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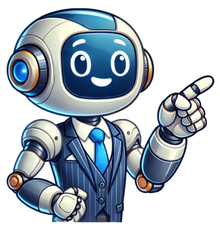

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But how planets like Earth form still remains a subject of great debate.Currently, there are two leading theories on planetary formation. Scientists continue to study planets in and out of our solar system in an effort to better understand which of these theories most accurately describes how the solar system and its planets formed.You may like The first and most widely accepted theory is the core accretion model, which works well to explain the formation of terrestrial planets like Earth but doesn't fully account for giant planets. The second theory, called the disk instability method, may account for the creation of larger planets.These two leading theories are joined by the pebble accretion theory which helps to additionally explain how different objects might form.Related: Earth's layers: Exploring our planet inside and outWhat is the core accretion model?Artist's conception of our solar system's solar nebula, the cloud of gas and dust from which Earth, the sun and our solar system's other planets planets formed. (Image credit: Painting copyright William K. Hartmann, Planetary Science Institute, Tucson)Approximately 4.6 billion years ago, our solar system was just a cloud of dust and gas known as a solar nebula. Gravity collapsed the material in on itself as it began to spin, condensing the matter and forming the sun in the center of the nebula.With the sun beginning to form, the remaining material started to clump up. Small particles drew together, bound by the force of gravity, into larger particles. The solar wind, a constant stream of charged particles that emanate from the sun's upper atmosphere, swept away lighter elements, such as hydrogen and helium.This left behind heavy, rocky materials that formed smaller terrestrial worlds like Earth. And farther away from the sun, the solar wind had less of an impact on lighter elements which allowed these elements to coalesce into gas giants. This process created our solar system's asteroids, comets, planets and moons.Earth's rocky core formed first, with heavy elements colliding and binding together. Dense material sank to the protoplanet's center while lighter material built up the crust. Earth's magnetic field is thought to have likely formed around this time.Early in its evolution, Earth suffered an impact by a large body that catapulted pieces of the young planet's mantle into space. Gravity pulled many of these pieces together to form the moon, which took up orbit around its creator.The late-stage phase of planet formation with protoplanets and planetismals is seen in this artist's depiction. (Image credit: Ashley Norris/Oxford University)The flow of the mantle beneath Earth's crust causes plate tectonics, the movement of the large plates of rock on the planet's surface. Collisions and friction gave rise to mountains and volcanoes, which began to spew gases.When Earth first formed it had barely any atmosphere. Its atmosphere began to form as the planet started to cool and gravity captured gases from Earth's volcanoes.While the population of comets and asteroids passing through the inner solar system is sparse today, they were more abundant when the planets and sun were young. Collisions between these cosmic bodies likely deposited much of the water on Earth's surface.Our planet lies in what is known as the Goldilocks zone, a region surrounding a star that is close enough for liquid water to exist on a planet's surface, with water neither freezing nor evaporating. Many scientists think that being in this zone, and the presence of liquid water, plays a key role in the existence of life.An artistic conception of the early Earth-moon system showing the Earth's surface after being bombarded with large impacts, causing magma extrusion on the surface, though some liquid water was retained. Image released on July 30, 2014. (Image credit: Simone Marchi)In observing exoplanets, scientists think that this core accretion model fits as the dominant formation process.Stars with more "metals" a term astronomers use for all chemical elements heavier than hydrogen and helium in their cores host more giant planets than their metal-poor cousins. 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With missions like this and others, scientists aim to study distant worlds to grow their understanding of how planets in different solar systems likely formed."In the core accretion scenario, the core of a planet must reach a critical mass before it is able to accrete gas in a runaway fashion," said the CHEOPS team."This critical mass depends upon many physical variables, among the most important of which is the rate of planetesimals accretion."Related: How fast is Earth moving?What is the disk instability model?While the core accretion model works for terrestrial planets, gas giants would need to evolve rapidly to grab hold of the significant mass of lighter gases they contain. But simulations with that model have not been able to account for this rapid formation. In those simulations, the process takes several million years, which is longer than light gases were available in the early solar system.But the core accretion model isn't the only explanation for how planets might come to be.According to a newer theory, disk instability, clumps of dust and gas bind together early in the solar system's existence. Over time, these clumps can slowly compact into a giant planet. These planets can form faster than those that form within the core accretion explanation, sometimes in as little as a thousand years, which allows them to trap the rapidly-vanishing lighter gases. These planets also quickly reach an orbit-stabilizing mass that keeps them from death-marching into the sun.According to exoplanetary astronomer Paul Wilson, if disk instability dominates the formation of planets, it should produce a wide number of worlds at large orders. 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In previous simulations, both large and medium-sized objects consumed their pebble-sized cousins at a relatively constant rate, but Levison's simulations suggest that the larger objects acted more like bullies, snatching away pebbles from the mid-sized masses to grow at a much faster rate."The larger objects now tend to scatter the smaller ones more than the smaller ones scatter them back, so the smaller ones end up getting scattered out of the pebble disk," study co-author Katherine Kretke, also from SwRI, told Space.com. "The bigger guy basically bullies the smaller one so they can eat all the pebbles themselves, and they can continue to grow up to form the cores of the giant planets."As scientists continue to study planets inside and outside of the solar system, they will better understand how Earth and its siblings formed.Additional resourcesFollow us at @Spacedotcom, Facebook or Google+.This article was updated on Jan. 5, 2022 by Space.com senior writer Chelsea GohdEarth's formation remains a strange, scientific mystery.We live on a planet in a solar system with seven other planets and have discovered thousands of exoplanets to date. But how planets like Earth form still remains a subject of great debate.Currently, there are two leading theories on planetary formation. 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"The bigger guy basically bullies the smaller one so they can eat all the pebbles themselves, and they can continue to grow up to form the cores of the giant planets."As scientists continue to study planets inside and outside of the solar system, they will better understand how Earth and its siblings formed.Additional resourcesFollow us at @Spacedotcom, Facebook or Google+.This article was updated on Jan. 5, 2022 by Space.com senior writer Chelsea GohdThird planet from the Sun"Planet Earth" redirects here. For other uses, see Earth (disambiguation) and Planet Earth (disambiguation).EarthThe Blue Marble, Apollo 17, December 1972DesignationsAlternative namesThe worldThe globeTerraTellusGaiaMother EarthSol IIIAdjectivesEarthlyTerrestrialTerranTellurianSymbol and Orbital characteristicsEpoch J2000[n 1]Aphelion152097597kmPerihelion147098450km[n 2]Semi-major axis149598023km[1]Eccentricity0.0167086[1]Orbital period (sidereal)365.256363004d[2](1.00001742096aj)Average orbital speed29.7827km/s[3]Mean anomaly358.617Inclination7.155 Sun's equator;1.57869 invariable plane;[4]0.00005 J2000 eclipticLongitudeof ascendingnode11.26064 J2000 ecliptic[3]Timeof perihelion2023-Jan-04[5]Argumentof perihelion114.20783[3]Satellites1, the MoonPhysical characteristicsMean radius6371.0km[6]Equatorial radius6378.137km[7][8]Polar radius6356.752km[9]Flattening1/298.257222101 (ETRS89)[10]Circumference40075.017km equatorial[8]40007.86km meridional[11][n 3]Surface area510072000km2[12][n 4]Land: 148940000km2Water: 361132000km2Volume1.083211012km3[3]Mass5.9721681024kg[13]Mean density5.513g/cm3[3]Surface gravity9.80665m/s2[14](exactly 1 g0)Moment of inertia factor0.3307[15]Escape velocity11.186km/s[3]Synodic rotation period1.0d (24h 00m 00s)Sidereal rotation period0.99726968d[16] (23h 56m 4.100s)Equatorial rotationvelocity0.4651km/s[17]Axial tilt23.4392811[2]Albedo0.434 geometric[3]0.294 Bond[3]Temperature255K (18C)(blackbody temperature)[18]Surface temp.minmeanmax[n 5]89.2C14.76C56.7CSurface equivalent dose rate0.274Sv/h[22]Absolute magnitude(H)3.99AtmosphereSurface pressure101.325kPa (at sea level)Composition by volume78.08% nitrogen (dry air)20.95% oxygen (dry air)1% water vapor (variable)0.9340% argon0.0415% carbon dioxide0.00182% neon0.00052% helium0.00017% methane0.00011% krypton0.00006% hydrogenSource:[3]Earth is the third planet from the Sun and the only astronomical object known to harbor life. This is enabled by Earth being an ocean world, the only one in the Solar System sustaining liquid surface water. Almost all of Earth's water is contained in its global ocean, covering 70.8% of Earth's crust. The remaining 29.2% of Earth's crust is land, most of which is located in the form of continental landmasses within Earth's land hemisphere. Most of Earth's land is at least somewhat humid and covered by vegetation, while large sheets of ice at Earth's polar deserts retain more water than Earth's groundwater, lakes, rivers, and atmospheric water combined. Earth's crust consists of slowly moving tectonic plates, which interact to produce mountain ranges, volcanoes, and earthquakes. Earth has a liquid outer core that generates a magnetosphere capable of deflecting most of the destructive solar winds and cosmic radiation.Earth has a dynamic atmosphere, which sustains Earth's surface conditions and protects it from most meteoroids and UV-light at entry. It has a composition of primarily nitrogen and oxygen. Water vapor is widely present in the atmosphere, forming clouds that cover most of the planet. The water vapor acts as a greenhouse gas and, together with other greenhouse gases in the atmosphere, particularly carbon dioxide (CO2), creates the conditions for both liquid surface water and water vapor to persist via the capturing of energy from the Sun's light. This process maintains the current average surface temperature of 14.76C (58.57F), at which water is liquid under normal atmospheric pressure. Differences in the amount of captured energy between geographic regions (as with the equatorial region receiving more sunlight than the polar regions) drive atmospheric and ocean currents, producing a global climate system with different climate regions, and a range of weather phenomena such as precipitation, allowing components such as nitrogen to cycle.Earth is rounded into an ellipsoid with a circumference of about 40,000 kilometres (25,000 miles). It is the densest planet in the Solar System. Of the four rocky planets, it is the largest and most massive. Earth is about eight light-minutes (1 AU) away from the Sun and orbits it, taking a year (about 365.25 days) to complete one revolution. Earth rotates around its own axis in slightly less than a day (in about 23 hours and 56 minutes). Earth's axis of rotation is tilted with respect to the perpendicular to its orbital plane around the Sun, producing seasons. Earth is orbited by one permanent natural satellite, the Moon, which orbits Earth at 384,400km (238,900mi)1.28 light secondsand is roughly a quarter as wide as Earth. The Moon's gravity helps stabilize Earth's axis, causes tides and gradually slows Earth's rotation. Likewise Earth's gravitational pull has already made the Moon's rotation tidally locked, keeping the same near side facing Earth.Earth, like most other bodies in the Solar System, formed about 4.5billion years ago from gas and dust in the early Solar System. During the first billion years of Earth's history, the ocean formed and then life developed within it. Life spread globally and has been altering Earth's atmosphere and surface, leading to the Great Oxidation Event two billion years ago. Humans emerged 300,000 years ago in Africa and have spread across every continent on Earth. Humans depend on Earth's biosphere and natural resources for their survival, but have increasingly impacted the planet's environment. Humanity's current impact on Earth's climate and biosphere is unsustainable, threatening the livelihood of humans and many other forms of life, and causing widespread extinctions.The Modern English word Earth developed, via Middle English, from an Old English noun most often spelled eore.[23] It has cognates in every Germanic language, from which Proto-Germanic*er has been reconstructed. In its earliest attestation, the word eore was used to translate the many senses of Latin terra and Greek g: the ground, its soil, dry land, the human world, the surface of the world (including the sea), and the globe itself. As with Roman Terra (or Tellus) and Greek Gaia, Earth may have been a personified goddess in Germanic paganism: late Norse mythology included Jr ('Earth'), a giantess often given as the mother of Thor.[24]Historically, Earth has been written in lowercase. During the Early Middle English period, its definite sense as "the globe" began being expressed using the phrase the earth. By the period of Early Modern English, capitalization of nouns began to prevail, and the earth was also written 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, though earth and forms with the earth remain common.[23] House styles now vary: Oxford spelling recognizes the lowercase form as the more common, with the capitalized form an acceptable variant. Another convention capitalizes Earth when appearing as a name, such as a description of the "Earth's atmosphere", but employs the lowercase when it is preceded by the, such as "the atmosphere of the earth". It almost always appears in lowercase in colloquial expressions such as "what on earth are you doing?"[25]The name Terra /tr/ TERR- is occasionally used in scientific writing; it also sees use in science fiction to distinguish humanity's inhabited planet from others,[26] while in poetry Tellus /tls/ TELL-s has been used to denote personification of the Earth.[27] Terra is also the name of the planet in some Romance languages, languages that evolved from Latin, like Italian and Portuguese, while in other Romance languages the word gave rise to names with slightly altered spellings, like the Spanish Tierra and the French Terre. The Latinate form Gaea (English: /di./ DJEE-) of the Greek poetic name Gaia ([i.a] or [j.ja]) is rare, though the alternative spelling Gaia has become common due to the Gaia hypothesis, in which case its pronunciation is /a./ GYE- rather than the more traditional English /e./ GAY-.[28]There are a number of adjectives for the planet Earth. The word earthly is derived from Earth. From the Latin Terra comes terran /trn/ TERR-n,[29] terrestrial /trstrl/ trr-EHST-ree-l,[30] and (via French) terrene /trin/ t-REEN,[31] and from the Latin Tellus comes tellurian /tlrn/ teh-LUURR-ee-n[32] and telluric.[33]Main articles: History of Earth and Timeline of natural historyFurther information: Early Earth and HadeanA 2012 artistic impression of the early Solar System's protoplanetary disk from which Earth and other Solar System bodies were formedThe oldest material found in the Solar System is dated to 4.5682+0.00020.0004 Ga (billion years) ago.[34] By 4.540.04Ga the primordial Earth had formed.[35] The bodies in the Solar System formed and evolved with the Sun. In theory, a solar nebula partitions a volume out of a molecular cloud by gravitational collapse, which begins to spin and flatten into a circumstellar disk, and then the planets grow out of that disk with the Sun. A nebula contains gas, ice grains, and dust (including primordial nuclides). According to nebular theory, planetesimals formed by accretion, with the primordial Earth being estimated as likely taking anywhere from 70 to 100 million years to form.[36]Estimates of the age of the Moon range from 4.5 Ga to significantly younger.[37] A leading hypothesis is that it was formed by accretion from material loosed from Earth after a Mars-sized object with about 10% of Earth's mass, named Theia, collided with Earth.[38] It hit Earth with a glancing blow and some of its mass merged with Earth.[39][40] Between approximately 4.0 and 3.8Ga, numerous asteroid impacts during the Late Heavy Bombardment caused significant changes to the greater surface environment of the Moon and, by inference, to that of Earth.[41]Main article: Geological history of EarthEarth's atmosphere and oceans were formed by volcanic activity and outgassing.[42] Water vapor from these sources condensed into the oceans, augmented by water and ice from asteroids, protoplanets, and comets.[43] Sufficient water to fill the oceans may have been on Earth since it formed.[44] In this model, atmospheric greenhouse gases kept the oceans from freezing when the newly forming Sun had only 70% of its current luminosity.[45] By 3.5Ga, Earth's magnetic field was established, which helped prevent the atmosphere from being stripped away by the solar wind.[46]Pale orange dot, an artist's impression of Early Earth, featuring its tinted orange methane-rich early atmosphere[47]As the molten outer layer of Earth cooled it formed the first solid crust, which is thought to have been mafic in composition. The first continental crust, which was more felsic in composition, formed by the partial melting of this mafic crust.[48] The presence of grains of the mineral zircon of Hadean age in Eoarchean sedimentary rocks suggests that at least some felsic crust existed as early as 4.4Ga, only 140Ma after Earth's formation.[49] There are two main models of how this initial small volume of continental crust evolved to reach its current abundance:[50] (1) a relatively steady growth up to the present day,[51] which is supported by the radiometric dating of continental crust globally and (2) an initial rapid growth in the volume of continental crust during the Archean, forming the bulk of the continental crust that now exists,[52][53] which is supported by isotopic evidence from hafnium in zircons and neodymium in sedimentary rocks. The two models and the data that support them can be reconciled by large-scale recycling of the continental crust, particularly during the early stages of Earth's history.[54]New continental crust forms as a result of plate tectonics, a process ultimately driven by the continuous loss of heat from Earth's interior. Over the period of hundreds of millions of years, tectonic forces have caused areas of continental crust to group together to form supercontinents that have subsequently broken apart. At approximately 750Ma, one of the earliest known supercontinents, Rodinia, began to break apart. The continents later recombined to form Pannotia at 600540Ma, then finally Pangaea, which also began to break apart at 180Ma.[55]The most recent pattern of ice ages began about 40Ma,[56] and then intensified during the Pleistocene about 3Ma.[57] High- and middle-latitude regions have since undergone repeated cycles of glaciation and thaw, repeating about every 21,000, 41,000 and 100,000 years.[58] The Last Glacial Period, colloquially called the "last ice age", covered large parts of the continents, to the middle latitudes, in ice and ended about 11,700 years ago.[59]Main articles: Abiogenesis, Earliest known life forms, and History of lifeChemical reactions led to the first self-replicating molecules about four billion years ago. A half billion years later, the last common ancestor of all current life arose.[60] The evolution of photosynthesis allowed the Sun's energy to be harvested directly by life forms. The resultant molecular oxygen (O2) accumulated in the atmosphere and due to interaction with ultraviolet solar radiation, formed a protective ozone layer (O3) in the upper atmosphere.[61] The incorporation of smaller cells within larger ones resulted in the development of complex cells called eukaryotes.[62] True multicellular organisms formed as cells within colonies became increasingly specialized. Aided by the absorption of harmful ultraviolet radiation by the ozone layer, life colonized Earth's surface.[63] Among the earliest fossil evidence for life is microbial mat fossils found in 3.48billion-year-old sandstone in Western Australia,[64] biogenic graphite found in 3.7billion-year-old metasedimentary rocks in Western Greenland,[65] and remains of biotic material found in 4.1billion-year-old rocks in Western Australia.[66][67] The earliest direct evidence of life on Earth is contained in 3.45billion-year-old Australian rocks showing fossils of microorganisms.[68][69]An artist's impression of the Archean, the eon after Earth's formation, featuring round stromatolites, which are early oxygen-producing forms of life from billions of years ago. After the Late Heavy Bombardment, Earth's crust had cooled, its water-rich barren surface is marked by continents and volcanoes, with the Moon still orbiting Earth half as far as it is today, appearing 2.8 times larger and producing strong tides.[70]During the Neoproterozoic, 1000 to 539Ma, much of Earth might have been covered in ice. This hypothesis has been termed "Snowball Earth", and it is of particular interest because it preceded the Cambrian explosion, when multicellular life forms significantly increased in complexity.[71][72] Following the Cambrian explosion, 535Ma, there have been at least five major mass extinctions and many minor ones.[73] Apart from the proposed current Holocene extinction event, the most recent was 66Ma, when an asteroid impact triggered the extinction of non-avian dinosaurs and other large reptiles, but largely spared small animals such as insects, mammals, lizards and birds. Mammalian life has diversified over the past 66Mys, and several million years ago, an African ape species gained the ability to stand upright.[74][75] This facilitated tool use and encouraged communication that provided the nutrition and stimulation needed for a larger brain, which led to the evolution of humans. The development of agriculture, and then civilization, led to humans having an influence on Earth and the nature and quantity of other life forms that continues to this day.[76]Main article: Future of EarthSee also: Global catastrophic riskConjectured illustration of the scorched Earth after the Sun has entered the red giant phase, about 57billion years in the futureEarth's expected long-term future is tied to that of the Sun. Over the next 1.1billion years, solar luminosity will increase by 10%, and over the next 3.5billion years by 40%.[77] Earth's increasing surface temperature will accelerate the inorganic carbon cycle, possibly reducing CO2 concentration to levels lethally low for current plants (10ppm for C4 photosynthesis) in approximately 100900million years.[78][79] A lack of vegetation would result in the loss of oxygen in the atmosphere, making current animal life impossible.[80] Due to the increased luminosity, Earth's mean temperature may reach 100C (212F) in 1.5billion years, and all ocean water will evaporate and be lost to space, which may trigger a runaway greenhouse effect, within an estimated 1.6 to 3billion years.[81] Even if the Sun were stable and eternal, a significant fraction of the water in the modern oceans would descend into the mantle, due to reduced steam venting from mid-ocean ridges as the core of the Earth slowly cools.[81][82]The Sun will evolve to become a red giant in about 5billion years. Models predict that the Sun will expand to roughly 1AU (150millionkm; 93millionmi), about 250 times its present radius.[77][83] 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 1.7AU (250millionkm; 160millionmi) from the Sun when the star reaches its maximum radius, otherwise, with tidal effects, it may enter the Sun's atmosphere and be vaporized, with the heavier elements sinking to the core of the dying sun.[77]Further information: GeophysicsMain article: Figure of the EarthFurther information: Earth radius, Earth's circumference, Earth curvature, and GeomorphologySee also: List of highest mountains on EarthEarth's western hemisphere showing topography relative to Earth's center instead of to mean sea level, as in common topographic mapsEarth has a rounded shape, through hydrostatic equilibrium,[84] with an average diameter of 12,742 kilometres (7,918mi), making it the fifth largest planetary sized and largest terrestrial object of the Solar System.[85]Due to Earth's rotation it has the shape of an ellipsoid, bulging at its equator; its diameter is 43 kilometres (27mi) longer there than at its poles.[86][87] Earth's shape also has local topographic variations; the largest local variations, like the Mariana Trench (10,925 metres or 35,843 feet below local sea level),[88] shortens Earth's average radius by 0.17% and Mount Everest (8,848 metres or 29,029 feet above local sea level) lengthens it by 0.14%.[n 6][90] Since Earth's surface is farthest out from its center of mass at its equatorial bulge, the summit of the volcano Chimborazo in Ecuador (6,384.4km or 3,967.1mi) is its farthest point out.[91][92] Parallel to the rigid land topography the ocean exhibits a more dynamic topography.[93]To measure the local variation of Earth's topography, geodesy employs an idealized Earth producing a geoid shape. Such a shape is gained if the ocean is idealized, covering Earth completely and without any perturbations such as tides and winds. The result is a smooth but irregular geoid surface, providing a mean sea level as a reference level for topographic measurements.[94]Further information: Planetary surface, Land cover, Land, Pedosphere, Ocean, Sea, Cryosphere, and PeplosphereA composite image of Earth, with its different types of surface discernible: Earth's surface dominating Ocean (blue), Africa with lush (green) to dry (brown) land and Earth's polar ice in the form of Antarctic sea ice (grey) covering the Antarctic or Southern Ocean and the Antarctic ice sheet (white) covering Antarctica.Relief of Earth's crustEarth's surface is the boundary between the atmosphere and the solid Earth and oceans. Defined in this way, it has an area of about 510millionkm2 (197millionsqmi).[12] Earth can be divided into two hemispheres: by latitude into the polar Northern and Southern hemispheres; or by longitude into the continental Eastern and Western hemispheres.Most of Earth's surface is ocean water: 70.8% or 361millionkm2 (139millionsqmi).[95] This vast pool of salty water is often called the world ocean,[96][97] and makes Earth with its dynamic hydrosphere a water world[98][99] or ocean world.[100][101] Indeed, in Earth's early history the ocean may have covered Earth completely.[102] The world ocean is commonly divided into the Pacific Ocean, Atlantic Ocean, Indian Ocean, Antarctic or Southern Ocean, and Arctic Ocean, from largest to smallest. The ocean covers Earth's oceanic crust, with the shelf seas covering the shelves of the continental crust to a lesser extent. The oceanic crust forms large oceanic basins with features like abyssal plains, seamounts, submarine volcanoes,[86] oceanic trenches, submarine canyons, oceanic plateaus, and a globe-spanning mid-ocean ridge system.[103] At Earth's polar regions, the ocean surface is covered by seasonally variable amounts of sea ice that often connects with polar land, permafrost and ice sheets, forming polar ice caps.Earth's land covers 29.2%, or 149millionkm2 (58millionsqmi) of Earth's surface. The land surface includes many islands around the globe, but most of the land surface is taken by the four continental landmasses, which are (in descending order): Africa-Eurasia, America (landmass), Antarctica, and Australia (landmass).[104][105][106] These landmasses are further broken down and grouped into the continents. The terrain of the land surface varies greatly and consists of mountains, deserts, plains, plateaus, and other landforms. The elevation of the land surface varies from a low point of 418m (1,371ft) at the Dead Sea, to a maximum altitude of 8,848m (29,029ft) at the top of Mount Everest. The mean height of land above sea level is about 797m (2,615ft).[107]Land can be covered by surface water, snow, ice, artificial structures or vegetation. Most of Earth's land hosts vegetation,[108] but considerable amounts of land are ice sheets (10%,[109] not including the equally large area of land under permafrost)[110] or deserts (33%).[111]The pedosphere is the outermost layer of Earth's land surface and is composed of soil and subject to soil formation processes. Soil is crucial for land to be arable. Earth's total arable land is 10.7% of the land surface, with 1.3% being permanent cropland.[112][113] Earth has an estimated 16.7millionkm2 (6.4millionsqmi) of cropland and 33.5millionkm2 (12.9millionsqmi) of pastureland.[114]The land surface and the ocean floor form the top of Earth's crust, which together with parts of the upper mantle form Earth's lithosphere. Earth's crust may be divided into oceanic and continental crust. Beneath the ocean-floor sediments, the oceanic crust is predominantly basaltic, while the continental crust may include lower density materials such as granite, sediments and metamorphic rocks.[115] Nearly 75% of the continental surfaces are covered by sedimentary rocks, although they form about 5% of the mass of the crust.[116]Earth's surface topography comprises both the topography of the ocean surface, and the shape of Earth's land surface. The submarine terrain of the ocean floor has an average bathymetric depth of 4km, and is as varied as the terrain above sea level. Earth's surface is continually being shaped by internal plate tectonic processes including earthquakes and volcanism; by weathering and erosion driven by ice, water, wind and temperature; and by biological processes including the growth and decomposition of biomass into soil.[117][118]Main article: Plate tectonicsEarth's major plates, which are:[119]Pacific PlateAfrican Plate[n 7]North American PlateEurasian PlateAntarctic PlateIndo-Australian PlateSouth American PlateEarth's mechanically rigid outer layer of Earth's crust and upper mantle, the lithosphere, is divided into tectonic plates. These plates are rigid segments that move relative to each other at one of three boundaries types: at convergent boundaries, two plates come together; at divergent boundaries, two plates are pulled apart; and at transform boundaries, two plates slide past one another laterally. Along these plate boundaries, earthquakes, volcanic activity, mountain-building, and oceanic trench formation can occur.[120] 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.[121]As the tectonic plates migrate, oceanic crust is subducted 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 recycles the oceanic crust back into the mantle. Due to this recycling, most of the ocean floor is less than 100Ma old. The oldest oceanic crust is located in the Western Pacific and is estimated to be 200Ma old.[122][123] By comparison, the oldest dated continental crust is 4,030Ma,[124] although zircons have been found preserved as clasts within Eoarchean sedimentary rocks that give ages up to 4,400Ma, indicating that at least some continental crust existed at that time.[49]The seven major plates are the Pacific, North American, Eurasian, African, Antarctic, Indo-Australian, and South American. Other notable plates include the Arabian Plate, the Caribbean Plate, the Nazca Plate off the west coast of South America and the Scotia Plate in the southern Atlantic Ocean. The Australian Plate fused with the Indian Plate between 50 and 55Ma. The fastest-moving plates are the oceanic plates, with the Cocos Plate advancing at a rate of 75mm/a (3.0in/year)[125] and the Pacific Plate moving 5269mm/a (2.02.7in/year). At the other extreme, the slowest-moving plate is the South American Plate, progressing at a typical rate of 10.6mm/a (0.42in/year).[126]Main article: Internal structure of EarthGeologic layers of Earth[127]Illustration of Earth's cutaway, not to scaleDepth[128](km)Component layer nameDensity(g/cm3)060Lithosphere[n 8]035Crust[n 9]2.22.935660Upper mantle3.44.46602890Lower mantle3.45.6100700Asthenosphere28905100Outer core9.912.251006378Inner core12.813.1Earth's interior, like that of the other terrestrial planets, is divided into layers by their chemical or physical (rheological) properties. The outer layer is a chemically distinct silicate solid crust, which is underlain by a highly viscous solid mantle. The crust is separated from the mantle by the Mohorovii discontinuity.[129] The thickness of the crust varies from about 6 kilometres (3.7mi) under the

5000 m.[187][188] A trojan asteroid companion, 2010 TK7, is librating around the leading Lagrange triangular point, L4, in Earth's orbit around the Sun.[189] The tiny near-Earth asteroid 2006 RH120 makes close approaches to the EarthMoon system roughly every twenty years. During these approaches, it can orbit Earth for brief periods of time.[190]As of September2021[update], there are 4,550 operational, human-made satellites orbiting Earth.[191] There are also inoperative satellites, including Vanguard 1, the oldest satellite currently in orbit, and over 16,000 pieces of tracked space debris.[n 13] Earth's largest artificial satellite is the International Space Station (ISS).[192]Main article: HydrosphereA view of Earth with its global ocean and cloud cover, which dominate Earth's surface and hydrosphere; at Earth's polar regions, its hydrosphere forms larger areas of ice cover.Earth's hydrosphere is the sum of Earth's water and its distribution. Most of Earth's hydrosphere consists of Earth's global ocean. Earth's hydrosphere also consists of water in the atmosphere and on land, including clouds, inland seas, lakes, rivers, and underground waters. The mass of the oceans is approximately 1.351018metric tons or about 1/4400 of Earth's total mass. The oceans cover an area of 361.8millionkm2 (139.7millionsqmi) with a mean depth of 3,682m (12,080ft), resulting in an estimated volume of 1.332billionkm3 (320millioncumi).[193]If all of Earth's crustal surface were at the same elevation as a smooth sphere, the depth of the resulting world ocean would be 2.7 to 2.8km (1.68 to 1.74mi).[194] About 97.5% of the water is saline; the remaining 2.5% is fresh water.[195][196] Most fresh water, about 68.7%, is present as ice in ice caps and glaciers.[197] The remaining 30% is ground water, 1% surface water (covering only 2.8% of Earth's land)[198] and other small forms of fresh water deposits such as permafrost, water vapor in the atmosphere, biological binding, etc.[199][200]In Earth's coldest regions, snow survives over the summer and changes into ice. This accumulated snow and ice eventually forms into glaciers, bodies of ice that flow under the influence of their own gravity. Alpine glaciers form in mountainous areas, whereas vast ice sheets form over land in polar regions. The flow of glaciers erodes the surface, changing it dramatically, with the formation of U-shaped valleys and other landforms.[201] Sea ice in the Arctic covers an area about as big as the United States, although it is quickly retreating as a consequence of climate change.[202]The average salinity of Earth's oceans is about 35grams of salt per kilogram of seawater (3.5% salt).[203] Most of this salt was released from volcanic activity or extracted from cool igneous rocks.[204] The oceans are also a reservoir of dissolved atmospheric gases, which are essential for the survival of many aquatic life forms.[205] Sea water has an important influence on the world's climate, with the oceans acting as a large heat reservoir.[206] Shifts in the oceanic temperature distribution can cause significant weather shifts, such as the El NioSouthern Oscillation.[207]The abundance of water, particularly liquid water, on Earth's surface is a unique feature that distinguishes it from other planets in the Solar System. Solar System planets with considerable atmospheres do partly host atmospheric water vapor, but they lack surface conditions for stable surface water.[208] Despite some moons showing signs of large reservoirs of extraterrestrial liquid water, with possibly even more volume than Earth's ocean, all of them are large bodies of water under a kilometers thick frozen surface layer.[209]Main article: Atmosphere of EarthA view of Earth with different layers of its atmosphere visible: the troposphere with its clouds casting shadows, a band of stratospheric blue sky at the horizon, and a line of green airglow of the lower thermosphere around an altitude of 100km, at the edge of spaceThe atmospheric pressure at Earth's sea level averages 101.325kPa (14.696psi),[210] with a scale height of about 8.5km (5.3mi).[3] A dry atmosphere is composed of 78.084% nitrogen, 20.946% oxygen, 0.934% argon, and trace amounts of carbon dioxide and other gaseous molecules.[210] Water vapor content varies between 0.01% and 4%[210] but averages about 1%.[3] Clouds cover around two-thirds of Earth's surface, more so over oceans than land.[211] The height of the troposphere varies with latitude, ranging between 8km (5mi) at the poles to 17km (11mi) at the equator, with some variation resulting from weather and seasonal factors.[212]Earth's biosphere has significantly altered its atmosphere. Oxygenic photosynthesis evolved 2.7Gya, forming the primarily nitrogenoxygen atmosphere of today.[61] This change enabled the proliferation of aerobic organisms and, indirectly, the formation of the ozone layer due to the subsequent conversion of atmospheric O2 into O3. The ozone layer blocks ultraviolet solar radiation, permitting life on land.[213] Other atmospheric functions important to life include transporting water vapor, providing useful gases, causing small meteors to burn up before they strike the surface, and moderating temperature.[214] This last phenomenon is the greenhouse effect: trace molecules within the atmosphere serve to capture thermal energy emitted from the surface, thereby raising the average temperature. Water vapor, carbon dioxide, methane, nitrous oxide, and ozone are the primary greenhouse gases in the atmosphere. Without this heat-retention effect, the average surface temperature would be 18C (0F), in contrast to the current +15C (59F),[215] and life on Earth probably would not exist in its current form.[216]Main articles: Weather and ClimateThe ITCZ's band of clouds over the Eastern Pacific and the Americas as seen from spaceWorldwide Kppen climate classificationsEarth's atmosphere has no definite boundary, gradually becoming thinner and fading into outer space.[217] Three-quarters of the atmosphere's mass is contained within the first 11km (6.8mi) of the surface; this lowest layer is called the troposphere.[218] 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 that drives the weather and climate through redistribution of thermal energy.[219]The primary atmospheric circulation bands consist of the trade winds in the equatorial region below 30 latitude and the westerlies in the mid-latitudes between 30 and 60.[220] Ocean heat content and currents are also important factors in determining climate, particularly the thermohaline circulation that distributes thermal energy from the equatorial oceans to the polar regions.[221]Earth receives 1361W/m2 ofsolar irradiance.[222][223] The amount of solar energy that reaches 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 0.4C (0.7F) per degree of latitude from the equator.[224] 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 (or equatorial), subtropical, temperate and polar climates.[225]Further factors that affect a location's climates are its proximity to oceans, the oceanic and atmospheric circulation, and topology.[226] Places close to oceans typically have colder summers and warmer winters, due to the fact that oceans can store large amounts of heat. The wind transports the cold or the heat of the ocean to the land.[227] Atmospheric circulation also plays an important role: San Francisco and Washington DC are both coastal cities at about the same latitude. San Francisco's climate is significantly more moderate as the prevailing wind direction is from sea to land.[228] Finally, temperatures decrease with height causing mountainous areas to be colder than low-lying areas.[229]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.[219] 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 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.[230]The commonly used Kppen climate classification system has five broad groups (humid tropics, arid, humid middle latitudes, continental and cold polar), which are further divided into more specific subtypes.[220] The Kppen system rates regions based on observed temperature and precipitation.[231] Surface air temperature can rise to around 55C (131F) in hot deserts, such as Death Valley, and can fall as low as 89C (128F) in Antarctica.[232][233]Earth's night-side upper atmosphere appearing from the bottom as bands of afterglow illuminating the troposphere in orange with silhouettes of clouds, and the stratosphere in white and blue. Next the mesosphere (pink area) extends to the orange and faintly green line of the lowest airglow, at about one hundred kilometers at the edge of space and the lower edge of the thermosphere (invisible). Continuing with green and red bands of aurorae stretching over several hundred kilometers.The upper atmosphere, the atmosphere above the troposphere,[234] is usually divided into the stratosphere, mesosphere, and thermosphere.[214] Each layer has a different lapse rate, defining the rate of change in temperature with height. Beyond these, the exosphere thins out into the magnetosphere, where the geomagnetic fields interact with the solar wind.[235] 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 Krmn line, defined as 100km (62mi) above Earth's surface, is a working definition for the boundary between the atmosphere and outer space.[236]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 loss of the atmosphere into space. Because unfixed hydrogen has a low molecular mass, it can achieve escape velocity more readily, and it leaks into outer space at a greater rate than other gases.[237] The leakage of hydrogen into space contributes to the shifting of Earth's atmosphere and surface from an initially reducing state to its current oxidizing 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.[238] Hence the ability of hydrogen to escape from the atmosphere may have influenced the nature of life that developed on Earth.[239] 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.[240]Main articles: Biosphere and History of lifeAn animation of the changing density of productive vegetation on land (low in brown; heavy in dark green) and phytoplankton at the ocean surface (low in purple; high in yellow)Earth is the only known place that has ever been habitable for life. Earth's life developed in Earth's early bodies of water some hundred million years after Earth formed. Earth's life has been shaping and inhabiting many particular ecosystems on Earth and has eventually expanded globally forming an overarching biosphere.[241]Therefore, life has impacted Earth, significantly altering Earth's atmosphere and surface over long periods of time, causing changes like the Great Oxidation Event.[242] Earth's life has also over time greatly diversified, allowing the biosphere to have different biomes, which are inhabited by comparatively similar plants and animals.[243] The different biomes developed at distinct elevations or water depths, planetary temperature latitudes and on land also with different humidity. Earth's species diversity and biomass reaches a peak in shallow waters and with forests, particularly in equatorial, warm and humid conditions. While freezing polar regions and high altitudes, or extremely arid areas are relatively barren of plant and animal life.[244]Earth provides liquid wateran environment where complex organic molecules can assemble and interact, and sufficient energy to sustain a metabolism.[245] Plants and other organisms take up nutrients from water, soils and the atmosphere. These nutrients are constantly recycled between different species.[246]A High Desert storm in the MojaveExtreme weather, such as tropical cyclones (including hurricanes and typhoons), occurs over most of Earth's surface and has a large impact on life in those areas. From 1980 to 2000, these events caused an average of 11,800 human deaths per year.[247] Many places are subject to earthquakes, landslides, tsunamis, volcanic eruptions, tornadoes, blizzards, floods, droughts, wildfires, and other calamities and disasters.[248] Human impact is felt in many areas due to pollution of the air and water, acid rain, loss of vegetation (overgrazing, deforestation, desertification), loss of wildlife, species extinction,[249] soil degradation, soil depletion and erosion.[250] Human activities release greenhouse gases into the atmosphere which cause global warming.[251] This is driving changes such as the melting of glaciers and ice sheets, a global rise in average sea levels, increased risk of drought and wildfires, and migration of species to colder areas.[252]Main article: Human geographySee also: WorldA composite image of artificial light emissions at night on a map of EarthOriginating from earlier primates in Eastern Africa 300,000years ago humans have since been migrating and with the advent of agriculture in the 10th millennium BC increasingly settling Earth's land.[253] In the 20th century Antarctica had been the last continent to see a first and until today limited human presence.Human population has since the 19th century grown exponentially to seven billion in the early 2010s,[254] and is projected to peak at around ten billion in the second half of the 21st century.[255] Most of the growth is expected to take place in sub-Saharan Africa.[255]Distribution and density of human population varies greatly around the world with the majority living in south to eastern Asia and 90% inhabiting only the Northern Hemisphere of Earth,[256] partly due to the hemispherical predominance of the world's land mass, with 68% of the world's land mass being in the Northern Hemisphere.[257] Furthermore, since the 19th century humans have increasingly converged into urban areas with the majority living in urban areas by the 21st century.[258]Beyond Earth's surface humans have lived on a temporary basis, with only a few special-purpose deep underground and underwater presences and a few space stations. The human population virtually completely remains on Earth's surface, fully depending on Earth and the environment it sustains. Since the second half of the 20th century, some hundreds of humans have temporarily stayed beyond Earth, a tiny fraction of whom have reached another celestial body, the Moon.[259][260]Earth has been subject to extensive human settlement, and humans have developed diverse societies and cultures. Most of Earth's land has been territorially claimed since the 19th century by sovereign states (countries) separated by political borders, and 205 such states exist today,[261] with only parts of Antarctica and a few small regions remaining unclaimed.[262] Most of these states together form the United Nations, the leading worldwide intergovernmental organization,[263] which extends human governance over the ocean and Antarctica, and therefore all of Earth.Main articles: Natural resource and Land useEarth's land use for human agriculture in 2019Earth has resources that have been exploited by humans.[264] Those termed non-renewable resources, such as fossil fuels, are only replenished over geological timescales.[265] Large deposits of fossil fuels are obtained from Earth's crust, consisting of coal, petroleum, and natural gas.[266] These deposits are used by humans both for energy production and as feedstock for chemical production.[267] Mineral ore bodies have also been formed within the crust through a process of ore genesis, resulting from actions of magmatism, erosion, and plate tectonics.[268] These metals and other elements are extracted by mining, a process which often brings environmental and health damage.[269]Earth's biosphere produces many useful biological products for humans, including food, wood, pharmaceuticals, oxygen, and the recycling of organic waste. The land-based ecosystem depends upon topsoil and fresh water, and the oceanic ecosystem depends on dissolved nutrients washed down from the land.[270] In 2019, 39millionkm2 (15millionsqmi) of Earth's land surface consisted of forest and woodlands, 12millionkm2 (4.6millionsqmi) was shrub and grassland, 40millionkm2 (15millionsqmi) were used for animal feed production and grazing, and 11millionkm2 (4.2millionsqmi) were cultivated as croplands.[271] Of the 1214% of ice-free land that is used for croplands, 2 percentage points were irrigated in 2015.[272] Humans use building materials to construct shelters.[273]Main articles: Human impact on the environment and Climate changeChange in average surface air temperature and drivers for that change. Human activity has caused increased temperatures, with natural forces adding some variability.[274]Human activities have impacted Earth's environments. Through activities such as the burning of fossil fuels, humans have been increasing the amount of greenhouse gases in the atmosphere, altering Earth's energy budget and climate.[251][275] It is estimated that global temperatures in the year 2020 were 1.2C (2.2F) warmer than the preindustrial baseline.[276] This increase in temperature, known as global warming, has contributed to the melting of glaciers, rising sea levels, increased risk of drought and wildfires, and migration of species to colder areas.[252]The concept of planetary boundaries was introduced to quantify humanity's impact on Earth. Of the nine identified boundaries, five have been crossed: Biosphere integrity, climate change, chemical pollution, destruction of wild habitats and the nitrogen cycle are thought to have passed the safe threshold.[277][278] As of 2018, no country meets the basic needs of its population without transgressing planetary boundaries. It is thought possible to provide all basic physical needs globally within sustainable levels of resource use.[279]Main articles: Earth in culture and Earth in science fictionTracy Caldwell Dyson, a NASA astronaut, observing Earth from the Cupola module at the International Space Station on 11September 2010Human cultures have developed many views of the planet.[280] The standard astronomical symbols of Earth are a quartered circle, ,[281] representing the four corners of the world, and a globus cruciger, . Earth is sometimes personified as a deity. In many cultures it is a mother goddess that is also the primary fertility deity.[282] Creation myths in many religions involve the creation of Earth by a supernatural deity or deities.[282] The Gaia hypothesis, developed in the mid-20th century, compared Earth's environments and life as a single self-regulating organism leading to broad stabilization of the conditions of habitability.[283][284][285]Images of Earth taken from space, particularly during the Apollo program, have been credited with altering the way that people viewed the planet that they lived on, called the overview effect, emphasizing its beauty, uniqueness and apparent fragility.[286][287] In particular, this caused a realization of the scope of effects from human activity on Earth's environment. Enabled by science, particularly Earth observation,[288] humans have started to take action on environmental issues globally,[289] acknowledging the impact of humans and the interconnectedness of Earth's environments.[290]Scientific investigation has resulted in several culturally transformative shifts in people's view of the planet. Initial belief in a flat Earth was gradually displaced in Ancient Greece by the idea of a spherical Earth, which was attributed to both the philosophers Pythagoras and Parmenides.[291][292] Earth was generally believed to be the center of the universe until the 16th century, when scientists first concluded that it was a moving object, one of the planets of the Solar System.[293]It was only during the 19th century that geologists realized Earth's age was at least many millions of years.[294] Lord Kelvin used thermodynamics to estimate the age of Earth to be between 20 million and 400million years in 1864, sparking a vigorous debate on the subject; it was only when radioactivity and radioactive 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.[295][296]Celestial sphereEarth phaseEarth scienceExtremes on EarthList of Solar System extremesOutline of EarthTable of physical properties of planets in the Solar SystemTimeline of the far future^ All astronomical quantities vary, both secularly and periodically. The quantities given are the values at the instant J2000.0 of the secular variation, ignoring all periodic variations.^ 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.Wilkinson, John (2009). Probing the New Solar System. CSIRO Publishing. p.144. ISBN978-0-643-09949-4.^ Earth's circumference is almost exactly 40,000km because the meter was calibrated on this measurementmore specifically, 1/10-millionth of the distance between the poles and the equator.^ Due to natural fluctuations, ambiguities surrounding ice shelves, and mapping conventions for vertical datums, exact values for land and ocean coverage are not meaningful. Based on data from the Vector Map and Global Landcover Archived 26 March 2015 at the Wayback Machine datasets, extreme values for coverage of lakes and streams are 0.6% and 1.0% of Earth's surface. The ice sheets of Antarctica and Greenland are counted as land, even though much of the rock that supports them lies below sea level.^ Source for minimum,[19] mean,[20] and maximum[21] surface temperature^ If Earth were shrunk to the size of a 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 and the abyssal plains, would feel smoother.[89]^ Including the 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. 43 (13): 379410. Bibcode:2005JAfES..43..379C. doi:10.1016/j.jafrearsci.2005.07.019.^ Locally varies between 5 and 200km.^ Locally varies between 5 and 70km.^ 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): 359361. Bibcode:1982A&A...105..359A.^ For Earth, the Hill radius is R H = a (m 3 M) 1 3 {\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 (1 3 332 , 946) 1 3 = 0.01 {\displaystyle \left({\frac {1}{3\cdot 332,946}}\right)^{\frac {1}{3}}=0.01} .^ Aphelion is 103.4% of the distance to perihelion. Due to the inverse square law, the radiation at perihelion is about 106.9% of the energy at aphelion.^ As of 4 January 2018, the United States Strategic Command tracked a total of 18,835 artificial objects, mostly debris. See: Anz-Meador, Phillip; Shoots, Debi, eds. (February 2018). "Satellite Box Score" (PDF). Orbital Debris Quarterly News. 22 (1): 12. Archived (PDF) from the original on 2 April 2019. Retrieved 18 April 2018.^ a b Simon, J.L.; etal. (February 1994). "Numerical expressions for precession formulae and mean elements for the Moon and planets". Astronomy and Astrophysics. 282 (2): 663683. Bibcode:1994A&A...282..663S.^ a b c d e Staff (13 March 2021). "Useful Constants". International Earth Rotation and Reference Systems Service. Archived from the original on 29 October 2012. Retrieved 8 June 2022.^ a b c d e f g h i j k l m Williams, David R. (15 November 2024). "Earth Fact Sheet". NASA/Goddard Space Flight Center. Archived from the original on 8 May 2013. Retrieved 30 December 2024.^ Allen, Clabon Walter; Cox, Arthur N. (2000). Arthur N. Cox (ed.). Allen's Astrophysical Quantities. Springer. p.294. ISBN978-0-387-98746-0. Archived from the original on 21 February 2023. Retrieved 13 March 2011.^ Park, Ryan (9 May 2022). "Horizons Batch Call for 2023 Perihelion". NASA/JPL. Archived from the original on 3 July 2022. Retrieved 3 July 2022.^ Various (2000). David R. Lide (ed.). Handbook of Chemistry and Physics (81sted.). CRC Press. ISBN978-0-8493-0481-1.^ "Selected Astronomical Constants, 2011". The Astronomical Almanac. Archived from the original on 26 August 2013. Retrieved 25 February 2011.^ a b World Geodetic System (WGS-84). Available online Archived 11 March 2020 at the Wayback Machine from National Geospatial-Intelligence Agency.^ Cazenave, Anny (1995). "Geoid, Topography and Distribution of Landforms" (PDF). In Ahrens, Thomas J (ed.). Global Earth Physics: A Handbook of Physical Constants. AGU Reference Shelf. Vol.1. Washington, DC: American Geophysical Union. Bibcode:1995geph.conf.....A. doi:10.1029/RF001. ISBN978-0-87590-851-9. Archived from the original (PDF) on 16 October 2006. Retrieved 3 August 2008.^ International Earth Rotation and Reference Systems Service (IERS) Working Group (2004). "General Definitions and Numerical Standards" (PDF). In McCarthy, Dennis D.; Petit, Grard (eds.). IERS Conventions (2003) (PDF). Frankfurt am Main: Verlag des Bundesamts fr Kartographie und Geodsie. p.12. ISBN978-3-89888-884-4. Archived (PDF) from the original on 12 August 2016. Retrieved 29 April 2016.^ Humerfelt, Sigurd (26 October 2010). "How WGS 84 defines Earth". Home Online. Archived from the original on 24 April 2011. Retrieved 29 April 2011.^ a b Pidwirny, Michael (2 February 2006). "Surface area of our planet covered by oceans and continents.(Table 8o-1)". University of British Columbia, Okanagan. Archived from the original on 9 December 2006. Retrieved 26 November 2007.^ "Planetary Physical Parameters". Jet Propulsion Laboratory. 2008. Retrieved 11 August 2022.^ The international system of units (SI) (PDF) (2008ed.). United States Department of Commerce, NIST Special Publication 330. p.52. Archived from the original (PDF) on 5 February 2009.^ Williams, James G. (1994). "Contributions to the Earth's obliquity rate, precession, and nutation". The Astronomical Journal. 108: 711. Bibcode:1994AJ....108..711W. doi:10.1086/117108. ISSN0004-6256. S2CID122370108.^ Allen, Clabon Walter; Cox, Arthur N. (2000). Arthur N. Cox (ed.). Allen's Astrophysical Quantities. Springer. p.296. ISBN978-0-387-98746-0. Archived from the original on 21 February 2023. Retrieved 17 August 2010.^ Allen, Clabon Walter; Cox, Arthur N. (2000). Arthur N. Cox (ed.). Allen's Astrophysical Quantities (4thed.). New York: AIP Press. p.244. ISBN978-0-387-98746-0. Archived from the original on 21 February 2023. Retrieved 17 August 2010.^ "Atmospheres and Planetary Temperatures". American Chemical Society. 18 July 2013. Archived from the original on 27 January 2023. Retrieved 3 January 2023.^ "World: Lowest Temperature". WMO Weather and Climate Extremes Archive. Arizona State University. Archived from the original on 23 March 2019. Retrieved 6 September 2020.^ Jones, P. D.; Harpham, C. (2013). "Estimation of the absolute surface air temperature of the Earth". Journal of Geophysical Research: Atmospheres. 118 (8): 32133217. Bibcode:2013JGRD..118.3213J. doi:10.1002/jgrd.50359. ISSN2169-8996.^ "World: Highest Temperature". WMO Weather and Climate Extremes Archive. Arizona State University. Archived from the original on 1 May 2018. Retrieved 6 September 2020.^ United Nations Scientific Committee on the Effects of Atomic Radiation (2008). Sources and effects of ionizing radiation. New York: United Nations (published 2010). Table 1. ISBN978-92-1-142274-0. Archived from the original on 16 July 2019. Retrieved 9 November 2012.^ a b "earth, n.1". Oxford English Dictionary (3ed.). Oxford, England: Oxford University Press. 2010. doi:10.1093/acref/9780199571123.001.0001. ISBN978-0-19-957112-3.^ Simek, Rudolf (2007). Dictionary of Northern Mythology. Translated by Hall, Angela. D. S. Brewer. p.179. ISBN978-0-85991-513-7.^ "earth". The New Oxford Dictionary of English (1sted.). Oxford: Oxford University Press. 1998. ISBN978-0-19-861263-6.^ "Terra". Oxford English Dictionary (Onlineed.). Oxford University Press. (Subscription or participating institution membership required.)^ "Tellus". Oxford English Dictionary (Onlineed.). Oxford University Press. (Subscription or participating institution membership required.)^ "Gaia". Oxford English Dictionary (Onlineed.). Oxford University Press. (Subscription or participating institution membership required.)^ "Terran". Oxford English Dictionary (Onlineed.). Oxford University Press. (Subscription or participating institution membership required.)^ "terrestrial". Oxford English Dictionary (Onlineed.). Oxford University Press. (Subscription or participating institution membership required.)^ "terrene". Oxford English Dictionary (Onlineed.). Oxford University Press. (Subscription or participating institution membership required.)^ "tellurian". Oxford English Dictionary (Onlineed.). Oxford University Press. (Subscription or participating institution membership required.)^ "telluric". Lexico UK English Dictionary. Oxford University Press. Archived from the original on 31 March 2021.^ Bouvier, Audrey; Wadhwa, Meenakshi (September 2010). "The age of the Solar System redefined by the oldest PbPb age of a meteoritic inclusion". Nature Geoscience. 3 (9): 637641. Bibcode:2010NatGe...3..637B. doi:10.1038/ngeo941.^ See:Dalrymple, G. Brent (1991). The Age of the Earth. California: Stanford University Press. ISBN978-0-8047-1569-0.Newman, William L. (9 July 2007). "Age of the Earth". Publications Services, USGS. Archived from the original on 23 December 2005. Retrieved 20 September 2007.Dalrymple, G. Brent (2001). "The age of the Earth in the twentieth century: a problem (mostly) solved". Geological Society, London, Special Publications. 190 (1): 205221. Bibcode:2001GSLSP.190..205D. doi:10.1144/GSL.SP.2001.190.01.14. S2CID130092094. Archived from the original on 11 November 2007. Retrieved 20 September 2007.^ Righter, K.; Schonbachler, M. (7 May 2018). "Ag Isotopic Evolution of the Mantle During Accretion: New Constraints from Pd and Ag MetalSilicate Partitioning". Differentiation: Building the Internal Architecture of Planets. 2084: 4034. Bibcode:2018LPICo2084.4034R. Archived from the original on 6 November 2020. Retrieved 25 October 2020.^ Tartse, Romain; Anand, Mahesh; Gattacceca, Jrme; Joy, Katherine H.; Mortimer, James I.; Pernet-Fisher, John F.; Russell, Sara; Snape, Joshua F.; Weiss, Benjamin P. (2019). "Constraining the Evolutionary History of the Moon and the Inner Solar System: A Case for New Returned Lunar Samples". Space Science Reviews. 215 (8): 54. Bibcode:2019SSRv..215...54T. doi:10.1007/s11214-019-0622-x. ISSN1572-9672.^ Reilly, Michael (22 October 2009). "Controversial Moon Origin Theory Rewrites History". Discovery News. Archived from the original on 9 January 2010. Retrieved 30 January 2010.^ a b Canup, R.; Asphaug, E. I. (2001). "Origin of the Moon in a giant impact near the end of the Earth's formation". Nature. 412 (6848): 708712. Bibcode:2001Natur.412..708C. doi:10.1038/35089010. PMID11507633. S2CID4413525.^ Meier, M. M. M.; Reufer, A.; Wieler, R. (4 August 2014). "On the origin and composition of Theia: Constraints from new models of the Giant Impact". Icarus. 242: 5. arXiv:1410.3819. Bibcode:2014Icar..242..316M. doi:10.1016/j.icarus.2014.08.003. ISSN0019-1035. S2CID119226112.^ Claeys, Philippe; Morbidelli, Alessandro (2011). "Late Heavy Bombardment". In Gargaud, Muriel; Amils, Prof Ricardo; Quintanilla, Jos Cernicharo; Cleaves II, Henderson James (Jim); Irvine, William M.; Pinti, Prof Daniele L.; Viso, Michel (eds.). Encyclopedia of Astrobiology. Springer Berlin Heidelberg. pp.909912. doi:10.1007/978-3-642-11274-4_869. ISBN978-3-642-11271-3.^ "Earth's Early Atmosphere and Oceans". Lunar and Planetary Institute. Universities Space Research Association. Archived from the original on 8 July 2019. Retrieved 27 June 2019.^ Morbidelli, A.; etal. (2000). "Source regions and time scales for the delivery of water to Earth". Meteoritics & Planetary Science. 35 (6): 13091320. Bibcode:2000M&PS...35.1309M. doi:10.1111/j.1945-5100.2000.tb01518.x.^ Piani, Laurette; etal. (2020). "Earth's water may have been inherited from material similar to enstatite chondrite meteorites". Science. 369 (6507): 11101113. Bibcode:2020Sci...369.1110P. doi:10.1126/science.aba1948. ISSN0036-8075. PMID32855337. S2CID221342529.^ Guinan, E. F.; Ribas, I. (2002). Benjamin Montesinos, Alvaro Gimenez and Edward F. Guinan (ed.). Our Changing Sun: The Role of Solar Nuclear Evolution and Magnetic Activity on Earth's Atmosphere and Climate. ASP Conference Proceedings: The Evolving Sun and its Influence on Planetary Environments. San Francisco: Astronomical Society of the Pacific. Bibcode:2002ASPC..269...85G. ISBN978-1-58381-109-2.^ Staff (4 March 2010). "Oldest measurement of Earth's magnetic field reveals battle between Sun and Earth for our atmosphere". Phys.org. Archived from the original on 27 April 2011. Retrieved 27 March 2010.^ Trainer, Melissa G.; etal. (28 November 2006). "Organic haze on Titan and the early Earth". Proceedings of the National Academy of Sciences. 103 (48): 1803518042. doi:10.1073/pnas.0608561103. ISSN0027-8424. PMC1838702. PMID17101962.^ a b McDonough, W.F.; Sun, S.-s. (1995). "The composition of the Earth". Chemical Geology. 120 (34): 223253. Bibcode:1995ChGeo.120..223M. doi:10.1016/0009-2541(94)00140-4. Archived from the original on 6 May 2023. Retrieved 6 May 2023.^ a b Harrison, T. M.; Blichert-Toft, J.; Mller, W.; Albarede, F.; Holden, P.; Mojzsis, S. (December 2005). "Heterogeneous Hadean hafnium: evidence of continental crust at 4.4 to 4.5 ga". Science. 310 (5756): 19471950. Bibcode:2005Sci...310.1947H. doi:10.1126/science.1117926. PMID16293721. S2CID11208727.^ Rogers, John James William; Santosh, M. (2004). Continents and Supercontinents. Oxford University Press US. p.48. ISBN978-0-19-516589-0.^ Hurley, P. M.; Rand, J. R. (June 1969). "Pre-drift continental nuclei". Science. 164 (3885): 12291242. Bibcode:1969Sci...164.1229H. doi:10.1126/science.164.3885.1229. PMID17772560.^ Armstrong, R. L. (1991). "The persistent myth of crustal growth" (PDF). Australian Journal of Earth Sciences. 38 (5): 613630. Bibcode:1991AuJES..38..613A. CiteSeerX10.1.1.527.9577. doi:10.1080/08120099108727995. Archived (PDF) from the original on 8 August 2017. Retrieved 24 October 2017.^ De Smet, J.; Van Den Berg, A.P.; Vlaar, N.J. (2000). "Early formation and long-term stability of continents resulting from decompression melting in a convecting mantle" (PDF). Tectonophysics. 322 (12): 1933. Bibcode:2000Tectp.322...19D. doi:10.1016/S0040-1951(00)00055-X. hdl:1874/1653. Archived from the original on 31 March 2021. Retrieved 25 August 2019.^ Dhuime, B.; Hawksworth, C.J.; Delavault, H.; Cawood, P.A. (2018). "Rates of generation and destruction of the continental crust: implications for continental growth". Philosophical Transactions A. 376 (2132). Bibcode:2018RSPTA.37670403D. doi:10.1098/rsta.2017.0403. PMC6189557. PMID30275156.^ Bradley, D.C. (2011). "Secular Trends in the Geologic Record and the Supercontinent Cycle". Earth-Science Reviews. 108 (12): 1633. Bibcode:2011ESRv..108...16B. CiteSeerX10.1.1.715.6618. doi:10.1016/j.earscirev.2011.05.003. S2CID140601854.^ Kinzler, Ro. "When and how did the ice age end? Could another one start?". Ology. American Museum of Natural History. Archived from the original on 27 June 2019. Retrieved 27 June 2019.^ Chalk, Thomas B.; etal. (12 December 2007). "Causes of ice age intensification across the Mid-Pleistocene Transition". Proc Natl Acad Sci U S A. 114 (50): 1311413119. doi:10.1073/pnas.1702143114. PMC5740680. PMID29180424.^ Staff. "Paleoclimatology The Study of Ancient Climates". Page Paleontology Science Center. Archived from the original on 4 March 2007. Retrieved 2 March 2007.^ Turner, Chris S.M.; etal. (2010). "The potential of New Zealand kauri (Agathis australis) for testing the synchronicity of abrupt climate change during the Last Glacial Interval (60,00011,700 years ago)". Quaternary Science Reviews. 29 (2728). Elsevier: 36773682. Bibcode:2010QSRv...29.3677T. doi:10.1016/j.quascirev.2010.08.017. Archived from the original on 31 March 2021. Retrieved 3 November 2020.^ Doolittle, W. Ford; Worm, Boris (February 2000). "Uprooting the tree of life" (PDF). Scientific American. 282 (6): 9095. Bibcode:2000SciAm.282b..90D. doi:10.1038/scientificamerican0200-90. PMID10710791. Archived from the original (PDF) on 15 July 2011.^ a b Zimmer, Carl (3 October 2013). "Earth's Oxygen: A Mystery Easy to Take for Granted". The New York Times. Archived from the original on 3 October 2013. Retrieved 3 October 2013.^ Berkner, L. V.; Marshall, L. C. (1965). "On the Origin and Rise of Oxygen Concentration in the Earth's Atmosphere". Journal of the Atmospheric Sciences. 22 (3): 225261. Bibcode:1965JAtS...22..225B. doi:10.1175/1520-0469(1965)0222.0.CO;2.^ Burton, Kathleen (29 November 2002). "Astrobiologists Find Evidence of Early Life on Land". NASA. Archived from the original on 11 October 2011. Retrieved 5 March 2007.^ Noffke, Nora; Christian, Daniel; Wacey, David; Hazen, Robert M. (8 November 2013). "Microbially Induced Sedimentary Structures Recording an Ancient Ecosystem in the ca. 3.48 Billion-Year-Old Dresser Formation, Pilbara, Western Australia". Astrobiology. 13 (12): 11031124. Bibcode:2013AsBio..13.1103N. doi:10.1089/ast.2013.1030. PMC3870916. PMID24205812.^ Ohtomo, Yoko; Kakegawa, Takeshi; Ishida, Akizumi; etal. (January 2014). "Evidence for biogenic graphite in early Archaean Isua metasedimentary rocks". Nature Geoscience. 7 (1): 2528. Bibcode:2014NatGe...7...25O. doi:10.1038/ngeo2025. ISSN1752-0894. S2CID54767854.^ Borenstein, Seth (19 October 2015). "Hints of life on what was thought to be desolate early Earth". Excite. Yonkers, NY: Mindspark Interactive Network. Associated Press. Archived from the original on 18 August 2016. Retrieved 20 October 2015.^ Bell, Elizabeth A.; Boehnike, Patrick; Harrison, T. Mark; Mao, Wendy L. (19 October 2015). "Potentially biogenic carbon preserved in a 4.1billion-year-old zircon". Proc. Natl. Acad. Sci. U.S.A. 112 (47): 145184521. Bibcode:2015PNAS..11214518B. doi:10.1073/pnas.1517557112. ISSN1091-6490. PMC4664351. PMID26483481. Early edition, published online before print.^ Tyrell, Kelly April (18 December 2017). "Oldest fossils ever found show life on Earth began before 3.5 billion years ago". University of WisconsinMadison. Archived from the original on 31 March 2021. Retrieved 18 December 2017.^ Schopf, J. William; Kitajima, Kouki; Spicuzza, Michael J.; Kudryavtsev, Anatolly B.; Valley, John W. (2017). "SIMS analyses of the oldest known assemblage of microfossils document their taxon-correlated carbon isotope compositions". PNAS. 115 (1): 5358. Bibcode:2018PNAS..115...53S. doi:10.1073/pnas.1718063115. PMC5776830. PMID29255053.^ "Earth-Moon Dynamics". Lunar and Planetary Institute. Archived from the original on 7 September 2015. Retrieved 2 September 2

August 2022). "Upper atmosphere Definition und Bedeutung". Collins Wrterbuch (in German). Archived from the original on 21 February 2023. Retrieved 26 August 2022.^ Staff (2004). "Stratosphere and Weather; Discovery of the Stratosphere". Science Week. Archived from the original on 13 July 2007. Retrieved 14 March 2007.^ de Crdoba, S. Sanz Fernndez (21 June 2004). "Presentation of the Karman separation line, used as the boundary separating Aeronautics and Astronautics". Fdration Aronautique Internationale. Archived from the original on 15 January 2010. Retrieved 21 April 2007.^ Liu, S. C.; Donahue, T. M. (1974). "The Aeronomy of Hydrogen in the Atmosphere of the Earth". Journal of the Atmospheric Sciences. 31 (4): 11181136. Bibcode:1974JAtS...31.1118L. doi:10.1175/1520-0469(1974)0312.0.CO;2.^ Catling, David C.; Zahnle, Kevin J.; McKay, Christopher P. (2001). "Biogenic Methane, Hydrogen Escape, and the Irreversible Oxidation of Early Earth". Science. 293 (5531): 839843. Bibcode:2001Sci...293..839C. CiteSeerX10.1.1.562.2763. doi:10.1126/science.1061976. PMID11486082. S2CID37386726.^ Abedon, Stephen T. (31 March 1997). "History of Earth". Ohio State University. Archived from the original on 29 November 2012. Retrieved 19 March 2007.^ Hunten, D. M.; Donahue, T. M (1976). "Hydrogen loss from the terrestrial planets". Annual Review of Earth and Planetary Sciences. 4 (1): 265292. Bibcode:1976AREPS...4..265H. doi:10.1146/annurev.ea.04.050176.001405.^ Rutledge, Kim; etal. (24 June 2011). "Biosphere". National Geographic. Archived from the original on 28 May 2022. Retrieved 1 November 2020.^ "NASA Astrobiology Institute". astrobiology.nasa.gov. Archived from the original on 17 November 2023. Retrieved 9 November 2023.^ "Interdependency between animal and plant species". BBC Bitesize. BBC. p.3. Archived from the original on 27 June 2019. Retrieved 28 June 2019.^ Hillebrand, Helmut (2004). "On the Generality of the Latitudinal Gradient" (PDF). American Naturalist. 163 (2): 192211. doi:10.1086/381004. PMID14970922. S2CID9886026. Archived (PDF) from the original on 22 September 2017. Retrieved 20 April 2018.^ Staff (September 2003). "Astrobiology Roadmap". NASA, Lockheed Martin. Archived from the original on 12 March 2012. Retrieved 10 March 2007.^ Singh, J. S.; Singh, S. P.; Gupta, S.R. (2013). Ecology environmental science and conservation (Firsted.). New Delhi: S. Chand & Company. ISBN978-93-83746-00-2. OCLC896866658. Archived from the original on 31 March 2021. Retrieved 1 November 2020.^ Smith, Sharon; Fleming, Lora; Solo-Gabriele, Helena; Gerwick, William H. (2011). Oceans and Human Health. Elsevier Science. p.212. ISBN978-0-08-087782-2.^ Alexander, David (1993). Natural Disasters. Springer Science & Business Media. p.3. ISBN978-1-317-93881-1. Archived from the original on 10 August 2023. Retrieved 9 August 2023.^ "What Is Climate Change?". United Nations. Archived from the original on 26 January 2023. Retrieved 17 August 2022.^ Goudie, Andrew (2000). The Human Impact on the Natural Environment. MIT Press. pp.52, 66, 69, 137, 142, 185, 202, 355, 366. ISBN978-0-262-57138-8.^ a b Cook, John; Oreskes, Naomi; Doran, Peter T.; Anderegg, William R. L.; Verheggen, Bart; Maibach, Ed W; Carlton, J. Stuart; Lewandowsky, Stephan; Skuce, Andrew G.; Green, Sarah A.; Nuccitelli, Dana; Jacobs, Peter; Richardson, Mark; Winkler, Brbel; Painting, Rob; Rice, Ken (2016). "Consensus on consensus: a synthesis of consensus estimates on human-caused global warming". Environmental Research Letters. 11 (4): 048002. Bibcode:2016ERL....11d8002C. doi:10.1088/1748-9326/11/4/048002. hdl:1983/34949783-dac1-4ce7-ad95-5dc0798930a6. ISSN1748-9326.^ a b "Global Warming Effects". National Geographic. 14 January 2019. Archived from the original on 18 January 2017. Retrieved 16 September 2020.^ "Introduction to Human Evolution | The Smithsonian Institution's Human Origins Program". humanorigins.si.edu. 11 July 2022. Archived from the original on 8 November 2023. Retrieved 9 November 2023.^ Gomez, Jim; Sullivan, Tim (31 October 2011). "Various '7 billionth' babies celebrated worldwide". Yahoo News. Associated Press. Archived from the original on 31 October 2011. Retrieved 31 October 2011.^ a b Harvey, Fiona (15 July 2020). "World population in 2100 could be 2 billion below UN forecasts, study suggests". The Guardian. ISSN0261-3077. Archived from the original on 4 September 2020. Retrieved 18 September 2020.^ Lutz, Ashley (4 May 2012). "MAP OF THE DAY: Pretty Much Everyone Lives In The Northern Hemisphere". Business Insider. Archived from the original on 19 January 2018. Retrieved 5 January 2019.^ Mndez, Abel (6 July 2011). "Distribution of landmasses of the Paleo-Earth". University of Puerto Rico at Arecibo. Archived from the original on 6 January 2019. Retrieved 5 January 2019.^ Ritchie, H.; Roser, M. (2019). "What share of people will live in urban areas in the future?". Our World in Data. Archived from the original on 29 October 2020. Retrieved 26 October 2020.^ Shayler, David; Vis, Bert (2005). Russia's Cosmonauts: Inside the Yuri Gagarin Training Center. Birkhuser. ISBN978-0-387-21894-6.^ Holmes, Oliver (19 November 2018). "Space: how far have we gone and where are we going?". The Guardian. ISSN0261-3077. Archived from the original on 6 October 2020. Retrieved 10 October 2020.^ "Member States | United Nations". United Nations. Archived from the original on 1 March 2023. Retrieved 3 January 2024.^ Lloyd, John; Mitchinson, John (2010). The Discretely Plumper Second QI Book of General Ignorance. Faber & Faber. pp.116117. ISBN978-0-571-29072-7.^ Smith, Courtney B. (2006). Politics and Process at the United Nations: The Global Dance (PDF). Lynne Reiner. pp.14. ISBN978-1-58826-323-0. Archived (PDF) from the original on 17 October 2020. Retrieved 14 October 2020.^ "What are the consequences of the overexploitation of natural resources?". Iberdrola. Archived from the original on 27 June 2019. Retrieved 28 June 2019.^ "13. Exploitation of Natural Resources". European Environment Agency. European Union. 20 April 2016. Archived from the original on 27 June 2019. Retrieved 28 June 2019.^ Huebsch, Russell (29 September 2017). "How Are Fossil Fuels Extracted From the Ground?". Sciencing. Leaf Group Media. Archived from the original on 27 June 2019. Retrieved 28 June 2019.^ "Electricity generation what are the options?". World Nuclear Association. Archived from the original on 27 June 2019. Retrieved 28 June 2019.^ Brimhall, George (May 1991). "The Genesis of Ores". Scientific American. 264 (5). Nature America: 8491. Bibcode:1991SciAm.264e..84B. doi:10.1038/scientificamerican0591-84. JSTOR24936905. Archived from the original on 6 November 2020. Retrieved 13 October 2020.^ Lunine, Jonathan I. (2013). Earth: Evolution of a Habitable World (seconded.). Cambridge University Press. pp.292294. ISBN978-0-521-61519-8.^ Rona, Peter A. (2003). "Resources of the Sea Floor". Science. 299 (5607): 673674. doi:10.1126/science.1080679. PMID12560541. S2CID129262186.^ Ritchie, H.; Roser, M. (2019). "Land Use". Our World in Data. Archived from the original on 11 April 2019. Retrieved 26 October 2020.^ IPCC (2019). "Summary for Policymakers" (PDF). IPCC Special Report on Climate Change and Land. p.8. Archived (PDF) from the original on 17 February 2020. Retrieved 25 September 2020.^ Tate, Nikki; Tate-Stratton, Dani (2014). Take Shelter: At Home Around the World. Orca Book Publishers. p.6. ISBN978-1-4598-0742-6.^ IPCC (2021). Masson-Delmotte, V.; Zhai, P.; Pirani, A.; Connors, S. L.; etal. (eds.). Climate Change 2021: The Physical Science Basis (PDF). Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, US: Cambridge University Press (In Press). SPM-7. Archived (PDF) from the original on 13 August 2021. Retrieved 2 June 2022.^ Lindsey, Rebecca (14 January 2009). "Climate and Earth's Energy Budget". Earth Observatory. NASA. Archived from the original on 2 October 2019. Retrieved 19 December 2021.^ "The State of the Global Climate 2020". World Meteorological Organization. 14 January 2021. Archived from the original on 29 November 2023. Retrieved 3 March 2021.^ DiGirolamo, Mike (8 September 2021). "We've crossed four of nine planetary boundaries. What does this mean?". Mongabay. Archived from the original on 27 January 2022. Retrieved 27 January 2022.^ Carrington, Damien (18 January 2022). "Chemical pollution has passed safe limit for humanity, say scientists". The Guardian. Archived from the original on 12 April 2022. Retrieved 27 January 2022.^ O'Neill, Daniel W.; Fanning, Andrew L.; Lamb, William F.; Steinberger, Julia K. (2018). "A good life for all within planetary boundaries". Nature Sustainability. 1 (2): 8895. Bibcode:2018NatSu...1...88O. doi:10.1038/s41893-018-0021-4. ISSN2398-9629. S2CID169679920. Archived from the original on 1 February 2022. Retrieved 30 January 2022.^ Widmer, Ted (24 December 2018). "What Did Plato Think the Earth Looked Like? For millenniums, humans have tried to imagine the world in space. Fifty years ago, we finally saw it". The New York Times. Archived from the original on 1 January 2022. Retrieved 25 December 2018.^ Liungman, Carl G. (2004). "Group 29: Multi-axes symmetric, both soft and straight-lined, closed signs with crossing lines". Symbols Encyclopedia of Western Signs and Ideograms. New York: Ionfox AB. pp.281282. ISBN978-91-972705-0-2.^ a b Stookey, Lorena Laura (2004). Thematic Guide to World Mythology. Westport, CN: Greenwood Press. pp.114115. ISBN978-0-313-31505-3.^ Lovelock, James E. (2009). The Vanishing Face of Gaia. Basic Books. p.255. ISBN978-0-465-01549-8.^ Lovelock, James E. (1972). "Gaia as seen through the atmosphere". Atmospheric Environment. 6 (8): 579580. Bibcode:1972AtmEn...6..579L. doi:10.1016/0004-6981(72)90076-5. ISSN1352-2310.^ Lovelock, J.E.; Margulis, L. (1974). "Atmospheric homeostasis by and for the biosphere: the gaia hypothesis". Tellus A. 26 (12): 210. Bibcode:1974Tell...26....2L. doi:10.3402/tellusa.v26i1-2.9731. S2CID129803613.^ Overbye, Dennis (21 December 2018). "Apollo 8's Earthrise: The Shot Seen Round the World Half a century ago today, a photograph from the moon helped humans rediscover Earth". The New York Times. Archived from the original on 1 January 2022. Retrieved 24 December 2018.^ Boulton, Matthew Myer; Heithaus, Joseph (24 December 2018). "We Are All Riders on the Same Planet Seen from space 50 years ago, Earth appeared as a gift to preserve and cherish. What happened?". The New York Times. Archived from the original on 1 January 2022. Retrieved 25 December 2018.^ "ESPI Evening Event "Seeing Our Planet Whole: A Cultural and Ethical View of Earth Observation"". ESPI European Space Policy Institute. 7 October 2021. Archived from the original on 27 January 2022. Retrieved 27 January 2022.^ "Two early images of Earth that bolstered the environmental movement CBC Radio". CBC. 16 April 2020. Archived from the original on 27 January 2022. Retrieved 27 January 2022.^ Bray, Karen; Eaton, Heather; Bauman, Whitney, eds. (3 October 2023). Earthly Things: Immanence, New Materialisms, and Planetary Thinking. Fordham University Press. doi:10.5422/fordham/9781531503055.001.0001. ISBN978-1-5315-0413-7.^ Kahn, Charles H. (2001). Pythagoras and the Pythagoreans: A Brief History. Indianapolis, IN and Cambridge, England: Hackett Publishing Company. p.53. ISBN978-0-87220-575-8. Archived from the original on 14 December 2023. Retrieved 9 August 2023.^ Garwood, Christine (2008). Flat earth: the history of an infamous idea (1sted.). New York: Thomas Dunne Books. pp.2631. ISBN978-0-312-38208-7. OCLC184822945. Archived from the original on 31 March 2021. Retrieved 6 November 2020.^ Arnett, Bill (16 July 2006). "Earth". The Nine Planets, A Multimedia Tour of the Solar System: one star, eight planets, and more. Archived from the original on 23 August 2000. Retrieved 9 March 2010.^ Monroe, James; Wicander, Reed; Hazlett, Richard (2007). Physical Geology: Exploring the Earth. Thomson Brooks/Cole. pp.263265. ISBN978-0-495-01148-4.^ Henshaw, John M. (2014). An Equation for Every Occasion: Fifty-Two Formulas and Why They Matter. Johns Hopkins University Press. pp.117118. ISBN978-1-4214-1491-1.^ Burchfield, Joe D. (1990). Lord Kelvin and the Age of the Earth. University of Chicago Press. pp.1318. ISBN978-0-226-08043-7.Listen to this article (1 hour and 10 minutes)This audio file was created from a revision of this article dated 22April2021(2021-04-22), and does not reflect subsequent edits.(Audio help More spoken articles)Earth Profile Solar System Exploration NASAEarth Observatory NASAEarth Videos International Space Station:Video (01:02) on YouTube Earth (time-lapse)Video (00:27) on YouTube Earth and auroras (time-lapse)Google Earth 3D, interactive mapInteractive 3D visualization of the Sun, Earth and Moon systemGPlates Portal (University of Sydney)Portals: Biology Earth sciences Ecology Geography Volcanoes Solar system Outer space Weather WorldEarth at Wikipedia's sister projects:Definitions from WiktionaryMedia from CommonsNews from WikinewsQuotations from WikiquoteTexts from WikisourceTextbooks from WikibooksResources from WikiversityRetrieved from " 2Second-largest asteroid of the main asteroid beltThis article is about the asteroid. For the Roman goddess, see Vesta (mythology). For other uses, see Vesta (disambiguation).4 VestaTrue color image of Vesta taken by Dawn. The massive Rheasilvia Crater dominates Vesta's south pole.DiscoveryDiscoveredbyHeinrich Wilhelm OlbersDiscoverydate29 March 1807DesignationsMPCdesignation(4) VestaPronunciation/vst/[1]Named afterVestaMinorplanet categoryMain belt (Vesta family)AdjectivesVestanVestian[a]Symbol (historically astronomical, now astrological)Orbital characteristics[6]Epoch 13September 2023(JD2453300.5)Aphelion2.57AU (384millionkm)Perihelion2.15AU (322millionkm)Semi-major axis2.36AU (353millionkm)Eccentricity0.0894Orbital period (sidereal)3.63yr (1325.86d)Average orbital speed19.34km/sMean anomaly169.4Inclination7.1422 to ecliptic5.58 to invariable plane[7]Longitudeof ascendingnode103.71Timeof perihelion26 December 2021[8]Argumentof perihelion151.66SatellitesNoneEarthMOID1.14AU (171millionkm)Proper orbital elements[9]Proper semi-major axis2.36151AUProper eccentricity0.098758Proper inclination6.39234Proper mean motion99.1888deg/ yrProper orbital period3.62944 yr(1325.654 d)Precession of perihelion36.8729 (2343 years)arcsec/ yrPrecessionof the ascendingnode39.5979 (2182 years)arcsec/ yrPhysical characteristicsDimensions572.6km 557.2km 446.4km[10]Mean diameter525.40.2km[10]Flattening0.2204Surface area(8.660.2)105km2[b][11]Volume7.4970107km3[10]Mass(2.5902710.000058)1020kg[12]Mean density3.4560.035g/cm3[10]Equatorial surfacegravity0.22m/s2 (0.022g0)Equatorial escape velocity0.36km/sSynodic rotation period0.2226d (5.342h)[6][13]Equatorial rotationvelocity93.1m/s[c]Axial tilt29Northpole right ascension20h 32m[d]Northpole declination48[d]Geometric albedo0.423[15]Temperaturemin: 75K (198C)max: 250K (23C)[16]Spectral typeV[6][17]Apparent magnitude5.1[18] to 8.48Absolute magnitude(H)3.20[6][15]Angular diameter0.70 to 0.22Vesta (minor-planet designation: 4 Vesta) is one of the largest objects in the asteroid belt, with a mean diameter of 525 kilometres (326mi).[10] It was discovered by the German astronomer Heinrich Wilhelm Matthias Olbers on 29 March 1807[6] and is named after Vesta, the virgin goddess of home and hearth from Roman mythology.[19]Vesta is thought to be the second-largest asteroid, both by mass and by volume, after the dwarf planet Ceres.[20][21][22] Measurements give it a nominal volume only slightly larger than that of Pallas (about 5% greater), but it is 25% to 30% more massive. It constitutes an estimated 9% of the mass of the asteroid belt.[23] Vesta is the only known remaining rocky protoplanet of the kind that formed the terrestrial planets.[24] Numerous fragments of Vesta were ejected by collisions one and two billion years ago that left two enormous craters occupying much of Vesta's southern hemisphere.[25][26] Debris from these events has fallen to Earth as howarditeeucritediogenite (HED) meteorites, which have been a rich source of information about Vesta.[27][28][29]Vesta is the brightest asteroid visible from Earth. It is regularly as bright as magnitude 5.1,[18] at which times it is faintly visible to the naked eye. Its maximum distance from the Sun is slightly greater than the minimum distance of Ceres from the Sun,[e] although its orbit lies entirely within that of Ceres.[30]NASA's Dawn spacecraft entered orbit around Vesta on 16 July 2011 for a one-year exploration and left the orbit of Vesta on 5 September 2012[31] en route to its final destination, Ceres. Researchers continue to examine data collected by Dawn for additional insights into the formation and history of Vesta.[32][33]Vesta, Ceres, and the Moon with sizes shown to scaleHeinrich Olbers discovered Pallas in 1802, the year after the discovery of Ceres. He proposed that the two objects were the remnants of a destroyed planet. He sent a letter with his proposal to the British astronomer William Herschel, suggesting that a search near the locations where the orbits of Ceres and Pallas intersected might reveal more fragments. These orbital intersections were located in the constellations of Cetus and Virgo.[34] Olbers commenced his search in 1802, and on 29 March 1807 he discovered Vesta in the constellation Virgoa coincidence, because Ceres, Pallas, and Vesta are not fragments of a larger body. Because the asteroid Juno had been discovered in 1804, this made Vesta the fourth object to be identified in the region that is now known as the asteroid belt. The discovery was announced in a letter addressed to German astronomer Johann H. Schrter dated 31 March.[35] Because Olbers already had credit for discovering a planet (Pallas; at the time, the asteroids were considered to be planets), he gave the honor of naming his new discovery to German mathematician Carl Friedrich Gauss, whose orbital calculations had enabled astronomers to confirm the existence of Ceres, the first asteroid, and who had computed the orbit of the new planet in the remarkably short time of 10 hours.[36][37] Gauss decided on the Roman virgin goddess of home and hearth, Vesta.[38]Vesta was the fourth asteroid to be discovered, hence the number4 in its formal designation. The name Vesta, or national variants thereof, is in international use with two exceptions: Greece and China. In Greek, the name adopted was the Hellenic equivalent of Vesta, Hestia (4); in English, that name is used for 46 Hestia (Greeks use the name "Hestia" for both, with the minor-planet numbers used for disambiguation). In Chinese, Vesta is called the 'hearth-god(dess) star', Zoshnxng, naming the asteroid for Vesta's role, similar to the Chinese names of Uranus, Neptune, and Pluto.[f]Upon its discovery, Vesta was, like Ceres, Pallas, and Juno before it, classified as a planet and given a planetary symbol. The symbol represented the altar of Vesta with its sacred fire and was designed by Gauss.[39][40] In Gauss's conception, now obsolete, this was drawn . His form is in the pipeline for Unicode 17.0 as U+1F777 .[41][42][g]The asteroid symbols were gradually retired from astronomical use after 1852, but the symbols for the first four asteroids were resurrected for astrology in the 1970s. The abbreviated modern astrological variant of the Vesta symbol is (U+26B6).[41][h]After the discovery of Vesta, no further objects were discovered for 38years, and during this time the Solar System was thought to have eleven planets.[47] However, in 1845, new asteroids started being discovered at a rapid pace, and by 1851 there were fifteen, each with its own symbol, in addition to the eight major planets (Neptune had been discovered in 1846). It soon became clear that it would be impractical to continue inventing new planetary symbols indefinitely, and some of the existing ones proved difficult to draw quickly. That year, the problem was addressed by Benjamin Apthorp Gould, who suggested numbering asteroids in their order of discovery, and placing this number in a disk (circle) as the generic symbol of an asteroid. Thus, the fourth asteroid, Vesta, acquired the generic symbol . This was soon coupled with the name into an official numbername designation, Vesta, as the number of minor planets increased. By 1858, the circle had been simplified to parentheses, (4) Vesta, which were easier to typeset. Other punctuation, such as 4) Vesta and 4, Vesta, was also briefly used, but had more or less completely died out by 1949.[48]SPHERE image is shown on the left, with a synthetic view derived from Dawn images shown on the right for comparison.[49]Photometric observations of Vesta were made at the Harvard College Observatory in 18801882 and at the Observatoire de Toulouse in 1909. These and other observations allowed the rotation rate of Vesta to be determined by the 1950s. However, the early estimates of the rotation rate came into question because the light curve included variations in both shape and albedo.[50]Early estimates of the diameter of Vesta ranged from 383 kilometres (238mi) in 1825, to 444km (276mi). E.C. Pickering produced an estimated diameter of 51317km (31911mi) in 1879, which is close to the modern value for the mean diameter, but the subsequent estimates ranged from a low of 390km (242mi) up to a high of 602km (374mi) during the next century. The measured estimates were based on photometry. In 1989, speckle interferometry was used to measure a dimension that varied between 498 and 548km (309 and 341mi) during the rotational period.[51] In 1991, an occultation of the star SAO 93228 by Vesta was observed from multiple locations in the eastern United States and Canada. Based on observations from 14 different sites, the best fit to the data was an elliptical profile with dimensions of about 550km 462km (342mi 287mi).[52] Dawn confirmed this measurement.[i] These measurements will help determine the thermal history, size of the core, role of water in asteroid evolution and what meteorites found on Earth come from these bodies, with the ultimate goal of understanding the conditions and processes present at the solar system's earliest epoch and the role of water content and size in planetary evolution.[53]Vesta became the first asteroid to have its mass determined. Every 18 years, the asteroid 197 Arete approaches within 0.04AU of Vesta. In 1966, based upon observations of Vesta's gravitational perturbations of Arete, Hans G. Hertz estimated the mass of Vesta at (1.200.08)1010M (solar masses).[54] More refined estimates followed, and in 2001 the perturbations of 17 Thetis were used to calculate the mass of Vesta to be (1.310.02)1010M.[55] Dawn determined it to be 1.30291010M.Vesta orbits the Sun between Mars and Jupiter, within the asteroid belt, with a period of 3.6 Earth years,[6] specifically in the inner asteroid belt, interior to the Kirkwood gap at 2.50AU. Its orbit is moderately inclined (i = 7.1, compared to 7 for Mercury and 17 for Pluto) and moderately eccentric (e = 0.09, about the same as for Mars).[6]True orbital resonances between asteroids are considered unlikely. Because of their small masses relative to their large separations, such relationships should be very rare.[56] Nevertheless, Vesta is able to capture other asteroids into temporary 1:1 resonant orbital relationships (for periods up to 2 million years or more) and about forty such objects have been identified.[57] Decameter-sized objects detected in the vicinity of Vesta by Dawn may be such quasi-satellites rather than proper satellites.[57]Olbers Regio (dark area) defines the prime meridian in the IAU coordinate system. It is shown here in a Hubble shot of Vesta, because it is not visible in the more detailed Dawn images.Claudia crater (indicated by the arrow at the bottom of the closeup image at right) defines the prime meridian in the Dawn/NASA coordinate system.Vesta's rotation is relatively fast for an asteroid (5.342h) and prograde, with the north pole pointing in the direction of right ascension 20h32min, declination +48 (in the constellation Cygnus) with an uncertainty of about 10. This gives an axial tilt of 29.[58]Two longitudinal coordinate systems are used for Vesta, with prime meridians separated by 150. The IAU established a coordinate system in 1997 based on Hubble photos, with the prime meridian running through the center of Olbers Regio, a dark feature 200km across. When Dawn arrived at Vesta, mission scientists found that the location of the pole assumed by the IAU was off by 10, so that the IAU coordinate system drifted across the surface of Vesta at 0.06 per year, and also that Olbers Regio was not discernible from up close, and so was not adequate to define the prime meridian with the precision they needed. They corrected the pole, but also established a new prime meridian 4 from the center of Claudia, a sharply defined crater 700 metres across, which they say results in a more logical set of mapping quadrangles.[59] All NASA publications, including images and maps of Vesta, use the Claudian meridian, which is unacceptable to the IAU. The IAU Working Group on Cartographic Coordinates and Rotational Elements recommended a coordinate system, correcting the pole but rotating the Claudian longitude by 150 to coincide with Olbers Regio.[60] It was accepted by the IAU, although it disrupts the maps prepared by the Dawn team, which had been positioned so they would not bisect any major surface features.[59][61]Relative sizes of the four largest asteroids. Vesta is second from left.This graph was using the legacy Graph extension, which is no longer supported. It needs to be converted to the new Chart extension.The mass of 4 Vesta (blue) compared to other large asteroids: 1 Ceres, 2 Pallas, 10 Hygiea, 704 Interamnia, 15 Eunomia and the remainder of the Main Belt. The unit of mass is1018 kg. Other objects in the Solar system with well-defined masses within a factor of 2 of Vesta's mass are Varda, Gknhmdm, and Salacia (245, 136, and 4921018 kg, respectively). No moons are in this range: the closest, Tethys (Saturn III) and Enceladus (Saturn II), are over twice and less than half of Vesta's mass.Vesta is the second most massive body in the asteroid belt, although it is only 28% as massive as Ceres, the most massive body.[62][23] Vesta is, however, the most massive body that formed in the asteroid belt, as Ceres is believed to have formed between Jupiter and Saturn. Vesta's density is lower than those of the four terrestrial planets but is higher than those of most asteroids, as well as all of the moons in the Solar System except Io. Vesta's surface area is about the same as the land area of Pakistan, Venezuela, Tanzania, or Nigeria; slightly under 900,000km2 (350,000sqmi; 90millionha; 220million acres). It has an only partially differentiated interior.[63] Vesta is only slightly larger (525.40.2km[10]) than 2 Pallas (5123km) in mean diameter,[64] but is about 25% more massive.Vesta's shape is close to a gravitationally relaxed oblate spheroid,[58] but the large concavity and protrusion at the southern pole (see 'Surface features' below) combined with a mass less than 51020kg precluded Vesta from automatically being considered a dwarf planet under International Astronomical Union (IAU) Resolution XXVI 5.[65] A 2012 analysis of Vesta's shape[66] and gravity field using data gathered by the Dawn spacecraft has shown that Vesta is currently not in hydrostatic equilibrium.[10][67]Temperatures on the surface have been estimated to lie between about 20C (253K) with the Sun overhead, dropping to about 190C (83.1K) at the winter pole. Typical daytime and nighttime temperatures are 60C (213K) and 130C (143K), respectively. This estimate is for 6 May 1996, very close to perihelion, although details vary somewhat with the seasons.[16]Further information: List of geological features on VestaBefore the arrival of the Dawn spacecraft, some Vestan surface features had already been resolved using the Hubble Space Telescope and ground-based telescopes (e.g., the Keck Observatory).[68] The arrival of Dawn in July 2011 revealed the complex surface of Vesta in detail.[69]Geologic map of Vesta (Mollweide projection).[70] The most ancient and heavily cratered regions are brown; areas modified by the Veneneia and Rheasilvia impacts are purple (the Saturnalia Fossae Formation, in the north)[71] and light cyan (the Divalia Fossae Formation, equatorial),[70] respectively; the Rheasilvia impact basin interior (in the south) is dark blue, and neighboring areas of Rheasilvia ejecta (including an area within Veneneia) are light purple-blue;[72][73] areas modified by more recent impacts or mass wasting are yellow/orange or green, respectively.Main articles: Rheasilvia and VeneneiaNorthern (left) and southern (right) hemispheres. The "Snowman" craters are at the top of the left image; Rheasilvia and Veneneia (green and blue) dominate the right. Parallel troughs are seen in both. Colors of the two hemispheres are not to scale,[j] and the equatorial region is not shown.South pole of Vesta, showing the extent of Rheasilvia crater.The most prominent of these surface features are two enormous impact basins, the 500-kilometre-wide (311mi) Rheasilvia, centered near the south pole; and the 400-kilometre-wide (249mi) Veneneia. The Rheasilvia impact basin is younger and overlies the Veneneia.[74] The Dawn science team named the younger, more prominent crater Rheasilvia, after the mother of Romulus and Remus and a mythical vestal virgin.[75] Its width is 95% of the mean diameter of Vesta. The crater is about 19km (12mi) deep. A central peak rises 23km (14mi) above the lowest measured part of the crater floor and the highest measured part of the crater rim is 31km (19mi) above the crater floor low point. It is estimated that the impact responsible excavated about 1% of the volume of Vesta, and it is likely that the Vesta family and V-type asteroids are the products of this collision. If this is the case, then the fact that 10km (6mi) fragments have survived bombardment until the present indicates that the crater is at most only about 1billion years old.[76] It would also be the site of origin of the HED meteorites. All the known V-type asteroids taken together account for only about 6% of the ejected volume, with the rest presumably either in small fragments, ejected by approaching the 3:1Kirkwood gap, or perturbed away by the Yarkovsky effect or radiation pressure. Spectroscopic analyses of the Hubble images have shown that this crater has penetrated deep through several distinct layers of the crust, and possibly into the mantle, as indicated by spectral signatures of olivine.[58]Subsequent analysis of data from the Dawn mission provided much greater detail on Rheasilvia's structure and composition, confirming it as one of the largest impact structures known relative to its parent body size.[74] The impact clearly modified the pre-existing very large, Veneneia structure, indicating Rheasilvia's younger age.[74] Rheasilvia's size makes Vesta's southern topography unique, creating a flattened southern hemisphere and contributing significantly to the asteroid's overall oblate shape.[69] Rheasilvia's ~22km (14mi) central peak stands as one of the tallest mountains identified in the Solar System.[74] Its base width of roughly 180km (110mi) and complex morphology distinguishes it from the simpler central peaks seen in smaller craters.[77] Numerical modeling indicates that such a large central structure within a ~505km (314mi) diameter basin requires formation on a differentiated body with significant gravity. Scaling laws for craters on smaller asteroids fail to predict such a feature; instead, impact dynamics involving transient crater collapse and rebound of the underlying material (potentially upper mantle) are needed to explain its formation.[77] Hydrocode simulations suggest the impactor responsible was likely 6070km (3743mi) across, impacting at roughly 5.4 km/s.[78] Models of impact angle (around 30-45 degrees from vertical) better match the detailed morphology of the basin and its prominent peak.[77] Crater density measurements on Rheasilvia's relatively unmodified floor materials and surrounding ejecta deposits, calibrated using standard lunar chronology functions adapted for Vesta's location, place the impact event at approximately 1 billion years ago.[79][70] This age makes Rheasilvia a relatively young feature on a protoplanetary body formed early in Solar System history. The estimated excavation of ~1% of Vesta's volume[74] provides a direct link to the Vesta family of asteroids (Vestoids) and the HED meteorites. Since Vesta's spectral signature matches that of the Vestoids and HEDs, this strongly indicates they are fragments ejected from Vesta most likely during the Rheasilvia impact.[27][79] The Dawn mission's VIR instrument helped to confirm the basin's deep excavation and compositional diversity. VIR mapping revealed spectral variations across the basin consistent with the mixing of different crustal layers expected in the HED meteorites. Signatures matching eucrites (shallow crustal basalts) and diogenites (deeper crustal orthopyroxenites) were identified, which usually correlate with specific morphological features like crater walls or slump blocks.[80][27] The confirmed signature of olivine-rich material, which were first hinted at by Hubble observations is strongest on the flanks of the central peak and in specific patches along the basin rim and walls, suggesting it is not uniformly distributed but rather exposed in distinct outcrops.[81][80] As the dominant mineral expected in Vesta's mantle beneath the HED-like crust,[10] the presence of olivine indicates the Rheasilvia impact penetrated Vesta's entire crust (~2040km (1225mi) thick in the region) and excavated material from the upper mantle.[81] Furthermore, the global stresses resulting from this massive impact are considered the likely trigger for the formation of the large trough systems, like Divalia Fossa, that encircle Vesta's equatorial regions.[82][69]The crater AeliaFeralia Planitia, an old, degraded impact basin or impact basin complex near Vesta's equator (green and blue). It is 270km (168mi) across and predates Rheasilvia (green at bottom)Several old, degraded craters approach Rheasilvia and Veneneia in size, although none are quite so large. They include Feralia Planitia, shown at right, which is 270km (168mi) across.[83] More-recent, sharper craters range up to 158km (98mi) Varronilla and 196km (122mi) Postumia.[84]Dust fills up some craters, creating so-called dust ponds. They are a phenomenon where pockets of dust are seen in celestial bodies without a significant atmosphere. These are smooth deposits of dust accumulated in depressions on the surface of the body (like craters), contrasting from the Rocky terrain around them.[85] On the surface of Vesta, we have identified both type1 (formed from impact melt) and type2 (electrostatically made) dust ponds within 030N/S, that is, Equatorial region. 10craters have been identified with such formations.[86]The "snowman craters" are a group of three adjacent craters in Vesta's northern hemisphere. Their official names, from largest to smallest (west to east), are Marcia, Calpurnia, and Minucia. Marcia is the youngest and cross-cuts Calpurnia. Minucia is the oldest.[70]"Snowman" craters by Dawn from 5,200km (3,200mi) in 2011Detailed image of the "Snowman" cratersThe majority of the equatorial region of Vesta is sculpted by a series of parallel troughs designated Divalia Fossae; its longest trough is 1020 kilometres (6.212.4mi) wide and 465 kilometres (289mi) long. Despite the fact that Vesta is a one-seventh the size of the Moon, Divalia Fossae dwarfs the Grand Canyon. A second series, inclined to the equator, is found further north. This northern trough system is named Saturnalia Fossae, with its largest trough being roughly 40km (25mi) wide and over 370km (230mi) long. These troughs are thought to be large-scale graben resulting from the impacts that created Rheasilvia and Veneneia craters, respectively. They are some of the longest chasms in the Solar System, nearly as long as Ithaca Chasma on Tethys. The troughs may be graben that formed after another asteroid collided with Vesta, a process that can happen only in a body that is differentiated,[82] which Vesta may not fully be. Alternatively, it is proposed that the troughs may be radial sculptures created by secondary cratering from Rheasilvia.[87]A section of Divalia Fossae, with parallel troughs to the north and southA computer-generated view of a portion of Divalia FossaeCompositional information from the visible and infrared spectrometer (VIR), gamma-ray and neutron detector (GRaND), and framing camera (FC), all indicate that the majority of the surface composition of Vesta is consistent with the composition of the howardite, eucrite, and diogenite meteorites.[88][89][90] The Rheasilvia region is richest in diogenite, consistent with the Rheasilvia-forming impact excavating material from deeper within Vesta. The presence of olivine within the Rheasilvia region would also be consistent with excavation of mantle material. However, olivine has only been detected in localized regions of the northern hemisphere, not within Rheasilvia.[32] The origin of this olivine is currently unclear. Though olivine was expected by astronomers to have originated from Vesta's mantle prior to the arrival of the Dawn orbiter, the lack of olivine within the Rheasilvia and Veneneia impact basins complicates this view. Both impact basins excavated Vestian material down to 60100km, far deeper than the expected thickness of ~3040km for Vesta's crust. Vesta's crust may be far thicker than expected or the violent impact events that created Rheasilvia and Veneneia may have mixed material enough to obscure olivine from observations. Alternatively, Dawn observations of olivine could instead be due to delivery by olivine-rich impactors, unrelated to Vesta's internal structure.[91]Pitted terrain has been observed in four craters on Vesta: Marcia, Cornelia, Numisia and Licinia.[92] The formation of the pitted terrain is proposed to be degassing of impact-heated volatile-bearing material. Along with the pitted terrain, curvilinear gullies are found in Marcia and Cornelia craters. The curvilinear gullies end in lobate deposits, which are sometimes covered by pitted terrain, and are proposed to form by the transient flow of liquid water after buried deposits of ice were melted by the heat of the impacts.[71] Hydrated materials have also been detected, many of which are associated with areas of dark material.[93] Consequently, dark material is thought to be largely composed of carbonaceous chondrite, which was deposited on the surface by impacts. Carbonaceous chondrites are comparatively rich in mineralogically bound OH.[90]Cut-away schematic of Vestan core, mantle, and crustEucrite meteoriteA large collection of potential samples from Vesta is accessible to scientists, in the form of over 1200HED meteorites (Vestan achondrites), giving insight into Vesta's geologic history and structure. NASA Infrared Telescope Facility (NASA IRTF) studies of asteroid (237442) 1999 TA10 suggest that it originated from deeper within Vesta than the HED meteorites.[94]Vesta is thought to consist of a metallic ironnickel core, variously estimated to be 90km (56mi)[63] to 220km (140mi)[10] in diameter, an overlying rocky olivine mantle, with a surface crust of similar composition to HED meteorites.From the first appearance of calciumaluminium-rich inclusions (the first solid matter in the Solar System, forming about 4.567billion years ago), a likely time line is as follows:[95][96][97][98][99]Timeline of the evolution of Vesta23million yearsAccretion completed45million yearsComplete or almost complete melting due to radioactive decay of 26Al, leading to separation of the metal core67million yearsProgressive crystallization of a convecting molten mantle. Convection stopped when about

(October 2007). "Dawn Mission to Vesta and Ceres" (PDF). Earth, Moon, and Planets. 101 (12): 6591. Bibcode:2007EM&P..101…65R. doi:10.1007/s11038-007-9151-9. S2CID46423305. Archived (PDF) from the original on 27 September 2011. Retrieved 13 June 2011.^ Cook, Jia-Rui C.; Brown, Dwayne C. (11 May 2011). "NASA's Dawn Captures First Image of Nearing Asteroid". NASA/JPL. Archived from the original on 29 January 2012. Retrieved 14 May 2011.^ Vega, Priscilla; Brown, Dwayne (16 July 2011). "NASA's Dawn Spacecraft Enters Orbit Around Asteroid Vesta". NASA. Archived from the original on 19 June 2012. Retrieved 17 July 2011.^ Dawn mission timeline Archived 19 October 2013 at the Wayback Machine^ Mid-continent Research for Education and Learning: McREL (27 September 2010). "Dawn Mission: Mission". Dawn Journal. Retrieved 29 March 2011.^ "Dawn has Departed the Giant Asteroid Vesta". NASA JPL. NASA. 5 September 2012. Retrieved 5 September 2012.^ a b Russell, C. T.; etal. (2013). "Dawn completes its mission at 4 Vesta". Meteoritics & Planetary Science. 48 (11): 20762089. Bibcode:2013M&PS...48.2076R. doi:10.1111/maps.12091.^ Roatsch, Thomas; etal. (2012). "High resolution Vesta High Altitude Mapping Orbit (HAMO) Atlas derived from Dawn framing camera images". Planetary and Space Science. 73 (1): 283286. Bibcode:2012P&SS...73..283R. doi:10.1016/j.pss.2012.08.021.^ Roatsch, Thomas; etal. (2013). "High-resolution Vesta Low Altitude Mapping Orbit Atlas derived from Dawn Framing Camera images". Planetary and Space Science. 85: 293298. Bibcode:2013P&SS...85..293R. doi:10.1016/j.pss.2013.06.024.^ "NASA's Journey Above Vesta". DLR Institute of Planetary Research video with NASA JPL imagery. NASA. 16 September 2011. Archived from the original on 22 April 2021. Retrieved 18 September 2011.^ "DLR public Dawn products site". Archived from the original on 16 October 2015.^ "NASA Dawn".^ "Dawn Public Data". Dawn [website]. Univ. California, Los Angeles. Retrieved 6 March 2015.^ Gingerich, Owen (2006). "The Path to Defining Planets" (PDF). Dissertatio cum Nuncio Sidereo Ill. Tertia. Vol.VIII, no.16. pp.45. Archived (PDF) from the original on 15 March 2015. Retrieved 13 March 2007.^ "Dawn Mission website of JPL/NASA". 22 October 2018.^ Bryant, Greg (2007). "Sky & Telescope: See Vesta at Its Brightest!". Retrieved 7 May 2007.^ "Vesta Finder". Sky & Telescope. Archived from the original on 12 June 2007. Retrieved 7 May 2007.^ Harrington, Philip S. (21 October 2010). Cosmic Challenge: The Ultimate Observing List for Amateurs. Cambridge University Press. p.75. ISBN9781139493680.^ a b James, Andrew (2008). "Vesta". Southern Astronomical Delights. Retrieved 6 November 2008.^ a b Yeomans, Donald K.; Chamberlin, Alan B. "Horizons Ephemeris". JPL Solar System Dynamics. Retrieved 9 January 2010.^ "Elements and Ephemeris for (4) Vesta". Minor Planet Center. Archived from the original on 4 March 2016.^ "2012 Astronomy Special". Nightskyonline.info. Archived from the original on 20 April 2012. Retrieved 23 November 2012.^ a b c d T. Flanders Ceres and Vesta: July 2012 April 2013 Sky & Telescope.The Dawn Mission to Minor Planets 4 Vesta and 1 Ceres, Christopher T. Russell and Carol A. Raymond (Editors), Springer (2011), ISBN978-1-4614-4903-4Keil, K.; Geological History of Asteroid 4 Vesta: The Smallest Terrestrial Planet in Asteroids III, William Bottke, Alberto Cellino, Paolo Paolicchi, and Richard P. Binzel (editors), University of Arizona Press (2002), ISBN0-8165-2281-2Wikimedia Commons has media related to Vesta (asteroid).This video explores Vesta's landscape, history and planet-like characteristics.Interactive 3D gravity simulation of the Dawn spacecraft in orbit around Vesta Archived 11 June 2020 at the Wayback MachineVesta Trek An integrated map browser of datasets and maps for 4 VestaJPL EphemerisViews of the Solar System: VestaHubbleSite: Hubble Maps the Asteroid VestaEncyclopdia Britannica, Vesta full articleHubbleSite: short movie composed from Hubble Space Telescope images from November 1994.Adaptive optics views of Vesta from Keck Observatory4 Vesta images at ESA/Hubble Archived 22 January 2009 at the Wayback MachineDawn at Vesta (NASA press kit on Dawn's operations at Vesta)NASA video Archived 22 April 2021 at the Wayback MachineVesta atlas4 Vesta at AstDyS-2, AsteroidsDynamic SiteEphemeris Observation prediction Orbital info Proper elements Observational info4 Vesta at the JPL Small-Body Database Close approach Discovery Ephemeris Orbit viewer Orbit parameters Physical parametersPortals: Stars Spaceflight Outer space ScienceRetrieved from " 3The following pages link to 4 Vesta External tools(link counttransclusion countsorted list) See help page for transcluding these entriesShowing 50 items.View (previous 50 | next 50) (20 | 50 | 100 | 250 | 500)Asteroid (links | edit)Apparent magnitude (links | edit)Comet (links | edit)Classical Kuiper belt object (links | edit)Deep Space 1 (links | edit)Earth (links | edit)Erosion (links | edit)Geology (links | edit)Galilean moons (links | edit)Giant planet (links | edit)Galileo project (links | edit)Interplanetary spaceflight (links | edit)Kuiper belt (links | edit)Human spaceflight (links | edit)Moon (links | edit)Mercury (planet) (links | edit)Meteorite (links | edit)Near-Earth object (links | edit)Oort cloud (links | edit)Olympus Mons (links | edit)Planet (links | edit)Planets beyond Neptune (links | edit)Plutino (links | edit)Planetary nomenclature (links | edit)Ring system (links | edit)Plate tectonics (links | edit)Ruthenium (links | edit)Sun (links | edit)Solar System (links | edit)Space exploration (links | edit)Space colonization (links | edit)Trans-Neptunian object (links | edit)Jupiter trojan (links | edit)Tau Ceti (links | edit)Venus (links | edit)Zodiacal light (links | edit)1800s (decade) (links | edit)1807 (links | edit)433 Eros (links | edit)NEAR Shoemaker (links | edit)Ion thruster (links | edit)Jupiter (links | edit)Geochemistry (links | edit)Callisto (moon) (links | edit)Europa (moon) (links | edit)List of hypothetical Solar System objects (links | edit)Basalt (links | edit)Vulcan (hypothetical planet) (links | edit)Triton (moon) (links | edit)Pluto (links | edit)View (previous 50 | next 50) (20 | 50 | 100 | 250 | 500)Retrieved from " WhatLinksHere/4_Vesta" The Earth formed over 4.6 billion years ago out of a mixture of dust and gas around the young sun.It grew larger thanks to countless collisions between dust particles, asteroids, and other growing planets, including one last giant impact that threw enough rock, gas, and dust into space to form the moon.Although the rocks that record the earliest parts of Earths history have been destroyed or deformed over time by more than four billion years of geology, scientists can use modern rocks, moon samples, and meteorites to figure out when and how the Earth and moon formed, and what they might once have looked like. The Earth, like all the other planets in the solar system, started out its life as a disc of dust and gas orbiting the young sun. The dust particles were brought together by the forces of drag to form clumps of rock that grew into what scientists call planetesimals, which are tens to hundreds of miles across, and then to Mars-sized protoplanets by colliding with each other.Earth grew to its final size through one last major collision with another Mars-sized object. This last collision, also known as the moon-forming impact, was so large thatin addition to adding lots of material to the Earththere was enough energy to vaporize some of the rock and metal from both the proto-Earth and the impacting object. This vapor formed a disc around the Earth that eventually cooled and clumped together to become the moon.We know this thanks to rigorous studies of meteorites and rock samples, including at the University of Chicago, in the 20th and 21st centuries.Understanding how the Earth and moon formed is important for piecing together the history of the solar system and answering questions like how long planets take to form, what planets are made of, and what makes a planet suitable for life. This alsoguides planetary scientists in their search for other habitable (or inhabited!) worlds in our solar system and beyond! Scientists now think the Earths story began around 4.6 billion years ago in a disk-shaped cloud of dust and gas rotating around the early sun, made up of material left behind after the suns formation.Within this disk, gas and dust particles of different sizes orbited the sun at slightly different speeds, allowing them to bump into each other and stick together. Eventually, they grew from tiny dust grains into boulders, then into largerplanetesimals that ranged from miles to hundreds of miles in diameter.Because these planetesimals were larger than the boulders, they had strong enough gravity to pull neighboring planetesimals out of orbits and absorb them through collisions, enabling some planetesimals to grow bigger and bigger until they reached thousands of miles in diameterabout the size of the moon and Mars.How do we know?The key is meteorites. Meteorites bring many different types of material from all over the solar system to Earth where scientists can study them. These materials include chondrulestiny pieces of dust and rock that have survived from before the planets formedand pieces of asteroids and planetesimals left behind by the planet-building process. Radioactive elements like uranium and hafnium are trapped inside the minerals that make up these objects when they form, which allows planetary scientists to tell how old they are.Using these measurements, and simulations of the physics of dust and planetesimal collisions, planetary scientists and astronomers have established that the dust-to-protoplanet process takes tens of millions of years.But the final stage of planet formation in our solar system may have taken much longer - up to a hundred million years or so. This was not only the last major addition of material to the Earth, but also the event that formed the moonand its one of the most debated parts of the story.How did the moon form?Several different formation theories for the moon have been proposed by scientists, The story that is best supported by all the available data, however, is that the moon formed during a giant impact between the proto-Earth, and another protoplanet roughly the size of Mars, sometimes called Theia.In this theory, the moon formed from the impact debrisa mixture of molten rock and hot gasflung out into space by the impact, potentially forming a disk of material known as a lunar synestia.Alternate theories suggested by scientists include:the moon broke away from the Earth (Fission theory)the moon formed elsewhere in the solar system and was captured by Earths gravity (Capture theory)the Earth and moon formed from the protoplanetary disk at the same time (Co-formation)How do we know?Samples of rock from the moon, brought to Earth by lunar meteorites and the Apollo moon landings, can be used to understand the history of the Moon and its relationship to the Earth through the chemistry of their minerals.Planetary scientists like Prof. Nicolas Dauphas and Prof. Andy Davis in the Geophysical Sciences Department at the University of Chicago make precise measurements of lunar samples to determine exactly what theyre made of, and identify the chemical fingerprints of different geological processes like the melting and mixing of rocks and the evaporation of gasses.The first big clue about where the moon came from comes from oxygen. Oxygen, like many other elements, is able to exist in multiple forms, known as isotopes. Different types of meteorites coming from the asteroids left over in the solar system after planet formation have different proportions of each of these oxygen isotopes. So, by measuring the oxygen isotopes of a given planet, planetary scientists can calculate the different types of asteroid that collided to form the planet. Lunar samples have a very similar oxygen isotope makeup to the Earth. Some scientists believe that the oxygen isotopes are similar because the object that hit Earth was made up of the same mixture of meteorites as the Earth itself, potentially suggesting that the impactor planet formed close by in the solar system.Other scientists propose that after the impact all of the oxygen was able to move around in the hot vapor surrounding the Earth and moon, mixing up all the different oxygen isotopes and erasing any original differences between the Earth and Theia.However, there are many differences between the chemistry of the Earth and the moon, too. At the high temperatures reached during planetary impacts, many elements that we are not used to thinking of as gasses - like potassium, zinc, and sodium - can exist as vapor. The concentrations of these volatile elements are much lower in lunar rocks than in rocks on Earth.One possibility is that the hot impact debris had a long time to evaporate these elements before it clumped together to form the moon. Another is that when the moon formed it started off very hot with a deep magma ocean - like the Earth - and the low gravity and lack of atmosphere on the moon allowed volatile elements that wouldnt escape from a larger object to evaporate into space.Both of these pieces of evidence are hard to explain without a giant impact. An impact origin for the moon provides the high temperatures needed to explain the lack of potassium, zinc, and sodium on the moon, and also an opportunity for lots of mixing between the proto-Earth and the material that would become the moon. But when did this impact take place?When did the Moon form?Scientists believe the moon formed during a giant impact about 60-175 million years after the solar system was born. To arrive at this estimate, they can use rocks from Earth.As large planetesimals grow, heat is released by repeated impacts and the radioactive decay of elements inside their mineralsenough to cause melting. This allows materials with different densities to separate, with metals like iron and nickel sinking to the inside to form a core and lighter rocks floating on top. By the time of the moon-forming impact, the Earth was already separated into these rock and metal layers. However, the intense force and heat of the impact re-melted the proto-Earth, re-mixing the separated rock and metal. After this mixing, the Earth was still hot enough for separation to occur again and form new rock and metal layers - this is the key to dating when the moon formed!When rock and metal mix, they are able to swap certain elements. Elements like hafnium prefer to be mixed in with rock than with metal. Hafnium decays over about 10 million years to form tungsten. The first time the Earth cooled and separated into rock and metal layers was early in the solar systems history, so lots of hafnium was present in the Earths rocky layer because it hadnt had time to decay to tungsten yet. By the time the moon-forming impact occurred, much of this early hafnium had decayed to tungsten. Elements like tungsten prefer to be mixed in with metal, so when the impact remixed the Earth, the newly formed tungsten sank into the metal core. This created a rocky outer layer with a lower concentration of hafnium than before, and a metal core with much more tungsten in it.Today, all of the hafnium is gone because it has a short half-life compared to the age of the Earth. However, not all is lost - this makes it very useful for working out the timing of events in the first hundred million years of the solar systems history. The concentration of tungsten in Earths rocks depends on when the most recent separation into rock and metal layers occurred. The concentration of tungsten in Earths rocks is too low to be explained by the metal and rock separating early on, which means something must have re-mixed the Earths layers. The best explanation for the heat and energy needed to do this is a giant impact about 60-175 million years after the solar system was born.What did the early Earth look like?After the moon-forming impact, Earth was a very different planet from the world we see today! Where the present-day Earth has oceans covering much of its surface, the early Earth was covered in a magma ocean - a layer of molten rock hundreds of miles deep that was melted by the energy released during the collision. Any water present would only exist as water vapor in the atmosphere.If that wasnt enough, the early sun was also far more active than it is today, blasting the entire solar system with UV radiation energetic enough to evaporate entire atmospheres.Over time, after the magma ocean cooled enough to form a solid surface, Earths atmosphere was replenished by volcanic eruptions, as well as water and other gasses delivered by comets and meteorites crashing into the surface.This was also the first step towards our planet developing plate tectonics. Plate tectonics describes the giant plates of crust that slowly move around Earths surface over hundreds of millions of years; it not only produces new rocks at volcanoes where the plates are moving apart, but can also recycle rocks from the Earths surface and atmosphere back into the interior where plates are coming together. This process - known as subduction - carries rocks, water, and carbon dioxide trapped in minerals back into the Earths interior where they can drive future volcanic eruptions, continuing the plate tectonic cycle.Some planetary scientists believe that plate tectonics is essential for a planet to develop life. This is because the repeated production and destruction of crust by plate tectonics both releases carbon dioxide to the atmosphere and removes it, helping keep temperatures on Earth similar (and comfortable for microbes, fish, and humans!) over billions of years.Whether a planet has plate tectonics is much more complicated than just having a solid surface, though, and might also depend on the types and amount of different asteroids, planetesimals, and protoplanets that the Earth is made of because of the way different chemicals and minerals can change how planet interiors behave over billions of years.What did the early moon look like?Most of us picture the moon as a desolate, grey place with craters and not much else, but it was surprisingly geologically active for much of its history. Like the Earth, the moon started off with a thick layer of molten rock on its surface.Unlike the Earth, though, the moons surface did not cool to form tectonic plates. Instead, it has a thick crust made up almost entirely of a light-colored mineral called feldspar. Feldspar is the main material that makes up the bright areas we can see on the moon today, also known as the lunar highlands. The feldspar crystalized as the magma ocean cooled, and was light enough to float to the moons surface, on top of other minerals and the remaining magma. (Planetary scientists can use the fact that this feldspar crust formed on the moon but not on the Earth to try and work out differences in the early chemistry and cooling conditions between the two objects to learn more about the moons formation.)The formation of a feldspar crust didnt mark the end of geological activity on the moon, though. The heat leftover by the impact, as well as more heat contributed by radioactive elements, was able to melt rock deep within the moon to fuel volcanoes on its surface. This melting produced basalt, a kind of dark-colored rock commonly found at volcanoes on Earth today in places like Hawaii and Iceland. The basalt spilled out over hundreds of kilometers across the moons surface, forming mare (meaning seas in Latin) up to a mile thick. These mare cover around 16% of the moons surface and are visible with the naked eye as the dark patches on the moon. Planetary scientists can tell that the basalt mare are younger than the feldspar highlands using the number of craters on the different surfaces. The mare have fewer craters on their top surfaces than the highlands because they have had less time to be hit by asteroids and meteorites. The youngest mare are thought to be only 1.1 billion years old, which means volcanoes were still erupting on the moon two billion years after the earliest accepted evidence for life on Earth!Another feature of the early moon was its orbit. Today, the moon is moving about 1.5 inches further away from the Earth every year. Planetary scientists have calculated the distance between the Earth and the Moon backwards in time and found that the moon used to be seventeen times closer (14,000 miles vs. 250,000 miles) when it formed.This changing distance between the Earth and the moon is an important clue about the details of the moon-forming impact because changing the size, speed and angles of approach of impactors in moon formation simulations changes the orbit of the final Earth-moon system. Planetary scientists need to find an impact simulation that can not only match the moons chemistry, but also how far it was from the Earth and how fast it was initially spinning.What questions remain?Although scientists agree that the moon formed because of an impact, the details of the impact are still up for debate. Scientists still dont agree on how big the impacting object was, how fast it was travelling, what it was made from, or even whether we should be calling it Theia." Some scientists even argue that multiple impacts might have formed the Moon, instead of just one!Lab experiments help scientists better understand what happens to different rock types and elements under the extreme conditions of large impact events. Prof. Nicolas Dauphas research group at UChicago evaporates metals under a vacuum to simulate the conditions present in the cloud of impact debris to try and explain why lunar rocks have so much less of elements like sodium, zinc, and potassium compared to the Earth.Some experiments can be too large for the lab, though, so computer simulations are also used to investigate the moon-forming impact. These simulations enable scientists to virtually smash together the proto-Earth and different types of planetesimals at many speeds and angles to figure out what combinations of properties are able to form a moon with the size and orbit we see today.In the future, new samples from the moon could give planetary scientists a wider range of different lunar rock types to work with. This is important because new samples might record different pieces of the moons history that arent present in the existing lunar rocks brought back by the Apollo missions. As measurement techniques improve, planetary scientists will also be able to measure new chemical signatures in lunar rocks, and improve upon existing measurements.The more measurements scientists have, the more ways they can test different theories about how our moon formed, its relationship to the Earth, and perhaps even how moons might be born around other planets far beyond our solar system!Last reviewed November 2024. Curious Kids is a series for children of all ages. If you have a question youd like an expert to answer, send it to CuriousKidsUS@theconversation.com. How was the Earth built? Noah, age 5, Florida It isnt easy to figure out how the Earth was built, because it happened 4 billion years ago, and no one was there to watch. So scientists have had to look at what the Earth looks like now and at all of the other planets, moons and debris in the solar system. Theyve concluded that the Earth was built in the same way that you would build a big snowball to make a snowman. The mass that would become our home rolled through planetary debris rocks floating in space for more than 100 million years, adding more and more material, until it grew into a full-size planet. How do scientists like me know this is what happened? First, studies of the size, composition and location of asteroids and comets, many of which are as old as the Earth, indicate that 4 billion years ago the solar system looked the way Saturn looks today, with rings of space rocks orbiting around the Sun. Theres still one such ring around the Sun its called the asteroid belt and lies between Mars and Jupiter, with the Suns gravity holding the rocks in orbit. The solar system that includes Earth formed from a spinning disk of dust and gases. All of the other bodies that we know as planets today began as similar rings of space debris. An eddy, or area of rolling, developed in each of these rings and caused the debris to clump up in a snowball effect. But these pieces of debris were asteroids that smashed violently into the growing planets. We can see those impacts on planets and moons whose surfaces havent weathered or reformed. If you look at the Moon or the planet Mercury, you can see that they are covered with craters from asteroid impacts. When asteroids or comets struck these building planets, they crashed into their surfaces at speeds as high as 40,000 to 50,000 miles per hour (65,000 to 80,000 kilometers per hour). The impacts caused huge explosions that emitted massive amounts of dust and broken or melted rock. In fact, scientists believe that the Moon was once part of the Earth, until a large asteroid crashed into the Earth so hard that the Moon broke away and shot into space. There, it began orbiting the Earth as it does now. Still under construction Most big asteroids and comets collided with the Earth when it was young, about 4 billion years ago. The number of such collisions has steadily decreased ever since. However, at least 100 tons of dust-size space rock rains down on the Earth every day, increasing the size of our planet bit by bit. The Earth also collides with space rocks, called meteors, that show up as shooting stars in the night sky. Some of these meteors come from an impact that struck Mars at some point, breaking away rock from the planet surface and shooting it into outer space. These rocks have been falling to Earth ever since. Whats the difference between an asteroid and a comet? Asteroids are large space rocks, while comets are large, dirty ice balls. Meteors are smaller typically the size of pebbles or even dust. About 65 million years ago, a huge asteroid struck the Earth in the Gulf of Mexico. The enormous Chicxulub explosion drove large tsunamis throughout the ocean and raised so much dust into the air that it made the dinosaurs go extinct. Another large asteroid impact, about 35 million years ago, made a huge crater in the area that is now the Chesapeake Bay, near Washington, D.C. More recently, in 1908, an asteroid likely exploded over Tunguska, Russia, flattening 830 square miles (2,150 square kilometers) of trees. Fortunately, no one lived in the area, so there were no known casualties. Barringer Crater in Arizona was caused by a meteor strike about 50,000 years ago. It measures about 0.75 miles (1.2 kilometers) across. D. Roddy, USGS/Wikipedia Once a mass of space debris was assembled into the Earth, many processes continued to shape the planets surface. Wind, water, heat and cold cause rocks to weather and break down and soil to erode. Mountains are created as pieces of Earths crust collide and crack. Rivers and glaciers wear down the planets surface to make it smoother. The Earth is a dynamic planet that is constantly being built, and these processes will continue for billions of years into the future. Hello, curious kids! Do you have a question youd like an expert to answer? Ask an adult to send your question to CuriousKidsUS@theconversation.com. Please tell us your name, age and the city where you live. And since curiosity has no age limit adults, let us know what youre wondering, too. We wont be able to answer every question, but we will do our best. Share copy and redistribute the material in any medium or format for any purpose, even commercially. Adapt remix, transform, and build upon the material for any purpose, even commercially. The licensor cannot revoke these freedoms as long as you follow the license terms. Attribution You must give appropriate credit , provide a link to the license, and indicate if changes were made . You may do so in any reasonable manner, but not in any way that suggests the licensor endorses you or your use. ShareAlike If you remix, transform, or build upon the material, you must distribute your contributions under the same license as the original. No additional restrictions You may not apply legal terms or technological measures that legally restrict others from doing anything the license permits. You do not have to comply with the license for elements of the material in the public domain or where your use is permitted by an applicable exception or limitation . No warranties are given. The license may not give you all of the permissions necessary for your intended use. For example, other rights such as publicity, privacy, or moral rights may limit how you use the material. Earth's formation remains a strange, scientific mystery.We live on a planet in a solar system with seven other planets and have discovered thousands of exoplanets to date. But how planets like Earth form still remains a subject of great debate.Currently, there are two leading theories on planetary formation. Scientists continue to study planets in and out of our solar system in an effort to better understand which of these theories most accurately describes how the solar system and its planets formed.You may like The first and most widely accepted theory is the core accretion model, which works well to explain the formation of terrestrial planets like Earth but doesn't fully account for giant planets. The second theory, called the disk instability method, may account for the creation of larger planets.These two leading theories are joined by the pebble accretion theory which helps to additionally explain how different objects might form.Related: Earth's layers: Exploring our planet inside and outWhat is the core accretion model?Artist's conception of our solar system's solar nebula, the cloud of gas and dust from which Earth, the sun and our solar system's other planets planets formed. (Image credit: Painting copyright William K. Hartmann, Planetary Science Institute, Tucson)Approximately 4.6 billion years ago, our solar system was just a cloud of dust and gas known as a solar nebula. Gravity collapsed the material in on itself as it began to spin, condensing the matter and forming the sun in the center of the nebula.With the sun beginning to form, the remaining material started to clump up. Small particles drew together, bound by the force of gravity, into larger particles. The solar wind, a constant stream of charged particles that emanate from the sun's upper atmosphere, swept away lighter elements, such as hydrogen and helium.This left behind heavy, rocky materials that formed smaller terrestrial worlds like Earth. And farther away from the sun, the solar wind had less of an impact on lighter elements which allowed these elements to coalesce into gas giants. This process created our solar system's asteroids, comets, planets and moons.Earth's rocky core formed first, with heavy elements colliding and binding together. Dense material sank to the protoplanet's center while lighter material built up the crust. Earth's magnetic field is thought to have likely formed around this time.Early in its evolution, Earth suffered an impact by a large body that catapulted pieces of the young planet's mantle into space. Gravity pulled many of these pieces together to form the moon, which took up orbit around its creator.The late-stage phase of planet formation with protoplanets and planetismals is seen in this artist's depiction. (Image credit: Ashley Norris/Oxford University)The flow of the mantle beneath Earth's crust causes plate tectonics, the movement of the large plates of rock on the planet's surface. Collisions and friction gave rise to mountains and volcanoes, which began to spew gases.When Earth first formed it had barely any atmosphere. Its atmosphere began to form as the planet started to cool and gravity captured gases from Earth's volcanoes.While the population of comets and asteroids passing through the inner solar system is sparse today, they were more abundant when the planets and sun were young. Collisions between these cosmic bodies likely deposited much of the water on Earth's surface.Our planet lies in what is known as the Goldilocks zone, a region surrounding a star that is close enough for liquid water to exist on a planet's surface, with water neither freezing nor evaporating. Many scientists think that being in this zone, and the presence of liquid water, plays a key role in the existence of life.An artistic conception of the early Earth-moon system showing the Earth's surface after being bombarded with large impacts, causing magma extrusion on the surface, though some liquid water was retained. Image released on July 30, 2014. (Image credit: Simone Marchi)In observing exoplanets, scientists think that this core accretion model fits as the dominant formation process.Stars with more "metals" a term astronomers use for all chemical elements heavier than hydrogen and helium in their cores host more giant planets than their metal-poor cousins. According to NASA, core accretion suggests that small, rocky worlds should be more common than the more massive gas giants.One finding that has helped to strengthen core accretion's legitimacy as an explanation for planet formation is the 2005 discovery of a giant planet with a massive core orbiting the sun-like star HD 149026."This is a confirmation of the core accretion theory for planet formation and evidence that planets of this kind should exist in abundance," said Greg Henry in a press release. Henry, an astronomer at Tennessee State University, Nashville, detected the dimming of the star.In 2019, the European Space Agency launched the CHaracterising ExOPlanet Satellite (CHEOPS), which was designed to study exoplanets ranging in sizes from super-Earths to Neptune. With missions like this and others, scientists aim to study distant worlds to grow their understanding of how planets in different solar systems likely formed."In the core accretion scenario, the core of a planet must reach a critical mass before it is able to accrete gas in a runaway fashion," said the CHEOPS team."This critical mass depends upon many physical variables, among the most important of which is the rate of planetesimals accretion."Related: How fast is Earth moving?What is the disk instability model?While the core accretion model works for terrestrial planets, gas giants would need to evolve rapidly to grab hold of the significant mass of lighter gases they contain. But simulations with that model have not been able to account for this rapid formation. In those simulations, the process takes several million years, which is longer than light gases were available in the early solar system.But the core accretion model isn't the only explanation for how planets might come to be.According to a newer theory, disk instability, clumps of dust and gas bind together early in the solar system's existence. Over time, these clumps can slowly compact into a giant planet. These planets can form faster than those that form within the core accretion explanation, sometimes in as little as a thousand years, which allows them to trap the rapidly-vanishing lighter gases. These planets also quickly reach an orbit-stabilizing mass that keeps them from death-marching into the sun.According to exoplanetary astronomer Paul Wilson, if disk instability dominates the formation of planets, it should produce a wide number of worlds at large orders. The four giant planets orbiting at significant distances around the star HD 9799 provides observational evidence for disk instability.Fomalhaut b, an exoplanet with a 2,000-year orbit around its star, could serve as an example of a world formed through disk instability, though the planet could also have been ejected due to interactions with its neighbors.What is pebble accretion?A visualization of a dusty disk orbiting a young star. (Image credit: NASA/JPL-Caltech)The disk instability model contends with the core accretion model's issue with time; specifically how quickly massive gas giants would have to grab lighter components. But another, recent model known as pebble accretion, also helps to fill in this explanatory gap.In this model, researchers have shown how smaller, pebble-sized objects could have fused together to build giant planets up to 1000 times faster than in other explanations."This is the first model that we know about that you start out with a pretty simple structure for the solar nebula from which planets form, and end up with the giant-planet system that we see," Harold Levison, an astronomer at the Southwest Research Institute (SwRI) in Colorado and lead study author of a paper describing and exploring the model, told Space.com in 2015.A few years earlier, in 2012, researchers Michiel Lambrechts and Anders Johansen from Lund University in Sweden proposed that tiny pebbles, once written off, held the key to rapidly building giant planets."They showed that the leftover pebbles from this formation process, which previously were thought to be unimportant, could actually be a huge solution to the planet-forming problem," Levison said.Levison and his team built on that research to model more precisely how tiny pebbles could form planets seen in the galaxy today. In previous simulations, both large and medium-sized objects consumed their pebble-sized cousins at a relatively constant rate, but Levison's simulations suggest that the larger objects acted more like bullies, snatching away pebbles from the mid-sized masses to grow at a much faster rate."The larger objects now tend to scatter the smaller ones more than the smaller ones scatter them back, so the smaller ones end up getting scattered out of the pebble disk," study co-author Katherine Kretke, also from SwRI, told Space.com. "The bigger guy basically bullies the smaller one so they can eat all the pebbles themselves, and they can continue to grow up to form the cores of the giant planets."As scientists continue to study planets inside and outside of the solar system, they will better understand how Earth and its siblings formed.Additional resourcesFollow us at @Spacedotcom, Facebook or Google+.This article was updated on Jan. 5, 2022 by Space.com senior writer Chelsea GohdEarth's formation remains a strange, scientific mystery.We live on a planet in a solar system with seven other planets and have discovered thousands of exoplanets to date. But how planets like Earth form still remains a subject of great debate.Currently, there are two leading theories on planetary formation. Scientists continue to study planets in and out of our solar system in an effort to better understand which of these theories most accurately describes how the solar system and its planets formed.You may like The first and most widely accepted theory is the core accretion model, which works well to explain the formation of terrestrial planets like Earth but doesn't fully account for giant planets. The second theory, called the disk instability method, may account for the creation of larger planets.These two leading theories are joined by the pebble accretion theory which helps to additionally explain how different objects might form.Related: Earth's layers: Exploring our planet inside and outWhat is the core accretion model?Artist's conception of our solar system's solar nebula, the cloud of gas and dust from which Earth, the sun and our solar system's other planets planets formed. (Image credit: Painting copyright William K. 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"The bigger guy basically bullies the smaller one so they can eat all the pebbles themselves, and they can continue to grow up to form the cores of the giant planets."As scientists continue to study planets inside and outside of the solar system, they will better understand how Earth and its siblings formed.Additional resourcesFollow us at @Spacedotcom, Facebook or Google+.This article was updated on Jan. 5, 2022 by Space.com senior writer Chelsea Gohd by Mary Caperton Morton Monday, May 15, 2017 Credit: K. Cantner, AGI. The basic story of Earths formation is familiar to most anyone who has taken a geology course: About 4.6 billion years ago, Earth formed when a rocky nucleus accreted dust and debris left over from the formation of our sun.At first, Earth did not look like a place that would eventually support life. But early on, the young, red-hot planet began laying the foundation for becoming a mature, hosp

as the Aldebaran IV incident demonstrates.2014 April, Harlan Ellison, Paingod: And Other Delusions, Open Road Media, page 31:[] enshrouded in bitterness and misery a man named Colin Marshack on an insignificant planet called Sol III, Earth, Terra, the world...2016 October, Stephen Baxter, Destiny's Children: Coalescent, Exultant, Transcendent, Resplendent, Orion Publishing Group, page 50:At last the ship made its final approach to Sol III: Earth.2017, Marc Baumgartner, Inheritance of Stars: New Worlds, tredition, page 388:VIRA, determine our current position and chart the fastest course to the next portal. We're going home to Earth! Current location: orbiting the moon of Sol III, also known as Earth. SolSol ISol IISol IVSol VSol VISol VIISol VIIISol IXSol X We live on Earths hard, rocky surface, breathe the air that surrounds the planet, drink the water that falls from the sky, and eat the food that grows in the soil. But Earth did not always exist within this expansive universe, and it was not always a hospitable haven for life.Billions of years ago, Earth, along with the rest of our solar system, was entirely unrecognizable, existing only as an enormous cloud of dust and gas. Eventually, a mysterious occurrenceone that even the worlds foremost scientists have yet been unable to determinecreated a disturbance in that dust cloud, setting forth a string of events that would lead to the formation of life as we know it. One common belief among scientists is that a distant star collapsed, creating a supernova explosion, which disrupted the dust cloud and caused it to pull together. This formed a spinning disc of gas and dust, known as a solar nebula. The faster the cloud spun, the more the dust and gas became concentrated at the center, further fueling the speed of the nebula. Over time, the gravity at the center of the cloud became so intense that hydrogen atoms began to move more rapidly and violently. The hydrogen protons began fusing, forming helium and releasing massive amounts of energy. This led to the formation of the star that is the center point of our solar systemthe sunroughly 4.6 billion years ago.Planet FormationThe formation of the sun consumed more than 99 percent of the matter in the nebula. The remaining material began to coalesce into various masses. The cloud was still spinning, and clumps of matter continued to collide with others. Eventually, some of those clusters of matter grew large enough to maintain their own gravitational pull, which shaped them into the planets and dwarf planets that make up our solar system today.Earth is one of the four inner, terrestrial planets in our solar system. Just like the other inner planetsMercury, Venus, and Marsit is relatively small and rocky. Early in the history of the solar system, rocky material was the only substance that could exist so close to the Sun and withstand its heat.In Earth's BeginningAt its beginning, Earth was unrecognizable from its modern form. At first, it was extremely hot, to the point that the planet likely consisted almost entirely of molten magma. Over the course of a few hundred million years, the planet began to cool and oceans of liquid water formed. Heavy elements began sinking past the oceans and magma toward the center of the planet. As this occurred, Earth became differentiated into layers, with the outermost layer being a solid covering of relatively lighter material while the denser, molten material sunk to the center.Scientists believe that Earth, like the other inner planets, came to its current state in three different stages. The first stage, described above, is known as accretion, or the formation of a planet from the existing particles within the solar system as they collided with each other to form larger and larger bodies. Scientists believe the next stage involved the collision of a protoplanet with a very young planet Earth. This is thought to have occurred more than 4.5 billion years ago and may have resulted in the formation of Earths moon. The final stage of development saw the bombardment of the planet with asteroids.Earths early atmosphere was most likely composed of hydrogen and helium. As the planet changed, and the crust began to form, volcanic eruptions occurred frequently. These volcanoes pumped water vapor, ammonia, and carbon dioxide into the atmosphere around Earth. Slowly, the oceans began to take shape, and eventually, primitive life evolved in those oceans.Contributions from AsteroidsOther events were occurring on our young planet at this time as well. It is believed that during the early formation of Earth, asteroids were continuously bombarding the planet, and could have been carrying with them an important source of water. Scientists believe the asteroids that slammed into Earth, the moon, and other inner planets contained a significant amount of water in their minerals, needed for the creation of life. It seems the asteroids, when they hit the surface of Earth at a great speed, shattered, leaving behind fragments of rock. Some suggest that nearly 30 percent of the water contained initially in the asteroids would have remained in the fragmented sections of rock on Earth, even after impact.A few hundred million years after this processaround 2.2 billion to 2.7 billion years agophotosynthesizing bacteria evolved. They released oxygen into the atmosphere via photosynthesis and, in a few hundred million years, were able to change the composition of the atmosphere into what we have today. Our modern atmosphere is comprised of 78 percent nitrogen and 21 percent oxygen, among other gases, which enables it to support the many lives residing within it. In the vast expanse of the cosmos, our home, Earth, emerges as a remarkable celestial body, bearing the signature of a complex and awe-inspiring birth. From the swirling clouds of stardust to the molten chaos of its early days, Earths formation is a captivating story that beckons us to explore the origins of our world. Understanding the intricacies of how our planet came into being is not merely a matter of scientific curiosity; it holds the key to unraveling the mysteries of life, geology, and even the fate of humanity. In this journey of discovery, we will delve into the formation of Earth, the cradle of life as we know it, uncovering the profound significance of this ancient tale for our present and future. Therefore, through the prism of Earths formation, we will gain insights into the fundamental processes that have shaped our planet and continue to influence our existence today. The universe we inhabit today is the result of a long and intricate evolutionary process, starting with the Big Bang. The Big Bang Theory stands as the cornerstone of modern cosmology, offering a profound understanding of how the universe itself came into existence. It reveals a story of cosmic expansion, the birth of galaxies, and the eventual emergence of our very own solar system. The Big Bang Theory, proposed in the early 20th century, posits that the universe originated from an infinitely dense and hot point known as a singularity. Approximately 13.8 billion years ago, this singularity suddenly expanded, giving rise to space, time, and matter. As the universe expanded, it cooled, and matter began to form, eventually coalescing into galaxies, stars, and planets. Within this grand cosmic narrative, the formation of our solar system is a remarkable subplot. It begins with a massive cloud of gas and dust, known as the solar nebula, which was enriched with elements synthesized in the cores of earlier generations of stars. Gravity played a pivotal role in the collapse of the solar nebula, causing it to contract and spin, forming a spinning disk. At the center of this spinning disk, the Sun ignited, becoming the gravitational anchor around which the rest of the material in the disk orbited. The remaining matter within the disk began to clump together due to gravitational attraction. These clumps, or planetesimals, collided and merged over vast stretches of time, giving rise to larger and larger bodies. Some of these grew into the planets, moons, and asteroids we recognize today. The formation of the solar system is a dynamic process that resulted in the distinct celestial bodies we observe in our cosmic neighborhood. The inner rocky planets, including Earth, formed closer to the Sun, while the outer gas giants like Jupiter and Saturn formed farther out, where the solar nebula contained more volatile elements. Understanding the Big Bang Theory and the formation of the solar system not only deepens our appreciation of the vast cosmos but also sheds light on the origins of our own planet and its place in the universe. It underscores the interconnectedness of all celestial bodies and the fascinating interplay of physical laws and cosmic phenomena that have shaped our existence. The story of Earths formation and differentiation into its distinct layers is a remarkable journey that unfolds over billions of years. Understanding this timeline and the intricate processes involved in shaping our planet is key to appreciating the complexity of the world we call home. Formation of Earth: 4.6 billion years ago: The formation of Earth began within the solar nebula, a cloud of gas and dust left over from the formation of the Sun. Dust particles collided and stuck together, forming ever-larger aggregates. These aggregates eventually grew into planetesimals, which were the building blocks of planets. 4.5 billion years ago: Earth was born through the accretion of these planetesimals. During this time, our planet was a hot, molten mass as a result of the energy generated by numerous impacts and gravitational compression. 4.4 billion years ago: Earths surface cooled and solidified, forming a thin crust. This marked the beginning of the Hadean Eon, a period of intense bombardment by asteroids and comets. Differentiation into Layers: Core Formation (4.5-4.4 billion years ago): As Earths interior continued to heat up due to radioactive decay and residual heat from its formation, heavy metallic elements like iron and nickel sank toward the center. This process led to the formation of Earths metallic core, which is divided into an inner solid core and an outer liquid core. The heat generated by the core is responsible for the generation of Earths magnetic field. Mantle Formation (4.4-3.5 billion years ago): Above the core, the mantle consists of solid rock, predominantly composed of silicate minerals. The mantle experiences convection currents, driving the movement of Earths tectonic plates and influencing the planets surface features and geological activity. Crust Formation (4.4-2.5 billion years ago): The Earths outermost layer, the crust, is composed of solid rock, with a mix of lighter silicate minerals. It is divided into the continental crust, found on the continents, and the oceanic crust, which underlies the Earths oceans. The crust is where most geological processes, including the formation of mountains, volcanoes, and earthquakes, occur. The process of Earths differentiation into these layers was a dynamic and gradual one, driven by the differences in density and composition of various materials. This layering not only defines the planets internal structure but also plays a crucial role in shaping its geological and geophysical processes. Understanding the timeline of Earths formation and the differentiation of its layers provides insight into the planets long and complex history. It helps us appreciate how Earths unique characteristics, including its magnetic field, geological activity, and diverse surface features, have been shaped by these ancient processes, ultimately creating the habitable world we know today. Earths chemical composition is a diverse and complex amalgamation of elements and compounds that make our planet a unique and habitable place in the universe. Understanding the key components of Earths composition and the roles of volatiles and refractories is essential in appreciating the planets geology, atmosphere, and life. Elements and Compounds Found on Earth: Silicon (Si): Silicon is one of the most abundant elements in Earths crust and is a fundamental component of various silicate minerals, which make up the majority of Earths rocks. Oxygen (O): Oxygen is the most abundant element in Earths crust and plays a critical role in the composition of water (H_2O) and the silicate minerals that form rocks. Iron (Fe): Iron is a crucial element in Earths core, contributing to the generation of its magnetic field. It is also present in various minerals and plays a role in the coloration of some rocks. Aluminum (Al): Aluminum is a common element in the Earths crust, and it is found in many silicate minerals, particularly in feldspars. Calcium (Ca): Calcium is a component of various minerals and is important for the formation of carbonate rocks like limestone and marble. Sodium (Na) and Potassium (K): These elements are essential constituents of many minerals and play a role in the chemistry of Earths oceans and minerals. Hydrogen (H): Hydrogen is a primary component of water and is also present in various organic compounds essential for life. Carbon (C): Carbon is a fundamental element in organic compounds, such as carbohydrates, proteins, and DNA, forming the basis of life on Earth. Nitrogen (N): Nitrogen is crucial for the composition of Earths atmosphere and is a key element in amino acids, proteins, and nucleic acids. Sulfur (S): Sulfur is found in various minerals and is essential for certain biological processes and the formation of minerals like gypsum and pyrite. Role of Volatiles and Refractories: Volatiles: Volatiles are elements and compounds that have relatively low boiling points. These include water (H_2O), carbon dioxide (CO_2), ammonia (NH_3), and methane (CH_4). Volatiles play a crucial role in Earths climate, weather, and the composition of its atmosphere. Water, in particular, is essential for life as we know it and is a key component in Earths hydrological cycle, supporting the existence of oceans, rivers, and the overall habitability of the planet. Refractories: Refractories are elements and compounds with higher boiling points, such as silicates and metals like iron. These materials are found in Earths solid crust, mantle, and core. Silicates, for example, dominate the composition of rocks, while iron is a major component of the core, contributing to the generation of Earths magnetic field. The balance and interplay between volatiles and refractories are crucial for Earths dynamic processes, including plate tectonics, volcanic activity, and the regulation of the planets climate. Earths chemical composition, shaped by the presence of these elements and compounds, has fostered the development of diverse ecosystems and has made our planet a truly exceptional and hospitable world in the vastness of the cosmos. Heavy Bombardment Period: Approximately 4.1 to 3.8 billion years ago, Earth and the inner solar system experienced a period of intense and frequent meteorite impacts. This era, known as the Heavy Bombardment Period or the Late Heavy Bombardment, was a chaotic time for our planets surface and had significant implications for the early Earth and its celestial neighbors. Effects of Meteorite Impacts on Earths Surface: Crater Formation: During the Heavy Bombardment Period, Earths surface was bombarded by a multitude of meteorites and asteroids. The impacts resulted in the formation of numerous impact craters of various sizes. These craters, when preserved, provide valuable insights into the history of impacts on our planet. Atmospheric Changes: The frequent meteorite impacts during this period had a profound effect on Earths atmosphere. The energy released from these impacts could have caused substantial changes in the composition of the early atmosphere. For instance, it may have released gases like water vapor, carbon dioxide, and methane. Magma Oceans and Geological Effects: Some of the most massive impacts during the Heavy Bombardment may have been energetic enough to cause the partial or complete melting of Earths surface, resulting in the formation of magma oceans. These geological processes influenced the differentiation of Earths interior and the formation of its crust. Formation of Early Oceans: Water is a crucial component of life, and it is believed that the Heavy Bombardment played a role in the delivery of water to Earth. Comets and water-rich asteroids impacting the early Earth could have contributed to the formation of Earths early oceans. Formation of the Moon (Giant Impact Hypothesis): One of the most notable consequences of the Heavy Bombardment Period is the Giant Impact Hypothesis, which suggests that the Moon was formed as a result of a colossal collision between Earth and a Mars-sized body. Heres a brief overview of this hypothesis: About 4.5 billion years ago, shortly after Earths formation, a massive object, sometimes referred to as Theia, collided with Earth. This catastrophic impact was so powerful that it led to the ejection of a significant amount of material from Earths mantle into space. The ejected material coalesced to form a disk of debris around Earth, which gradually accreted into the Moon. The composition of the Moon is, in part, a reflection of this collision, with a mix of material from both Earth and Theia. The Giant Impact Hypothesis explains various features of the Moon, such as its lack of a substantial iron core (which remained on Earth), its geological composition, and the similarities and differences between Earth and the Moon. The formation of the Moon through this giant impact not only influenced the evolution of our natural satellite but also played a role in shaping the Earth-Moon system, including aspects of Earths axial tilt and its gravitational influence on tides. It is a testament to the profound impact that meteorite impacts and celestial collisions have had on the history and development of our planet and its cosmic surroundings. Earths Atmosphere and Composition: The early Earths atmosphere was markedly different from the one we know today. It primarily consisted of volatile compounds, such as water vapor (H_2O), carbon dioxide (CO_2), nitrogen (N_2), methane (CH_4), and ammonia (NH_3). Notably, there was a lack of significant amounts of free oxygen (O_2) in the atmosphere during this period, as oxygen was primarily bound to other elements. Reducing Atmosphere: The early atmosphere was considered reducing, meaning that it had a surplus of compounds with electrons that could be readily shared with other elements. This reducing environment was conducive to the formation of complex organic molecules, which are essential for the development of life. Volcanic Activity: Volcanic eruptions and outgassing from the Earths interior were significant contributors to the composition of the early atmosphere. These emissions released gases like carbon dioxide, water vapor, and sulfur dioxide, influencing the planets early climate and chemistry. Origin of Water on Earth: The origin of Earths water is a subject of ongoing scientific investigation, with multiple theories proposed to explain its presence. Some of the leading theories include: Cometary Delivery: It is believed that a significant portion of Earths water was delivered by comets or water-rich asteroids during the Late Heavy Bombardment period, around 4.1 to 3.8 billion years ago. These celestial bodies contained water ice, which could have melted upon impact with Earth and contributed to the formation of the planets early oceans. Volcanic Outgassing: Some water may have been released from the Earths interior through volcanic activity. Water vapor and other volatile compounds trapped in the Earths mantle could have been gradually released through volcanic eruptions and then condensed to form the early oceans. Hydrated Minerals: Water may have also been present in the building blocks of Earth, such as hydrated minerals in the materials that formed the planet. These minerals could have released water during the Earths formation and differentiation. The exact proportion of water contributed by each of these sources is still a subject of ongoing research, but it is likely that a combination of these processes played a role in forming Earths oceans. Formation of Continents and Oceans: The formation of continents and oceans on Earth was a dynamic and complex process that unfolded over geological time scales. Key processes involved include: Crust Formation: The Earths early crust was initially composed of solidified basaltic rocks. These rocks formed the foundation for the future continents and ocean basins. Continental Crust Formation: Over time, the Earths crust evolved as it underwent processes like partial melting, fractional crystallization, and plate tectonics. These processes resulted in the differentiation of the crust into the lighter continental crust, rich in granitic rocks. Ocean Formation: The depressions and low-lying areas in the Earths crust filled with water to form the early oceans. This process was influenced by the balance between tectonic activity, erosion, and sedimentation. Plate Tectonics: Plate tectonics, a crucial geological process, played a significant role in shaping the Earths surface. The movement of tectonic plates led to the creation of continents through the collision and convergence of landmasses and the formation of ocean basins through seafloor spreading. The formation of continents and oceans significantly affected Earths climate, geology, and the evolution of life. Continents provided a variety of environments for different ecosystems to thrive, while oceans played a role in regulating Earths climate and supporting marine life. This dynamic interplay between the Earths geology, its changing atmosphere, and the emergence of life continues to be a fascinating subject of study in Earth sciences. Prebiotic Chemistry: The emergence of life on Earth is a complex and intriguing process that likely began with prebiotic chemistry the chemistry that occurred before life as we know it existed. Prebiotic chemistry involves the formation of organic molecules from inorganic compounds. Key processes and factors in prebiotic chemistry include: Abiotic Synthesis: Prebiotic chemistry includes the formation of essential organic molecules from inorganic precursors. Under the right conditions, these reactions can yield amino acids, nucleotides, and other building blocks of life. Miller-Urey Experiment: The famous Miller-Urey experiment, conducted in the 1950s, demonstrated that the conditions thought to exist on the early Earth (including a reducing atmosphere and lightning) could produce amino acids, suggesting that the prebiotic synthesis of organic compounds was possible. Hydrothermal Vents: Hydrothermal vent systems on the ocean floor are believed to be sites where prebiotic chemistry could have taken place. These environments provide the necessary heat, minerals, and chemical gradients for the formation of organic molecules. Early Life Forms: The transition from prebiotic chemistry to early life forms is one of the most challenging questions in the study of the origin of life. While there is no definitive evidence of how life began, several hypotheses and models have been proposed: RNA World Hypothesis: This hypothesis suggests that early life forms were based on ribonucleic acid (RNA) rather than deoxyribonucleic acid (DNA). RNA can both store genetic information and catalyze chemical reactions, making it a plausible candidate for the first self-replicating molecule. Iron-Sulfur World Hypothesis: Some researchers propose that life may have originated at hydrothermal vents, where iron and nickel sulfide minerals could have acted as catalysts for the synthesis of organic molecules. Clay Hypothesis: Minerals, particularly clay minerals, may have played a role in concentrating and organizing organic molecules, possibly facilitating the emergence of early life. The Role of Geology in the Emergence of Life: Geology played a crucial role in the emergence of life on Earth through several key processes: Mineral Catalysts: Minerals have been proposed as catalysts for chemical reactions essential to lifes emergence. The surfaces of minerals can provide a template for the assembly of organic molecules, and some minerals may have catalytic properties that promote important reactions. Hydrothermal Systems: Hydrothermal vent systems, often found at mid-ocean ridges, are environments rich in geological activity. They release hot, mineral-rich fluids into the ocean, potentially creating favorable conditions for prebiotic chemistry. Subsurface Habitats: Geological features such as subsurface aquifers and rock formations can provide protected and stable environments where prebiotic chemistry and the emergence of early life might have occurred. Plate Tectonics: The movement of Earths tectonic plates is responsible for recycling materials, creating new landmasses, and maintaining geological diversity. These geological processes influence the distribution of habitats and the availability of resources essential for life. While the exact sequence of events leading to lifes emergence remains a topic of scientific inquiry and debate, the interplay between prebiotic chemistry, early life forms, and geological processes underscores the interconnected nature of Earths geology and the origins of life. Understanding these processes is not only fundamental to the history of life on our planet but also sheds light on the potential for life to emerge elsewhere in the universe. Plate tectonics is a fundamental concept in geology that explains the movement of Earths lithosphere, the rigid outer shell, in large, distinct plates. The interactions and movements of these plates play a pivotal role in shaping the geological evolution of our planet. Here are key aspects of how plate tectonics influence geological evolution: Divergent Boundaries: At divergent boundaries, tectonic plates move away from each other. This movement leads to the upwelling of molten rock from the mantle, creating mid-ocean ridges. As new crust forms and spreads, it gradually pushes older crust aside. Divergent boundaries are responsible for the creation of ocean basins and contribute to the overall growth of Earths crust. Convergent Boundaries: Convergent boundaries are characterized by the collision of tectonic plates. When an oceanic plate collides with a continental plate, the denser oceanic plate is subducted beneath the continental plate, creating deep ocean trenches and volcanic mountain ranges on the continental plate. When two continental plates collide, they can form massive mountain ranges, such as the Himalayas. The intense geological activity at convergent boundaries results in the formation of mountain chains, earthquakes, and volcanic arcs. Transform Boundaries: At transform boundaries, tectonic plates slide past one another horizontally. The friction and stress between plates build up over time until they suddenly release, causing earthquakes. The San Andreas Fault in California is a well-known example of a transform boundary. The movement of plates along transform boundaries can lead to the creation of fault lines, and their interactions play a crucial role in shaping the Earths crust. Hotspots: Hotspots are areas of intense volcanic activity that are not associated with plate boundaries. Instead, they occur as a result of plumes of hot mantle material rising through the Earths lithosphere. As the overlying tectonic plate moves, it creates a chain of volcanic islands or seamounts. The Hawaiian Islands, for example, were formed by the Pacific Plate moving over a hotspot. Subduction Zones: Subduction zones, typically found at convergent boundaries, are regions where one tectonic plate is forced beneath another. The descending plate melts and forms magma in the mantle, which can lead to volcanic arcs and the release of heat and pressure that drive seismic activity. Subduction zones are key features in the formation of island arcs, deep-sea trenches, and volcanic mountain ranges. The effects of plate tectonics on geological evolution are profound. They influence the formation and destruction of continents, the creation of mountain ranges, the distribution of earthquakes and volcanic activity, and the recycling of Earths crust over geological time scales. The ongoing movement of tectonic plates is a dynamic and continuous process, shaping the Earths surface and impacting the evolution of its landscapes and ecosystems. It is a testament to the ever-changing nature of our planet and a driving force behind the geological diversity we observe today. Geological Evidence of Past Climate Change: Sedimentary Rock Layers: Sedimentary rocks, such as limestone and shale, contain valuable clues about past climates. The presence of specific fossils, sediment types, and layering patterns in these rocks can provide insights into the environmental conditions that prevailed during their formation. For instance, the presence of coral fossils in limestone suggests a warm, shallow sea environment. Glacial Deposits: Glacial deposits, including moraines, till, and glacial striations, serve as indicators of past ice ages and glaciations. These features provide evidence of colder climates and the presence of glaciers in regions that are now ice-free. Fossil Record: The distribution and diversity of fossils can reveal significant changes in climate over geological time. For example, the presence of tropical plant fossils in areas that are currently temperate or polar regions suggests a much warmer climate in the past. Tree Rings and Ice Cores: The study of tree rings and ice cores offers records of past climate variations. Tree rings provide information about temperature and precipitation, while ice cores contain information about past atmospheric composition, including greenhouse gas concentrations. Mass Extinctions and Their Causes: Permian-Triassic Extinction (The Great Dying): Occurring approximately 252 million years ago, this is the most severe mass extinction in Earths history. The causes may have included massive volcanic eruptions, known as the Siberian Traps, which released large amounts of volcanic gases and led to climate change. Cretaceous-Paleogene Extinction: Occurring around 66 million years ago, this event wiped out the dinosaurs. The leading theory is that a massive asteroid impact in the Yucatan Peninsula, along with volcanic activity, caused widespread fires, darkness, and a nuclear winter effect, drastically altering the climate and ecosystems. End-Permian Extinction: About 252 million years ago, this event was associated with extensive volcanic eruptions in the Siberian Traps. The release of volcanic gases, including carbon dioxide, led to abrupt global warming and ocean acidification, severely impacting marine life. End-Cretaceous Extinction: The impact of a large asteroid, along with volcanic activity, led to rapid environmental changes. Acid rain, wildfires, and darkness caused by the impact triggered global cooling and disrupted food chains, affecting numerous species. Impact of Continental Drift on Climate: The movement of continents, driven by plate tectonics, has had a significant impact on Earths climate over geological time scales: Paleoclimatic Shifts: As continents drift and collide, they can change the distribution of landmasses, affecting ocean currents and atmospheric circulation patterns. For instance, the collision of India with Asia uplifted the Himalayas and altered weather patterns, impacting the Asian monsoon. Ocean Currents: The configuration of continents influences the direction and strength of ocean currents. The closure of the Isthmus of Panama, connecting North and South America, had a profound impact on ocean circulation, leading to changes in climate and marine ecosystems. Biogeography: Continental drift affects the distribution of species and the formation of biomes. As landmasses move, they can create barriers or connections that influence the movement of organisms and climate zones. Carbon Cycle: The positions of continents can affect the carbon cycle. The weathering of rocks on continents can draw down carbon dioxide from the atmosphere, influencing greenhouse gas concentrations and climate. Continental drift and its associated effects on climate have played a crucial role in shaping Earths geological and environmental history. They have influenced the evolution of life, the distribution of ecosystems, and the overall trajectory of the planets climate over millions of years. In conclusion, the story of Earths formation is a captivating journey through billions of years of cosmic evolution. Key points in Earths formation include the initial birth of our planet within the solar nebula, the differentiation into layers, and the dynamic interplay of geological processes that have shaped the Earth we know today. As we delve into Earths formation, we are met with the realization that this ancient tale continues to be a subject of ongoing scientific research and discovery. New findings constantly deepen our understanding of the intricate processes and events that have crafted our planet. From the exploration of Earths chemical composition to the investigation of its geological history, the quest to comprehend our worlds origins remains an ever-evolving endeavor. The significance of understanding Earths formation extends far beyond scientific curiosity. It holds profound implications for our planets future. By unraveling the mysteries of how Earth came into being, we gain insights into the fundamental processes that govern our world. We learn about the geological forces that continue to shape our landscapes, the mechanisms that regulate our climate, and the origins of life itself. Furthermore, a comprehensive understanding of Earths formation equips us with valuable knowledge that can inform our stewardship of the planet. It underscores the interconnectedness of all living and non-living elements on Earth, emphasizing the delicate balance we must maintain to ensure the sustainability of our ecosystems and the well-being of our species. In a world where climate change, resource depletion, and environmental challenges are pressing concerns, the lessons learned from Earths formation serve as a guidepost for responsible and informed decision-making. By appreciating the profound significance of our planets origin story, we are better equipped to shape a future that preserves the beauty, diversity, and vitality of Earth for generations to come.

How did earth's magnetic field originate. How did oxygen originate on earth. How did life originate on earth biology. How long ago did earth originate. How did humans originate on earth. Based on the narrative how did the earth's moon originate. How did water originate on earth. How did oxygen originate on earth what evidence supports this. How did earth day originate. Explain how did the life originated on the earth. How did life originate on earth. How did earth's oceans originate. How did gold originate on earth. How long ago did life originate on earth. How did life originate on earth short answer.