipedia.org/wiki/Nodule_(geology)) in other rocks like ["Knorr" rock](https://en.wikipedia.org/wiki/List_of_rocks_on_Mars#Curiosity) and ["Wernicke" rock](https://en.wikipedia.org/wiki/List_of_rocks_on_Mars#Curiosity).[[87]](https://en.wikipedia.org/wiki/Mars#cite_note-NASA-20130318-88)[[88]](https://en.wikipedia.org/wiki/Mars#cite_note-BBC-20130319-89)[[89]](https://en.wikipedia.org/wiki/Mars#cite_note-MSN-20130120-90) Analysis using the rover's [DAN instrument](https://en.wikipedia.org/wiki/Curiosity_(rover)#Dynamic_Albedo_of_Neutrons_.28DAN.29) provided evidence of subsurface water, amounting to as much as 4% water content, down to a depth of 60 cm (24 in), in the rover's traverse from the [*Bradbury Landing*](https://en.wikipedia.org/wiki/Bradbury_Landing) site to the *Yellowknife Bay* area in the [*Glenelg*](https://en.wikipedia.org/wiki/Glenelg,_Mars) terrain.[[87]](https://en.wikipedia.org/wiki/Mars#cite_note-NASA-20130318-88) On September 28, 2015, NASA announced that they had found conclusive evidence of hydrated [brine](https://en.wikipedia.org/wiki/Brine) flows on [recurring slope lineae](https://en.wikipedia.org/wiki/Recurring_slope_lineae), based on spectrometer readings of the darkened areas of slopes.[[90]](https://en.wikipedia.org/wiki/Mars#cite_note-91)[[91]](https://en.wikipedia.org/wiki/Mars#cite_note-92)[[92]](https://en.wikipedia.org/wiki/Mars#cite_note-Ojhaetal2015-93) These observations provided confirmation of earlier hypotheses based on timing of formation and rate of growth that these dark streaks resulted from water flowing in the very shallow subsurface.[[93]](https://en.wikipedia.org/wiki/Mars#cite_note-SeasonalFlows-94) The streaks contain hydrated salts, perchlorates, which have water molecules in their crystal structure.[[94]](https://en.wikipedia.org/wiki/Mars#cite_note-95) The streaks flow downhill in Martian summer, when the temperature is above –23 degrees Celsius, and freeze at lower temperatures.[[95]](https://en.wikipedia.org/wiki/Mars#cite_note-96)

Researchers think that much of the low northern plains of the planet were [covered with an ocean](https://en.wikipedia.org/wiki/Mars_ocean_hypothesis) hundreds of meters deep, though this remains controversial.[[96]](https://en.wikipedia.org/wiki/Mars#cite_note-Head1999-97) In March 2015, scientists stated that such an ocean might have been the size of Earth's [Arctic Ocean](https://en.wikipedia.org/wiki/Arctic_Ocean). This finding was derived from the ratio of water and [deuterium](https://en.wikipedia.org/wiki/Deuterium) in the modern Martian atmosphere compared to the ratio found on Earth. Eight times as much deuterium was found at Mars than exists on Earth, suggesting that ancient Mars had significantly higher levels of water. Results from the *Curiosity* rover had previously found a high ratio of deuterium in [Gale Crater](https://en.wikipedia.org/wiki/Gale_Crater), though not significantly high enough to suggest the presence of an ocean. Other scientists caution that this new study has not been confirmed, and point out that Martian climate models have not yet shown that the planet was warm enough in the past to support bodies of liquid water.[[97]](https://en.wikipedia.org/wiki/Mars#cite_note-NYT-20150305-98)

#### Polar caps

*Main article:*[*Martian polar ice caps*](https://en.wikipedia.org/wiki/Martian_polar_ice_caps)

[](https://en.wikipedia.org/wiki/File:Martian_north_polar_cap.jpg)

North polar early summer ice cap (1999)

[](https://en.wikipedia.org/wiki/File:South_Polar_Cap_of_Mars_during_Martian_South_summer_2000.jpg)

South polar midsummer ice cap (2000)

Mars has two permanent polar ice caps. During a pole's winter, it lies in continuous darkness, chilling the surface and causing the [deposition](https://en.wikipedia.org/wiki/Deposition_(phase_transition)) of 25–30% of the atmosphere into slabs of [CO2](https://en.wikipedia.org/wiki/Carbon_dioxide) ice ([dry ice](https://en.wikipedia.org/wiki/Dry_ice)).[[98]](https://en.wikipedia.org/wiki/Mars#cite_note-icarus169-99) When the poles are again exposed to sunlight, the frozen CO2 [sublimes](https://en.wikipedia.org/wiki/Sublimation_(physics)), creating enormous winds that sweep off the poles as fast as 400 km/h (250 mph). These seasonal actions transport large amounts of dust and water vapor, giving rise to Earth-like frost and large [cirrus clouds](https://en.wikipedia.org/wiki/Cirrus_cloud). Clouds of water-ice were photographed by the [*Opportunity*](https://en.wikipedia.org/wiki/Opportunity_rover) rover in 2004.[[99]](https://en.wikipedia.org/wiki/Mars#cite_note-clouds-100)

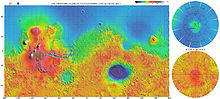
The polar caps at both poles consist primarily (70%) of water ice. Frozen carbon dioxide accumulates as a comparatively thin layer about one metre thick on the north cap in the northern winter only, whereas the south cap has a permanent dry ice cover about eight metres thick. This permanent dry ice cover at the south pole is peppered by [flat floored, shallow, roughly circular pits](https://en.wikipedia.org/wiki/Swiss_cheese_features), which repeat imaging shows are expanding by meters per year; this suggests that the permanent CO2 cover over the south pole water ice is degrading over time.[[100]](https://en.wikipedia.org/wiki/Mars#cite_note-malin2001-101) The northern polar cap has a diameter of about 1,000 km (620 mi) during the northern Mars summer,[[101]](https://en.wikipedia.org/wiki/Mars#cite_note-mira-102) and contains about 1.6 million cubic kilometres (380,000 cu mi) of ice, which, if spread evenly on the cap, would be 2 km (1.2 mi) thick.[[102]](https://en.wikipedia.org/wiki/Mars#cite_note-brown-103) (This compares to a volume of 2.85 million cubic kilometres (680,000 cu mi) for the [Greenland ice sheet](https://en.wikipedia.org/wiki/Greenland_ice_sheet).) The southern polar cap has a diameter of 350 km (220 mi) and a thickness of 3 km (1.9 mi).[[103]](https://en.wikipedia.org/wiki/Mars#cite_note-phillips-104) The total volume of ice in the south polar cap plus the adjacent layered deposits has been estimated at 1.6 million cubic km.[[104]](https://en.wikipedia.org/wiki/Mars#cite_note-sci315-105) Both polar caps show spiral troughs, which recent analysis of [SHARAD](https://en.wikipedia.org/wiki/SHARAD) ice penetrating radar has shown are a result of [katabatic winds](https://en.wikipedia.org/wiki/Katabatic_wind) that spiral due to the [Coriolis Effect](https://en.wikipedia.org/wiki/Coriolis_Effect).[[105]](https://en.wikipedia.org/wiki/Mars#cite_note-Onset_and_migration_of_spiral_troughs_on_Mars_revealed_by_orbital_radar-106)[[106]](https://en.wikipedia.org/wiki/Mars#cite_note-Mystery_Spirals_on_Mars_Finally_Explained-107)

The seasonal frosting of areas near the southern ice cap results in the formation of transparent 1-metre-thick slabs of dry ice above the ground. With the arrival of spring, sunlight warms the subsurface and pressure from subliming CO2builds up under a slab, elevating and ultimately rupturing it. This leads to [geyser-like eruptions](https://en.wikipedia.org/wiki/Martian_geyser) of CO2 gas mixed with dark basaltic sand or dust. This process is rapid, observed happening in the space of a few days, weeks or months, a rate of change rather unusual in geology – especially for Mars. The gas rushing underneath a slab to the site of a geyser carves a spiderweb-like pattern of radial channels under the ice, the process being the inverted equivalent of an erosion network formed by water draining through a single plughole.[[107]](https://en.wikipedia.org/wiki/Mars#cite_note-2006-100-108)[[108]](https://en.wikipedia.org/wiki/Mars#cite_note-Kieffer2000-109)[[109]](https://en.wikipedia.org/wiki/Mars#cite_note-Portyankina-110)[[110]](https://en.wikipedia.org/wiki/Mars#cite_note-Hugh2006-111)

### Geography and naming of surface features

*Main article:*[*Geography of Mars*](https://en.wikipedia.org/wiki/Geography_of_Mars)

*See also:*[*Category:Surface features of Mars*](https://en.wikipedia.org/wiki/Category:Surface_features_of_Mars)

[](https://en.wikipedia.org/wiki/File:Mars_topography_(MOLA_dataset)_with_poles_HiRes.jpg)

A [MOLA](https://en.wikipedia.org/wiki/Mars_Orbiter_Laser_Altimeter)-based topographic map showing highlands (red and orange) dominating the southern hemisphere of Mars, lowlands (blue) the northern. Volcanic plateaus delimit regions of the northern plains, whereas the highlands are punctuated by several large impact basins.

Although better remembered for mapping the Moon, [Johann Heinrich Mädler](https://en.wikipedia.org/wiki/Johann_Heinrich_M%C3%A4dler) and [Wilhelm Beer](https://en.wikipedia.org/wiki/Wilhelm_Beer) were the first "areographers". They began by establishing that most of Mars's surface features were permanent and by more precisely determining the planet's rotation period. In 1840, Mädler combined ten years of observations and drew the first map of Mars. Rather than giving names to the various markings, Beer and Mädler simply designated them with letters; Meridian Bay (Sinus Meridiani) was thus feature "*a*".[[111]](https://en.wikipedia.org/wiki/Mars#cite_note-sheehan_ch04-112)

Today, features on Mars are named from a variety of sources. Albedo features are named for classical mythology. Craters larger than 60 km are named for deceased scientists and writers and others who have contributed to the study of Mars. Craters smaller than 60 km are named for towns and villages of the world with populations of less than 100,000. Large valleys are named for the word "Mars" or "star" in various languages; small valleys are named for rivers.[[112]](https://en.wikipedia.org/wiki/Mars#cite_note-usgs-113)

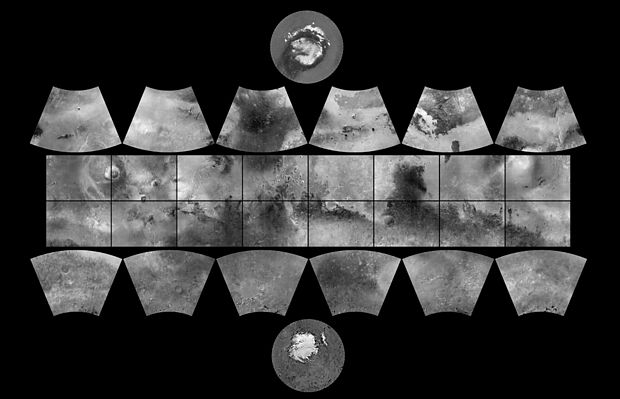
Large [albedo](https://en.wikipedia.org/wiki/Albedo) features retain many of the older names, but are often updated to reflect new knowledge of the nature of the features. For example, *Nix Olympica* (the snows of Olympus) has become *Olympus Mons* (Mount Olympus).[[113]](https://en.wikipedia.org/wiki/Mars#cite_note-viking_1950_2000-114) The surface of Mars as seen from Earth is divided into two kinds of areas, with differing albedo. The paler plains covered with dust and sand rich in reddish iron oxides were once thought of as Martian "continents" and given names like [Arabia Terra](https://en.wikipedia.org/wiki/Arabia_Terra) (*land of Arabia*) or [Amazonis Planitia](https://en.wikipedia.org/wiki/Amazonis_Planitia) (*Amazonian plain*). The dark features were thought to be seas, hence their names [Mare Erythraeum](https://en.wikipedia.org/wiki/Mare_Erythraeum), Mare Sirenum and [Aurorae Sinus](https://en.wikipedia.org/wiki/Aurorae_Sinus). The largest dark feature seen from Earth is [Syrtis Major Planum](https://en.wikipedia.org/wiki/Syrtis_Major_Planum).[[114]](https://en.wikipedia.org/wiki/Mars#cite_note-seds_huygens-115) The permanent northern polar ice cap is named [Planum Boreum](https://en.wikipedia.org/wiki/Planum_Boreum), whereas the southern cap is called [Planum Australe](https://en.wikipedia.org/wiki/Planum_Australe).

Mars's equator is defined by its rotation, but the location of its [Prime Meridian](https://en.wikipedia.org/wiki/Prime_Meridian) was specified, as was Earth's (at [Greenwich](https://en.wikipedia.org/wiki/Greenwich)), by choice of an arbitrary point; Mädler and Beer selected a line in 1830 for their first maps of Mars. After the spacecraft [Mariner 9](https://en.wikipedia.org/wiki/Mariner_9) provided extensive imagery of Mars in 1972, a small crater (later called [Airy-0](https://en.wikipedia.org/wiki/Airy-0)), located in the [Sinus Meridiani](https://en.wikipedia.org/wiki/Sinus_Meridiani) ("Middle Bay" or "Meridian Bay"), was chosen for the definition of 0.0° longitude to coincide with the original selection.[[115]](https://en.wikipedia.org/wiki/Mars#cite_note-archinal_caplinger-116)

Because Mars has no oceans and hence no "sea level", a zero-elevation surface had to be selected as a reference level; this is called the *areoid*[[116]](https://en.wikipedia.org/wiki/Mars#cite_note-NASAMola2007-117) of Mars, analogous to the terrestrial [geoid](https://en.wikipedia.org/wiki/Geoid). Zero altitude was defined by the height at which there is 610.5 [Pa](https://en.wikipedia.org/wiki/Pascal_(unit))(6.105 [mbar](https://en.wikipedia.org/wiki/Bar_(unit))) of atmospheric pressure.[[117]](https://en.wikipedia.org/wiki/Mars#cite_note-pers66-118) This pressure corresponds to the [triple point](https://en.wikipedia.org/wiki/Triple_point) of water, and it is about 0.6% of the sea level surface pressure on Earth (0.006 atm).[[118]](https://en.wikipedia.org/wiki/Mars#cite_note-lunine99-119) In practice, today this surface is defined directly from satellite gravity measurements.

#### Map of quadrangles

For mapping purposes, the [United States Geological Survey](https://en.wikipedia.org/wiki/United_States_Geological_Survey) divides the surface of Mars into thirty "[quadrangles](https://en.wikipedia.org/wiki/Quadrangle_(geography))", each named for a prominent physiographic feature within that quadrangle.[[119]](https://en.wikipedia.org/wiki/Mars#cite_note-mapping_mars-120)[[120]](https://en.wikipedia.org/wiki/Mars#cite_note-121) The quadrangles can be seen and explored via the interactive image map below.



The thirty cartographic [quadrangles](https://en.wikipedia.org/wiki/List_of_quadrangles_on_Mars) of Mars, defined by the [United States Geological Survey](https://en.wikipedia.org/wiki/United_States_Geological_Survey).[[119]](https://en.wikipedia.org/wiki/Mars#cite_note-mapping_mars-120)[[121]](https://en.wikipedia.org/wiki/Mars#cite_note-122) The quadrangles are numbered with the prefix "MC" for "Mars Chart."[[122]](https://en.wikipedia.org/wiki/Mars#cite_note-123) Click on a quadrangle name link and you will be taken to the corresponding article. North is at the top; [0°N 180°W](https://tools.wmflabs.org/geohack/geohack.php?pagename=Mars&params=0_N_180_W_globe:Mars) is at the far left on the [equator](https://en.wikipedia.org/wiki/Mars#Geography). The map images were taken by the [Mars Global Surveyor](https://en.wikipedia.org/wiki/Mars_Global_Surveyor).

[**0°N 180°W**](https://tools.wmflabs.org/geohack/geohack.php?pagename=Mars&params=0_N_180_W_globe:Mars)

[**0°N 0°W**](https://tools.wmflabs.org/geohack/geohack.php?pagename=Mars&params=0_N_0_W_globe:Mars)

[**90°N 0°W**](https://tools.wmflabs.org/geohack/geohack.php?pagename=Mars&params=90_N_0_W_globe:Mars)

[**MC-01**](https://en.wikipedia.org/wiki/Mare_Boreum_quadrangle)

[**Mare Boreum**](https://en.wikipedia.org/wiki/Mare_Boreum_quadrangle)

[**MC-02**](https://en.wikipedia.org/wiki/Diacria_quadrangle)

[**Diacria**](https://en.wikipedia.org/wiki/Diacria_quadrangle)

[**MC-03**](https://en.wikipedia.org/wiki/Arcadia_quadrangle)

[**Arcadia**](https://en.wikipedia.org/wiki/Arcadia_quadrangle)

[**MC-04**](https://en.wikipedia.org/wiki/Mare_Acidalium_quadrangle)

[**Mare Acidalium**](https://en.wikipedia.org/wiki/Mare_Acidalium_quadrangle)

[**MC-05**](https://en.wikipedia.org/wiki/Ismenius_Lacus_quadrangle)

[**Ismenius Lacus**](https://en.wikipedia.org/wiki/Ismenius_Lacus_quadrangle)

[**MC-06**](https://en.wikipedia.org/wiki/Casius_quadrangle)

[**Casius**](https://en.wikipedia.org/wiki/Casius_quadrangle)

[**MC-07**](https://en.wikipedia.org/wiki/Cebrenia_quadrangle)

[**Cebrenia**](https://en.wikipedia.org/wiki/Cebrenia_quadrangle)

[**MC-08**](https://en.wikipedia.org/wiki/Amazonis_quadrangle)

[**Amazonis**](https://en.wikipedia.org/wiki/Amazonis_quadrangle)

[**MC-09**](https://en.wikipedia.org/wiki/Tharsis_quadrangle)

[**Tharsis**](https://en.wikipedia.org/wiki/Tharsis_quadrangle)

[**MC-10**](https://en.wikipedia.org/wiki/Lunae_Palus_quadrangle)

[**Lunae Palus**](https://en.wikipedia.org/wiki/Lunae_Palus_quadrangle)

[**MC-11**](https://en.wikipedia.org/wiki/Oxia_Palus_quadrangle)

[**Oxia Palus**](https://en.wikipedia.org/wiki/Oxia_Palus_quadrangle)

[**MC-12**](https://en.wikipedia.org/wiki/Arabia_quadrangle)

[**Arabia**](https://en.wikipedia.org/wiki/Arabia_quadrangle)

[**MC-13**](https://en.wikipedia.org/wiki/Syrtis_Major_quadrangle)

[**Syrtis Major**](https://en.wikipedia.org/wiki/Syrtis_Major_quadrangle)

[**MC-14**](https://en.wikipedia.org/wiki/Amenthes_quadrangle)

[**Amenthes**](https://en.wikipedia.org/wiki/Amenthes_quadrangle)

[**MC-15**](https://en.wikipedia.org/wiki/Elysium_quadrangle)

[**Elysium**](https://en.wikipedia.org/wiki/Elysium_quadrangle)

[**MC-16**](https://en.wikipedia.org/wiki/Memnonia_quadrangle)

[**Memnonia**](https://en.wikipedia.org/wiki/Memnonia_quadrangle)

[**MC-17**](https://en.wikipedia.org/wiki/Phoenicis_Lacus_quadrangle)

[**Phoenicis**](https://en.wikipedia.org/wiki/Phoenicis_Lacus_quadrangle)

[**MC-18**](https://en.wikipedia.org/wiki/Coprates_quadrangle)

[**Coprates**](https://en.wikipedia.org/wiki/Coprates_quadrangle)

[**MC-19**](https://en.wikipedia.org/wiki/Margaritifer_Sinus_quadrangle)

[**Margaritifer**](https://en.wikipedia.org/wiki/Margaritifer_Sinus_quadrangle)

[**MC-20**](https://en.wikipedia.org/wiki/Sinus_Sabaeus_quadrangle)

[**Sabaeus**](https://en.wikipedia.org/wiki/Sinus_Sabaeus_quadrangle)

[**MC-21**](https://en.wikipedia.org/wiki/Iapygia_quadrangle)

[**Iapygia**](https://en.wikipedia.org/wiki/Iapygia_quadrangle)

[**MC-22**](https://en.wikipedia.org/wiki/Mare_Tyrrhenum_quadrangle)

[**Tyrrhenum**](https://en.wikipedia.org/wiki/Mare_Tyrrhenum_quadrangle)

[**MC-23**](https://en.wikipedia.org/wiki/Aeolis_quadrangle)

[**Aeolis**](https://en.wikipedia.org/wiki/Aeolis_quadrangle)

[**MC-24**](https://en.wikipedia.org/wiki/Phaethontis_quadrangle)

[**Phaethontis**](https://en.wikipedia.org/wiki/Phaethontis_quadrangle)

[**MC-25**](https://en.wikipedia.org/wiki/Thaumasia_quadrangle)

[**Thaumasia**](https://en.wikipedia.org/wiki/Thaumasia_quadrangle)

[**MC-26**](https://en.wikipedia.org/wiki/Argyre_quadrangle)

[**Argyre**](https://en.wikipedia.org/wiki/Argyre_quadrangle)

[**MC-27**](https://en.wikipedia.org/wiki/Noachis_quadrangle)

[**Noachis**](https://en.wikipedia.org/wiki/Noachis_quadrangle)

[**MC-28**](https://en.wikipedia.org/wiki/Hellas_quadrangle)

[**Hellas**](https://en.wikipedia.org/wiki/Hellas_quadrangle)

[**MC-29**](https://en.wikipedia.org/wiki/Eridania_quadrangle)

[**Eridania**](https://en.wikipedia.org/wiki/Eridania_quadrangle)

[**MC-30**](https://en.wikipedia.org/wiki/Mare_Australe_quadrangle)

[**Mare Australe**](https://en.wikipedia.org/wiki/Mare_Australe_quadrangle)

#### Impact topography

[](https://en.wikipedia.org/wiki/File:PIA15038_-_Spirit_lander_and_Bonneville_Crater_on_Mars.jpg)

Bonneville crater and *Spirit* rover's lander

The [dichotomy](https://en.wikipedia.org/wiki/Martian_dichotomy) of Martian topography is striking: northern plains flattened by lava flows contrast with the southern highlands, pitted and cratered by ancient impacts. Research in 2008 has presented evidence regarding a theory proposed in 1980 postulating that, four billion years ago, the northern hemisphere of Mars was struck by an object one-tenth to two-thirds the size of Earth's [Moon](https://en.wikipedia.org/wiki/Moon). If validated, this would make the northern hemisphere of Mars the site of an [impact crater](https://en.wikipedia.org/wiki/Impact_crater) 10,600 by 8,500 km (6,600 by 5,300 mi) in size, or roughly the area of Europe, Asia, and Australia combined, surpassing the [South Pole–Aitken basin](https://en.wikipedia.org/wiki/South_Pole%E2%80%93Aitken_basin) as the largest impact crater in the Solar System.[[16]](https://en.wikipedia.org/wiki/Mars#cite_note-northcratersn-17)[[17]](https://en.wikipedia.org/wiki/Mars#cite_note-northcraterguard-18)

[https://upload.wikimedia.org/wikipedia/commons/thumb/e/e8/PIA18381-Mars-FreshAsteroidImpact2012-Before27March-After28March.jpg/220px-PIA18381-Mars-FreshAsteroidImpact2012-Before27March-After28March.jpg](https://en.wikipedia.org/wiki/File:PIA18381-Mars-FreshAsteroidImpact2012-Before27March-After28March.jpg)

Fresh [asteroid](https://en.wikipedia.org/wiki/Asteroid) impact on Mars at[3.34°N 219.38°E](https://tools.wmflabs.org/geohack/geohack.php?pagename=Mars&params=3.34_N_219.38_E_globe:Mars) – *before*/March 27 &*after*/March 28, 2012 ([MRO](https://en.wikipedia.org/wiki/Mars_Reconnaissance_Orbiter))[[123]](https://en.wikipedia.org/wiki/Mars#cite_note-NASA-20140522-124)

Mars is scarred by a number of impact craters: a total of 43,000 craters with a diameter of 5 km (3.1 mi) or greater have been found.[[124]](https://en.wikipedia.org/wiki/Mars#cite_note-wright03-125) The largest confirmed of these is the [Hellas impact basin](https://en.wikipedia.org/wiki/Hellas_Planitia), a light [albedo feature](https://en.wikipedia.org/wiki/Albedo_feature) clearly visible from Earth.[[125]](https://en.wikipedia.org/wiki/Mars#cite_note-ucar_geography-126) Due to the smaller mass of Mars, the probability of an object colliding with the planet is about half that of Earth. Mars is located closer to the [asteroid belt](https://en.wikipedia.org/wiki/Asteroid_belt), so it has an increased chance of being struck by materials from that source. Mars is more likely to be struck by short-period [comets](https://en.wikipedia.org/wiki/Comet), *i.e.*, those that lie within the orbit of Jupiter.[[126]](https://en.wikipedia.org/wiki/Mars#cite_note-emp9-127) In spite of this, there are far fewer craters on Mars compared with the Moon, because the atmosphere of Mars provides protection against small meteors. Craters can have a morphology that suggests the ground became wet after the meteor impacted.[[127]](https://en.wikipedia.org/wiki/Mars#cite_note-emp45-128)

#### Volcanoes

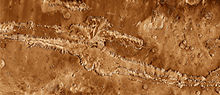
[](https://en.wikipedia.org/wiki/File:Olympus_Mons_alt.jpg)

[Viking 1](https://en.wikipedia.org/wiki/Viking_1) image of [Olympus Mons](https://en.wikipedia.org/wiki/Olympus_Mons). The volcano and related terrain are approximately 550 km (340 mi) across.

*Main article:*[*Volcanology of Mars*](https://en.wikipedia.org/wiki/Volcanology_of_Mars)

The [shield volcano](https://en.wikipedia.org/wiki/Shield_volcano) [Olympus Mons](https://en.wikipedia.org/wiki/Olympus_Mons) (*Mount Olympus*) is an extinct volcano in the vast upland region [Tharsis](https://en.wikipedia.org/wiki/Tharsis), which contains several other large volcanoes. Olympus Mons is roughly three times the height of [Mount Everest](https://en.wikipedia.org/wiki/Mount_Everest), which in comparison stands at just over 8.8 km (5.5 mi).[[128]](https://en.wikipedia.org/wiki/Mars#cite_note-scsdes49-129) It is either the tallest or second-tallest mountain in the Solar System, depending on how it is measured, with various sources giving figures ranging from about 21 to 27 km (13 to 17 mi) high.[[129]](https://en.wikipedia.org/wiki/Mars#cite_note-130)[[130]](https://en.wikipedia.org/wiki/Mars#cite_note-glenday09-131)

#### Tectonic sites

[](https://en.wikipedia.org/wiki/File:016vallesmarineris_reduced0.25.jpg)

[Valles Marineris](https://en.wikipedia.org/wiki/Valles_Marineris) ([*2001 Mars Odyssey*](https://en.wikipedia.org/wiki/2001_Mars_Odyssey))

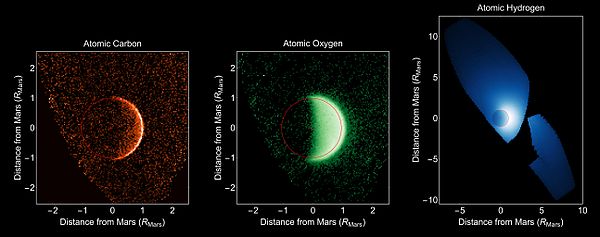
The large canyon, [Valles Marineris](https://en.wikipedia.org/wiki/Valles_Marineris) (Latin for "[Mariner](https://en.wikipedia.org/wiki/Mariner_program) Valleys", also known as Agathadaemon in the old canal maps), has a length of 4,000 km (2,500 mi) and a depth of up to 7 km (4.3 mi). The length of Valles Marineris is equivalent to the length of Europe and extends across one-fifth the circumference of Mars. By comparison, the [Grand Canyon](https://en.wikipedia.org/wiki/Grand_Canyon) on Earth is only 446 km (277 mi) long and nearly 2 km (1.2 mi) deep. Valles Marineris was formed due to the swelling of the [Tharsis](https://en.wikipedia.org/wiki/Tharsis) area, which caused the crust in the area of Valles Marineris to collapse. In 2012, it was proposed that Valles Marineris is not just a [graben](https://en.wikipedia.org/wiki/Graben), but a plate boundary where 150 km (93 mi) of [transverse motion](https://en.wikipedia.org/wiki/Transform_fault) has occurred, making Mars a planet with possibly a two-[tectonic plate](https://en.wikipedia.org/wiki/Tectonic_plate) arrangement.[[131]](https://en.wikipedia.org/wiki/Mars#cite_note-tectonic-132)[[132]](https://en.wikipedia.org/wiki/Mars#cite_note-Lin.2C_An-133)

#### Holes

Images from the [Thermal Emission Imaging System](https://en.wikipedia.org/wiki/Thermal_Emission_Imaging_System) (THEMIS) aboard NASA's [Mars Odyssey orbiter](https://en.wikipedia.org/wiki/2001_Mars_Odyssey) have revealed seven possible [cave](https://en.wikipedia.org/wiki/Cave) entrances on the flanks of the volcano [Arsia Mons](https://en.wikipedia.org/wiki/Arsia_Mons).[[133]](https://en.wikipedia.org/wiki/Mars#cite_note-cushing_titus_wynn07-134) The caves, named after loved ones of their discoverers, are collectively known as the "seven sisters".[[134]](https://en.wikipedia.org/wiki/Mars#cite_note-nau070328-135) Cave entrances measure from 100 to 252 m (328 to 827 ft) wide and they are estimated to be at least 73 to 96 m (240 to 315 ft) deep. Because light does not reach the floor of most of the caves, it is possible that they extend much deeper than these lower estimates and widen below the surface. "Dena" is the only exception; its floor is visible and was measured to be 130 m (430 ft) deep. The interiors of these caverns may be protected from micrometeoroids, UV radiation, [solar flares](https://en.wikipedia.org/wiki/Solar_flare) and high energy particles that bombard the planet's surface.[[135]](https://en.wikipedia.org/wiki/Mars#cite_note-bbc070317-136)

### Atmosphere

*Main article:*[*Atmosphere of Mars*](https://en.wikipedia.org/wiki/Atmosphere_of_Mars)

[](https://en.wikipedia.org/wiki/File:PIA18613-MarsMAVEN-Atmosphere-3UV-Views-20141014.jpg)

[Escaping atmosphere](https://en.wikipedia.org/wiki/Atmosphere_of_Mars) on Mars ([carbon](https://en.wikipedia.org/wiki/Carbon), [oxygen](https://en.wikipedia.org/wiki/Oxygen), and [hydrogen](https://en.wikipedia.org/wiki/Hydrogen)) by [MAVEN](https://en.wikipedia.org/wiki/MAVEN) in [UV](https://en.wikipedia.org/wiki/Ultraviolet%E2%80%93visible_spectroscopy)[[136]](https://en.wikipedia.org/wiki/Mars#cite_note-NASA-20141014-NJ-137)

Mars lost its [magnetosphere](https://en.wikipedia.org/wiki/Magnetosphere) 4 billion years ago,[[137]](https://en.wikipedia.org/wiki/Mars#cite_note-swind-138) possibly because of numerous asteroid strikes,[[138]](https://en.wikipedia.org/wiki/Mars#cite_note-139) so the [solar wind](https://en.wikipedia.org/wiki/Solar_wind) interacts directly with the Martian [ionosphere](https://en.wikipedia.org/wiki/Ionosphere), lowering the atmospheric density by stripping away atoms from the outer layer. Both [Mars Global Surveyor](https://en.wikipedia.org/wiki/Mars_Global_Surveyor) and [Mars Express](https://en.wikipedia.org/wiki/Mars_Express) have detected ionised atmospheric particles trailing off into space behind Mars,[[137]](https://en.wikipedia.org/wiki/Mars#cite_note-swind-138)[[139]](https://en.wikipedia.org/wiki/Mars#cite_note-swind2-140) and this atmospheric loss is being studied by the [MAVEN](https://en.wikipedia.org/wiki/MAVEN) orbiter. Compared to Earth, the [atmosphere](https://en.wikipedia.org/wiki/Celestial_body_atmosphere) of Mars is quite rarefied. [Atmospheric pressure](https://en.wikipedia.org/wiki/Atmospheric_pressure)on the surface today ranges from a low of 30 [Pa](https://en.wikipedia.org/wiki/Pascal_(unit)) (0.030 [kPa](https://en.wikipedia.org/wiki/Pascal_(unit))) on [Olympus Mons](https://en.wikipedia.org/wiki/Olympus_Mons) to over 1,155 Pa (1.155 kPa) in [Hellas Planitia](https://en.wikipedia.org/wiki/Hellas_Planitia), with a mean pressure at the surface level of 600 Pa (0.60 kPa).[[140]](https://en.wikipedia.org/wiki/Mars#cite_note-bolonkin09-141) The highest atmospheric density on Mars is equal to that found 35 km (22 mi)[[141]](https://en.wikipedia.org/wiki/Mars#cite_note-atkinson07-142) above Earth's surface. The resulting mean surface pressure is only 0.6% of that of Earth (101.3 kPa). The [scale height](https://en.wikipedia.org/wiki/Scale_height) of the atmosphere is about 10.8 km (6.7 mi),[[142]](https://en.wikipedia.org/wiki/Mars#cite_note-carr06-143) which is higher than Earth's (6 km (3.7 mi)) because the surface gravity of Mars is only about 38% of Earth's, an effect offset by both the lower temperature and 50% higher average molecular weight of the atmosphere of Mars.

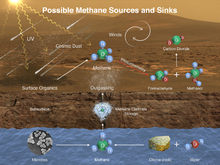
[](https://en.wikipedia.org/wiki/File:Mars_atmosphere_2.jpg)

The tenuous [atmosphere of Mars](https://en.wikipedia.org/wiki/Atmosphere_of_Mars) visible on the horizon

The atmosphere of Mars consists of about 96% [carbon dioxide](https://en.wikipedia.org/wiki/Carbon_dioxide), 1.93% [argon](https://en.wikipedia.org/wiki/Argon) and 1.89% [nitrogen](https://en.wikipedia.org/wiki/Nitrogen) along with traces of [oxygen](https://en.wikipedia.org/wiki/Oxygen) and water.[[7]](https://en.wikipedia.org/wiki/Mars#cite_note-nssdc-8)[[143]](https://en.wikipedia.org/wiki/Mars#cite_note-Abundance-144) The atmosphere is quite dusty, containing particulates about 1.5 [µm](https://en.wikipedia.org/wiki/%CE%9Cm) in diameter which give the Martian sky a [tawny](https://en.wikipedia.org/wiki/Tawny_(color)) color when seen from the surface.[[144]](https://en.wikipedia.org/wiki/Mars#cite_note-dusty-145) It may take on a [pink](https://en.wikipedia.org/wiki/Pink_(color)) hue due to [iron oxide](https://en.wikipedia.org/wiki/Iron_oxide) particles suspended in it.[[14]](https://en.wikipedia.org/wiki/Mars#cite_note-Rees2012-15)

[Methane](https://en.wikipedia.org/wiki/Methane) has been detected in the [Martian atmosphere](https://en.wikipedia.org/wiki/Atmosphere_of_Mars#Methane) with a [mole fraction](https://en.wikipedia.org/wiki/Mole_fraction) of about 30 [ppb](https://en.wikipedia.org/wiki/Parts_per_billion);[[145]](https://en.wikipedia.org/wiki/Mars#cite_note-methane-me-146)[[146]](https://en.wikipedia.org/wiki/Mars#cite_note-methane-147) it occurs in extended plumes, and the profiles imply that the methane was released from discrete regions. In northern midsummer, the principal plume contained 19,000 metric tons of methane, with an estimated source strength of 0.6 kilograms per second.[[147]](https://en.wikipedia.org/wiki/Mars#cite_note-plumes-148)[[148]](https://en.wikipedia.org/wiki/Mars#cite_note-hand08-149) The profiles suggest that there may be two local source regions, the first centered near [30°N 260°W](https://tools.wmflabs.org/geohack/geohack.php?pagename=Mars&params=30_N_260_W_globe:Mars)and the second near [0°N 310°W](https://tools.wmflabs.org/geohack/geohack.php?pagename=Mars&params=0_N_310_W_globe:Mars).[[147]](https://en.wikipedia.org/wiki/Mars#cite_note-plumes-148) It is estimated that Mars must produce 270 tonnes per year of methane.[[147]](https://en.wikipedia.org/wiki/Mars#cite_note-plumes-148)[[149]](https://en.wikipedia.org/wiki/Mars#cite_note-results-150)

Methane can exist in the Martian atmosphere for only a limited period before it is destroyed—estimates of its lifetime range from 0.6–4 years.[[147]](https://en.wikipedia.org/wiki/Mars#cite_note-plumes-148)[[150]](https://en.wikipedia.org/wiki/Mars#cite_note-nature460-151) Its presence despite this short lifetime indicates that an active source of the gas must be present. [Volcanic](https://en.wikipedia.org/wiki/Volcanism) activity, [cometary](https://en.wikipedia.org/wiki/Comet) impacts, and the presence of [methanogenic](https://en.wikipedia.org/wiki/Methanogen) [microbial](https://en.wikipedia.org/wiki/Microorganism) life forms are among possible sources. Methane could be produced by a non-biological process called [*serpentinization*](https://en.wikipedia.org/wiki/Serpentinite)[[b]](https://en.wikipedia.org/wiki/Mars#cite_note-serpentinization-152) involving water, carbon dioxide, and the mineral [olivine](https://en.wikipedia.org/wiki/Olivine), which is known to be common on Mars.[[151]](https://en.wikipedia.org/wiki/Mars#cite_note-olivine-153)

[](https://en.wikipedia.org/wiki/File:PIA19088-MarsCuriosityRover-MethaneSource-20141216.png)

Potential sources and sinks of[methane](https://en.wikipedia.org/wiki/Atmosphere_of_Mars#Methane) (CH  
4) on Mars

The [*Curiosity*](https://en.wikipedia.org/wiki/Curiosity_(rover)) rover, which landed on Mars in August 2012, is able to make measurements that distinguish between different isotopologues of methane,[[152]](https://en.wikipedia.org/wiki/Mars#cite_note-154) but even if the mission is to determine that microscopic Martian life is the source of the methane, the life forms likely reside far below the surface, outside of the rover's reach.[[153]](https://en.wikipedia.org/wiki/Mars#cite_note-155) The first measurements with the [Tunable Laser Spectrometer (TLS)](https://en.wikipedia.org/wiki/Sample_Analysis_at_Mars) indicated that there is less than 5 ppb of methane at the landing site at the point of the measurement.[[154]](https://en.wikipedia.org/wiki/Mars#cite_note-156)[[155]](https://en.wikipedia.org/wiki/Mars#cite_note-Science-20121102-157)[[156]](https://en.wikipedia.org/wiki/Mars#cite_note-Space-20121102-158)[[157]](https://en.wikipedia.org/wiki/Mars#cite_note-NYT-20121102-159) On September 19, 2013, NASA scientists, from further measurements by *Curiosity*, reported no detection of [atmospheric methane](https://en.wikipedia.org/wiki/Atmospheric_methane) with a measured value of 0.18±0.67 ppbv corresponding to an upper limit of only 1.3 ppbv (95% confidence limit) and, as a result, conclude that the probability of current methanogenic microbial activity on Mars is reduced.[[158]](https://en.wikipedia.org/wiki/Mars#cite_note-SJ-20130919-160)[[159]](https://en.wikipedia.org/wiki/Mars#cite_note-SCI-20130919-161)[[160]](https://en.wikipedia.org/wiki/Mars#cite_note-NYT-20130919-162)

The [Mars Orbiter Mission](https://en.wikipedia.org/wiki/Mars_Orbiter_Mission) by [India](https://en.wikipedia.org/wiki/India) is searching for methane in the atmosphere,[[161]](https://en.wikipedia.org/wiki/Mars#cite_note-payload-163) while the [ExoMars Trace Gas Orbiter](https://en.wikipedia.org/wiki/ExoMars_Trace_Gas_Orbiter), planned to launch in 2016, would further study the methane as well as its decomposition products, such as [formaldehyde](https://en.wikipedia.org/wiki/Formaldehyde) and [methanol](https://en.wikipedia.org/wiki/Methanol).[[162]](https://en.wikipedia.org/wiki/Mars#cite_note-Mustard-164)

On December 16, 2014, NASA reported the *Curiosity* rover detected a "tenfold spike", likely localized, in the amount of [methane](https://en.wikipedia.org/wiki/Methane) in the [Martian atmosphere](https://en.wikipedia.org/wiki/Atmosphere_of_Mars). Sample measurements taken "a dozen times over 20 months" showed increases in late 2013 and early 2014, averaging "7 parts of methane per billion in the atmosphere." Before and after that, readings averaged around one-tenth that level.[[163]](https://en.wikipedia.org/wiki/Mars#cite_note-NASA-20141216-GW-165)[[164]](https://en.wikipedia.org/wiki/Mars#cite_note-NYT-20141216-KC-166)

Ammonia was tentatively detected on Mars by the Mars Express satellite, but with its relatively short lifetime, it is not clear what produced it.[[165]](https://en.wikipedia.org/wiki/Mars#cite_note-davidw-167) Ammonia is not stable in the Martian atmosphere and breaks down after a few hours. One possible source is volcanic activity.[[165]](https://en.wikipedia.org/wiki/Mars#cite_note-davidw-167)

#### Aurora

In 1994 the European Space Agency's [Mars Express](https://en.wikipedia.org/wiki/Mars_Express) found an ultraviolet glow coming from "magnetic umbrellas" in the southern hemisphere. Mars does not have a global magnetic field which guides charged particles entering the atmosphere. Mars has multiple umbrella-shaped magnetic fields mainly in the southern hemisphere, which are remnants of a global field that decayed billions of years ago.

In late December 2014, NASA's MAVEN spacecraft detected evidence of widespread auroras in Mars's northern hemisphere and descended to approximately 20–30 degrees North latitude of Mars's equator. The particles causing the aurora penetrated into the Martian atmosphere, creating auroras below 100 km above the surface, Earth's auroras range from 100 km to 500 km above the surface. Magnetic fields in the solar wind drape over Mars, into the atmosphere, and the charged particles follow the solar wind magnetic field lines into the atmosphere, causing auroras to occur outside the magnetic umbrellas.[[166]](https://en.wikipedia.org/wiki/Mars#cite_note-168)

On March 18, 2015, NASA reported the detection of an [aurora](https://en.wikipedia.org/wiki/Aurora) that is not fully understood and an unexplained dust cloud in the [atmosphere of Mars](https://en.wikipedia.org/wiki/Atmosphere_of_Mars).[[167]](https://en.wikipedia.org/wiki/Mars#cite_note-NASA-20150318-169)

### Climate

*Main article:*[*Climate of Mars*](https://en.wikipedia.org/wiki/Climate_of_Mars)

[**Dust storm**](https://en.wikipedia.org/wiki/Dust_storm)**on Mars**

[](https://en.wikipedia.org/wiki/File:PIA16450-MarsDustStorm-20121118.jpg)

November 18, 2012

[](https://en.wikipedia.org/wiki/File:PIA16454-MarsDustStorm-20121125.jpg)

November 25, 2012

[*Opportunity*](https://en.wikipedia.org/wiki/Opportunity_(rover)) and [*Curiosity*](https://en.wikipedia.org/wiki/Curiosity_(rover))rovers are noted.

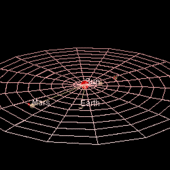
Of all the planets in the Solar System, the seasons of Mars are the most Earth-like, due to the similar tilts of the two planets' rotational axes. The lengths of the Martian seasons are about twice those of Earth's because Mars's greater distance from the Sun leads to the Martian year being about two Earth years long. Martian surface temperatures vary from lows of about −143 °C (−225 °F) at the winter polar caps[[10]](https://en.wikipedia.org/wiki/Mars#cite_note-cold-11) to highs of up to 35 °C (95 °F) in equatorial summer.[[11]](https://en.wikipedia.org/wiki/Mars#cite_note-hot-12) The wide range in temperatures is due to the thin atmosphere which cannot store much solar heat, the low atmospheric pressure, and the low [thermal inertia](https://en.wikipedia.org/wiki/Volumetric_heat_capacity) of Martian soil.[[168]](https://en.wikipedia.org/wiki/Mars#cite_note-nasa_surface-170) The planet is 1.52 times as far from the Sun as Earth, resulting in just 43% of the amount of sunlight.[[169]](https://en.wikipedia.org/wiki/Mars#cite_note-disc920901-171)

If Mars had an Earth-like orbit, its seasons would be similar to Earth's because its [axial tilt](https://en.wikipedia.org/wiki/Axial_tilt) is similar to Earth's. The comparatively large [eccentricity](https://en.wikipedia.org/wiki/Orbital_eccentricity) of the Martian orbit has a significant effect. Mars is near [perihelion](https://en.wikipedia.org/wiki/Apsis) when it is summer in the southern hemisphere and winter in the north, and near [aphelion](https://en.wikipedia.org/wiki/Apsis) when it is winter in the southern hemisphere and summer in the north. As a result, the seasons in the southern hemisphere are more extreme and the seasons in the northern are milder than would otherwise be the case. The summer temperatures in the south can be up to 30 [K](https://en.wikipedia.org/wiki/Kelvin) (30 °C; 54 °F) warmer than the equivalent summer temperatures in the north.[[170]](https://en.wikipedia.org/wiki/Mars#cite_note-goodman97-172)

Mars has the largest [dust storms](https://en.wikipedia.org/wiki/Dust_storm) in the Solar System. These can vary from a storm over a small area, to gigantic storms that cover the entire planet. They tend to occur when Mars is closest to the Sun, and have been shown to increase the global temperature.[[171]](https://en.wikipedia.org/wiki/Mars#cite_note-philips01-173)

## Orbit and rotation

*Main article:*[*Orbit of Mars*](https://en.wikipedia.org/wiki/Orbit_of_Mars)

[](https://en.wikipedia.org/wiki/File:Marsorbitsolarsystem.gif)

Mars is about 230 million kilometres (143,000,000 mi) from the Sun; its orbital period is 687 (Earth) days, depicted in red. Earth's orbit is in blue.

Mars's average distance from the Sun is roughly 230 million kilometres (143,000,000 mi), and its orbital period is 687 (Earth) days. The solar day (or [sol](https://en.wikipedia.org/wiki/Timekeeping_on_Mars)) on Mars is only slightly longer than an Earth day: 24 hours, 39 minutes, and 35.244 seconds.[[172]](https://en.wikipedia.org/wiki/Mars#cite_note-174) A Martian year is equal to 1.8809 Earth years, or 1 year, 320 days, and 18.2 hours.[[7]](https://en.wikipedia.org/wiki/Mars#cite_note-nssdc-8)

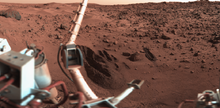
The axial tilt of Mars is 25.19 degrees relative to its [orbital plane](https://en.wikipedia.org/wiki/Orbital_plane), which is similar to the axial tilt of Earth.[[7]](https://en.wikipedia.org/wiki/Mars#cite_note-nssdc-8) As a result, Mars has seasons like Earth, though on Mars, they are nearly twice as long because its orbital period is that much longer. In the present day epoch, the orientation of the [north pole](https://en.wikipedia.org/wiki/North_pole) of Mars is close to the star [Deneb](https://en.wikipedia.org/wiki/Deneb).[[12]](https://en.wikipedia.org/wiki/Mars#cite_note-barlow08-13) Mars passed an [aphelion](https://en.wikipedia.org/wiki/Aphelion) in March 2010[[173]](https://en.wikipedia.org/wiki/Mars#cite_note-mars2010-175) and its [perihelion](https://en.wikipedia.org/wiki/Perihelion) in March 2011.[[174]](https://en.wikipedia.org/wiki/Mars#cite_note-Mars2011-176) The next aphelion came in February 2012[[174]](https://en.wikipedia.org/wiki/Mars#cite_note-Mars2011-176)and the next perihelion came in January 2013.[[174]](https://en.wikipedia.org/wiki/Mars#cite_note-Mars2011-176)

Mars has a relatively pronounced [orbital eccentricity](https://en.wikipedia.org/wiki/Orbital_eccentricity) of about 0.09; of the seven other planets in the Solar System, only [Mercury](https://en.wikipedia.org/wiki/Mercury_(planet)) has a larger orbital eccentricity. It is known that in the past, Mars has had a much more circular orbit. At one point, 1.35 million Earth years ago, Mars had an eccentricity of roughly 0.002, much less than that of Earth today.[[175]](https://en.wikipedia.org/wiki/Mars#cite_note-mars_eccentricity-177) Mars's cycle of eccentricity is 96,000 Earth years compared to Earth's cycle of 100,000 years.[[176]](https://en.wikipedia.org/wiki/Mars#cite_note-Meeus2003-178) Mars has a much longer cycle of eccentricity with a period of 2.2 million Earth years, and this overshadows the 96,000-year cycle in the eccentricity graphs. For the last 35,000 years, the orbit of Mars has been getting slightly more eccentric because of the gravitational effects of the other planets. The closest distance between Earth and Mars will continue to mildly decrease for the next 25,000 years.[[177]](https://en.wikipedia.org/wiki/Mars#cite_note-Baalke2003-179)

## Habitability and search for life

### Search for life

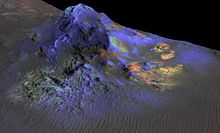
*Main articles:*[*Life on Mars*](https://en.wikipedia.org/wiki/Life_on_Mars)*and*[*Viking lander biological experiments*](https://en.wikipedia.org/wiki/Viking_lander_biological_experiments)

[](https://en.wikipedia.org/wiki/File:Mars_Viking_11d128.png)

Viking 1 lander's sampling arm scooped up soil samples for tests ([Chryse Planitia](https://en.wikipedia.org/wiki/Chryse_Planitia))

The current understanding of [planetary habitability](https://en.wikipedia.org/wiki/Planetary_habitability)—the ability of a world to develop environmental conditions favorable to the emergence of life—favors planets that have liquid water on their surface. Most often this requires the orbit of a planet to lie within the [habitable zone](https://en.wikipedia.org/wiki/Planetary_Habitability_Index), which for the Sun extends from just beyond Venus to about the [semi-major axis](https://en.wikipedia.org/wiki/Semi-major_axis) of Mars.[[178]](https://en.wikipedia.org/wiki/Mars#cite_note-Nowack-180) During perihelion, Mars dips inside this region, but Mars's thin (low-pressure) atmosphere prevents liquid water from existing over large regions for extended periods. The past flow of liquid water demonstrates the planet's potential for habitability. Recent evidence has suggested that any water on the Martian surface may have been too salty and acidic to support regular terrestrial life.[[179]](https://en.wikipedia.org/wiki/Mars#cite_note-saltlife-181)

The lack of a magnetosphere and the extremely thin atmosphere of Mars are a challenge: the planet has little [heat transfer](https://en.wikipedia.org/wiki/Heat_transfer) across its surface, poor insulation against bombardment of the [solar wind](https://en.wikipedia.org/wiki/Solar_wind) and insufficient atmospheric pressure to retain water in a liquid form (water instead [sublimes](https://en.wikipedia.org/wiki/Sublimation_(phase_transition)) to a gaseous state). Mars is nearly, or perhaps totally, geologically dead; the end of volcanic activity has apparently stopped the recycling of chemicals and minerals between the surface and interior of the planet.[[180]](https://en.wikipedia.org/wiki/Mars#cite_note-hannsson97-182)

[](https://en.wikipedia.org/wiki/File:PIA19673-Mars-AlgaCrater-ImpactGlassDetected-MRO-20150608.jpg)

Detection of [impact glass](https://en.wikipedia.org/wiki/Impactite) deposits (green spots) at [Alga crater](https://en.wikipedia.org/wiki/List_of_craters_on_Mars:_A-G), a possible site for preserved [ancient life](https://en.wikipedia.org/wiki/Life_on_Mars)[[181]](https://en.wikipedia.org/wiki/Mars#cite_note-NASA-20150608-183)

Evidence suggests that the planet was once significantly more habitable than it is today, but whether living [organisms](https://en.wikipedia.org/wiki/Organism) ever existed there remains unknown. The [Viking probes](https://en.wikipedia.org/wiki/Viking_probes) of the mid-1970s carried experiments designed to detect microorganisms in Martian soil at their respective landing sites and had positive results, including a temporary increase of CO2 production on exposure to water and nutrients. This sign of life was later disputed by scientists, resulting in a continuing debate, with NASA scientist [Gilbert Levin](https://en.wikipedia.org/wiki/Gilbert_Levin) asserting that Viking may have found life. A re-analysis of the Viking data, in light of modern knowledge of [extremophile](https://en.wikipedia.org/wiki/Extremophile) forms of life, has suggested that the Viking tests were not sophisticated enough to detect these forms of life. The tests could even have killed a (hypothetical) life form.[[182]](https://en.wikipedia.org/wiki/Mars#cite_note-physorg070107-184) Tests conducted by the Phoenix Mars lander have shown that the soil has a [alkaline](https://en.wikipedia.org/wiki/Alkaline) [pH](https://en.wikipedia.org/wiki/PH) and it contains magnesium, sodium, potassium and chloride.[[183]](https://en.wikipedia.org/wiki/Mars#cite_note-nutrient-185) The soil nutrients may be able to support life, but life would still have to be shielded from the intense ultraviolet light.[[184]](https://en.wikipedia.org/wiki/Mars#cite_note-UV-186) A recent analysis of martian meteorite EETA79001 found 0.6 ppm ClO4−, 1.4 ppm ClO3−, and 16 ppm NO3−, most likely of martian origin. The ClO3− suggests presence of other highly oxidizing oxychlorines such as ClO2− or ClO, produced both by UV oxidation of Cl and X-ray radiolysis of ClO4−. Thus only highly refractory and/or well-protected (sub-surface) organics or life forms are likely to survive.[[185]](https://en.wikipedia.org/wiki/Mars#cite_note-187) A 2014 analysis of the Phoenix WCL showed that the Ca(ClO4)2 in the Phoenix soil has not interacted with liquid water of any form, perhaps for as long as 600 Myr. If it had, the highly soluble Ca(ClO4)2 in contact with liquid water would have formed only CaSO4. This suggests a severely arid environment, with minimal or no liquid water interaction.[[186]](https://en.wikipedia.org/wiki/Mars#cite_note-188)

Scientists have proposed that carbonate globules found in [meteorite](https://en.wikipedia.org/wiki/Meteorite) [ALH84001](https://en.wikipedia.org/wiki/Allan_Hills_84001), which is thought to have originated from Mars, could be fossilized microbes extant on Mars when the meteorite was blasted from the Martian surface by a meteor strike some 15 million years ago. This proposal has been met with skepticism, and an exclusively inorganic origin for the shapes has been proposed.[[187]](https://en.wikipedia.org/wiki/Mars#cite_note-am89-189)

Small quantities of [methane](https://en.wikipedia.org/wiki/Methane) and [formaldehyde](https://en.wikipedia.org/wiki/Formaldehyde) detected by Mars orbiters are both claimed to be possible evidence for life, as these [chemical compounds](https://en.wikipedia.org/wiki/Chemical_compound) would quickly break down in the Martian atmosphere.[[188]](https://en.wikipedia.org/wiki/Mars#cite_note-icarus172-190)[[189]](https://en.wikipedia.org/wiki/Mars#cite_note-form-191) Alternatively, these compounds may instead be replenished by volcanic or other geological means, such as [serpentinization](https://en.wikipedia.org/wiki/Serpentinization).[[151]](https://en.wikipedia.org/wiki/Mars#cite_note-olivine-153)

[Impact glass](https://en.wikipedia.org/wiki/Impactite), formed by the impact of meteors, which on Earth can preserve signs of life, has been found on the surface of the impact craters on Mars.[[190]](https://en.wikipedia.org/wiki/Mars#cite_note-brown20140418-192)[[191]](https://en.wikipedia.org/wiki/Mars#cite_note-Schultz2014-193) Likewise, the glass in impact craters on Mars could have preserved signs of life if life existed at the site.[[192]](https://en.wikipedia.org/wiki/Mars#cite_note-nasapr20150608-194)[[193]](https://en.wikipedia.org/wiki/Mars#cite_note-brown20150608-195)[[194]](https://en.wikipedia.org/wiki/Mars#cite_note-sciam20150612-196)

## Moons

*Main articles:*[*Moons of Mars*](https://en.wikipedia.org/wiki/Moons_of_Mars)*,*[*Phobos (moon)*](https://en.wikipedia.org/wiki/Phobos_(moon))*, and*[*Deimos (moon)*](https://en.wikipedia.org/wiki/Deimos_(moon))

[](https://en.wikipedia.org/wiki/File:Phobos_colour_2008.jpg)

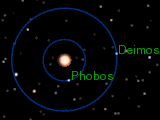
Enhanced-color HiRISE image of [Phobos](https://en.wikipedia.org/wiki/Phobos_(moon)), showing a series of mostly parallel grooves and[crater chains](https://en.wikipedia.org/wiki/Crater_chain), with [Stickney crater](https://en.wikipedia.org/wiki/Stickney_(crater)) at right

[](https://en.wikipedia.org/wiki/File:Deimos-MRO.jpg)

Enhanced-color HiRISE image of [Deimos](https://en.wikipedia.org/wiki/Deimos_(moon)) (not to scale), showing its smooth blanket of[regolith](https://en.wikipedia.org/wiki/Regolith)

Mars has two relatively small natural moons, [Phobos](https://en.wikipedia.org/wiki/Phobos_(moon)) (about 22 km (14 mi) in diameter) and [Deimos](https://en.wikipedia.org/wiki/Deimos_(moon)) (about 12 km (7.5 mi) in diameter), which orbit close to the planet. Asteroid capture is a long-favored theory, but their origin remains uncertain.[[195]](https://en.wikipedia.org/wiki/Mars#cite_note-esa31031-197) Both satellites were discovered in 1877 by [Asaph Hall](https://en.wikipedia.org/wiki/Asaph_Hall); they are named after the characters [Phobos](https://en.wikipedia.org/wiki/Phobos_(mythology)) (panic/fear) and [Deimos](https://en.wikipedia.org/wiki/Deimos_(mythology)) (terror/dread), who, in [Greek mythology](https://en.wikipedia.org/wiki/Greek_mythology), accompanied their father [Ares](https://en.wikipedia.org/wiki/Ares), god of war, into battle. Mars was the Roman counterpart of Ares.[[196]](https://en.wikipedia.org/wiki/Mars#cite_note-theoi-198)[[197]](https://en.wikipedia.org/wiki/Mars#cite_note-qjras19-199) In modern [Greek](https://en.wikipedia.org/wiki/Greek_language), though, the planet retains its ancient name *Ares* (Aris: *Άρης*).[[198]](https://en.wikipedia.org/wiki/Mars#cite_note-Greek_Names_of_the_Planets-200)

From the surface of Mars, the motions of Phobos and Deimos appear different from that of the [Moon](https://en.wikipedia.org/wiki/Moon). Phobos rises in the west, sets in the east, and rises again in just 11 hours. Deimos, being only just outside [synchronous orbit](https://en.wikipedia.org/wiki/Synchronous_orbit) – where the orbital period would match the planet's period of rotation – rises as expected in the east but slowly. Despite the 30-hour orbit of Deimos, 2.7 days elapse between its rise and set for an equatorial observer, as it slowly falls behind the rotation of Mars.[[199]](https://en.wikipedia.org/wiki/Mars#cite_note-phobos.html-201)

[](https://en.wikipedia.org/wiki/File:Orbits_of_Phobos_and_Deimos.gif)

Orbits of Phobos and Deimos (to scale)

Because the orbit of Phobos is below synchronous altitude, the [tidal forces](https://en.wikipedia.org/wiki/Tidal_force) from the planet Mars are gradually lowering its orbit. In about 50 million years, it could either crash into Mars's surface or break up into a ring structure around the planet.[[199]](https://en.wikipedia.org/wiki/Mars#cite_note-phobos.html-201)

The origin of the two moons is not well understood. Their low albedo and [carbonaceous chondrite](https://en.wikipedia.org/wiki/Carbonaceous_chondrite) composition have been regarded as similar to asteroids, supporting the capture theory. The unstable orbit of Phobos would seem to point towards a relatively recent capture. But both have [circular orbits](https://en.wikipedia.org/wiki/Circular_orbit), near the equator, which is unusual for captured objects and the required capture dynamics are complex. Accretion early in the history of Mars is plausible, but would not account for a composition resembling asteroids rather than Mars itself, if that is confirmed.

A third possibility is the involvement of a third body or a type of impact disruption.[[200]](https://en.wikipedia.org/wiki/Mars#cite_note-ellis07-202) More-recent lines of evidence for Phobos having a highly porous interior,[[201]](https://en.wikipedia.org/wiki/Mars#cite_note-Andert-203) and suggesting a composition containing mainly [phyllosilicates](https://en.wikipedia.org/wiki/Phyllosilicates) and other minerals known from Mars,[[202]](https://en.wikipedia.org/wiki/Mars#cite_note-Giuranna-204) point toward an origin of Phobos from material ejected by an impact on Mars that reaccreted in Martian orbit,[[203]](https://en.wikipedia.org/wiki/Mars#cite_note-Blast-205) similar to the[prevailing theory](https://en.wikipedia.org/wiki/Giant_impact_hypothesis) for the origin of Earth's moon. Although the [VNIR](https://en.wikipedia.org/wiki/VNIR) spectra of the moons of Mars resemble those of outer-belt asteroids, the [thermal infrared](https://en.wikipedia.org/wiki/Thermal_infrared) spectra of Phobos are reported to be inconsistent with [chondrites](https://en.wikipedia.org/wiki/Chondrite) of any class.[[202]](https://en.wikipedia.org/wiki/Mars#cite_note-Giuranna-204)

Mars may have moons smaller than 50 to 100 metres (160 to 330 ft) in diameter, and a dust ring is predicted to exist between Phobos and Deimos.[[19]](https://en.wikipedia.org/wiki/Mars#cite_note-adler-20)

## Exploration

*Main article:*[*Exploration of Mars*](https://en.wikipedia.org/wiki/Exploration_of_Mars)

[](https://en.wikipedia.org/wiki/File:Sol454_Marte_spirit.jpg)

Panorama of [Gusev crater](https://en.wikipedia.org/wiki/Gusev_(Martian_crater)), where*Spirit* rover examined volcanic basalts

Dozens of crewless [spacecraft](https://en.wikipedia.org/wiki/Spacecraft), including [orbiters](https://en.wikipedia.org/wiki/Orbiter), [landers](https://en.wikipedia.org/wiki/Mars_lander), and [rovers](https://en.wikipedia.org/wiki/Mars_rover), have been sent to Mars by the [Soviet Union](https://en.wikipedia.org/wiki/Soviet_space_program), the [United States](https://en.wikipedia.org/wiki/NASA), [Europe](https://en.wikipedia.org/wiki/ESA), and [India](https://en.wikipedia.org/wiki/ISRO) to study the planet's surface, climate, and geology. Presently, information is being relayed from seven active probes on or in-orbit around Mars, including five orbiters and two rovers. This includes [*2001 Mars Odyssey*](https://en.wikipedia.org/wiki/2001_Mars_Odyssey),[[204]](https://en.wikipedia.org/wiki/Mars#cite_note-nasa081009-206) [*Mars Express*](https://en.wikipedia.org/wiki/Mars_Express), [*Mars Reconnaissance Orbiter*](https://en.wikipedia.org/wiki/Mars_Reconnaissance_Orbiter) (MRO, [MAVEN](https://en.wikipedia.org/wiki/MAVEN), [Mars Orbiter Mission](https://en.wikipedia.org/wiki/Mars_Orbiter_Mission),[*Opportunity*](https://en.wikipedia.org/wiki/Opportunity_(rover)), and [*Curiosity*](https://en.wikipedia.org/wiki/Curiosity_(rover)). The public can request MRO images of Mars via the [HiWish program](https://en.wikipedia.org/wiki/HiWish_program).

The [Mars Science Laboratory](https://en.wikipedia.org/wiki/Mars_Science_Laboratory), named *Curiosity*, launched on November 26, 2011, and reached Mars on August 6, 2012 [UTC](https://en.wikipedia.org/wiki/UTC). It is larger and more advanced than the Mars Exploration Rovers, with a movement rate up to 90 m (300 ft) per hour.[[205]](https://en.wikipedia.org/wiki/Mars#cite_note-home-207) Experiments include a laser chemical sampler that can deduce the make-up of rocks at a distance of 7 m (23 ft).[[206]](https://en.wikipedia.org/wiki/Mars#cite_note-laser-208) On February 10, 2013, the [*Curiosity* rover](https://en.wikipedia.org/wiki/Mars_Science_Laboratory) obtained the first deep rock samples ever taken from another planetary body, using its on-board drill.[[207]](https://en.wikipedia.org/wiki/Mars#cite_note-209)

On September 24, 2014, [Mars Orbiter Mission](https://en.wikipedia.org/wiki/Mars_Orbiter_Mission) (MOM), launched by the [Indian Space Research Organisation](https://en.wikipedia.org/wiki/Indian_Space_Research_Organisation), reached Mars orbit. ISRO launched MOM on November 5, 2013, with the aim of analyzing the Martian atmosphere and topography. The Mars Orbiter Mission used a [Hohmann transfer orbit](https://en.wikipedia.org/wiki/Hohmann_transfer_orbit) to escape Earth's gravitational influence and catapult into a nine-month-long voyage to Mars. The mission is the first successful Asian interplanetary mission.[[208]](https://en.wikipedia.org/wiki/Mars#cite_note-210)

### Future

*Main article:*[*Exploration of Mars § Timeline of Mars exploration*](https://en.wikipedia.org/wiki/Exploration_of_Mars#Timeline_of_Mars_exploration)

Planned for March 2016 is the launch of the [InSight](https://en.wikipedia.org/wiki/InSight) lander, together with two identical [CubeSats](https://en.wikipedia.org/wiki/CubeSat) that will fly by Mars and provide landing [telemetry](https://en.wikipedia.org/wiki/Telemetry). The lander and CubeSats are planned to arrive at Mars in September 2016.[[209]](https://en.wikipedia.org/wiki/Mars#cite_note-211)

The [European Space Agency](https://en.wikipedia.org/wiki/European_Space_Agency), in collaboration with [Roscosmos](https://en.wikipedia.org/wiki/Russian_Federal_Space_Agency), will deploy the [ExoMars Trace Gas Orbiter](https://en.wikipedia.org/wiki/ExoMars_Trace_Gas_Orbiter) and [*Schiaparelli* lander](https://en.wikipedia.org/wiki/ExoMars#Schiaparelli_EDM_lander) in 2016, and the [ExoMars rover](https://en.wikipedia.org/wiki/ExoMars_rover) in 2018. NASA plans to launch its [Mars 2020](https://en.wikipedia.org/wiki/Mars_2020) [astrobiology](https://en.wikipedia.org/wiki/Astrobiology) rover in 2020.

The United Arab Emirates' [*Mars Hope*](https://en.wikipedia.org/wiki/Mars_Hope) orbiter is planned for launch in 2020, reaching Mars orbit in 2021. The probe will make a global study of the Martian atmosphere.[[210]](https://en.wikipedia.org/wiki/Mars#cite_note-212)

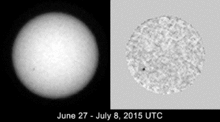
Several plans for a [human mission to Mars](https://en.wikipedia.org/wiki/Human_mission_to_Mars) have been proposed throughout the 20th century and into the 21st century, but no active plan has an arrival date sooner than 2025.

## Astronomy on Mars

*Main article:*[*Astronomy on Mars*](https://en.wikipedia.org/wiki/Astronomy_on_Mars)

[](https://en.wikipedia.org/wiki/File:15-ml-06-phobos2-A067R1.jpg)

[Phobos](https://en.wikipedia.org/wiki/Phobos_(moon)) [transits](https://en.wikipedia.org/wiki/Transit_(astronomy)) the [Sun](https://en.wikipedia.org/wiki/Sun)([*Opportunity*](https://en.wikipedia.org/wiki/Opportunity_(rover)); March 10, 2004)

[](https://en.wikipedia.org/wiki/File:PIA19801-TrackingSunspotsOnTheSunFromMars-20150708.gif)

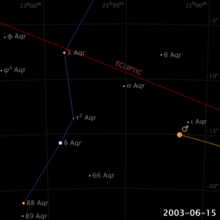
Tracking [sunspots](https://en.wikipedia.org/wiki/Sunspot) from Mars

With the existence of various orbiters, landers, and rovers, it is possible to do [astronomy](https://en.wikipedia.org/wiki/Astronomy) from Mars. Although Mars's moon Phobos appears about one third the [angular diameter](https://en.wikipedia.org/wiki/Angular_diameter) of the full moon on Earth, Deimos appears more or less star-like and appears only slightly brighter than Venus does from Earth.[[211]](https://en.wikipedia.org/wiki/Mars#cite_note-pl_org_deimos-213)

There are various phenomena, well-known on Earth, that have been observed on Mars, such as [meteors](https://en.wikipedia.org/wiki/Meteor) and [auroras](https://en.wikipedia.org/wiki/Aurora).[[212]](https://en.wikipedia.org/wiki/Mars#cite_note-aurora-214) A [transit of Earth as seen from Mars](https://en.wikipedia.org/wiki/Transit_of_Earth_from_Mars) will occur on November 10, 2084.[[213]](https://en.wikipedia.org/wiki/Mars#cite_note-jbaa93-215) There are [transits of Mercury](https://en.wikipedia.org/wiki/Transit_of_Mercury_from_Mars) and [transits of Venus](https://en.wikipedia.org/w/index.php?title=Transit_of_Venus_from_Mars&action=edit&redlink=1), and the moons Phobos and Deimos are of sufficiently small [angular diameter](https://en.wikipedia.org/wiki/Angular_diameter) that their partial "eclipses" of the Sun are best considered transits (see [Transit of Deimos from Mars](https://en.wikipedia.org/wiki/Transit_of_Deimos_from_Mars)).[[214]](https://en.wikipedia.org/wiki/Mars#cite_note-nature436-216)[[215]](https://en.wikipedia.org/wiki/Mars#cite_note-sd040317-217)

On October 19, 2014, [Comet Siding Spring](https://en.wikipedia.org/wiki/C/2013_A1) passed extremely close to Mars, so close that the [coma](https://en.wikipedia.org/wiki/Comae) may have enveloped Mars.[[216]](https://en.wikipedia.org/wiki/Mars#cite_note-NASA-20141019-218)[[217]](https://en.wikipedia.org/wiki/Mars#cite_note-NYT-20141019-219)[[218]](https://en.wikipedia.org/wiki/Mars#cite_note-ESA-20141020-220)[[219]](https://en.wikipedia.org/wiki/Mars#cite_note-ISRO_MOM_safe_after_Mars_comet_flyby-221)[[220]](https://en.wikipedia.org/wiki/Mars#cite_note-SD-20131201-222)[[221]](https://en.wikipedia.org/wiki/Mars#cite_note-NS-20131206-223)

## Viewing

[](https://en.wikipedia.org/wiki/File:Apparent_retrograde_motion_of_Mars_in_2003.gif)

Animation of the apparent retrograde motion of Mars in 2003 as seen from Earth

Because the orbit of Mars is eccentric, its [apparent magnitude](https://en.wikipedia.org/wiki/Apparent_magnitude) at opposition from the Sun can range from −3.0 to −1.4. The minimum brightness is magnitude +1.6 when the planet is in conjunction with the Sun.[[9]](https://en.wikipedia.org/wiki/Mars#cite_note-MallamaSky-10) Mars usually appears distinctly yellow, orange, or red; the actual color of Mars is closer to [butterscotch](https://en.wikipedia.org/wiki/Butterscotch), and the redness seen is just dust in the planet's atmosphere. [NASA](https://en.wikipedia.org/wiki/NASA)'s *Spirit* rover has taken pictures of a greenish-brown, mud-colored landscape with blue-grey rocks and patches of light red sand.[[222]](https://en.wikipedia.org/wiki/Mars#cite_note-lloyd06-224) When farthest away from Earth, it is more than seven times farther away than when it is closest. When least favorably positioned, it can be lost in the Sun's glare for months at a time. At its most favorable times—at 15- or 17-year intervals, and always between late July and late September—a lot of surface detail can be seen with a [telescope](https://en.wikipedia.org/wiki/Telescope). Especially noticeable, even at low magnification, are the [polar ice caps](https://en.wikipedia.org/wiki/Polar_ice_cap).[[223]](https://en.wikipedia.org/wiki/Mars#cite_note-shallowsky-225)

As Mars approaches opposition, it begins a period of [retrograde motion](https://en.wikipedia.org/wiki/Apparent_retrograde_motion), which means it will appear to move backwards in a looping motion with respect to the background stars. The duration of this retrograde motion lasts for about 72 days, and Mars reaches its peak luminosity in the middle of this motion.[[224]](https://en.wikipedia.org/wiki/Mars#cite_note-zeilik02-226)

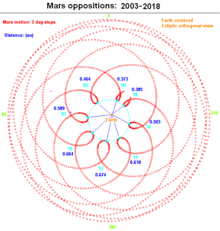
### Closest approaches

#### Relative

The point at which Mars's geocentric longitude is 180° different from the Sun's is known as [opposition](https://en.wikipedia.org/wiki/Opposition_(planets)), which is near the time of closest approach to Earth. The time of opposition can occur as much as 8.5 days away from the closest approach. The distance at close approach varies between about 54[[225]](https://en.wikipedia.org/wiki/Mars#cite_note-Laskar2003-227) and about 103 million km due to the planets' [elliptical](https://en.wikipedia.org/wiki/Ellipse) orbits, which causes comparable variation in [angular size](https://en.wikipedia.org/wiki/Angular_size).[[226]](https://en.wikipedia.org/wiki/Mars#cite_note-nasa051103-228) The last Mars opposition occurred on April 8, 2014 at a distance of about 93 million km.[[227]](https://en.wikipedia.org/wiki/Mars#cite_note-sheehan970202-229) The next Mars opposition occurs on May 22, 2016 at a distance of 76 million km.[[227]](https://en.wikipedia.org/wiki/Mars#cite_note-sheehan970202-229) The average time between the successive oppositions of Mars, its [synodic period](https://en.wikipedia.org/wiki/Synodic_period), is 780 days but the number of days between the dates of successive oppositions can range from 764 to 812.[[228]](https://en.wikipedia.org/wiki/Mars#cite_note-astropro-230)

As Mars approaches opposition it begins a period of [retrograde motion](https://en.wikipedia.org/wiki/Apparent_retrograde_motion), which makes it appear to move backwards in a looping motion relative to the background stars. The duration of this retrograde motion is about 72 days.

#### Absolute, around the present time

[](https://en.wikipedia.org/wiki/File:Mars_oppositions_2003-2018.png)

Mars oppositions from 2003–2018, viewed from above the ecliptic with Earth centered

Mars made its closest approach to Earth and maximum apparent brightness in nearly 60,000 years, 55,758,006 km (0.37271925 AU; 34,646,419 mi), [magnitude](https://en.wikipedia.org/wiki/Magnitude_(astronomy)) −2.88, on August 27, 2003 at 9:51:13 UT. This occurred when Mars was one day from opposition and about three days from its [perihelion](https://en.wikipedia.org/wiki/Perihelion), making it particularly easy to see from Earth. The last time it came so close is estimated to have been on September 12, [57 617 BC](https://en.wikipedia.org/wiki/Middle_Paleolithic), the next time being in 2287.[[229]](https://en.wikipedia.org/wiki/Mars#cite_note-rao030822-231) This record approach was only slightly closer than other recent close approaches. For instance, the minimum distance on August 22, 1924 was 0.37285 [AU](https://en.wikipedia.org/wiki/Astronomical_unit), and the minimum distance on August 24, 2208 will be 0.37279 [AU](https://en.wikipedia.org/wiki/Astronomical_unit).[[176]](https://en.wikipedia.org/wiki/Mars#cite_note-Meeus2003-178)

## Historical observations

*Main article:*[*History of Mars observation*](https://en.wikipedia.org/wiki/History_of_Mars_observation)

The history of observations of Mars is marked by the oppositions of Mars, when the planet is closest to Earth and hence is most easily visible, which occur every couple of years. Even more notable are the perihelic oppositions of Mars, which occur every 15 or 17 years and are distinguished because Mars is close to perihelion, making it even closer to Earth.

### Ancient and medieval observations

The existence of Mars as a wandering object in the night sky was recorded by the ancient [Egyptian astronomers](https://en.wikipedia.org/wiki/Egyptian_astronomy) and by 1534 BCE they were familiar with the [retrograde motion](https://en.wikipedia.org/wiki/Retrograde_motion) of the planet.[[230]](https://en.wikipedia.org/wiki/Mars#cite_note-paob85-232) By the period of the [Neo-Babylonian Empire](https://en.wikipedia.org/wiki/Neo-Babylonian_Empire), the [Babylonian astronomers](https://en.wikipedia.org/wiki/Babylonian_astronomers) were making regular records of the positions of the planets and systematic observations of their behavior. For Mars, they knew that the planet made 37 [synodic periods](https://en.wikipedia.org/wiki/Synodic_period), or 42 circuits of the zodiac, every 79 years. They invented arithmetic methods for making minor corrections to the predicted positions of the planets.[[231]](https://en.wikipedia.org/wiki/Mars#cite_note-north08-233)[[232]](https://en.wikipedia.org/wiki/Mars#cite_note-swerdlow98-234)

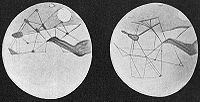
In the fourth century BCE, [Aristotle](https://en.wikipedia.org/wiki/Aristotle) noted that Mars disappeared behind the Moon during an [occultation](https://en.wikipedia.org/wiki/Occultation), indicating the planet was farther away.[[233]](https://en.wikipedia.org/wiki/Mars#cite_note-poor08-235) [Ptolemy](https://en.wikipedia.org/wiki/Ptolemy), a Greek living in [Alexandria](https://en.wikipedia.org/wiki/Alexandria),[[234]](https://en.wikipedia.org/wiki/Mars#cite_note-google-236) attempted to address the problem of the orbital motion of Mars. Ptolemy's model and his collective work on astronomy was presented in the multi-volume collection [*Almagest*](https://en.wikipedia.org/wiki/Almagest), which became the authoritative treatise on [Western astronomy](https://en.wikipedia.org/wiki/History_of_astronomy#Medieval_Western_Europe) for the next fourteen centuries.[[235]](https://en.wikipedia.org/wiki/Mars#cite_note-google7-237) Literature from ancient China confirms that Mars was known by[Chinese astronomers](https://en.wikipedia.org/wiki/Chinese_astronomy) by no later than the fourth century BCE.[[236]](https://en.wikipedia.org/wiki/Mars#cite_note-needham_ronan85-238) In the fifth century CE, the [Indian astronomical](https://en.wikipedia.org/wiki/Indian_astronomy) text [*Surya Siddhanta*](https://en.wikipedia.org/wiki/Surya_Siddhanta) estimated the diameter of Mars.[[237]](https://en.wikipedia.org/wiki/Mars#cite_note-jse97-239) In the [East Asian](https://en.wikipedia.org/wiki/East_Asian) cultures, Mars is traditionally referred to as the "fire star" (火星), based on the [Five elements](https://en.wikipedia.org/wiki/Five_elements_(Chinese_philosophy)).[[238]](https://en.wikipedia.org/wiki/Mars#cite_note-240)[[239]](https://en.wikipedia.org/wiki/Mars#cite_note-241)[[240]](https://en.wikipedia.org/wiki/Mars#cite_note-242)

During the seventeenth century, [Tycho Brahe](https://en.wikipedia.org/wiki/Tycho_Brahe) measured the [diurnal parallax](https://en.wikipedia.org/wiki/Diurnal_parallax) of Mars that [Johannes Kepler](https://en.wikipedia.org/wiki/Johannes_Kepler) used to make a preliminary calculation of the relative distance to the planet.[[241]](https://en.wikipedia.org/wiki/Mars#cite_note-taton03-243) When the telescope became available, the diurnal parallax of Mars was again measured in an effort to determine the Sun-Earth distance. This was first performed by [Giovanni Domenico Cassini](https://en.wikipedia.org/wiki/Giovanni_Domenico_Cassini) in 1672. The early parallax measurements were hampered by the quality of the instruments.[[242]](https://en.wikipedia.org/wiki/Mars#cite_note-hirschfeld01-244) The only [occultation](https://en.wikipedia.org/wiki/Occultation) of Mars by Venus observed was that of October 13, 1590, seen by [Michael Maestlin](https://en.wikipedia.org/wiki/Michael_Maestlin) at [Heidelberg](https://en.wikipedia.org/wiki/Heidelberg).[[243]](https://en.wikipedia.org/wiki/Mars#cite_note-sat57-245) In 1610, Mars was viewed by [Galileo Galilei](https://en.wikipedia.org/wiki/Galileo_Galilei), who was first to see it via telescope.[[244]](https://en.wikipedia.org/wiki/Mars#cite_note-jha15-246) The first person to draw a map of Mars that displayed any terrain features was the Dutch astronomer[Christiaan Huygens](https://en.wikipedia.org/wiki/Christiaan_Huygens).[[245]](https://en.wikipedia.org/wiki/Mars#cite_note-arizona-247)

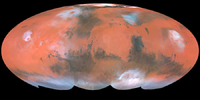
### Martian "canals"

[](https://en.wikipedia.org/wiki/File:Karte_Mars_Schiaparelli_MKL1888.png)

Map of Mars by Giovanni Schiaparelli

[](https://en.wikipedia.org/wiki/File:Lowell_Mars_channels.jpg)

Mars sketched as observed by Lowell before 1914 (south on top)

[](https://en.wikipedia.org/wiki/File:Mars_HST_Mollweide_map_1999.png)

Map of Mars from the [*Hubble Space Telescope*](https://en.wikipedia.org/wiki/Hubble_Space_Telescope) as seen near the 1999 opposition (north on top)

*Main article:*[*Martian canal*](https://en.wikipedia.org/wiki/Martian_canal)

By the 19th century, the resolution of telescopes reached a level sufficient for surface features to be identified. A perihelic opposition of Mars occurred on September 5, 1877. In that year, Italian astronomer [Giovanni Schiaparelli](https://en.wikipedia.org/wiki/Giovanni_Schiaparelli)used a 22 cm (8.7 in) telescope in [Milan](https://en.wikipedia.org/wiki/Milan) to help produce the first detailed map of Mars. These maps notably contained features he called *canali*, which were later shown to be an [optical illusion](https://en.wikipedia.org/wiki/Optical_illusion). These *canali* were supposedly long, straight lines on the surface of Mars, to which he gave names of famous rivers on Earth. His term, which means "channels" or "grooves", was popularly mistranslated in English as "canals".[[246]](https://en.wikipedia.org/wiki/Mars#cite_note-snyder01-248)[[247]](https://en.wikipedia.org/wiki/Mars#cite_note-sagan80-249)

Influenced by the observations, the orientalist [Percival Lowell](https://en.wikipedia.org/wiki/Percival_Lowell) founded an [observatory](https://en.wikipedia.org/wiki/Lowell_Observatory) which had 30 and 45 cm (12 and 18 in) telescopes. The observatory was used for the exploration of Mars during the last good opportunity in 1894 and the following less favorable oppositions. He published several books on Mars and life on the planet, which had a great influence on the public.[[248]](https://en.wikipedia.org/wiki/Mars#cite_note-basalla06-250)[[249]](https://en.wikipedia.org/wiki/Mars#cite_note-NYT-20151001-251) The *canali* were independently found by other astronomers, like[Henri Joseph Perrotin](https://en.wikipedia.org/wiki/Henri_Joseph_Perrotin) and [Louis Thollon](https://en.wikipedia.org/wiki/Louis_Thollon) in Nice, using one of the largest telescopes of that time.[[250]](https://en.wikipedia.org/wiki/Mars#cite_note-maria_lane05-252)[[251]](https://en.wikipedia.org/wiki/Mars#cite_note-ba3-253)

The seasonal changes (consisting of the diminishing of the polar caps and the dark areas formed during Martian summer) in combination with the canals lead to speculation about life on Mars, and it was a long-held belief that Mars contained vast seas and vegetation. The telescope never reached the resolution required to give proof to any speculations. As bigger telescopes were used, fewer long, straight *canali* were observed. During an observation in 1909 by [Flammarion](https://en.wikipedia.org/wiki/Camille_Flammarion) with an 84 cm (33 in) telescope, irregular patterns were observed, but no *canali* were seen.[[252]](https://en.wikipedia.org/wiki/Mars#cite_note-zahnle01-254)

Even in the 1960s articles were published on Martian biology, putting aside explanations other than life for the seasonal changes on Mars. Detailed scenarios for the metabolism and chemical cycles for a functional ecosystem have been published.[[253]](https://en.wikipedia.org/wiki/Mars#cite_note-science136_3510-255)

### Spacecraft visitation

*Main article:*[*Exploration of Mars*](https://en.wikipedia.org/wiki/Exploration_of_Mars)

Once [spacecraft](https://en.wikipedia.org/wiki/Spacecraft) visited the planet during NASA's [Mariner missions](https://en.wikipedia.org/wiki/Mariner_program) in the 1960s and 70s these concepts were radically broken. The results of the Viking life-detection experiments aided an intermission in which the hypothesis of a hostile, dead planet was generally accepted.[[254]](https://en.wikipedia.org/wiki/Mars#cite_note-ward_brownlee00-256)

Mariner 9 and Viking allowed better maps of Mars to be made using the data from these missions, and another major leap forward was the [Mars Global Surveyor](https://en.wikipedia.org/wiki/Mars_Global_Surveyor) mission, launched in 1996 and operated until late 2006, that allowed complete, extremely detailed maps of the Martian topography, magnetic field and surface minerals to be obtained.[[255]](https://en.wikipedia.org/wiki/Mars#cite_note-Distant_worlds:_milestones_in_planetary_exploration-257) These maps are available online; for example, at [Google Mars](https://en.wikipedia.org/wiki/Google_Mars). [Mars Reconnaissance Orbiter](https://en.wikipedia.org/wiki/Mars_Reconnaissance_Orbiter) and[Mars Express](https://en.wikipedia.org/wiki/Mars_Express) continued exploring with new instruments, and supporting lander missions. NASA provides two online tools: [Mars Trek](https://en.wikipedia.org/w/index.php?title=Mars_Trek&action=edit&redlink=1), which provides visualizations of the planet using data from 50 years of exploration, and[Experience Curiosity](https://en.wikipedia.org/wiki/Experience_Curiosity), which simulates traveling on Mars in 3-D with Curiosity.[[256]](https://en.wikipedia.org/wiki/Mars#cite_note-258)

## In culture

*Main articles:*[*Mars in culture*](https://en.wikipedia.org/wiki/Mars_in_culture)*and*[*Mars in fiction*](https://en.wikipedia.org/wiki/Mars_in_fiction)

[Mars symbol.svg](https://en.wikipedia.org/wiki/File:Mars_symbol.svg)

Mars is named after the [Roman](https://en.wikipedia.org/wiki/Ancient_Rome) [god of war](https://en.wikipedia.org/wiki/Mars_(mythology)). In different cultures, Mars represents masculinity and youth. [Its symbol](https://en.wikipedia.org/wiki/Gender_symbol), a circle with an arrow pointing out to the upper right, is used as a symbol for the male gender.

The many failures in Mars exploration probes resulted in a satirical counter-culture blaming the failures on an Earth-Mars "[Bermuda Triangle](https://en.wikipedia.org/wiki/Bermuda_Triangle)", a "[Mars Curse](https://en.wikipedia.org/wiki/Exploration_of_Mars#Mars_Curse)", or a "Great Galactic Ghoul" that feeds on Martian spacecraft.[[257]](https://en.wikipedia.org/wiki/Mars#cite_note-dinerman04-259)

### Intelligent "Martians"

*Main article:*[*Mars in fiction*](https://en.wikipedia.org/wiki/Mars_in_fiction)

The fashionable idea that Mars was populated by intelligent [Martians](https://en.wikipedia.org/wiki/Martian) exploded in the late 19th century. [Schiaparelli's](https://en.wikipedia.org/wiki/Giovanni_Schiaparelli) "canali" observations combined with [Percival Lowell](https://en.wikipedia.org/wiki/Percival_Lowell)'s books on the subject put forward the standard notion of a planet that was a drying, cooling, dying world with ancient civilizations constructing irrigation works.[[258]](https://en.wikipedia.org/wiki/Mars#cite_note-prion-260)

[](https://en.wikipedia.org/wiki/File:Kirks_Soap_Yerkes_Mars.jpg)

An 1893 soap ad playing on the popular idea that Mars was populated

Many other observations and proclamations by notable personalities added to what has been termed "Mars Fever".[[259]](https://en.wikipedia.org/wiki/Mars#cite_note-fergus04-261) In 1899 while investigating atmospheric radio noise using his receivers in his Colorado Springs lab, inventor [Nikola Tesla](https://en.wikipedia.org/wiki/Nikola_Tesla) observed repetitive signals that he later surmised might have been radio communications coming from another planet, possibly Mars. In a 1901 interview Tesla said:

It was some time afterward when the thought flashed upon my mind that the disturbances I had observed might be due to an intelligent control. Although I could not decipher their meaning, it was impossible for me to think of them as having been entirely accidental. The feeling is constantly growing on me that I had been the first to hear the greeting of one planet to another.[[260]](https://en.wikipedia.org/wiki/Mars#cite_note-tesla01-262)

Tesla's theories gained support from [Lord Kelvin](https://en.wikipedia.org/wiki/Lord_Kelvin) who, while visiting the United States in 1902, was reported to have said that he thought Tesla had picked up Martian signals being sent to the United States.[[261]](https://en.wikipedia.org/wiki/Mars#cite_note-cheney81-263) Kelvin "emphatically" denied this report shortly before departing America: "What I really said was that the inhabitants of Mars, if there are any, were doubtless able to see New York, particularly the glare of the electricity."[[262]](https://en.wikipedia.org/wiki/Mars#cite_note-nyt020511-264)

In a [*New York Times*](https://en.wikipedia.org/wiki/New_York_Times) article in 1901, [Edward Charles Pickering](https://en.wikipedia.org/wiki/Edward_Charles_Pickering), director of the [Harvard College Observatory](https://en.wikipedia.org/wiki/Harvard_College_Observatory), said that they had received a telegram from [Lowell Observatory](https://en.wikipedia.org/wiki/Lowell_Observatory) in [Arizona](https://en.wikipedia.org/wiki/Arizona) that seemed to confirm that Mars was trying to communicate with Earth.[[263]](https://en.wikipedia.org/wiki/Mars#cite_note-nyt2-265)

Early in December 1900, we received from Lowell Observatory in Arizona a telegram that a shaft of light had been seen to project from Mars (the Lowell observatory makes a specialty of Mars) lasting seventy minutes. I wired these facts to Europe and sent out neostyle copies through this country. The observer there is a careful, reliable man and there is no reason to doubt that the light existed. It was given as from a well-known geographical point on Mars. That was all. Now the story has gone the world over. In Europe it is stated that I have been in communication with Mars, and all sorts of exaggerations have spring up. Whatever the light was, we have no means of knowing. Whether it had intelligence or not, no one can say. It is absolutely inexplicable.[[263]](https://en.wikipedia.org/wiki/Mars#cite_note-nyt2-265)

Pickering later proposed creating a set of mirrors in [Texas](https://en.wikipedia.org/wiki/Texas), intended to signal Martians.[[264]](https://en.wikipedia.org/wiki/Mars#cite_note-fradin99-266)

In recent decades, the high-resolution mapping of the surface of Mars, culminating in [Mars Global Surveyor](https://en.wikipedia.org/wiki/Mars_Global_Surveyor), revealed no artifacts of habitation by "intelligent" life, but pseudoscientific speculation about intelligent life on Mars continues from commentators such as[Richard C. Hoagland](https://en.wikipedia.org/wiki/Richard_C._Hoagland). Reminiscent of the *canali* controversy, these speculations are based on small scale features perceived in the spacecraft images, such as 'pyramids' and the '[Face on Mars](https://en.wikipedia.org/wiki/Face_on_Mars)'. Planetary astronomer [Carl Sagan](https://en.wikipedia.org/wiki/Carl_Sagan) wrote:

Mars has become a kind of mythic arena onto which we have projected our Earthly hopes and fears.[[247]](https://en.wikipedia.org/wiki/Mars#cite_note-sagan80-249)

[](https://en.wikipedia.org/wiki/File:War-of-the-worlds-tripod.jpg)

Martian tripod illustration from the 1906 French edition of *The War of the Worlds* by H. G. Wells

The depiction of Mars in fiction has been stimulated by its dramatic red color and by nineteenth century scientific speculations that its surface conditions might support not just life but intelligent life.[[265]](https://en.wikipedia.org/wiki/Mars#cite_note-lightman97-267) Thus originated a large number of[science fiction](https://en.wikipedia.org/wiki/Science_fiction) scenarios, among which is [H. G. Wells](https://en.wikipedia.org/wiki/H._G._Wells)' [*The War of the Worlds*](https://en.wikipedia.org/wiki/The_War_of_the_Worlds), published in 1898, in which Martians seek to escape their dying planet by invading Earth.

Influential works included [Ray Bradbury](https://en.wikipedia.org/wiki/Ray_Bradbury)'s [*The Martian Chronicles*](https://en.wikipedia.org/wiki/The_Martian_Chronicles), in which human explorers accidentally destroy a Martian civilization, [Edgar Rice Burroughs](https://en.wikipedia.org/wiki/Edgar_Rice_Burroughs)' [*Barsoom* series](https://en.wikipedia.org/wiki/Barsoom), [C. S. Lewis](https://en.wikipedia.org/wiki/C._S._Lewis)' novel [*Out of the Silent Planet*](https://en.wikipedia.org/wiki/Out_of_the_Silent_Planet) (1938),[[266]](https://en.wikipedia.org/wiki/Mars#cite_note-sanford09-268) and a number of [Robert A. Heinlein](https://en.wikipedia.org/wiki/Robert_A._Heinlein) stories before the mid-sixties.[[267]](https://en.wikipedia.org/wiki/Mars#cite_note-buker02-269)

[Jonathan Swift](https://en.wikipedia.org/wiki/Jonathan_Swift) made reference to the moons of Mars, about 150 years before their actual discovery by [Asaph Hall](https://en.wikipedia.org/wiki/Asaph_Hall), detailing reasonably accurate descriptions of their orbits, in the 19th chapter of his novel [*Gulliver's Travels*](https://en.wikipedia.org/wiki/Gulliver%27s_Travels).[[268]](https://en.wikipedia.org/wiki/Mars#cite_note-jonathan_swift-270)

A comic figure of an intelligent Martian, [Marvin the Martian](https://en.wikipedia.org/wiki/Marvin_the_Martian), appeared on television in 1948 as a character in the [Looney Tunes](https://en.wikipedia.org/wiki/Looney_Tunes) [animated cartoons](https://en.wikipedia.org/wiki/Animated_cartoon) of [Warner Brothers](https://en.wikipedia.org/wiki/Warner_Brothers), and has continued as part of popular culture to the present.[[269]](https://en.wikipedia.org/wiki/Mars#cite_note-rabkin05-271) In the 1950s, TV shows such as [*I Love Lucy*](https://en.wikipedia.org/wiki/I_Love_Lucy) made light of the popular belief in life on Mars; for example, when Lucy and Ethel were hired to portray Martians landing on the top of the [Empire State Building](https://en.wikipedia.org/wiki/Empire_State_Building) as a publicity stunt for an upcoming movie.

After the [Mariner](https://en.wikipedia.org/wiki/Mariner_program) and [Viking](https://en.wikipedia.org/wiki/Viking_program) spacecraft had returned pictures of Mars as it really is, an apparently lifeless and canal-less world, these ideas about Mars had to be abandoned, and a vogue for accurate, realist depictions of human colonies on Mars developed, the best known of which may be [Kim Stanley Robinson](https://en.wikipedia.org/wiki/Kim_Stanley_Robinson)'s [*Mars* trilogy](https://en.wikipedia.org/wiki/Mars_trilogy). Pseudo-scientific speculations about the Face on Mars and other enigmatic landmarks spotted by [space probes](https://en.wikipedia.org/wiki/Space_probe) have meant that ancient civilizations continue to be a popular theme in science fiction, especially in film.[[270]](https://en.wikipedia.org/wiki/Mars#cite_note-miles_peters-272)

The theme of a Martian colony that fights for independence from Earth is a major plot element in the novels of [Greg Bear](https://en.wikipedia.org/wiki/Greg_Bear) as well as the movie [*Total Recall*](https://en.wikipedia.org/wiki/Total_Recall_(1990_film)) (based on a short story by [Philip K. Dick](https://en.wikipedia.org/wiki/Philip_K._Dick)) and the television series [*Babylon 5*](https://en.wikipedia.org/wiki/Babylon_5). Video games use this element, including [*Red Faction*](https://en.wikipedia.org/wiki/Red_Faction) and the [*Zone of the Enders*](https://en.wikipedia.org/wiki/Zone_of_the_Enders) series. Mars (and its moons) were the setting for the popular [*Doom*](https://en.wikipedia.org/wiki/Doom_(series)) video game franchise and the later [*Martian Gothic*](https://en.wikipedia.org/wiki/Martian_Gothic).

## See also

|  |  |
| --- | --- |
| Book icon | * [**Book: Mars**](https://en.wikipedia.org/wiki/Book:Mars) * [**Book: Solar System**](https://en.wikipedia.org/wiki/Book:Solar_System) |

* [Colonization of Mars](https://en.wikipedia.org/wiki/Colonization_of_Mars)
* [Composition of Mars](https://en.wikipedia.org/wiki/Composition_of_Mars)
* [Darian calendar](https://en.wikipedia.org/wiki/Darian_calendar)
* [Exploration of Mars](https://en.wikipedia.org/wiki/Exploration_of_Mars)
* [Extraterrestrial life](https://en.wikipedia.org/wiki/Extraterrestrial_life)
* [Geodynamics of Mars](https://en.wikipedia.org/wiki/Geodynamics_of_Mars)
* [Geology of Mars](https://en.wikipedia.org/wiki/Geology_of_Mars)
* [List of artificial objects on Mars](https://en.wikipedia.org/wiki/List_of_artificial_objects_on_Mars)
* [List of chasmata on Mars](https://en.wikipedia.org/wiki/List_of_chasmata_on_Mars)
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* [List of mountains on Mars](https://en.wikipedia.org/wiki/List_of_mountains_on_Mars)
* [List of quadrangles on Mars](https://en.wikipedia.org/wiki/List_of_quadrangles_on_Mars)
* [List of rocks on Mars](https://en.wikipedia.org/wiki/List_of_rocks_on_Mars)
* [List of valles on Mars](https://en.wikipedia.org/wiki/List_of_valles_on_Mars)
* [Seasonal flows on warm Martian slopes](https://en.wikipedia.org/wiki/Seasonal_flows_on_warm_Martian_slopes)
* [Terraforming of Mars](https://en.wikipedia.org/wiki/Terraforming_of_Mars)
* [Water on Mars](https://en.wikipedia.org/wiki/Water_on_Mars)

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| |  | | --- | | * [Mars Hubble.jpg](https://en.wikipedia.org/wiki/File:Mars_Hubble.jpg)[**Mars portal**](https://en.wikipedia.org/wiki/Portal:Mars)      * [Solar system.jpg](https://en.wikipedia.org/wiki/File:Solar_system.jpg)[**Solar System portal**](https://en.wikipedia.org/wiki/Portal:Solar_System) | |

## Notes

* 1. ^ [Jump up to:***a***](https://en.wikipedia.org/wiki/Mars#cite_ref-best-fit_ellipsoid_3-0) [***b***](https://en.wikipedia.org/wiki/Mars#cite_ref-best-fit_ellipsoid_3-1) [***c***](https://en.wikipedia.org/wiki/Mars#cite_ref-best-fit_ellipsoid_3-2) Best-fit [ellipsoid](https://en.wikipedia.org/wiki/Ellipsoid)
  2. [**Jump up^**](https://en.wikipedia.org/wiki/Mars#cite_ref-serpentinization_152-0) There are many [*serpentinization*](https://en.wikipedia.org/wiki/Serpentinite) reactions. [Olivine](https://en.wikipedia.org/wiki/Olivine) is a [solid solution](https://en.wikipedia.org/wiki/Solid_solution) between [forsterite](https://en.wikipedia.org/wiki/Forsterite) and [fayalite](https://en.wikipedia.org/wiki/Fayalite) whose general formula is (Fe,Mg)2SiO4. The reaction producing methane from olivine can be written as: *Forsterite + Fayalite + Water + Carbonic acid → Serpentine + Magnetite + Methane* , or (in balanced form): 18Mg2SiO4 + 6Fe2SiO4 + 26H2O + CO2 → 12Mg3Si2O5(OH)4 + 4Fe3O4 + CH4

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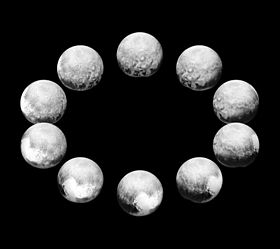
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# Pluto

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*This article is about the dwarf planet. For other uses, see*[*Pluto (disambiguation)*](https://en.wikipedia.org/wiki/Pluto_(disambiguation))*.*

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| --- | --- |
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| [Nh-pluto-in-true-color 2x JPEG-edit-frame.jpg](https://en.wikipedia.org/wiki/File:Nh-pluto-in-true-color_2x_JPEG-edit-frame.jpg)  Full-disc view of Pluto in near-true color, imaged by[*New Horizons*](https://en.wikipedia.org/wiki/New_Horizons)[[a]](https://en.wikipedia.org/wiki/Pluto#cite_note-caption-1) | |
| **Discovery** | |
| **Discovered by** | [Clyde W. Tombaugh](https://en.wikipedia.org/wiki/Clyde_Tombaugh) |
| **Discovery date** | February 18, 1930 |
| **Designations** | |
| [**MPC designation**](https://en.wikipedia.org/wiki/Minor_planet_designation) | **134340 Pluto** |
| **Pronunciation** | [Listen](https://upload.wikimedia.org/wikipedia/commons/2/25/En-us-Pluto.ogg)[**i**](https://en.wikipedia.org/wiki/File:En-us-Pluto.ogg)[/ˈpluːtoʊ/](https://en.wikipedia.org/wiki/Help:IPA_for_English) |
| **Named after** | [Pluto](https://en.wikipedia.org/wiki/Pluto_(mythology)) |
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| [**Aphelion**](https://en.wikipedia.org/wiki/Aphelion) | * 49.319 [AU](https://en.wikipedia.org/wiki/Astronomical_unit) * (7,378.07 Gm) * February, 2114 |
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| [**Eccentricity**](https://en.wikipedia.org/wiki/Orbital_eccentricity) | 0.24905 |
| [**Orbital period**](https://en.wikipedia.org/wiki/Orbital_period) | * 248.00 [years](https://en.wikipedia.org/wiki/Julian_year_(astronomy))[[2]](https://en.wikipedia.org/wiki/Pluto#cite_note-Pluto_Fact_Sheet-3) * 90,581 d[[2]](https://en.wikipedia.org/wiki/Pluto#cite_note-Pluto_Fact_Sheet-3) * 14,164.4 Plutonian [solar days](https://en.wikipedia.org/wiki/Solar_day)[[3]](https://en.wikipedia.org/wiki/Pluto#cite_note-planet_years-4) |
| [**Synodic period**](https://en.wikipedia.org/wiki/Orbital_period) | 366.73 days[[2]](https://en.wikipedia.org/wiki/Pluto#cite_note-Pluto_Fact_Sheet-3) |
| **Average**[**orbital speed**](https://en.wikipedia.org/wiki/Orbital_speed) | 4.67 km/s[[2]](https://en.wikipedia.org/wiki/Pluto#cite_note-Pluto_Fact_Sheet-3) |
| [**Mean anomaly**](https://en.wikipedia.org/wiki/Mean_anomaly) | 14.53 [deg](https://en.wikipedia.org/wiki/Degree_(angle)) |
| [**Inclination**](https://en.wikipedia.org/wiki/Orbital_inclination) | * 17.1405° * (11.88° to Sun's equator) |
| [**Longitude of ascending node**](https://en.wikipedia.org/wiki/Longitude_of_the_ascending_node) | 110.299° |
| [**Argument of perihelion**](https://en.wikipedia.org/wiki/Argument_of_periapsis) | 113.834° |
| **Known**[**satellites**](https://en.wikipedia.org/wiki/Natural_satellite) | [5](https://en.wikipedia.org/wiki/Moons_of_Pluto) |
| **Physical characteristics** | |
| **Mean radius** | * 1,187±4 km[[5]](https://en.wikipedia.org/wiki/Pluto#cite_note-Stern2015-7) * 0.18 [Earths](https://en.wikipedia.org/wiki/Earth_radius) |
| [**Flattening**](https://en.wikipedia.org/wiki/Flattening) | <1%[[5]](https://en.wikipedia.org/wiki/Pluto#cite_note-Stern2015-7) |
| [**Surface area**](https://en.wikipedia.org/wiki/Spheroid#Surface_area) | * 1.77×107 km2[[c]](https://en.wikipedia.org/wiki/Pluto#cite_note-Surface_area-8) * 0.035 Earths |
| [**Volume**](https://en.wikipedia.org/wiki/Volume) | * (7.006±0.071)×109 km3[[d]](https://en.wikipedia.org/wiki/Pluto#cite_note-Volume-9) * 0.00647 Earths |
| [**Mass**](https://en.wikipedia.org/wiki/Mass) | * (1.303±0.003)×1022 kg[[5]](https://en.wikipedia.org/wiki/Pluto#cite_note-Stern2015-7) * 0.00218 [Earths](https://en.wikipedia.org/wiki/Earth_mass) * 0.177 [Moons](https://en.wikipedia.org/wiki/Moon_mass) |
| **Mean**[**density**](https://en.wikipedia.org/wiki/Density) | 1.860±0.013 g/cm3[[5]](https://en.wikipedia.org/wiki/Pluto#cite_note-Stern2015-7) |
| [**Surface gravity**](https://en.wikipedia.org/wiki/Surface_gravity) | * 0.620 [m/s2](https://en.wikipedia.org/wiki/Acceleration)[[e]](https://en.wikipedia.org/wiki/Pluto#cite_note-Surface_gravity-10) * 0.063 [g](https://en.wikipedia.org/wiki/G-force) |
| [**Escape velocity**](https://en.wikipedia.org/wiki/Escape_velocity) | 1.212 km/s[[f]](https://en.wikipedia.org/wiki/Pluto#cite_note-Escape_velocity-11) |
| **Sidereal**[**rotation period**](https://en.wikipedia.org/wiki/Rotation_period) | * 6.387230 d * 6 d, 9 h, 17 m, 36 s |
| **Equatorial rotation velocity** | 47.18 km/h |
| [**Axial tilt**](https://en.wikipedia.org/wiki/Axial_tilt) | 119.591°±0.014° (to orbit)[[6]](https://en.wikipedia.org/wiki/Pluto#cite_note-BuieGrundyYoung_2006-12)[[g]](https://en.wikipedia.org/wiki/Pluto#cite_note-Axial_tilt-13) |
| **North pole**[**right ascension**](https://en.wikipedia.org/wiki/Right_ascension) | 132.993°[[7]](https://en.wikipedia.org/wiki/Pluto#cite_note-Archinal-14) |
| **North pole**[**declination**](https://en.wikipedia.org/wiki/Declination) | −6.163°[[7]](https://en.wikipedia.org/wiki/Pluto#cite_note-Archinal-14) |
| [**Albedo**](https://en.wikipedia.org/wiki/Albedo) | 0.49 to 0.66 ([geometric](https://en.wikipedia.org/wiki/Geometric_albedo), varies by 35%)[[2]](https://en.wikipedia.org/wiki/Pluto#cite_note-Pluto_Fact_Sheet-3)[[8]](https://en.wikipedia.org/wiki/Pluto#cite_note-Hamilton-15) |
| |  |  |  |  | | --- | --- | --- | --- | | **Surface**[**temp.**](https://en.wikipedia.org/wiki/Temperature) | **min** | **mean** | **max** | | [**Kelvin**](https://en.wikipedia.org/wiki/Kelvin) | 33 K | 44 K (−229 °C) | 55 K | | |
| [**Apparent magnitude**](https://en.wikipedia.org/wiki/Apparent_magnitude) | 13.65[[2]](https://en.wikipedia.org/wiki/Pluto#cite_note-Pluto_Fact_Sheet-3) to 16.3[[9]](https://en.wikipedia.org/wiki/Pluto#cite_note-AstDys-Pluto-16) (mean is 15.1)[[2]](https://en.wikipedia.org/wiki/Pluto#cite_note-Pluto_Fact_Sheet-3) |
| [**Absolute magnitude *(H)***](https://en.wikipedia.org/wiki/Absolute_magnitude#Solar_System_bodies_.28H.29) | −0.7[[10]](https://en.wikipedia.org/wiki/Pluto#cite_note-jpldata-17) |
| [**Angular diameter**](https://en.wikipedia.org/wiki/Angular_diameter) | 0.06″ to 0.11″[[2]](https://en.wikipedia.org/wiki/Pluto#cite_note-Pluto_Fact_Sheet-3)[[h]](https://en.wikipedia.org/wiki/Pluto#cite_note-Angular_size-18) |
| **Atmosphere** | |
| **Surface**[**pressure**](https://en.wikipedia.org/wiki/Atmospheric_pressure) | 1.0 [Pa](https://en.wikipedia.org/wiki/Pascal_(unit)) (2015)[[5]](https://en.wikipedia.org/wiki/Pluto#cite_note-Stern2015-7)[[12]](https://en.wikipedia.org/wiki/Pluto#cite_note-20) |
| [**Composition by volume**](https://en.wikipedia.org/wiki/Atmospheric_chemistry#Atmospheric_composition) | [Nitrogen](https://en.wikipedia.org/wiki/Nitrogen), [methane](https://en.wikipedia.org/wiki/Methane), [carbon monoxide](https://en.wikipedia.org/wiki/Carbon_monoxide)[[11]](https://en.wikipedia.org/wiki/Pluto#cite_note-Physorg_April_19.2C_2011-19) |

[](https://en.wikipedia.org/wiki/File:NH-Pluto-Day1-TenImages-20150714-20151120.jpg)

Mosaic of best-resolution images of Pluto from different angles

**Pluto** ([minor-planet designation](https://en.wikipedia.org/wiki/Minor-planet_designation): **134340 Pluto**) is a [dwarf planet](https://en.wikipedia.org/wiki/Dwarf_planet) in the [Kuiper belt](https://en.wikipedia.org/wiki/Kuiper_belt), a ring of [bodies beyond Neptune](https://en.wikipedia.org/wiki/Trans-Neptunian_object).[[13]](https://en.wikipedia.org/wiki/Pluto#cite_note-NYT-20160714-21) It was the first Kuiper belt object to be discovered. It is the largest and second-most-massive known dwarf planet in the [Solar System](https://en.wikipedia.org/wiki/Solar_System) and the ninth-largest and tenth-most-massive known object directly orbiting the [Sun](https://en.wikipedia.org/wiki/Sun). It is the largest known trans-Neptunian object by volume but is less massive than [Eris](https://en.wikipedia.org/wiki/Eris_(dwarf_planet)), a dwarf planet in the [scattered disc](https://en.wikipedia.org/wiki/Scattered_disc). Like other Kuiper belt objects, Pluto is primarily made of ice and rock[[14]](https://en.wikipedia.org/wiki/Pluto#cite_note-Wiley-2005-22) and is relatively small—about one-sixth the mass of the [Moon](https://en.wikipedia.org/wiki/Moon) and one-third its volume. It has a moderately[eccentric](https://en.wikipedia.org/wiki/Orbital_eccentricity) and inclined orbit during which it ranges from 30 to 49 [astronomical units](https://en.wikipedia.org/wiki/Astronomical_unit) or AU (4.4–7.4 billion km) from the Sun. This means that Pluto periodically comes closer to the Sun than [Neptune](https://en.wikipedia.org/wiki/Neptune), but a stable [orbital resonance](https://en.wikipedia.org/wiki/Orbital_resonance) with Neptune prevents them from colliding. Light from the Sun takes about 5.5 hours to reach Pluto at its average distance (39.5 AU).

Pluto was discovered by [Clyde Tombaugh](https://en.wikipedia.org/wiki/Clyde_Tombaugh) in 1930, and was originally considered the [ninth planet](https://en.wikipedia.org/wiki/Planets_beyond_Neptune) from the Sun. After 1992, its [planethood](https://en.wikipedia.org/wiki/Planet) was questioned following the discovery of several objects of similar size in the Kuiper belt. In 2005, Eris, which is 27% more massive than Pluto, was discovered, which led the [International Astronomical Union](https://en.wikipedia.org/wiki/International_Astronomical_Union) (IAU) to [define the term "planet"](https://en.wikipedia.org/wiki/IAU_definition_of_planet) formally for the first time the following year.[[15]](https://en.wikipedia.org/wiki/Pluto#cite_note-hubblesite2007.2F24-23) This definition excluded Pluto and reclassified it as a member of the new "dwarf planet" category.[[16]](https://en.wikipedia.org/wiki/Pluto#cite_note-BBC-Akwagyiram_2005-08-02-24)

Pluto has [five known moons](https://en.wikipedia.org/wiki/Moons_of_Pluto): [Charon](https://en.wikipedia.org/wiki/Charon_(moon)) (the largest, with a diameter just over half that of Pluto), [Styx](https://en.wikipedia.org/wiki/Styx_(moon)), [Nix](https://en.wikipedia.org/wiki/Nix_(moon)), [Kerberos](https://en.wikipedia.org/wiki/Kerberos_(moon)), and [Hydra](https://en.wikipedia.org/wiki/Hydra_(moon)).[[17]](https://en.wikipedia.org/wiki/Pluto#cite_note-Showalter-25) Pluto and Charon are sometimes considered a [binary system](https://en.wikipedia.org/wiki/Binary_system_(astronomy)) because the [barycenter](https://en.wikipedia.org/wiki/Barycenter) of their orbits does not lie within either body.[[18]](https://en.wikipedia.org/wiki/Pluto#cite_note-Olkin_2003-26) The IAU has not formalized a definition for binary dwarf planets, and Charon is officially classified as a [moon](https://en.wikipedia.org/wiki/Natural_satellite) of Pluto.[[19]](https://en.wikipedia.org/wiki/Pluto#cite_note-IAU_Pluto-27)

On July 14, 2015, the [*New Horizons*](https://en.wikipedia.org/wiki/New_Horizons) [spacecraft](https://en.wikipedia.org/wiki/Spacecraft) became the first spacecraft to [fly by](https://en.wikipedia.org/wiki/Planetary_flyby) Pluto.[[20]](https://en.wikipedia.org/wiki/Pluto#cite_note-NYT-20150714-kc-28)[[21]](https://en.wikipedia.org/wiki/Pluto#cite_note-AP-20150714-29)[[22]](https://en.wikipedia.org/wiki/Pluto#cite_note-NYT-20150718-30) During its brief flyby, *New Horizons* made detailed measurements and observations of Pluto and its moons.[[13]](https://en.wikipedia.org/wiki/Pluto#cite_note-NYT-20160714-21)[[23]](https://en.wikipedia.org/wiki/Pluto#cite_note-NYT-20160317-31)[[24]](https://en.wikipedia.org/wiki/Pluto#cite_note-NASA-20160317-32)[[25]](https://en.wikipedia.org/wiki/Pluto#cite_note-NASA-20160317-sci-33)

## Contents

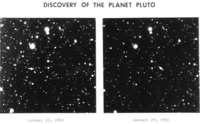
  [[hide](https://en.wikipedia.org/wiki/Pluto)]

* [1History](https://en.wikipedia.org/wiki/Pluto#History)
  + [1.1Discovery](https://en.wikipedia.org/wiki/Pluto#Discovery)
  + [1.2Name](https://en.wikipedia.org/wiki/Pluto#Name)
  + [1.3Planet X disproved](https://en.wikipedia.org/wiki/Pluto#Planet_X_disproved)
  + [1.4Classification](https://en.wikipedia.org/wiki/Pluto#Classification)
    - [1.4.1IAU classification](https://en.wikipedia.org/wiki/Pluto#IAU_classification)
* [2Orbit](https://en.wikipedia.org/wiki/Pluto#Orbit)
  + [2.1Relationship with Neptune](https://en.wikipedia.org/wiki/Pluto#Relationship_with_Neptune)
    - [2.1.1Other factors](https://en.wikipedia.org/wiki/Pluto#Other_factors)
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* [3Rotation](https://en.wikipedia.org/wiki/Pluto#Rotation)
* [4Geology](https://en.wikipedia.org/wiki/Pluto#Geology)
  + [4.1Surface](https://en.wikipedia.org/wiki/Pluto#Surface)
  + [4.2Internal structure](https://en.wikipedia.org/wiki/Pluto#Internal_structure)
* [5Mass and size](https://en.wikipedia.org/wiki/Pluto#Mass_and_size)
* [6Atmosphere](https://en.wikipedia.org/wiki/Pluto#Atmosphere)
* [7Satellites](https://en.wikipedia.org/wiki/Pluto#Satellites)
* [8Origin](https://en.wikipedia.org/wiki/Pluto#Origin)
* [9Observation and exploration](https://en.wikipedia.org/wiki/Pluto#Observation_and_exploration)
  + [9.1Observation](https://en.wikipedia.org/wiki/Pluto#Observation)
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* [10Gallery](https://en.wikipedia.org/wiki/Pluto#Gallery)
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* [11See also](https://en.wikipedia.org/wiki/Pluto#See_also)
* [12Notes](https://en.wikipedia.org/wiki/Pluto#Notes)
* [13References](https://en.wikipedia.org/wiki/Pluto#References)
* [14Further reading](https://en.wikipedia.org/wiki/Pluto#Further_reading)
* [15External links](https://en.wikipedia.org/wiki/Pluto#External_links)

## History

### Discovery

*Further information:*[*Planets beyond Neptune*](https://en.wikipedia.org/wiki/Planets_beyond_Neptune)

[](https://en.wikipedia.org/wiki/File:Pluto_discovery_plates.png)

Discovery photographs of Pluto

[](https://en.wikipedia.org/wiki/File:Clyde_W._Tombaugh.jpeg)

Clyde Tombaugh, in Kansas

In the 1840s, [Urbain Le Verrier](https://en.wikipedia.org/wiki/Urbain_Le_Verrier) used [Newtonian mechanics](https://en.wikipedia.org/wiki/Classical_mechanics) to predict the position of the then-undiscovered planet [Neptune](https://en.wikipedia.org/wiki/Neptune) after analysing perturbations in the orbit of [Uranus](https://en.wikipedia.org/wiki/Uranus).[[26]](https://en.wikipedia.org/wiki/Pluto#cite_note-34) Subsequent observations of Neptune in the late 19th century led astronomers to speculate that Uranus's orbit was being disturbed by another planet besides Neptune.

In 1906, [Percival Lowell](https://en.wikipedia.org/wiki/Percival_Lowell)—a wealthy Bostonian who had founded the [Lowell Observatory](https://en.wikipedia.org/wiki/Lowell_Observatory) in [Flagstaff, Arizona](https://en.wikipedia.org/wiki/Flagstaff,_Arizona), in 1894—started an extensive project in search of a possible ninth planet, which he termed "[Planet X](https://en.wikipedia.org/wiki/Planet_X)".[[27]](https://en.wikipedia.org/wiki/Pluto#cite_note-Tombaugh1946-35)By 1909, Lowell and [William H. Pickering](https://en.wikipedia.org/wiki/William_Henry_Pickering) had suggested several possible celestial coordinates for such a planet.[[28]](https://en.wikipedia.org/wiki/Pluto#cite_note-Hoyt-36) Lowell and his observatory conducted his search until his death in 1916, but to no avail. Unknown to Lowell, his surveys had captured two faint images of Pluto on March 19 and April 7, 1915, but they were not recognized for what they were.[[28]](https://en.wikipedia.org/wiki/Pluto#cite_note-Hoyt-36)[[29]](https://en.wikipedia.org/wiki/Pluto#cite_note-Littman1990-37) There are fourteen other known [prediscovery](https://en.wikipedia.org/wiki/Precovery) observations, with the oldest made by the [Yerkes Observatory](https://en.wikipedia.org/wiki/Yerkes_Observatory) on August 20, 1909.[[30]](https://en.wikipedia.org/wiki/Pluto#cite_note-BuchwaldDimarioWild2000-38)

Percival's widow, Constance Lowell, entered into a ten-year legal battle with the Lowell Observatory over her late husband's legacy, and the search for Planet X did not resume until 1929.[[31]](https://en.wikipedia.org/wiki/Pluto#cite_note-FOOTNOTECroswell199750-39) [Vesto Melvin Slipher](https://en.wikipedia.org/wiki/Vesto_Melvin_Slipher), the observatory director, summarily handed the job of locating Planet X to 23-year-old [Clyde Tombaugh](https://en.wikipedia.org/wiki/Clyde_Tombaugh), who had just arrived at the Lowell Observatory after Slipher had been impressed by a sample of his astronomical drawings.[[31]](https://en.wikipedia.org/wiki/Pluto#cite_note-FOOTNOTECroswell199750-39)

Tombaugh's task was to systematically image the night sky in pairs of photographs, then examine each pair and determine whether any objects had shifted position. Using a [blink comparator](https://en.wikipedia.org/wiki/Blink_comparator), he rapidly shifted back and forth between views of each of the plates to create the illusion of movement of any objects that had changed position or appearance between photographs. On February 18, 1930, after nearly a year of searching, Tombaugh discovered a possible moving object on photographic plates taken on January 23 and 29 of that year. A lesser-quality photograph taken on January 21 helped confirm the movement.[[32]](https://en.wikipedia.org/wiki/Pluto#cite_note-FOOTNOTECroswell199752-40) After the observatory obtained further confirmatory photographs, news of the discovery was telegraphed to the [Harvard College Observatory](https://en.wikipedia.org/wiki/Harvard_College_Observatory) on March 13, 1930.[[28]](https://en.wikipedia.org/wiki/Pluto#cite_note-Hoyt-36)

### Name

*See also:*[*Venetia Burney*](https://en.wikipedia.org/wiki/Venetia_Burney)

The discovery made headlines around the globe. The [Lowell Observatory](https://en.wikipedia.org/wiki/Lowell_Observatory), which had the right to name the new object, received more than 1,000 suggestions from all over the world, ranging from Atlas to Zymal.[[33]](https://en.wikipedia.org/wiki/Pluto#cite_note-pluto_guide-41)Tombaugh urged Slipher to suggest a name for the new object quickly before someone else did.[[33]](https://en.wikipedia.org/wiki/Pluto#cite_note-pluto_guide-41) Constance Lowell proposed [*Zeus*](https://en.wikipedia.org/wiki/Zeus), then *Percival* and finally *Constance*. These suggestions were disregarded.[[34]](https://en.wikipedia.org/wiki/Pluto#cite_note-Mager-42)

The name Pluto, after the [god of the underworld](https://en.wikipedia.org/wiki/Pluto_(mythology)), was proposed by [Venetia Burney](https://en.wikipedia.org/wiki/Venetia_Burney) (1918–2009), a then eleven-year-old schoolgirl in [Oxford](https://en.wikipedia.org/wiki/Oxford), England, who was interested in [classical mythology](https://en.wikipedia.org/wiki/Classical_mythology).[[35]](https://en.wikipedia.org/wiki/Pluto#cite_note-Venetia-43) She suggested it in a conversation with her grandfather [Falconer Madan](https://en.wikipedia.org/wiki/Falconer_Madan), a former librarian at the [University of Oxford](https://en.wikipedia.org/wiki/University_of_Oxford)'s [Bodleian Library](https://en.wikipedia.org/wiki/Bodleian_Library), who passed the name to astronomy professor [Herbert Hall Turner](https://en.wikipedia.org/wiki/Herbert_Hall_Turner), who cabled it to colleagues in the United States.[[35]](https://en.wikipedia.org/wiki/Pluto#cite_note-Venetia-43)

The object was officially named on May 25, 1930.[[36]](https://en.wikipedia.org/wiki/Pluto#cite_note-The_Times_27_May_1930-44)[[37]](https://en.wikipedia.org/wiki/Pluto#cite_note-NYTimes_25_May_1930-45) Each member of the Lowell Observatory was allowed to vote on a short-list of three: [Minerva](https://en.wikipedia.org/wiki/Minerva) (which was already the name for an asteroid), [Cronus](https://en.wikipedia.org/wiki/Cronus) (which had lost reputation through being proposed by the unpopular astronomer [Thomas Jefferson Jackson See](https://en.wikipedia.org/wiki/Thomas_Jefferson_Jackson_See)), and Pluto. Pluto received every vote.[[38]](https://en.wikipedia.org/wiki/Pluto#cite_note-FOOTNOTECroswell199754.E2.80.9355-46) The name was announced on May 1, 1930.[[35]](https://en.wikipedia.org/wiki/Pluto#cite_note-Venetia-43) Upon the announcement, Madan gave Venetia £5 (equivalent to 300 [GBP](https://en.wikipedia.org/wiki/GBP), or 450 [USD](https://en.wikipedia.org/wiki/USD) in 2014)[[39]](https://en.wikipedia.org/wiki/Pluto#cite_note-inflation-UK-47) as a reward.[[35]](https://en.wikipedia.org/wiki/Pluto#cite_note-Venetia-43)

The final choice of name was helped in part by the fact that the first two letters of *Pluto* are the initials of Percival Lowell. Pluto's [astronomical symbol](https://en.wikipedia.org/wiki/Astronomical_symbol) ([♇](https://en.wikipedia.org/wiki/File:Pluto_symbol.svg), [Unicode](https://en.wikipedia.org/wiki/Unicode) U+2647, ♇) was then created as a [monogram](https://en.wikipedia.org/wiki/Monogram)constructed from the letters "PL".[[40]](https://en.wikipedia.org/wiki/Pluto#cite_note-JPL.2FNASA_Pluto.27s_Symbol-48) Pluto's [astrological symbol](https://en.wikipedia.org/wiki/Astrological_symbol) resembles that of [Neptune](https://en.wikipedia.org/wiki/Neptune) ([Neptune symbol.svg](https://en.wikipedia.org/wiki/File:Neptune_symbol.svg)), but has a circle in place of the middle prong of the trident ([Pluto's astrological symbol.svg](https://en.wikipedia.org/wiki/File:Pluto%27s_astrological_symbol.svg)).

The name was soon embraced by wider culture. In 1930, [Walt Disney](https://en.wikipedia.org/wiki/Walt_Disney) was apparently inspired by it when he introduced for [Mickey Mouse](https://en.wikipedia.org/wiki/Mickey_Mouse) a canine companion named [Pluto](https://en.wikipedia.org/wiki/Pluto_(Disney)), although [Disney](https://en.wikipedia.org/wiki/The_Walt_Disney_Company) animator [Ben Sharpsteen](https://en.wikipedia.org/wiki/Ben_Sharpsteen)could not confirm why the name was given.[[41]](https://en.wikipedia.org/wiki/Pluto#cite_note-Heinrichs2006-49) In 1941, [Glenn T. Seaborg](https://en.wikipedia.org/wiki/Glenn_T._Seaborg) named the newly created [element](https://en.wikipedia.org/wiki/Chemical_element) [plutonium](https://en.wikipedia.org/wiki/Plutonium) after Pluto, in keeping with the tradition of naming elements after newly discovered planets, following [uranium](https://en.wikipedia.org/wiki/Uranium), which was named after [Uranus](https://en.wikipedia.org/wiki/Uranus), and [neptunium](https://en.wikipedia.org/wiki/Neptunium), which was named after [Neptune](https://en.wikipedia.org/wiki/Neptune).[[42]](https://en.wikipedia.org/wiki/Pluto#cite_note-ClarkHobart2000-50)

Most languages use the name "Pluto" in various transliterations.[[i]](https://en.wikipedia.org/wiki/Pluto#cite_note-51) In Japanese, [Houei Nojiri](https://en.wikipedia.org/wiki/Houei_Nojiri) suggested the translation *Meiōsei* (冥王星[**?**](https://en.wikipedia.org/wiki/Help:Installing_Japanese_character_sets), "Star of the King (God) of the Underworld"), and this was borrowed into Chinese, Korean, and Vietnamese.[[43]](https://en.wikipedia.org/wiki/Pluto#cite_note-RenshawIhara2000-52)[[44]](https://en.wikipedia.org/wiki/Pluto#cite_note-nineplan-53)[[45]](https://en.wikipedia.org/wiki/Pluto#cite_note-Bathrobe-54) Some [Indian languages](https://en.wikipedia.org/wiki/Languages_of_India) use the name Pluto, but others, such as [Hindi](https://en.wikipedia.org/wiki/Hindi), use the name of [*Yama*](https://en.wikipedia.org/wiki/Yama), the Guardian of Hell in [Hindu](https://en.wikipedia.org/wiki/Hindu) and [Buddhist](https://en.wikipedia.org/wiki/Yama_(East_Asia)) mythology.[[44]](https://en.wikipedia.org/wiki/Pluto#cite_note-nineplan-53) [Polynesian languages](https://en.wikipedia.org/wiki/Polynesian_languages) also tend to use the indigenous god of the underworld, as in [Maori](https://en.wikipedia.org/wiki/Maori_language) [*Whiro*](https://en.wikipedia.org/wiki/Whiro).[[44]](https://en.wikipedia.org/wiki/Pluto#cite_note-nineplan-53)

### Planet X disproved

Once found, Pluto's faintness and lack of a resolvable disc cast doubt on the idea that it was Lowell's [Planet X](https://en.wikipedia.org/wiki/Planets_beyond_Neptune).[[27]](https://en.wikipedia.org/wiki/Pluto#cite_note-Tombaugh1946-35) Estimates of Pluto's mass were revised downward throughout the 20th century.[[46]](https://en.wikipedia.org/wiki/Pluto#cite_note-55)

|  |  |  |
| --- | --- | --- |
| **Mass estimates for Pluto** | | |
| **Year** | **Mass** | **Estimate by** |
| 1915 | 7 Earth | [Lowell](https://en.wikipedia.org/wiki/Percival_Lowell) (prediction for [Planet X](https://en.wikipedia.org/wiki/Planet_X))[[27]](https://en.wikipedia.org/wiki/Pluto#cite_note-Tombaugh1946-35) |
| 1931 | 1 Earth | [Nicholson](https://en.wikipedia.org/wiki/Seth_Barnes_Nicholson) & [Mayall](https://en.wikipedia.org/wiki/Nicholas_U._Mayall)[[47]](https://en.wikipedia.org/wiki/Pluto#cite_note-RAS1931.91-56)[[48]](https://en.wikipedia.org/wiki/Pluto#cite_note-Nicholson_et_al_1930-57)[[49]](https://en.wikipedia.org/wiki/Pluto#cite_note-Nicholson_et_al_1931-58) |
| 1948 | 0.1 (1/10) Earth | [Kuiper](https://en.wikipedia.org/wiki/Gerard_Kuiper)[[50]](https://en.wikipedia.org/wiki/Pluto#cite_note-Kuiper_10.1086.2F126255-59) |
| 1976 | 0.01 (1/100) Earth | [Cruikshank](https://en.wikipedia.org/wiki/Dale_Cruikshank), Pilcher, & [Morrison](https://en.wikipedia.org/wiki/David_Morrison_(astrophysicist))[[51]](https://en.wikipedia.org/wiki/Pluto#cite_note-FOOTNOTECroswell199757-60) |
| 1978 | 0.0015 (1/650) Earth | [Christy](https://en.wikipedia.org/wiki/James_W._Christy) & [Harrington](https://en.wikipedia.org/wiki/Robert_Sutton_Harrington)[[52]](https://en.wikipedia.org/wiki/Pluto#cite_note-ChristyHarrington1978-61) |
| 2006 | 0.00218 (1/459) Earth | [Buie](https://en.wikipedia.org/wiki/Marc_W._Buie) et al.[[6]](https://en.wikipedia.org/wiki/Pluto#cite_note-BuieGrundyYoung_2006-12) |

Astronomers initially calculated its mass based on its presumed effect on Neptune and Uranus. In 1931, Pluto was calculated to be roughly the mass of Earth, with further calculations in 1948 bringing the mass down to roughly that of Mars.[[48]](https://en.wikipedia.org/wiki/Pluto#cite_note-Nicholson_et_al_1930-57)[[50]](https://en.wikipedia.org/wiki/Pluto#cite_note-Kuiper_10.1086.2F126255-59) In 1976, Dale Cruikshank, Carl Pilcher and David Morrison of the [University of Hawaii](https://en.wikipedia.org/wiki/University_of_Hawaii) calculated Pluto's[albedo](https://en.wikipedia.org/wiki/Albedo#Astronomical_albedo) for the first time, finding that it matched that for [methane](https://en.wikipedia.org/wiki/Methane) ice; this meant Pluto had to be exceptionally luminous for its size and therefore could not be more than 1 percent the mass of Earth.[[51]](https://en.wikipedia.org/wiki/Pluto#cite_note-FOOTNOTECroswell199757-60) (Pluto's albedo is 1.4–1.9 times greater than that of Earth.[[2]](https://en.wikipedia.org/wiki/Pluto#cite_note-Pluto_Fact_Sheet-3))

In 1978, the discovery of Pluto's moon [Charon](https://en.wikipedia.org/wiki/Charon_(moon)) allowed the measurement of Pluto's mass for the first time: roughly 0.2% that of Earth, and far too small to account for the discrepancies in the orbit of Uranus. Subsequent searches for an alternative Planet X, notably by [Robert Sutton Harrington](https://en.wikipedia.org/wiki/Robert_Sutton_Harrington),[[53]](https://en.wikipedia.org/wiki/Pluto#cite_note-SeidelmannHarrington1988-62) failed. In 1992, [Myles Standish](https://en.wikipedia.org/wiki/E._Myles_Standish) used data from[*Voyager 2*](https://en.wikipedia.org/wiki/Voyager_2)*'*s flyby of [Neptune](https://en.wikipedia.org/wiki/Neptune) in 1989, which had revised the estimates of Neptune's mass downward by 0.5%—an amount comparable to the mass of Mars—to recalculate its gravitational effect on Uranus. With the new figures added in, the discrepancies, and with them the need for a Planet X, vanished.[[54]](https://en.wikipedia.org/wiki/Pluto#cite_note-Standish1993-63) Today, the majority of scientists agree that Planet X, as Lowell defined it, does not exist.[[55]](https://en.wikipedia.org/wiki/Pluto#cite_note-Standage2000-64) Lowell had made a prediction of Planet X's orbit and position in 1915 that was fairly close to Pluto's actual orbit and its position at that time; [Ernest W. Brown](https://en.wikipedia.org/wiki/Ernest_W._Brown) concluded soon after Pluto's discovery that this was a coincidence,[[56]](https://en.wikipedia.org/wiki/Pluto#cite_note-Tenn1994-65) a view still held today.[[54]](https://en.wikipedia.org/wiki/Pluto#cite_note-Standish1993-63)

### Classification

*Further information:*[*Definition of planet*](https://en.wikipedia.org/wiki/Definition_of_planet)



Artistic comparison of **Pluto**, [Eris](https://en.wikipedia.org/wiki/Eris_(dwarf_planet)), [Makemake](https://en.wikipedia.org/wiki/Makemake),[Haumea](https://en.wikipedia.org/wiki/Haumea), [Sedna](https://en.wikipedia.org/wiki/90377_Sedna), [2007 OR10](https://en.wikipedia.org/wiki/(225088)_2007_OR10), [Quaoar](https://en.wikipedia.org/wiki/50000_Quaoar), [Orcus](https://en.wikipedia.org/wiki/90482_Orcus), and [Earth](https://en.wikipedia.org/wiki/Earth)along with the [Moon](https://en.wikipedia.org/wiki/Moon).

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* [e](https://en.wikipedia.org/w/index.php?title=Template:TNO_imagemap&action=edit)

]

From 1992 onward, many bodies were discovered orbiting in the same area as Pluto, showing that Pluto is part of a population of objects called the [Kuiper belt](https://en.wikipedia.org/wiki/Kuiper_belt). This made its official status as a planet controversial, with many questioning whether Pluto should be considered together with or separately from its surrounding population. Museum and planetarium directors occasionally created controversy by omitting Pluto from planetary models of the Solar System. The [Hayden Planetarium](https://en.wikipedia.org/wiki/Hayden_Planetarium) reopened—in February 2000, after renovation—with a model of only eight planets, which made headlines almost a year later.[[57]](https://en.wikipedia.org/wiki/Pluto#cite_note-Tyson2001-66)

As objects increasingly closer in size to Pluto were discovered in the region, it was argued that Pluto should be reclassified as one of the Kuiper belt objects, just as [Ceres](https://en.wikipedia.org/wiki/Ceres_(dwarf_planet)), [Pallas](https://en.wikipedia.org/wiki/2_Pallas), [Juno](https://en.wikipedia.org/wiki/3_Juno)and [Vesta](https://en.wikipedia.org/wiki/4_Vesta) eventually lost their planet status after the discovery of many other [asteroids](https://en.wikipedia.org/wiki/Asteroid). On July 29, 2005, astronomers at [Caltech](https://en.wikipedia.org/wiki/Caltech) announced the discovery of a new [trans-Neptunian object](https://en.wikipedia.org/wiki/Trans-Neptunian_object), [Eris](https://en.wikipedia.org/wiki/Eris_(dwarf_planet)), which was substantially more massive than Pluto and the most massive object discovered in the Solar System since [Triton](https://en.wikipedia.org/wiki/Triton_(moon)) in 1846. Its discoverers and the press initially called it the [tenth planet](https://en.wikipedia.org/wiki/Tenth_planet), although there was no official consensus at the time on whether to call it a planet.[[58]](https://en.wikipedia.org/wiki/Pluto#cite_note-NASA-JPL_press_release_07-29-2005-67) Others in the astronomical community considered the discovery the strongest argument for reclassifying Pluto as a minor planet.[[59]](https://en.wikipedia.org/wiki/Pluto#cite_note-what-68)

#### IAU classification

*Main article:*[*IAU definition of planet*](https://en.wikipedia.org/wiki/IAU_definition_of_planet)

The debate came to a head on August 24, 2006 with an [IAU resolution](https://en.wikipedia.org/wiki/IAU_definition_of_planet) that created an official definition for the term "planet". According to this resolution, there are three main conditions for an object in the [Solar System](https://en.wikipedia.org/wiki/Solar_System) to be considered a planet:

1. The object must be in orbit around the [Sun](https://en.wikipedia.org/wiki/Sun).
2. The object must be massive enough to be rounded by its own gravity. More specifically, its own gravity should pull it into a shape of [hydrostatic equilibrium](https://en.wikipedia.org/wiki/Hydrostatic_equilibrium).
3. It must have [cleared the neighborhood](https://en.wikipedia.org/wiki/Clearing_the_neighbourhood) around its orbit.[[60]](https://en.wikipedia.org/wiki/Pluto#cite_note-IAU2006_GA26-5-6-69)[[61]](https://en.wikipedia.org/wiki/Pluto#cite_note-IAU0603-70)

Pluto fails to meet the third condition, because its mass is only 0.07 times that of the mass of the other objects in its orbit (Earth's mass, by contrast, is 1.7 million times the remaining mass in its own orbit).[[59]](https://en.wikipedia.org/wiki/Pluto#cite_note-what-68)[[61]](https://en.wikipedia.org/wiki/Pluto#cite_note-IAU0603-70)The IAU further decided that bodies that, like Pluto, meet criteria 1 and 2 but do not meet criterion 3 would be called [dwarf planets](https://en.wikipedia.org/wiki/Dwarf_planet). On September 13, 2006, the IAU included Pluto, and [Eris](https://en.wikipedia.org/wiki/Eris_(dwarf_planet)) and its moon [Dysnomia](https://en.wikipedia.org/wiki/Dysnomia_(moon)), in their [Minor Planet Catalogue](https://en.wikipedia.org/wiki/Minor_Planet_Catalogue), giving them the official [minor planet designations](https://en.wikipedia.org/wiki/Minor_planet_designation) "(134340) Pluto", "(136199) Eris", and "(136199) Eris I Dysnomia".[[62]](https://en.wikipedia.org/wiki/Pluto#cite_note-IAUC_8747-71) Had Pluto been included upon its discovery in 1930, it would have likely been designated 1164, following [1163 Saga](https://en.wikipedia.org/wiki/1163_Saga), which was discovered a month earlier.[[63]](https://en.wikipedia.org/wiki/Pluto#cite_note-72)

There has been some resistance within the astronomical community toward the reclassification.[[64]](https://en.wikipedia.org/wiki/Pluto#cite_note-geoff2006c-73)[[65]](https://en.wikipedia.org/wiki/Pluto#cite_note-Ruibal-1999-74)[[66]](https://en.wikipedia.org/wiki/Pluto#cite_note-Britt-2006-75) [Alan Stern](https://en.wikipedia.org/wiki/Alan_Stern), principal investigator with [NASA](https://en.wikipedia.org/wiki/NASA)'s [*New Horizons*](https://en.wikipedia.org/wiki/New_Horizons) mission to Pluto, publicly derided the IAU resolution, stating that "the definition stinks, for technical reasons".[[67]](https://en.wikipedia.org/wiki/Pluto#cite_note-geoff2006a-76) Stern's contention was that, by the terms of the new definition, Earth, Mars, Jupiter, and Neptune, all of which share their orbits with asteroids, would be excluded.[[68]](https://en.wikipedia.org/wiki/Pluto#cite_note-newscientistspace-77) He argued that all big spherical moons, including the [Moon](https://en.wikipedia.org/wiki/Moon), should likewise be considered planets.[[69]](https://en.wikipedia.org/wiki/Pluto#cite_note-News.discovery.com-78) His other claim was that because less than five percent of astronomers voted for it, the decision was not representative of the entire astronomical community.[[68]](https://en.wikipedia.org/wiki/Pluto#cite_note-newscientistspace-77) [Marc W. Buie](https://en.wikipedia.org/wiki/Marc_W._Buie), then at Lowell Observatory, voiced his opinion on the new definition on his website and petitioned against the definition.[[70]](https://en.wikipedia.org/wiki/Pluto#cite_note-Buie2006_IAU_response-79) Others have supported the IAU. Mike Brown, the astronomer who discovered [Eris](https://en.wikipedia.org/wiki/Eris_(dwarf_planet)), said "through this whole crazy circus-like procedure, somehow the right answer was stumbled on. It's been a long time coming. Science is self-correcting eventually, even when strong emotions are involved."[[71]](https://en.wikipedia.org/wiki/Pluto#cite_note-Overbye2006-80)

Public reception to the IAU decision was mixed. Although many accepted the reclassification, some sought to overturn the decision with online petitions urging the IAU to consider reinstatement. A resolution introduced by some members of the [California State Assembly](https://en.wikipedia.org/wiki/California_State_Assembly) facetiously called the IAU decision a "scientific heresy".[[72]](https://en.wikipedia.org/wiki/Pluto#cite_note-DeVore2006-81) The [New Mexico House of Representatives](https://en.wikipedia.org/wiki/New_Mexico_House_of_Representatives) passed a resolution in honor of Tombaugh, a longtime resident of that state, that declared that Pluto will always be considered a planet while in New Mexican skies and that March 13, 2007, was Pluto Planet Day.[[73]](https://en.wikipedia.org/wiki/Pluto#cite_note-Holden2007-82)[[74]](https://en.wikipedia.org/wiki/Pluto#cite_note-Gutierrez2007-83) The [Illinois Senate](https://en.wikipedia.org/wiki/Illinois_Senate) passed a similar resolution in 2009, on the basis that Clyde Tombaugh, the discoverer of Pluto, was born in Illinois. The resolution asserted that Pluto was "unfairly downgraded to a 'dwarf' planet" by the IAU.[[75]](https://en.wikipedia.org/wiki/Pluto#cite_note-ILGA_SR0046-84) Some members of the public have also rejected the change, citing the disagreement within the scientific community on the issue, or for sentimental reasons, maintaining that they have always known Pluto as a planet and will continue to do so regardless of the IAU decision.[[76]](https://en.wikipedia.org/wiki/Pluto#cite_note-Sapa-AP-85)

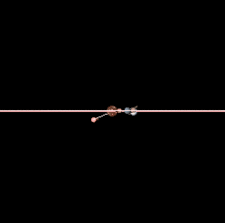
In 2006, in its 17th annual words of the year vote, the [American Dialect Society](https://en.wikipedia.org/wiki/American_Dialect_Society) voted [*plutoed*](https://en.wikipedia.org/wiki/Plutoed) as the word of the year. To "pluto" is to "demote or devalue someone or something".[[77]](https://en.wikipedia.org/wiki/Pluto#cite_note-msnbc-86)

Researchers on both sides of the debate gathered on August 14–16, 2008, at the Johns Hopkins University [Applied Physics Laboratory](https://en.wikipedia.org/wiki/Applied_Physics_Laboratory) for a conference that included back-to-back talks on the current IAU definition of a planet.[[78]](https://en.wikipedia.org/wiki/Pluto#cite_note-Minkel2008-87) Entitled "The Great Planet Debate",[[79]](https://en.wikipedia.org/wiki/Pluto#cite_note-The_Great_Planet_Debate-88) the conference published a post-conference press release indicating that scientists could not come to a consensus about the definition of planet.[[80]](https://en.wikipedia.org/wiki/Pluto#cite_note-PSIedu_press_release_2008-09-19-89) Just before the conference, on June 11, 2008, the IAU announced in a press release that the term "[plutoid](https://en.wikipedia.org/wiki/Plutoid)" would henceforth be used to refer to Pluto and other objects that have an orbital [semi-major axis](https://en.wikipedia.org/wiki/Semi-major_axis) greater than that of Neptune and enough mass to be of near-spherical shape.[[81]](https://en.wikipedia.org/wiki/Pluto#cite_note-IAU0804-90)[[82]](https://en.wikipedia.org/wiki/Pluto#cite_note-Discover_2009-JANp76-91)[[83]](https://en.wikipedia.org/wiki/Pluto#cite_note-Science_News.2C_July_5.2C_2008_p._7-92)

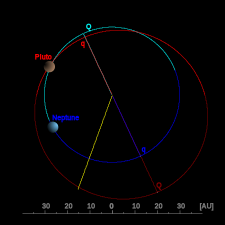
## Orbit

Pluto's orbital period is 248 years. Its orbital characteristics are substantially different from those of the planets, which follow nearly circular orbits around the Sun close to a flat reference [plane](https://en.wikipedia.org/wiki/Plane_(mathematics)) called the [ecliptic](https://en.wikipedia.org/wiki/Ecliptic). In contrast, Pluto's orbit is moderately [inclined](https://en.wikipedia.org/wiki/Orbital_inclination) relative to the ecliptic (over 17°) and moderately [eccentric](https://en.wikipedia.org/wiki/Orbital_eccentricity) ([elliptical](https://en.wikipedia.org/wiki/Elliptical)). This eccentricity means a small region of Pluto's orbit lies nearer the Sun than [Neptune](https://en.wikipedia.org/wiki/Neptune)'s. The Pluto–Charon [barycenter](https://en.wikipedia.org/wiki/Barycentric_coordinates_(astronomy)) came to [perihelion](https://en.wikipedia.org/wiki/Apsis) on September 5, 1989,[[1]](https://en.wikipedia.org/wiki/Pluto#cite_note-jpl-ssd-horizons-2)[[j]](https://en.wikipedia.org/wiki/Pluto#cite_note-Perihelion-93) and was last closer to the Sun than Neptune between February 7, 1979, and February 11, 1999.[[84]](https://en.wikipedia.org/wiki/Pluto#cite_note-pluto990209-94)

In the long term, Pluto's orbit is [chaotic](https://en.wikipedia.org/wiki/Chaos_theory). Although computer simulations can be used to predict its position for several million years (both [forward and backward](https://en.wikipedia.org/wiki/Time_reversibility) in time), after intervals longer than the [Lyapunov time](https://en.wikipedia.org/wiki/Lyapunov_time) of 10–20 million years, calculations become speculative: Pluto is sensitive to immeasurably small details of the Solar System, hard-to-predict factors that will gradually change Pluto's position in its orbit.[[85]](https://en.wikipedia.org/wiki/Pluto#cite_note-sussman88-95)[[86]](https://en.wikipedia.org/wiki/Pluto#cite_note-wisdom91-96)

[](https://en.wikipedia.org/wiki/File:Plutoorbit1.5sideview.gif)

Orbit of Pluto—ecliptic view. This "side view" of Pluto's orbit (in red) shows its large inclination to the [ecliptic](https://en.wikipedia.org/wiki/Ecliptic).

[](https://en.wikipedia.org/wiki/File:TheKuiperBelt_Orbits_Pluto_Polar.svg)

Orbit of Pluto—polar view. This "view from above" shows how Pluto's orbit (in red) is less circular than Neptune's (in blue), and how Pluto is sometimes closer to the Sun than Neptune. The darker halves of both orbits show where they pass below the [plane of the ecliptic](https://en.wikipedia.org/wiki/Plane_of_the_ecliptic).

### Relationship with Neptune

Despite Pluto's orbit appearing to cross that of Neptune when viewed from directly above, the two objects' orbits are aligned so that they can never collide or even approach closely. There are several reasons why.

At the simplest level, one can examine the two orbits and see that they do not intersect. When Pluto is closest to the Sun, and hence closest to Neptune's orbit as viewed from above, it is also the farthest above Neptune's path. Pluto's orbit passes about 8 [AU](https://en.wikipedia.org/wiki/Astronomical_unit) above that of Neptune, preventing a collision.[[87]](https://en.wikipedia.org/wiki/Pluto#cite_note-huainn01-97)[[88]](https://en.wikipedia.org/wiki/Pluto#cite_note-Hunter2004-98)[[89]](https://en.wikipedia.org/wiki/Pluto#cite_note-malhotra-9planets-99) Pluto's [ascending and descending nodes](https://en.wikipedia.org/wiki/Orbital_node), the points at which its orbit crosses the ecliptic, are currently separated from Neptune's by over 21°.[[90]](https://en.wikipedia.org/wiki/Pluto#cite_note-Williams2010-100)

This alone is not enough to protect Pluto; [perturbations](https://en.wikipedia.org/wiki/Perturbation_(astronomy)) from the planets (especially Neptune) could alter aspects of Pluto's orbit (such as its [orbital precession](https://en.wikipedia.org/wiki/Apsidal_precession)) over millions of years so that a collision could be possible. Some other mechanism or mechanisms must therefore be at work. The most significant of these is that Pluto lies in the 2:3 [mean-motion resonance](https://en.wikipedia.org/wiki/Orbital_resonance) with [Neptune](https://en.wikipedia.org/wiki/Neptune): for every two orbits that Pluto makes around the Sun, Neptune makes three. The two objects then return to their initial positions and the cycle repeats, each cycle lasting about 500 years. This pattern is such that, in each 500-year cycle, the first time Pluto is near [perihelion](https://en.wikipedia.org/wiki/Perihelion), Neptune is over 50° *behind* Pluto. By Pluto's second perihelion, Neptune will have completed a further one and a half of its own orbits, and so will be a similar distance *ahead* of Pluto. Pluto and Neptune's minimum separation is over 17 AU, which is greater than Pluto's minimum separation from [Uranus](https://en.wikipedia.org/wiki/Uranus) (11 AU).[[89]](https://en.wikipedia.org/wiki/Pluto#cite_note-malhotra-9planets-99)

The 2:3 resonance between the two bodies is highly stable, and is preserved over millions of years.[[91]](https://en.wikipedia.org/wiki/Pluto#cite_note-sp-345-101) This prevents their orbits from changing relative to one another; the cycle always repeats in the same way, and so the two bodies can never pass near each other. Thus, even if Pluto's orbit were not inclined, the two bodies could never collide.[[89]](https://en.wikipedia.org/wiki/Pluto#cite_note-malhotra-9planets-99)

#### Other factors

Numerical studies have shown that over periods of millions of years, the general nature of the alignment between the orbits of Pluto and Neptune does not change.[[87]](https://en.wikipedia.org/wiki/Pluto#cite_note-huainn01-97)[[92]](https://en.wikipedia.org/wiki/Pluto#cite_note-williams71-102) There are several other resonances and interactions that govern the details of their relative motion, and enhance Pluto's stability. These arise principally from two additional mechanisms (besides the 2:3 mean-motion resonance).

First, Pluto's [argument of perihelion](https://en.wikipedia.org/wiki/Argument_of_perihelion), the angle between the point where it crosses the ecliptic and the point where it is closest to the Sun, [librates](https://en.wikipedia.org/wiki/Libration) around 90°.[[92]](https://en.wikipedia.org/wiki/Pluto#cite_note-williams71-102) This means that when Pluto is closest to the Sun, it is at its farthest above the plane of the Solar System, preventing encounters with Neptune. This is a direct consequence of the [Kozai mechanism](https://en.wikipedia.org/wiki/Kozai_mechanism),[[87]](https://en.wikipedia.org/wiki/Pluto#cite_note-huainn01-97) which relates the eccentricity of an orbit to its inclination to a larger perturbing body—in this case Neptune. Relative to Neptune, the amplitude of libration is 38°, and so the angular separation of Pluto's perihelion to the orbit of Neptune is always greater than 52° (90°–38°). The closest such angular separation occurs every 10,000 years.[[91]](https://en.wikipedia.org/wiki/Pluto#cite_note-sp-345-101)

Second, the longitudes of ascending nodes of the two bodies—the points where they cross the ecliptic—are in near-resonance with the above libration. When the two longitudes are the same—that is, when one could draw a straight line through both nodes and the Sun—Pluto's perihelion lies exactly at 90°, and hence it comes closest to the Sun when it is highest above Neptune's orbit. This is known as the *1:1 superresonance*. All the [Jovian planets](https://en.wikipedia.org/wiki/Jovian_planets), particularly Jupiter, play a role in the creation of the superresonance.[[87]](https://en.wikipedia.org/wiki/Pluto#cite_note-huainn01-97)

To understand the nature of the libration, imagine a polar point of view, looking down on the ecliptic from a distant vantage point where the planets orbit [counterclockwise](https://en.wikipedia.org/wiki/Counterclockwise). After passing the ascending node, Pluto is interior to Neptune's orbit and moving faster, approaching Neptune from behind. The strong gravitational pull between the two causes [angular momentum](https://en.wikipedia.org/wiki/Angular_momentum) to be transferred to Pluto, at Neptune's expense. This moves Pluto into a slightly larger orbit, where it travels slightly more slowly, according to [Kepler's third law](https://en.wikipedia.org/wiki/Kepler%27s_third_law). As its orbit changes, this has the gradual effect of changing the perihelion and longitude of Pluto's orbit (and, to a lesser degree, of Neptune). After many such repetitions, Pluto is sufficiently slowed, and Neptune sufficiently speeded up, that Neptune begins to catch up with Pluto at the opposite side of its orbit (near the opposing node to where we began). The process is then reversed, and Pluto loses angular momentum to Neptune, until Pluto is sufficiently speeded up that it begins to catch Neptune again at the original node. The whole process takes about 20,000 years to complete.[[89]](https://en.wikipedia.org/wiki/Pluto#cite_note-malhotra-9planets-99)[[91]](https://en.wikipedia.org/wiki/Pluto#cite_note-sp-345-101)

### Quasi-satellite

In 2012, it was hypothesized that [(15810) 1994 JR1](https://en.wikipedia.org/wiki/(15810)_1994_JR1) could be a [quasi-satellite](https://en.wikipedia.org/wiki/Quasi-satellite) of Pluto, a specific type of co-orbital configuration.[[93]](https://en.wikipedia.org/wiki/Pluto#cite_note-quasi-103) According to the hypothesis, the object would be a quasi-satellite of Pluto for about 350,000 years out of every two-million-year period.[[93]](https://en.wikipedia.org/wiki/Pluto#cite_note-quasi-103)[[94]](https://en.wikipedia.org/wiki/Pluto#cite_note-S.26T-104) This hypothesis was disproven in 2016, when more-accurate observations of the position of 1994 JR1 were made by *New Horizons*.[[95]](https://en.wikipedia.org/wiki/Pluto#cite_note-2016maynasa-105)

## Rotation

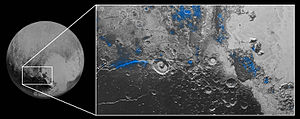
Pluto's [rotation period](https://en.wikipedia.org/wiki/Rotation_period), its day, is equal to 6.39 [Earth](https://en.wikipedia.org/wiki/Earth) days.[[96]](https://en.wikipedia.org/wiki/Pluto#cite_note-axis-106) Like [Uranus](https://en.wikipedia.org/wiki/Uranus), Pluto rotates on its "side" on its orbital plane, with an axial tilt of 120°, and so its seasonal variation is extreme; at its [solstices](https://en.wikipedia.org/wiki/Solstice), one-fourth of its surface is in continuous daylight, whereas another fourth is in continuous darkness.[[97]](https://en.wikipedia.org/wiki/Pluto#cite_note-oregon-107)

The amount of light from the Sun on Pluto is weak, analogous to twilight on Earth. NASA has posted a "Pluto Time" calculator[[98]](https://en.wikipedia.org/wiki/Pluto#cite_note-pluto-time-108) that determines when the light on Earth is equivalent to that on Pluto on a clear day. For example, on July 13, 2015, at the coordinates of the Applied Physics Laboratory where the probe was constructed, the Pluto Time was 8:38 p.m.,[[98]](https://en.wikipedia.org/wiki/Pluto#cite_note-pluto-time-108)[[99]](https://en.wikipedia.org/wiki/Pluto#cite_note-109) four minutes later than the apparent sunset of 8:34 p.m. reported for that location by NOAA.[[100]](https://en.wikipedia.org/wiki/Pluto#cite_note-110)

## Geology

[](https://en.wikipedia.org/wiki/File:Pluto-01_Stern_03_Pluto_Color_TXT.jpg)

High-resolution [MVIC](https://en.wikipedia.org/wiki/New_Horizons#Ralph_telescope) image of Pluto in enhanced color to bring out differences in surface composition

[](https://en.wikipedia.org/wiki/File:NH-Pluto-WaterIceDetected-BlueRegions-Released-20151008.jpg)

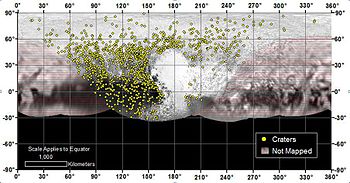
Regions where water ice has been detected (blue regions)

*Main articles:*[*Geology of Pluto*](https://en.wikipedia.org/wiki/Geology_of_Pluto)*and*[*Geography of Pluto*](https://en.wikipedia.org/wiki/Geography_of_Pluto)

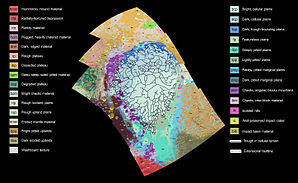
Due to Pluto's distance from Earth, in-depth study from Earth is difficult. On July 14, 2015, [NASA](https://en.wikipedia.org/wiki/NASA)'s [*New Horizons*](https://en.wikipedia.org/wiki/New_Horizons) [space probe](https://en.wikipedia.org/wiki/Space_probe) flew through the Pluto system, and the information it gathered will be transmitted to Earth until late 2016.[[101]](https://en.wikipedia.org/wiki/Pluto#cite_note-NASA-20150115.28b.29-111)[[102]](https://en.wikipedia.org/wiki/Pluto#cite_note-112)

### Surface

Pluto's surface is composed of more than 98 percent [nitrogen ice](https://en.wikipedia.org/wiki/Solid_nitrogen), with traces of [methane](https://en.wikipedia.org/wiki/Methane) and [carbon monoxide](https://en.wikipedia.org/wiki/Carbon_monoxide).[[103]](https://en.wikipedia.org/wiki/Pluto#cite_note-tobias-113) [Nitrogen](https://en.wikipedia.org/wiki/Nitrogen) and carbon monoxide are most abundant on the anti-Charon face of Pluto (around 180° longitude, where [Tombaugh Regio](https://en.wikipedia.org/wiki/Tombaugh_Regio)'s western lobe, [Sputnik Planum](https://en.wikipedia.org/wiki/Sputnik_Planum), is located), whereas methane is most abundant near 300° east.[[104]](https://en.wikipedia.org/wiki/Pluto#cite_note-Grundy_2013-114) Pluto's surface is quite varied, with large differences in both brightness and color.[[105]](https://en.wikipedia.org/wiki/Pluto#cite_note-Buie_2010_light_curve-115) Pluto is one of the most contrastive bodies in the Solar System, with as much contrast as [Saturn](https://en.wikipedia.org/wiki/Saturn)'s moon [Iapetus](https://en.wikipedia.org/wiki/Iapetus_(moon)).[[106]](https://en.wikipedia.org/wiki/Pluto#cite_note-Buie_web_map-116) The color varies between charcoal black, dark orange and white.[[107]](https://en.wikipedia.org/wiki/Pluto#cite_note-Hubble2010-117) Pluto's color is more similar to that of [Io](https://en.wikipedia.org/wiki/Io_(moon)) with slightly more orange, significantly less red than [Mars](https://en.wikipedia.org/wiki/Mars).[[108]](https://en.wikipedia.org/wiki/Pluto#cite_note-Buie_2010_surface-maps-118) [Notable geographical features](https://en.wikipedia.org/wiki/Geography_of_Pluto) include [Tombaugh Regio](https://en.wikipedia.org/wiki/Tombaugh_Regio), or the "Heart" (a large bright area on the side opposite Charon), [Cthulhu Regio](https://en.wikipedia.org/wiki/Cthulhu_Regio), or the "Whale" (a large dark area on the trailing hemisphere), and the "[Brass Knuckles](https://en.wikipedia.org/wiki/Brass_Knuckles_(Pluto))" (a series of equatorial dark areas on the leading hemisphere). [Sputnik Planum](https://en.wikipedia.org/wiki/Sputnik_Planum), the western lobe of the "Heart", is a 1000-km-wide plain of frozen nitrogen and carbon monoxide ices, divided into polygonal cells which are interpreted as [convection cells](https://en.wikipedia.org/wiki/Convection_cell) that carry floating blocks of water ice crust and [sublimation](https://en.wikipedia.org/wiki/Sublimation_(phase_transition)) pits towards their margins;[[109]](https://en.wikipedia.org/wiki/Pluto#cite_note-McKinnon2016-119)[[110]](https://en.wikipedia.org/wiki/Pluto#cite_note-Trowbridge2016-120) there are obvious signs of glacial flows both into and out of the plain.[[111]](https://en.wikipedia.org/wiki/Pluto#cite_note-Pluto_updates-121)[[112]](https://en.wikipedia.org/wiki/Pluto#cite_note-Umurhan2016-01-08-122) It has no craters that were visible to [*New Horizons*](https://en.wikipedia.org/wiki/New_Horizons), indicating that its surface is less than 10 million years old.[[113]](https://en.wikipedia.org/wiki/Pluto#cite_note-Marchis2016-123) The New Horizons science team summarized initial findings as "Pluto displays a surprisingly wide variety of geological landforms, including those resulting from [glaciological](https://en.wikipedia.org/wiki/Glaciology) and surface–atmosphere interactions as well as impact, [tectonic](https://en.wikipedia.org/wiki/Plate_tectonics), possible [cryovolcanic](https://en.wikipedia.org/wiki/Cryovolcano), and [mass-wasting](https://en.wikipedia.org/wiki/Mass_wasting) processes."[[5]](https://en.wikipedia.org/wiki/Pluto#cite_note-Stern2015-7)

[](https://en.wikipedia.org/wiki/File:PIA20154-Pluto-MapOfOver1000Craters-20151110.jpg)

Distribution of over 1000 craters of all ages on Pluto. The variation in density (with none found in [Sputnik Planum](https://en.wikipedia.org/wiki/Sputnik_Planum)) indicates a long history of varying geological activity.

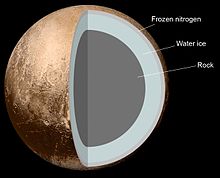
[](https://en.wikipedia.org/wiki/File:Pluto%27s_Sputnik_Planum_geologic_map_(cropped).jpg)

Geologic map of Sputnik Planum and surroundings ([context](https://commons.wikimedia.org/wiki/File:Pluto%27s_Sputnik_Planum_geologic_map_-_context.jpg)), with [convection cell](https://en.wikipedia.org/wiki/Convection_cell) margins outlined in black

[](https://en.wikipedia.org/wiki/File:Pluto%E2%80%99s_Heart_-_Like_a_Cosmic_Lava_Lamp.jpg)

[Sputnik Planum](https://en.wikipedia.org/wiki/Sputnik_Planum) is covered with churning nitrogen ice "cells" that are geologically young and turning over due to [convection](https://en.wikipedia.org/wiki/Convection_cell).

### Internal structure

[](https://en.wikipedia.org/wiki/File:Internal_Structure_of_Pluto.jpg)

Internal structure of Pluto[[114]](https://en.wikipedia.org/wiki/Pluto#cite_note-Hussmann2006-124)

* **1.** Frozen nitrogen[[103]](https://en.wikipedia.org/wiki/Pluto#cite_note-tobias-113)
* **2.** Water ice
* **3.** Rock

Pluto's density is 1.860±0.013 g/cm3.[[5]](https://en.wikipedia.org/wiki/Pluto#cite_note-Stern2015-7) Because the decay of radioactive elements would eventually heat the ices enough for the rock to separate from them, scientists expect that Pluto's internal structure is differentiated, with the rocky material having settled into a dense [core](https://en.wikipedia.org/wiki/Core_(geology)) surrounded by a [mantle](https://en.wikipedia.org/wiki/Mantle_(geology)) of water ice. The diameter of the core is hypothesized to be approximately 1700 km, 70% of Pluto's diameter.[[114]](https://en.wikipedia.org/wiki/Pluto#cite_note-Hussmann2006-124) It is possible that such heating continues today, creating a [subsurface ocean](https://en.wikipedia.org/wiki/Subsurface_ocean) of liquid water some 100 to 180 km thick at the core–mantle boundary.[[114]](https://en.wikipedia.org/wiki/Pluto#cite_note-Hussmann2006-124)[[115]](https://en.wikipedia.org/wiki/Pluto#cite_note-pluto.jhuapl_Inside_Story-125)

## Mass and size

|  |  |  |
| --- | --- | --- |
| **Selected size estimates for Pluto** | | |
| **Year** | **Radius (diameter)** | **Notes** |
| **1993** | 1195 (2390) km | Millis, et al.[[116]](https://en.wikipedia.org/wiki/Pluto#cite_note-Millis_10.1006.2Ficar.1993.1126-126) (if no haze)[[117]](https://en.wikipedia.org/wiki/Pluto#cite_note-Plutosize-127) |
| **1993** | 1180 (2360) km | Millis, et al. (surface & haze)[[117]](https://en.wikipedia.org/wiki/Pluto#cite_note-Plutosize-127) |
| **1994** | 1164 (2328) km | Young & Binzel[[118]](https://en.wikipedia.org/wiki/Pluto#cite_note-YoungBinzel_10.1006.2Ficar.1994.1056-128) |
| **2006** | 1153 (2306) km | Buie, et al.[[6]](https://en.wikipedia.org/wiki/Pluto#cite_note-BuieGrundyYoung_2006-12) |
| **2007** | 1161 (2322) km | Young, Young, & Buie[[119]](https://en.wikipedia.org/wiki/Pluto#cite_note-Young2007-129) |
| **2011** | 1180 (2360) km | Zalucha, et al.[[120]](https://en.wikipedia.org/wiki/Pluto#cite_note-Zalucha2011-130) |
| **2014** | 1184 (2368) km | Lellouch, et al.[[121]](https://en.wikipedia.org/wiki/Pluto#cite_note-Lellouch_2015-131) |
| **2015** | 1187 (2374) km | *New Horizons* measurement[[122]](https://en.wikipedia.org/wiki/Pluto#cite_note-NHPC_20150724-132) |

Pluto's diameter is 2374±8 km[[5]](https://en.wikipedia.org/wiki/Pluto#cite_note-Stern2015-7) and its mass is (1.303±0.003)×1022 kg, 17.7% that of the [Moon](https://en.wikipedia.org/wiki/Moon) (0.22% that of Earth).[[123]](https://en.wikipedia.org/wiki/Pluto#cite_note-Davies2001-133) Its [surface area](https://en.wikipedia.org/wiki/Surface_area) is 1.665×107 km2, or roughly the same surface area as[Russia](https://en.wikipedia.org/wiki/Russia). Its [surface gravity](https://en.wikipedia.org/wiki/Surface_gravity) is 0.063 *g* (compared to 1 *g* for Earth).

The discovery of Pluto's satellite [Charon](https://en.wikipedia.org/wiki/Charon_(moon)) in 1978 enabled a determination of the mass of the Pluto–Charon system by application of [Newton's formulation of Kepler's third law](https://en.wikipedia.org/wiki/Kepler%27s_laws_of_planetary_motion#Deriving_Kepler.27s_third_law). Observations of Pluto in occultation with Charon allowed scientists to establish Pluto's diameter more accurately, whereas the invention of [adaptive optics](https://en.wikipedia.org/wiki/Adaptive_optics) allowed them to determine its shape more accurately.[[124]](https://en.wikipedia.org/wiki/Pluto#cite_note-Close_2000-134)

[](https://en.wikipedia.org/wiki/File:Pluto,_Earth_%26_Moon_size_comparison.jpg)

Size comparisons: [Earth](https://en.wikipedia.org/wiki/Earth), the[Moon](https://en.wikipedia.org/wiki/Moon), and Pluto

With less than 0.2 lunar masses, Pluto is much less massive than the [terrestrial planets](https://en.wikipedia.org/wiki/Terrestrial_planet), and also less massive than seven [moons](https://en.wikipedia.org/wiki/Natural_satellite): [Ganymede](https://en.wikipedia.org/wiki/Ganymede_(moon)), [Titan](https://en.wikipedia.org/wiki/Titan_(moon)), [Callisto](https://en.wikipedia.org/wiki/Callisto_(moon)), [Io](https://en.wikipedia.org/wiki/Io_(moon)), the[Moon](https://en.wikipedia.org/wiki/Moon), [Europa](https://en.wikipedia.org/wiki/Europa_(moon)), and [Triton](https://en.wikipedia.org/wiki/Triton_(moon)). The mass is much less than thought before Charon was discovered.

Pluto is more than twice the diameter and a dozen times the mass of the [dwarf planet](https://en.wikipedia.org/wiki/Dwarf_planet) [Ceres](https://en.wikipedia.org/wiki/Ceres_(dwarf_planet)), the largest object in the [asteroid belt](https://en.wikipedia.org/wiki/Asteroid_belt). It is less massive than the dwarf planet [Eris](https://en.wikipedia.org/wiki/Eris_(dwarf_planet)), a [trans-Neptunian object](https://en.wikipedia.org/wiki/Trans-Neptunian_object) discovered in 2005, though Pluto has a larger diameter of 2374 km[[122]](https://en.wikipedia.org/wiki/Pluto#cite_note-NHPC_20150724-132) compared to Eris's approximate diameter of 2326 km.[[125]](https://en.wikipedia.org/wiki/Pluto#cite_note-NewHorizons_PlutoSize-135)

Determinations of Pluto's size had been complicated by its atmosphere,[[119]](https://en.wikipedia.org/wiki/Pluto#cite_note-Young2007-129) and hydrocarbon haze.[[117]](https://en.wikipedia.org/wiki/Pluto#cite_note-Plutosize-127) In March 2014, Lellouch, de Bergh et al. published findings regarding methane mixing ratios in Pluto's atmosphere consistent with a Plutonian diameter greater than 2360 km, with a "best guess" of 2368 km.[[121]](https://en.wikipedia.org/wiki/Pluto#cite_note-Lellouch_2015-131) On July 13, 2015, images from NASA's *New Horizons* mission Long Range Reconnaissance Imager (LORRI), along with data from the other instruments, determined Pluto's diameter to be 2,370 km (1,470 mi),[[125]](https://en.wikipedia.org/wiki/Pluto#cite_note-NewHorizons_PlutoSize-135)[[126]](https://en.wikipedia.org/wiki/Pluto#cite_note-emily-136) which was later revised to be 2,372 km (1,474 mi) on July 24,[[122]](https://en.wikipedia.org/wiki/Pluto#cite_note-NHPC_20150724-132) and later to 2374±8 km.[[5]](https://en.wikipedia.org/wiki/Pluto#cite_note-Stern2015-7)

## Atmosphere

[](https://en.wikipedia.org/wiki/File:Blue_hazes_over_backlit_Pluto.jpg)

A near-true-color image of Pluto taken by NASA's [*New Horizons*](https://en.wikipedia.org/wiki/New_Horizons) probe after its flyby. The photo shows blue haze layers in Pluto's atmosphere.

*Main article:*[*Atmosphere of Pluto*](https://en.wikipedia.org/wiki/Atmosphere_of_Pluto)

Pluto has a tenuous [atmosphere](https://en.wikipedia.org/wiki/Atmosphere) consisting of [nitrogen](https://en.wikipedia.org/wiki/Nitrogen) (N2), [methane](https://en.wikipedia.org/wiki/Methane) (CH4), and [carbon monoxide](https://en.wikipedia.org/wiki/Carbon_monoxide) (CO), which are in [equilibrium with their ices](https://en.wikipedia.org/wiki/Equilibrium_vapor_pressure) on Pluto's surface.[[127]](https://en.wikipedia.org/wiki/Pluto#cite_note-NYT-20150724-ap-137)[[128]](https://en.wikipedia.org/wiki/Pluto#cite_note-Croswell1992-138) According to the measurements by *New Horizons*, the surface pressure is about 1 [Pa](https://en.wikipedia.org/wiki/Pascal_(unit)) (10 [μbar](https://en.wikipedia.org/wiki/Bar_(unit))),[[5]](https://en.wikipedia.org/wiki/Pluto#cite_note-Stern2015-7) roughly one million to 100,000 times less than Earth's atmospheric pressure. It was initially thought that, as Pluto moves away from the Sun, its atmosphere should gradually freeze onto the surface; however, studies of *New Horizons* data and ground-based occultations show that Pluto's atmospheric density actually increases, and that it likely remains gaseous throughout Pluto's orbit.[[129]](https://en.wikipedia.org/wiki/Pluto#cite_note-Olkin_2015-139)[[130]](https://en.wikipedia.org/wiki/Pluto#cite_note-skyandtel-140) *New Horizons* observations showed that atmospheric escape of nitrogen to be 10,000 times less than expected.[[130]](https://en.wikipedia.org/wiki/Pluto#cite_note-skyandtel-140) Alan Stern has contended that even a small increase in Pluto's surface temperature can lead to exponential increases in Pluto's atmospheric density; from 18 to as much as 280 millibars (three times that of Mars to a quarter that of the Earth). At such densities, nitrogen could flow across the surface as liquid.[[130]](https://en.wikipedia.org/wiki/Pluto#cite_note-skyandtel-140) Just like sweat cools the body as it evaporates from the skin, the [sublimation](https://en.wikipedia.org/wiki/Sublimation_(phase_transition)) of Pluto's atmosphere cools its surface.[[131]](https://en.wikipedia.org/wiki/Pluto#cite_note-KerThan2006-CNN-141) The presence of atmospheric gases was traced up to 1670 kilometers high, although the atmosphere does not have a sharp upper boundary.

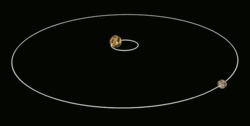
The presence of methane, a powerful [greenhouse gas](https://en.wikipedia.org/wiki/Greenhouse_gas), in Pluto's atmosphere creates a [temperature inversion](https://en.wikipedia.org/wiki/Inversion_(meteorology)), with the average temperature of its atmosphere tens of degrees warmer than its surface,[[132]](https://en.wikipedia.org/wiki/Pluto#cite_note-Lellouch_2009-142) though observations by *New Horizons* have revealed Pluto's upper atmosphere to be far colder than expected (70 K, as opposed to about 100 K).[[130]](https://en.wikipedia.org/wiki/Pluto#cite_note-skyandtel-140) Pluto's atmosphere is divided into roughly 20 regularly spaced haze layers up to 150 km high,[[5]](https://en.wikipedia.org/wiki/Pluto#cite_note-Stern2015-7)thought to be the result of pressure waves created by airflow across Pluto's mountains.[[130]](https://en.wikipedia.org/wiki/Pluto#cite_note-skyandtel-140)

## Satellites

*Main article:*[*Moons of Pluto*](https://en.wikipedia.org/wiki/Moons_of_Pluto)

Pluto has five known [natural satellites](https://en.wikipedia.org/wiki/Natural_satellite): [Charon](https://en.wikipedia.org/wiki/Charon_(moon)), first identified in 1978 by astronomer [James Christy](https://en.wikipedia.org/wiki/James_W._Christy); [Nix](https://en.wikipedia.org/wiki/Nix_(moon)) and [Hydra](https://en.wikipedia.org/wiki/Hydra_(moon)), both discovered in 2005;[[133]](https://en.wikipedia.org/wiki/Pluto#cite_note-Gugliotta2005-143) [Kerberos](https://en.wikipedia.org/wiki/Kerberos_(moon)), discovered in 2011;[[134]](https://en.wikipedia.org/wiki/Pluto#cite_note-P4-144) and [Styx](https://en.wikipedia.org/wiki/Styx_(moon)), discovered in 2012.[[135]](https://en.wikipedia.org/wiki/Pluto#cite_note-145) The satellites' orbits are circular (eccentricity < 0.006) and coplanar with Pluto's equator (inclination < 1°),[[136]](https://en.wikipedia.org/wiki/Pluto#cite_note-Buie2012-146)[[137]](https://en.wikipedia.org/wiki/Pluto#cite_note-ShowalterHamilton2015-147) and therefore tilted approximately 120° relative to Pluto's orbit. The Plutonian system is highly compact: the five known satellites orbit within the inner 3% of the region where [prograde orbits](https://en.wikipedia.org/wiki/Prograde_orbit) would be stable.[[138]](https://en.wikipedia.org/wiki/Pluto#cite_note-Sternetal_2005-148) Closest to Pluto is Charon, which is large enough to be in [hydrostatic equilibrium](https://en.wikipedia.org/wiki/Hydrostatic_equilibrium) and to cause the [barycenter](https://en.wikipedia.org/wiki/Barycenter) of the Pluto–Charon system to be outside Pluto. Beyond Charon there are four much smaller [circumbinary](https://en.wikipedia.org/wiki/Circumbinary) moons, Styx, Nix, Kerberos, and Hydra.

The orbital periods of all Pluto's moons are linked in a system of [orbital resonances](https://en.wikipedia.org/wiki/Orbital_resonance) and [near resonances](https://en.wikipedia.org/wiki/Orbital_resonance#Coincidental_.27near.27_ratios_of_mean_motion).[[137]](https://en.wikipedia.org/wiki/Pluto#cite_note-ShowalterHamilton2015-147)[[139]](https://en.wikipedia.org/wiki/Pluto#cite_note-Witze2015-149) When [precession](https://en.wikipedia.org/wiki/Apsidal_precession) is accounted for, the orbital periods of Styx, Nix, and Hydra are in an exact 18:22:33 ratio.[[137]](https://en.wikipedia.org/wiki/Pluto#cite_note-ShowalterHamilton2015-147) There is a sequence of approximate ratios, 3:4:5:6, between the periods of Styx, Nix, Kerberos, and Hydra with that of Charon; the ratios become closer to being exact the further out the moons are.[[137]](https://en.wikipedia.org/wiki/Pluto#cite_note-ShowalterHamilton2015-147)[[140]](https://en.wikipedia.org/wiki/Pluto#cite_note-Matson-150)

[](https://en.wikipedia.org/wiki/File:Pluto-Charon_System.gif)

An oblique view of the Pluto–Charon system showing that Pluto orbits a point outside itself. Also visible is the mutual [tidal locking](https://en.wikipedia.org/wiki/Tidal_locking) between the two bodies.

The Pluto–Charon system is one of the few in the Solar System whose [barycenter](https://en.wikipedia.org/wiki/Barycenter) lies outside the primary body; [617 Patroclus](https://en.wikipedia.org/wiki/617_Patroclus) is a smaller example, and the [Sun–Jupiter](https://en.wikipedia.org/wiki/Jupiter#Mass_and_size) system is the only larger one.[[141]](https://en.wikipedia.org/wiki/Pluto#cite_note-RichardsonWalsh2005-151) The similar sizes of Charon and Pluto has prompted some astronomers to call it a [double dwarf planet](https://en.wikipedia.org/wiki/Double_planet).[[142]](https://en.wikipedia.org/wiki/Pluto#cite_note-Sicardyetal2006nature-152) The system is also unusual among planetary systems in that each is [tidally locked](https://en.wikipedia.org/wiki/Tidal_locking) to the other, which means that Pluto and Charon always have the same hemisphere facing each other. From any position on either body, the other is always at the same position in the sky, or always obscured.[[143]](https://en.wikipedia.org/wiki/Pluto#cite_note-Young1997-153) This also means that the rotation period of each is equal to the time it takes the entire system to rotate around its barycenter.[[96]](https://en.wikipedia.org/wiki/Pluto#cite_note-axis-106)

In 2007, observations by the [Gemini Observatory](https://en.wikipedia.org/wiki/Gemini_Observatory) of patches of ammonia hydrates and water crystals on the surface of Charon suggested the presence of active cryo-geysers.[[144]](https://en.wikipedia.org/wiki/Pluto#cite_note-spaceflightnow2007_Ice_machine-154)

Pluto's moons are hypothesized to have been formed by a collision between Pluto and a similar-sized body, early in the history of the Solar System. The collision released material that consolidated into the moons around Pluto.[[145]](https://en.wikipedia.org/wiki/Pluto#cite_note-nasa.gov-155) However, Kerberos has a much lower albedo than the other moons of Pluto,[[146]](https://en.wikipedia.org/wiki/Pluto#cite_note-spaceweirdmoons-156) which is difficult to explain with a giant collision.[[147]](https://en.wikipedia.org/wiki/Pluto#cite_note-nationalgeorandombeat-157)

[](https://en.wikipedia.org/wiki/File:Pluto_moon_P5_discovery_with_moons%27_orbits.jpg)

[](https://en.wikipedia.org/wiki/File:Pluto_charon_150709_color_final.png)

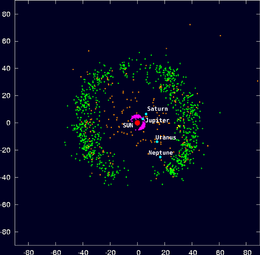
[](https://en.wikipedia.org/wiki/File:Nh-pluto_moons_family_portrait-truecolor.png)

[](https://en.wikipedia.org/wiki/File:Charon_in_Color_(HQ).jpg)

**1.** The Pluto system: Pluto, Charon, [Styx](https://en.wikipedia.org/wiki/Styx_(moon)), [Nix](https://en.wikipedia.org/wiki/Nix_(moon)), [Kerberos](https://en.wikipedia.org/wiki/Kerberos_(moon)), and [Hydra](https://en.wikipedia.org/wiki/Hydra_(moon)), imaged by the Hubble Space Telescope in July 2012. **2.** Pluto and Charon, to scale. Image acquired by *New Horizons* on July 8, 2015. **3.** Family portrait of the five moons of Pluto, to scale.[[148]](https://en.wikipedia.org/wiki/Pluto#cite_note-hubblesite.org-158) **4.** Pluto's moon Charon as viewed by *New Horizons* on July 13, 2015

## Origin

*Further information:*[*Kuiper belt*](https://en.wikipedia.org/wiki/Kuiper_belt)*and*[*Nice model*](https://en.wikipedia.org/wiki/Nice_model)

[](https://en.wikipedia.org/wiki/File:Outersolarsystem_objectpositions_labels_comp.png)

Plot of the known Kuiper belt objects, set against the four [giant planets](https://en.wikipedia.org/wiki/Giant_planet)

Pluto's origin and identity had long puzzled astronomers. One early hypothesis was that Pluto was an escaped moon of Neptune, knocked out of orbit by its largest current moon, [Triton](https://en.wikipedia.org/wiki/Triton_(moon)). This idea was eventually rejected after dynamical studies showed it to be impossible because Pluto never approaches Neptune in its orbit.[[149]](https://en.wikipedia.org/wiki/Pluto#cite_note-159)

Pluto's true place in the [Solar System](https://en.wikipedia.org/wiki/Solar_System) began to reveal itself only in 1992, when astronomers began to find small icy objects beyond Neptune that were similar to Pluto not only in orbit but also in size and composition. This trans-Neptunian population is thought to be the source of many [short-period comets](https://en.wikipedia.org/wiki/Short-period_comet). Pluto is now known to be the largest member of the [Kuiper belt](https://en.wikipedia.org/wiki/Kuiper_belt),[[k]](https://en.wikipedia.org/wiki/Pluto#cite_note-wiki-kbo-160) a stable belt of objects located between 30 and 50 AU from the Sun. As of 2011, surveys of the Kuiper belt to magnitude 21 were nearly complete and any remaining Pluto-sized objects are expected to be beyond 100 AU from the Sun.[[150]](https://en.wikipedia.org/wiki/Pluto#cite_note-Sheppard2011-161) Like other Kuiper-belt objects (KBOs), Pluto shares features with [comets](https://en.wikipedia.org/wiki/Comet); for example, the [solar wind](https://en.wikipedia.org/wiki/Solar_wind) is gradually blowing Pluto's surface into space.[[151]](https://en.wikipedia.org/wiki/Pluto#cite_note-pluto.jhuapl_cousin-162) It has been claimed that if Pluto were placed as near to the Sun as Earth, it would develop a tail, as comets do.[[152]](https://en.wikipedia.org/wiki/Pluto#cite_note-Tyson1999-163) This claim has been disputed with the argument that Pluto's escape velocity is too high for this to happen.[[153]](https://en.wikipedia.org/wiki/Pluto#cite_note-164)

Though Pluto is the largest Kuiper belt object discovered,[[117]](https://en.wikipedia.org/wiki/Pluto#cite_note-Plutosize-127) Neptune's moon [Triton](https://en.wikipedia.org/wiki/Triton_(moon)), which is slightly larger than Pluto, is similar to it both geologically and atmospherically, and is thought to be a captured Kuiper belt object.[[154]](https://en.wikipedia.org/wiki/Pluto#cite_note-PlanetaryOrg_Triton-165) Eris ([see above](https://en.wikipedia.org/wiki/Pluto#Classification)) is about the same size as Pluto (though more massive) but is not strictly considered a member of the Kuiper belt population. Rather, it is considered a member of a linked population called the[scattered disc](https://en.wikipedia.org/wiki/Scattered_disc).

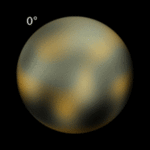
A large number of Kuiper belt objects, like Pluto, are in a 2:3 orbital resonance with Neptune. KBOs with this orbital resonance are called "[plutinos](https://en.wikipedia.org/wiki/Plutino)", after Pluto.[[155]](https://en.wikipedia.org/wiki/Pluto#cite_note-Jewitt2004-166)

Like other members of the Kuiper belt, Pluto is thought to be a residual [planetesimal](https://en.wikipedia.org/wiki/Planetesimal); a component of the original [protoplanetary disc](https://en.wikipedia.org/wiki/Protoplanetary_disc) around the [Sun](https://en.wikipedia.org/wiki/Sun) that failed to fully coalesce into a full-fledged planet. Most astronomers agree that Pluto owes its current position to a [sudden migration](https://en.wikipedia.org/wiki/Planetary_migration) undergone by Neptune early in the Solar System's formation. As Neptune migrated outward, it approached the objects in the proto-Kuiper belt, setting one in orbit around itself (Triton), locking others into resonances, and knocking others into chaotic orbits. The objects in the [scattered disc](https://en.wikipedia.org/wiki/Scattered_disc), a dynamically unstable region overlapping the Kuiper belt, are thought to have been placed in their current positions by interactions with Neptune's migrating resonances.[[156]](https://en.wikipedia.org/wiki/Pluto#cite_note-Hahn2005-167) A computer model created in 2004 by Alessandro Morbidelli of the [Observatoire de la Côte d'Azur](https://en.wikipedia.org/wiki/C%C3%B4te_d%27Azur_Observatory) in [Nice](https://en.wikipedia.org/wiki/Nice) suggested that the migration of Neptune into the Kuiper belt may have been triggered by the formation of a 1:2 resonance between Jupiter and Saturn, which created a gravitational push that propelled both Uranus and Neptune into higher orbits and caused them to switch places, ultimately doubling Neptune's distance from the Sun. The resultant expulsion of objects from the proto-Kuiper belt could also explain the [Late Heavy Bombardment](https://en.wikipedia.org/wiki/Late_Heavy_Bombardment) 600 million years after the Solar System's formation and the origin of the [Jupiter trojans](https://en.wikipedia.org/wiki/Jupiter_trojan).[[157]](https://en.wikipedia.org/wiki/Pluto#cite_note-Levison2007-168) It is possible that Pluto had a near-circular orbit about 33 AU from the Sun before Neptune's migration [perturbed](https://en.wikipedia.org/wiki/Perturbation_(astronomy)) it into a resonant capture.[[158]](https://en.wikipedia.org/wiki/Pluto#cite_note-Malhotra1995-169) The Nice model requires that there were about a thousand Pluto-sized bodies in the original planetesimal disk, which included Triton and Eris.[[157]](https://en.wikipedia.org/wiki/Pluto#cite_note-Levison2007-168)

## Observation and exploration

Pluto's distance from Earth makes its in-depth study and [exploration](https://en.wikipedia.org/wiki/Space_exploration) difficult. On July 14, 2015, [NASA](https://en.wikipedia.org/wiki/NASA)'s [*New Horizons*](https://en.wikipedia.org/wiki/New_Horizons) [space probe](https://en.wikipedia.org/wiki/Space_probe) flew through the Pluto system, providing much information about it.[[25]](https://en.wikipedia.org/wiki/Pluto#cite_note-NASA-20160317-sci-33)

### Observation

[](https://en.wikipedia.org/wiki/File:Pluto_animiert_200px.gif)

Computer-generated rotating image of Pluto based on observations by the [Hubble Space Telescope](https://en.wikipedia.org/wiki/Hubble_Space_Telescope) in 2002–2003

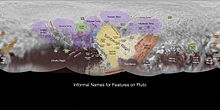
Pluto's visual [apparent magnitude](https://en.wikipedia.org/wiki/Apparent_magnitude) averages 15.1, brightening to 13.65 at perihelion.[[2]](https://en.wikipedia.org/wiki/Pluto#cite_note-Pluto_Fact_Sheet-3) To see it, a telescope is required; around 30 cm (12 in) aperture being desirable.[[159]](https://en.wikipedia.org/wiki/Pluto#cite_note-SSC2002-170) It looks star-like and without a visible disk even in large telescopes, because its [angular diameter](https://en.wikipedia.org/wiki/Angular_diameter) is only 0.11".

The earliest maps of Pluto, made in the late 1980s, were brightness maps created from close observations of eclipses by its largest moon, Charon. Observations were made of the change in the total average brightness of the Pluto–Charon system during the eclipses. For example, eclipsing a bright spot on Pluto makes a bigger total brightness change than eclipsing a dark spot. Computer processing of many such observations can be used to create a brightness map. This method can also track changes in brightness over time.[[160]](https://en.wikipedia.org/wiki/Pluto#cite_note-YoungBinzelCrane2001-171)[[161]](https://en.wikipedia.org/wiki/Pluto#cite_note-BuieTholenHorne1992-172)

Better maps were produced from images taken by the [Hubble Space Telescope](https://en.wikipedia.org/wiki/Hubble_Space_Telescope) (HST), which offered higher [resolution](https://en.wikipedia.org/wiki/Angular_resolution), and showed considerably more detail,[[106]](https://en.wikipedia.org/wiki/Pluto#cite_note-Buie_web_map-116) resolving variations several hundred kilometers across, including polar regions and large bright spots.[[108]](https://en.wikipedia.org/wiki/Pluto#cite_note-Buie_2010_surface-maps-118) These maps were produced by complex computer processing, which finds the best-fit projected maps for the few pixels of the Hubble images.[[162]](https://en.wikipedia.org/wiki/Pluto#cite_note-Buie_mapmaking-173) These remained the most detailed maps of Pluto until the flyby of [*New Horizons*](https://en.wikipedia.org/wiki/New_Horizons) in July 2015, because the two cameras on the HST used for these maps were no longer in service.[[162]](https://en.wikipedia.org/wiki/Pluto#cite_note-Buie_mapmaking-173)

### Exploration

*Main articles:*[*Exploration of Pluto*](https://en.wikipedia.org/wiki/Exploration_of_Pluto)*and*[*New Horizons*](https://en.wikipedia.org/wiki/New_Horizons)

[](https://en.wikipedia.org/wiki/File:Pluto-Map-Annotated.jpg)

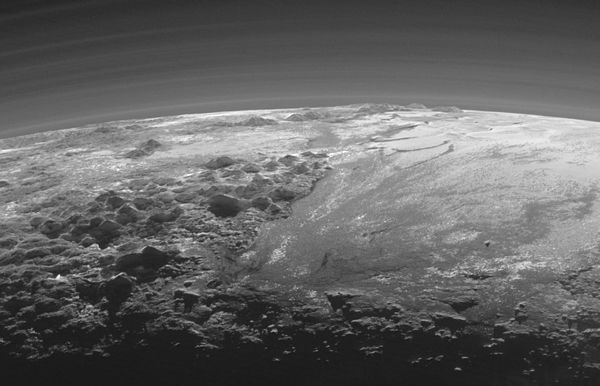
The portions of Pluto's surface mapped by *New Horizons* (annotated)

The *New Horizons* spacecraft, which [flew by](https://en.wikipedia.org/wiki/Planetary_flyby) Pluto in July 2015, is the first and so far only attempt to explore Pluto directly. Launched in 2006, it captured its first (distant) images of Pluto in late September 2006 during a test of the Long Range Reconnaissance Imager.[[163]](https://en.wikipedia.org/wiki/Pluto#cite_note-pluto.jhuapl_First_Pluto_Sighting-174) The images, taken from a distance of approximately 4.2 billion kilometers, confirmed the spacecraft's ability to track distant targets, critical for maneuvering toward Pluto and other Kuiper belt objects. In early 2007 the craft made use of a [gravity assist](https://en.wikipedia.org/wiki/Gravity_assist) from [Jupiter](https://en.wikipedia.org/wiki/Jupiter).

*New Horizons* made its closest approach to Pluto on July 14, 2015 after a 3,462-day journey across the Solar System. Scientific observations of Pluto began five months before the closest approach and continued for at least a month after the encounter. Observations were conducted using a [remote sensing](https://en.wikipedia.org/wiki/Remote_sensing) package that included [imaging](https://en.wikipedia.org/wiki/Digital_imaging) instruments and a radio science investigation tool, as well as [spectroscopic](https://en.wikipedia.org/wiki/Spectroscopy) and other experiments. The scientific goals of *New Horizons* were to characterize the global geology and morphology of Pluto and its moon Charon, map their surface composition, and analyze Pluto's neutral atmosphere and its escape rate.

## Gallery

[](https://en.wikipedia.org/wiki/File:PIA19948-NH-Pluto-Norgay-Hillary-Mountains-2050714.jpg)

[](https://en.wikipedia.org/wiki/File:PIA19947-NH-Pluto-Norgay-Hillary-Mountains-2050714.jpg)

View of the [Norgay Montes](https://en.wikipedia.org/wiki/Norgay_Montes) (left-foreground), [Hillary Montes](https://en.wikipedia.org/wiki/Hillary_Montes) (left-skyline), and [Sputnik Planum](https://en.wikipedia.org/wiki/Sputnik_Planum) (right).  
Near-sunset view includes several layers of atmospheric haze.

[](https://en.wikipedia.org/wiki/File:NH-Pluto-SphericalMosaic-20150910.jpg)

Spherical mosaic of *New Horizons* images showing the expanse of [Sputnik Planum](https://en.wikipedia.org/wiki/Sputnik_Planum)  
(released September 10, 2015)[[164]](https://en.wikipedia.org/wiki/Pluto#cite_note-NASA-20150910-175)[[165]](https://en.wikipedia.org/wiki/Pluto#cite_note-NYT-20150910-176)

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| |  | | --- | | [https://upload.wikimedia.org/wikipedia/commons/thumb/6/6c/PIA19873-Pluto-NewHorizons-FlyingPastImage-20150714.jpg/300px-PIA19873-Pluto-NewHorizons-FlyingPastImage-20150714.jpg](https://en.wikipedia.org/wiki/File:PIA19873-Pluto-NewHorizons-FlyingPastImage-20150714.jpg) | | Pluto as viewed by *New Horizons* during flyby (color; [animation](http://photojournal.jpl.nasa.gov/archive/PIA19873_FLYTHROUGH_ANIMATION_V5.mp4); July 14, 2015)[[166]](https://en.wikipedia.org/wiki/Pluto#cite_note-NASA-20150828-177) | |

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| |  | | --- | | [https://upload.wikimedia.org/wikipedia/commons/thumb/4/48/PIA19856-PlutoCharon-NewHorizons-Color-20150714.jpg/600px-PIA19856-PlutoCharon-NewHorizons-Color-20150714.jpg](https://en.wikipedia.org/wiki/File:PIA19856-PlutoCharon-NewHorizons-Color-20150714.jpg) | | Pluto and Charon as viewed by *New Horizons* (highest-resolution; color; July 14, 2015) | |

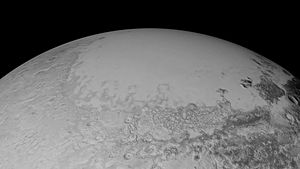
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| |  | | --- | | [https://upload.wikimedia.org/wikipedia/commons/thumb/5/58/NH-PlutoCharon-Color-NewHorizons-20150711.jpg/344px-NH-PlutoCharon-Color-NewHorizons-20150711.jpg](https://en.wikipedia.org/wiki/File:NH-PlutoCharon-Color-NewHorizons-20150711.jpg) | | Pluto and Charon as viewed by *New Horizons* (natural color; July 11, 2015) |  |  | | --- | | [https://upload.wikimedia.org/wikipedia/commons/thumb/4/45/NH-071315-PlutoCharon-FalseColorComposite-20150713.jpg/320px-NH-071315-PlutoCharon-FalseColorComposite-20150713.jpg](https://en.wikipedia.org/wiki/File:NH-071315-PlutoCharon-FalseColorComposite-20150713.jpg) | | Pluto and Charon as viewed by *New Horizons* ([false color](https://en.wikipedia.org/wiki/False_color); July 13, 2015) | |

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| |  | | --- | | [https://upload.wikimedia.org/wikipedia/commons/thumb/b/b6/NH-71015-Pluto-NewHorizons-20150709.png/140px-NH-71015-Pluto-NewHorizons-20150709.png](https://en.wikipedia.org/wiki/File:NH-71015-Pluto-NewHorizons-20150709.png) | | Pluto viewed by *New Horizons* (July 9, 2015) |  |  | | --- | | [https://upload.wikimedia.org/wikipedia/commons/thumb/5/5b/Pluto_by_LORRI%2C_11_July_2015.jpg/140px-Pluto_by_LORRI%2C_11_July_2015.jpg](https://en.wikipedia.org/wiki/File:Pluto_by_LORRI,_11_July_2015.jpg) | | Pluto viewed by *New Horizons* (July 11, 2015) |  |  | | --- | | [https://upload.wikimedia.org/wikipedia/commons/thumb/3/3b/071215-Pluto-NewHorizons-20150711.png/140px-071215-Pluto-NewHorizons-20150711.png](https://en.wikipedia.org/wiki/File:071215-Pluto-NewHorizons-20150711.png) | | Pluto viewed by *New Horizons* (July 11, 2015) |  |  | | --- | | [https://upload.wikimedia.org/wikipedia/commons/thumb/5/5c/NH-7-13-15-Pluto-NewHorizons-20150712.png/140px-NH-7-13-15-Pluto-NewHorizons-20150712.png](https://en.wikipedia.org/wiki/File:NH-7-13-15-Pluto-NewHorizons-20150712.png) | | Pluto viewed by *New Horizons* (July 12, 2015) |  |  | | --- | | [https://upload.wikimedia.org/wikipedia/commons/thumb/e/e8/NH-Pluto-bw-NewHorizons-20150713a.jpg/140px-NH-Pluto-bw-NewHorizons-20150713a.jpg](https://en.wikipedia.org/wiki/File:NH-Pluto-bw-NewHorizons-20150713a.jpg) | | Pluto viewed by *New Horizons* (July 13, 2015) | |

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| |  | | --- | | [https://upload.wikimedia.org/wikipedia/commons/thumb/2/26/Pluto-11jul-color.jpg/179px-Pluto-11jul-color.jpg](https://en.wikipedia.org/wiki/File:Pluto-11jul-color.jpg) | | Pluto as viewed by *New Horizons* (color; July 11, 2015) |  |  | | --- | | [https://upload.wikimedia.org/wikipedia/commons/thumb/5/5a/Pluto_by_LORRI_and_Ralph%2C_13_July_2015.jpg/180px-Pluto_by_LORRI_and_Ralph%2C_13_July_2015.jpg](https://en.wikipedia.org/wiki/File:Pluto_by_LORRI_and_Ralph,_13_July_2015.jpg) | | Pluto as viewed by *New Horizons* (color; July 13, 2015) | |

### Videos

**Pluto flyover animated (July 14, 2015)**



(00:30; [released September 18, 2015](https://en.wikipedia.org/wiki/File:Pluto-FlyoverAnimation-20150918.webm))



(00:50; [released December 5, 2015](https://en.wikipedia.org/wiki/File:15-02652-PlutoFilm-50sec-20150714.webm))



This mosaic strip – extending across the hemisphere that faced the New Horizons spacecraft as it flew past Pluto. (No Audio - 1080p 60fps)

## See also

* ***https://upload.wikimedia.org/wikipedia/commons/thumb/8/83/Solar_system.jpg/22px-Solar_system.jpg***[***Solar System portal***](https://en.wikipedia.org/wiki/Portal:Solar_System)

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| Book icon | * [**Book: Dwarf Planets of the Solar System & Their Satellites**](https://en.wikipedia.org/wiki/Book:Dwarf_Planets_of_the_Solar_System_%26_Their_Satellites) * [**Book: Solar System**](https://en.wikipedia.org/wiki/Book:Solar_System) |

* [*How I Killed Pluto and Why It Had It Coming*](https://en.wikipedia.org/wiki/How_I_Killed_Pluto_and_Why_It_Had_It_Coming)
* [Pluto in astrology](https://en.wikipedia.org/wiki/Planets_in_astrology#Pluto)
* [Pluto in fiction](https://en.wikipedia.org/wiki/Pluto_in_fiction)

## Notes

* 1. [**Jump up^**](https://en.wikipedia.org/wiki/Pluto#cite_ref-caption_1-0) This is a [composite](https://en.wikipedia.org/wiki/Digital_compositing) of four near-true color photographs taken by the [*New Horizons*](https://en.wikipedia.org/wiki/New_Horizons) spacecraft on July 14, 2015 from a distance of 720,000 km (450,000 mi). The most prominent feature in the image, the bright, youthful plains of [Tombaugh Regio](https://en.wikipedia.org/wiki/Tombaugh_Regio) and[Sputnik Planum](https://en.wikipedia.org/wiki/Sputnik_Planum), can be seen at lower right. It contrasts the darker, more cratered terrain of [Cthulhu Regio](https://en.wikipedia.org/wiki/Cthulhu_Regio) at lower left. Because of Pluto's 119.591° tilt at its axis, the southern hemisphere is barely visible in this image; the [equator](https://en.wikipedia.org/wiki/Equator) runs through Cthulhu and the southern parts of Sputnik Planum.
  2. [**Jump up^**](https://en.wikipedia.org/wiki/Pluto#cite_ref-MeanElements_6-0) The mean elements here are from the Theory of the Outer Planets (TOP2013) solution by the Institut de mécanique céleste et de calcul des éphémérides (IMCCE). They refer to the standard equinox J2000, the barycenter of the Solar System, and the epoch J2000.
  3. [**Jump up^**](https://en.wikipedia.org/wiki/Pluto#cite_ref-Surface_area_8-0) Surface area derived from the radius *r*: {\displaystyle 4\pi r^{2}}**.**
  4. [**Jump up^**](https://en.wikipedia.org/wiki/Pluto#cite_ref-Volume_9-0) Volume *v* derived from the radius *r*: {\displaystyle 4\pi r^{3}/3}**.**
  5. [**Jump up^**](https://en.wikipedia.org/wiki/Pluto#cite_ref-Surface_gravity_10-0) Surface gravity derived from the mass *M*, the [gravitational constant](https://en.wikipedia.org/wiki/Gravitational_constant) *G* and the radius *r*: {\displaystyle GM/r^{2}}.
  6. [**Jump up^**](https://en.wikipedia.org/wiki/Pluto#cite_ref-Escape_velocity_11-0) Escape velocity derived from the mass *M*, the [gravitational constant](https://en.wikipedia.org/wiki/Gravitational_constant) *G* and the radius *r*: {\displaystyle {\sqrt {2GM/r}}}.
  7. [**Jump up^**](https://en.wikipedia.org/wiki/Pluto#cite_ref-Axial_tilt_13-0) Based on the orientation of Charon's orbit, which is assumed the same as Pluto's spin axis due to the mutual [tidal locking](https://en.wikipedia.org/wiki/Tidal_locking).
  8. [**Jump up^**](https://en.wikipedia.org/wiki/Pluto#cite_ref-Angular_size_18-0) Based on geometry of minimum and maximum distance from Earth and Pluto radius in the factsheet
  9. [**Jump up^**](https://en.wikipedia.org/wiki/Pluto#cite_ref-51) The equivalence is less close in languages whose [phonology](https://en.wikipedia.org/wiki/Phonology)differs widely from [Greek's](https://en.wikipedia.org/wiki/Ancient_Greek_phonology), such as [Somali](https://en.wikipedia.org/wiki/Somali_language) *Buluuto* and [Navajo](https://en.wikipedia.org/wiki/Navajo_language)*Tłóotoo*.
  10. [**Jump up^**](https://en.wikipedia.org/wiki/Pluto#cite_ref-Perihelion_93-0) The discovery of Charon in 1978 allowed astronomers to accurately calculate the mass of the Plutonian system. But it did not indicate the two bodies' individual masses, which could only be estimated after other moons of Pluto's were discovered in late 2005. As a result, because Pluto came to perihelion in 1989, most Pluto perihelion date estimates are based on the Pluto–Charon [barycenter](https://en.wikipedia.org/wiki/Barycenter). Charon came to perihelion [4 September 1989.](http://ssd.jpl.nasa.gov/horizons.cgi?find_body=1&body_group=mb&sstr=901) The Pluto–Charon barycenter came to perihelion [5 September 1989.](http://ssd.jpl.nasa.gov/horizons.cgi?find_body=1&body_group=mb&sstr=9) Pluto came to perihelion [8 September 1989.](http://ssd.jpl.nasa.gov/horizons.cgi?find_body=1&body_group=mb&sstr=999)
  11. [**Jump up^**](https://en.wikipedia.org/wiki/Pluto#cite_ref-wiki-kbo_160-0) The dwarf planet [Eris](https://en.wikipedia.org/wiki/Eris_(dwarf_planet)) is roughly the same size as Pluto, about 2330 km; Eris is, however, 28% more massive than Pluto. [Eris](https://en.wikipedia.org/wiki/Eris_(dwarf_planet)) is a [scattered-disc object](https://en.wikipedia.org/wiki/Scattered-disc_object), often considered a distinct population from Kuiper-belt objects like Pluto; Pluto is the largest body in the Kuiper belt proper, which excludes the scattered-disc objects.

## References

* 1. ^ [Jump up to:***a***](https://en.wikipedia.org/wiki/Pluto#cite_ref-jpl-ssd-horizons_2-0) [***b***](https://en.wikipedia.org/wiki/Pluto#cite_ref-jpl-ssd-horizons_2-1) [*"Horizon Online Ephemeris System for Pluto Barycenter"*](http://ssd.jpl.nasa.gov/horizons.cgi?find_body=1&body_group=mb&sstr=9).[*JPL Horizons On-Line Ephemeris System*](https://en.wikipedia.org/wiki/JPL_Horizons_On-Line_Ephemeris_System)@ Solar System Dynamics Group*. Retrieved January 16, 2011*. (set Observer Location to @0 to place the observer at the center of the Sun-Jupiter system)
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